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Species Identification of the Stylohyoid Bone for North American Artiodactyls

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SPECIES IDENTIFICATION OF THE STYLOHYOID BONE FOR NORTH AMERICAN ARTIODACTYLS

A Thesis
Presented to
The Graduate Faculty
Central Washington University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Cultural and Environmental Resource Management

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by
Thomas Anthony Hale
March 2016

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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Thomas Anthony Hale

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ABSTRACT

SPECIES IDENTIFICATION OF THE STYLOHYOID BONE FOR NORTH AMERICAN ARTIODACTYLS

by

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March 2016

Zooarchaeologists cannot identify mammal species by their stylohyoid bones. Current trends in zooarchaeological research stress the need for rigorous and accessible identification methodology. I examined the stylohyoids of 15 hooved mammals: cattle, bison, domestic sheep, bighorn sheep, Dall sheep, mountain goat, domestic goat, elk, caribou, white-tailed deer, mule deer, moose, pronghorn antelope, domestic pig, and horse. Objectives included documenting how to side the stylohyoid (left or right), and producing species identification criteria based on large samples. A total of 325 samples were measured from eight repositories. Written descriptions, photographs, and success ratios for metrics and distinct traits are included for each species. Results indicate that stylohyoids can be sided based on longitudinal curvature, and that broad categories such as large vs. small ungulates, medium categories such as family and genus, and several species can be identified with more than 90% probability using combinations of measurements and ratios.

ACKNOWLEDGEMENTS

Dr. Patrick Lubinski, my committee chair, has been indefatigable in his patience and willingness to mentor a listless pupil. Dr. John Bowen and Professor Lourdes Henebry-Deleon, my other committee members, thank you for your indispensable knowledge and expertise that made my research possible. My gratitude extends to individuals at the repositories I utilized: Jeff Bradley, Collections Manager of the mammal collection at the Burke Museum of Natural History and Culture, University of Washington, Seattle; Dr. Danny Walker, administrator of the University of Wyoming Comparative Osteology and Zooarchaeology Collection in Laramie; M. Kathryn Jones and Laura A. Halverson Monahan, registrar and curator of collections, respectively, and undergraduate Hannah Myles at the University of Wisconsin Zoological Museum in Madison; Chris Conroy, Mammal Collection Staff Curator, and volunteers Johnny Sin and Jun Hyung Sin at the University of California Museum of Vertebrate Zoology in Berkeley; Dr. Kelly Cassidy, Curator of the at the Charles R. Conner Museum at Washington State University, Pullman; graduate student Paige Hawthorne at the Department of Anthropology, Washington State University, Pullman; and Professor Richard Meadow at Harvard University's Peabody Museum of Archaeology and Ethnology, Cambridge.

Mathia Scherer, Eric Brouwer and Ian Gray provided encouragement, support and faith as I wandered through the graduate student experience. I appreciate Ayla Aymond for her dogged assistance at the Burke Museum. Immeasurable thanks to you all.

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CHAPTER I

INTRODUCTION

Accurate species identification of animal bones on archaeological sites is a prerequisite for adequate analysis and interpretation. The most common approach to species identification is based on understanding the distinctive shape and size of individual bones (Bochenski 2008) by comparison to known-species comparative skeletons. There is an acute need for rigorous methods of identification and publication of identification criteria, especially given the difficulty of gaining access to sufficient comparative skeletal collections (Driver 1992; Wolverton 2013). According to Driver (1992:23-24) useful guides must provide a key for each individual element, highlight distinctive physical attributes, and be based on a large numbers of specimens.

The hyoid complex is a bilateral set of six bones in the throat region of mammals. Located at the base of the mandible (Figure 1), the stylohyoid is the largest of the hyoid complex (Figure 2), is relatively flat, has a wide proximal end, and acts as the suspension apparatus for the hyoid complex (Saber and Hofmann 1985:48-49). Common to all ungulates or hooved mammals (Saber and Hofmann 1985:43), the stylohyoid is part of a small complex of bones which also includes the tympanohyoid, epihyoid, ceratohyoid, thyrohyoid, and basihyoid (Figure 2). Overall the stylohyoid could be described as somewhat Y or T-shaped if turned on its side. Almost free floating, it is orientated between the mandible rami and is attached to the temporal bones by cartilaginous rods (Getty 1975:31; see Figure 3). Among artiodactyls (even-toed ungulates) the structure and morphology of the hyoid is probably a result of functional specialization associated with the tongue and its use for procuring vegetation (Saber and Hofmann 1985:43).

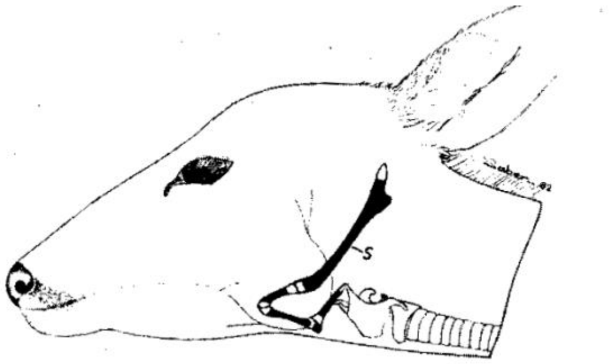


Figure 1. Illustration of European roe deer with hyoid complex in situ (Saber and Hofmann 1985: Figure 1). The “S” indicates the stylohyoid bone.

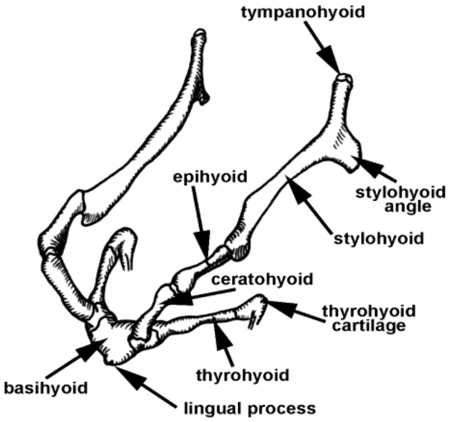


Figure 2. Sheep hyoid bone complex, modified from Getty (1975: Figure 26-63). Courtesy of Danny Walker.

The stylohyoid bone has never been examined in an academic setting to establish if it is useful for species identification, despite the extensive research on osteological species variation in general. This neglect is not restricted to North America. Only two

Figure 3. Anatomical location of hyoid complex. Shown is a lateral view (side view) of a deer's right stylohyoid still attached to the temporal bone of the cranium, as indicated by the red arrow. Sample prepared by Tom Hale, CWU specimen PL-497.

peer reviewed journal articles address the stylohyoid and its potential as a species indicator. The first was published in 1985 by Saber and Hofmann, and the article describes a comparison of six European ruminant species based on their hyoids. These authors concluded that while the basic morphology of the hyoid was similar for all six species, distinct variations were observable. The second was published in 2014 and compares the hyoids of domestic and wild pigs (Dimitrov et al. 2014).

As such it is fair to describe the stylohyoid as representative of a zooarchaeological data gap. Given the overall familiarity zooarchaeologists have for artiodactyl osteology (e.g., Balkwill and Cumbaa 1992; Boessneck 1969; Brown and Gustafson 1979; Ford 1990; Gehr 1995; Hildebrand 1955; Hillson 1996; Jones and Manning 1992; Lawrence 1951; Prummel and Frisch 1986; Schmidt 1972; Zeder and Lapham 2010), the comparatively little information available concerning stylohyoids is unusual. The methods and research presented here will help address and correct that gap for several North American artiodactyls, and perhaps indicate future avenues of research.

Purpose of Study

The primary goal of my research was to document potential methods for siding the stylohyoid, and to identify species based on morphological variations of the stylohyoid. Siding an element entailed documenting its asymmetries in order to understand if it is from the right or left side of the animal. Species identification entailed documenting the measurements and unusual features that separate one animal species from another. It is fair to establish from the beginning that this author limited research to most of the artiodactyls found in the continental United States. This choice was made in an effort to appropriately scale the project for a master of science thesis.

The first objective is to establish the most intuitive and practical way to side the stylohyoid based on morphology. This was determined by the shape and curvature of the element when viewed from a known perspective. A straightforward example of this method would be to orientate the bone from anterior to posterior (front to back), then view the element dorsally (from above) and record if the stylohyoid is convex or concave along its longitudinal axis.

The second was to establish the osteometric parameters and/or discrete traits that best identify the species in question. In order to accomplish this goal the stylohyoids for 14 species common to the continental U.S. were examined. These species include: *Bos taurus* (domestic cattle), *Bison bison* (bison), *Cervus elaphus* (elk), *Alces americanus* (moose), *Rangifer tarandus* (Caribou), *Ovis aries* (domestic sheep), *Ovis canadensis* (bighorn sheep), *Ovis dalli* (Dall sheep), *Capra hircus* (domestic goat), *Oreamnos americanus* (mountain goat), *Odocoileus hemionus* (mule deer), *Odocoileus virginianus* (white-tailed deer), *Antilocapra americana* (pronghorn antelope), *Sus scrofa* (domestic pig), and *Equus caballus* (horse). Any species-distinct morphological traits or measurements were described, photographed, and drawn. Probabilities and success rates were calculated for each trait based on sample size.

Significance of Study

While the overall significance of species identification has been touched upon, the specific importance of the stylohyoid lies in its relative obscurity and its potential to be included in the archaeological record. The stylohyoid is a relatively small element that could easily be overlooked in archaeological sites/assemblages where larger, more robust elements draw more attention from researchers. Moreover its anatomical location between the mandible rami suggests that it could be useful for identifying butchery behavior in the archaeological record.

The first point, that the stylohyoid is a poorly documented element can hardly be argued. The lack of previous literature dedicated to the hyoid complex suggests that it is a subject worthy of osteometric and zooarchaeological interest. The reader will remember that only one journal article has been published on the stylohyoid. That article, while useful, is almost 30 years old and published in a European journal dedicated to anatomy.

To date no zooarchaeological quantification and interpretation of the stylohyoid bone has been undertaken.

The archaeological importance of the stylohyoid is also an area of underdeveloped potential. The fact that the stylohyoid is a relatively small and obscure element suggests that its frequency and recovery from archaeological sites could be underrepresented. The hyoid's position between the mandibular rami and close to the tongue means that it is situated in an ideal location to receive cut marks associated with stone tools and prehistoric butchery patterns, as evidenced by a number of sites throughout North America (e.g., Frison 1970, 1973). Moreover, stylohyoids have been documented as worked and modified pendants or ornaments (e.g., Frison 1971; Lucius 1980). The archaeological significance of modified ornaments or bone tools is beyond the scope of this thesis project. However, the fact that stylohyoids are present within the archaeological record as intentionally and unintentionally modified elements highlights their relevance for further research. The academic significance of an element that has the utility for both identifying species and contributing to our understanding of prehistoric hunting behaviors is hard to ignore. The fact that so little effort has been dedicated to the stylohyoids of North American artiodactyls suggests a data gap that will be partially filled by this research project.

Organization of Thesis

Chapter II is dedicated to background information on the stylohyoid bone and a review of prior literature on bone identification and archaeological occurrence of modified hyoids. Chapter III covers methods and a basic description of which repositories were visited for data acquisition. The exact measurements that were taken, which ones were kept for analysis, and which ones were discarded (and why they were discarded) are also addressed. A discussion of discrete traits and how they will be analyzed is included here, as well as basic information on how the element was sided, and how age was recorded and utilized for the current research project. Chapter IV covers basic results and includes information on siding and sample information for each species. Tables are provided that indicate overall sample size, mean measurement data, value ranges for each measurement for each species. Conclusions on siding, taxa identification, and future work are covered in Chapter V.

CHAPTER II

BACKGROUND ON STYLOHYOID

Archaeological Occurrence of Artiodactyl Stylohyoids

The archaeological significance of the stylohyoid element is beyond the scope of this research project. A detailed treatment of recovery rates, and the frequencies and types of modifications seen on artiodactyl hyoids, would require a second thesis. However, the following is a brief synopsis of known archaeological occurrences and some cultural modifications made to the element.

A sample of modified artiodactyl stylohyoid bones from archaeological sites is provided in Table 1 and discussed here. Pronghorn stylohyoids have been recovered with cut marks from several sites in southwestern Wyoming, including Ceramic and Firehole Basin (see Figures 4, 5, and 6). Bighorn sheep stylohyoids with drilled holes and/or sinew wrappings have been recovered from the Cowboy Cave and Walters Cave sites in Utah (see Figure 7). Bison stylohyoids have been recovered from several other sites in Wyoming, such as Wardell and Glenrock, with cutmarks and butchery related breaks. Another Wyoming site, Eden-Farson, produced a bison stylohyoid pendant with a drilled hole as seen in Figure 8.

Table 1. Some Examples of Modified Archaeological Stylohyoids

Species	Modification	Site	Reference
Bighorn sheep *(Ovis canadensis)*[1]	Pendants (drilled and/or wrapped with sinew)	Cowboy Cave, UT Walters Cave, UT	Lucius 1980:100, Figure 42
Bison *(Bison bison)*	Cuts & breaks	Wardell, WY (48SU301)	Frison 1973:47, 87
Bison *(Bison bison)*	Cuts & breaks	Glenrock, WY (48CO304)	Frison 1970:22; Frison 1973:88
Bison *(Bison* bison)	Pendant (drilled)	Eden-Farson, WY (48SW304)	Frison 1971:276, Figure 8r; Walker, p.c. 9/24/13
White-tail deer (*Odocoileus virginianus*)	Cutmarks	Lyman, OH	Murphy 1973:17
White-tail deer (*Odocoileus virginianus*	Cutmarks	Mill Pond, WI (47CR186)	Theler 1987:Table 64
White-tail deer (*Odocoileus virginianus*	Cutmarks	Rhoads, IL (11LO8)	Parmalee and Klippel 1983:Table 3
Pronghorn *(Antilocapridae americana)*	Cutmarks	Ceramic, WY (48SW10233)	Lubinski 2000:Figure E.7
Pronghorn *(Antilocapridae americana)*	Cutmarks	Firehole Basin, WY (48SW1217)	Lubinski and Metcalf 1996.

Note: Contributors to this table include Steve Kuehn, Jim Theler, and Danny Walker.

[1] This identification was not provided by Lucius (1980) but based on the results of the identification guide later in this thesis, I make this identification with confidence.

Many sites have modified deer hyoids. Three example sites from eastern states include Lyman, Mill Pond, and Rhoads, all of which have produced white-tailed deer stylohyoids with butchery cutmarks. Parmalee and Klippel (1983) note that 3 out of 61 stylohyoid specimens at the Rhoads site display butchery related cultural modifications. They go on to say that “The tongue was known to have been a prized part of the animal and it was undoubtedly always removed, but only five percent of the hyoids were cut. Typically this element is scored during removal of the tongue.” (Parmalee and Klippel 1983:294).

Figure 4. Archaeological sample of pronghorn stylohyoid from the Firehole Basin site (48SW1217) in southwestern Wyoming, with sub-parallel butchery marks on lateral side of angle. Sample courtesy of Western Wyoming Community College, catalog no. SW1217-374.

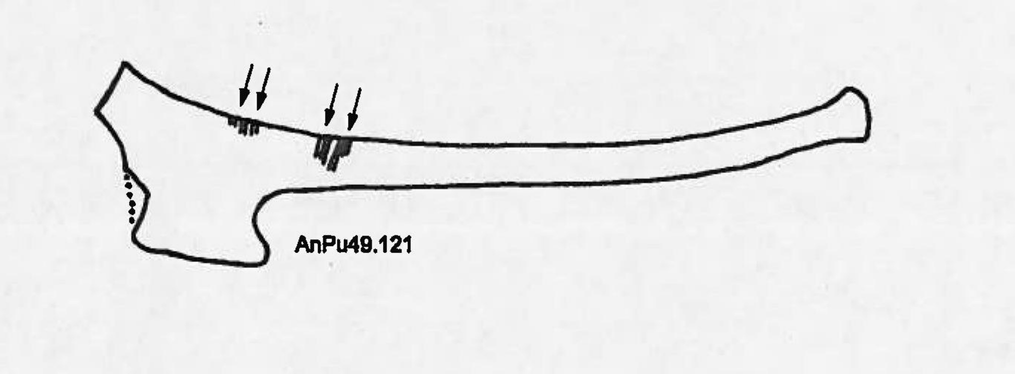


Figure 5. Sketched example of butchered hyoid from Lubinski (2000:Figure E.7). This was recovered from the Ceramic site (48SW10233) in southwest Wyoming.

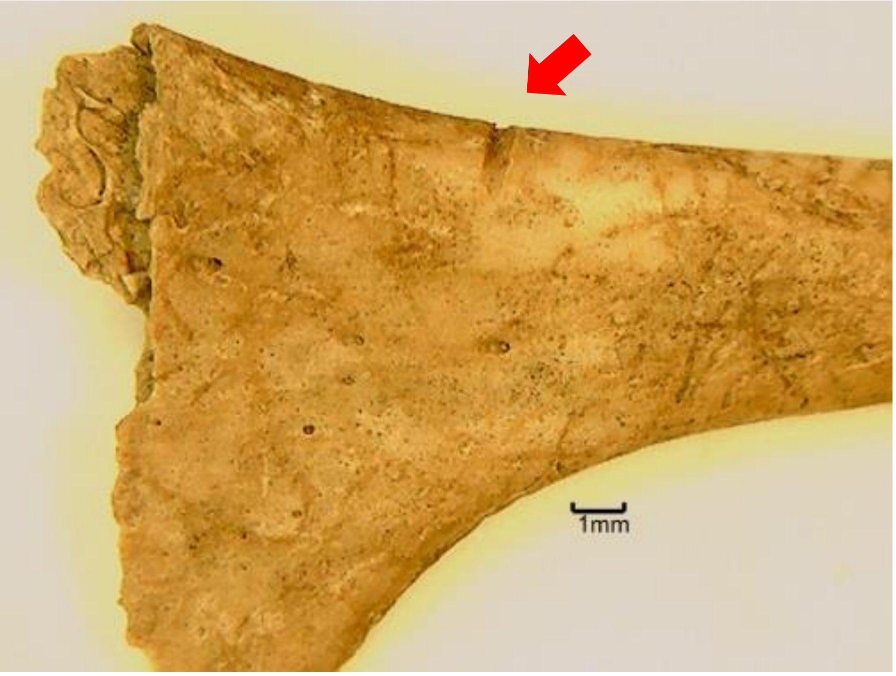


Figure 6. Archaeological sample of pronghorn stylohyoid from the Firehole Basin site (48SW1217) in southwestern Wyoming with V-shaped butchery mark along the proximal-dorsal edge. Sample courtesy of Western Wyoming Community College, catalog no. SW1217-225.

Figure 7. Stylohyoid pendants from Cowboy Cave, Utah. Detail of larger photograph by Lucius (1980: Figure 42). Based on the results of this study in the following thesis, these hyoids, at least (d), are bighorn sheep.

Figure 8. Drilled bison hyoid from Eden-Farson site (48SW304), Wyoming, superimposed over a modern bison hyoid. Image courtesy of Danny Walker.

Bone Identification Literature Review

Although little prior work has addressed hyoids, volumes of work by archaeologists have been conducted on the identification of mammals in general, and more specifically North American artiodactyls. These resources include Balkwill and Cumbaa (1992), Boessneck (1969), Brown and Gustafson (1979), Ford (1990), Gehr (1995), Gilbert (1990), Hildebrand (1955), Hillson (1996), Jones and Manning (1992), Lawrence (1951), O’Connor (2000), Olsen (1964), and Schmidt (1972). Zeder and Lapham (2010) went so far as to independently test previously established criteria for differentiating sheep and goats, including blind testing done by analysts of various experience levels. This list is by no means exhaustive but conveys the academic and professional interest archaeologists invest in species identification within the faunal record, and provide a starting point from which to research the stylohyoid.

Previous skeletal element guides use a combination of visual, qualitative, and quantitative methods to describe differences between animal species. For example, Ford's (1990) guide dedicated to the carpals of antelope, deer, bighorn sheep, and mountain goats utilized sketch drawings and textual descriptions to communicate the basic differences among the carpals of the relevant artiodactyls. Her guide included descriptions of the radial, intermediate, ulnar, accessory, second/third, and fourth carpals, and included views from multiple orientations. Basic and specific aspects of morphology were addressed, but no photography or quantitative analysis was undertaken.

Alternatively, Brown and Gustafson utilized sketch drawings, textual descriptions of specific traits, and osteometric ratios in their 1979 key dedicated to the postcranial elements of cattle/bison, elk, and horses. Their key included all post-cranial skeletal elements with the exception of ribs, coccygeal vertebrae, sterna, and sesamoid bones (1979:4). Their basic methodology was to provide a three column table that accompanied three species specific sketches for each post-cranial element. Each column summarized the morphology and relevant osteometric ratios for cattle/bison, elk, or horses. This provided an easy way for the reader to compare the written description to the associated sketch drawing.

Yet another approach was that taken by Balkwill and Cumbaa in their 1992 guide to the post-cranial bones of cattle and bison. These authors chose to provide sketches of each post-cranial element (for both species) from multiple orientations. Species specific traits were then described using language such as “squared” or “pointed’, “triangular” or “rounded”, and “strongly indented” or “less indented”. A third category of “intermediate” was also included for each trait. Tables for each element and orientation (paired with the element sketch) were then utilized. Data within the tables included the sample size, how often the trait was observed (e.g., a trait was observed for bison as squared 20/24 times, pointed 3/24 times, and intermediate 1/24 times), and the overall success percentage rate for identifying each species. These authors concentrated exclusively on discrete morphological traits and did not use any osteometric measurements or ratios.

Species Identification Pilot Study

Before describing my methods and objectives I would like to mention a pilot study directly relevant to my research. CWU undergraduate student Jenny Huilca conducted a stylohyoid species identification project for her Anthropology 425 - Zooarchaeology class assignment, then expanded for a campus-wide scholarly symposium in 2013 (Huilca 2013). Her study utilized 35 stylohyoids of eight artiodactyl species from the CWU and Burke Museum repositories. Tentative conclusions drawn from this pilot study suggested that maximum length can be used to differentiate bison, cattle, and elk on the one hand from deer, pronghorn, bighorn sheep and domestic sheep on the other hand. Osteometric cut-off points that fall between species (or at the least minimize overlap) were established to further differentiate sheep from deer or pronghorn, as well as elk from cattle and bison.

CHAPTER III

METHODS

This thesis had two major aims: to determine how to correctly side the stylohyoid element and to develop criteria for species identification from the element. This siding study involved removing stylohyoids from animal carcasses, paying close attention to anatomical side, until a sufficient sample was reached. The species identification study involved examination and measurement of stylohyoids from identified reference collections, attempting to gather stylohyoid samples of at least 25 individual animals of each species.

Siding the Stylohyoids

Prior to this study, it was not completely clear how to side a stylohyoid, and different zooarchaeologists queried by Dr. Lubinski provided opposing views on the correct side. In order to address this problem, I built on an initial, unreported study conducted by Dr. Lubinski in 1994 by extracting stylohyoids from additional animal carcasses. In all cases I was careful to keep track from which anatomical side a specimen was obtained. I attempted to obtain multiple species in order to ensure siding criteria that were as widely useful as possible. The complete list of specimens reported for this project is provided in Table 2.

Some additional information may complement Table 2. In “butchering events” referred to below, the extractor removed one or both stylohyoids from a carcass while it was being butchered for food. The March 11 and March 27, 2015, events both took place in Kittitas County at a commercial ranch, with significant help by Anne Salow on March 11. The road kill extractions involved removing the stylohyoid from deer heads brought back to the CWU Zooarchaeology Laboratory in Dean Hall. Five of these specimens were obtained from the Washington State Department of Transportation (WSDOT) Bullfrog Road facility in Cle Elum, Washington. This facility is the location of road-kill animals collected on area highways by WSDOT. In this case, heads were cut from the carcasses of five observed deer by undergraduate students Sydney Hanson and Erik Wakeland on February 12, 2014, and returned to the Zooarchaeology Laboratory where I supervised stylohyoid extraction. The single WDFW entry refers to a deer head that I dissected after the Zooarchaeology Lab obtained it from a donation by Washington Department of Fish and Wildlife law enforcement officer Corey Peterson. The single "buried skeleton" entry refers to horse hyoids excavated from a carcass buried at a Kittitas County, Washington farm and excavated by Professor Lourdes Henebry-DeLeon as part of a class project.

Stylohyoid Species Identification

To discover criteria for identifying the element to species, I obtained stylohyoids from eight osteological reference collections (see Table 3). In most cases, this meant traveling to the collection facility and looking through the skeleton boxes for the stylohyoids of species of interest. In some cases, volunteers at those facilities saved me time by going through the boxes and finding these bones beforehand. Except for the

Table 2. Specimens Obtained For Siding Project

Date	Source	Extractor	Notes
1994 Sept	Butchering event	P. Lubinski	From hunter: 1 *Cervus elaphus* (PL-060)
1994 Sept	Butchering event	P. Lubinski	From hunter: 1 *Antilocapra americana* (PL-062)
1994 Sept	Field skeleton	P. Lubinski	1 *Bos taurus* (PL-063)
1994 Sept	Field skeleton	P. Lubinski	1 *Ovis aries* (PL-064)
2013 May 8	Road kill	T. Hale	From I-90: 1 *Odocoileus sp.* (PL-482)
2013 Dec 2	Butchering event	J. Theler	From hunter: 1 *Odocoileus virginianus* (PL-481)
2014 Feb 5	WDFW Freezer	T. Hale	From law enforcement freezer: 1 *Odocoileus sp.* (PL-483)
2014 Feb 12	Road kill	T. Hale	From WSDOT facility: 5 *Odocoileus* (PL-491 & 492, 493, 494 & 495)
2014 Mar 1	Butchering event	T. Hale	From hunter: 1 *Cervus elaphus* (PL-496)
2014 Mar 14	Road kill	T. Hale	From State Route 10: 2 *Odocoileus* (PL-497 & 498)
2015 Mar 11	Butchering event	T. Hale	From anonymous ranch: 2 *Capra hircus* (PL-525 & 526), and 10 *Ovis aries* (PL-515, 516, 517, 518, 519, 520, 521,522, 523 & 524)
2015 Mar 27	Butchering event	T. Hale	From anonymous ranch: 3 *Bos taurus* (PL-529, 530 & 531)
2015 May	Buried skeleton	L. DeLeon	From excavated skeleton: 1 *Equus caballus* (PL-540)

CWU collection where hyoids were already set aside, in no case was it possible to find the element except by searching the boxes of complete skeletons, and roughly 2/3 of the reported complete skeletons were missing stylohyoids. Presumably these small bones are often missed by museum preparators. In three cases, hyoids were pulled by museum staff or volunteers and mailed to me as a temporary loan.

Table 3. Stylohyoid Species Sample

Abbreviation	Collection, University	City, State	How Obtained	Analyst	Specimens Observed (individuals)
Burke	Burke Museum, University of Washington	Seattle, WA	In person, 21 Feb. & 16-18 April 2014	T. Hale	62 *(7 Alces, 14 Antilocapra, 4 Bison, 6 Cervus, 18 Odocoileus h., 5 Odocoileus v., 1 Oreamnos, 1 O. aries, 6 O. canadensis)*
Conner	Charles R. Conner Museum, Washington State University	Pullman, WA	In person, 31 July 2015	T. Hale	9 *(1 Alces, 1 Bison, 1 Cervus, 3 Oreamnos, 1 O. aries, 2 Rangifer)*
CWU	Zooarchaeology Laboratory, Central Washington University	Ellensburg, WA	In person.	T. Hale	40 *(3 Antilocapra, 4 Bos t., 2 Capra, 6 Cervus, 1 Equus, 4 Odocoileus h., 4 Odocoileus v., 16 O. aries)*
Harvard	Harvard Peabody Museum of Archaeology & Ethnology	Boston, MA	Via mail loan 3 February 2016	T. Hale	8 (1 *B. taurus*, 1 *O. aries*, 6 *C. hircus*)
UCB	Museum of Vertebrate Zoology, University of California	Berkeley, CA	In person, 19 June 2015	P. Lubinski	21 (3 *Alces*, 14 *Cervus*,, 1 *Oreamnos*, 3 *Rangifer*)
			Via mail loan 7 October 2015	T. Hale	11 *(2 Bos t., 4 Capra, 1 Equus, 4 O. aries)*
Wisc	University of Wisconsin Zoological Museum	Madison, WI	In person, 8-10 June 2014	T. Hale	66 *(5 Alces, 6 Antilocapra, 10 Bison, 6 Bos t., 6 Capra, 2 Odocoileus h., 18 Odocoileus v., 6 O. aries, 2 O. canadensis,3 O. dalli, 2 Rangifer)*
			Via mail loan 10 April 2015	T. Hale	6 *(3 Alces, 1 Cervus, 2 O. dalli)*
WSU	Department of Anthropology, Washington State University	Pullman, WA	In person, 31 July 2015	T. Hale	5 *(3 Bison, 1 Bos t., 1 Rangifer)*

Table 3. Stylohyoid Species Sample (concluded)

Abbreviation	Collection, University	City, State	How Obtained	Analyst	Specimens Observed (individuals)
Wyo	Comparative Osteology Collection, University of Wyoming	Laramie, WY	In person, 2-6 June 2014	T. Hale	142 *(9 Alces, 29 Antilocapra, 26 Bison, 4 Bos t., 9 Cervus, 12 Odocoileus h., 13 Odocoileus v., 3 Oreamnos, 1 O. aries, 33 O. canadensis, 1 O. dalli, 2 Rangifer)*

When recording stylohyoid traits for species identification, it was necessary to determine side. Siding the element is important in order to avoid artificially inflating the sample numbers. Only measurements from one side (as in either the left or the right) stylohyoid of an individual animal were utilized in the species identification study. This decision is justified because bilateral symmetry dictates that an animal's left and right sides will be almost identical biometrically, and using both the left and right stylohyoid would be tantamount to measuring a single element twice. The decision to use either the left or right from an individual animal depended on the skeleton itself, but where both hyoids were in good shape the left side was chosen as a matter of protocol.

For each stylohyoid chosen for observation, measurements and observations were recorded on a paper form, and several photographs were taken. Specifics of the methods of measurement, observations on discrete traits, observations on animal age, and photographs are provided below. Also recorded were animal sex, and collection information (primarily state) recorded on the specimen box and from collection databases. Any pathological samples (with abnormalities due to disease or advanced age) were not to be used for either metric or discrete trait analysis.

Data collection was conducted by this author and by Dr. Patrick Lubinski. We took osteometric measurements of all elements using standard digital calipers (Control Company Traceable Digital Calipers Model 3415 or Mitutoyo Digimati) to the 0.01 mm. When a measurement was too wide to fit into the calipers (i.e., more than 280 mm), it was measured to the nearest mm on an osteometric board. Originally, there were 12 measurements taken. However, it became apparent after measuring the first two collections that dorsal and ventral curvatures were unreliable measurements, due to the difficulty of holding the calipers against an appropriately scaled surface perpendicular to the table or work station. As such those measurements were discarded and not used in the final analysis. There were 10 final measurements taken consistently (Table 4 and Figure 9).

Table 4. Measurements Used in This Study

Measurement (Abbreviation)	Description
Maximum Height (MH)	Maximum distance from posterior end of dorsal process to ventral end of the angle, regardless of orientation to long axis
Maximum Length (ML)	Maximum distance from the end of the anterior process to the posterior end of either the dorsal process or the angle (depending on which is greater), regardless of orientation to long axis
Anterior Epiphysis Width (AEW)	Maximum distance from outermost points along the dorsal and ventral lines of the anterior process
Anterior Epiphysis Thickness (AET)	Maximum distance from outermost points along the lateral and medial sides of the anterior process
Mid-Shaft Width (MSW)	Maximum distance from outermost points along the dorsal and ventral lines at mid-shaft
Mid-Shaft Thickness (MST)	Maximum distance from outermost points along the lateral and medial sides at mid-shaft
Dorsal Process Width (DPW)	Maximum distance from outermost points along the dorsal and ventral lines of the dorsal process
Dorsal Process Thickness (DPT)	Maximum distance from outermost points along the lateral and medial sides of the dorsal process
Angle Width (AW)	Maximum distance from outermost points along the dorsal and ventral lines of the angle
Angle Thickness (AT)	Maximum distance from outermost points along the lateral and medial sides of the angle

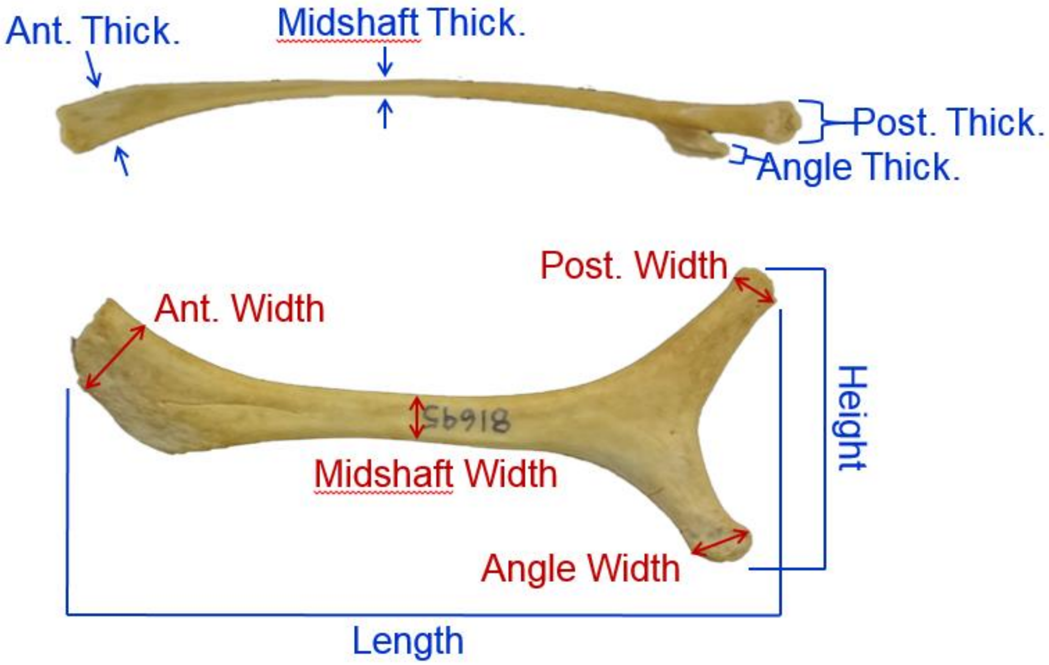
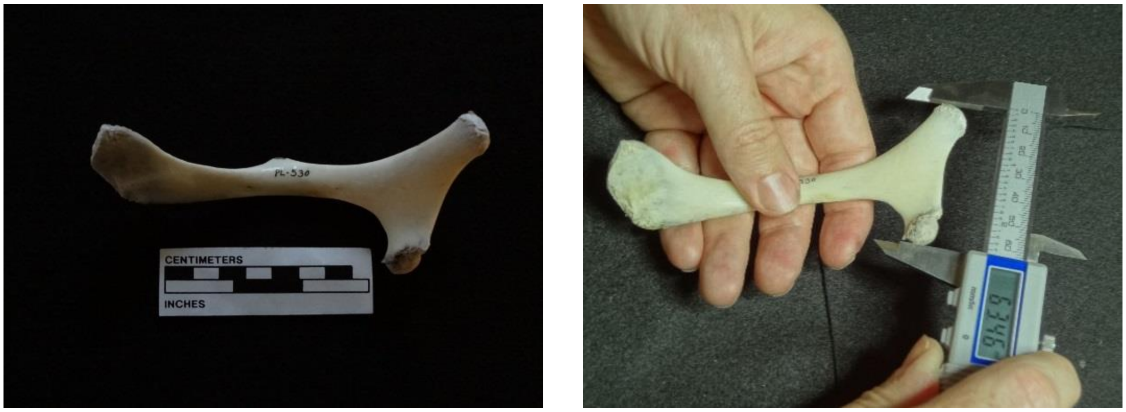


Figure 9. Measurements used in this study and depicted on a bighorn sheep stylohyoid (Wisc-81695).

The following images (Figures 10 and 11) document the measurements recorded and how they were taken using digital calipers. These images are staged in the CWU Zoological Laboratory and are not from actual instances of data acquisition. The element used for these examples is a stylohyoid from domestic cattle from the CWU collection (PL-530).

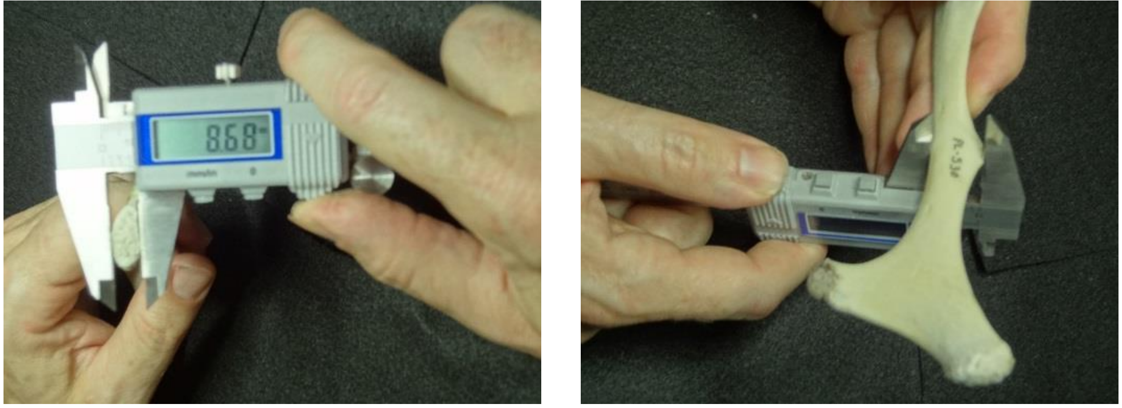


CWU cattle PL-530 used in the following images

Maximum height (MH)

Maximum length (ML)

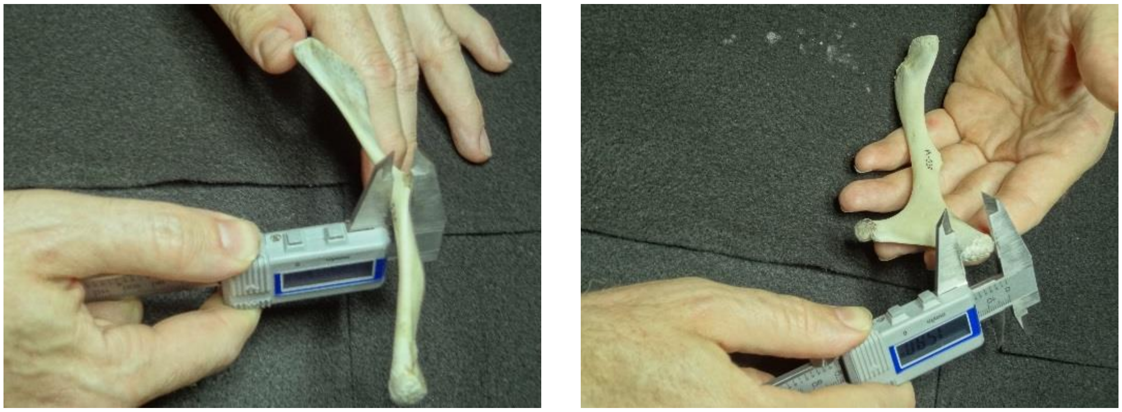
Anterior epiphysis width (AEW)



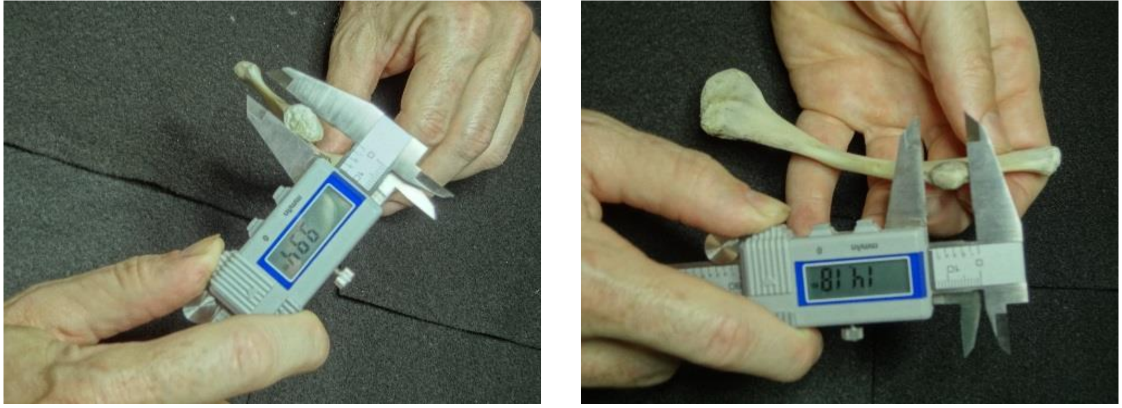
Anterior epiphysis thickness (AET)

Mid-shaft width (MSW)

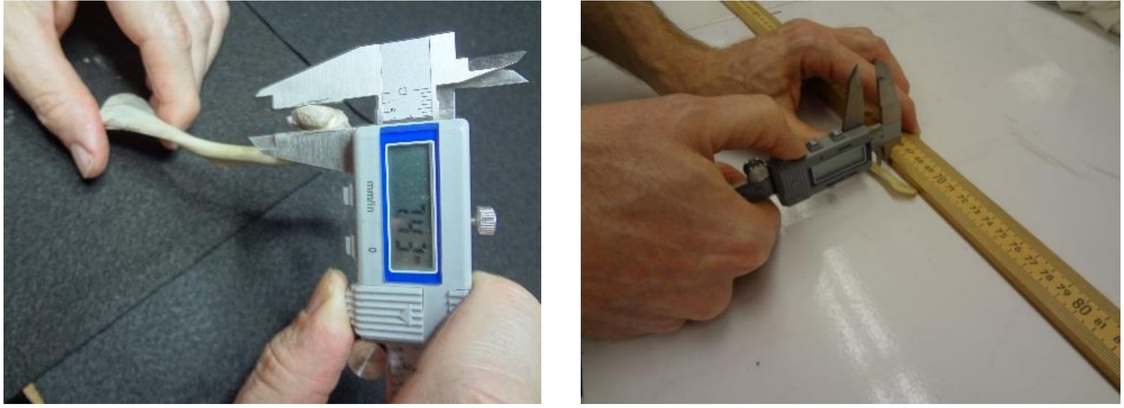
Figure 10. Illustration of hyoid measurement protocols, part 1 of 2.



Mid-shaft thickness (MST) Dorsal process width (DPW)



Dorsal process thickness (DPT) Angle width (AW)



Angle thickness (AT) Dorsal curvature. (Not used)

Figure 11. Illustration of hyoid measurement protocols, part 2 of 2.

In addition to measurements, any morphologically distinct traits or features were described and photographed. A morphologically distinct trait is any discrete trait that is found on an element for a specific species. Such traits can be particular (100% unique) to a species or they can be typical (not 100% unique but still common) of a species. For the purpose of this study discrete traits are marked as either present or absent. No value is given to a trait with an intermediate expression. When a single measurement or ratio is unable to reliably separate taxa it may be possible to increase the quantitative reliability of the metric and discrete trait analysis by combining probabilities. In such cases two or more discriminatory criteria will be added together to increase their success probability. Adding probabilities follows the formula 1-((1-A)*(1-B)). So, for example, if one had an unknown hyoid with a ML of 90 mm and a DPW of 6.5, and there is a 99.5% (A) probability of being a small ungulate from the first measure and a 99.6% (B) probability for the second measure., the resulting probability is 1 - ((1-0.995) * (1-0.996)) = 0.99998. This corresponds with a 99.998% probability that it is a small ungulate.

The age of the animals from which stylohyoids were observed is of importance to the study because the size and morphology of the element can change as an animal matures. For example, Figure 12 shows the considerable change from a neonatal bison to an adult. The study needed some way to control for this issue and its potential effect on the metric analysis data.

Figure 12. Change in stylohyoid from neonatal to adult. Shown at top is a two day-old bison measuring 49.33 mm ML and at bottom an adult bison measuring 163.5 mm ML. The neonatal bison is Wisc-32270 and the adult bison is Burke-35536.

The age of the specimens was originally to be determined by two methods. First, any information available from the different repositories was recorded for future use. This includes age, sex, collection locale, and year of acquisition. This information was generally available on the side of the box holding the skeletal remains. For easy and fast recoding purposes a photograph was taken of each box tag so that all relevant information was available for current research. This method was retained throughout the analysis. A second method initially undertaken and later discarded was to take photographs of each specimen’s mandible when available, and gather data on their tooth eruption sequence (Figure 13). From this data the specimens were originally to be divided into rough age categories.

Figure 13. Juvenile Mountain Goat mandibles with third molars still in crypt. Note the teardrop shaped opening behind tooth row and on the right. The third molar is an adult tooth. Sample courtesy of the Burke Museum (Specimen #34310).

However, it was decided after some initial examination of the metric data that age categories would not be particularly helpful for scientists dealing with stylohyoids from the archaeological or paleontological record. In those situations researchers will not have corresponding tooth eruption and/or age data for the element in question. Therefore it was decided that a simpler age cut-off, accessible to archaeologists, was needed for the current Master's research. It was decided that samples old enough to utilize for osteometric purposes would have a fused epiphyses at the stylohyoid angle. This fast and reliable cut-off has the advantages of simplicity and accessibility to researchers working on stylohyoid species identification (Figure 14).

Figure 14. Left domestic cattle stylohyoids, one with a fused epiphysis at the angle (above), and one unfused with missing epiphyses (below). Both samples are from 23 month-old Wagyu/Black Angus cross males, and suggest that the animals reach maturity at approximately two years. Courtesy of CWU (PL-530 and PL-529).

In addition to osteometric measurements, and data on fusion, sex, and collection locale, each stylohyoids was photographed as time allowed. These color digital photographs generally include the lateral and dorsal views to confirm siding, fusion/age, and for general record keeping. A sample of these photographs is included in the final thesis in order to provide visual context and perspective for the reader. The entire photo collection is available in a digital appendix. These photographs also allowed for observation of discrete traits not originally thought of when the analysis began.

User Error Pilot Study

To aid in the understanding of discriminatory metrics a small pilot study was preformed to evaluate measurement reliability and user error. The author re-measured Maximum Length (ML), Maximum Height (MH), Anterior Epiphysis Width (AEW), and Angle Width (AW) 30 times on a total of six CWU elements including: domestic cattle PL-530 (*Bos taurus*), Pronghorn antelope PL-57 (*Antilocapra*), domestic sheep PL-271 (*Ovis aries*), elk PL-60 (*Cervus*), moose PL-547 (*Alces*), and Mule deer PL-59 (*Odocoileus hemionus*). Those thirty measurement values were averaged and then compared to the actual value initially measured and recorded for those elements. The standard deviation (SD), coefficient of variance (CV), spread and range for each measurement and element in the pilot study was also calculated. All of this data including mean, SD, CV, original recorded value, difference between mean and recorded value, spread, and range were put into tables for each of the hyoids measured (Tables 5-10).

Table 5. Pilot Study *Bos taurus* PL-530 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	137.25	63.29	19.59	18.18
SD	±0.056	±0.022	±0.847	±0.219
CV	0.0004	0.0004	0.0432	0.012
Recorded	137.35	63.22	19.70	18.24
Difference	0.10	0.07	0.11	0.06
Spread	137.08 - 137.31	63.22-63.32	15.59-20.46	17.58-18.79
Range	0.23	0.1	4.87	1.21

Table 6. Pilot Study *Antilocapra americana* PL-57 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	81.56	20.37	4.23	13.09
SD	±0.047	±0.177	±0.026	±0.294
CV	0.0006	0.009	0.006	0.0225
Recorded	81.48	20.48	4.22	12.77
Difference	0.08	0.11	0.01	0.32
Spread	81.43-81.61	20.13-20.81	4.16-4.26	12.7-13.91
Range	.18	0.68	.10	1.21

Table 7. Pilot Study *Ovis aries* PL-271 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	64.28	26.17	9.11	9.64
SD	±0.025	±0.051	±0.121	±0.163
CV	0.0004	0.0019	0.0133	0.0169
Recorded	64.24	26.21	9.26	9.08
Difference	0.04	0.04	0.15	0.56
Spread	64.2-64.3	26.1-26.4	8.73-9.28	9.21-9.9
Range	0.10	0.30	0.55	0.69

Table 8 Pilot Study *Cervus elaphus* PL-60 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	113.68	39.05	10.86	5.38
SD	±0.063	±0.014	±0.03	±0.136
CV	0.0006	0.0003	0.0028	0.0252
Recorded	113.75	39.15	10.92	5.12
Difference	0.07	0.1	0.06	0.26
Spread	113.55-113.78	39.02-39.08	10.78-10.90	5.03-5.77
Range	0.23	0.06	0.12	0.74

Table 9. Pilot Study *Alces americana* PL-547 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	146.14	35.35	12.25	12.61
SD	±0.081	±0.014	±0.06	±0.08
CV	0.0006	0.0004	0.0049	0.0064
Recorded	146.39	35.8	12.42	12.65
Difference	0.25	0.45	0.17	0.04
Spread	145.89-146.24	35.31-35.37	11.96-12.30	12.48-12.74
Range	0.35	0.06	0.34	0.26

Table 10. Pilot Study *Odocoileus hemionus* PL-59 Data

	ML (mm)	MH (mm)	AEW (mm)	AW (mm)
Mean	76.21	21.62	5.44	7.48
SD	±0.092	±0.019	±0.044	±0.046
CV	0.0012	0.0009	0.0082	0.0062
Recorded	76.25	21.62	5.45	7.51
Difference	0.04	0.0	0.01	0.03
Spread	76.01-76.35	21.57-21.64	5.37-5.53	7.44-7.66
Range	0.34	0.07	0.16	0.22

In order to comprehend the full impact of the pilot study data and the effects of user error, the entire metric analysis (involving ML, MH, AEW, and AW) was run a second time. This second analysis made use of the measurement value (from the n = 30 pilot study test values) farthest from the original recorded value. By choosing the value with the greatest difference from the original number, it was hoped that any resulting difference in the metric analysis would be highlighted.

In reality the use of the maximum pilot study test values had no impact on the metric analysis and the resulting taxa identification. When the greatest difference value was used for these six test specimens, there was no change to the identification category for any ratio (e.g. which deer species group the specimen would be placed in). The results of the pilot study indicate that user error will have no meaningful impact on the discriminatory metric analysis utilized in this research, although this is an admittedly small study with only one, experienced analyst.

Species Identification Data Analysis

After data were obtained from each collection, it was entered into a Microsoft Excel spreadsheet for analysis. The spreadsheet contained all metric data plus pertinent discrete trait data from the initial observations. These data were used first in a simple discrimination into size group by maximum length. They were further manipulated by creating a number of metric ratios to explore mathematical ways to discriminate among species.

Discrete traits were scored as present or absent during the analysis at each repository and recorded in the author's notes. For example pronghorn antelope show a unique longitudinal curve that is S-shaped, a feature not seen in any other species. While the total sample for pronghorn antelope is 52 stylohyoids, only 48 were complete enough to identify the presence or absence of the S-curve. The S-curve was recorded on 46 of those, and yielding a success ratio of 46/48 and a success probability of 95.8%.

Species are divided into one of two general Size Class categories developed by Lubinski (2013:131). Small ungulates (hoofed mammals), comprising Lubinski's Size Class 5, are defined as animals ranging between 25-200 kilograms and include domestic sheep, bighorn sheep, Dall sheep, domestic goat, mountain goat, mule deer, white-tail deer, and pronghorn antelope. Large ungulates, comprising Lubinski’s Size Class 6, are defined as animals ranging between 200-1500 kilograms, and include domestic cattle, bison, elk, moose, caribou, and horse.

CHAPTER IV

RESULTS

Siding Results

Determining the side of an element requires a detailed knowledge of its morphology and its anatomical relationship within the parent animal. Because so little is known about the stylohyoid there was some confusion as to how to accurately determine the left from right stylohyoid. The most obvious trait useful for this endeavor is the distinct longitudinal curvature that the bone displays when viewed dorsally (from above) or ventrally (from below). The question that needed to be answered was does the stylohyoid curve inward toward the medial plane, or does it curve outward toward the lateral side? Another way to say this would be: does the stylohyoid display convexity or concavity on the lateral side?

Dr. Lubinski undertook some initial research into this question during his dissertation work in the mid-1990s. The majority of his research indicated that the stylohyoid is concave on the lateral side. This included removal of the right stylohyoid from one *Bos taurus,* the left and right stylohyoid from one *Odocoileus hemionus*, and the left stylohyoid from one *Ovis aries*. However, he also removed the left and right stylohyoid from one *Cervus elaphus* and recorded the curvature as convex on the lateral side. To increase confusion, a colleague of Dr. Lubinski mailed us the left and right stylohyoid complex from one *Odocoileus virginianus* in December of 2013. These were also recorded as convex on the lateral side. This situation was later cleared up and verified as convex to the medial side.

In order to clarify the siding question we decided to extract the stylohyoid bone from several artiodactyl carcasses and one perissodactyl (odd-toed hooved mammal) carcass obtained locally. This author removed one or both stylohyoids from 23 animals, including 7 *Odocoileus sp.*, 1 *Cervus elaphus*, 11 *Ovis aries*, 2 *Capra hircus*, and 3 *Bos taurus*. Also, the stylohyoid of 1 *Equus caballus* was collected by undergraduate students of Professor Lourdes Henebry-Deleon as a field exercise in her 2015 forensics field school. All of these samples were recorded as concave on the lateral side. These results, in addition to Dr. Lubinski's older results, suggest that stylohyoid bones curve toward the medial when viewed dorsally. A sample of the results is depicted in Figure 15, the full results from our siding data are summarized in Table 11, and example extracted hyoid complexes are shown in Figures 16 and 17.

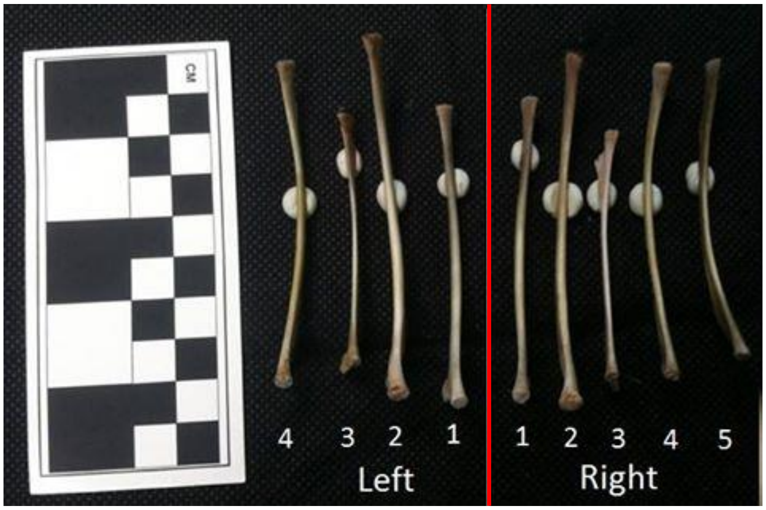


Figure 15. Left and right deer stylohyoids extracted by author at CWU in 2014. Notice the curvature toward the red medial line. Dorsal view. Anterior to top.

Table 11. Summary of Stylohyoid Siding Data

Species	CWU Specimen	Side	Concave on	Extraction notes
Antilocapra americana	PL-062	R	Lateral	P. Lubinski Sept, 1994
Bos taurus	PL-063	R	Lateral	P. Lubinski Sept, 1994
Bos taurus	PL-529	L	Lateral	T. Hale March 27, 2015
Bos taurus	PL-530	L	Lateral	T. Hale March 27, 2015
Bos taurus	PL-531	L	Lateral	T. Hale March 27, 2015
Cervus elaphus	PL-060	L & R	Medial	P. Lubinski Oct 15, 1994
Cervus elaphus	PL-496	L & R	Lateral	T. Hale March 1, 2014
Odocoileus hemionus	PL-059	L & R	Lateral	P. Lubinski Oct 6, 1994
Odocoileus hemionus	PL-495	L & R	Lateral	T. Hale Feb 12, 2014
Odocoileus hemionus	PL-494	L & R	Lateral	T. Hale Feb 12, 2014
Odocoileus sp.	PL-482	L	Lateral	T. Hale May 8, 2014
Odocoileus sp.	PL-483	L & R	Lateral	T. Hale Feb 5, 2014
Odocoileus sp.	PL-491	R	Lateral	T. Hale Feb 12, 2014
Odocoileus sp.	PL-492	L & R	Lateral	T. Hale Feb 12, 2014
Odocoileus sp.	PL-493	L & R	Lateral	T. Hale Feb 12, 2014
Odocoileus virginianus	PL-481	L & R	Medial	J. Theler Dec 2, 2013
Ovis aries	PL-064	L	Lateral	P. Lubinski Sept, 1994
Ovis aries	PL-515	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-516	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-517	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-518	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-519	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-520	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-521	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-522	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-523	L	Lateral	T. Hale March 11, 2015
Ovis aries	PL-524	L	Lateral	T. Hale March 11, 2015
Capra hircus	PL-525	L & R	Lateral	T. Hale March 11, 2015
Capra hircus	PL-526	R	Lateral	T. Hale March 11, 2015
Equus caballus	PL-540	L & R	Lateral	L. Henebry-Deleon May, 2015

Sp. = unknown species

Figure 16 Dorsal view (from above) of elk hyoid bone complex with esophageal tissue still attached. The posterior end (back end) is toward the scale. Note the convexity toward the medial plane (the imaginary center line that would divide the animal). Sample prepared by Tom Hale, CWU (PL-496).

Figure 17 Dorsal (from above) view of deer hyoid bone complex. The posterior end is toward the scale. Note the convexity toward the medial plane. Sample prepared by Tom Hale, CWU (PL-483).

The siding results can be summarized as follows: artiodactyl stylohyoids display a strong longitudinal curvature when viewed dorsally. Sample specimens from more than twenty-five animals are convex to the medial plane. Put more simply, stylohyoids curve inward when viewed from above or below.

Species Results

Having determined side, I moved on to species identification. The following tables summarize the sample size (Table 12) and osteometric data (Tables 13 and 14) collected for the 5 species in question. Samples were divided into usable and unusable categories based on age and pathology. Samples deemed old enough to utilize for osteometric purposes have a fused epiphysis at the stylohyoid angle. Younger samples, deemed either fetal or neonatal, were considered juveniles too small to offer reliable metric data but will be used for discrete traits if there is a distinct pattern regardless of age.

In the following tables and discussion, species are ordered largest to smallest according to Size Class, and sub-ordered according to taxonomic family. Mammalian size classes used in this thesis are derived from Lubinski (2013). Size Class 6 taxonomic families are considered large-hooved mammals for the purposes of this study, and will be addressed in the order of Bovidae, Cervidae, and Equidae. Size Class 5 comprises small-hooved mammals and addressed in the order of Bovidae, Cervidae, and Antilocapridae.

Table 12. Total Sample Sizes for All Species

Species	Total	Unfused	Pathological	Fused
Large Hoofed Mammals (Size Class 6):				
Family Bovidae::				
Domestic cattle *(Bos taurus)*	14	11	0	6
Bison *(Bison bison*)	43	17	0	26
Family Cervidae:				
Elk *(Cervus elaphus)*	34	1	1*	32
Moose *(Alces americanus)*	25	3	0	22
Caribou *(Rangifer tarandus)*	10	1	0	9
Family Equidae:				
Horse *(Equus caballus)*	2	1	0	1
Small Hoofed Mammals (Size Class 5):				
Family Bovidae:				
Domestic sheep *(Ovis aries)*	30	0	0	30
Bighorn sheep *(Ovis canadensis)*	41	0	0	41
Dall sheep *(Ovis dalli)*	6	0	0	6
Domestic goat *(Capra hircus)*	18	0	0	18
Mountain goat *(Oreamnos americanus)*	8	2	0	6
Family Cervidae				
Mule deer *(Odocoileus hemionus)*	36	0	0	36
White-tailed deer *(Odocoileus virginianus)*	40	0	0	40
Family Antilocapridae:				
Pronghorn *(Antilocapra americana)*	52	0	0	52
TOTAL	359	36	1	325

*Single pathological specimen is a zoo *Cervus elaphus* that lived to the extreme age of 19 years and was atypical, extensively remodeled bone.

Table 13. Measurement Means (mm) for Size Class 6 Species, Fused Samples Only

Measurement	Cattle	Bison	Elk	Moose	Caribou	Horse
MH	58.29	61.61	37.70	38.35	27.06	57.82
ML	140.76	152.30	117.38	140.47	106.36	189.5
AEW	21.11	15.94	11.75	14.98	8.12	9.75
AET	7.88	6.26	5.85	4.40	5.30	4.63
MSW	14.11	11.00	7.19	7.68	5.58	13.36
MST	5.66	4.39	3.62	3.54	2.91	2.82
DPW	13.75	10.85	9.62	9.41	7.35	13.60
DPT	10.51	8.17	5.96	7.60	4.48	11.40
AW	15.47	16.07	5.49	10.81	7.74	9.98
AT	5.80	4.00	1.96	2.08	2.19	3.70
Sample size	6	26	32	22	9	1

Table 14. Measurement Means (mm) for Size Class 5 Species, Fused Samples Only

Measurement	Domestic sheep	Bighorn sheep	Dall sheep	Domestic goat	Mt. goat	Mule deer	White-tail deer	Prong-horn
MH	28.4	28.02	28.48	27.98	28.80	20.53	22.21	22.95
ML	59.83	65.05	64.83	58.00	81.95	71.35	74.29	77.60
AEW	10.27	8.83	8.32	8.02	9.36	5.98	6.66	4.67
AET	3.04	3.25	3.22	2.87	3.66	3.03	3.08	3.21
MSW	5.47	4.35	4.42	4.79	5.32	4.20	4.53	3.83
MST	2.19	1.80	1.87	1.80	2.84	1.85	2.11	1.72
DPW	5.60	5.09	5.60	4.96	6.56	4.56	4.94	4.79
DPT	3.54	3.63	3.70	3.33	3.90	4.02	4.48	3.28
AW	7.06	5.99	5.26	4.48	6.72	5.47	5.59	10.99
AT	2.71	2.36	2.04	1.90	2.57	1.84	2.30	1.81
Sample size	30	41	6	18	6	36	40	52

This order was chosen to facilitate easy discussion and reference based on the division of stylohyoid samples into Size Classes based on Maximum Length (as discussed below). The sub-order was chosen because closely related species within a taxonomic family are likely candidates for confusion when exact identification is the goal. As such, bovid species are grouped together based on similarities in their gross morphology, followed by cervids for the same reason. Species with more unique morphological patterns, like horse and pronghorn, are addressed last within their respective Size Class, as they are harder to confuse with either bovids or cervids. Following a summary of each species will be a discussion of osteometric and discrete traits that can be used to distinguish between species and species groups.

Domestic Cattle *(Bos taurus)*, Size Class 6, Bovid

The *Bos taurus* samples were derived from the CWU, University of Wyoming, Washington State University, UC Berkeley, the Harvard Peabody Museum of Archaeology and Ethnology, and University of Wisconsin-Madison collections. There was a total of 17samples, with 11 of those being unfused, and 6 being fully fused. Table 15 summarizes the sample. As this is a domesticated species, the geographic origin is not very helpful, but breed could be relevant. Three specimens in the sample (2 fused and 1 unfused) are a Wagyu/Black Angus cross. No other breed information is available for the sample. The sex distribution in the sample is 5 males, 7 females, and 5 unknown. Measurement data are provided in Table 16.

Table 15. Summary of *Bos taurus* Stylohyoid Sample

Category		Side		Sex			
	Total	Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	12	11	1	4	3	5	WSU-Ant S-98; CWU-529, 531; Harvard-627AR; UWyo-8491B, 9161B, 9284B; Wisc-20007, 22306, 22344, 25136, 67375
Fused	6	3	3	1	4	1	CWU-063, 530; UC Berkeley-33499, 114370; UWyo-8507B; Wisc-36489
Totals	18	14	4	5	7	6	

Table 16. Measurement Data (mm) for Fused *Bos taurus* (Domestic Cattle) Hyoids

Measurement	n	Range	Mean
Maximum Height	6	49.13-73.86	58.29
Maximum Length	5	117.45-171.75	140.76
Anterior Epiphysis Width	5	19.70-27.00	21.11
Anterior Epiphysis Thickness	5	5.49-9.99	7.88
Mid-Shaft Width	6	10.81-17.49	14.11
Mid-Shaft Thickness	6	4.24-6.73	5.66
Dorsal Process Width	6	11.12-16.21	13.75
Dorsal Process Thickness	6	7.8-13.24	10.51
Angle Width	6	11.02-22.50	15.47
Angle Thickness	6	2.38-7.43	5.80

The stylohyoids of domestic cattle display a rather unique gross morphology with typically high values for maximum and distal heights, a rather extreme convexity toward the medial side, overall robusticity, and a distinctive beak or protuberance located mid-shaft and along the dorsal ridge (Figure 18 and 19). Because of their robusticity, relatively long angle and resulting t-shape typical of bovids, plus their unique dorsal beak, cattle are relatively easy to identify despite our small sample size.

Figure 18. Left stylohyoid from 23-month-old *Bos taurus*, lateral view, with prominent dorsal beak located mid-shaft indicated by red arrow. Sample courtesy of CWU (PL-530).

Figure 19. Left stylohyoid from 23-month-old *Bos taurus*, dorsal view, with prominent dorsal beak located mid-shaft indicated by red arrow. Sample courtesy of CWU (PL-530).

Bison *(Bison bison)*, Size Class 6, Bovid

The *Bison bison* samples were derived from the Burke Museum, the University of Wyoming, University of Wisconsin-Madison, the Conner Museum, and the WSU-Anthropology collections. There was a total of 43 samples, with 17 of those being unfused, and 26 being fully fused. Table 17 summarizes the sample. The sex distribution for the sample is 12 males, 17 females, and 14 unknown. As this is a wild species with notable sexual dimorphism, sex might correspond to discernible osteometric differences. Geographic origin could be similarly important, but since bison were nearly extirpated and all (unless some Yellowstone) reference skeletons are from captive herds, it was not described here. Measurement data are provided in Table 18, and sample images in Figures 20 and 21.

Table 17. Summary of *Bison bison* Sample

Category		Side		Sex			
	Total	Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	17	13	4	4	6	7	UWyo-0351B, 0359B, 0360B, 8221B, 8229B, 8232B, 8238B, 8284B, 8285B, 8286B, 8287B, 8288B, 8289B; Wisc-21295, 28551, 31101, 32270
Fused	26	20	6	8	11	7	Burke-35535, 12548; Conner-86-270; UWyo-0353B, 0389B, 8385B, 8501B, 8504B, 8505B, 8506B, 8509B, 8510B, 8529B, 8530B, 8638B, 9073B; Wisc-16483, 16569, 27361, 36499, 36623, 36808; WSU-95, 97, 94
Totals	43	33	10	12	17	14	

Table 18. Measurement Data (mm) for Fused *Bison bison* (Bison) Hyoids

Measurement	n	Range	Mean
Maximum Height	25	37.22-82.2	61.61
Maximum Length	23	92.00-193.5	152.30
Anterior Epiphysis Width	24	9.42-20.53	15.94
Anterior Epiphysis Thickness	24	3.91-9.17	6.26
Mid-Shaft Width	26	7.5-16.65	11.00
Mid-Shaft Thickness	26	3.12-7.39	4.39
Dorsal Process Width	26	4.21-14.08	10.85
Dorsal Process Thickness	26	5.62-10.27	8.17
Angle Width	24	7.66-27.87	16.07
Angle Thickness	25	2.26-6.29	4.00

Figure 20. Left stylohyoid from adult *Bison bison*, lateral view. Sample courtesy of the University of Wisconsin-Madison (36808).

Figure 21. Left stylohyoid from adult *Bison bison*, dorsal view. Sample courtesy of the University of Wisconsin-Madison (36808).

Bison lack a dorsal beak like that seen on most cattle, but overall have no distinct traits that can be universally attributed to them with quantitative conviction. However, during the data collection phase of research some bison stylohyoids were noted as displaying a nutrient foramen (a small opening for blood vessels) on the anterior articular surface. The sample below (Figure 22) is one pair of bison stylohyoids with such foramena. This trait was noticed mid-way through the data collection phase of research, and as such it cannot be quantified for the entire sample. However, it was recorded on a total of 6 adult bison (University of Wisconsin-Madison 36499, 36623 and 36808 and Washington State University 95, 97, and 94), but not on any other species.

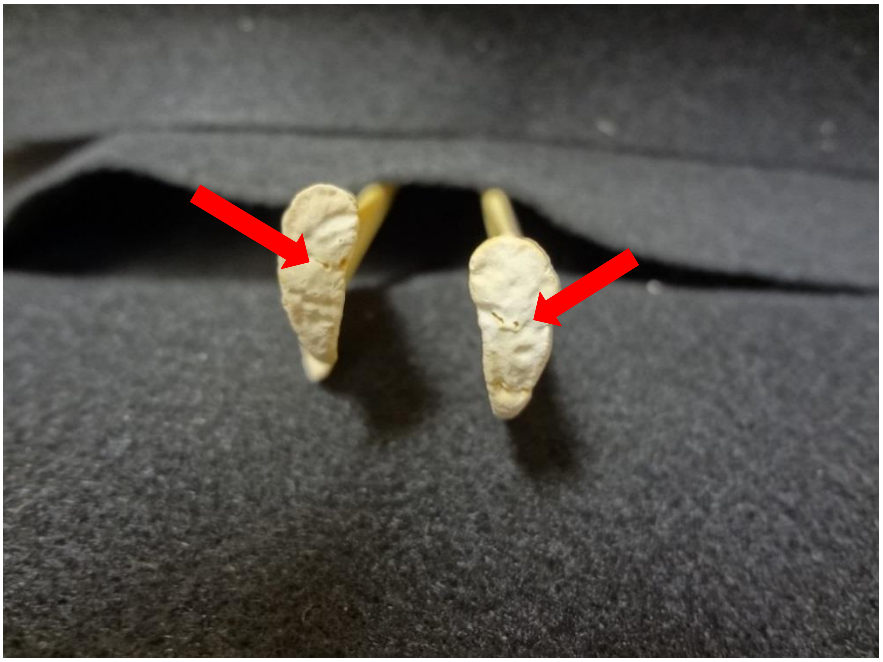


Figure 22. Nutrient foramen on anterior articular surface of *Bison bison*. Samples courtesy of University of University of Wisconsin –Madison (36623 L and R).

Elk *(Cervus elaphus)*, Size Class 6, Cervid

The *Cervus elaphus* samples were derived from the Burke Museum, CWU, University of Wyoming, University of Wisconsin-Madison, UC Berkeley, and the Conner Museum collections. There is a total of 34 samples, with 1 of those being unfused, 1 pathological due to extreme age, and 32 being fully fused. Table 19 summarizes the sample. The sex distribution of the sample is 16 males, 10 females, and 8 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. Of the fused sample, 7 are from the state of Washington, 8 are from Wyoming, 14 are from California, 1 is from Oregon, 1 is from a zoo, and 1 is unknown. The pathological specimen was a 19-year-old zoo animal, and the unfused sample was from the state of Wyoming. Measurement data are provided in Table 20.

Table 19. Summary of *Cervus elaphus* Stylohyoid (Elk) Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	1	1	0	0	0	1	Wyo-8772B;
Pathological	1	1	0	1	0	0	Burke-81997;
Fused	32	24	8	15	10	7	Burke-31682, 31683, 31684, 31685, 32143; Conner-64-73; CWU-60, 313, 358; UC Berkeley-83439, 57123, 57127, 57129, 73108, 83437, 57124, 83436, 57121, 57126, 57128, 83435, 83438, 57125; UWyo-8240B, 8265B, 8268B, 8392B, 8421B, 8494B, 8634B, 8862B; Wisc-31503
Totals	34	26	8	16	10	8	

Table 20. Measurement Data (mm) for Fused *Cervus elaphus* (Elk) Hyoids

Measurement	n	Range	Mean
Maximum Height	30	26.76-47.56	37.70
Maximum Length	30	88.16-136.98	117.38
Anterior Epiphysis Width	29	8.82-14.3	11.75
Anterior Epiphysis Thickness	29	4.46-7.91	5.85
Mid-Shaft Width	32	3.99-9.36	7.19
Mid-Shaft Thickness	32	1.94-4.9	3.62
Dorsal Process Width	30	7.32-11.7	9.62
Dorsal Process Thickness	30	4.86-7.25	5.96
Angle Width	30	1.33-16.12	5.49
Angle Thickness	30	1.09-2.64	1.96

The stylohyoids of elk are typical of the morphological profile displayed by cervids (Figures 23 and 24). Compared to similar sized bovids they are more linear, with gracile mid-shafts and shorter maximum height values on the proximal ends. As such they tend to be less T-shaped than bovids, and their overall appearance is more gracile.

Figure 23. Left stylohyoid from adult *Cervus elaphus*, lateral view. Sample courtesy of the University of Wyoming (8634B).

Figure 24. Left stylohyoid from adult *Cervus elaphus*, dorsal view. Sample courtesy of the University of Wyoming (8634B).

Moose *(Alces americanus)*, Size Class 6, Cervid

The *Alces americanus* samples were derived from CWU, the Burke Museum, University of Wyoming, University of Wisconsin-Madison, the Conner Museum, and UC Berkeley collections. There is a total of 25 samples, with 3 of those being unfused and 22 being fully fused. Table 21 summarizes the sample. The sex distribution is 10 males, 11 females, and 5 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. Of the fused sample 9 are from the state of Wyoming, 1 is from Alaska, 3are from British Columbia, 7 are from a zoo, 1 is from the state of Washington, and 1 is unknown. Of the unfused sample, 2 are from Wyoming and 1 is from Alaska. Measurement data are provided in Table 22, and sample images are provided in Figures 25 and 26.

Table 21. Summary of *Alces americanus* (Moose) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	3	3	0	0	1	3	Conner-13-268; UWyo-8215B, 8473;
Fused	22	16	6	10	10	2	Burke-39424, 39425, 39479, 60332; UCB-43907, 43908,40301; CWU 547; UWyo-8159B, 875B8, 8563B, 8394B, 8412B, 8753B, Unk; Wisc-25694, 25695, 27418, 27438, 27439, 31504, 36920
Totals	25	19	6	10	11	5	

Table 22. Measurement Data (mm) for Fused *Alces americanus* (Moose) Hyoids

Measurement	n	Range	Mean
Maximum Height	21	23.56-48.75	38.23
Maximum Length	20	87.22-162.00	140.75
Anterior Epiphysis Width	20	11.52-19.59	14.86
Anterior Epiphysis Thickness	21	3.57-5.81	4.44
Mid-Shaft Width	22	5.56-9.43	7.66
Mid-Shaft Thickness	22	2.71-4.13	3.53
Dorsal Process Width	21	6.8-12.03	9.36
Dorsal Process Thickness	21	5.44-9.08	7.58
Angle Width	22	3.28-20.48	10.89
Angle Thickness	22	1.31-3.65	2.06

Figure 25. Left stylohyoid from adult *Alces americanus*, lateral view. Sample courtesy of the Burke Museum (39479)
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Figure 26. Left stylohyoid from adult *Alces americanus*, dorsal view. Sample courtesy of the Burke Museum (39479).

The stylohyoids of moose are typical of the morphological profile displayed by cervids. Overall their average dimensions are very similar to elk. One point of interest is the degree of variability that moose stylohyoids display in terms of their angle shape. The photo below (Figure 27) of three moose stylohyoids from the University of Wisconsin-Madison, illustrates the range of angle shapes that the element can display.

Figure 27. Moose stylohyoids with ‘point' (top), ‘blade’ (middle), and ‘rounded’ (bottom) angle shapes, lateral view. Samples courtesy of University of Wisconsin-Madison (27418, 27439, and 36920).

Caribou *(Rangifer tarandus)*, Size Class 6, Cervid

The *Rangifer tarandus* samples were derived from the University of Wyoming, University of Wisconsin-Madison, UC Berkeley, the Conner Museum, and the WSU-Anthropology collections. There is a total of 10 samples, with 1 of those being a unfused and 9 being fully fused. Table 23 summarizes the sample. The sex distribution is 5 males, 3 females, and 2 unknown. As this is a wild species geographic origin might correspond to discernible osteometric differences. Of the fused samples 2 are from Alaska, 3 are from British Columbia, 2 are from zoos, 1 is from a university research herd, and 1 is of unknown origin. The unfused sample is a ranch herd animal.

Measurement data are provided in Table 24, and images are provided in Figures 28 and 29.

Table 23. Summary of *Rangifer tarandus* (Reindeer) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	1	1	0	0	1	0	UWyo-8399B;
Fused	9	4	5	5	2	2	Conner-91-724, 01-59; UCB 42615, 42616, 125601; UWyo-8615B; Wisc-21571, 28566; WSU 324
Totals	10	5	5	5	3	2	

Table 24. Measurement Data (mm) for Fused *Rangifer tarandus* (Caribou) Hyoids

Measurement	n	Range	Mean
Maximum Height	9	21.84-30.29	27.06
Maximum Length	7	88.83-118.17	106.36
Anterior Epiphysis Width	7	6.43-9.15	8.12
Anterior Epiphysis Thickness	7	3.48-6.57	5.30
Mid-Shaft Width	9	4.58-6.51	5.58
Mid-Shaft Thickness	9	2.32-3.58	2.91
Dorsal Process Width	9	5.35-9.83	7.35
Dorsal Process Thickness	9	3.24-5.79	4.48
Angle Width	9	5.47-10.04	7.74
Angle Thickness	9	1.28-2.94	2.19

Figure 28. Left stylohyoid from adult *Rangifer tarandus*, lateral view. Samples courtesy of the University of Wisconsin-Madison (21571).

Figure 29. Left stylohyoid from adult *Rangifer tarandus*, dorsal view. Samples courtesy of the University of Wisconsin-Madison (21571).

The morphology of caribou is typical of cervids in general, and is particularly similar to both *Odocoileus* species. Their average size, however, is somewhere between the larger cervids (elk and moose), and the smaller deer species (white-tail and mule deer). Because caribou lack any unique discrete traits, identification will rely exclusively on their moderate osteometric values.

Horse *(Equus caballus)*, Size Class 6, Equidae

The *Equus caballus* sample was obtained from the CWU and UC Berkeley collections. There was a total sample of 2 specimens, including 1 fused and 1 unfused. Table 25 summarizes the sample. The sex distribution for the sample is 1 female and 1 unknown. As this is a domesticated specie the geographic origin is not very helpful, and no breed information was available. This is the only observed species outside the Order Artiodactyla, and is instead part of the Order Perissodactyla. It was included here for completeness, as it is the only large hoofed mammal besides artiodactyls likely to be found on a North American archaeological site. Measurement data are provided in Table 26, and sample images are provided in Figures 30 and 31.

Table 25. Summary of *Equus caballus* (Horse) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	1	0	1	0	1	0	UCB-140671
Fused	1	1	0	0	0	1	CWU-540
Totals	2	1	1	0	1	1	

Table 26. Measurement Data (mm) for Fused *Equus caballus* (Horse) Hyoid

Measurement	n	Range	Mean
Maximum Height	1	57.82	N/A
Maximum Length	1	189.5	N/A
Anterior Epiphysis Width	1	9.75	N/A
Anterior Epiphysis Thickness	1	4.63	N/A
Mid-Shaft Width	1	13.36	N/A
Mid-Shaft Thickness	1	2.82	N/A
Dorsal Process Width	1	13.60	N/A
Dorsal Process Thickness	1	11.40	N/A
Angle Width	1	9.98	N/A
Angle Thickness	1	3.70	N/A

The stylohyoids of horses are atypical of the morphological profile displayed by either cervids or bovids. The anterior process is very narrow and appears as more of a point, with little of the width or flare that has been seen in artiodactyls. However, given the exceedingly small sample size of one, these observations should be considered descriptive. This species is not considered further in this thesis.

Domestic sheep *(Ovis aries),* Size Class 5, Bovid

The *Ovis aries* samples were derived from the Burke Museum, CWU, University of Wyoming, University of Wisconsin-Madison, UC Berkeley, the Harvard Peabody Museum of Archaeology and Ethnology, and the Conner Museum collections. There was a total of 30 samples, all being fully fused. Table 27 summarizes the sample. The sex distribution for the sample is 2 males, 10 females, and 18 unknown. As this is a domesticated species the geographic origin is not very helpful, but breed could be

Figure 30. Left stylohyoid of *Equus caballus*, lateral view. Sample courtesy of CWU (PL-540).

Figure 31. Left stylohyoid of *Equus caballus*, dorsal view. Sample courtesy of CWU (PL-540).

relevant. Only CWU samples 515 through 524 and 527 and 528 can be attributed to a particular breed. These samples are from a hybrid Texel/Coupworth cross breed. Measurement data are provided in Table 27, and sample images are provided in Figures 32 and 33. The stylohyoids of domestic sheep are typical of the morphological profile displayed by Size Class 5 bovids. Despite being shorter on average than either Bighorn or Dall sheep, domestic sheep appear more robust or heavy for a given length.

Table 27. Summary of *Ovis aries* (Domestic Sheep) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	29	24	6	2	10	18	Burke-74148; Conner 11-11; CWU-18, 172, 263, 271, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 527, 528; Harvard 577AR; UCB-18906, 19029, 90698, 90699; UWyo-8158B; Wisc-20011, 21636, 21706, 21722, 34595, 36486
Totals	30	24	6	2	10	18	

Table 28. Measurement Data (mm) for Fused *Ovis aries* (Domestic Sheep) Hyoids

Measurement	n	Range	Mean
Maximum Height	30	22.10-34.57	28.40
Maximum Length	30	48.51-74.87	59.83
Anterior Epiphysis Width	30	5.94-13.46	10.27
Anterior Epiphysis Thickness	30	1.99-4.21	3.04
Mid-Shaft Width	30	4.12-11.8	5.47
Mid-Shaft Thickness	30	1.50-3.08	2.19
Dorsal Process Width	30	4.1-6.79	5.60
Dorsal Process Thickness	30	2.53-6.22	3.54
Angle Width	30	4.74-9.71	7.06
Angle Thickness	30	2.01-3.44	2.71

Figure 32. Left stylohyoid from adult *Ovis aries*, lateral view. Sample courtesy of the University of Wisconsin-Madison (21636).

Figure 33. Left stylohyoid from adult *Ovis aries*, dorsal view. University of Wisconsin-Madison (21636).

Bighorn sheep *(Ovis canadensis)*, Size Class 5, Bovid

The *Ovis canadensis* samples were derived from the Burke Museum, University of Wyoming, and University of Wisconsin-Madison collections. There is a total of 41 samples, all being fully fused. Table 29 summarizes the sample. The sex distribution for the sample is 9 males, 30 females, and 2 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. A total of 10 are from the state of Colorado, 3 are from the state of Washington, 1 is from the state of Nevada, and 27 are from the state of Wyoming. Measurement data are provided in Table 30, and sample images are provided in Figures 34 and 35.

Table 29. Summary of *Ovis canadensis* (Bighorn Sheep) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	41	34	7	9	30	2	Burke-39468, 39469, 39480, 81686, 81695, 81696; UWyo-8204, 8209, 8210, 8224, 8251, 8252, 8253, 8260, 8269, 8309, 8310, 8334, 8351, 8352, 8355, 8356, 8360, 8380, 8428, 8434, 8475, 8544, 8505, 8565, 8616, 8620, 8628, 8629, 8643, 8855, 9075, 9125, 9376; Wisc-29448, 30702
Totals	41	34	7	9	30	2	

Table 30. Measurement Data (mm) for Fused *Ovis canadensis* (Bighorn Sheep) Hyoids

Measurement	n	Range	Mean
Maximum Height	41	21.08-34.65	28.02
Maximum Length	41	50.17-78.09	65.05
Anterior Epiphysis Width	41	6.74-11.9	8.83
Anterior Epiphysis Thickness	41	2.25-4.15	3.25
Mid-Shaft Width	41	1.8-5.28	4.35
Mid-Shaft Thickness	41	1.23-4.12	1.80
Dorsal Process Width	41	3.91-6.2	5.09
Dorsal Process Thickness	41	2.43-4.9	3.63
Angle Width	40	3.3-8.84	5.99
Angle Thickness	40	1.45-3.53	2.36

Figure 34. Left stylohyoid from seven-year-old *Ovis canadensis*, lateral view. Sample courtesy of the University of Wyoming (8260B).

Figure 35. Left stylohyoid from seven-year-old *Ovis canadensis*, dorsal view. University of Wyoming (8260B).

Dall sheep *(Ovis dalli)*, Size Class 5, Bovid

The *Ovis dalli* samples were derived from the University of Wyoming and University of Wisconsin-Madison collections. There is a total of 6 samples, all being fully fused. Table 31 summarizes the sample. The sex distribution of the sample is evenly split with 3 males and 3 females. As this is a wild species, geographic origin might correspond to discernible osteometric differences, but all 6 specimens are from captive animals. Five are from zoos and 1 is from the University of Alaska research herd. Measurement data are provided in Table 32, and sample images are provided in Figures 36 and 37.

Table 31. Summary of *Ovis dalli* (Dall Sheep) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	6	5	1	3	3	0	UWyo-8767B; Wisc-27437, 27605, 27660, 28562, 36559
Totals	6	5	1	3	3	0	

Table 32. Measurement Data (mm) for Fused *Ovis dalli* (Dall sheep) Hyoids

Measurement	n	Range	Mean
Maximum Height	6	24.13-34.76	28.48
Maximum Length	6	57.94-69.46	64.83
Anterior Epiphysis Width	6	7.23-10.0	8.32
Anterior Epiphysis Thickness	6	2.78-3.67	3.22
Mid-Shaft Width	6	4.2-4.85	4.42
Mid-Shaft Thickness	6	2.18-1.93	1.87
Dorsal Process Width	6	4.4-6.29	5.60
Dorsal Process Thickness	6	3.05-4.46	3.70
Angle Width	6	4.01-6.35	5.26
Angle Thickness	6	1.55-2.61	2.04

Figure 36. Left stylohyoid from adult *Ovis dalli*, lateral view. Sample courtesy of the University of Wisconsin-Madison (28562).

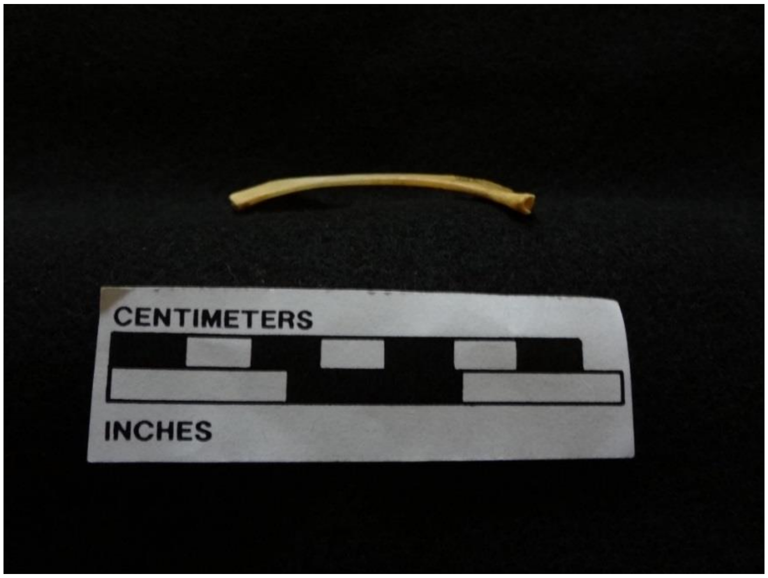

Figure 37. Left stylohyoid from adult *Ovis dalli*, dorsal view. Sample courtesy of the University of Wisconsin-Madison (28562).

The stylohyoids of both Bighorn and Dall sheep are typical of the morphological profile displayed by Size Class 5 bovids. The stylohyoids of both wild sheep species are very similar in terms of dimensions and morphology but are more gracile than domestic sheep, with slightly greater average height and length values.

Domestic goat *(Capra hircus)*, Size Class 5, Bovid

The *Capra hircus* samples were derived from CWU, the UC Berkeley, the Harvard Peabody Museum of Archaeology and Ethnology, and University of Wisconsin-Madison collections. There is a total of 18 samples, all being fully fused. Table 33 summarizes the sample. The sex distribution of the sample is 3 males, 2 females, and 13 unknown. As this is a domesticated species, the geographic origin is not very helpful, but breed could be relevant. Only CWU samples PL-525 and PL-526 can be attributed to a particular breed as Boer goats. Of interesting note, 8 of the specimens are from the Galapagos Islands. Measurement data are provided in Table 34, and sample images are provided in Figures 38 and 39.

Table 33. Summary of *Capra hircus* (Domestic Goat) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	18	12	6	3	2	13	CWU-525, 526; Harvard 342AR, 399AR, 536AR, 607AR, 504AR, 396AR; UCB-18976, 90729, 125520, 125525; Wisc-22325, 25767, 25768, 25769, 29614, 30291
Totals	18	12	6	3	2	13	

Table 34. Measurement Data (mm) for Fused *Capra hircus* (Domestic Goat) Hyoids

Measurement	n	Range	Mean
Maximum Height	16	23.05-36.21	27.98
Maximum Length	16	48.80-65.69	58.00
Anterior Epiphysis Width	16	6.13-10.36	8.02
Anterior Epiphysis Thickness	16	2.00-4.05	2.87
Mid-Shaft Width	18	4.06-6.66	4.79
Mid-Shaft Thickness	18	1.16-2.39	1.80
Dorsal Process Width	17	3.74-6.75	4.96
Dorsal Process Thickness	17	2.43-4.48	3.33
Angle Width	15	3.48-5.51	4.48
Angle Thickness	15	1.29-2.81	1.90

Figure 38. Left stylohyoid from adult *Capra hircus*, lateral view. Sample of the University of Wisconsin-Madison (29614).

Figure 39. Left stylohyoid from adult *Capra hircus*, dorsal view. Sample of the University of Wisconsin-Madison (29614).

Mountain goat *(Oreamnos americanus)*, Size Class 5, Bovid

The *Oreamnos americanus* samples were derived from the Burke Museum, University of Wyoming, UC Berkeley, and the Conner Museum collections. There is a total of 8 samples, with 2 unfused, and 6 being fully fused. Table 35 summarizes the sample. The sex distribution of the sample is 4 males, 2 females, and 2 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. Of the fused sample, 1 is from Wyoming, 1 is from Colorado, 1 is from British Columbia, and 3 are from Washington State. The 2 unfused samples are from Colorado and Washington. Measurement data are provided in Table 36, and sample images are provided in Figures 40 and 41.

Table 35. Summary of *Oreamnos americanus* (Mountain Goat) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	2	2	0	1	0	1	Conner 47-184; UWyo-8195B;
Fused	6	3	3	3	2	1	Burke-59673; Conner 42-27, 49-23; UWyo-8442B, 9074; UCB-43909
Totals	8	5	3	4	2	2	

The stylohyoids of both domestic and wild goats are typical of the morphological profile displayed by Size Class 5 bovids. They follow the general T-shaped pattern, with relatively high maximum height values for a given length. However their osteometric values are different enough that reliable separation of *Capra* and *Oreamnos* is possible as detailed below.

Table 36. Measurement Data (mm) for Fused *Oreamnos americanus* (Mountain Goat) Hyoids

Measurement	n	Range	Mean
Maximum Height	5	22.75-37.08	28.80
Maximum Length	4	74.38-89.01	81.95
Anterior Epiphysis Width	4	7.85-11.23	9.36
Anterior Epiphysis Thickness	4	3.13-4.22	3.66
Mid-Shaft Width	6	4.14-6.35	5.32
Mid-Shaft Thickness	6	2.23-3.63	2.84
Dorsal Process Width	5	6.02-7.15	6.56
Dorsal Process Thickness	5	3.43-4.42	3.90
Angle Width	6	5.03-7.30	6.72
Angle Thickness	6	1.41-3.13	2.57

Figure 40. Right stylohyoid from adult *Oreamnos americanus*, lateral view. Sample courtesy of the University of Wyoming (8442B).

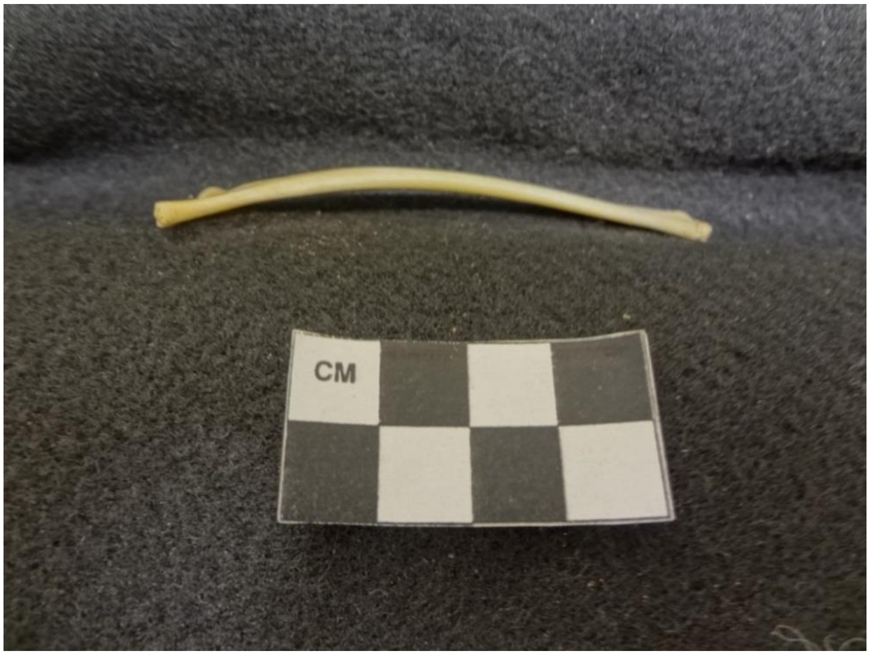

Figure 41. Right stylohyoid from adult *Oreamnos americanus*, dorsal view. Sample courtesy of the University of Wyoming (8442B).

Mule deer *(Odocoileus hemionus)*, Size Class 5, Cervid

The *Odocoileus hemionus* samples were derived from the Burke Museum, CWU, University of Wyoming, and University of Wisconsin-Madison collections. There is a total of 36 samples, all being fully fused. Table 37 summarizes the sample. The sex distribution for the sample is almost evenly split, with 18 males, 17 females, and 1 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. One is from the state of Alaska, 20 are from the state of Washington, 1 is from New Mexico, and 14 are from Wyoming. Measurement data are provided in Table 38, and sample images are provided in Figures 42 and 43.

Table 37. Summary of *Odocoileus hemionus* (Mule Deer) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	36	32	4	18	17	1	Burke-32087, 32098, 32620, 33428, 33456, 34272, 59658, 59660, 59661, 59662, 59663, 59664, 59665, 59666, 59667, 59671, 75784, 82193; CWU-59, 494, 495, 498; UWyo-8168B, 8226B, 8227B, 8365B, 8411B, 8414B, 8476B, 8525B, 8810B, 8811B, 9390B, 9483B; Wisc-20004, 25620
Totals	36	32	4	18	17	1	

Table 38. Measurement Data (mm) for Fused *Odocoileus hemionus* (Mule Deer) Hyoids

Measurement	n	Range	Mean
Maximum Height	36	12.05-30.72	20.53
Maximum Length	36	50.62-85.44	71.35
Anterior Epiphysis Width	36	3.96-7.93	5.98
Anterior Epiphysis Thickness	36	2.27-3.61	3.03
Mid-Shaft Width	36	3.43-5.29	4.20
Mid-Shaft Thickness	36	1.22-3.3	1.85
Dorsal Process Width	36	3.53-5.77	4.56
Dorsal Process Thickness	36	3.01-6.15	4.02
Angle Width	36	3.00-8.38	5.47
Angle Thickness	36	1.32-2.45	1.84

The stylohyoids of mule deer are typical of the morphological profile displayed by cervids. Compared to similar-sized bovids they are more linear and tend to be less T-shaped, displaying a more Y-shaped profile.

Figure 42. Left stylohyoid from adult *Odocoileus hemionus*, lateral view. Sample courtesy of the University of Wyoming (9483B).

Figure 43. Left stylohyoid from adult *Odocoileus hemionus*, dorsal view. Sample courtesy of the University of Wyoming (9483B).

White-tailed deer *(Odocoileus virginianus)*, Size Class 5, Cervid

The *Odocoileus virginianus* samples were derived from the Burke Museum, CWU, University of Wyoming, and University of Wisconsin-Madison collections. There is a total of 40 samples, all being fully fused. Table 39 summarizes the sample. The sex distribution of the sample is 25 males, 12 females, and 3 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. Ten are from the state of Wyoming, 6 are from the state of Washington, 2 are from Saskatchewan, 1 is from North Dakota, 1 is from Georgia, 1 is from Arizona, 18 are from the state of Wisconsin, and 1 is from a zoo. Measurement data are provided in Table 40, and sample images are provided in Figures 44 and 45.

Table 39. Summary of *Odocoileus virginianus* (White-Tailed Deer) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	40	30	10	25	12	3	Burke-32122, 32123, 32130, 32132, 32135; CWU-8, 189, 286, 481; UWyo-8067B, 8160B, 8244B, 8245B, 8495B, 8539B, 8562B, 8570B, 8630B, 8754B, 8797B, 8868B, 9071B; Wisc-21957, 23460, 25627, 25659, 30637, 30638, 30639, 30640, 30641, 60342, 30643, 30644, 30645, 31629, 34364, 34455, 37155,37643
Totals	40	30	10	25	12	3	

Table 40. Measurement Data (mm) for Fused *Odocoileus virginianus* (White-Tailed Deer) Hyoids

Measurement	n	Range	Mean
Maximum Height	40	5.18-29.86	22.21
Maximum Length	40	47.28-94.56	74.29
Anterior Epiphysis Width	40	4.44-8.46	6.66
Anterior Epiphysis Thickness	40	1.82-5.26	3.08
Mid-Shaft Width	40	3.29-5.33	4.53
Mid-Shaft Thickness	40	1.3-6.15	2.11
Dorsal Process Width	40	3.0-6.49	4.94
Dorsal Process Thickness	40	2.98-7.52	4.48
Angle Width	40	2.47-9.48	5.59
Angle Thickness	40	1.16-4.84	2.30

Figure 44. Left stylohyoid from adult *Odocoileus virginianus*, lateral view. Sample courtesy of CWU (PL-286).

Figure 45. Left stylohyoid from adult *Odocoileus virginianus*, dorsal view. Sample courtesy of CWU (PL-286).

The stylohyoids of both white-tail and mule deer are typical of the morphological profile displayed by cervids. Compared to similar sized bovids they are more linear and tend to be less T-shaped, displaying a more Y-shaped profile. The overall morphological profiles of mule and white-tail deer are so similar it is impossible to osteometrically differentiate between the two using any single measurement or ratio.

Pronghorn antelope (*Antilocapra americana*), Size Class 5, Antilocapridae

The *Antilocapra americana* samples were derived from the Burke Museum, CWU, University of Wyoming, and University of Wisconsin-Madison collections. There is a total of 52 samples, all being fully fused. Table 41 summarizes the sample. The sex distribution of the sample is 19 males, 27 females, and 6 unknown. As this is a wild species, geographic origin might correspond to discernible osteometric differences. Forty-seven are from the state of Wyoming, 4 are from the state of Colorado, and 1 is unknown. Measurement data are provided in Table 42.

Table 41. Summary of *Antilocapra americana* (Pronghorn Antelope) Stylohyoid Sample

Category	Total	Side		Sex			
		Left	Right	Male	Female	Unk	Collection location & specimen number
Unfused	0	0	0	0	0	0	N.A.
Fused	52	40	12	19	27	6	Burke-33495, 33496, 33497, 33498, 33500, 34166, 34314, 34315, 38617, 38618, 38619, 38620, 38622, 39423; CWU-38, 57, 62; UWyo-8080B, 8081B, 8083B, 8084B, 8086B, 8199B, 8361B, 8403B, 8409B, 9091B, 9093B, 9094B, 9099B, 9100B, 9101B, 9102B, 9103B, 9104B, 9107B, 9109B, 9112B 9113B, 9117B, 9271B, 9273B, 9281B, 9314B, 9980B, 9981B; Wisc-16420, 27450, 27456, 25162, 27452, 27458
Totals	52	40	12	19	27	6	

Table 42. Measurement Data (mm) for Fused *Antilocapra americana* (Pronghorn Antelope) Hyoids

Measurement	n	Range	Mean
Maximum Height	52	15.11-31.03	22.95
Maximum Length	47	62.64-90.33	77.60
Anterior Epiphysis Width	46	3.59-5.93	4.67
Anterior Epiphysis Thickness	47	2.57-4.08	3.21
Mid-Shaft Width	51	2.99-4.36	3.83
Mid-Shaft Thickness	51	1.16-2.34	1.72
Dorsal Process Width	52	3.5-6.47	4.79
Dorsal Process Thickness	52	1.97-4.42	3.28
Angle Width	52	7.66-17.11	10.99
Angle Thickness	49	1.00-2.95	1.81

Overall antelope stylohyoids are distinctive in their long, straight, gracile body, in terms of angle morphology, and in having a uniquely S-curve when viewed dorsally (Figures 46 and 47). Another of the antelope's unique traits is the shape variability of the angle. This includes blade-forward, blade-backward, rounded, and hook type angle shapes (Figure 48).

Figure 46. Left stylohyoid from adult *Antilocapra americana*, lateral view. Sample courtesy of the University of Wisconsin-Madison (25162).

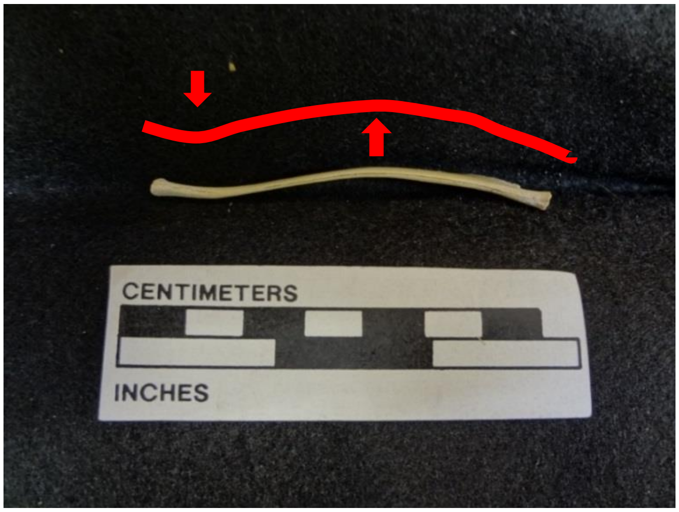

Figure 47. Left stylohyoid from adult *Antilocapra americana*, dorsal view with unique S-curve indicated by red line and arrows. Samples courtesy of University of the Wisconsin-Madison (25162).

Rounded angle (University of Wyoming (8361B)

Hook angle (University of Wyoming 8409B).

Blade-backward angle (University of Wyoming 9981B).

Blade-forward angle (University of Wisconsin 25162).

Figure 48. Variation in angle morphology of pronghorn antelope. All are left stylohyoids from adult animals.

Domestic pig (*Sus scrofa*), Size Class 5, Suidae

The *Sus scrofa* samples were derived from the Harvard Peabody Museum of Archaeology and Ethnology. There were a total of 2 samples. The morphology of *Sus scrofa* is so radically different (Figure 49) from other artiodactyls or *Equus caballus* no useful comparisons can be made. Pigs will therefore not be addressed further as part of this research. It should be noted that the basihyoid is quite distinctive and could be used instead (see Figure 50) as described in Dimitrov et al. (2014) for distinguishing between wild and domestic pigs using that element.

Figure 49. Stylohyoid from *Sus scrofa*, unknown view or side. Sample courtesy the Harvard Peabody Museum of Archaeology and Ethnology (ZM627AR).

Figure 50. Basihyoid from *Sus scrofa*, ventral view. Sample courtesy of CWU (PL-478).

Distinguishing Between Taxa

In order to facilitate a clear understanding of how best to utilize the following information when identifying taxa, a simple strategy will be suggested. When dealing with an unknown stylohyoid researchers should begin their analysis by asking the broadest question possible, and pare down their classification to the level of species. It would be most practical to use the following sequence of questions regarding the element in question: What size animal does it represent? What Linnaean family does the element represent? What species does the element represent?

Small vs. Large Ungulates

The first distinction to be made in separating hyoids by species is by general size group. Species are divided into one of two general Size Class categories developed by Dr.

Lubinski (Lubinski 2013:131). Small ungulates (hoofed mammals), comprising Lubinski's Size Class 5, are defined as animals ranging between 25-200 kilograms and include domestic sheep, bighorn sheep, Dall sheep, domestic goat, mountain goat, mule deer, white-tail deer, and pronghorn antelope. Large ungulates, comprising Lubinski's Size Class 6, are defined as animals ranging between 200-1500 kilograms, and include domestic cattle, bison, elk, moose, caribou, and horse.

The small vs. large ungulate distinction is made fairly readily by maximum length. Utilizing a 91 mm cut-off to separate the size groups' results in a correct category placement for 302 out of 306 (98.7%) specimens. More specifically 219 out of 220 small ungulates and 83 out of 86 large ungulates fall on the 'correct' side of the 91 mm cut-off.

The four outliers that fell on the 'wrong' side of the 91 mm cut-off include one *Alces* (87.2 mm), one *Cervus* (88.2 mm), one *Rangifer* (88.8 mm), and one *O. virginianus* (94.6 mm). It was not possible to obtain a maximum length measurement on nineteen (n = 19) fused stylohyoids from the total metric sample (n = 325), due to missing anterior or posterior portions of the element. For a full quantitative description of separating animal size by maximum length (ML) see Table 43.

Table 43. Separating Small and Large Ungulates by Maximum Length*

Size	ML <91 mm	ML ≥91 mm	Success Ratio	Success Probability
Small	219	1	219/220	99.5%
Large	3	83	83/86	96.5%
Totals	222	84	302/306	98.7%

* The Size Class 5 sample that fell below the 91 mm cut-off included all antelope (n = 47), all *Capra* (n = 16), all *O. hemionus* (n = 35), all but one *O. virginianus* (n = 39), all *Oreamnos* (n = 4), all *O. aries* (n = 30), all *O. canadensis* (n = 41), and all *O. dalli* (n = 6). The Size Class 6 sample with values equal to or greater than the 91 mm cut-off include all but one *Alces* (n = 19), all *Bison* (n = 23), all *Bos* (n = 5), all but one *Cervus* (n = 29), all *Equus* (n = 1), and all but one *Rangifer* (n = 6). Outliers that fell on the 'wrong'

side of the 91 mm cut-off include one *Alces* (87.2 mm), one *Cervus* (88.2 mm), one *Rangifer* (88.8 mm), and one *O. virginianus* (94.6 mm).

A convenient alternative to ML for separating small vs. large ungulates is made possible by the dorsal-process width (DPW) measurement. Utilizing a 6.8 mm cut-off to separate the size group's places 315 out of 320 specimens into the correct size category. More specifically 226 out of 227 small ungulates, and 89 out of 93 large ungulates fall on the 'correct' side of the 6.8 mm cut-off. The five outliers that fell on the 'wrong' side of the 6.8 mm cut-off include one *Oreamnos* (7.2 mm), three *Rangifer* (6.7 mm, 6.2 mm, and 5.4 mm), and one *Bison* (4.2 mm). This division gives a total probability for correctly dividing small and large ungulates of 98.4%, and is therefore almost as reliable as ML. However DPW may be a more practical divisor when dealing with partial elements which lack the more fragile anterior end. For a full quantitative description of separating animal size by dorsal-process width (DPW) see Table 44. It was not possible to obtain a DPW measurement on five fused stylohyoids from the total metric sample (n = 325), due to the element being incomplete.

Table 44. Separating Small and Large Ungulates by Dorsal Process Width*

	DPW <6.8 mm	DPW ≥6.8	Success Ratio	Success Probability
Small	226	1	226/227	99.6%
Large	4	89	89/93	95.7%
Totals	230	90	315/320	98.4%

*The Size Class 5 sample that fell below the 6.8 mm cut-off included all antelope (n = 52), all *Capra* (n = 17), all *O. hemionus* (n = 36), all *O. virginianus* (n = 40), all but one *Oreamnos* (n = 4), all *O. aries* (n = 30), all *O. canadensis* (n = 41), and all *O. dalli* (n = 6). The Size Class 6 sample with values equal to or greater than the 6.8 mm cut-off include all *Alces* (n = 21), all but one *Bison* (n = 25), all *Bos* (n = 6), all *Cervus* (n = 29), all *Equus* (n = 1), and all but three *Rangifer* (n = 6). Outliers that fell on the 'wrong' side of the 6.8 mm cut-off include one *Oreamnos* (7.2 mm), three *Rangifer* (6.7 mm, 6.2 mm, and 5.4 mm), and one *Bison* (4.2 mm).

If both the maximum length and the dorsal process width are used together, one could gain confidence in size group assignment by combining the probabilities. Adding probabilities follows the formula 1-((1-A)*(1-B)). So, for example, if one had an unknown hyoid with a ML of 90 mm and a DPW of 6.5, there is a 99.5% (A) probability of being a small ungulate from the first measure and a 99.6% (B) probability for the second measure. In decimals A becomes 0.995, and B becomes 0.996. Combining these probabilities results in the following formula;

$$1 - ((1-0.995) * (1-0.996)) = 0.99998$$

This corresponds with a 99.998% probability that it is a small ungulate. A similar approach can be taken with all group distinctions below that have multiple separation criteria, including distinct traits.

To test for an alternative to length for separating small vs. large ungulates, I attempted to use maximum height (MH). This attempt is shown in Table 45. This metric was not very successful, especially for Size 6 ungulates, and so was not investigated further. It is not recommended if ML or DPW is available.

Table 45. Separating Small and Large Ungulates by Maximum Height

Size	MH <35 mm	MH ≥35 mm	Success Ratio	Success Probability
Small	224	2	224/226	99.1%
Large	22	70	70/92	76.1%
Totals	246	72	294/318	92.5%

Bovids vs. Cervids

Once a hyoid is assigned to either the small or large ungulate category based on either ML or DPW, the next logical step is to separate bovids from cervids. There is an easy metric way to separate deer, elk, moose and antelope from cattle, bison, sheep and goats. This ready distinction can be made between antilocaprids (pronghorn family) and cervids on one side, and bovids on the other using their Max Length/Max Height (ML/MH) ratio. The bovids have more T-shaped stylohyoids with relatively longer angles than the other groups. This observation is borne out with similar ML/MH ratios for most of the specimens in our sample. In this case 118 out of 124 bovids, 129 out of 133 cervids, and 45 out of 47 antelope have values on a predictable side of the 2.8 ML/MH cutoff. Put yet another way, 96.3% of this sample follows the observed morphological pattern. For all species only six bovids had an ML/MH value greater than 2.8, and only four cervids and two antelope had a value less than 2.8. This is from a total sample of (n = 304) specimens that had measurable ML/MH ratios. This metric grouping provides a convenient and quantitatively justifiable means of separating the more Y-shaped cervids/antilocaprids from the more T-shaped bovids. Table 46 summarizes the use of ML/MH for separating bovids from cervids and antelope for the entire sample.

Table 46. Separating Bovids from Cervids/Antelope by ML/MH*

Taxa	ML/MH <2.8	ML/MH ≥2.8	Success Ratio	Success Probability
Bovids	118	6	118/124	95.2%
Cervids/antelope	6	174	174/180	96.7%
Totals	124	180	292/304	96.1%

*The bovid sample with values below the 2.8 cut off include twenty-two *Bison* (n = 22), five *Bos* (n = 5), fifteen *Capra* (n = 15), one *Oreamnos* (n = 1), thirty *O. aries* (n = 30), thirty-nine *O. canadensis* (n = 39), and all six *O. dalli* (n = 6). The cervid/antelope sample with values above the cut-off include forty-five antelope (n = 45), twenty *Alces* (n = 20), twenty-nine *Cervus* (n = 29), thirty-five *O. hemionus* (n = 35), thirty-eight *O. virginianus* (n = 38), and seven *Rangifer* (n = 7). Outliers on the wrong side of the cut-off included three *Oreamnos* (2.8, 2.9, and 3.3), two *O. canadensis* (2.9 and 3.1), one *Bison* (2.9), two antelope (2.6 and 2.7), one *Cervus* (2.6), one *O. hemionus* (2.4), and two *O. virginianus* (2.3 and 2.4).

The following two tables (Tables 47 and 48) summarize the success rates for using ML/MH on large and then small ungulates respectively, with cut-offs of 2.8 and 3 respectively. The third table (Table 49) addresses small ungulates as well, but excludes antelope from the analysis. Again such an approach would be useful if the researcher were to separate small and large ungulates initially, then move on to more specific discriminatory questions.

Table 47. Success Rates for Separating Large Bovids from Cervids/*Equus* Using ML/MH*

	ML <2.8	ML ≥2.8	Success Ratio	Success Probability
Bovids	27	1	27/28	96.4%
Cervids/*Equus*	1	57	57/58	98.3%
Totals	28	58	84/86	97.7%

*The Size Class 6 bovid sample with values below the 2.8 cut-off includes all but one *Bison* (n = 22), and all *Bos* (n = 5). The Size Class 6 Cervid/*Equus* sample with values greater than or equal to the 2.8 cut-off includes all *Alces* (n = 20), all but one *Cervus* (n = 29), all *Equus* (n = 1), and all *Rangifer* (n = 7). Outliers that fell on the 'wrong' side of the 2.8 cut-off include one *Bison* (2.9) and one *Cervus* (2.6).

Table 48. Separating Small Bovids from Small Cervids/Antelope by ML/MH*

Taxa	ML/MH <3.0	ML/MH ≥3.0	Success Ratio	Success Probability
Small bovids	94	2	94/96	98.0%
Small cervids/antilocaprids	6	117	117/123	95.1%
Totals	100	119	211/219	96.3%

*Outliers that fell on the wrong side of the 3.0 cut-off include three *O. virginianus* (2.3, 2.4, and 2.8), one *O. hemionus* (2.4), two antelope (2.6 and 2.7), one *O. canadensis* (3.1), and one *Oreamnos* (3.3).

Table 49. Separating Small Bovids from Cervids by ML/MH (Excludes Pronghorn)*

Taxa	ML/MH <3.0	ML/MH ≥3.0	Success Ratio	Success Probability
Small bovids	94	2	94/96	97.9%
Small cervids	4	72	72/76	94.7%
Totals	98	74	166/172	96.5%

*Outliers that fell on the wrong side of the 3.0 cut-off include three *O. virginianus* (2.3, 2.4, and 2.8), one *O. hemionus* (2.4), one *O. canadensis* (3.1), and one *Oreamnos* (3.3).

Table 50 summarizes an alternative metric (ML/AEW) for separating small bovids from small cervids. ML/AEW is slightly more effective than ML/MH for this purpose (97.7% vs.96.5% success probability), and increases the total available sample by n = 1.

Table 50. Success Rates for Separating Small Bovids from Cervids Using ML/AEW*

	ML/AEW ≤9.0	ML/AEW >9.0	Success Ratio	Success Probability
Small Bovids	94	3	94/97	96.9%
Small Cervids	1	75	75/76	98.7%
Totals	95	78	169/173	97.7%

*The SC 5 bovid sample with values below or equal to the 9.0 cut-off include all *Capra* (n = 10), all but one *Oreamnos* (n = 3), all but one *O. aries* (n = 28), all *O. canadensis* (n = 41), and all but one *O. dalli* (n = 5). The Size Class 5 cervid sample with values greater than the 9 cut-off include all *O. hemionus* (n = 36), and all but one *O. virginianus* (n = 39). Outliers on the 'wrong' side of the 9 cut-off include one *O. virginianus* (7.7), one *Oreamnos* (9.5), one *O. aries* (9.4), and one *O. dalli* (9.2).

Unfortunately the same metric does not work well for separating large bovids and small cervids. The overall success probability for ML/AEW falls from 97.7% when used for small ungulates, to 72.3% when used to separate larger animals (Table 51).

Table 51. Success Rate for Separating Large Bovids from Cervids Using ML/AEW

	ML/AEW <9.4	ML/AEW ≥9.4	Success Ratio	Success Probability
Large Bovids	18	10	18/28	64.3%
Large Cervids	13	42	42/55	76.4%
Totals	31	52	60/83	72.3%

ML/AEW is also a decent metric for separating antelope from small cervids/bovids. If a cut-off of 14.4 (Table 52) is utilized the success ratios will be 42/46 for antelope, and 169/173 for small cervids/bovids. These ratios produce success probabilities of 91.3% and 97.7% respectively. The outliers will be limited to four (n = 4) antelope, one (n = 1) *O. virginianus*, and three (n = 3) *O. hemionus*. Small bovids are well isolated by the 14.4 cut-off, and do not show values any larger than 9.5.

Table 52. Success Rate for Separating Antelope from Small Cervids/Bovids with ML/AEW*

	ML/AEW <14.4	ML/AEW ≥14.4	Success Ratio	Success Probability
Antelope	4	46	42/46	91.3%
Small cervids/bovids	169	4 (cervids)	169/173	97.7%
Totals	173	50	201/219	96.2%

* The outliers are limited to four antelope (12.9, 13.1, 12.2, and 13.5), one *O. virginianus* (15.2), and three *O. hemionus* (15.1, 15.4, and 15.8).

Large Bovids (*Bison* vs. *Bos*)

After separating bovids from cervids/antelope, the next logical step is to separate closely related species within the same Size Class. If dealing with a large bovid hyoid, the only two possibilities are domestic cattle or bison. Domestic cattle and bison can be reliably separated using discrete trait analysis, discriminatory metrics, or a combination of both. As a general rule it is easiest to differentiate *Bos taurus* from *Bison bison* by the presence or absence of the dorsal beak, which is absent on all of the bison in our sample (see Table 53 for success rate).

Table 53. Success Rates for Separating *Bos* from *Bison* Using Dorsal Beak

	Dorsal beak present	Dorsal beak absent	Success Ratio	Success Probability
Bos	15	3	14/17	82.4%
Bison	0	44	44/44	100%
Totals	15	47	58/61	95.1%

The stylohyoids of bison also have a fairly unique gross morphology that is easily discernible from similar-sized cervids, and fairly distinct from its closest related species observed here, domestic cattle (see Figure 51). Bison stylohyoids are relatively robust and can be exceptionally long, with a maximum length value of 193.5 mm. While relatively robust it is worth noting that their mean measurements are universally smaller than domestic cattle. Their general morphology when compared to domestic cattle appears less extreme, with more moderate end dimensions and a more moderate convexity. Two useful metrics for separating cattle and bison are ML/All Thick and ML/DPT (see Tables 54 and 55). Both provide 100% separation given the current sample, although samples larger than the ones used here (especially for cattle at n = 5) might yield lower success ratios.

Figure 51. Comparison of *Bos taurus* (top) and *Bison bison* (bottom), both Size Class 6 bovids, lateral view. Samples courtesy of University of Wisconsin –Madison (36489 and 36808).

Table 54. Success Rates for Separating *Bos* from *Bison* Using ML/All Thick

	ML/All Thick <5	ML/All Thick ≥5	Success Ratio	Success Probability
Bos	5	0	5/5	100%
Bison	0	23	23/23	100%
Totals	5	23	28/28	100%

*"All Thick" refers to AET, MST, PDT, and AT combined. The entire *Bos taurus* sample (n = 5) fell below the 5 cut-off, and the entire *Bison* sample (n = 23) scored values above that same cut-off.

Table 55. Success Rates for Separating *Bos* from *Bison* Using ML/DPT

	ML/DPT<14	ML/DPT ≥14	Success Ratio	Success Probability
Bos	5	0	5/5	100%
Bison	0	23	23/23	100%
Totals	5	23	28/28	100%

*The entire *Bos taurus* sample (n = 5) fell below the 14 cut-off, and the entire *Bison* sample (n = 23) scored values above that same cut-off.

Large Cervids (*Alces* vs. *Cervus* vs. *Rangifer*)

If identifying large cervid hyoid the three possibilities are elk, moose, or caribou. It is possible to separate these three species based on either discrete traits, discriminatory metrics, or a combination of both. The stylohyoids of all three are typical of the morphological profile displayed by cervids. Moose and elk are very similar in their overall dimensions, while caribou are intermediate between elk and moose on one hand, and both deer species on the other. The basic morphology of caribou more closely resembles white-tail and mule deer than either elk or moose.

Moose and caribou stylohyoids have one distinctive trait that sets them apart from elk. The anterior-ventral portion (AVP) of the stylohyoid is rounded or “sled-like”, compared to the obtuse angle seen in elk. Again this trait is highly reliable. In the moose sample 21 of 21 specimens exhibit a rounded AVP as do 8 of 9 caribou. Conversely, an obtuse AVP was observed in 28 of 31 elk specimens (Figures 52 and 53; Table 56).

Figure 52. Elk hyoid with obtuse angle of the anterior-ventral portion, indicated by red line, lateral view. Sample courtesy of CWU (PL-358).

Figure 53. Moose stylohyoid with rounded anterior-ventral portion, indicated by red line, lateral view. Sample courtesy of the University of Wisconsin-Madison (UWZS-25695).

Table 56. Discrete Trait Analysis for Obtuse or Rounded Anterior-Ventral Portion (AVP)

Species	Obtuse AVP	Rounded AVP	Success Ratio	Success Probability
Elk	28	3	28/31	90.3%
Moose	0	21	21/21	100%
Caribou	1	8	8/9	88.9%
Totals	29	32	57/61	93.4%

Multiple discriminatory metrics are available for reliably separating large cervids. For example, *Rangifer* can be separated from *Alces* and *Cervus* by way of either AEW or ML/AEW+DPT. The AEW measurement (Table 57) provides an almost perfect division of the sample, with a single outlier (n = 1 *Cervus*) on the wrong side of the 9.5 mm cut-off, and a total success probability of 98.2%. Using ML/AEW+DPT (Table 58) perfectly divides the *Rangifer* sample from *Cervus/Alces*.

Table 57. Success Rates for Separating *Rangifer* from *Cervus*/*Alces* Using AEW*

	AEW <9.5 mm	AEW ≥9.5 mm	Success Ratio	Success Probability
Rangifer	7	0	7/7	100%
Cervus/Alces	1	48	48/49	98%
Totals	8	48	55/56	98.2%

*The entire *Rangifer* sample (n = 7) fell below the 9.5 mm cut-off, and all but one of the *Cervus/Alces* sample (n = 48) fell above the cut-off. The single *Cervus* outlier that fell on the wrong side of the cut-off has a value of 8.8 mm.

Table 58. Success Rates for Separating *Rangifer* from *Cervus*/*Alces* Using ML/AEW+DPT*

	AEW <7.7 mm	AEW ≥7.7 mm	Success Ratio	Success Probability
Rangifer	7	0	7/7	100%
Cervus/Alces	0	49	49/49	100%
Totals	7	49	56/56	100%

*The entire *Rangifer* sample (n = 7) fell below the 7.7 cut-off, and the entire *Cervus/Alces sample* (n = 49) fell above the cut-off.

Now that caribou have been isolated from the large cervid category, the next step would be to separate *Cervus* and *Alces*. The most effective metrics for doing so include ML/AET (Table 59) and ML/All Thick (Table 60). ML/AET separates the elk and moose sample almost perfectly, having only a single *Alces* outlier that falls on the wrong side of the cut-off, and a combined success probability of 98%. ML/All Thick is almost as effective, with only two outliers on the wrong sides of the cut-off (one *Alces* and one *Cervus*), and a combined success rate of 95.9%.

Table 59. Success Rates for Separating *Cervus* from *Alces* Using ML/AET*

	ML/AET <26	ML/AET ≥26	Success Ratio	Success Probability
Cervus	29	0	29/29	100%
Alces	1	19	19/20	94.7%
Totals	30	19	48/49	98%

*The entire *Cervus* (n = 29) sample fell below the 26 cut-off, and all but one (n = 9) of the *Alces* sample fell above the cut-off. The single *Alces* outlier has a value of 21.3.

Table 60. Success Rates for Separating *Cervus* from *Alces* Using ML/All Thick*

	ML/All Thick <7.4	ML/All Thick ≥7.4	Success Ratio	Success Probability
Cervus	28	1	28/29	95%
Alces	1	19	19/20	96.6%
Totals	29	20	47/49	95.9%

*The single *Cervus* outlier on the wrong side of the cutoff has a value of 8.4, and the single *Alces* outlier has a value of 5.2.

It is also possible to separate *Cervus* and *Rangifer* from one another by way of ML/AEW+MSW (Table 61) and ML/AEW (Table 62). While somewhat cumbersome because it requires three different measurements, ML/AEW+MSW separates the two large cervid species in question with a 100% success probability. Only slightly less reliable for the purpose of separating *Cervus* and *Rangifer* is the ML/AEW metric. When MSW is dropped from the equation the cut-off changes to from 7 to 12, and a single *Cervus* falls on the wrong side of the cut-off. The combined success rate for ML/AEW is 97.2%.

Table 61. Success Rates for Separating *Cervus* from *Rangifer* Using ML/AEW+MSW*

	ML/AEW+MSW <7	ML/AEW+MSW ≥7	Success Ratio	Success Probability
Cervus	29	0	29/29	100%
Rangifer	0	7	7/7	100%
Totals	29	7	36/36	100%

*The entire *Cervus* sample (n = 29) fell below the 7 cut-off, and the entire *Rangifer* sample (n = 7) scored values above that same cut-off.

Table 62. Success Rates for Separating *Cervus* from *Rangifer* Using ML/AEW*

	ML/AEW <12	ML/AEW ≥12	Success Ratio	Success Probability
Cervus	28	1	28/29	96.6%
Rangifer	0	7	7/7	100%
Totals	28	8	35/36	97.2%

*All but one of the *Cervus* sample (n = 28) fell below the 12 cut-off. The entire *Rangifer* sample fell above the 12 cut-off (n = 7). The single *Cervus* outlier (n = 1) on the ‘wrong’ side of the 12 cut-off has a value of 12.6.

Also, *Alces* can be separated from *Rangifer* by way of AEW or by ML/AEW+DPT (in much the same way that these two metrics were used to separate *Rangifer* from *Cervus/Alces* previously). These two particular metrics are 100% successful when separating just *Alces* and *Rangifer*. AEW has the benefit of simplicity, and it increases the sample by n = 1 when used instead of the more complicated ML/AEW+DPT. Tables 63 and 64 summarize the discriminatory data for these metrics.

Table 63. Success Rates for Separating *Alces* from *Rangifer* Using AEW*

	AEW <11 mm	AEW ≥11 mm	Success Ratio	Success Probability
Alces	0	20	20/20	100%
Rangifer	7	0	7/7	100%
Totals	20	7	27/27	100%

*The entire *Alces* sample (n = 20) fell below the 11 mm cut-off, and the entire *Rangifer* sample (n = 7) fell above that same cut-off.

Table 64. Success Rates for Separating *Alces* from *Rangifer* Using ML/AEW+DPT*

	ML/AEW+DPT <7.7	ML/AEW+DPT ≥7.7	Success Ratio	Success Probability
Alces	19	0	19/19	100%
Rangifer	0	7	7/7	100%
Totals	19	7	26/26	100%

*The entire *Alces* sample (n = 19) fell below the 7.7 cut-off, and the entire *Rangifer* sample (n = 7) fell above that same cut-off.

Pronghorn (*Antilocapra americana*) vs. Other Small Ungulates

Moving on to small ungulates, it is practical to first separate pronghorn antelope from all other taxa. Their unique morphology, featuring a distinctive S-curve, makes this an easy starting point. The stylohyoids of antelope are atypical of the morphological profile displayed by either cervids or bovids. The stylohyoids of antelope are long for Size Class 5 species, having an average length of 77.59 mm, compared to 74.29 mm for white-tail, and 71.35 mm for mule deer. Overall, antelope stylohyoids are very gracile with a linear profile and very slender mid-shaft dimensions. The average distal height and mid-shaft height for antelope is 4.72 mm and 3.84 mm respectively, giving it a narrower distal and mid-shaft profile than any other species in question.

Of particular utility for species identification is the distinctive S-curve, a trait that is specific to antelope and almost universal to the current sample. This distinct trait is highly useful for identifying antelope, and is visible on 46 out of 48 elements in the sample where it was recorded (Table 65). The S-curve, plus the antelope's unique gross morphology and profile, should make its identification relatively straightforward when compared to Size Class-5 cervids and bovids. When metricaly distinguishing antelope from small cervids and bovids one formula is of particular use. The unusually long angle of antelope can be divided by the anterior-ephipysis width (AW/AEW) to produce a 100% success probability (Table 66).

Table 65. Distinct Trait Analysis for S-Curve in Pronghorn Antelope and Convex Curve in Deer

Species	S-curve	Convex to medial	Success Ratio	Success Probability
Antelope	46	2	46/48	95.8%
Mule-deer	0	36	36/36	0%
White-tail	0	40	40/40	0%
Totals	46	78	122/124	98.4%

Table 66. Success Rates for Separating Small Bovids/Cervids from Antelope Using AW/AEW*

	AW/AEW <1.6	AW/AEW >1.6	Success Ratio	Success Probability
Bovids/cervids	165	0	165/165	100%
Antelope	0	46	46/46	100%
Totals	165	46	211/211	100%

*The entire Size Class 5 bovid/cervid sample (n = 165) fell below the 1.6 cut-off, and the entire antelope sample (n = 46) fell above that same cut-off.

Small Bovids (*Capra, Oreamnos, Ovis aries, Ovis canadensis, Ovis dalli*)

It is well known among zooarchaeologists that the post-cranial bones of sheep and goats are difficult to reliably separate (Perrone and Mackinnon 2013, Prummel and Frisch 1986, Zeder and Lapham 2010). Small bovids are all part of the Tribe Caprini and are closely matched in general size and weight. Additionally, no discrete traits were observed that might reliably mark one species from another. These discriminatory difficulties are compounded by the small sample size available for several species in the study, including *Capra* (n = 18), *Oreamnos* (n = 6), and *Ovis dalli* (n = 6). As a result no single measurement ratio was successful for separating sheep from goats in general. It may be possible to reliably separate sheep and goats by way of combinatorial probabilities, but that form of metrics analysis not yet been conducted. However, metric analysis was successful when separating domesticated from wild bovids within the overall small bovid category. In particular it is possible to separate domestic sheep (*Ovis aires*) from wild sheep (*Ovis canadensis* and *Ovis dalli*), and to separate domestic goat (*Capra*) from wild goat (*Oreamnos*).

Sheep (*Ovis aries* vs. *Ovis canadensis/Ovis dalli*)

The stylohyoids of domestic and wild sheep are typical of the morphological profile displayed by bovids. Despite being shorter on average than either Bighorn or Dall sheep, domestic sheep express greater average values for anterior epiphysis width, mid-shaft height, mid-shaft thickness, dorsal-process width, angle width, and angle thickness. As such, domestic sheep appear more robust or heavy for a given length (Figure 54), while Bighorn and Dall sheep are more gracile, but have slightly greater average height and length values than their domesticated cousin.

Figure 54. From top to bottom Bighorn sheep, domestic sheep, Dall sheep, lateral view. Samples courtesy of University of Wisconsin-Madison (29448, 21722, and 36559).

The two wild species of sheep are so similar osteometrically, it is impossible to reliably separate them (Figure 55). The average difference between Bighorn and Dall sheep is just 0.3 mm when all ten measurements are added. Compare that figure to the 3.4 mm average difference between the larger and easy to separate *Bos taurus* and *Bison bison*. The wild sheep species are just too similar metrically to make any reliable distinctions. As such the two wild sheep species will be placed in the same category for the purpose of this exercise. It may be possible to make more reliable distinctions between the two wild sheep species in the future by way of combinatorial probabilities, but those metric analyses have not yet been undertaken. Unfortunately, none of the three sheep species display any discrete traits valuable for identification.

Figure 55. From top to bottom (1) Bighorn sheep, (2 & 3) Dall sheep. Size Class-5 bovids, lateral view. Samples courtesy of the University of Wisconsin-Madison (29448, 27605, and 36559).

The most effective metric for separating domestic and wild sheep is ML/MST. The overall success probability is just over 90% for the entire sample, but drops to 86.2% for *Ovis aries* alone. While not ideal, no other metric provides better success for separating sheep. ML/MSW provided the next best option, with a total success probability of 85.7%. Tables 67 and 68 summarize the sample details.

Table 67. Success Rates for Separating *Ovis aries* from *Ovis canadensis/Ovis dalli* Using ML/MST*

	ML/MH <30.7	ML/MH ≥30.7	Success Ratio	Success Probability
O. aries	25	4	26/30	86.7%
O. canadensis/O. dalli	3	44	44/47	93.6%
Totals	28	48	70/77	90.9%

*Twenty-five (n = 25) of the *O. aries* sample fell below the 30.7 cut-off. The *O. canadensis/O. dalli* sample with values greater or equal to the 30.7 cut-off include thirty-eight (n = 38) *O. canadensis* and all six *O. dalli* (n = 6). Outliers on the 'wrong' side of the 30.7 cut-off include four *O. aries* (32.3, 33.6, 33.6 and 36.9), and three *O. canadensis* (15.0, 28.9, and 29.9).

Table 68. Success Rates for Separating *Ovis aries* from *Ovis canadensis/Ovis dalli* Using ML/MSW*

	ML/MSW<13.9	ML/MSW ≥13.9	Success Ratio	Success Probability
O. aries	29	1	29/30	96.7%
O. canadensis/O. dalli	10	37	37/47	78.8%
Totals	39	38	66/77	85.7%

*Twenty-nine (n = 29) of the *O. aries* sample fell below the 13.9 cut-off. The *O. canadensis/O. dalli* sample with values greater than or equal to than 13.9 cut-off include thirty-two (n = 32) *O. canadensis* and all five *O. dalli* (n = 5). Outliers on the 'wrong' side of the 13.9 cut-off include one *O. aries* (n = 1), nine *O. canadensis* (n = 9), and one *O. dalli* (n = 1).

Goats (*Capra hircus* vs. *Oreamnos americanus*)

The stylohyoids of both domestic and wild goats are typical of the morphological profile displayed by bovids. They follow the general T-shaped pattern, with relatively high maximum height values for a given length. Domestic goat stylohyoids are more gracile in comparison to other small bovids. This tendency toward gracility is so pronounced that, with the exception of the average mid-shaft height value of Bighorn and Dall sheep, domestic goats are smaller on average than any other Size Class 5 bovid. The sample size of for mountain goats is so small (n = 6) it is hard to draw conclusions or make comparisons. *Oreamnos* follow the general T-shaped pattern, but have generally higher mean values for all measurements (with the exception of AEW, MSW, AW, and AT for domestic sheep, DPT for Mule and White-tail deer, and AW for pronghorn) than any small ungulate species in question. Goats do not display any distinct traits that are unique to their species, which is unfortunate given the general similarity they share with domestic sheep (Figure 56).

Figure 56. Domestic goat (top) and domestic sheep (bottom), lateral view. Samples courtesy of the University of Wisconsin-Madison (25769 and 21722).

The two most effective metrics for separating *Capra* from *Oreamnos* are ML/MSW (Table 69) and ML/MH (Table 70), as both produce success probabilities of 100%. ML/MSW is particularly effective in that the sample breaks at 15.0 (*Capra*) and 15.6 (*Oreamnos*). ML/MH breaks at 2.3 (*Capra*) and 2.4 (*Oreamnos*). The natural buffer of 0.6 between the two species suggest that ML/MSW is the more reliable discriminatory metric, plus it boasts a larger sample by one (n = 1).

Table 69. Success Rates for Separating *Capra* from *Oreamnos* Using ML/MSW*

	ML/MSW ≤15	ML/MSW>15	Success Ratio	Success Probability
Capra	16	0	16/16	100%
Oreamnos	0	4	4/4	100%
Totals	16	4	20/20	100%

*The entire *Capra* sample (n = 16) fell below the 15 cut-off, and the entire *Oreamnos* sample (n = 4) fell above that same cut-off.

Table 70. Success Rates for Separating *Capra* from *Oreamnos* Using ML/MH*

	ML/MH <2.4	ML/MH ≥2.4	Success Ratio	Success Probability
Capra	15	0	15/15	100%
Oreamnos	0	4	4/4	100%
Totals	15	4	19/19	100%

*The entire *Capra* sample (n = 15) fell below the 2.4 cut-off, and the entire *Oreamnos* sample (n = 4) fell above that same cut-off.

Small Cervids (*Odocoileus hemionus* vs. *Odocoileus virginianus*)

The stylohyoids of mule and whitetail deer are typical of the morphological profile displayed by cervids. Compared to similar-sized bovids they are more linear, with longer average maximum lengths, and shorter average maximum height values. As such they tend to be less T-shaped than bovids, and their overall appearance is more of a Y-profile.

Mule deer and white-tail deer are the only two small cervids in question, and their overall morphological profile is so similar (Figure 57), it is impossible to reliably differentiate between the two. The average difference between Mule and White-tail deer is just 0.7 mm when all ten measurements are added. Compare those numbers to the average differences between two large cervids that are easily separated. Elk and moose have an average difference of 3.6 mm for all 10 measurements. The average difference between the smaller cervids is simply not enough to metrically discriminate between the two species, just as it is not possible to do the same for Bighorn and Dall sheep. Tables 71 and 72 highlight the impracticality of identification by way of AEW and ML/AEW, which are two of the more successful metrics for this purpose. Their overall success probability is rather low, however, at 72.4% and 67.1%, respectively. Lastly, neither species displays any discrete trait that would be useful for differentiating between them. As such the two deer species will be lumped together for the purpose of this exercise.

Figure 57. Left and right White-tail stylohyoids (above PL-286 and PL-189) from two separate animals, compared with left and right mule deer stylohyoids (below PL-494 and PL-498) from two separate animals, lateral view. Note the overall similarity between the two species. Samples courtesy of CWU.

Table 71. Success Rates for Separating *Odocoileus hemionus* from *Odocoileus virginianus* Using AEW

	AEW<6 mm	AEW ≥6 mm	Success Ratio	Success Probability
O. hemionus	22	14	22/36	61.1%
O. virginianus	6	34	33/40	82.5%
Totals	28	48	55/76	72.4%

Table 72. Success Rates for Separating *Odocoileus hemionus* from *Odocoileus virginianus* Using ML/AEW

	ML/AEW <11.63	ML/AEW ≥11.63	Success Ratio	Success Probability
O. hemionus	22	14	22/36	61.1%
O. virginianus	11	29	29/40	72.5%
Totals	33	43	51/76	67.1%

On the other hand, if the combinatorial probability formula is used for *Odocoileus hemionus* and *Odocoileus virginianus,* success probabilities calculated for AEW and ML/AEW are much more promising.

$1 - ((1-0.611) * (0.611)) = 84.9\%$ *Odocoileus hemionus*

$1 - ((1-0.825) * (0.725)) = 95.2\%$ *Odocoileus virginianus*

Future analysis will include more combined metrics like these in the hopes of attaining a 90% or better success probability for both of the deer species.

CHAPTER V

CONCLUSIONS

The overall results for this research project are satisfactory. The original research goals included documenting how to side the stylohyoid (left or right), and determining if osteometric and/or discrete trait analysis could be utilized to reliably identify North American artiodactyl species based on their stylohyoids. Both goals were met. The following sections reiterate some of the salient details concerning siding and taxa identification. Future objectives relating to this project, including finding larger samples for analysis and the ultimate goal of publication, are also addressed.

Stylohyoid Siding

The results of this research project clearly indicate that artiodactyl stylohyoids display a curvature that is convex to the medial plane when the element is viewed from above. This author removed one or both stylohyoids from twenty-three animals, including seven (n = 7) *Odocoileus sp.*, one (n = 1) *Cervus elaphus*, eleven (n = 11) *Ovis aries*, two (n = 2) *Capra hircus*, and three (n = 3) *Bos taurus*. Also, the stylohyoids of one (n = 1) *Equus caballus* was provided by Professor Lourdes Deleon. All of these samples were recorded as concave on the lateral side. These results, in addition to some previous work conducted by Dr. Lubinski, strongly suggest that stylohyoid bones curve toward the medial when viewed dorsally.

Taxa Identification

The use of discriminatory metrics and discrete trait analysis was successful in identifying different levels of artiodactyl taxa. This includes broad categories such as Size Class (large vs. small ungulates), medium categories such as family and genus, and identification to the level of species. In more than twenty (n = >20) separate cases discriminatory metrics proved capable of making successful distinctions with total success probabilities greater than 90%.

Discrete trait analysis was successful any time a discrete trait was present. In three (n = 3) cases discrete trait analysis generated total success probabilities greater than 90%. Those cases include: dorsal beak on domestic cattle (*Bos taurus*), obtuse-ventral portion on elk (*Cervus elaphus)*, and the S-curve on pronghorn antelope (*Antilocapra americana*).

Both metric and discrete trait analysis proved to have some limitations. In the Family Bovidae, Tribe Caprini in particular, metric analysis was unable to successfully separate goats from sheep within the small bovid category. This failure was compounded by the small sample size for some Size Class 5 bovids (*Capra* n = 18, *Oreamnos* n = 6, and *Ovis dalli* n = 6), and the lack of any observable discrete traits on small bovids.

In the case of the two wild sheep species and the two deer species neither metric nor discrete trait analysis proved feasible. The combined average difference for all 10 measurements for Bighorn (*Ovis canadensis*) and Dall sheep (*Ovis dalli*) was only 0.03 mm. The combined difference for Mule deer (*Odocoileus hemionus*) and White-tail deer (*Odocoileus virginianus*) is only 0.07 mm. These metrics suggest that wild sheep species and deer species are simply too similar in size and morphology to reliably identify when a single criterion is used.

However, the use of multiple criteria in combination takes advantage of the power of additive or combinatorial probabilities, and using criteria in combination can provide satisfactory results even for very similar species such as the two species of deer. Additive probabilities were not calculated for every possible combination of criteria above, but this exercise would considerably enhance any attempted identification.

Future Work

A minimum sample size of n = 30 is desirable for all species in question. Therefore it would be beneficial to increase the current sample size for the following species: Domestic cattle *(Bos taurus),* bison *(Bison bison*), moose *(Alces americanus),* caribou *(Rangifer tarandus),* horse *(Equus caballus),* Dall sheep *(Ovis dalli),* domestic goat *(Capra hircus), and* mountain goat *(Oreamnos americanus).* A brief inspection of domestic pig *(Sus Scrofa)* stylohyoids suggests they are too different in morphology to warrant inclusion in this research project.

The University of Michigan Museum of Zoology has a large comparative collection and has agreed to lend a small sample of their available stylohyoids for analysis. These results will be added to the research dataset after this thesis. There are still a number of additional large osteological collections in the United States which have not been contacted for inclusion in this research project. The Smithsonian Museum of Natural History, the Harvard Museum of Comparative Zoology, the Yale Peabody

Museum of Natural History, and the Philip L. Wright Zoological Museum at the University of Montana are options for consideration. With enough patience it may be possible to raise the current sample numbers to a minimum of (n = 30) for every species in question.

Peer Reviewed Journal Article Manuscript

At present this author and Dr. Lubinski plan on using this Master's research as the basis of a peer reviewed research article. We plan to generate a manuscript based on the results of this study for submission to the *International Journal of Osteoarchaeology*. This manuscript will include the useful discriminating metrics discussed here, plus possibly more metrics for broken specimens that do not rely on maximum length, and hopefully larger sample sizes for some of the small species samples.

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APPENDIX

Photographs and digital data are available through contacting either Dr. Patrick Lubinski of Central Washington University, or Thomas Hale. Dr. Lubinski can be contacted via email at lubinski@cwu.edu. Tom Hale can be contacted via email at tomhalem@gmail.com. Measurement data is recorded in a Microsoft Access database and also an Excel spreadsheet.