THE EASTERN BERINGIAN CHRONOLOGY OF QUATERNARY EXTINCTIONS: A METHODOLOGICAL APPROACH TO RADIOCARBON EVALUATION

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ABSTRACT

Debate continues on the global phenomenon of human dispersal and subsequent megafauna extinctions. In Eastern Beringia, species chronologies are only generally established and do not provide enough information for comparisons to Late Pleistocene human colonization and climate change. To establish an accurate chronology for these species, 948 radiocarbon dates associated with *Mammuthus*, *Equus*, *Bison*, and archaeological occupations were compiled and rated for reliability through a standardized method. The results indicate that 8.7% of the radiocarbon dates were reliable, 85.4% were moderately reliable, and 7.3% were unreliable. Using refined species chronologies can significantly influence interpretations of radiocarbon date frequencies and paleodemographic studies.

KEYWORDS: Eastern Beringia, megafauna extinctions, radiocarbon dates

INTRODUCTION

A diverse and contentious literature exists on the initial human dispersal and subsequent selective extinctions of large mammals throughout the world, including once abundant woolly mammoth (*Mammuthus primigenius*), steppe bison (*Bison priscus*), and caballoid and hemionid horses (*Equus*) in Beringia (Barnosky 1989; Choquenot and Bowman 1998; Ficcarelli et al. 2003; Guthrie 2003, 2006; Hughes et al. 2003; Kurtén and Anderson 1980; Solow et al. 2006; Stuart 1991; Weinstock et al. 2005). Numerous models have been offered to explain this phenomenon (Haynes 2009), including overhunting by humans (Alroy 2001; Martin 1966, 1984), climate change (Guthrie 1984, 1990), hyper-disease (Greenwood et al. 2001), a comet explosion over Canada (Firestone et al. 2007), and variants of these hypotheses (Bulte et al. 2006; Burney and Flannery 2005; see Koch and Barnosky 2006 for a full review). These models cannot be critically evaluated until a refined and reliable ^{14}C chronology is available to use (Burney et al. 2004; Fiedel 2009; Guthrie 2003, 2004, 2006; Haile et al. 2009; Harington 1977, 1978, 1980a, 1980b, 1984, 1997, 2003; Harington and Clulow 1973; Harington and Eggleston-Stott 1996; Johnson 2005; Kuzmin and Tankersley 1996; MacPhee et al. 2002; Mead and Meltzer 1984; Orlova et al. 2003; Rasic and Matheus 2007; Roberts et al. 2001; Shapiro et al. 2004; Solow et al. 2006; Spriggs 1989; Spriggs and Anderson 1993; Stuart et al. 2002; Vasil'ev et al. 2002). This paper presents a standardized methodology for evaluating ^{14}C dates which is then applied to the chronologies of *Mammuthus, Equus*, *Bison*, and human occupations during the Pleistocene and Early Holocene in Eastern Beringia, the landmass bordered on the east by the Mackenzie River (Northwest Territories, Canada) and on the west by the Bering and Chukchi seas (Hopkins 1967, 1996).

BIASES OF THE FOSSIL RECORD IN EASTERN BERINGIA

Since gold was discovered in the Klondike in 1896 and in the Fairbanks mining district of Alaska in the early 1900s, stripping operations at placer mines have yielded an unprecedented volume of Pleistocene faunal remains washed out of frozen ground (Frick 1930; Froese et al. 2009; Geist 1955; Morse 2003). Pleistocene fauna from Alaska and Yukon Territory are also known from the fossil collecting efforts of Otto Geist and Childs Frick in the 1930s and 40s. Most fossil localities are known from creeks and drainages, areas with greater surface exposure through erosion (Hopkins 1996; Irving and Harington 1973; Jackson and Harington 1991; Jopling et al. 1981; MacPhee et al. 2002; Schweger 2008; Zazula, McaKay, et al. 2009). For instance, numerous fossil bones were recovered in the Old Crow Flats, Yukon Territory, eroded from river banks and redeposited on river bars and beaches (Harington 1975, 1977, 1978, 1980a, 1980b, 1984, 1989, 1996, 1997, 2003, 2007; Harington and Clulow 1973; Harington and Eggleston-Stott 1996; Morlan 1990; Morlan and Cinq-Mars 1982). Sea dredging in the Chukchi Sea, Bristol Bay, and St. Lawrence Island maritime zones also produced Pleistocene fauna (Dixon 1983; Guthrie 2003, 2004).

Faunal remains from Eastern Beringia have long been exposed to cold mean annual temperatures, commonly appearing well preserved with little surface cracking and subaerial weathering. Only in rare cases are complete or mostly complete skeletons found, occasionally with preserved hair, hide, and soft tissue (Guthrie 1990; Guthrie and Stoker 1990; Harington 2007; Zazula, McaKay, et al. 2009). Many curated specimens are of Pleistocene age and retain well-preserved collagen, ideal for ^{14}C dating (Guthrie 1990, 2003, 2004, 2006; MacPhee et al. 2002). However, because of the concentration of mining activities and other early expeditions, discoveries of Pleistocene faunal remains are biased to the Old Crow Flats and the Dawson City and Fairbanks mining districts, leaving much of the Kuskokwim drainage, Kenai and Alaska peninsulas, Aleutian Islands, Brooks Range, and southwest Alaska underrepresented. This geographic bias of fossil localities is compounded by researcher bias toward the terminal Pleistocene.

Many fossil remains have been recovered from muck deposits, loess aggraded with permafrost, which is preferentially found on north- and east-facing slopes (Froese et al. 2009; Kotler and Burn 2000); thus, the distribution of loess and permafrost influences fossil preservation and discovery (Surovell and Brantingham 2007; Surovell et al. 2009). For instance, loess accumulations are usually restricted to small areas near glacial outwash deposits and large braided rivers (Walker and Everett 1991). Soil type, temperature, and geothermal characteristics affect permafrost distribution. Permafrost is found discontinuously across Eastern Beringia (Brown 1960; Froese et al. 2009) and consists of only 23% of the land area in the northern hemisphere (Jorgenson et al. 2001). Further, terminal Pleistocene sediments tend to be poorly preserved in Yukon Territory (Zazula pers. comm. 2009; Zazula, Hare, et al. 2009). Despite the incomplete fossil record, geographically separated fossil loci and occasional discoveries across the study area provide a relatively large and widely distributed sample size (Guthrie 1990, 2003, 2004, 2006; Porter 1986, 1988; Thorson and Guthrie 1992; Weber et al. 1981).

Recent paleodemographic approaches have used temporal frequency distributions of archaeological occupations as a relative measure of human population sizes; population increases should be reflected by an increase in the number of ^{14}C-dated archaeological occupations (Bever 2006; Graf 2005, 2008, 2009; Mason et al. 2001; Potter 2008; Surovell and Brantingham 2007; Surovell et al. 2009; Wygal 2007, 2008, 2009, in press). A similar NISP (number of identified specimens) approach can be applied as a relative measure of extinct faunal population size. However, taphonomic processes also influence the likelihood that sites will be preserved. While younger sites and fossil remains tend to be over-represented in the fossil record, they are also exposed to taphonomic processes biased towards surficial weathering and erosion. Therefore, the probability that a site will survive increases with time as it is buried and protected from surficial destructive processes (Surovell and Brantingham 2007; Surovell et al. 2009). Biases in site preservation can be corrected using Bayesian methods and ratio measures of dated remains to their geologic contexts to accurately reflect paleodemographic histories (Buck and Bard 2007; Debruyne et al. 2008; Drummond et al. 2005; Solow et al. 2006; Surovell et al. 2009).

METHODS OF ANALYSIS[1]

A total of 948 *Equus, Mammuthus, Bison,* and archaeological ^{14}C dates ranging from 54,000 cal. BP to the mid-Holocene from 258 localities was derived from published literature. Many of the dates (40%) were cross-referenced in the Canadian Archaeological Radiocarbon Database, particularly those derived from the Old Crow Flats and Dawson City mining districts (Morlan 2008). Recent ^{14}C dating programs (Barnes et al. 2007; Debruyne et al. 2008; Guthrie 2003, 2004, 2006; Shapiro et al. 2003, 2004) have substantially augmented available chronometric data for mammoth, bison, and horse. While this study aimed to identify all ^{14}C dates associated with *Mammuthus*, *Equus* and *Bison*, it did not quantify all archaeological occupations, especially those occurring after megafauna species extinctions. Therefore, archaeological sites spanned 14,500–7,500 cal. BP with an emphasis on Late Pleistocene and Early Holocene sites. A comprehensive list of *B. bison* ^{14}C dates was not compiled because this species did not become extinct as did *B. priscus* (Shapiro et al. 2004; Wilson et al. 2008). Faunal remains from archaeological sites also were used to evaluate temporal frequency distributions of extinct fauna.

Radiocarbon ages were converted to calendar years using the Cologne Radiocarbon Calibration and Paleoclimate Research Package HULU curve to facilitate comparison to paleoclimate proxy records (Danzeglocke et al. 2007; Johnsen et al. 1995; Langway et al. 1985). Dates can be calibrated back to 26,000 cal. BP (Reimer et al. 2004), but beyond 12,400 cal. BP the precision decreases because the earlier proxy records are coarser (Beck et al. 2001; Fiedel 1999, 2000, 2002; Ramsey et al. 2006; Reimer et al. 2004). Radiocarbon dates are statistical age estimates, but their median values were treated as single points in this study, after Wygal (2007, 2008, 2009, in press).

Although the capable range of the ^{14}C technique conveniently overlaps the time span affecting North American Quaternary extinctions, interpreting data associated with ^{14}C dates is both a methodological and qualitative exercise (Hedges and van Klinken 1992; Stafford et al. 1991; Surovell and Brantingham 2007; Van der Plicht 2000). Beyond selectively accepting or rejecting ^{14}C determinations on a case by case basis, a standardized method quantifying the reliability of age determinations is essential to eliminate researcher bias. This analysis was modeled after previous studies of ^{14}C evaluations that focused on either the archaeological record (Graf 2005, 2008, 2009; Pettitt et al. 2003; Wygal 2009, in press) or extinction chronologies (Burney et al. 2004; Gillespie et al. 2006; MacPhee et al. 2002; Mead and Meltzer 1984), but this method is more flexible in that it is easily adapted and applied to both archaeological and paleontological questions. Evaluative criteria were subdivided into seven categories: material dated, pretreatment methods, association with event, geologic context, reported age, precision, and averaged dates (Table 1). Each date was rated blindly to prevent preferential scoring or evaluation.

We next describe how each of the categories was considered in our rating system.

MATERIAL DATED

The type of material used for radiocarbon dating is a significant consideration because not all organic material produces equally reliable determinations. For instance, consider the caribou tibia flesher from Old Crow originally dated to 31,320 ± 2970 cal. BP (GX 1640) (Bonnichsen 1979; Harington 1975; Irving and Harington 1973). This age was disputed because it significantly predated the accepted age for the human colonization of North America (Guthrie 1980). A later attempt to acquire a reliable date on the specimen used more advanced collagen extraction techniques that yielded a late Holocene age (1,260±150 cal. BP) (Morlan et al. 1990). A discrepancy of over 25,000 years from the first dating attempt of this bone tool indicated that radiocarbon dates derived from bone material must be carefully scrutinized because the porous nature of bone facilitates contamination from intrusive material (Gillespie et al. 2006; Morlan et al. 1990).

To compensate for discrepancies caused by material type, this study scored dated material on a scale of 1–5 (following Mead and Meltzer 1984 and Pettitt et al. 2003). Soil carbonates, wood, and peat have a high probability of carbon contamination (Kuzmin and Tankersley 1996; Mead and Meltzer 1984) and were assigned one point. Apatite or unspecified bone fractions are slightly more reliable, receiving two points, and collagen, enamel, and ivory received three points. Most ages on mammoth and horse were derived from bone and teeth because they were museum specimens lacking associated organic material. Hair, tissue, hide, and horn were awarded four points. Associated charcoal or specifically targeted amino

1. All the ^{14}C ages included in this study were derived from the published literature with the exception of assay Beta-235489, on a *Bison priscus* skull from Denali National Park and Preserve (>42,000 ^{14}C yr BP, petrous bone). The entire corpus of ^{14}C ages is presented as a supplemental data file, posted on the *Alaska Journal of Anthropology* web site (https://www5031.ssldomain.com/alaskaanthropology/store/index.cfm?do=cat&cid=69). These data include laboratory numbers, radiocarbon ages, context, bibliographic citations and references, as well as the rating justifications employed in this study.

acids such as hydroxyproline and glycine are most reliable (Gillespie 1970; Hedges and van Klinken 1992) and scored five points (Table 1).

PRETREATMENT

Pretreatment methods have variable effects on date reliability. Complications occur when measured carbon is present in extremely low quantity or is contaminated (Pettitt et al. 2003; Taylor 1997), but new techniques and the visual examination of collagen for purity and contamination have reduced this complication (Burney et al. 2004; Stafford et al. 1982, 1987, 1991). In the literature we surveyed, pretreatment methods were rarely documented, but notable exceptions exist (Bonnichsen 1979; Guthrie 2003, 2004, 2006; Harington 1975; Irving and Harington 1973; Morlan et al. 1990). The advent of AMS (accelerator mass spectrometry) and advances in decontamination procedures reduced the need for bulk sample dating, required significantly less carbon, and produced more reliable results than standard radiometric counting (Aitken 1990; Beaumont et al. 2010; Gillespie et al. 2006; Long et al. 1989; Potter 2005; Stafford et al. 1982, 1987, 1988, 1991; Taylor 1987).

As a substitute for undocumented pretreatment processes, the primary criterion for pretreatment evaluation was the year in which a sample was analyzed because of significant methodological improvements that have occurred over time. Rated on a scale of 1–5, material dated before 1970 received one point (following Pettitt et al. 2003), those dated between 1971 and 1980 received two points, and those dated between 1981 and 1990 received three points. Between 1991 to present, pretreatment was scored four points when collagen was purified through gelatinization, acid wash, and other filtration methods. Following Burney et al. (2004), the highest score, five points, was used only when collagen was analyzed between 1991 to the present through gelatinization and alkali pretreatment methods, when specific amino acids were targeted, and/or collagen was visually inspected for pure white collagen (Table 1). These criteria do not reflect the quality of research, but are a relative measure of the available technology when samples were dated (Beaumont et al. 2010). For instance, most of Guthrie's (2003, 2004, 2006) specimens were derived from enamel and bone collagen and pretreated through the U.S. National AMS Radiocarbon Laboratory, Tucson, Arizona, with ultrafiltration (Brown et al. 1988). These specimens each received four points for pretreatment.

ASSOCIATION

Perhaps the most important criterion to evaluate the quality of ^{14}C dates is interpretive: the relevance of the dated sample to the research question. For instance, a wood sample recovered from the surface of a river point bar cannot confidently be justified as associated with the time of death of animal remains lying nearby. Rated on a scale of 0–4, dates were assigned a zero when the association of the sample to the research question was unknown or unclear. A score of one was applied when disturbance and/or recovery from a secondary context was documented. Two points were assigned for probable associations through spatial patterning or stratigraphic association. A score of three represents a high probability of association and was used when dated material was recovered in close association with archaeological and/or faunal remains remains pertinent to the research question or from a primary context. Finally, the highest score, four, was applied to samples that are diagnostic, or the association with the event or fossil is certain. For instance, directly dated hearth charcoal is diagnostic of human activity and directly dated collagen, apatite, or enamel are considered certain associations with the geologic date of the death of the animal (Table 1). Pettitt et al. (2003:1689) also rated the level of association between the research question and dated sample but did not develop specific criteria to distinguish associations of full certainty, high probability, probability, reasonable possibility, and low possibility. Associational criteria in this analysis were modeled from those developed by Graf (2009).

GEOLOGIC CONTEXT

An additional interpretive control on date reliability is the geologic context from which the sample was taken and its relationship to the research question. While the radiocarbon date itself provides a temporal context of a specimen, its reliability cannot be fully assessed in the absence of information from its geologic context (Solow et al. 2006). A score of zero was applied when geologic context was unknown or undocumented, or for surface finds. Unfortunately, detailed geologic contexts were not documented for many specimens because bones were rarely recorded *in situ* (Guthrie 1990). A score of one point was given if materials were buried but lacked additional dates to verify relative chronology, or if they came from a buried site in which dating reversals decreased the integ-

Table 1. Evaluation Method

Score	Material Dated
1	Wood, peat, soil carbonates
2	Apatite or unspecified bone fraction
3	Collagen, enamel, ivory
4	Hair, tissue, hide, horn
5	Charcoal or hydroxyproline, glycine
	Pretreatment Methods
1	Undocumented, or date analyzed before 1970
2	Analyzed between 1971–1980
3	Analyzed between 1981–1990
4	Analyzed between 1991–present, collagen is purified through gelatinization, acid wash, and other ultrafiltration
5	Analyzed between 1991–present, collagen is purified through gelatinization, alkali pretreatment and/or is visually inspected for pure white collagen
	Association with Event
0	Association unknown
1	High degree of disturbance or in secondary context
2	Probable association. Spatial patterning suggests association
3	High probability. In primary context
4	Certainty or sample is diagnostic
	Geologic Context
0	Geologic context unknown or from the surface
1	Buried in a stratified site with no corroborating dates or dates with reversals
2	Buried in a stratified site with 1 date in sequence, or from same occupation/stratigraphic layer which are statistically equivalent at 2σ
3	Buried in a neatly stratified site with three dates in sequence, or dates from the same occupation/stratigraphic layer which are statistically equivalent at 2σ
4	Buried in stratified site with >3 dates in sequence, or dates from the same occupation/stratigraphic layer which are statistically equivalent at 2σ
	Reported Age
1	Infinite Measurement
2	Measurements >40,160 cal. BP (35,000 rcybp)
3	Measurements <40,160 cal. BP (35,000 rcybp)
	Precision (Standard deviation of date, in radiocarbon years)
1	>150
3	51–150
5	0–50
	Averaged Dates
1	Dates are averaged with statistical outliers
2	Dates are averaged with no statistical outliers, or not averaged

rity of the geologic context. In buried sites, one date in stratigraphic sequence or two dates from the same strata equivalent at 2 sigma received two points. When three dates were in sequence, or were statistically equivalent at 2 sigma from the same stratigraphic layer, a score of three was applied. Dates from buried sites with more than three dates in sequence, or equivalent at 2 sigma in the same strata, were given four points (Table 1). These criteria were biased towards archaeological sites because they tended to receive more intensive geological evaluations and thus received higher scores in general. Pettitt et al. (2003) also developed criteria evaluating the geologic context based on the number of ^{14}C dates in sequence. Graf's (2009) criteria for geologic context employed the ratio of dates in sequence to assign reliability scores.

REPORTED AGE, PRECISION, AND AVERAGED DATES

While the radiocarbon technique is functional up to 40,000 BP, the method declines in accuracy with age, especially when determinations are close to this limit (Ramsey et al. 2006). Pettitt et al. (2003) used a stringent criterion (34,290 cal. BP/30,000 rcybp [^{14}C yr BP]) as the threshold for the upper bracket of ^{14}C date reliability. On a scale of 1–3, this analysis scored infinite dates one point, measurements older than 40,160 cal. BP (35,000 rcybp) were scored two points, and measurements younger than 40,160 cal. BP received three points.

Technological advances in radiocarbon dating have increased the precision of reported ages, allowing researchers to address progressively more complex questions. This analysis applied a scale of 1–5, in which dates with standard deviations greater than 150 were scored one point, dates with standard deviations between 51 and 150 were given three points, and those with standard deviations less than 50 were rated five points. Graf (2009) used five categories for date precision, with standard deviations up to ±1,000 years receiving the lowest scores for reliability.

Dates with overlapping standard deviations at 2 sigma were averaged when coming from single archaeological occupations or from the same faunal specimen. All non-overlapping dates at >2 sigma were eliminated. Long and Rippeteau's (1974) weighted averaging method was utilized to give more weight to the more precise dates. When dates were averaged but the original determinations were not reported, or were averaged with statistical outliers at 2 sigma, they received one point. Unaveraged dates or averaged dates with no statistical outliers at 2 sigma received two points. Comprehensive reliability scores were calculated by summing points assigned from each evaluation criterion to arrive at a number between 0 and 28 (Table 1). Higher scores represent more reliable ^{14}C dates.

RESULTS

The 948 evaluated ^{14}C dates were distributed normally across the complete range of possible scores (0–28) and grouped into three categories, unreliable, moderately reliable, and reliable dates (Table 2), analogous to Graf's (2009:694) "the Good, the Bad, and the Ugly." Scores between 0 and 14 represent unreliable dates, scores of 15–21 denote moderately reliable dates and should be accepted with caution, and scores 22–28 are considered reliable. Unreliable dates (n = 69) were derived from specimens lacking documented geologic context and association, and dated material primarily consisted of wood and peat, although several specimens dated using apatite and collagen fractions were included. Most unreliable dates ranged from 42,000 cal. BP to 35,000 cal. BP, and were published in the 1970s and 80s. Most of the Old Crow specimens which were dated multiple times were independently determined to be unreliable or at the lowest range of moderately reliable dates (Bonnichsen 1979; Harington 1977, 1989; Morlan et al. 1990). Redating these materials with current techniques may strengthen the reliability of these data in conjunction with additional geological investigations. Moderately reliable dates (n = 796) constituted the majority of this data set. They were derived primarily from collagen, apatite, and enamel in certain associations with the death of the animal. Pretreatment protocols included recent and older methods. Reliable dates (n = 83) always possessed documented geologic contexts, high degrees of association, and were calculated with recent technological advancements. Virtually every reliable determination was supported by multiple dates from individual sites. Thus, reliable dates were biased towards archaeological sites and many were from charcoal. No dates were calculated from identified amino acids.

MAMMUTHUS

The mammoth radiocarbon dates represented 49.4% of the entire data set (n = 468). Of these, 33 dates were considered unreliable (3.5% of all dates, 7.1% of the mammoth dates, and 48% of all unreliable dates). Substantially more mammoth dates were considered moderately reliable (n = 416), comprising over half of the overall moderately reliable set (52.3% of the moderately reliable dates, 88.9% of mammoth dates, and 43.9% of the entire data set) (Fig. 1; Table 2). The oldest mammoth dates, >54,000 cal. BP from Ikpikpuk River, were considered moderately reliable; of a total of five dates, each scored 16 points. An additional 103 infinite dates on mammoth remains also were included in this analysis and primarily considered moderately reliable (Debruyne et al. 2008). A specimen from Old Crow locality CRH-12 dated to 53,060 ± 4,060 cal. BP (Bonnichsen 1979; Harington 2003; Morlan et al. 1990) is considered unreliable (score = 14). Reliable dates (n = 19) comprised 4% of the mammoth sample, 22.9% of the reliable dates and 2% of the entire sample. The last known mammoth in Eastern Beringia, dated 6,40 ± 50 cal. BP, occurred at Qagnax Cave, St. Paul, Pribilof Islands (Veltre et al. 2004, 2008); the date is considered reliable (score = 25). The latest evidence for mammoths on the mainland occurred at Swan Point, a human occupation in the Tanana Valley dated to 11,960 ± 170 cal. BP. The date, on hearth charcoal, scored 24 and is considered reliable (Holmes 1998, 2001; Holmes et al. 1996). Trail Creek Cave, northwest Alaska, possessed Late Pleistocene mammoth remains, but they were not associated with a human occupation (Sattler et al. 2001; Vinson 1993). Dated 13,250 ± 110 cal. BP, this date is considered moderately reliable (score=18). Mammoth remains from Lost Chicken Creek were dated to 11,650 ± 280 cal. BP (score = 19) (Harington 2003).

BISON

Radiocarbon dates associated with bison remains represented 25.4% of the entire data set (n = 241) (Table 2). Of these, 18 dates are considered unreliable (1.9% of the entire data set, 26% of all unreliable dates, and 7.5% of the bison dates). Significantly more dates are considered moderately reliable (n = 199, 82.6% of the bison, 25% of the moderately reliable dates, and 21% of the entire data set). Fewer bison received a reliable score (n = 24), including the *B. priscus* carcass recovered from Tsiigehtchic, Northwest Territories, Canada (13,700 ± 70 cal. BP, score=23), which possessed preserved horn cores, sheath, and mummified soft tissue (Zazula, MacKay, et al. 2009). In sum, 9.9% of the bison ^{14}C dates are considered reliable; bison dates comprised 28.9% of the reliable dates and 2.5% of the entire data set (Fig. 2). The oldest bison date was 58,200 ± 3900 cal. BP from the Black River, Yukon Flats; it is considered moderately reliable (score = 16) (Shapiro et al. 2004). There were also 163 infinite dates that ranged from unreliable to moderately reliable (Shapiro et al. 2004). The youngest dated bison occurrence in Eastern Beringia in this sample, 3,090 ± 180 cal. BP, was derived from charcoal at Pelly Farm (score=18), but it represents *B. bison* (Lowdon et al. 1970; MacNeish 1964; Shapiro et al. 2004; Stephenson et al. 2001; Wilson et al. 2008). The youngest *B. priscus* remains, 10,070 ± 120 cal. BP, were derived from the Gerstle River site in the Tanana Valley (Potter 2005, 2007; Shapiro et al. 2004), and the date is considered reliable (score = 24). The Dry Creek archaeological site in the Nenana Valley also yielded *B. priscus* remains (Bigelow and Powers 1994; Hoffecker et al. 1996; Powers and Hoffecker 1989; Thorson and Hamilton 1977). They date to 10,640 ± 300 cal. BP, which is considered moderately reliable (score = 17). A cluster of ^{14}C dates associated with *B. priscus* remains from the Porcupine River, Engigstciak, and the Little John site also clustered between 10,110 ± 340 cal. BP and 10,940 ± 40 cal. BP (Fig. 2) (Easton et al. 2007; Harington and Morlan 2002; Shapiro et al. 2004).

EQUUS

The horse radiocarbon dates represented 17.2% of the entire data set (n = 163) (Table 2). Of these, 16 dates are considered unreliable (9.8% of the horse, 23.2% of unreliable dates, and 1.7% of the entire set), and 146 are considered moderately reliable (89.6% of the horse sample, 18.3% of

Table 2. Distribution of evaluated dates by reliability and taxon

Rating Category	Taxon	Frequency	% Taxon	% Rating Category	% Data Set
Unreliable					
0–14	All	69		100%	7.3%
0–14	Mammoth	33	7.1%	48%	3.5%
0–14	Bison	18	7.5%	26%	1.9%
0–14	Horse	16	9.8%	23.2%	1.7%
0–14	Human Evidence	2	2.6%	2.8%	0.2%
Moderately Reliable					
15–21	All	796		100%	84%
15–21	Mammoth	416	88.9%	52.3%	43.9%
15–21	Bison	199	82.6%	25%	21%
15–21	Horse	146	89.6%	18.3%	15.4%
15–21	Human Evidence	35	46.1%	4.4%	3.7%
Reliable					
22–28	All	83		100%	8.7%
22–28	Mammoth	19	4.0%	22.9%	2%
22–28	Bison	24	9.9%	28.9%	2.5%
22–28	Horse	1	0.6%	1.2%	0.1%
22–28	Human Evidence	39	51.3%	47%	4.1%

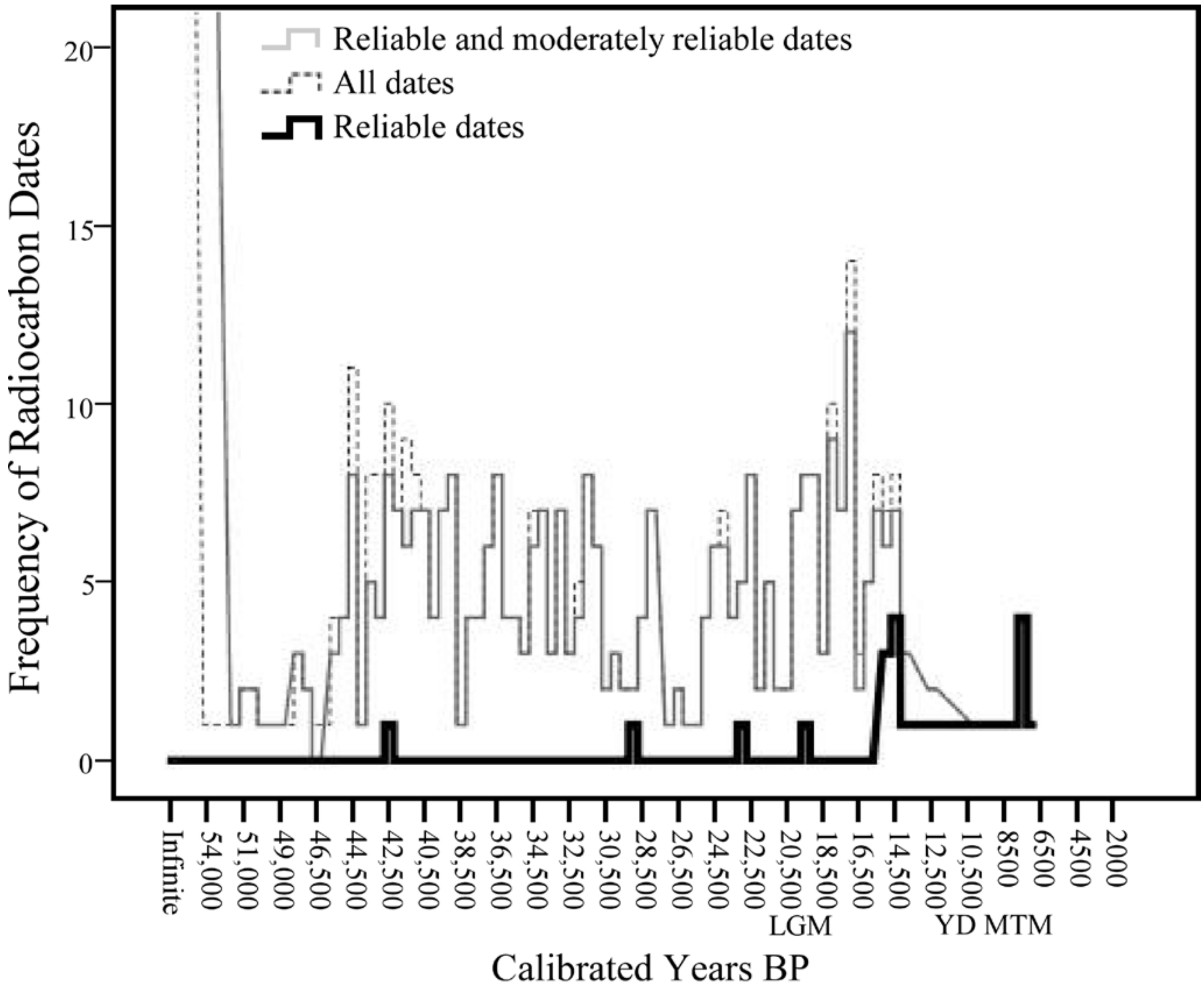

Figure 1. Frequencies of radiocarbon dates associated with mammoth remains. LGM = Last Glacial Maximum, YD = Younger Dryas, and MTM = Milankovitch Thermal Maximum.

the moderately reliable set, and 15.4% of the entire set; see Fig. 3). The oldest ^{14}C date associated with horse remains was >53,000 cal. BP from Hershel Island, Pauline Cove, Northwest Territories (Zazula, Hare, et al. 2009) (score = 15). Four additional infinite dates are considered moderately reliable (Zazula, Hare, et al. 2009). A specimen from Sixtymile Locality 3 is dated to 49,960 ± 1,640 cal. BP (score = 16) (Harington 2003).

Only one ^{14}C date on horse remains is considered reliable and represents the latest known occurrence of horse in Eastern Beringia. Derived from the Swan Point archaeological site, horse molar dentine collagen has been dated to 13,850±120 cal. BP (score = 23) (Holmes in press). Considered moderately reliable, horse remains from Bluefish Cave 3 were dated to 14,580±680 cal. BP (score = 16) (Burke and Cinq-Mars 1996; Cinq-Mars 1979) and a sample from Upper Cleary Creek was dated to 14,880 ± 150 cal. BP (score=19) (Guthrie 2006). Younger ^{14}C dates from spruce wood associated with horse remains at Lost Chicken Creek are considered unreliable (scores ranged from 11–14 on nine samples; Fig. 3) (Porter 1988; Trimble and Robinson 1989).

ARCHAEOLOGICAL OCCUPATIONS

Radiocarbon dates from archaeological sites (n = 76) represented 8% of the entire data set (Fig. 4; Table 2). Of these, two dates are considered unreliable, representing 2.8% of all unreliable dates, 2.6% of the archaeological site sample, and 0.2% of the entire sample. Unreliable dates were from the Tingmiakpuk site dated from caribou remains (8,320±70 cal. BP, score=11) (Mason et al. 2001) and the

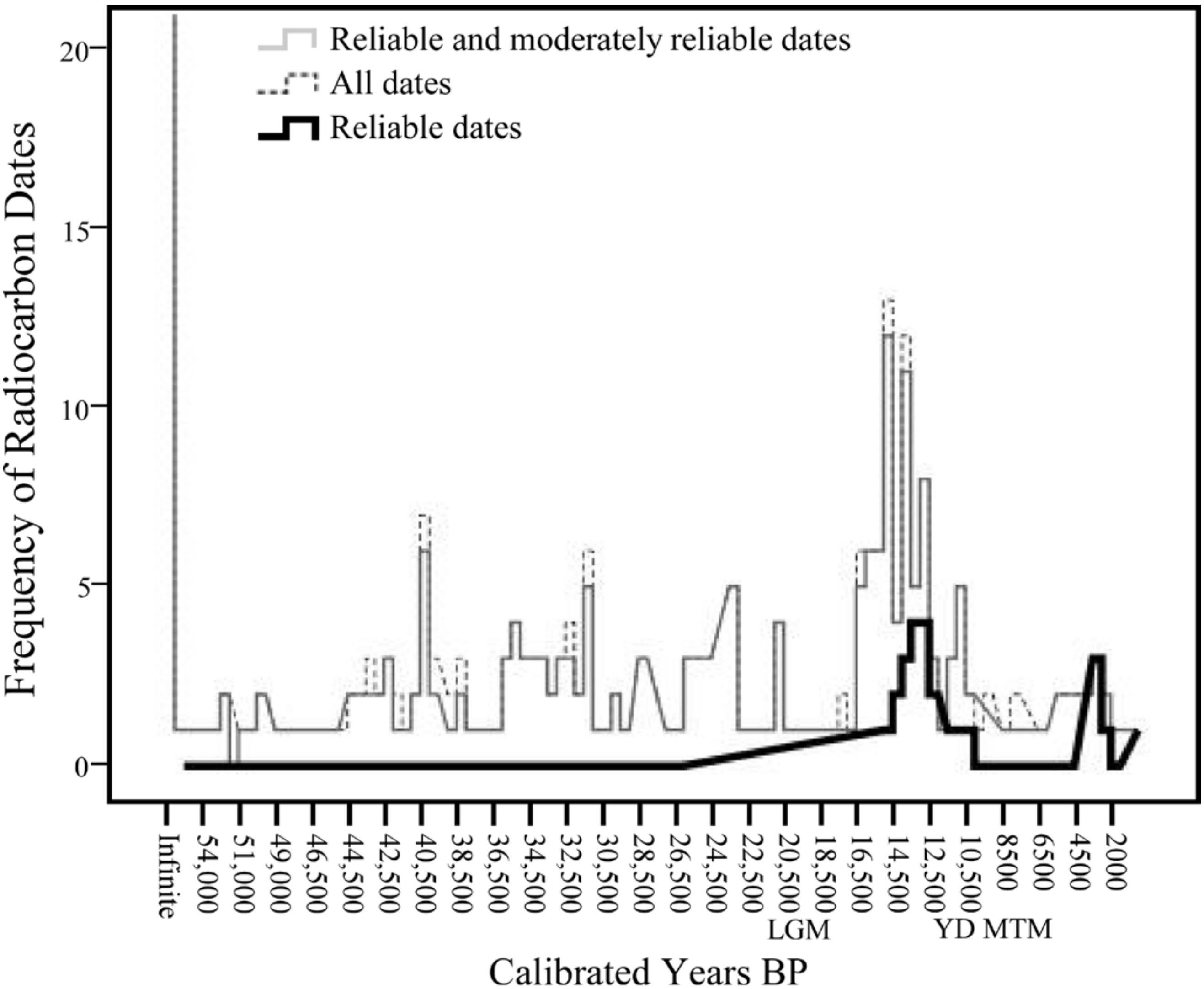

Figure 2. Frequencies of radiocarbon dates associated with bison remains. LGM = Last Glacial Maximum, YD = Younger Dryas, and MTM = Milankovitch Thermal Maximum.

Akmak occupation at Onion Portage dated to 10,900±210 cal. BP (score=13, K-1583) (Anderson 1988; Hamilton and Goebel 1999). Slightly less than half (n=35, 46.1%) are considered moderately reliable (4.4% of the moderately reliable dates and 3.7% of the entire data set). The Healy Lake ^{14}C dates from all stratigraphic levels (Cook 1969, 1996) fall within the low end of moderately reliable dates (scores 16–18). Over half of the ^{14}C dates associated with archaeological remains are considered reliable (n=39, 51.3%), constituting 47% of overall reliable dates and 4.1% of the entire set. The earliest archaeological occupation is dated to 14,100±110 cal. BP from Swan Point, Tanana Valley and is rated 28, the highest possible score (Fig. 4) (Holmes in press; Holmes and Crass 2003).

DISCUSSION

Patterns in the temporal distributions of human occupations and extinct fauna are here reconsidered after examining the sample of reliable and moderately reliable radiometric dates. A Q-Q plot of the reliability of radiocarbon dates indicated the data were normally distributed and that no time period was associated with more anomalous or moderately reliable dates than another. A single mammoth date older than 35,000 cal. BP was considered reliable. Two mammoths reliably dated between 35,000 and 20,000 cal. BP were recovered in the Brooks Range (Guthrie 2004, 2006). The single date considered reliable between 20,000 and 18,000 cal. BP was from a mammoth recovered from Epiguruk (Hamilton 1996; Hamilton et

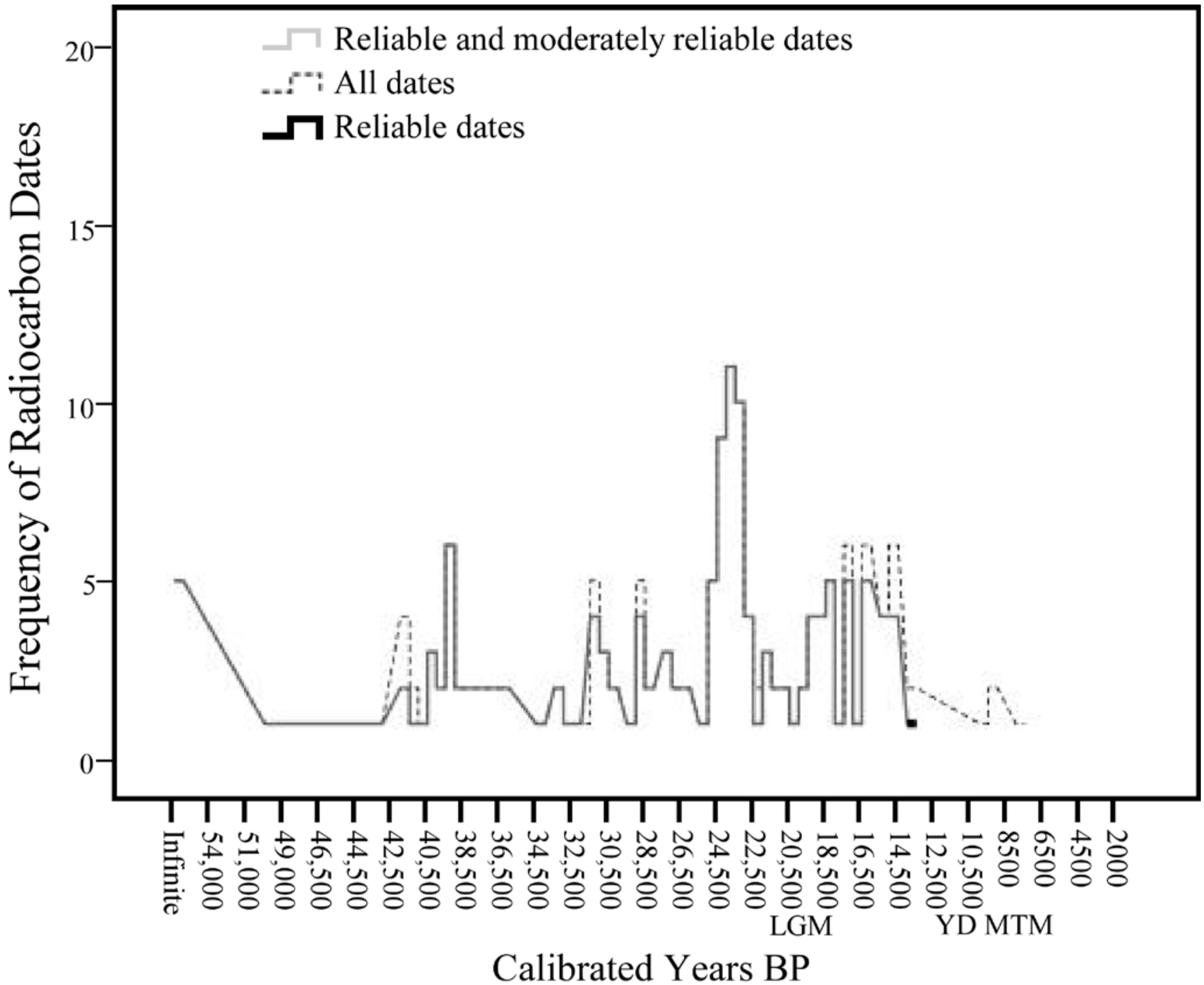

Figure 3. Frequencies of radiocarbon dates associated with horse remains. LGM = Last Glacial Maximum, YD = Younger Dryas, and MTM = Milankovitch Thermal Maximum.

al. 1993). From 18,000 to 16,000 cal. BP, just after the LGM, no ^{14}C dates were considered reliable (Table 3). Seven data points between 16,000 and 14,000 cal. BP were considered reliable, including bison remains from the Ikpikpuk River (Guthrie 2004, 2006) and mammoth remains from Swan Point (Holmes in press; Holmes and Crass 2003). Between 14,000 and 12,000 cal. BP a cluster of reliable dates includes 13 archaeological occupations from central and northern Alaska, 13 dates from bison remains from the Fairbanks area, and 5 dates associated with mammoth remains from the Tanana Valley (Table 3). The youngest ^{14}C date from horse remains was contemporaneous with the earliest human occupation in Eastern Beringia at the Swan Point site (Holmes in press; Holmes and Crass 2003).

The ^{14}C dates for some taxa are more reliable than others. A chi-square test indicated that there are differences in taxon reliability (p<0.001, χ^2=200.531, df=6). This was reflected in the high percentage of reliable archaeological sites (Table 2) and was largely a function of sample bias: many paleontological samples were recovered from undocumented contexts, but archaeological sites tended to be well documented. There were also differences in reliability between extinct taxa, excluding archaeological occupations (p<0.001, χ^2=20.846, df=4). Only a single horse date was considered reliable, in contrast to numerous mammoth and bison dates.

Numerous researchers have used ^{14}C dates as a proxy for population size (Bever 2006; Bocquet-Appel and Demars 2000; Buck and Bard 2007; Drummond et al. 2005; Graham et al. 1996; Guthrie 2006; Kuzmin 2008;

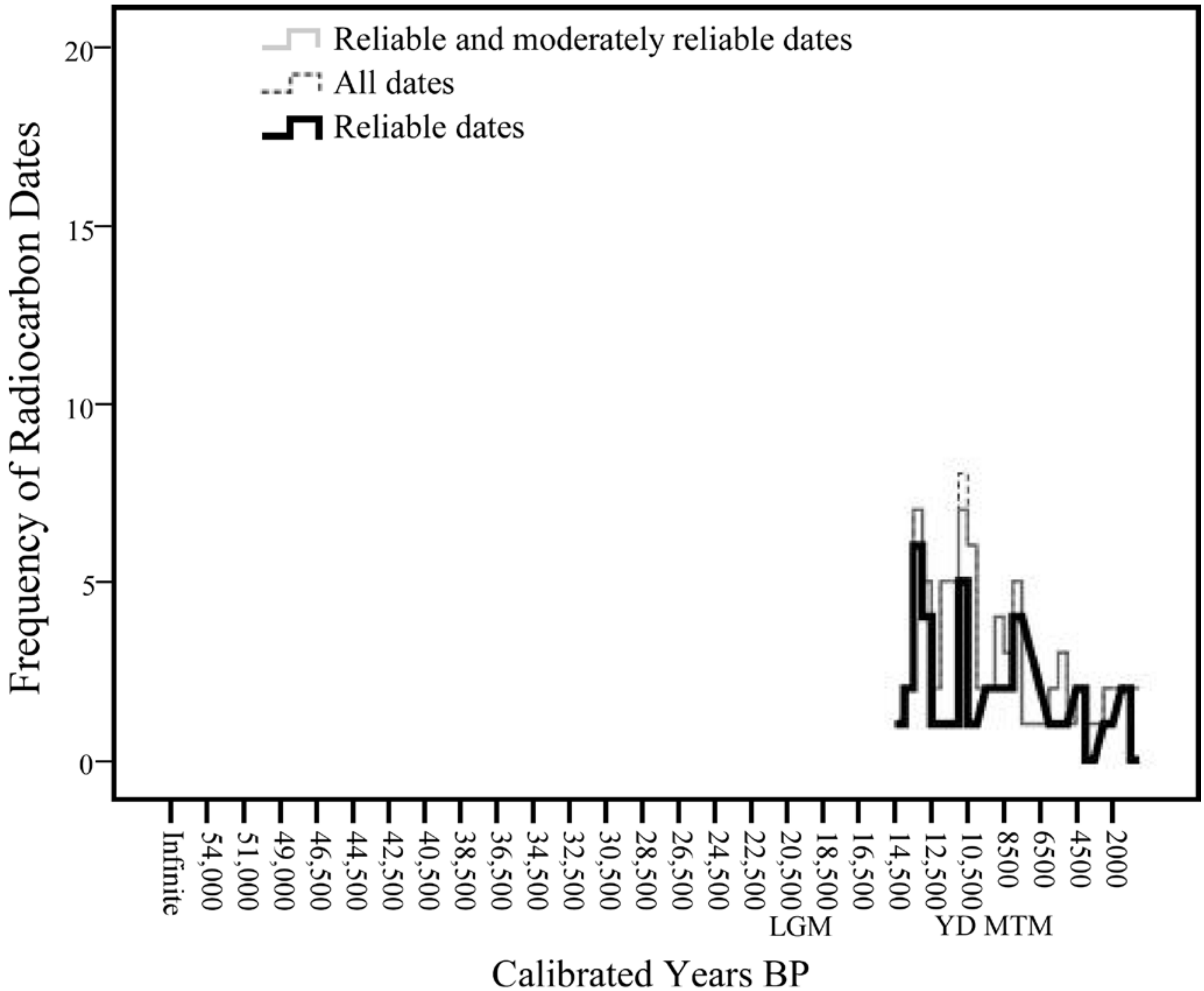

Figure 4. Frequencies of radiocarbon dates associated with archaeological sites. LGM = Last Glacial Maximum, YD = Younger Dryas, and MTM = Milankovitch Thermal Maximum.

Table 3. Temporal distribution of reliable and moderately reliable dates

Years cal. BP	Mammoth	Mammoth	Bison	Bison	Horse	Horse	Human Evidence	Human Evidence
	Moderately Reliable	Reliable	Moderately Reliable	Reliable	Moderately Reliable	Reliable	Moderately Reliable	Reliable
0–6,000	0	0	6	5	0	0	9	7
6,000–12,000	3	7	10	3	0	0	23	18
12,000–14,000	5	5	14	13	0	1	3	13
14,000–16,000	17	3	25	3	8	0	0	1
16,000–18,000	31	0	8	0	12	0	0	0
18,000–20,000	24	1	3	0	15	0	0	0
20,000–35,000	116	2	56	0	77	0	0	0
35,000–infinite	220	1	77	0	34	0	0	0

Kuzmin and Keates 2005; MacPhee et al. 2002; Mason et al. 2001; Matheus et al. 2003; Shapiro and Cooper 2003; Shapiro et al. 2003, 2004; Sher 1997; Stuart 2005; Surovell and Brantingham 2007; Surovell et al. 2005, 2009; Ugan and Byers 2007; Vasil'chuk et al. 1997). Surovell et al. (2009) demonstrated that when statistically correcting for sample bias, the general temporal frequency distribution pattern was not substantially different, but the relative intensity of ^{14}C frequency changes was significantly affected. While we did not correct for sample bias created by the likelihood that the fossil record is incomplete, it is essential that in the future evaluations are made of the temporal frequency distributions of species and dates before carrying out paleodemographic studies of mammoth, bison, horse, and archaeological occupations in Eastern Beringia. Molecular data and life history reconstructions derived from ^{14}C dates cannot be considered reliable unless the dates have been evaluated and standardized (Bever 2006; Debruyne et al. 2008; Drummond et al. 2005; Fox-Dobbs et al. 2006; Haile et al. 2009; Koch and Barnosky 2006; Mason et al. 2001; Potter 2008; Shapiro et al. 2004; Surovell and Brantingham 2007; Szpak et al. 2010; Wygal 2007, 2008, 2009, in press).

For archaeological sites, the overall pattern in ^{14}C frequencies was similar between the refined (moderately reliable and reliable dates) and unrefined records (the entire ^{14}C sample), but the relative intensity of ^{14}C fluctuations changes dramatically when the more refined radiocarbon record is used. In particular, an increase of ^{14}C dates at 11,000 cal. BP and decrease at 10,000 cal. BP were substantially more dramatic when eliminating the unreliable and moderately reliable dates (Fig. 4). The frequency of ^{14}C dates associated with archaeological sites (Fig. 4) in this study contradicted the findings of Bever (2006) and Potter (2008) in that this study showed a substantial decrease in the number of dated archaeological sites after the Early Holocene. Because this study focused on human occupations that were coeval with extinct Pleistocene taxa, sample size was more robust for sites post-dating the Early Holocene. These contradictory patterns also may be a reflection of the use of a refined ^{14}C record.

Radiocarbon date frequencies associated with mammoths consistently fluctuated from 50,000 cal. BP to the terminal Pleistocene with peaks occurring at 41,500 cal. BP, 35,000 cal. BP, and the end of the LGM 17,000 cal. BP. Reliable and moderately reliable ^{14}C dates are absent between 27,000–26,000 cal. BP and just after 13,000 cal. BP. These gaps expanded significantly when examining only the reliable dates, but the absence of ^{14}C dates immediately following 13,000 cal. BP reflected the last known mammoth remains on the mainland until the Mid-Holocene mammoths that survived on island refugia (Veltre et al. 2004, 2008). Mammoths and humans coexisted for approximately one to two thousand years before their extinction on the mainland.

Debruyne et al. (2008) presented a skyline plot of mammoth population estimates for the late Pleistocene which differs from the temporal frequency distribution of mammoth remains in this study. Based on 131 radiocarbon-dated samples and ancient DNA analysis, their data indicated regular population growth during Marine Isotope Stage 4 (MIS4) and decreased populations between 65,000 and 25,000 BP (MIS3) during an interstadial. In contrast, the ^{14}C frequencies associated with mammoths in this study increased between 54,000 and 41,500 cal. BP and decreased after 41,500 cal. BP. Further, a molecular analysis of "sedimentary" ancient DNA, or *sed*aDNA, demonstrated that woolly mammoth and horse survived to 10,500 BP in interior Alaska, later than radiocarbon-dated macrofossils (Haile et al. 2009). This is at least one millennium later than macrofossil evidence for extinctions. Perhaps a refined radiocarbon record would alter the conclusions of these studies (Debruyne et al. 2008; Haile et al. 2009).

Bison are thought to have entered North America during the middle Pleistocene between 300 and 130 ka (Kurtén and Anderson 1980; Shapiro et al. 2004). Reliable and moderately reliable ^{14}C dates show the presence of bison between 62,500 and 42,000 cal. BP and an increase at 41,000 cal. BP, 31,500 cal. BP, 23,500 cal. BP, and 14,000 cal. BP. However, if only the reliable dates are used, *Bison priscus* does not appear in the fossil record until 14,000 cal. BP. Unlike *Equus* and *Mammuthus*, the genus *Bison* did not become entirely extinct in the north, so the persistence of bison well into the Holocene reflects the existence of *B. bison*, not steppe bison (*B. priscus*). Rasic and Matheus (2007) demonstrated *B. priscus* in northern Alaska became extinct between 11,920 and 11,480 cal. BP, and their conclusion is consistent with our analysis. Modern and ancient DNA analyses of Russian, Alaskan, Canadian, Chinese, and lower North American bison samples indicated that bison genetic diversity and frequencies decreased drastically around 32,000 cal. BP, well before the first human occupation (Shapiro et al. 2004). However, examining the temporal frequency distributions of the moderately reliable and reliable bison dates from this study indicated a decrease at 32,000 cal. BP followed by a rebound at 23,500 cal. BP and 14,000 cal. BP. This difference may reflect the elimination of 18 unreliable dates from this analysis.

The frequencies of reliable and moderately reliable ^{14}C dates associated with horse remains were at their highest at 39,500 cal. BP and 24,000 cal. BP, followed by significant decreases and a slight increase of ^{14}C dates during the LGM. This differs from the entire horse sample, which shows high frequencies of ^{14}C dates at 42,000 cal. BP, 31,500 cal. BP, and 29,000 cal. BP. Unlike the mammoth and bison ^{14}C date frequencies, horse ^{14}C dates drop in number during and just before the LGM. Horse becomes extinct after the Bölling warm period, supporting Buck and Bard's (2007) conclusions.

HUMAN-FAUNA INTERACTIONS

Reconstructing prehistoric foraging strategies in Eastern Beringia largely depends upon identifications of fauna preserved in archaeological sites, especially from the Tanana and Nenana Valley sites, Alaska and southwest Yukon Territory (Easton et al. 2007; Holmes 1996, 2001, in press; Potter 2005, 2007; Yesner 2001). Yesner (2001:317) proposed that the human dispersal into interior Alaska was a "push" and "pull" phenomenon. While the flooding of the land bridge may have "pushed" people out of Western Beringia, the presence of appealing habitats supporting migratory waterfowl, bison, and wapiti in the east may have "pulled" early inhabitants into central Alaska.

Direct evidence of human-fauna interactions comes from archaeological sites where faunal remains are associated with prehistoric artifacts (*cf.* Haile et al. 2009). Mammoth tusk fragments dated 18,890±89 cal. BP (CAMS-9898, score=23) at the Broken Mammoth site in the Tanana Valley were recovered from a component dated between 13,660±170 cal. BP and 12,950±80 cal. BP (scores=24). This fossil ivory led Yesner (2001) to argue that old ivory had been scavenged from the Tanana River floodplain. These dates were considered reliable in this analysis and support Yesner's (2001) interpretation. Mammoth ivory at the nearby Swan Point site was dated to 14,020±160 cal. BP (NSRL-2001, CAMS-17045, score=24) (Holmes in press; Holmes et al. 1996) and was contemporaneous with charcoal dates from associated features (score=28), indicating humans were coeval with mammoths. Stuart et al. (2002) recognized the complications that scavenged ivory and bone in archaeological sites present for interpretation, and therefore dates and context alone are insufficient for strong interpretations of contemporaneity. The Tanana Valley is particularly significant because it has yielded the latest known reliable mammoth, horse, and *B. priscus* occurrences on the mainland, all of which were recovered from archaeological contexts. Undoubtedly, this phenomenon is a function of excellent preservation conditions as well as intense investigations in the region.

Based on the presence of fossil ivory in archaeological sites, ivory was probably scavenged and mammoths may not have been hunted. However, the lack of mammoth kill sites is balanced by the lack of bison, horse, caribou, sheep, and wapiti kill sites in Eastern Beringia (Solow et al. 2006; Surovell et al. 2005; Surovell and Waguespack 2009; Waguespack and Surovell 2003; Wygal this volume). Alternatively, bison were likely hunted based on the presence of postcrania and contemporaneity at Dry Creek (Bigelow and Powers 1994; Powers and Hoffecker 1989), Delta River Overlook (Holmes and Bacon 1982), Broken Mammoth (Holmes et al. 1996; Yesner 2001), and Gerstle River (Potter 2005, 2007). Horse remains at the Swan Point archaeological site also suggest humans may have hunted horses in the Late Pleistocene (Holmes in press).

CONCLUSIONS

This study developed a standardized method for evaluating the reliability of radiocarbon dates and evaluated a large percentage of published radiocarbon dates associated with mammoth, bison, horse, and archaeological remains. Of 948 evaluated dates, 8.7% (n = 83) were considered reliable, 84% (n = 796) moderately reliable and 7.3% (n = 69) unreliable. The final appearance of mammoths in Eastern Beringia occurred on an island refugium at 6,400 ± 50 cal. BP (Veltre et al. 2004, 2008), uncolonized by humans until the historic period (Rubicz et al. 2003). The last occurrence of *B. priscus* was in the Tanana Valley at the Gerstle River archaeological site, dated 10,070 ± 120 cal. BP (Potter 2005, 2007; Shapiro et al. 2004). *Equus* became extinct before *B. priscus* but was survived by *B. bison* and mid-Holocene mammoths (Buck and Bard 2007). The earliest reliable date for a human presence in Eastern Beringia comes from Swan Point (14,100±110 cal. BP) (Holmes and Crass 2003). Therefore, humans, mammoths, bison, and horses coexisted for several millennia in Eastern Beringia.

Interpretations based on biogeographic distribution may be substantially altered by including only radiocarbon data which are the most reliable. The overall pattern in ^{14}C frequencies was similar between the refined (reliable and moderately reliable ^{14}C dates) and unrefined (all ^{14}C dates) records of mammoth, bison, horse, and human occupations, but the relative intensity of ^{14}C frequency fluctuations differs when only the refined radiocarbon data are used. In particular, these frequency changes are dramatic when we eliminated (1) the unreliable and moderately reliable dates at 11,000 and 10,000 cal. BP with archaeological occupations and (2) dates of mammoth remains from 28,000 to 23,000 cal. BP. Using only the reliable dates significantly limited the sample size of dated megafaunal remains, also skewing ^{14}C frequencies. For instance, if only reliable dates are used, *Bison priscus* and horse do not appear in the fossil record until the Late Pleistocene. The use of unevaluated ^{14}C dates has the potential to significantly misrepresent patterns in temporal frequency distributions, but the problem can be addressed by using robust methods of date evaluation.

There were a number of biases in this study, including geographic preference towards fossil localities and an increased availability of specimens dating or post-dating the LGM. Therefore, higher ^{14}C frequencies at this time may simply reflect a greater research emphasis and/or a taphonomic bias toward better preservation of more recent organic material. Continued paleontological and archaeological investigations as well as ancient DNA and life history studies will enhance efforts to examine complex extinction processes in finer detail. Future studies using these refined data can correct for the incomplete fossil record following Surovell et al. (2009) when reconstructing paleodemographic histories relative to climate proxy records and human occupation of Eastern Beringia. These studies should be performed with refined ^{14}C dates because they clearly influence interpretations of temporal frequency distributions and, by extension, paleodemography.

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