

2013

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Mann, Daniel H.; Groves, Pamela; Kunz, Michael L.; Reanier, Richard E.; and Gaglioti, Benjamin V., "Ice-age megafauna in Arctic Alaska: extinction, invasion, survival" (2013). *USGS Staff -- Published Research*. 921.

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## Ice-age megafauna in Arctic Alaska: extinction, invasion, survival



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## ARTICLE INFO

## Article history:

Received 7 June 2012

Received in revised form

12 March 2013

Accepted 14 March 2013

Available online 30 April 2013

## Keywords:

Arctic

Extinction

Megafauna

Climate change

Woolly mammoth

Steppe bison

Horse

Pleistocene

Ice age

Peat

Alaska

Bones

## ABSTRACT

Radical restructuring of the terrestrial, large mammal fauna living in arctic Alaska occurred between 14,000 and 10,000 years ago at the end of the last ice age. Steppe bison, horse, and woolly mammoth became extinct, moose and humans invaded, while muskox and caribou persisted. The ice age megafauna was more diverse in species and possibly contained 6× more individual animals than live in the region today. Megafaunal biomass during the last ice age may have been 30× greater than present. Horse was the dominant species in terms of number of individuals. Lions, short-faced bears, wolves, and possibly grizzly bears comprised the predator/scavenger guild. The youngest mammoth so far discovered lived ca 13,800 years ago, while horses and bison persisted on the North Slope until at least 12,500 years ago during the Younger Dryas cold interval. The first people arrived on the North Slope ca 13,500 years ago. Bone-isotope measurements and foot-loading characteristics suggest megafaunal niches were segregated along a moisture gradient, with the surviving species (muskox and caribou) utilizing the warmer and moister portions of the vegetation mosaic. As the ice age ended, the moisture gradient shifted and eliminated habitats utilized by the dryland, grazing species (bison, horse, mammoth). The proximate cause for this change was regional paludification, the spread of organic soil horizons and peat. End-Pleistocene extinctions in arctic Alaska represent local, not global extinctions since the megafaunal species lost there persisted to later times elsewhere. Hunting seems unlikely as the cause of these extinctions, but it cannot be ruled out as the final blow to megafaunal populations that were already functionally extinct by the time humans arrived in the region.

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## 1. Introduction

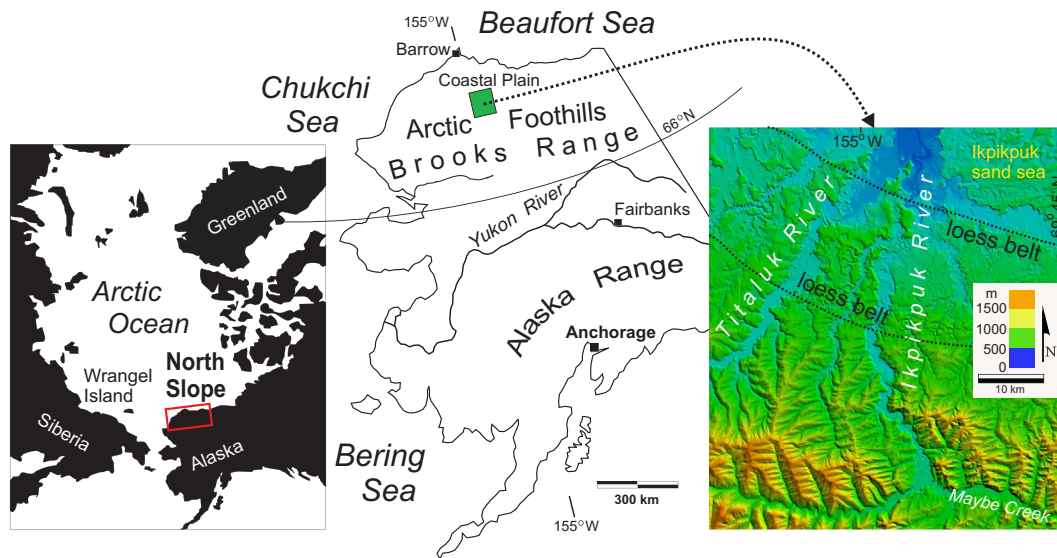
By understanding the causes of extinctions in the past, we may be better able to manage extinction threats in the future. In today's world, large herbivorous mammals are often keystone species in their ecosystems and many of them are threatened by extinction. Large numbers of megafaunal species (terrestrial mammals weighing >44 kg) became extinct at the end of the Pleistocene for reasons that remain controversial. End-Pleistocene extinctions of megafauna were regionally idiosyncratic (Barnosky et al., 2004), though many involved either overhunting by humans and/or loss of critical habitats. The main causes of habitat loss were climate changes, human activities, or a combination of both (Koch and Barnosky, 2006).

Some of the most accessible examples of prehistoric megafaunal extinctions occurred in the Arctic at the end of the last ice age (14,000–10,000 years ago). Climatic and environmental changes have been particularly large and abrupt at high latitudes (Miller et al., 2010), and megafaunal remains are often superbly preserved there in permafrost (perennially frozen ground). Moreover, humans were a late arrival to the North American Arctic and were never numerous there until late in the Holocene.

Here we examine patterns of change in populations of megafauna over the last 40,000 years on North Slope of Alaska, the tundra region north of the Brooks Range (Fig. 1). During the last ice age between ca 43 cal ka BP and 10 cal ka BP (calendar years before AD 1950 × 1000), twelve megafauna species inhabited the North Slope of Alaska. Two of these, moose (*Alces alces*) and humans, first arrived after 14 cal ka BP, and four species (caribou, *Rangifer tarandus*; muskox, *Ovibos moschatus*; wolf, *Canis lupus*; and grizzly bear, *Ursus arctos*) survived the end of the ice age apparently *in situ*.

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**Fig. 1.** Location map. The upper reaches of the Ikpikpuk and Titaluk Rivers are well-known for their accumulations of Pleistocene mammal bones. The loess belt borders the southern margin of the Ikpikpuk Sand Sea, a large dune field that was active in glacial times. Loess and sand sheet deposits exceed about 5 m thickness on upland surfaces in this loess belt.

The other six megafauna species (steppe bison, *Bison priscus*; horse, *Equus* sp.; woolly mammoth, *Mammuthus primigenius*; saiga antelope, *Saiga tatarica*; lion, *Panthera spelaea*; and short-faced bear, *Arctodus simus*) all disappeared from the North Slope before 10 cal ka BP. A thirteenth megafauna species, mastodon (*Mammuthus americanum*), probably became extinct in the region long before, perhaps at the end of the Last Interglacial (Marine Isotope Stage 5e) (G. Zazula, unpublished data).

Our goals in this paper are to present a new series of  $^{14}\text{C}$ -dated megafauna bones, to estimate extinction times for various taxa, to describe the taphonomic processes at work on this landscape, to infer faunal composition during the last ice age (here considered 43.5–10 cal ka BP), to estimate animal numbers and biomass, and to infer dietary differences between megafaunal species based on the carbon and nitrogen isotopes in their bones. We conclude with an assessment of the probable causes of end-Pleistocene extinction in this particular region.

## 2. Background: end-Pleistocene extinctions on the Mammoth Steppe

During the ice ages, Alaska's North Slope was part of the Mammoth Steppe, the now-vanished biome that intermittently extended from northwest Europe to the Yukon Territory (Guthrie, 1990; Yurtsev, 2001). Megafaunal extinctions in the Mammoth Steppe have been assigned several different causes. In this brief review, we focus first on Alaska and the Yukon and then widen the scope to Eurasia.

Guthrie et al. (2001) blamed the demise of the Mammoth Steppe on the moistening of continental interiors. As sea level rose in post-glacial times, maritime air masses invaded northern Alaska more frequently, transforming summer climate from sunny, dry, and warm to its present state of cloudy, damp, and relatively cold (Mann et al., 2001). Paleoenvironmental records from arctic Alaska lend support to Guthrie's ideas in the form of evidence for sweeping changes in hillslope erosion, floodplain dynamics, and vegetation – all triggered by increases in effective moisture during the Pleistocene–Holocene transition (Mann et al., 2002, 2010). Mesic–hydric vegetation dominated by sedges and shrubs spread across the region early in post-glacial times (Oswald et al., 1999), replacing the formerly dominant graminoids and forbs (Zazula et al., 2006,

2011), and probably lowering soil temperatures (Blok et al., 2010). Shrubs tend to be better defended by anti-herbivory compounds against mammalian herbivores than are grasses and forbs, so range quality for grazers would have declined as moist tundra spread (Guthrie, 2006). The same moistening of summer climate at the end of the Pleistocene that caused the vegetation to change also stabilized dune fields and restricted loess deposition (Carter, 1993). This permitted soil acidification to proceed unhindered by the inputs of unweathered mineral material in the form of loess and blowing sand (Walker et al., 2001). Lower soil pH and enhanced production of hard-to-decompose plant litter contributed to the development of peat, which among its other disadvantages for megafauna made locomotion difficult for species adapted for running across firm ground (Guthrie, 1990).

Unlike Guthrie's emphasis on the factors responsible for causing the collapse of an entire megafaunal ecosystem, Stuart et al. (2004) stress the importance of autecological factors driving the extinction of individual species in Eurasia. They point out that both woolly mammoth and Irish elk (*Megaloceros giganteus*) were highly mobile and responded to post-glacial climate change by shifting their ranges over great distances. These range shifts allowed survival of these two species into Holocene times.

In a study that pioneered the use of ancient DNA to infer the causes of Pleistocene extinction at high latitudes, Shapiro et al. (2004) correlated megafaunal population sizes with genetic diversity in dated bones and concluded that *B. priscus* underwent marked population fluctuations at high latitudes before humans were present there. From this they concluded environmental changes were more important than human impacts in causing extinctions. Similarly, Campos et al. (2010) studied changes in the genetic diversity of muskoxen using bones from the Arctic. They found that major bottlenecks in genetic diversity, which they interpreted as reflecting bottlenecks in population size, were not correlated with the arrival dates of humans. On this basis, they argued that muskox population dynamics are better explained by environmental changes than by hunting.

By comparing dates of extinction, genetic changes, and human arrival in different regions, Lorenzen et al. (2011) inferred that environmental changes driven by shifts in climate caused the extinctions of muskox and the woolly rhinoceros (*Coelodonta antiquitatis*) in Eurasia. They think that a combination of climate change

and human influences caused the extinction of steppe bison and horse in Eurasia. The most certain findings from the Lorenzen et al. (2011) study are that each megafauna species responded independently to environmental changes and interactions with humans, and that there is no way to predict which megafauna species became extinct based on their genetic characteristics (MacPhee et al., 2005) or the geographies of their ranges. These findings imply that chance played a major role in megafaunal extinctions in the Arctic, just as it does in many other ecological dynamics (Doak et al., 2008).

The most singular hypothesis for the cause of late Pleistocene extinctions of arctic megafauna was the suggestion by MacPhee and Marx (1997) that a disease epidemic wiped them out. These authors proposed that humans and their commensals introduced a deadly disease to previously naïve species, which then died in the resulting epidemic.

Nogués-Bravo et al. (2008) combined computer models of climate-determined geographic ranges with models of population dynamics to infer how the geographic range of woolly mammoth changed over time. They inferred that 90% of suitable mammoth habitat disappeared from Siberia between 42 and 6 cal ka BP. As their habitat shrank, mammoth populations declined, making them more vulnerable to human hunting. They see synergistic effects between human hunting and climate change as the cause of mammoth extinction in arctic Siberia. In a similar vein, MacDonald et al. (2012) mapped the shifting range of mammoth in Siberia after 40 cal ka BP and compared it to what is known about vegetation changes and the archaeological record. They concur with Guthrie's ideas about the importance of climate-driven changes in soils and vegetation being the proximate causes of mammoth extinction. Like Nogués-Bravo et al. (2008), they suggest humans were at most a synergistic factor in mammoth extinction in arctic Siberia.

Based on a large collection of dated mammoth bones from arctic Siberia, Nikolskiy et al. (2011) observed that mammoth populations fluctuated synchronously with global climate changes, increasing during interstadials and decreasing during the coldest times. They found that mammoths survived on mainland Siberia until 10.7 cal ka BP. Nikolskiy et al. (2011) suggest human hunting served as the *coup de grâce* for a species already pushed into extinction debt by unfavorable environmental changes during the early Holocene. "Extinction debt" is the persistence of individuals of a species after its habitat is no longer able to support a viable population of that species.

Ancient DNA reveals that lions underwent significant population fluctuations in the Arctic before human arrival, perhaps pre-saging the processes that would ultimately cause their extinction at the end of the Pleistocene (Barnett et al., 2009). In Eurasia, the cave lion, *P. spelaea*, became extinct in the interval 14–14.5 cal ka BP, probably in response to environmental changes affecting the abundance of its prey (Stuart and Lister, 2011). The role of humans in the extinction of arctic lions remains ambiguous.

DNA analyses of *Ursus arctos* (brown/grizzly bear) bones indicate that striking phylogeographic changes occurred within this species over the last 40,000 years in northwestern North America including eastern Beringia (Barnes et al., 2002). As with lions, muskoxen, and steppe bison, significant population bottlenecks and range shifts occurred in grizzly bears long before human entry into the New World.

In a magisterial review of the  $^{14}\text{C}$  ages of a large collection of woolly rhinoceros bones from across Eurasia, Stuart and Lister (2012) find that the geographic range of this species contracted eastward starting ca 35 cal ka BP, and that final extinction occurred ca 14 cal ka BP in northeastern Siberia, the coldest, driest part of this species' range. They infer that woolly rhinoceros' extinction was caused by environmental changes, namely deeper snowpacks that

interfered with wintertime foraging and a shift in vegetation to shrubs and trees.

In summary, previous studies show that arctic megafaunal species responded individually to environmental changes and human impacts at the end of the ice age. On the other hand, there is no escaping the fact that soils and vegetation form the bases of ecosystems and that the particular soils and vegetation that had once supported the Mammoth Steppe disappeared at the end of the Pleistocene. Which megafaunal species became extinct in the Arctic cannot be predicted based on their preexisting geographic ranges or genetic diversity. There is evidence that arctic megafauna populations experienced marked population bottlenecks during the period 30–50 cal ka BP, which in some parts of the Arctic was long before humans arrived. The occurrence of large fluctuations in megafauna populations during prehistoric times in the Arctic is consistent with the dynamics of caribou and muskox populations in historical times when extreme weather events and climate changes have caused local and even regional extirpations (Klein, 1991; Forchhammer and Boertmann, 1993; Post et al., 2009). As in other parts of the world (Barnosky et al., 2004), there was no universal agent of end-Pleistocene extinction in every sector of the Mammoth Steppe.

### 3. Regional setting

#### 3.1. Physiography and geology

Alaska's North Slope lies between the Brooks Range and the Arctic Ocean (Fig. 1). It covers approximately 207,000 km<sup>2</sup>, an area the size of the state of Nebraska. The North Slope has two physiographic units: the Arctic Foothills flanking the northern side of the Brooks Range and the Arctic Coastal Plain lying between the Arctic Foothills and the Arctic Ocean. Much of the North Slope has never been glaciated, and during the Last Glacial Maximum ca 19 cal ka BP glaciers terminated near the northern range front of the Brooks Range (Briner and Kaufman, 2008). North-flowing rivers have deposited extensive gravel deposits on the Arctic Coastal Plain and redistributed older, marine deposits left by Tertiary and Pleistocene sea-level high stands (Dinter et al., 1990). Intense periglacial activity in the form of ice-wedge polygons, pingos, and thermokarst lakes has reworked this unconsolidated sediment (Jorgenson and Shur, 2007). During dry intervals in the Pleistocene, sandy sediments on the Coastal Plain were incorporated into sand dunes forming the Ikpikpuk Sand Sea (Carter, 1981). Inactive today, this dune field was fully active in late Pleistocene times but had stabilized by ca 10 cal ka BP (Carter, 1993). A 30-km belt of thick loess and sand-sheet deposits borders the southern margin of the former sand sea (Carter, 1988), and both the Ikpikpuk and Titaluk Rivers pass through this loess belt upstream of their confluence (Fig. 1). Topography in the headwaters of the Titaluk and Ikpikpuk Rivers consists of rolling hills rising to 450 m asl. The underlying bedrock is predominately Cretaceous sandstone, which contains occasional bentonitic shales and silicified tuff beds (Mull et al., 2005).

#### 3.2. Modern climate and permafrost

The North Slope is underlain by continuous permafrost hundreds of meters thick (Jorgenson et al., 2008). Active layers, the uppermost layers of the ground that freeze and thaw annually, are typically 15–40 cm thick (Bockheim and Hinkel, 2005). July is the warmest month, and July mean air temperature increases from 4 °C at Point Barrow on the coast to 12 °C at near the Brooks Range (Zhang et al., 1996). Mean annual precipitation also increases inland from 200 mm at Point Barrow to 320 mm near the range front. About half

this precipitation falls as snow that persists on the ground for 7–9 months.

### 3.3. The rivers

The upper reaches of the Ikpikpuk and Titaluk Rivers are well-known sources of Pleistocene mammal bones (Guthrie and Stoker, 1990). The channel reaches we surveyed lie within the Arctic Foothills, upstream of the Titaluk–Ikpikpuk confluence (Fig. 1). Both rivers are low-gradient, meandering streams whose headwaters lie 100 km north of the Brooks Range along the northern fringe of the Arctic Foothills (Mann et al., 2010). They have nival flow regimes in which the short-lived, breakup flood is the only significant high-water event during most years, and stream discharge drops steadily as the summer progresses. Both rivers have neutral to slightly basic pHs ranging between 6.5 and 7.6 in July and August, with the Titaluk being the more basic of the two. The upper Ikpikpuk River has a low gradient of 0.0003, and the Titaluk's gradient is even lower at 0.0002. The Ikpikpuk drainage basin upstream of the Titaluk confluence covers 4400 km<sup>2</sup>, and the Titaluk drains an area of 2680 km<sup>2</sup>. Hillslope water tracks flowing through peatlands (McNamara et al., 1999) cover large portions of the watersheds of both rivers. The Ikpikpuk and the Titaluk Rivers flow through sinuous, meandering channels lined by willow (*Salix* spp.) shrubs (Fig. 2). The Ikpikpuk carries a predominately sandy bedload with significant amounts of granule- and pebble gravel in its thalweg. The Titaluk River is finer grained with a predominately sandy bedload and significant amounts of suspended silt derived from the beds of former thaw lakes that the river has breached by lateral erosion. Base level in both rivers today is controlled by a series of bedrock knick points exposed in the valley floors. These bedrock highs are probably associated with anticlines that strike southeast–northwest across the area (Mull et al., 2005). In their upper reaches, both the Ikpikpuk and the Titaluk have now incised through their unconsolidated valley fills down to bedrock at multiple locations.

### 3.4. Modern vegetation

Today, the vegetation of the North Slope is a Low Arctic tundra mosaic encompassing Bioclimatic Subzones C, D, and E (CAVM Team, 2003; Walker et al., 2011). Sedge/grass and moss wetlands

occupy the northern edge of the Coastal Plain, while sedge, moss, and dwarf-shrub wetlands are abundant further inland. A third main vegetation type, tussock-sedge dwarf-shrub moss tundra, covers much of the Arctic Foothills (Walker et al., 1994). Peat is widespread in the Arctic Foothills today, even on hillslopes. Occasional stands of *Populus balsamifera* (balsam poplar) trees occur in valleys (Bockheim et al., 2003). Of interest for the interpretation of bone isotopes is that the vast majority of grass species living in Alaska today are C3 species, and no C4 grasses are known from glacial times (Wooller et al., 2007; Gaglioti et al., 2011).

### 3.5. Modern megafauna

Mammals with body masses >44 kg that live on the North Slope today include moose, caribou, muskox, grizzly bear, and wolf. Polar bears (*Ursus maritimus*) rarely range inland from the coast, and wolverines (*Gulo gulo*) weigh <30 kg and so do not qualify as megafauna. Moose reach their northern range limit on the North Slope where they are restricted to gallery thickets of willow along rivers. The North Slope lies near the latitudinal midpoint of the geographic range of caribou, which extends poleward to Greenland. Muskoxen are the most arctic-obligate of the three large herbivores on the North Slope, which lies near the southern limit of their natural distribution today. Muskox became extinct on the North Slope in the mid-1800s as a result of climate change and, possibly, hunting (Lent, 1988). They were reintroduced to Alaska from Greenland in the 1930s and returned to the North Slope in the 1970s. The North Slope lies at the northern, geographical range limit of grizzly bears. Wolves are the most widely distributed of the surviving megafauna and live as far north as northern Greenland today.

Present-day population estimates for North Slope megafaunal species are problematic because of the remoteness of the region, the large fluctuations in their population sizes over decadal time scales, and the large home ranges of individuals of these species. Caribou are by far the most abundant species, with the Teshekpuk herd that sometimes occupies the headwaters of the Ikpikpuk and Titaluk Rivers estimated at 64,000 animals (ADNR, 2011). In some years, caribou from the much larger Western Arctic Herd cross into the Titaluk/Ikpikpuk basin. In 2011, caribou population density in Game Management Area 26A, the western half of the North Slope to the west of the lower Colville River, was estimated at 2.6 animals/



Fig. 2. A view of the upper Ikpikpuk River in late July 2011. The point bar in the foreground is about 40 m in width.

km<sup>2</sup> (US BLM, 2012). Moose numbers in the same region ca 2011 were approximately 0.01 animals/km<sup>2</sup>, muskoxen 0.001/km<sup>2</sup>, grizzly bears 0.01 km<sup>2</sup>, and wolves 0.004/km<sup>2</sup> (US BLM, 2012; D. Yokel, pers. comm. 2013; P. Groves unpublished data).

## 4. Methods

### 4.1. Bone collections

We collected most megafauna bones from point bars and eroding bluffs along the upper 80 km of the Ikpikpuk and Titaluk Rivers and their tributaries (Fig. 1). A few come from other North Slope alluvial river valleys and from blowouts in the former sand sea. No data on archaeological bone material are presented here. Our collection technique was literally a random walk in which we traversed river point bars and the bases of river bluffs on foot and in canoes looking for bones and teeth. Occasionally we used masks and snorkels to collect bones from the river bottom. We collected megafaunal remains from the same river bars and bluffs along the upper Ikpikpuk annually since 1998. The Titaluk River was visited less regularly. We collected all the intact bones that we judged to be eventually identifiable, regardless of species, with the exception of mammoth tusk fragments, which we ignored.

It is important to note that both the collection of bones and the selection of specimens for <sup>14</sup>C dating are random processes as regards bone age. It is impossible to judge visually whether a bone is 100 years old or >43,000 years old. This is because of the sometimes exceptional preservation of bones that have been stored in frozen and/or anaerobic sediment in the floodplains of these rivers. MacPhee et al. (2002) reached a similar conclusion working with Pleistocene bones in northern Siberia. Our original goal was to date fifty bones each of mammoth, horse, caribou, muskox, and bison. Additional bones of these taxa were later dated when exceptional specimens (e.g., skulls, bones with soft tissue) were discovered. We dated most of the bones we found that belonged to rare taxa (moose, saiga, mastodon, lion, and bear).

The total collection consists of 4090 bones and teeth, all of which are either already stored in the University of Alaska Museum of the North or are in the process of being accessioned there. We identified bones to genus by comparison to reference collections at the University of Alaska Museum and using standard references. Unidentified specimens accounted for 5% of the total collection. A random subsample ( $n = 1145$ ) of the collection was assessed for scavenger gnawing, root etching, and general weathering state (Behrensmeier, 1978).

In addition to collecting bones, we also surveyed their concentrations on river bars to detect relationships with geological processes. This was done by conducting transects from the upstream to downstream ends of point bars. Transects were oriented parallel to the shoreline down the middle of each bar. We surveyed a 20-m wide swath, collecting every bone fragment encountered. Distances were estimated using the global positioning system. At the approximate center of each point bar, we recorded Wentworth-scale particle sizes at 5-m intervals along another transect oriented perpendicular to the shoreline and extending to the top of the bar.

To reconstruct the species composition of the fauna, we first assumed that each bone identified to species represented a separate individual. We then corrected the counts of each species by the percentage of the <sup>14</sup>C-dated bones of that species dating to between 43.5 and 10 cal ka BP.

### 4.2. Radiocarbon dating and stable isotopes

We <sup>14</sup>C-dated collagen from 496 bones that had definitive identifications and were in good condition (bone weathering

stages 0, 1, and 2 of Behrensmeier (1978)) using accelerator mass spectrometry (Appendix A). Collagen extraction was by the modified Longin method currently in use by Beta Analytic, Inc. An additional 67 dates for North Slope megafaunal bones were taken from the literature. Most of these came from prior collections by Dale Guthrie and Sam Stoker along the same reaches of the Ikpikpuk and Titaluk Rivers where we collected. In what follows in this report, we excluded bones from further consideration that had either infinite ages or finite ages >43.5 <sup>14</sup>C ka BP and/or standard deviations >750 years. This resulted in a subset of 245 bones. In cases where duplicate dates were obtained on the same bone, the average of the two dates was used. All dates were normalized for  $\delta^{13}\text{C}$ . Published dates that lacked  $\delta^{13}\text{C}$  values were normalized using standard procedures (<http://calib.qub.ac.uk/calib/manual/chapter5.html>) using average  $\delta^{13}\text{C}$  values measured in bones of the same genus. All radiocarbon dates were calibrated using OXCAL 4.1 (<http://c14.arch.ox.ac.uk/html>; Bronk Ramsey, 2009) and the IntCal 09 calibration curve (Reimer et al., 2009). Probability density distributions were generated in OXCAL 4.1.

Measurements of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  in bone collagen were made using an Elemental Analyzer Isotope Ratio Mass Spectrometer. Typical errors in these measurements are  $\pm 0.5\%$ . Ordinations of bone isotopes were performed in Matlab (MathWorks, 2012). Our interpretations of stable isotope measurement rely on reviews by Högberg (1997), Heaton (1999), Ben-David et al. (2001), Hedges et al. (2005), Wooller et al. (2007), Koch et al. (2009), and Ben-David and Flaherty (2012).

Ultrafiltration techniques were not used in the <sup>14</sup>C dating of these bones. Because of the low amounts of <sup>14</sup>C remaining in old bones (<3% of modern at ca 30 cal ka BP), contamination of bone collagen by younger organics can be a critical issue in certain settings. Ultrafiltration techniques (Brown et al., 1988) can remove contamination and improve the accuracy of bone-collagen dates (Higham et al., 2012). As yet there has been no systematic comparison between ultrafiltered and non-ultrafiltered dates of the same bones sourced from permafrost environments. Although only a few were from permafrost environments, of five woolly rhinoceros bones dated by both methods, three returned older ages and two returned younger ages when re-dated using ultrafiltration (Stuart and Lister, 2012). In lieu of re-dating our entire collection using ultrafiltration techniques, we assume that contamination by younger carbon is minimal in the bones we dated since they have resided for much of their history either in permafrost or in anoxic sediments beneath river channels.

### 4.3. Estimating extinction times

An extinction time is when the last individual of some species died. Estimating extinction times is problematic because we will never discover and date the last surviving individual (Signor and Lipps, 1982) and because taphonomic processes can change over time. Also, megafaunal populations probably fluctuated in size over time, particularly at high latitudes and especially given the rapid tempo of climate changes during the ice age.

Despite the inherent complexity of extinction and taphonomy, several statistical approaches have been used to estimate extinction time. Solow's (1993, 2003) equation describes probability of extinction in relation to the number of sightings of a species over a given period. McNerny et al. (2006) modified Solow's equation to account for different lengths of sighting periods. Bradshaw et al. (2012) modified the McNerny approach by weighting sightings inversely according to time since last sighting under the assumption that sighting rates typically decline over time, so that the most recent sighting rate is the most informative. In the case of bones, this implies that the probability of preservation decreases with age

and/or that animal populations decline to extinction along sigmoidal, linear, or exponential trajectories.

Many of the assumptions used in the statistical methods just described are debatable. When dealing with time scales of tens of millennia, it is particularly hazardous to assume that sightings are equally likely over time and that the intervals between these sightings conform to some theoretical distribution. It is likely that populations fluctuated and taphonomic/geological processes changed over such long time scales. Assumptions about the trajectories of population decline preceding extinction are also tenuous because the demographic trajectories of populations approaching extinction can vary widely. Familiar examples include the contrasting extinction trajectories of the passenger pigeon (*Ectopistes migratorius*) and California condor (*Gymnogyps californianus*). The ecological idiosyncrasies of extinction, the Signor-Lipps Effect, and the possibility of taphonomic nonstationarity undermine the credibility of even the most elegant statistical estimates of extinction times.

Our strategy for estimating extinction times emphasizes simplicity. We use OXCAL's simplest-case, "boundary" function because it accounts for the measurement and calibration uncertainties in  $^{14}\text{C}$  dating. The "boundary" calculation assumes extinction occurred abruptly without a preceding decline in population size and that dated samples were uniformly sampled from the phase in question (Bronk Ramsey, 2009). A Bayesian approach similar to OXCAL's was used by Buck and Bard (2007) to estimate the extinction time of Alaskan Pleistocene horses. We also employ an empirical version of Solow's (1993) sighting-frequency method. This involves estimating the probabilities of time-since-last-sighting empirically from time series of dated bones. To do this, we first use OXCAL's "interval" function to estimate the duration of gaps between the 95% probability distributions of consecutive  $^{14}\text{C}$  ages of bones of different taxa. Next, we group these age gaps into consecutive 100-year, age-gap bins. Finally, we calculate the probability of encountering an age gap within the fossil record that exceeds each of these 100-year intervals. This gap-probability method yields the probability of encountering absence-gaps of varying durations given that the species was still living on the landscape and given that taphonomic and population processes remained constant through time.

#### 4.4. Estimates of animal numbers and biomasses

We make speculative estimates of the population sizes of ice-age species using caribou as a standard. As detailed in Section 6.3, the record of dated caribou bones suggests the population density of this species has remained roughly constant over the last 40,000 years. Knowing the population density of caribou in the region today (ADNR, 2011; US BLM, 2012), we use the abundances of the different megafaunal species in the bone collection relative to caribou to estimate the paleo-population densities of these other species. The body masses of different species used for biomass estimates come from Guthrie (1968).

## 5. Results

### 5.1. Post-mortem modification of bones

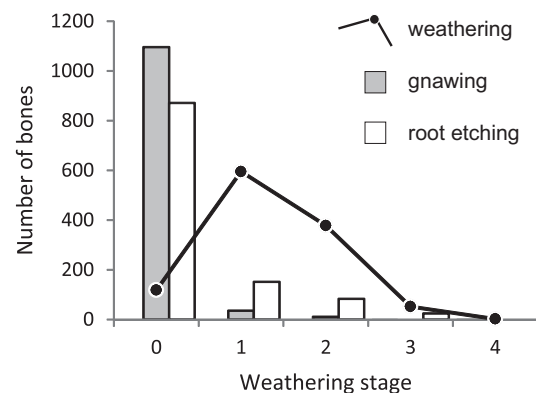
Only a few of the bones we collected were still articulated. Most occurred as single bones comingled with the bones and teeth of other species and other individuals. Some bones were modified by *post-mortem* processes, the most common ones being gnawing by scavengers, surface corrosion by plant roots (root etching), and general chemical and physical weathering. The latter category includes the interacting processes of bacterial decay, breakage by

animal trampling and river ice, as well as damage caused by drying and cracking. Around 10% of the bones we collected still contained marrow and sometimes had bits of tissue attached. Despite their fresh appearance, some bones in this condition yielded infinite  $^{14}\text{C}$  ages. About half of all bones fall into Weathering Stage 1 of Behrensmeyer (1978) in which there is some surface cracking on the bone (Fig. 3). Weathering Stage 3 bones that show extensive cracking, flaking, and dissolution pits account for only 10% of the total. Very few bones display gnawing by scavengers like fox, wolverine, wolf, or bear. Evidence of root etching is only slightly more frequent, suggesting that few of the bones spent time in the active layer of soils. We did not quantify bone breakage patterns. In summary, most bones were not scavenged before they were interred in sediment, and very few spent time exposed to plant roots in the active layer of a soil. Nonetheless, the majority of bones have spent long enough exposed to surface conditions to accumulate a slight degree of chemical and physical weathering.

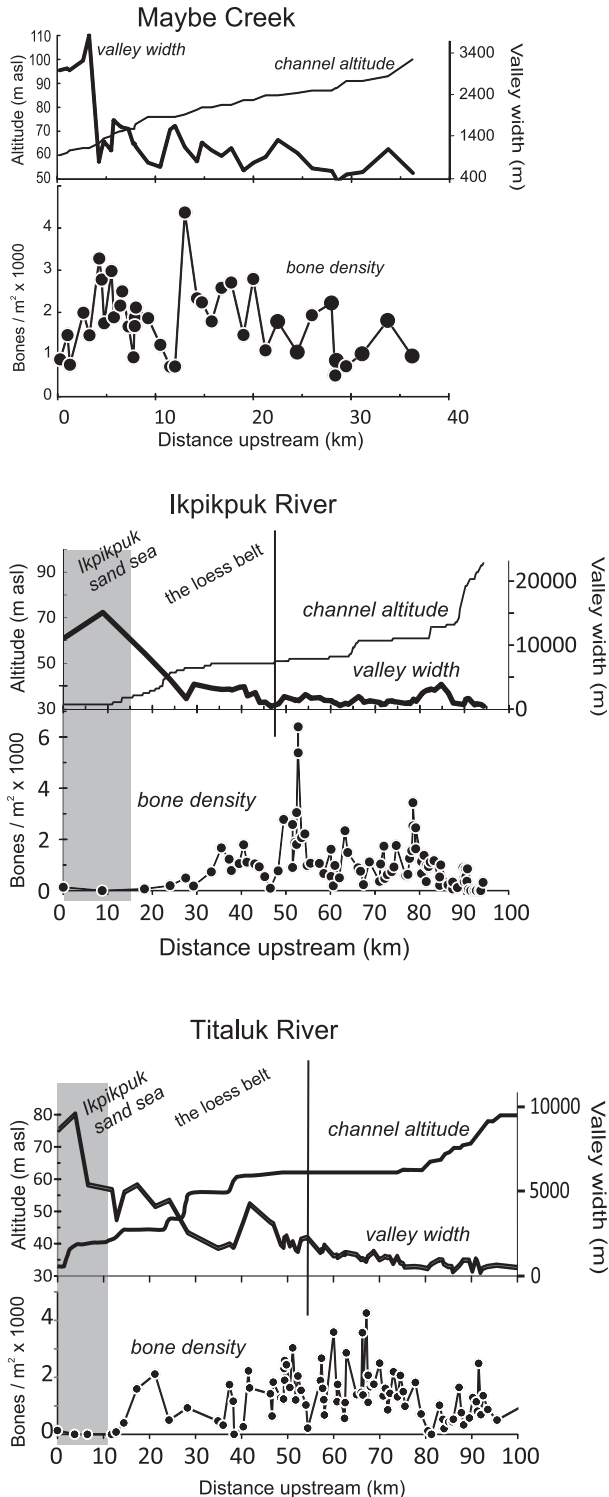
### 5.2. Spatial distribution of bones

In the course of collecting bones, we noticed several distributional patterns, which at this stage remain anecdotal. The first is Andre Sher's rule: Pleistocene bones are most abundant on the first few point bars downstream of large eroding bluffs of Quaternary sediment. The second pattern is that bones tend to collect in channel thalwegs. Third, bones are most abundant on the upstream end of point bars where they are associated with the coarsest particle sizes (pebbles to coarse sand). We suspect this reflects a combination of steep gradients in current velocity at this location during break-up floods and the actions of ice floes that bulldoze sediment upwards onto the upstream edges of point bars. Fourth, bones are not randomly distributed within the valley fill below present river level. Rather they occur in widely separated *Konzentrat-Lagerstätten* (literally: "concentrated storage places", or colloquially: "bone closets"), which serve as source areas for many of the bones found on downstream river bars. These *Lagerstätten* are presently below river level and so are poorly exposed, but their dimensions and sediment characteristics are consistent with old channel fills lying near base level in the river valleys.

Detailed surveys of the concentration of bones on river bars indicate a lack of correlation with valley gradient in the Ikpikpuk, Titaluk, and Maybe Creek valleys (Fig. 4); however, bone



**Fig. 3.** Weathering characteristics of a random sample of 1145 bones. **General weathering state** (adapted from Behrensmeyer, 1978), Stage 0: no cracks or flakes, Stage 1: cracking parallel to fiber structure, Stage 2: outermost layers show thin flaking, Stage 3: surface has rough fibrous patches 1–1.5 mm deep, Stage 4: surface is rough and fibrous with loose splinters, Stage 5: bone falls apart *in situ*. **Root etching** Stage 0: no etching, Stage 1: <33% of surface etched, Stage 2: 33–66% of surface etched, Stage 3: >66% of surface etched. **Gnawing** Stage 0: no gnaw marks, Stage 1: single area of gnawing, Stage 2: multiple areas of gnawing; badly scarred.



**Fig. 4.** Bone concentrations on river point bars compared to valley slope, valley width, and the location of the Ikpikpuk Sand Sea.

concentration does decline markedly where valleys widen. In the case of the Ikpikpuk and Titaluk valleys, bone concentration drops sharply where these rivers enter the former sand sea, at which point they lose any bedrock control over lateral channel position. The same is true for Maybe Creek where it debouches into the floodplain of the larger Ikpikpuk River (Fig. 4). As mentioned earlier, coarser particle size seems to be correlated with bone density at the upstream ends of point bars, but no relationship was

found between particle size and bone occurrence at the scale of entire river valleys, except that the concentration of bones falls to zero where the Ikpikpuk and Titaluk enter the former sand sea and their sediment becomes entirely sand. The key inference from these observations is that bones are most abundant where paleochannels have been laterally constrained by bedrock-controlled valley walls.

### 5.3. Relative abundances of different taxa

In terms of individual animals, horses were the most abundant taxon on the North Slope between 43.5 and 10 cal ka BP (Fig. 5). Based on the lengths of their metacarpal bones, on the fact that hemionid horses became extinct in Alaska ca 34 cal ka BP (Guthrie, 2003; Weinstock et al., 2005), and on the identification of a partly mummified horse leg from the Titaluk River (Guthrie and Stoker, 1990), these were caballine horses belonging to the Eurasian species complex of *Equus ferus*. Steppe bison were the next most abundant taxon and comprised 23% of all identified bones, followed by caribou with 16%. Woolly mammoth and muskox each accounted for 9% of the collected bones. Predators (lion, bear, and wolf) together comprised approximately 2%. In terms of biomass, mammoth comprised an estimated 49% of the total (Fig. 5), followed by horse and bison, both at around 23%. Caribou and muskox comprised only about 3% of the total megafaunal biomass, and predators comprised <1%. Moose, which only arrived in the region ca 14 cal ka BP, also comprised <1%. The situation is radically different today when caribou comprise >97% of both the total number of megafauna on the North Slope and the total megafaunal biomass there. On the modern landscape, moose, muskox, wolf and bear each comprise <1% of the total number and biomass of the megafauna.

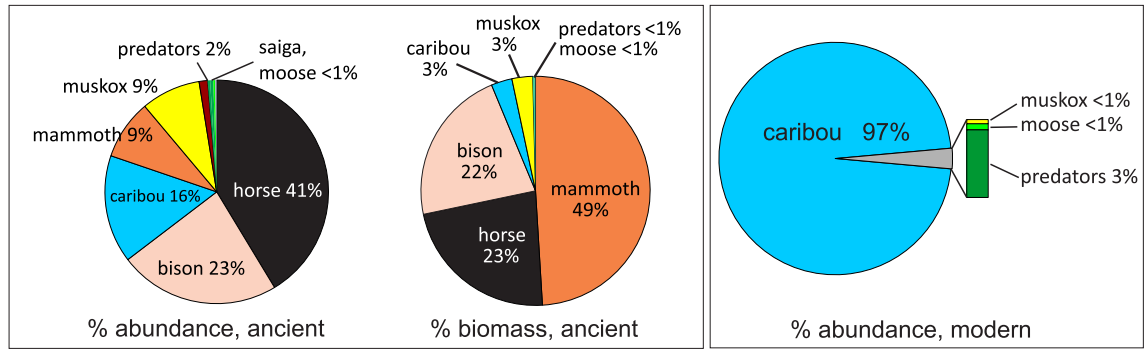
### 5.4. Temporal patterns of species abundance

The most striking difference in timing among the different taxa is that 95% of the dated horse bones ( $n = 103$ ) and 78% of the lion bones ( $n = 9$ ) are younger than 43.5 cal ka BP (Fig. 6, Table 1). In contrast, the majority of muskox and mammoth bones are >43.5 cal ka BP. Dated bones of all taxa exhibit a discontinuous, spikey distribution through time (Fig. 7). Because <sup>14</sup>C calibration causes distortions in these types of probability-density plots (Williams, 2012), and because the older part of the <sup>14</sup>C-calibration curve is currently being updated with new Lake Suigetsu varve data (Bronk Ramsey et al., 2012), we have postponed making detailed comparisons between these probability-density graphs and global climate events.

The youngest dates on extinct taxa provide limiting estimates on their extinction times (Fig. 8). The youngest horse and bison both lived ca 12.5 cal ka BP during the Younger Dryas chronozone. The two youngest horse bones in our collection (Beta-339279 and -331878) were found in blowouts within the Ikpikpuk Sand Sea 100 km distant from the upper Ikpikpuk basin. These new dates are approximately 1700 years younger than previous estimates of when horse became extinct in Alaska (Guthrie, 2003; Buck and Bard, 2007). Bison bones dating to ca 10.5 cal ka BP (Fig. 8) were excavated at the Engigstciak archaeological site 600 km east of the study area in the northwestern Yukon Territory (Cinq-Mars et al., 1991; MacNeish, 2000), though it is uncertain whether these bison represent *B. priscus* or *Bison occidentalis*.

Estimates of extinction time come from two other sources as well. The “boundary” calculation in OXCAL suggests horse became extinct between 11 and 12.6 cal ka BP (Fig. 9). Similarly, bison’s estimated extinction occurred between 10 and 12.6 cal ka BP, and mammoth’s between about 11 and 14.2 cal ka BP.





**Fig. 5.** Percentages of identifiable bones ( $n = 1932$ ) dating to between 43.5 and 10  $^{14}\text{C}$  yr BP belonging to different taxa. For the ice age percentages, counts of identified bones are corrected using the percentage of the bones of that taxon dating to  $>10$  and  $<43.5$   $^{14}\text{C}$  yr BP. Biomass estimates are based on typical body masses listed in Table 1.

Analysis of the duration of dating gaps between the 95% probability density distributions of calibrated dates (Fig. 10) suggests in the case of horse ( $n = 94$  age gaps) there is a  $>0.05$  probability of finding a horse that is 0–1300 years younger than the youngest one we now have. This would postpone the extinction date for horse to ca 11.1 cal ka BP (Fig. 8). Similarly based on dating gaps there is a  $>0.05$  probability of finding a bison as young as 10.6 and a mammoth as young as 11.8 cal ka BP in the study area.

Humans and moose arrived on the North Slope before horse, bison, and mammoth became extinct. The oldest date on archaeological charcoal comes from the Mesa Site (Kunz and Reanier, 1994; Mann et al., 2001) in the Arctic Foothills and dates to 13.5 cal ka BP (Fig. 8). OXCAL’s “boundary” function estimates that humans may have first arrived on the North Slope ca 13.6 cal yr BP (Fig. 9). The oldest date for moose is 14.1 cal ka BP, and OXCAL estimates the lower (oldest) boundary of the “moose zone” at 16 cal ka BP.

5.5. Bone isotopes

Measurements of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  reveal clear differences between megafaunal species. Known grazers (horse, mammoth, and bison) have  $\delta^{15}\text{N}$  values centered between 4 and 9‰. Browsers like moose and mastodon, which are known to have subsisted largely on shrubs and trees, have  $\delta^{15}\text{N}$  values between  $-1.0$  and 3‰.  $\delta^{13}\text{C}$  values vary less between species, but the combination of the two isotopes suggests separation between the diets of all species (Fig. 11). The species pairs showing the most overlap are steppe bison and muskox, moose and mastodon, and mammoth and horse. Of course, mastodon and moose were not contemporaries because

mastodon probably became extinct at the end of the Last Interglacial (G. Zazula unpublished data).

Measurements of  $\delta^{13}\text{C}$  reveal shifts of 1–2‰ in all species after 43.5 cal ka BP (Fig. 12).  $\delta^{15}\text{N}$  measurements show greater variability over time than  $\delta^{13}\text{C}$ . Interestingly, the most striking changes in bone isotopes are not associated with the Pleistocene/Holocene boundary or the beginning of the Bølling–Allerød ca 14 cal ka BP but occurred earlier in time. Horse  $\delta^{15}\text{N}$  decreased by 6‰ over a 3500-year period beginning ca 16 cal ka BP. A decline of similar magnitude in caribou bones began ca 20 cal ka BP, while bison  $\delta^{15}\text{N}$  began a 3‰ decline beginning ca 25 cal ka BP (Fig. 12).

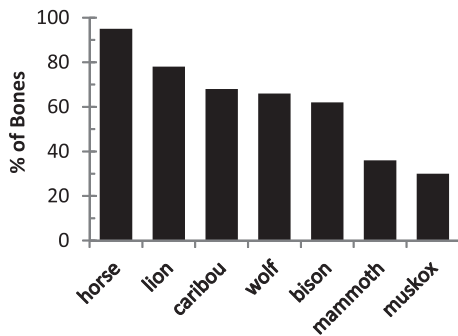
6. Discussion

6.1. Taphonomic pathways

The upper reaches of the Ikpikpuk and Titaluk are unusual among North Slope rivers in that their combination of low gradient, sand-dominated bedload, and nival flow regime favors the preservation of mammal bones. In contrast, streams with headwaters in the Brooks Range have subnival flow regimes involving frequent summer floods. They also possess steeper gradients and hence have higher flow velocities, and, with some exceptions, carry coarser bedloads that are less friendly to bones. We have descended most of the major rivers crossing the North Slope from the Brooks Range and found very few bones along any of them.

The processes responsible for incorporating bones into floodplain sediments and preserving them in the Ikpikpuk and Titaluk valleys differ from those operating in the uplands of Interior Alaska (Guthrie, 1990). There most carcasses were buried by mass movements, most of which involved slumps of loess-rich material at the foot of steep slopes. Bones later entered stream systems when they were exhumed by the lateral migration of channels. In the course of being carried downstream, bones tended to be concentrated (along with the gold) in the lowest levels of sediment overlying bedrock. This Interior-Alaska model predicts that more bones are preserved where more loess is present on the landscape. It also predicts that bones are most abundant where tributary streams enter larger valleys since these steeper tributary streams are carrying bones from their surrounding hillslopes. Neither of these patterns was observed in our study area.

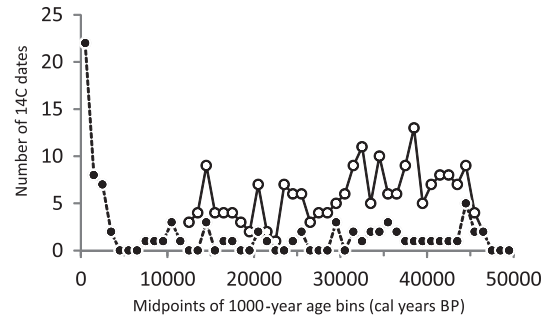
Our conceptual model of how bones are preserved and concentrated in the Ikpikpuk and Titaluk incorporates some of the same processes just described and adds a few others (Fig. 13). The limited amount of *post-mortem* alteration suggests most bones were incorporated quickly – perhaps in  $<10$  years – into sediment. There was little opportunity for scavengers to gnaw the bones or for roots to corrode them. Rapid burial is prerequisite to avoid



**Fig. 6.** Percentages of bones younger than 43.5  $^{14}\text{C}$  yr BP. Counts of the total number of identified bones of each taxon are adjusted by the percentage of the  $^{14}\text{C}$ -dated bones of that taxon falling between 10 and 43.5  $^{14}\text{C}$  yr BP. Most horse and lion bones post-date 43.5  $^{14}\text{C}$  ka BP.

**Table 1**  
Estimates of ice-age numbers of megafaunal population densities and biomasses.

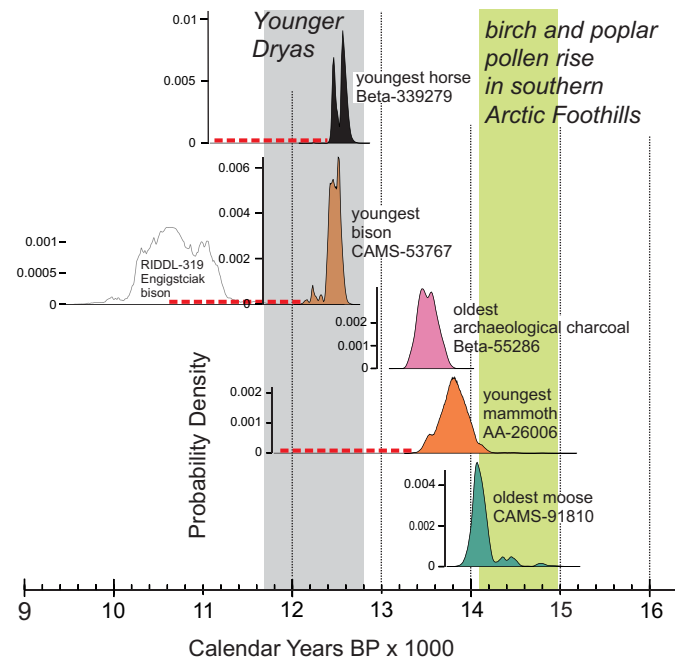
Species	Body mass (kg)	Modern population density (indiv./km <sup>2</sup> )	Modern biomass (kg/km <sup>2</sup> )	% of total animals (inferred from bone counts)	Caribou relative abundance index	Ice-age population density (indiv./km <sup>2</sup> ) this study	Ice-age population densities at Duvanniy Yar, Lena River, Siberia (Zimov et al., 2012) (indiv./km <sup>2</sup> )	Ice-age population densities, eastern Beringia (Matheus, 2003) (indiv./km <sup>2</sup> )	Ice-age population densities, Beringia (Redmann, 1982) (indiv./km <sup>2</sup> )	Ice-age population densities, Beringia (Bliss and Richards, 1982) (indiv./km <sup>2</sup> )	Ice-age biomass (kg/km <sup>2</sup> ) this study	Ice-age biomass, eastern Beringia (Matheus, 2003) (kg/km <sup>2</sup> )
Muskox	180	0.001	0.2	9	0.56	1.5	—	—	0.7–1.4	—	270	—
Caribou	100	2.6	260	16	1	2.6	15	—	0.3–0.6	—	260	—
Horse	290	0	0	41	2.56	6.7	7.5	1	0.5–1.3	—	1940	180
Bison	500	0	0	23	1.43	3.7	5	0.6	0.2–0.5	—	1850	400
Mammoth	3000	0	0	9	0.56	1.5	1	0.08	0.02–0.04	—	4500	300
Carnivores (bear, wolf)	75 avg.	0.011	0.8	2	0.12	0.3	1.25 (lions + wolves)	—	—	—	22	—
Moose	360	0.007	2.5	<1	0.003	0	0	—	—	—	0	—
Totals	—	2.62	264	100%	—	16.3	29.75	1.7	1.7–3.8	—	8840	1000



**Fig. 7.** Numbers of <sup>14</sup>C-dated bones <43.5 <sup>14</sup>C ka BP in 1000-year age bins. Open circles = extinct species (mammoth, horse, bison; n = 203). Solid dots = extant species (moose, caribou, muskox; n = 88).

scavengers. Other possible explanations for the limited evidence of carnivore gnawing are a predominance of winter kills and/or high prey abundance (Haynes, 1982, 1983); however, these alternatives seem unlikely because in the region today caribou carcasses are converted into broad scatters of gnawed and shattered bones within several years of death. Some of these bones may persist for decades on the ground surface, but they persist as gnawed fragments, and this is not the condition of the majority of Pleistocene bones we find.

The mixed nature of the bone assemblage in which bones of all species and all ages occur together on the same sand bar is consistent with the river repeatedly exhuming bones from the valley fill and then redepositing them. As in Guthrie’s model for Interior Alaska, we think that bones are progressively elutriated downward in the valley fill by repeated episodes of erosion and redeposition. Elutriation occurs because of density differences between bones and the sandy matrix. Because the bedload of these rivers is fine grained and because the annual flood is a singular



**Fig. 8.** Probability-density distributions of the youngest dates of extinct species and the oldest dates of humans and moose. The red dashed lines are period in which the probability of there being a time gap of this duration or longer is >0.05 (see Fig. 10). The bison from Engigstciak comes from 600 km east of the study areas and is not positively identified to species.

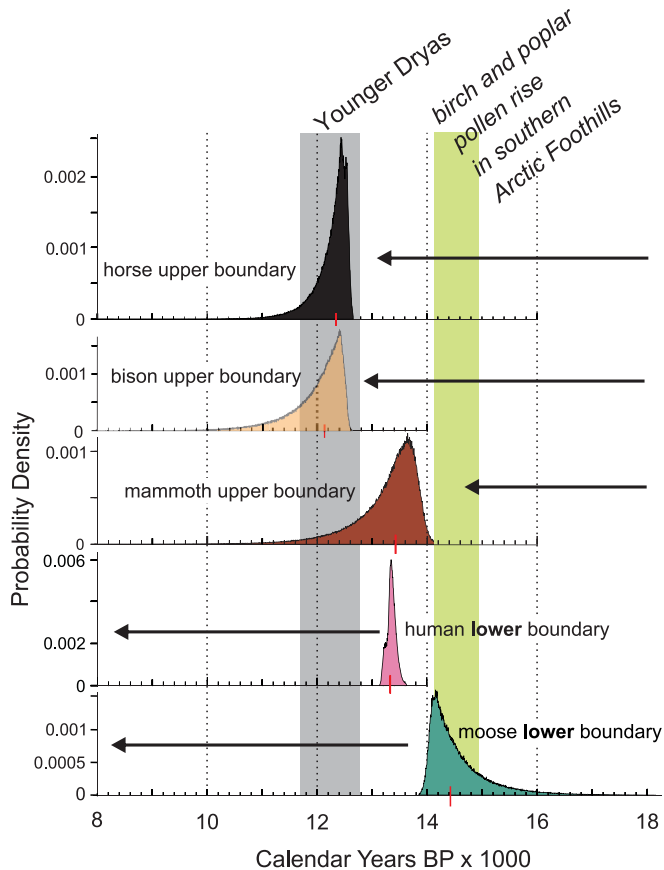


Fig. 9. OXCAL-estimated upper (youngest) boundaries for extinct species and lower (oldest) boundaries for humans and moose.

event, this exhumation and redeposition process is relatively gentle.

We think that bones enter the valley fills of the Titaluk and Ikpiqpuk through two different routes. The first involves animals dying on upland surfaces near the river and being rapidly buried by loess or sand sheet sediment there (Fig. 13). We are uncertain how exactly this burial occurred before scavengers and weathering altered the bones. Perhaps animals died in thermokarst hollows (Boeskorov et al., 2011) or in ravines that drifted over with snow, sand, and/or loess during the winter. At the few places where the rivers are eroding old upland surfaces today, bones sequestered via this first pathway are tumbling into the river channel where they

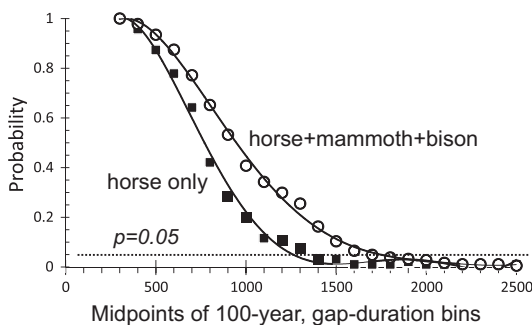


Fig. 10. Probability of encountering gaps between calibrated ages at 95% probability. Open circles show the duration of gaps between the 95% probability distributions of consecutive dated bones of combined mammoth, horse, and bison ( $n = 184$ ,  $R^2 = 0.998$ ). Black squares = consecutive gaps between horse dates only ( $n = 94$ ,  $R^2 = 0.995$ ).

are concentrated in the channel thalweg and join bones arriving via the second taphonomic pathway.

The second pathway involves animals dying on the floodplain where they were quickly buried by fluvial sediment. Repeated bouts of exhumation and reburial mix the bones of different carcasses. Progressive elutriation during repeated episodes of valley-fill incision (Mann et al., 2010) concentrates the bones in abandoned channel fills at progressively deeper levels in the valley fills. Laterally, these channel fills are concentrated where the valley walls are narrowest. Vertically, they become concentrated in valley reaches that are immediately upstream of bedrock knick points on the valley floor. Observations consistent with this pathway are a) concentrations of bones in the thalweg at the base of bluffs that are shedding bones into the river, b) the influence of valley width on bone density (Fig. 4), and c) the fact that most of the bones we collected originated upstream of the loess belt (Figs. 1 and 4).

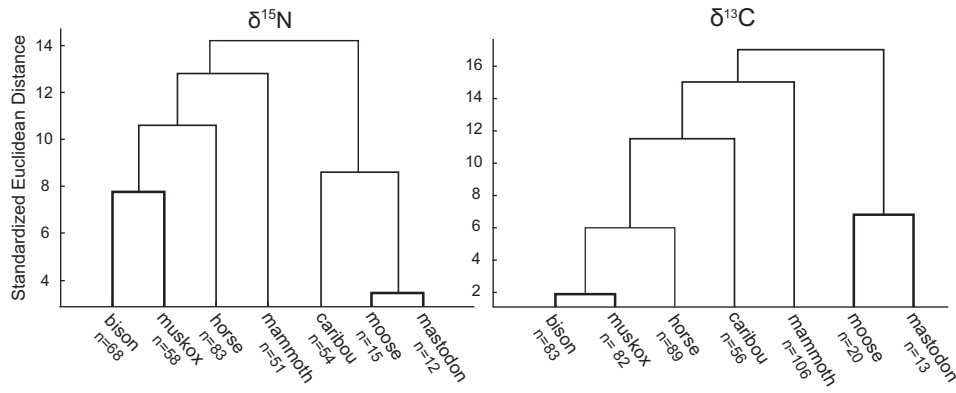
What were the relative contributions of these two different taphonomic pathways? There is only one situation where we are able to associate particular bones with the sedimentary units where they were initially deposited. This is at cutbanks on the lower Titaluk River located within the loess belt. At these locations (the Russian and Carter sections), 5–10 m of fluvial sand and gravel are overlain by 15–40 m of sand sheet and loess (Guthrie and Stoker, 1990; Mann et al., unpublished data). We have obtained multiple  $^{14}\text{C}$  dates on these fluvial and aeolian units, so we know when they were deposited. At the same sections, we have dated seven megafauna bones, and by knowing their ages we can assign them an origin in either the fluvial or aeolian unit. Three of these seven have ages consistent with deposition in the fluvial unit, and the other four have ages requiring they originated from the overlying aeolian unit. A fifth undated specimen consists of the shattered skull of a mammoth calf encountered while excavating a buried soil in the loess unit. This one example confirms the existence of the two taphonomic pathways; however, keep in mind that most dated bones (>75%) come from upstream of the loess belt, implying that most entered through the floodplain-first pathway.

To summarize, there are two pathways for interring bones in the valley fills of these rivers. The first pathway involves megafauna dying in the uplands and being rapidly buried by aeolian sedimentation. Bones initially deposited in the uplands later fall into the channel when the rivers erode laterally into these deposits of loess and sand sheets. The second pathway starts on the floodplain where dead animals are quickly buried by fluvial sedimentation. These bones are mixed downstream with those entering via the upland path and are similarly elutriated downward in the valley fills. We think that the second, floodplain pathway is the main one because the majority of the bones we collected came from upstream of the loess belt.

## 6.2. Implications of taphonomic processes for the fossil record

Bones entering the valley fill via the upland-loess pathway are much less likely to do so at times when rates of loess and sand-sheet deposition are low. The Ikpiqpuk Sand Sea probably stabilized ca 10,000 cal yr BP (Carter, 1993) and as it revegetated, the supply of aeolian sediment to adjacent areas ceased. So the upland-loess pathway probably operated only during the late Pleistocene, and even then its intensity would have varied episodically according to the activity of the dune field.

In contrast, the floodplain pathway has probably operated continuously. Even today when the rivers are in a state of maximum incision compared to their levels during the Lateglacial and early Holocene (Mann et al., 2010), channels continue to migrate, bluffs erode, and overbank deposition occurs. This pathway has probably

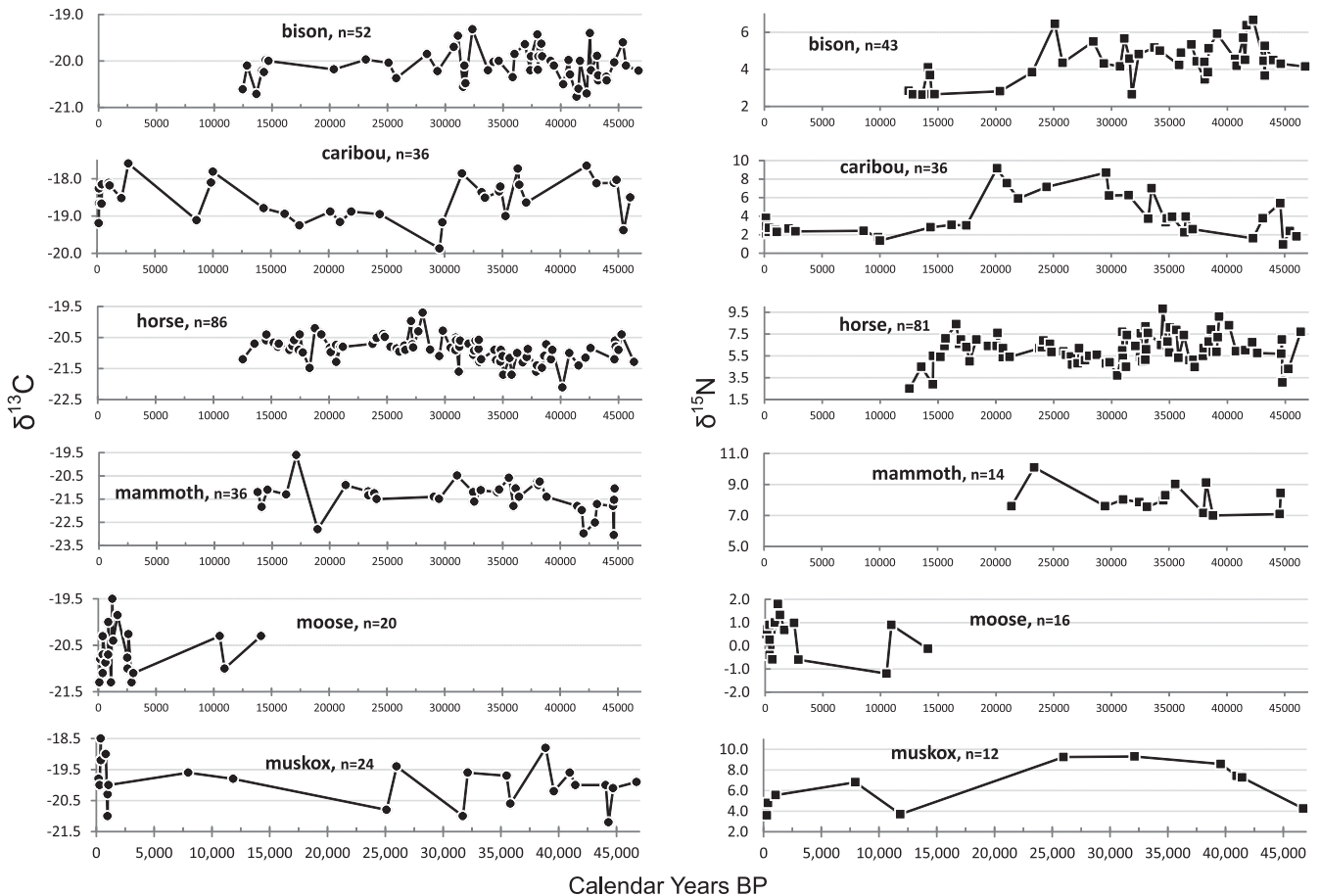


**Fig. 11.** Ordination of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  describe similarities in diet. Bones of all ages are included here. Euclidean distance to population mean is a measure of departure from central tendency in isotopic niche.

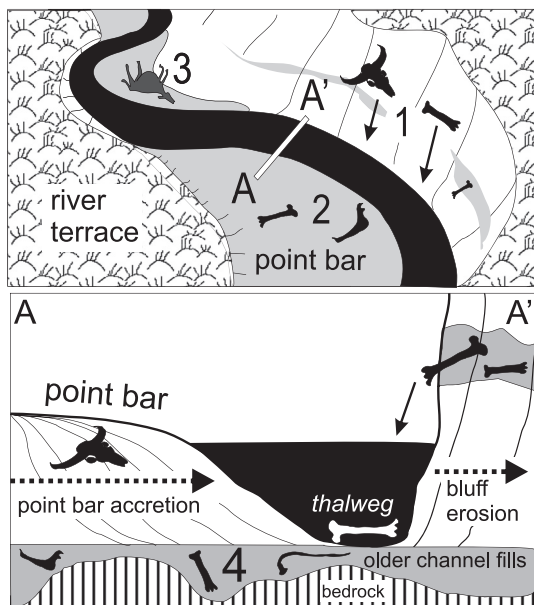
sampled the extant megafauna at about the same rate throughout the last 40,000 years. Because most of the bones we dated came from upstream of the loess belt, we think that shifts in taphonomy had minimal influence over the rate at which bones have been incorporated into the fossil record. In what follows, taphonomic processes are assumed to have been constant over the last 40,000 years.

Once incorporated in the valley fill, bones have an extremely low probability of loss. Several observations support this interpretation: a) This is an arctic environment where the ice-free season during which the rivers flow and bones are vulnerable to

physical and chemical weathering is brief: 3–5 months at most. b) The channel-fill deposits where we think many bones eventually are stored are the geologically most stable sites on this landscape. This is because they are situated at low levels in the valley fills where they are protected from most river erosion by bedrock sills. c) If bones are exhumed by the river, they have a high probability of being rapidly reburied. Even if they spend several months exposed at the surface of a point bar, the combination of low current velocities and an arctic climate mean they will probably survive intact until reburial. Quantitative evidence for a decreasing probability of bone loss through time is described in the next section.



**Fig. 12.** Changing  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values in dated bones through time.



**Fig. 13.** Conceptual model of taphonomic processes operating in the study area. Bones enter flood-plain deposits via two pathways. In the first, bones buried by aeolian sediment on uplands in the loess belt (1) are eroded from cutbanks and concentrated in channel thalweg. Break-up floods carry some bones onto point bars (2), where they are reworked back into sandy sediments. The second pathway involves animals dying on the active floodplain (3), where their bones are dispersed, rapidly buried, and mingled with bones from the first pathway. Once in the floodplain, bones are gradually elutriated from the sandy matrix and concentrated in channel fills upstream of bedrock outcrops (4).

### 6.3. How many megafauna were there?

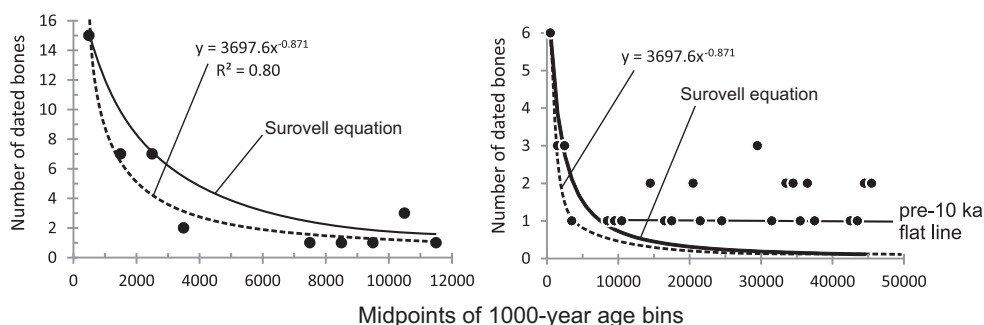
We can estimate the population densities of the extinct megafauna between 45 and 10 cal ka BP by accepting the conceptual model just described for the dynamics of bones in the study area and making several assumptions about how caribou population density changed over time. We use caribou as the standard to estimate the numbers of other species because many more caribou were dated than muskoxen, and unlike moose, caribou are present throughout the record. Assuming that taphonomic processes have remained constant, the distribution of bone ages through time is a function of changing population sizes. Probability of discovery typically increases toward the present day because taphonomic loss increases into the past. This rise-to-present curve links paleo-population sizes to modern ones. There is no rise to the present in the  $^{14}\text{C}$ -dates of the extinct species, but the frequency of dated bones of the extant species (moose, muskox, and caribou) increases

greatly after 4–5 cal ka BP. We combined the  $^{14}\text{C}$  ages of bones of these three species to get a clearer description of the shape of the rise-to-present curve. Similar patterns result from using the caribou dates alone (Fig. 14). The Surovell equation fitted to these data describes the rise to present of geological deposits (Surovell et al., 2009; Williams, 2012).

Both the Surovell equation and the moose/caribou/muskox power law underestimate the number of pre-10 cal ka BP caribou dates (Fig. 14), suggesting that the actual taphonomic loss rate declines to near-zero values for bones >10,000 years old. This is consistent with the taphonomic model described earlier. Alternatively, there were more caribou during the ice age than there are today. Since our goal is to use these curves to estimate paleo-population sizes, the conservative approach is to assume a zero-loss rate for bones >10,000 years old. The taphonomic-loss relationship that best describes both the observed rise to the present and the pre-10 cal ka BP distribution of caribou ages is an “L”-shaped one that follows a power law equation back to ca 10 cal ka BP and a flat line before then (Fig. 14).

Assuming that caribou populations were similar in the early Holocene as they are today, and assuming that taphonomic loss “flat-lines” in the years prior to 10 cal ka BP, and by knowing what population densities of caribou are today, we can use the relative abundances of the bones of the different taxa (Fig. 5) to estimate the population densities of the extinct taxa on the ice-age landscape (Table 1). Today, there are approximately 2.6 caribou/km<sup>2</sup> on the North Slope west of the lower Colville River. Based on the assumptions just stated, caribou numbers during the ice age were at least 2.6 animals/km<sup>2</sup>. Among the ice-age bones, caribou are 1.8× more abundant than muskox and mammoth, 1.4× less abundant than bison, and 2.6× less abundant than horse (Fig. 5a, Table 1). If caribou were present on the ice-age landscape at a density of 2.6 individuals/km<sup>2</sup>, then there would have been 1.5 muskox, 1.5 mammoth/km<sup>2</sup>, 3.7 bison/km<sup>2</sup>, and 6.7 horse/km<sup>2</sup> during that same period. The total number of megafaunal animals would have been 16/km<sup>2</sup>. Today, there are approximately 2.6 megafauna/km<sup>2</sup> in the region, which means that megafauna of all species combined were approximately 6× more numerous during the ice age than today. Based on these estimates, biomass during the ice age was approximately 8800 kg/km<sup>2</sup>, which was about 30× greater than today (Table 1). In comparison, grassland and savannah ecosystems in East and Central Africa in recent times have supported megafaunal biomasses ranging from 4000 to 20,000 kg/km<sup>2</sup> (Kruuk, 1972; Schaller, 1972; Coe et al., 1976; Redmann, 1982).

Previous estimates have been made of megafaunal population densities and biomasses in the Mammoth Steppe of eastern Beringia during the ice age. Redmann (1982) and Bliss and Richards (1982) combined estimates of the carrying capacities of lower



**Fig. 14.** LEFT: The Rise to Present of  $^{14}\text{C}$ -dated moose, muskoxen, and caribou ( $n = 38$ ). Zero values have been dropped. Not included here are eight muskox specimens collected from possible archaeological contexts north of the study area. The dashed line is a power law fitted to these data. The solid line is the fitted Surovell equation originally derived from the taphonomic loss of volcanic ash deposits in terrestrial environments. RIGHT: The number of  $^{14}\text{C}$ -dated muskoxen ( $n = 25$ ) and caribou ( $n = 42$ ) compared to the equations fitted in the left-hand panel.

latitude grasslands and high latitude ecosystems to calculate how many megafauna could have been supported. Redmann's (1982) estimates are somewhat similar to ours, while those of Bliss and Richards (1982) are roughly an order of magnitude lower. Matheus (2003) arrived at values similar to Bliss and Richards (1982).

Zimov et al. (2012) arrived at population estimates similar to our's for the interval 40–10 cal ka BP along the lower Lena River in northeastern Siberia (Table 1). Working with bones eroding out of the valley-fill deposit exposed at Duvanniy Yar (Strauss et al., 2012), Zimov calculated the number of animal carcasses per volume of sediment, divided by the total age of the deposit. Muskox bones are absent at Duvanniy Yar, and caribou bones are more abundant there than on the North Slope, but the relative abundances of the other taxa are similar. Zimov et al. (2012) assert that other Quaternary bone beds in northern Siberia evidence megafauna population densities similar to those at Duvanniy Yar.

So how many megafauna were there on the Mammoth Steppe? Keeping in mind that this biome had a continental extent and that climate changed in a complex fashion over the tens of thousands of years during which it existed, the estimates in Table 1 agree that the Mammoth Steppe supported a significantly larger biomass of megafauna than live in the same regions today. Our data and those of Zimov et al. (2012), which are the only "hard" data relevant to this question, both indicate megafaunal animals were 6–12× more abundant than today, at least in certain parts of the Arctic and at certain times during the ice age. They also suggest that total megafaunal biomass may have been 30× greater. At these high animal densities, feedbacks between the herbivorous megafauna and the rangeland ecology (McNaughton, 1984) would be inevitable (Zimov et al., 1995, 2012).

Possible errors in our estimates of megafauna numbers and biomasses fall into four categories: instability of modern caribou populations, changing taphonomic processes, misinterpretation of the species composition of the bone fauna, and fluctuating populations during the ice age.

- 1) **Caribou populations fluctuate so much today that it is difficult to assign a typical, Holocene population density**, and this could undermine their usefulness as a standard for estimating the prehistoric population sizes of other megafauna. Since record-keeping started 50 years ago, the sizes of the Teshekpuk and Western Arctic herds have fluctuated by nearly an order of magnitude (Vors and Boyce, 2009; US BLM, 2012). Due to the brevity of records, there is no way to know how typical these rapid shifts are.
- 2) **Taphonomic processes have changed.** It could be that bone deposition has been less likely during the Holocene than during the ice age. Certainly the loess-upland pathway of bone sequestration and storage has not operated for much of the Holocene, and perhaps the floodplain pathway captured and stored more bones while in an ice-age state than during the current interglacial. If this is true, then we are overestimating animal populations during the ice age.
- 3) **The relative abundances of species were different than how we reconstructed them.** In calculating the relative abundances of different species in the bone fauna (Fig. 5), we make no allowances for interspecific differences in the sizes of bones, their preservation potentials, or the differing behaviors of the various species that could influence the likelihood of their bones of being preserved. Size-biasing can affect the representation of bone assemblages (Behrensmeier et al., 1979) particularly for species weighing <100 kg; however, for animals larger than caribou, size-biasing is probably not an important issue (Western and Behrensmeier, 2009; Miller,

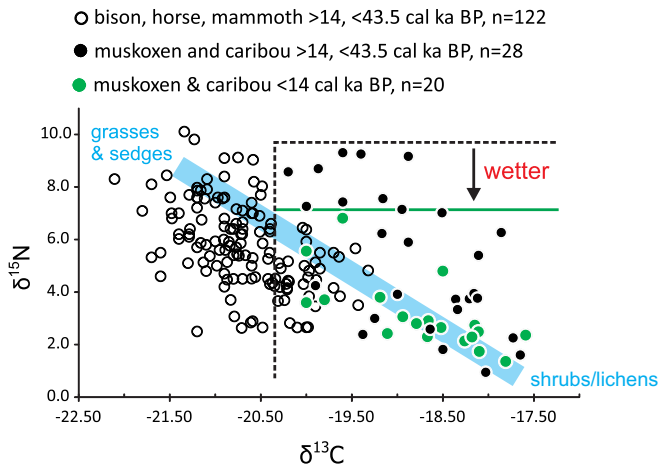
2011). That said, mammoths are probably overrepresented in the collection by virtue of their large bones, their tusks, and their large and breakage-resistant teeth. But even if we halve the number of mammoth to 0.75 individuals/km<sup>2</sup> during the ice age, this reduces the numbers of megafauna only slightly and lowers total megafauna biomass by only 25%.

- 4) **The "ice age" was not a period of uniform climate.** The equable climates of the present interglacial have created long-term, ecological stases that are unusual from the perspective of the last 100,000 years. The millennial-scale effects of the Dansgaard–Oeschger cycles and Heinrich Events that are so prominent in the Greenland ice-core records affected places as distant as Lake Baikal (Prokopenko et al., 2001), Yakutia (Müller et al., 2010), the Sea of Okhotsk (Gorbarenko et al., 2007), and Peru (Kanner et al., 2012). These short-lived bouts of rapid climate change undoubtedly affected northern Alaska as well. It could be that the greater abundances of megafauna that we infer during the ice age represent short-lived peaks in megafauna abundance. The "spike-iness" of the probability density distributions of megafaunal ages (Fig. 7) is consistent with this idea. It is probably deceptive to cite what may be short-lived, maximum animal densities as representative of the entire ice age.

#### 6.4. Implications of isotopes

Comparisons of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  between species and over time provide information about their diets and clues about why some species became extinct. Species that are known from their current natural history (moose) and their dental morphology (mastodon) to be dedicated browsers have the most similar isotope values of any species pair (Fig. 11). The next closest pair is composed of muskox and bison. Today, muskoxen have a diverse diet of forbs, graminoids, and shrubs. Bison, who are often considered to be obligate grazers (Fox-Dobbs et al., 2008, 2012), in fact subsist on a mixed diet of grass, sedge, forbs, and shrubs in parts of Interior Alaska today (Gardner et al., 2007). Like muskox, steppe bison's descendant species, *Bison bison*, has been a fugitive species in northern Alaska during post-glacial times. It was intermittently present south of the Brooks Range during the Holocene (Stephenson et al., 2001), and several herds of introduced *B. bison* persist on outwash plains in the region today. It seems that the bison–muskox niche is still present in the region but only in widely scattered patches.

The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of caribou and muskox bones indicate that during the ice age these species occupied one end of the dietary phase space defined by these isotopes (Fig. 15). This was the case prior to 14 cal ka BP and became even more pronounced afterward. The isotopic values of a plant are controlled by complex interactions between its physiology, soil moisture, temperature, soil fertility, and atmospheric CO<sub>2</sub> levels (Heaton, 1999; Stevens and Hedges, 2004; Koch et al., 2009). Although trophic fractionation means that plant and bone isotope values do not match exactly, measurements of modern plants from northern Alaska indicate that graminoids tend to be enriched in <sup>15</sup>N and depleted in <sup>13</sup>C compared to forbs, lichens, and shrubs (Nadelhoffer et al., 1996; Ben-David et al., 2001; Wooller et al., 2007; Fox-Dobbs et al., 2008). When considered together, the isotopic values of modern plants and the bone-isotope values are consistent with the interpretation that on the ice-age landscape muskoxen and caribou were eating plant taxa that today are associated with moist acidic tundra. The further depletion in  $\delta^{15}\text{N}$  after ca 14 cal ka BP (Fig. 15) suggests muskox and caribou diet shifted even closer toward values characteristic of moist acidic tundra. Additional support for the idea that during the ice age muskoxen and caribou fed in the plant



**Fig. 15.** Shifts in bone-isotope values after 14 cal ka BP. During the ice age, the diets of muskoxen and caribou occupied the part of the  $\delta^{15}\text{N}/\delta^{13}\text{C}$  phase space corresponding to plants growing in warmer/wetter habitats and most resembling the isotopic values of moist acidic tundra that today covers much of the Arctic Foothills today. In post-glacial times, the diets of these species shifted even further toward moist values. The blue diagonal line illustrates the relative gradient in present day isotopic values of arctic plant taxa.

communities most similar to the ones dominating the landscape today comes from the inverse correlation between  $\delta^{15}\text{N}$  and mean annual precipitation (Heaton, 1999; Hedges et al., 2005) and the positive correlation between mean annual temperature and  $\delta^{13}\text{C}$  that exists in some regions (Van Klinken et al., 1994; Heaton, 1999; lacumin et al., 2006). As to why more enriched bone  $\delta^{13}\text{C}$  values are associated with moister vegetation types, as opposed to more depleted ones as would be predicted by global patterns of  $\delta^{13}\text{C}$  and precipitation (Diefendorf et al., 2010; Kohn, 2010), we can only point out that isotope fractionation occurs through multiple interacting processes and that the patterns exhibited in local vegetation trump global trends when interpreting bone isotopes. The lower pH and nutrient levels found in moist acidic tundra compared to well-drained, graminoid-dominated vegetation (Heaton, 1999) might have contributed to the higher  $\delta^{13}\text{C}$  values found in the bones of caribou and muskoxen exploiting the moister, warmer parts of the ice-age vegetation mosaic. Also, some of the enrichment in  $^{13}\text{C}$  in caribou and muskox bones after 14 cal ka BP was probably due to increasing levels of  $\text{CO}_2$  in atmosphere (Stevens and Hedges, 2004; lacumin et al., 2006).

Decreasing  $\delta^{15}\text{N}$  values in muskoxen and caribou bones after 14 cal ka BP (Fig. 15) probably reflect the impacts of regional paludification, the spread of peat and organic soils across previously well-drained mineral soils. Paludification would have closed the open nitrogen cycle that formerly operated in warmer, better drained mineral soils and intensified the recycling of N from organic compounds and therefore its fractionation (Stevens and Hedges, 2004). The spread of organic soils was accompanied by the replacement of grass- and forb-dominated vegetation by moisture-loving sedges, mosses, lichens, and shrubs, all of which have lower  $\delta^{15}\text{N}$  values (Nadelhoffer et al., 1996; Fox-Dobbs et al., 2008). A decline in  $\delta^{15}\text{N}$  is also consistent with the spread of colder, more stable soils with shallower rooting depths (Nadelhoffer et al., 1996), all of which are features of a paludified landscape.

Additional evidence for the effects of regional paludification may come from the  $\delta^{15}\text{N}$  record in horse bones, the taxon with the most dated bones (Fig. 12). Beginning ca 16 cal ka BP,  $\delta^{15}\text{N}$  declined rapidly, falling about 6‰ over 4000 years. A similar decline in  $\delta^{15}\text{N}$  over the same period occurred in horses in northwest Europe

where it is attributed to the combined effects of changing water availability, temperature, soil processes, and mycorrhizal associations (Stevens and Hedges, 2004). All these processes are involved in paludification, which causes soils to cool, soil moisture to increase, rooting depths to decrease, and overall vegetation to change drastically. The size reduction in Alaskan horses that started ca 25 cal ka BP and culminated at their extinction (Guthrie, 2003) could be related to declines in range quality caused by paludification.

In bison and caribou from the North Slope, directional shifts in  $\delta^{15}\text{N}$  started before regional paludification did (Fig. 12). A striking decline in the  $\delta^{15}\text{N}$  of caribou bones began ca 20 cal ka BP, 4000 years before the decline in horse  $\delta^{15}\text{N}$  began. Bison began a unidirectional shift to lower  $\delta^{15}\text{N}$  values earlier still at ca 25 cal ka BP. These successive declines in  $\delta^{15}\text{N}$  could reflect the idiosyncratic physiological responses of the different species to the same changes in aridity, soils, and vegetation as the North Slope moved into the full glacial conditions and then out again. But it is unclear why these changes were unidirectional toward less positive  $\delta^{15}\text{N}$  values. The non-synchronicity of  $\delta^{15}\text{N}$  in different megafaunal species on the North Slope contrasts with the synchronicity observed in Interior Alaska, where they are attributed to shifts in vegetation driven by regional climate change (Fox-Dobbs et al., 2008). Compared to  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$  values from North Slope bones are relatively stable through time. As Fox-Dobbs et al. (2008) found for megafauna in Interior Alaska, North Slope  $\delta^{13}\text{C}$  values do not show the pronounced decline that occurred after ca 15 cal ka BP in Europe (Stevens and Hedges, 2004).

#### 6.5. What caused megafaunal extinctions on the North Slope?

The disappearance of mammoth, horse, and bison from the North Slope between 14 and 11 cal ka BP were local, not global extinctions. With the possible exception of short-faced bear, whose fossil record is exceedingly sparse, all of these species survived to more recent times somewhere else. Mammoth survived to ca 6.6 cal ka BP on St. Paul Island in the Bering Sea (Guthrie, 2004; Veltre et al., 2008) and to ca 4 cal ka BP on Wrangel Island in northern Siberia (Vartanyan et al., 2008). *B. priscus* underwent phylogenetic extinction, and its descendants survive in Eurasia and North America (Shapiro et al., 2004; Wilson et al., 2008). Both saiga antelope and caballine horses survive today in Asia. Not all the North Slope's megafauna departed. Caribou, muskoxen, and grizzly bears survived in place, while moose and humans immigrated to the region about the same time mammoth, bison, and horse disappeared. The local extinction of some megafaunal species and the arrival of new ones – including humans – indicates the end of the Pleistocene was a period of extensive range adjustments in arctic Alaska. What caused these range adjustments?

The simplest interpretation of the shifting ranges of megafauna at the end of the Pleistocene on the North Slope is that they were responses to a unidirectional shift in the same, major axis of environmental variation that had differentiated between megafaunal niches within the ice-age landscape. As Guthrie (2001) suggested, this critical niche axis was moisture, which is intimately connected to air temperature as described by the Clausius–Clapeyron relationship. The moisture niches of present and former North Slope megafauna are delineated by their diets and the ratios between their body masses and foot surface areas.

Diet can be inferred from bone isotopes (Fig. 15), tooth anatomy, and natural history. The arid extreme of the moisture gradient was shared by horse, bison, saiga, and mammoth, with muskoxen and caribou in the middle, and moose, humans, and mastodon (potentially anyway) at the extreme wet end where shrubs and trees grow. While human diet was only indirectly dependent on

moisture, it was highly dependent on summer temperatures being warm enough ( $>10$ – $12$  °C in summer) to permit the large shrubs and trees needed for firewood to grow on the North Slope (Guthrie, 2006). In the Arctic, this wood-dependence allies people closely with mastodon and moose at the moist end of the gradient.

Based on foot loading (Guthrie, 1990), bison, horse, and saiga occupied the extreme arid end of the moisture gradient because of their small foot sizes relative to their body masses, which would have greatly impeded their locomotion over the water-saturated, peaty landscapes that became widespread in post-glacial times. Living elephants possess foot-loading values only slightly less than horses. Muskoxen are significantly lighter on their feet than any of the above species, and caribou have the lowest foot-loading of all. Moose have higher foot-loading values than muskoxen but unlike the latter are adept at extracting their feet from deep mud and at transferring their weight onto their dewclaws and forelimbs.

When the regional moisture gradient shifted from dry to wet at the end of the ice age, the dryland-specialists (horse, bison, and mammoth) lost their niches, while the mesic specialists (caribou and muskox) retained theirs. The spread of moist, wood-rich habitats allowed the hydric specialists (moose and humans) to invade the region. At a landscape scale, this radical shift in the moisture–niche axis was manifested as paludification. In this sense, paludification was the proximate cause megafaunal extinctions on the North Slope. This was Guthrie's (1990, 2001) basic hypothesis, and it fits with how post-glacial changes in climate affected the biophysical processes that he asserts were important in maintaining the Mammoth Steppe. We know that paludification began on the North Slope ca 16 cal ka BP (Jones and Yu, 2010) and that the present-day tundra vegetation types were in place, at least in the Arctic Foothills, by 9–10.5 cal ka BP (Mann et al., 2002). This chronology is consistent with the estimated extinction dates of horse, bison, and mammoth on the North Slope (Figs. 8 and 9), with the decrease in  $\delta^{15}\text{N}$  in horses that began ca 16 cal ka BP (Fig. 11), and with the arrival of moose and humans between 13.5 and 14.5 cal ka BP (Figs. 8 and 9).

#### 6.6. A role for humans?

People arrived in arctic Alaska only recently compared to the Eurasian Arctic, where they first appeared  $>34,000$  years ago (Pitulko et al., 2004; Slimak et al., 2011). The earliest archaeological date from the North Slope has a  $2\sigma$  range of 13.7–13.3 cal ka BP (Kunz and Reanier, 1994; Mann et al., 2001) (Fig. 8). We have only a vague idea of what animal species were hunted by these early people. Most archaeological sites pre-dating 10 cal ka BP occur along the northern front of the Brooks Range in places where caribou concentrate today during migration (Rasic, 2011). There are only two known associations between megafaunal remains and early humans in the region. The first is near the U.S.–Canada border where human-modified bones of bison of uncertain species date between 12 and 10.6 cal ka BP (Cinq-Mars et al., 1991). The second is on the Kivalina River at the western end of the Brooks Range where Paleoindian artifacts and associated caribou bones date between 13.1 and 11.1 cal ka BP (Hedman and Rasic, unpublished data). At the time of European contact, caribou were a staple food for people in the interior of northern Alaska, and human population sizes closely tracked caribou abundance (Burch, 1972, 1980; Lent, 1988).

The population density of aboriginal people on the North Slope in the mid-19th century provides a limiting estimate of how many people might have lived there during the late Pleistocene. In AD 1840, approximately 3000 Iñupiat people lived north of the Brooks Range and west of the Colville River mouth (Burch, 1980). If we add 500 more people to account for those living along the less productive coastline east of the Colville River, human population

density on the North Slope around the time of European contact would have been about 0.02 persons/km<sup>2</sup> (1 person/50 km<sup>2</sup>). In AD 1840, people were concentrated in coastal areas where they exploited the rich marine mammal resource. Population densities at the end of the Pleistocene were probably much lower than in 1840 because systematic hunting of marine mammals in arctic Alaska only began ca 5 cal ka BP (Ackerman, 1998). Ethnographic records from arctic Alaska and Canada suggest caribou-dependent, inland groups had significantly lower population densities of  $<0.01$  persons/km<sup>2</sup> ( $<1$  person/100 km<sup>2</sup>) (Burch, 1972), which is similar to the densities of wolves and bears on the landscape today (Table 1). Human ecology in northern Alaska during the Pleistocene–Holocene transition was probably much more like the caribou-reliant, inland Iñupiat lifestyle than it was like the coastal one ca 1840, and, judging from the scarcity of archaeological sites dating to the Pleistocene–Holocene transition and early Holocene, it is likely that the North Slope lay near the northern range limit of humans at this time. There are no ethnographic records of ecosystem modification by burning caused by humans in arctic Alaska, and there are no indications that human predation ever had a significant effect on caribou population density there.

In summary, there is no direct evidence that humans played a role in the extinction of megafauna on the North Slope. In fact, humans coexisted with horse and bison for 1000 years before these species became extinct. During this time, people were probably rare visitors north of the Brooks Range. Mammoth is the only megafauna species whose youngest dated remains coincide with the first arrival of humans, and, based on the age-gap analyses (Fig. 8), we anticipate finding younger mammoth bones eventually.

## 7. Conclusions

**Taphonomy:** Bones become incorporated into the valley fills of the Ikpikpuk and Titaluk rivers via two different pathways. The first involves rapid burial of bones by aeolian sediment on upland surfaces within about 30 km of the active Ikpikpuk Sand Sea. Migrating river channels later eroded these bones out of the sand sheet and loess deposits. This pathway accounts for a minority of the bones we collected. The second, more frequent pathway involved animals dying on river floodplains and being rapidly buried by fluvial sediment. In both pathways, bones are disarticulated and mixed with those of other species and of other ages during multiple episodes of reworking by these low-gradient, sandy rivers. As the lighter sand is carried downstream, bones are elutriated downwards into the valley fills until they come to rest in channel-fill deposits above bedrock strath terraces. If a bone survives the first 4000 years, it has likely been deeply buried within the valley fill and will survive indefinitely.

**Timing of extinction:** New dates postpone the demise of the Mammoth Steppe in northern Alaska several thousand years later than previously thought (Guthrie, 2003; Buck and Bard, 2007). Horse and bison persisted until at least 12.5 cal yr BP, which coincides with the early part of the Younger Dryas chronozone. By way of reference, flooding of the Bering Strait was complete by ca 12 cal ka BP (Keigwin et al., 2006). Bison and horse may have been the last survivors of the Mammoth Steppe megafauna on the North Slope, though there may still be a  $>5\%$  chance of discovering a mammoth dating to as young as 12 cal ka BP. The age of the youngest dated lion is ca 13.2 cal ka BP, indicating an intact megafaunal food chain persisted to at least that time. Humans were hunting along the northern front of the Brooks Range by at least 13.5 cal ka BP, so they potentially interacted with bison and horse, and possibly with mammoth, for ca 1000 years.

**Composition of the ice-age megafauna:** In terms of numbers of individuals, horse was the dominant megafaunal species on the



North Slope between ca 40 and 12 cal ka BP. Bison and caribou were less abundant than horse while mammoth and muskox were comparatively scarce, and saiga were rare. Lion, short-faced bear, wolf, and grizzly bear comprised the megafaunal predator/scavenger guild. The fact that the majority of horse and lion bones post-date 40 cal ka BP suggest horse became much more abundant after ca 40 cal ka BP and that lion populations tracked horse abundance. Moose arrived ca 14 cal ka BP, slightly before people did. Mastodon has probably been absent from the North Slope since the end of the Last Interglacial.

**Animal Numbers and Biomasses:** The ice age fauna was more diverse than today with five abundant herbivore species living in the region as compared to a single abundant herbivore species (caribou) and two much less abundant species (muskox and moose) living there today. There were many more megafaunal individuals living on the North Slope during the ice age than today. Conservatively, there were 6× more of them, and they comprised 30× more megafaunal biomass than present today. These ice-age estimates probably represent short-lived, peak populations that occurred only during particularly favorable times.

**Isotopes suggest changes in moisture were important:** Changing values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  in bones suggest that during the ice age the surviving megafaunal species (muskox and caribou) utilized the warmer, wetter portions of the regional vegetation mosaic most like the moist acidic tundra vegetation that is widespread in the region today, while horse, bison, and mammoth were dryland specialists. Shifts in  $\delta^{15}\text{N}$  values through time are consistent with the idea that paludification progressively degraded range conditions for horse, perhaps the most grass-dependent taxon, starting ca 16 cal ka BP.

**Causes of extinction:** The disappearance of bison, horse, mammoth, saiga, and lion from northern Alaska at the end of the ice age represent local, not global extinctions since all these taxa survived later elsewhere. The most important driver of these range shifts was probably a change in moisture availability that manifested itself as regional paludification. Dryland specialists (bison, horse, and mammoth) were forced out as climate shifted toward wetter/warmer conditions, which favored the invasion of moose, humans, and the shrubby both these species depended upon. Muskox and caribou, which isotope measurements suggest utilized the mesic portion of the moisture gradient during the ice age, were able to persist in the region during post-glacial times. The fact that the terminal dates of horse and bison coincide with the Younger Dryas suggest that rapid climate changes during this period may have been involved in the extinctions of these two species. It is unlikely humans played a role in megafaunal extinctions in this particular part of the world for two reasons. First, they were a rare species on the North Slope at the end of the Pleistocene. Second, they coexisted with horse and bison for at least 1000 years before these species disappeared. On the other hand, humans may have been the last straw for megafaunal species already in states of extinction debt.

## Acknowledgments

Paul Matheus contributed greatly to this study in its early stages, and we regret his decision to forsake extinct megafauna in favor of raising live ones. Dale Guthrie provided interesting discussions and identified problematic specimens. We thank Dave Murray, Dave Meltzer, Dave Klein, Jeff Rasic, and Greg Streveler for comments on earlier drafts of this manuscript. Hector Porphyrio, Ben Jones, Miriam Jones, Guido Grosse, Carson Baughman, Warren Beck, and Dave Yokel provided useful insights. We thank Stacie McIntosh for helping make this project happen, and Connie Adkins, Keeland McNulty, Mel Cambell, and Molly Yazwinski for assistance in the field. This study

was funded by the Bureau of Land Management's Arctic Field Office and National Science Foundation grant ARC-0902169.

## Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.quascirev.2013.03.015>.

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Appendix A. Radiocarbon ages of terrestrial, mammalian, megafauna species from the North Slope of Alaska.

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Alces</i>	this study	KIG05-4.1	30186	Kigalik R.	antler	Beta-339266	107	0.3	-23.40	0.50	107	0.3	120	
<i>Alces</i>	this study	MAY12-64	30187	Maybe Cr.	antler	Beta-339275	116	0.3	-21.30	0.60	116	0.3	103	
<i>Alces</i>	this study	IK08-129	30181	Ikpikpuk R.	antler	Beta-339280	210	30	-20.80	0.70	210	30	178	
<i>Alces</i>	this study	TIT10-58	30188	Titaluk R.	antler	Beta-339271	290	30	-20.70	0.90	290	30	383	
<i>Alces</i>	this study	IK12-094	30184	Maybe Cr.	antler	Beta-339281	310	30	-21.10	-0.40	310	30	387	
<i>Alces</i>	this study	IK02-210	10355	Ikpikpuk R.	mandible	CAMS-91966	320	35	-20.30	0.26	320	35	388	
<i>Alces</i>	this study	IK01-404	11844	Ikpikpuk R.	mandible	CAMS-92094	665	35	-20.87	-0.59	665	35	628	
<i>Alces</i>	this study	IK12-077	30183	Ikpikpuk R.	cranium	Beta-339274	950	30	-20.70	1.00	950	30	854	
<i>Alces</i>	this study	IK99-229	10691	Ikpikpuk R.	mandible	CAMS-64459	980	40	-20.00	8.56	980	40	872	
<i>Alces</i>	this study	IK08-016	30180	Ikpikpuk R.	mandible	Beta-339268	1,180	30	-21.30	1.80	1,180	30	1,107	
<i>Alces</i>	this study	IK99-393	n/a	Ikpikpuk R.	metatarsal	Beta-134225	1,280	40	-19.50	n/a	1,280	40	1,221	
<i>Alces</i>	this study	IK99-776	11066	Ikpikpuk R.	mandible	CAMS-64474	1,370	40	-20.40	1.33	1,370	40	1,294	
<i>Alces</i>	this study	IK99-556	10996	Ikpikpuk R.	mandible	CAMS-64467	1,760	40	-19.85	0.68	1,760	40	1,668	
<i>Alces</i>	this study	IK01-023	12022	Ikpikpuk R.	mandible	CAMS-92076	2,450	35	-20.77	0.99	2,450	35	2,515	
<i>Alces</i>	this study	GAAR-7846	n/a	Killik R.	n.r. PM <sup>b</sup>	CAMS-58096	2,460	40	-21.00	n/a	2,460	40	2,539	
<i>Alces</i>	this study	IK98-0888	3288	Ikpikpuk R.	mandible	CAMS-64418	2,540	50	-20.26	n/a	2,540	50	2,611	
<i>Alces</i>	this study	IK12-096	30185	Ikpikpuk R.	antler	Beta-339282	2,790	30	-21.30	-0.60	2,790	30	2,891	
<i>Alces</i>	this study	KIG09-2	n/a	Kigalik R.	cranium	Beta-263035	2,900	40	-21.10	n/a	2,900	40	3,040	
<i>Alces</i>	this study	TIT12-35	30191	Titaluk R.	antler	Beta-339283	9,310	40	-20.30	-1.20	9,310	40	10,518	
<i>Alces</i>	this study	IK09-70	30182	Ikpikpuk R.	antler	Beta-339270	9,610	40	-21.00	0.90	9,610	40	10,938	
<i>Alces</i>	this study	IK99-472	10922	Ikpikpuk R.	tooth	CAMS-91810	12,245	40	-20.30	-0.13	12,245	40	14,100	
<i>Arctodus</i>	Harington, 2003 <sup>i</sup>	ROM:VP 43646	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	TO-2539	27,190	280	n/a	n/a	27,190	280	31,393	
<i>Arctodus</i>	this study	T99-033	8685	Titaluk R.	metapodial	CAMS-58092 <sup>#</sup>	42,600	2,200	-19.00	n/a	42,600	2,200	46,488	
<i>Arctodus</i>	this study	T99-033	8685	Titaluk R.	metapodial	CAMS-58095 <sup>#</sup>	46,500	3,600	-18.60	n/a	46,500	3,600	49,016	
<i>Bison</i>	this study	IK98-0343	9079	Ikpikpuk R.	humerus	CAMS-53767	10,510	50	-20.61	2.84	10,510	50	12,473	
<i>Bison</i>	this study	IK98-1114	9896	Ikpikpuk R.	astragalus	CAMS-53891	10,990	50	-20.10	2.65	10,990	50	12,854	
<i>Bison</i>	this study	IK98-0027	8847	Ikpikpuk R.	astragalus	CAMS-53756	11,810	50	-20.71	2.63	11,810	50	13,663	

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Bison</i>	this study	IK98-0528	9577	Ikpikpuk R.	humerus	CAMS-53774	12,270	50	-20.21	4.10	12,270	50	14,148	
<i>Bison</i>	this study	IK98-0303	n/a	Ikpikpuk R.	vertebra	CAMS-58091	12,320	60	-20.24	3.69	12,320	60	14,320	
<i>Bison</i>	this study	IK98-0142	8801	Ikpikpuk R.	metatarsal	CAMS-53760	12,410	50	-19.98	2.66	12,410	50	14,468	
<i>Bison</i>	this study	IK01-428	11664	Ikpikpuk R.	astragalus	AA-48281	12,560	130	-20.00	2.66	12,560	130	14,716	
<i>Bison</i>	this study	IK98-0661	9464	Ikpikpuk R.	metapodial	CAMS-53777	17,160	80	-20.18	2.82	17,160	80	20,362	
<i>Bison</i>	this study	IK98-0504	9238	Ikpikpuk R.	femur	CAMS-53772	19,420	100	-19.97	3.84	19,420	100	23,136	
<i>Bison</i>	this study	IK98-1090	9804	Ikpikpuk R.	astragalus	CAMS-53890	21,040	120	-20.04	6.45	21,040	120	25,106	
<i>Bison</i>	this study	IK98-0401	8842	Ikpikpuk R.	metatarsal	CAMS-53770	21,530	130	-20.37	4.35	21,530	130	25,766	
<i>Bison</i>	this study	IK98-1254	9967	Ikpikpuk R.	humerus	CAMS-53901	23,680	170	-19.85	5.50	23,680	170	28,427	
<i>Bison</i>	this study	IK98-0302	8998	Ikpikpuk R.	metatarsal	CAMS-53764	24,500	180	-20.22	4.31	24,500	180	29,335	
<i>Bison</i>	this study	IK98-1184	10031	Ikpikpuk R.	horn core	CAMS-53899	25,980	230	-19.70	4.16	25,980	230	30,745	
<i>Bison</i>	this study	IK98-1043	10043	Ikpikpuk R.	astragalus	CAMS-53888	26,550	230	-19.46	5.66	26,550	230	31,109	
<i>Bison</i>	this study	IK98-0095	9206	Ikpikpuk R.	tibia	CAMS-53758	27,400	260	-20.56	4.57	27,400	260	31,556	
<i>Bison</i>	this study	IK98-0374	n/a	Ikpikpuk R.	metatarsal	CAMS-53768	27,590	280	-20.48	2.65	27,590	280	31,760	
<i>Bison</i>	this study	IK05-18.1	29449	Ikpikpuk R.	cranium	Beta-308262	27,600	140	-20.10	n/a	27,600	140	31,666	
<i>Bison</i>	this study	IK98-1115	9897	Ikpikpuk R.	astragalus	CAMS-53892	28,120	290	-19.32	4.82	28,120	290	32,357	
<i>Bison</i>	this study	IK98-0616	9648	Ikpikpuk R.	metacarpal	CAMS-53775	29,040	340	-20.20	5.17	29,040	340	33,711	
<i>Bison</i>	this study	IK98-1164	10073	Ikpikpuk R.	metacarpal	CAMS-53897	29,570	340	-20.02	5.00	29,570	340	34,177	
<i>Bison</i>	this study	IK98-0430	9038	Ikpikpuk R.	metacarpal	CAMS-53771	30,000	540	-20.00	n/a	30,000	540	34,638	
<i>Bison</i>	this study	IK98-0256	9156	Ikpikpuk R.	metatarsal	CAMS-53763	31,410	420	-20.35	4.23	31,410	420	35,844	
<i>Bison</i>	this study	IK98-0096	9207	Ikpikpuk R.	tibia	CAMS-53759	31,630	440	-19.85	4.89	31,630	440	36,002	
<i>Bison</i>	this study	IK98-1035	9988	Ikpikpuk R.	humerus	CAMS-53885	32,270	470	-19.64	5.34	32,270	470	36,900	
<i>Bison</i>	this study	IK01-215	11742	Ikpikpuk R.	metatarsal	AA-48772	32,300	1,500	-20.20	4.43	32,300	1,500	37,359	
<i>Bison</i>	this study	IK09-15	29454	Ikpikpuk R.	cranium	Beta-308267	32,870	200	-19.90	n/a	32,870	200	37,428	
<i>Bison</i>	this study	IK01-433	11669	Ikpikpuk R.	radius	AA-48282	33,000	1,500	-19.90	3.45	33,000	1,500	38,062	
<i>Bison</i>	this study	IK98-0012	9172	Ikpikpuk R.	femur	CAMS-53755	33,280	530	-19.43	3.50	33,280	530	37,981	
<i>Bison</i>	this study	IK98-1323	9877	Ikpikpuk R.	femur	CAMS-53903	33,320	540	-20.19	4.40	33,320	540	38,023	
<i>Bison</i>	this study	IK01-460	11934	Ikpikpuk R.	astragalus	AA-48775	33,520	940	-19.90	5.13	33,520	940	38,395	
<i>Bison</i>	this study	IK98-1121	11159	Ikpikpuk R.	metacarpal	CAMS-53894	33,580	550	-19.63	3.84	33,580	550	38,326	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Bison</i>	this study	IK01-234	11947	Ikpikpuk R.	astragalus	AA-48773	34,100	1,000	-20.00	5.92	34,100	1,000	39,128	
<i>Bison</i>	this study	TIT11-88	29460	Titaluk R.	cranium	Beta-308271	34,440	240	-20.10	n/a	34,440	240	39,410	
<i>Bison</i>	this study	IK05-18.2	29450	Ikpikpuk R.	cranium	Beta-308263	35,060	250	-20.50	n/a	35,060	250	40,214	
<i>Bison</i>	this study	IK98-0659	9462	Ikpikpuk R.	mandible	CAMS-53776	35,580	720	-19.98	4.56	35,580	720	40,679	
<i>Bison</i>	this study	IK98-0916	9348	Ikpikpuk R.	astragalus	CAMS-53782	35,710	730	-20.29	4.19	35,710	730	40,808	
<i>Bison</i>	this study	IK98-1222	9899	Ikpikpuk R.	metatarsal	CAMS-53900	36,320	780	-20.77	5.70	36,320	780	41,375	
<i>Bison</i>	this study	IK01-373	11981	Ikpikpuk R.	astragalus	AA-48278	36,500	2,300	-20.00	6.37	36,500	2,300	41,674	
<i>Bison</i>	this study	IK98-0863	9327	Ikpikpuk R.	astragalus	CAMS-53914	36,520	800	-20.60	4.51	36,520	800	41,539	
<i>Bison</i>	this study	IK98-1120	9906	Ikpikpuk R.	metatarsal	CAMS-53893	37,460	890	-20.70	6.66	37,460	890	42,248	
<i>Bison</i>	this study	IK11-37	29457	Ikpikpuk R.	cranium	Beta-306117	38,010	370	-19.40	n/a	38,010	370	42,530	
<i>Bison</i>	this study	IK08-31	29452	Ikpikpuk R.	cranium	Beta-308265	38,150	330	-20.20	n/a	38,150	330	42,617	
<i>Bison</i>	this study	IK98-0377	8811	Ikpikpuk R.	radius	CAMS-53769	38,700	1,000	-19.89	4.46	38,700	1,000	43,150	
<i>Bison</i>	this study	IK98-0889	9343	Ikpikpuk R.	astragalus	CAMS-53779	38,800	1,100	-20.31	3.66	38,800	1,100	43,245	
<i>Bison</i>	this study	IK98-0890	9532	Ikpikpuk R.	astragalus	CAMS-53780	38,800	1,100	-20.42	5.26	38,800	1,100	43,245	
<i>Bison</i>	this study	IK98-0915	9347	Ikpikpuk R.	astragalus	CAMS-53781	39,800	1,200	-20.34	4.51	39,800	1,200	43,942	
<i>Bison</i>	this study	IK98-0174	8931	Ikpikpuk R.	astragalus	CAMS-53761	39,850	1,200	-20.42	4.50	39,850	1,200	43,976	
<i>Bison</i>	this study	IK98-1122	9919	Ikpikpuk R.	metacarpal	CAMS-53895	40,700	1,300	-20.03	4.30	40,700	1,300	44,628	
<i>Bison</i>	this study	IK09-16	29455	Ikpikpuk R.	cranium	Beta-308268	42,000	490	-19.60	n/a	42,000	490	45,378	
<i>Bison</i>	this study	TIT10-09	29459	Titaluk R.	cranium	Beta-308270	42,400	520	-20.10	n/a	42,400	520	45,649	
<i>Bison</i>	this study	IK98-1045	10045	Ikpikpuk R.	mandible	CAMS-53889	43,000	1,800	-20.21	4.15	43,000	1,800	46,736	
<i>Bison</i>	this study	IK10-12	29456	Ikpikpuk R.	cranium	Beta-308269	44,520	650	-20.00	n/a	44,520	650	47,730	
<i>Bison</i>	this study	IK98-1042	n/a	Ikpikpuk R.	radius	CAMS-53887	44,800	2,200	-19.59	3.48	44,800	2,200	47,782	
<i>Bison</i>	this study	IK98-1125	9923	Ikpikpuk R.	astragalus	CAMS-53896	45,300	2,400	-20.01	4.53	45,300	2,400	47,945	
<i>Bison</i>	this study	IK06-22	29451	Ikpikpuk R.	cranium	Beta-308264	45,610	740	-20.10	n/a	45,610	740	48,811	
<i>Bison</i>	this study	IK98-0032	9090	Ikpikpuk R.	metacarpal	CAMS-53757	46,100	2,200	-20.61	3.26	46,100	2,200	48,337	
<i>Bison</i>	this study	IK98-0305	8917	Ikpikpuk R.	radius	CAMS-53766	46,100	2,600	-20.10	5.65	46,100	2,600	48,191	
<i>Bison</i>	this study	IK09-14	29453	Ikpikpuk R.	cranium	Beta-308266	46,280	810	-19.00	n/a	46,280	810	49,279	
<i>Bison</i>	this study	IK98-0671	9303	Ikpikpuk R.	metatarsal	CAMS-53778	47,000	2,900	-20.46	6.15	47,000	2,900	48,432	
<i>Bison</i>	this study	IK98-0928	9506	Ikpikpuk R.	astragalus	CAMS-53783	49,600	4,000	-20.25	-3.27	49,600	4,000	52,926	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Bison</i>	Shapiro et al., 2004	IK01-216	11743	Ikpikpuk R.	metatarsal	OxA-11136	49,700	1,400	-19.80	n/a	49,700	1,400	49,962	
<i>Bison</i>	this study	IK98-0527	9567	Ikpikpuk R.	vertebra	CAMS-53773	50,000	4,200	-20.70	2.66	50,000	4,200	53,784	
<i>Bison</i>	this study	IK01-074	11863	Ikpikpuk R.	metatarsal	AA-48770	38,000	> than	-20.00	5.78	38,000	> than	n/a	
<i>Bison</i>	this study	IK99-501	10881	Ikpikpuk R.	metatarsal	AA-48766	39,000	> than	-20.40	3.98	39,000	> than	n/a	
<i>Bison</i>	this study	IK99-145	10738	Ikpikpuk R.	cranium	AA-48262	39,400	> than	-19.10	3.95	39,400	> than	n/a	
<i>Bison</i>	this study	IK01-315	11687	Ikpikpuk R.	metacarpal	AA-48774	40,000	> than	-19.50	7.64	40,000	> than	n/a	
<i>Bison</i>	this study	IK99-717	11226	Ikpikpuk R.	astragalus	AA-48247	40,300	> than	-19.70	n/a	40,300	> than	n/a	
<i>Bison</i>	this study	IK01-098	11770	Ikpikpuk R.	metatarsal	AA-48270	40,700	> than	-19.70	5.87	40,700	> than	n/a	
<i>Bison</i>	this study	IK01-143	11943	Ikpikpuk R.	metatarsal	AA-48248	40,900	> than	-19.99	6.56	40,900	> than	n/a	
<i>Bison</i>	this study	IK01-095	11701	Ikpikpuk R.	metacarpal	AA-48269	41,000	> than	-19.20	4.91	41,000	> than	n/a	
<i>Bison</i>	this study	IK01-260	12012	Ikpikpuk R.	radius	AA-48274	41,000	> than	-19.80	6.50	41,000	> than	n/a	
<i>Bison</i>	this study	IK99-141	11142	Ikpikpuk R.	astragalus	AA-48243	41,100	> than	-19.16	2.80	41,100	> than	n/a	
<i>Bison</i>	this study	IK01-065	11855	Ikpikpuk R.	astragalus	AA-48266	41,100	> than	-20.40	4.26	41,100	> than	n/a	
<i>Bison</i>	this study	IK01-088	11676	Ikpikpuk R.	metatarsal	AA-48268	41,100	> than	-20.20	6.47	41,100	> than	n/a	
<i>Bison</i>	this study	IK99-530	10858	Ikpikpuk R.	metacarpal	AA-48767	41,100	> than	-19.80	6.89	41,100	> than	n/a	
<i>Bison</i>	this study	IK99-567	11233	Ikpikpuk R.	astragalus	AA-48246	41,500	> than	-20.30	6.23	41,500	> than	n/a	
<i>Bison</i>	this study	TIT11-92	29461	Titaluk R.	cranium	Beta-306118	43,500	> than	-18.10	n/a	43,500	> than	n/a	
<i>Bison</i>	this study	IK12-001	29458	Ikpikpuk R.	entire skeleton	Beta-324600	43,500	> than	-20.00	4.20	43,500	> than	n/a	
<i>Bison</i>	this study	IK98-0218	8851	Ikpikpuk R.	astragalus	CAMS-53762	46,600	> than	-20.40	2.69	46,600	> than	n/a	
<i>Bison</i>	this study	IK98-1041	10041	Ikpikpuk R.	radius	CAMS-53886	48,500	> than	-19.52	4.04	48,500	> than	n/a	
<i>Bison</i>	this study	IK98-1299	9819	Ikpikpuk R.	ulna	CAMS-53902	49,500	> than	-20.05	3.30	49,500	> than	n/a	
<i>Bison</i>	this study	IK98-1015	9912	Ikpikpuk R.	horn core	CAMS-53784	49,900	> than	-20.36	2.03	49,900	> than	n/a	
<i>Bison</i>	this study	IK98-1167	10090	Ikpikpuk R.	astragalus	CAMS-53898	49,900	> than	-20.20	4.86	49,900	> than	n/a	
<i>Canis</i>	this study	TIT10-60	30193	Titaluk R.	mandible	Beta-339272	13,000	50	-18.10	7.10	13,000	50	15,618	
<i>Canis</i>	this study	IK99-702	11055	Ikpikpuk R.	mandible	CAMS-58094	37,200	1,100	-21.20	n/a	37,200	1,100	42,057	
<i>Canis</i>	this study	IK08-096	30192	Ikpikpuk R.	femur	Beta-339269	43,500	> than	-20.00	8.90	43,500	> than	n/a	
<i>Equus</i>	this study	Tes57-02	30196	Tesh 57	phalange	Beta-339279	10,570	40	-21.20	2.50	10,570	40	12,537	
<i>Equus</i>	this study	JDL12-1	29462	Judy Cr.	cranium	Beta-331878	11,710	50	-20.70	4.50	11,710	50	13,559	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Equus</i>	this study	IK01-353	11953	Ikpikpuk R.	mandible	CAMS-92091	12,465	40	-20.59	2.89	12,465	40	14,556	
<i>Equus</i>	this study	IK02-109	3294	Ikpikpuk R.	metacarpal	CAMS-120651 #	12,480	35	-20.41	5.50	12,480	35	14,618	
<i>Equus</i>	this study	IK02-109	3294	Ikpikpuk R.	metacarpal	CAMS-121738 #	12,490	45	-20.40	5.50	12,490	45	14,638	
<i>Equus</i>	this study	IK99-033	3300	Ikpikpuk R.	tooth	CAMS-120673	12,780	35	-20.67	5.40	12,780	35	15,214	
<i>Equus</i>	this study	IK07-08	29463	Ikpikpuk R.	metacarpal	Beta-331866	12,980	50	-20.80	6.40	12,980	50	15,563	
<i>Equus</i>	this study	TIT05-07.1	29464	Titaluk R.	metacarpal	Beta-331882	13,010	60	-20.70	7.10	13,010	60	15,655	
<i>Equus</i>	this study	TIT10-35	29465	Titaluk R.	metacarpal	Beta-331883	13,400	50	-20.90	8.40	13,400	50	16,574	
<i>Equus</i>	this study	IK98-0537	3283	Ikpikpuk R.	metatarsal	CAMS-91792	13,685	40	-20.77	6.60	13,685	40	16,826	
<i>Equus</i>	this study	IK98-0111	3284	Ikpikpuk R.	metatarsal	CAMS-120655	13,925	40	-20.59	7.00	13,925	40	16,975	
<i>Equus</i>	this study	TIT09-02	29466	Titaluk R.	cranium	Beta-263037	14,290	70	-20.90	n/a	14,290	70	17,374	
<i>Equus</i>	this study	TIT11-069	29467	Titaluk R.	mandible	Beta-331887	14,360	60	-20.40	6.30	14,360	60	17,463	
<i>Equus</i>	this study	T04-001	3289	Titaluk R.	tibia	CAMS-120711	14,540	45	-20.98	5.00	14,540	45	17,730	
<i>Equus</i>	this study	IK99-335	3295	Ikpikpuk R.	metatarsal	CAMS-120676	15,095	40	-21.48	7.00	15,095	40	18,318	
<i>Equus</i>	this study	MAY08-02	29468	Maybe Cr.	cranium	Beta-258461	15,630	70	-20.20	n/a	15,630	70	18,776	
<i>Equus</i>	this study	WC11-09	29469	Wolf Cr.	phalange	Beta-331891	16,170	60	-20.40	6.40	16,170	60	19,324	
<i>Equus</i>	this study	IK99-461	3299	Ikpikpuk R.	metatarsal	CAMS-120683	16,885	45	-20.83	6.40	16,885	45	20,079	
<i>Equus</i>	this study	IK99-514	3290	Ikpikpuk R.	metacarpal	CAMS-120685	16,925	45	-20.97	7.60	16,925	45	20,145	
<i>Equus</i>	this study	IK99-774	3297	Ikpikpuk R.	metacarpal	CAMS-92073	17,290	60	-20.74	5.38	17,290	60	20,600	
<i>Equus</i>	this study	IK99-562	3286	Ikpikpuk R.	metatarsal	CAMS-120700	17,300	60	-21.29	6.20	17,300	60	20,609	
<i>Equus</i>	this study	TIT10-03	29470	Titaluk R.	cranium	Beta-283250	17,670	70	-20.80	n/a	17,670	70	20,982	
<i>Equus</i>	this study	BR12-01	29471	Bronx Cr.	astragalus	Beta-331862	17,720	70	-20.80	5.40	17,720	70	21,192	
<i>Equus</i>	this study	IK98-0246	3280	Ikpikpuk R.	metatarsal	CAMS-120656 #	19,880	70	-20.71	6.20	19,880	70	23,740	
<i>Equus</i>	this study	IK98-0246	3280	Ikpikpuk R.	metatarsal	CAMS-121741 #	19,900	60	-20.70	6.20	19,900	60	23,761	
<i>Equus</i>	this study	IK02-191	3298	Ikpikpuk R.	metacarpal	CAMS-91964	20,050	70	-20.51	6.29	20,050	70	23,983	
<i>Equus</i>	this study	T02-016	3292	Titaluk R.	metatarsal	CAMS-120703	20,190	70	-20.51	6.90	20,190	70	24,110	
<i>Equus</i>	this study	IK01-342	3285	Ikpikpuk R.	metacarpal	CAMS-120647 #	20,640	80	-20.37	6.60	20,640	80	24,643	
<i>Equus</i>	this study	IK01-342	3285	Ikpikpuk R.	metacarpal	CAMS-121734 #	20,720	90	-20.40	6.60	20,720	90	24,711	
<i>Equus</i>	this study	IK99-207	3293	Ikpikpuk R.	metacarpal	CAMS-91802	20,850	80	-20.48	5.85	20,850	80	24,809	
<i>Equus</i>	this study	IK10-01	29472	Ikpikpuk R.	cranium	Beta-283242	21,210	90	-20.80	n/a	21,210	90	25,300	



Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ - normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Equus</i>	this study	IK99-442	3282	Ikpikpuk R.	metacarpal	CAMS-91809	21,560	80	-20.85	5.91	21,560	80	25,844	
<i>Equus</i>	this study	IK99-789	3291	Ikpikpuk R.	cranium	CAMS-120702	21,750	80	-20.95	5.60	21,750	80	26,061	
<i>Equus</i>	this study	IK99-577	10890	Ikpikpuk R.	metacarpal	CAMS-91983	22,110	90	-20.76	5.44	22,110	90	26,497	
<i>Equus</i>	this study	IK10-073	29473	Ikpikpuk R.	metacarpal	Beta-331872	22,170	90	-20.90	4.70	22,170	90	26,591	
<i>Equus</i>	this study	IK02-200	10354	Ikpikpuk R.	mandible	CAMS-91965	22,330	90	-19.97	4.81	22,330	90	27,077	
<i>Equus</i>	this study	IK99-711	10885	Ikpikpuk R.	metatarsal	CAMS-120701	22,450	90	-20.72	6.20	22,450	90	27,195	
<i>Equus</i>	this study	IK99-430	10715	Ikpikpuk R.	metatarsal	CAMS-120682 <sup>#</sup>	22,410	80	-20.84	n/a	22,410	80	27,158	
<i>Equus</i>	this study	IK99-430	10715	Ikpikpuk R.	metatarsal	CAMS-121755 <sup>#</sup>	22,600	90	-20.80	n/a	22,600	90	27,320	
<i>Equus</i>	this study	IK07-02	29474	Ikpikpuk R.	metacarpal	Beta-331864	22,860	90	-20.30	5.10	22,860	90	27,708	
<i>Equus</i>	this study	IK06-23	30194	Ikpikpuk R.	cranium	Beta-339267	23,230	90	-19.70	5.50	23,230	90	28,080	
<i>Equus</i>	this study	IK01-320	11735	Ikpikpuk R.	metatarsal	CAMS-120646 <sup>#</sup>	23,790	110	-20.88	5.60	23,790	110	28,549	
<i>Equus</i>	this study	IK01-320	11735	Ikpikpuk R.	metatarsal	CAMS-121733 <sup>#</sup>	24,070	100	-20.90	5.60	24,070	100	28,898	
<i>Equus</i>	this study	IK08-080	29484	Ikpikpuk R.	metacarpal	Beta-331870	24,690	110	-21.10	4.80	24,690	110	29,516	
<i>Equus</i>	this study	IK99-129	10814	Ikpikpuk R.	mandible	CAMS-91801	24,900	100	-20.28	4.90	24,900	100	29,824	
<i>Equus</i>	this study	T02-001	8607	Titaluk R.	mandible	CAMS-91958	25,680	140	-20.83	3.70	25,680	140	30,496	
<i>Equus</i>	this study	IK01-218	11745	Ikpikpuk R.	metatarsal	CAMS-120717 <sup>#</sup>	26,210	130	-20.91	6.00	26,210	130	30,933	
<i>Equus</i>	this study	IK01-218	11745	Ikpikpuk R.	metatarsal	CAMS-121731 <sup>#</sup>	26,130	120	-20.90	6.00	26,130	120	30,876	
<i>Equus</i>	this study	IK12-063	30195	Ikpikpuk R.	mandible	Beta-339273	26,190	120	-20.50	7.70	26,190	120	30,922	
<i>Equus</i>	this study	IK99-367	10548	Ikpikpuk R.	metatarsal	CAMS-120679 <sup>#</sup>	26,020	120	-20.58	5.30	26,020	120	30,792	
<i>Equus</i>	this study	IK99-367	10548	Ikpikpuk R.	metatarsal	CAMS-121752 <sup>#</sup>	26,460	130	-20.60	5.30	26,460	130	31,079	
<i>Equus</i>	this study	KIK08-01	29475	Kikiakrorak R.	metacarpal	Beta-331879	26,770	140	-21.60	4.60	26,770	140	31,207	
<i>Equus</i>	this study	IK11-001	29476	Ikpikpuk R.	metacarpal	Beta-331874	26,890	150	-20.80	4.50	26,890	150	31,257	
<i>Equus</i>	this study	TIT11-070	29477	Titaluk R.	mandible	Beta-331888	27,060	140	-20.60	7.40	27,060	140	31,326	
<i>Equus</i>	this study	IK12-015	29478	Ikpikpuk R.	metacarpal	Beta-331877	27,930	150	-20.70	6.40	27,930	150	32,052	
<i>Equus</i>	this study	IK97-102	8622	Ikpikpuk R.	metacarpal	Beta-117138	28,120	250	-24.50	n/a	28,120	250	32,351	
<i>Equus</i>	this study	IK01-080	11647	Ikpikpuk R.	mandible	CAMS-92078 <sup>#</sup>	27,810	210	-21.06	5.37	27,810	210	31,936	
<i>Equus</i>	this study	IK01-080	11647	Ikpikpuk R.	mandible	CAMS-91781 <sup>#</sup>	28,600	200	-21.06	5.37	28,600	200	33,023	
<i>Equus</i>	this study	IK01-459	11933	Ikpikpuk R.	metapodial	CAMS-91957	28,260	210	-20.92	7.56	28,260	210	32,532	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Equus</i>	this study	IK10-074	29479	Ikpikpuk R.	metacarpal	Beta-331873	28,330	150	-20.60	5.00	28,330	150	32,643
<i>Equus</i>	this study	IK99-244	10834	Ikpikpuk R.	metacarpal	CAMS-120675	28,500	160	-20.58	8.20	28,500	160	32,937
<i>Equus</i>	this study	IK98-1176	10009	Ikpikpuk R.	metacarpal	CAMS-91797	28,500	200	-20.87	5.14	28,500	200	32,917
<i>Equus</i>	this study	T04-004	11353	Titaluk R.	radius	CAMS-120712	28,540	170	-21.29	6.10	28,540	170	32,983
<i>Equus</i>	this study	IK01-368	12011	Ikpikpuk R.	metatarsal	CAMS-121736	28,690	160	-21.20	7.60	28,690	160	33,142
<i>Equus</i>	this study	IK06-17	29480	Ikpikpuk R.	metacarpal	Beta-331863	29,560	150	-20.90	6.50	29,560	150	34,283
<i>Equus</i>	this study	IK99-254	10644	Ikpikpuk R.	metacarpal	CAMS-91806	29,700	200	-21.23	9.81	29,700	200	34,417
<i>Equus</i>	this study	IK99-383	11205	Ikpikpuk R.	metatarsal	CAMS-120680 <sup>#</sup>	29,830	190	-21.26	6.40	29,830	190	34,596
<i>Equus</i>	this study	IK99-383	11205	Ikpikpuk R.	metatarsal	CAMS-121753 <sup>#</sup>	30,560	200	-21.30	6.40	30,560	200	34,999
<i>Equus</i>	this study	TIT11-071	29481	Titaluk R.	mandible	Beta-331889	30,260	190	-20.90	6.80	30,260	190	34,834
<i>Equus</i>	this study	IK07-06	29495	Ikpikpuk R.	metacarpal	Beta-331865	30,560	160	-21.10	5.80	30,560	160	34,986
<i>Equus</i>	this study	TIT11-072	29482	Titaluk R.	mandible	Beta-331890	30,610	200	-21.70	8.10	30,610	200	35,040
<i>Equus</i>	this study	IK98-0539	9548	Ikpikpuk R.	mandible	CAMS-91793	30,900	300	-21.16	7.87	30,900	300	35,596
<i>Equus</i>	this study	IK01-183	11878	Ikpikpuk R.	metatarsal	CAMS-92083	31,230	270	-21.70	5.32	31,230	270	35,770
<i>Equus</i>	this study	IK08-082	29483	Ikpikpuk R.	metacarpal	Beta-331869	31,680	190	-21.00	7.40	31,680	190	36,248
<i>Equus</i>	this study	TIT10-38	29485	Titaluk R.	metacarpal	Beta-331886	32,250	220	-21.30	5.10	32,250	220	36,732
<i>Equus</i>	this study	IK98-1142	9972	Ikpikpuk R.	mandible	CAMS-91796	32,600	300	-21.13	5.13	32,600	300	37,072
<i>Equus</i>	this study	IK01-282	11794	Ikpikpuk R.	metacarpal	CAMS-92089	32,700	300	-20.87	4.47	32,700	300	37,173
<i>Equus</i>	this study	IK09-51	29486	Ikpikpuk R.	metacarpal	Beta-331871	33,150	200	-21.60	5.50	33,150	200	37,898
<i>Equus</i>	this study	TIT10-36	29487	Titaluk R.	metacarpal	Beta-331884	33,200	240	-21.40	6.20	33,200	240	37,946
<i>Equus</i>	this study	IK98-0288	8859	Ikpikpuk R.	metatarsal	CAMS-120721 <sup>#</sup>	33,420	340	-21.45	6.80	33,420	340	38,132
<i>Equus</i>	this study	IK98-0288	8859	Ikpikpuk R.	metatarsal	CAMS-121742 <sup>#</sup>	33,820	290	-21.50	6.80	33,820	290	38,713
<i>Equus</i>	this study	IK98-0112	9021	Ikpikpuk R.	metacarpal	CAMS-91790	33,800	400	-21.09	7.91	33,800	400	38,591
<i>Equus</i>	this study	IK99-790	10910	Ikpikpuk R.	mandible	CAMS-92074	33,870	350	-20.72	5.86	33,870	350	38,758
<i>Equus</i>	this study	IK01-369	11973	Ikpikpuk R.	metacarpal	CAMS-92093 <sup>#</sup>	33,900	400	-21.16	5.87	33,900	400	38,817
<i>Equus</i>	this study	IK01-369	11973	Ikpikpuk R.	metacarpal	CAMS-91782 <sup>#</sup>	34,200	400	-21.16	5.87	34,200	400	39,229
<i>Equus</i>	this study	IK01-150	12014	Ikpikpuk R.	mandible	CAMS-92081	34,210	370	-21.20	7.21	34,210	370	39,172
<i>Equus</i>	this study	TIT10-37	29488	Titaluk R.	metacarpal	Beta-331885	34,320	270	-20.90	9.10	34,320	270	39,288
<i>Equus</i>	this study	IK99-404	11122	Ikpikpuk R.	metacarpal	CAMS-120681 <sup>#</sup>	34,690	340	-22.11	8.30	34,690	340	39,746

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Equus</i>	this study	IK99-404	11122	Ikpihpuk R.	metacarpal	CAMS-121754 <sup>#</sup>	35,380	360	-22.10	8.30	35,380	360	40,594
<i>Equus</i>	this study	IK98-0009	9169	Ikpihpuk R.	mandible	CAMS-91789	35,500	400	-21.00	5.93	35,500	400	40,751
<i>Equus</i>	this study	IK98-0394	8814	Ikpihpuk R.	metacarpal	CAMS-91791	36,500	500	-21.40	6.02	36,500	500	41,553
<i>Equus</i>	this study	IK01-121	11782	Ikpihpuk R.	metacarpal	CAMS-92079	37,400	540	-21.15	6.75	37,400	540	42,152
<i>Equus</i>	this study	IK99-806	11068	Ikpihpuk R.	metacarpal	CAMS-92075	38,090	590	-20.84	5.76	38,090	590	42,587
<i>Equus</i>	this study	IK08-079	29489	Ikpihpuk R.	metacarpal	Beta-331868	40,880	400	-21.20	5.70	40,880	400	44,656
<i>Equus</i>	this study	IK08-078	29490	Ikpihpuk R.	metacarpal	Beta-331867	40,960	370	-20.60	7.00	40,960	370	44,705
<i>Equus</i>	this study	IK99-111	10544	Ikpihpuk R.	metacarpal	CAMS-91799	41,000	800	-20.79	3.07	41,000	800	44,758
<i>Equus</i>	this study	IK12-011	29491	Ikpihpuk R.	metacarpal	Beta-331876	41,410	570	-20.90	4.20	41,410	570	45,003
<i>Equus</i>	this study	IK12-010	29492	Ikpihpuk R.	metacarpal	Beta-331875	41,840	410	-20.40	4.30	41,840	410	45,268
<i>Equus</i>	this study	IK02-072	10534	Ikpihpuk R.	metatarsal	CAMS-120650 <sup>#</sup>	42,500	1,000	-21.27	7.70	42,500	1,000	45,917
<i>Equus</i>	this study	IK02-072	10534	Ikpihpuk R.	metatarsal	CAMS-121737 <sup>#</sup>	43,700	1,000	-21.30	7.70	43,700	1,000	47,063
<i>Equus</i>	this study	IK02-026	10434	Ikpihpuk R.	mandible	CAMS-91959	46,770	1,710	-20.70	1.65	46,770	1,710	46,977
<i>Equus</i>	this study	IK10-02	29493	Ikpihpuk R.	cranium	Beta-283243	42,800	> than	-20.90	n/a	42,800	> than	n/a
<i>Equus</i>	this study	KIK12-02	29494	Kikiakrorak R.	phalange	Beta-331880	43,500	> than	-21.00	5.70	43,500	> than	n/a
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9371	<b>19,250</b>	<b>360</b>	<b>-21.1</b>	n/a	19,314	360	22,986
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9274	<b>20,810</b>	<b>410</b>	<b>-21.1</b>	n/a	20,874	410	24,958
<i>Equus</i>	Guthrie & Stoker, 1990	AK-109-V-1	23920	Titaluk R.	mandible	GX-13939	21,220	800	n/a	n/a	21,220	800	25,509
<i>Equus</i>	Guthrie & Stoker, 1990	AK-109-V-2	23919	Titaluk R.	radius	GX-13941	21,420	440	n/a	n/a	21,420	440	25,603
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9318	<b>23,910</b>	<b>470</b>	<b>-21.1</b>	n/a	23,974	470	28,876
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9275	<b>32,270</b>	<b>1,500</b>	<b>-21.1</b>	n/a	32,334	1,500	37,015
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9319	<b>40,000</b>	<b>&gt; than</b>	<b>-21.1</b>	n/a	40,064	> than	n/a
<i>Equus</i>	Guthrie & Stoker, 1990	n/a	n/a	Ikpihpuk R.	n.r. <sup>a</sup>	I-9320	<b>40,000</b>	<b>&gt; than</b>	<b>-21.1</b>	n/a	40,064	> than	n/a
<i>Equus</i>	Harington, 2003 <sup>i</sup>	n/a	n/a	Titaluk R.	n.r. <sup>a</sup>	USGS-804	28,700	460	n/a	n/a	28,700	460	33,251

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Equus</i>	Lorenzen et al., 2011	n/a	n/a	Pt. Barrow	n.r. <sup>a</sup>	CAMS-145093	19,830	100	n/a	n/a	19,830	100	23,692
<i>Equus</i>	Lorenzen et al., 2011	n/a	n/a	Pt. Barrow	n.r. <sup>a</sup>	CAMS-145113	20,720	110	n/a	n/a	20,720	110	24,712
<i>Equus</i>	Lorenzen et al., 2011	n/a	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AAR-11185	25,460	230	n/a	n/a	25,460	230	30,298
<i>Equus</i>	Lorenzen et al., 2011	n/a	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	CAMS-91789	35,500	400	n/a	n/a	35,500	400	40,708
<i>Mammut</i>	G. Zazula, pers. comm.	MAY12-69	n/a	Maybe Cr.	molar	UCIAMS-117238 <sup>h</sup>	31,780	360	-20.96	2.08	31,780	360	36,274
<i>Mammut</i>	G. Zazula, pers. comm.	MAY12-45	30200	Maybe Cr.	molar	UCIAMS-117241	47,000	2,300	-20.94	3.46	47,000	2,300	47,806
<i>Mammut</i>	G. Zazula, pers. comm.	IK01-277	12060	Ikpikpuk R.	molar	UCIAMS-117236	49,800	3,300	-20.88	3.05	49,800	3,300	51,801
<i>Mammut</i>	G. Zazula, pers. comm.	MAY12-70	n/a	Maybe Cr.	molar	UCIAMS-117237	46,100	> than	-21.13	3.50	46,100	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	KIG12-15	30199	Kigalik R.	molar	UCIAMS-117235	46,400	> than	-20.88	3.16	46,400	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK10-106	30201	Ikpikpuk R.	molar	UCIAMS-117232	47,500	> than	-20.81	3.01	47,500	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK99-237	2414	Ikpikpuk R.	molar	UCIAMS-117234	48,100	> than	-20.76	4.08	48,100	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK01-321	12047	Ikpikpuk R.	molar	UCIAMS-117240	48,800	> than	-20.67	3.54	48,800	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK08-127	30198	Ikpikpuk R.	molar	UCIAMS-117243	51,200	> than	-20.73	2.98	51,200	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK99-328	11095	Ikpikpuk R.	molar	UCIAMS-117233	51,200	> than	-21.19	3.08	51,200	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK05-3.5	30197	Ikpikpuk R.	molar	UCIAMS-117242	51,700	> than	-21.19	2.80	51,700	> than	n/a
<i>Mammut</i>	G. Zazula, pers. comm.	IK98-963	9705	Ikpikpuk R.	molar	UCIAMS-117239	51,700	> than	-20.96	2.77	51,700	> than	n/a
<i>Mammut</i>	this study	IK98-967	n/a	Ikpikpuk R.	molar	CAMS-91794	54,000	> than	-20.99	n/a	54,000	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	UNM6648	30202	C. Lisburne	n.r. <sup>a</sup>	AA-26006	11,910	130	-21.20	n/a	11,910	130	13,757
<i>Mammuthus</i>	Guthrie, 2004	IK24	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17614	12,190	130	-21.84	n/a	12,190	130	14,100
<i>Mammuthus</i>	Guthrie, 2004	AK204-V-1	28809	Ikpikpuk R.	n.r. <sup>a</sup>	AA-14954	12,490	170	-21.10	n/a	12,490	170	14,615

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Mammuthus</i>	Guthrie, 2004	UNM11997	n/a	Point Hope	n.r. <sup>a</sup>	AA-26028	13,290	140	-21.30	n/a	13,290	140	16,232
<i>Mammuthus</i>	this study	KIK10- SK	29496	Kikiakrorak R.	cranium	Beta-283246	14,070	60	-19.60	n/a	14,070	60	17,110
<i>Mammuthus</i>	Guthrie, 2004	UMN6068c	n/a	Point Hope	n.r. <sup>a</sup>	AA-26015	15,740	230	-22.80	n/a	15,740	230	18,956
<i>Mammuthus</i>	Gal, 1982 <sup>j</sup>	49MIS117	n/a	Utukok R.	n.r. <sup>a</sup>	Shell-6713A	<b>17,300</b>	<b>800</b>	<b>-21.5</b>	n/a	17,357	800	20,808
<i>Mammuthus</i>	this study	IK02-181	10522	Ikpikpuk R.	fibula	CAMS-120653 <sup>#</sup>	17,870	60	-20.90	7.60	17,870	60	21,358
<i>Mammuthus</i>	this study	IK02-181	10522	Ikpikpuk R.	fibula	CAMS-121739 <sup>#</sup>	17,965	50	-20.90	7.60	17,965	50	21,427
<i>Mammuthus</i>	this study	IK01-257	12016	Ikpikpuk R.	molar	CAMS-92087	19,530	80	-21.34	10.11	19,530	80	23,355
<i>Mammuthus</i>	Guthrie, 2004	IK13	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17620	19,560	330	-21.17	n/a	19,560	330	23,350
<i>Mammuthus</i>	Guthrie, 2004	IK3	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17623	19,970	350	-21.25	n/a	19,970	350	23,870
<i>Mammuthus</i>	this study	HAR-057-1	n/a	Nuiqsit	femur	Beta-192036	20,150	110	-21.50	n/a	20,150	110	24,080
<i>Mammuthus</i>	Guthrie, 2004	UNM6068a	n/a	Point Hope	n.r. <sup>a</sup>	AA-26013	24,193	510	-21.40	n/a	24,193	510	29,030
<i>Mammuthus</i>	this study	IK98-0339	9053	Ikpikpuk R.	scapula	CAMS-120677 <sup>#</sup>	24,460	130	-21.49	7.60	24,460	130	29,323
<i>Mammuthus</i>	this study	IK98-0339	9053	Ikpikpuk R.	scapula	CAMS-121751 <sup>#</sup>	24,850	110	-21.50	7.60	24,850	110	29,702
<i>Mammuthus</i>	this study	T02-110	n/a	Titaluk R.	n.r. PM <sup>b</sup>	CAMS-91967	26,410	150	-20.49	8.03	26,410	150	31,052
<i>Mammuthus</i>	Guthrie, 2004	IK8	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17616 <sup>*</sup>	28,020	810	-21.61	n/a	28,020	810	32,541
<i>Mammuthus</i>	this study	IK99-120b	10688	Ikpikpuk R.	mandible	CAMS-91800	28,200	200	-21.20	7.86	28,200	200	32,446
<i>Mammuthus</i>	this study	IK01-040	11998	Ikpikpuk R.	radius	CAMS-92077 <sup>#</sup>	28,220	210	-21.20	7.56	28,220	210	32,472
<i>Mammuthus</i>	this study	IK01-040	11998	Ikpikpuk R.	radius	CAMS-91783 <sup>#</sup>	29,100	200	-21.20	7.56	29,100	200	33,787
<i>Mammuthus</i>	this study	IK99-495	10851	Ikpikpuk R.	mandible	CAMS-120684	29,740	190	-21.20	7.97	29,740	190	34,517
<i>Mammuthus</i>	this study	IK98-0063	9096	Ikpikpuk R.	tibia	CAMS-121740 <sup>#</sup>	30,730	200	-21.10	8.30	30,730	200	35,170
<i>Mammuthus</i>	this study	IK98-0063	9096	Ikpikpuk R.	tibia	CAMS-120654 <sup>#</sup>	29,250	200	-21.08	8.30	29,250	200	33,938
<i>Mammuthus</i>	this study	IK99-745	10905	Ikpikpuk R.	molar	CAMS-92072	30,990	250	-20.58	9.03	30,990	250	35,547
<i>Mammuthus</i>	Guthrie, 2004	AK323-V-1	29130	Ikpikpuk R.	n.r. <sup>a</sup>	AA-22574	31,100	1,200	-21.80	n/a	31,100	1,200	35,944
<i>Mammuthus</i>	Guthrie, 2004	IK35	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17602	31,300	1,200	-21.04	n/a	31,300	1,200	36,129
<i>Mammuthus</i>	Guthrie, 2004	UMN6068b	n/a	Point Hope	n.r. <sup>a</sup>	AA-26014	31,600	1,200	-21.40	n/a	31,600	1,200	36,426
<i>Mammuthus</i>	this study	IK99-5001	8632	Ikpikpuk R.	tusk	CAMS-91779 <sup>#</sup>	33,000	300	-20.77	7.16	33,000	300	37,677
<i>Mammuthus</i>	this study	IK99-5001	8632	Ikpikpuk R.	tusk	CAMS-91968 <sup>#</sup>	33,530	340	-20.77	7.16	33,530	340	38,254

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Mammuthus</i>	Guthrie, 2004	AK268-V-1	28766	Ikpikpuk R.	n.r. <sup>a</sup>	AA-22575	33,300	1,600	n/a	n/a	33,300	1,600	38,388
<i>Mammuthus</i>	this study	T02-032	8635	Titaluk R.	femur	CAMS-121756 <sup>#</sup>	33,340	280	-20.90	n/a	33,340	280	38,075
<i>Mammuthus</i>	this study	T02-032	8635	Titaluk R.	femur	CAMS-120705 <sup>#</sup>	33,370	290	-20.90	n/a	33,370	290	38,100
<i>Mammuthus</i>	Guthrie, 2004	IK14	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17619	33,400	1,600	-26.60	n/a	33,400	1,600	38,486
<i>Mammuthus</i>	this study	IK99-575	11028	Ikpikpuk R.	molar	CAMS-91812 <sup>#</sup>	33,400	300	-20.75	9.12	33,400	300	38,126
<i>Mammuthus</i>	this study	IK99-575	11028	Ikpikpuk R.	molar	CAMS-91780 <sup>#</sup>	33,600	400	-20.75	9.12	33,600	400	38,343
<i>Mammuthus</i>	this study	T02-033	n/a	Titaluk R.	n.r. PM <sup>b</sup>	CAMS-120706 <sup>#</sup>	33,880	300	-21.40	7.00	33,880	300	38,787
<i>Mammuthus</i>	this study	T02-033	n/a	Titaluk R.	n.r. PM <sup>b</sup>	CAMS-121757 <sup>#</sup>	33,920	310	-21.40	7.00	33,920	310	38,838
<i>Mammuthus</i>	Harington, 2003 <sup>i</sup>	49IKR-VP	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	USGS-807	36,400	560	-21.80	n/a	36,400	560	41,471
<i>Mammuthus</i>	Guthrie, 2004	IK4	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17627	36,700	2,300	-21.98	n/a	36,700	2,300	41,865
<i>Mammuthus</i>	Guthrie, 2004	IK17	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17616 <sup>*</sup>	36,800	2,500	-22.98	n/a	36,800	2,500	42,026
<i>Mammuthus</i>	Guthrie, 2004	AK1014	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-22615	37,400	2,600	-18.80	n/a	37,400	2,600	42,619
<i>Mammuthus</i>	Guthrie, 2004	IK10	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17622	37,800	2,700	-22.51	n/a	37,800	2,700	43,011
<i>Mammuthus</i>	Guthrie, 2004	IK33	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17605	38,000	2,700	-21.72	n/a	38,000	2,700	43,186
<i>Mammuthus</i>	Guthrie, 2004	IK6	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17628	39,700	3,400	-23.05	n/a	39,700	3,400	44,642
<i>Mammuthus</i>	Guthrie, 2004	IK25	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17615	39,800	3,400	-21.05	n/a	39,800	3,400	44,711
<i>Mammuthus</i>	this study	IK98-1275	10080	Ikpikpuk R.	humerus	CAMS-120670	40,760	830	-21.80	7.09	40,760	830	44,580
<i>Mammuthus</i>	this study	IK99-235	10752	Ikpikpuk R.	molar	CAMS-91803	40,870	820	-21.53	8.44	40,870	820	44,660
<i>Mammuthus</i>	this study	IK98-1102	9823	Ikpikpuk R.	vertebra	CAMS-120666 <sup>#</sup>	45,100	1,400	-21.42	7.80	45,100	1,400	48,141
<i>Mammuthus</i>	this study	IK98-1102	9823	Ikpikpuk R.	vertebra	CAMS-121748 <sup>#</sup>	46,900	1,400	-21.40	7.80	46,900	1,400	47,162
<i>Mammuthus</i>	this study	IK01-250	11964	Ikpikpuk R.	tibia	CAMS-120643 <sup>#</sup>	47,300	1,500	-21.49	6.68	47,300	1,500	47,604
<i>Mammuthus</i>	this study	IK01-250	11964	Ikpikpuk R.	tibia	CAMS-120718 <sup>#</sup>	48,760	2,200	-21.49	6.68	48,760	2,200	49,485
<i>Mammuthus</i>	this study	IK01-201	11715	Ikpikpuk R.	molar	CAMS-92085	48,040	2,000	-21.39	8.17	48,040	2,000	48,619
<i>Mammuthus</i>	this study	IK01-166	11821	Ikpikpuk R.	ulna	CAMS-120716	49,310	1,950	-20.85	6.55	49,310	1,950	49,857
<i>Mammuthus</i>	this study	IK01-147	12001	Ikpikpuk R.	femur	CAMS-92080	49,490	2,400	-21.32	n/a	49,490	2,400	50,383
<i>Mammuthus</i>	this study	IK98-1033	9970	Ikpikpuk R.	scapula	CAMS-120665	49,700	2,500	-21.43	7.42	49,700	2,500	50,687
<i>Mammuthus</i>	this study	IK01-291	n/a	Ikpikpuk R.	tusk	CAMS-120645 <sup>#</sup>	48,900	1,900	-21.22	8.24	48,900	1,900	49,415

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Mammuthus</i>	this study	IK01-291	n/a	Ikpikpuk R.	tusk	CAMS-121732 <sup>#</sup>	51,000	2,400	-21.20	8.24	51,000	2,400	51,893
<i>Mammuthus</i>	this study	IK99-070	10694	Ikpikpuk R.	mandible	CAMS-91798 <sup>#</sup>	49,000	> than	-22.32	9.48	49,000	> than	n/a
<i>Mammuthus</i>	this study	IK99-070	10694	Ikpikpuk R.	mandible	CAMS-91778 <sup>#</sup>	51,900	3,200	-22.32	9.48	51,900	3,200	53,746
<i>Mammuthus</i>	this study	IK98-1012	9933	Ikpikpuk R.	cranium	CAMS-120664	50,800	2,400	-21.39	7.07	50,800	2,400	51,693
<i>Mammuthus</i>	this study	IK99-524	11007	Ikpikpuk R.	molar	CAMS-91811	51,000	2,900	-21.78	9.68	51,000	2,900	52,432
<i>Mammuthus</i>	this study	IK01-355	12004	Ikpikpuk R.	vertebra	CAMS-120648 <sup>#</sup>	49,400	2,400	-21.66	n/a	49,400	2,400	50,293
<i>Mammuthus</i>	this study	IK01-355	12004	Ikpikpuk R.	vertebra	CAMS-121735 <sup>#</sup>	52,800	3,000	-21.70	n/a	52,800	3,000	54,362
<i>Mammuthus</i>	this study	IK98-1013	9934	Ikpikpuk R.	scapula	CAMS-120722 <sup>#</sup>	47,300	1,800	-21.82	7.35	47,300	1,800	47,756
<i>Mammuthus</i>	this study	IK98-1013	9934	Ikpikpuk R.	scapula	CAMS-121747 <sup>#</sup>	55,700	4,300	-21.80	7.35	55,700	4,300	59,726
<i>Mammuthus</i>	this study	IK02-173	10458	Ikpikpuk R.	fibula	CAMS-91963	51,900	3,200	-21.33	6.38	51,900	3,200	53,746
<i>Mammuthus</i>	this study	IK98-1243	9945	Ikpikpuk R.	radius	CAMS-121750 <sup>#</sup>	51,800	2,700	-21.70	6.81	51,800	2,700	52,995
<i>Mammuthus</i>	this study	IK98-1243	9945	Ikpikpuk R.	radius	CAMS-120668 <sup>#</sup>	53,400	3,900	-21.72	6.81	53,400	3,900	56,510
<i>Mammuthus</i>	this study	IK98-1195	9811	Ikpikpuk R.	radius	CAMS-120667 <sup>#</sup>	50,400	2,700	-21.09	6.08	50,400	2,700	51,595
<i>Mammuthus</i>	this study	IK98-1195	9811	Ikpikpuk R.	radius	CAMS-121749 <sup>#</sup>	55,500	> than	-21.10	6.08	55,500	> than	n/a
<i>Mammuthus</i>	this study	IK01-274	n/a	Ikpikpuk R.	femur	CAMS-92088	53,000	3,700	-21.42	9.84	53,000	3,700	55,705
<i>Mammuthus</i>	this study	IK01-170	11824	Ikpikpuk R.	molar	CAMS-92082	53,600	3,900	-21.82	n/a	53,600	3,900	56,710
<i>Mammuthus</i>	Guthrie, 2004	IK27	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17610	31,000	> than	-21.00	n/a	31,000	> than	n/a
<i>Mammuthus</i>	Guthrie, 1990	n/a	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	I-9342	<b>35,000</b>	<b>&gt;than</b>	<b>-21.5</b>	n/a	35,057	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK16	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17612	35,700	> than	-20.50	n/a	35,700	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK23	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17626	36,800	> than	-21.21	n/a	36,800	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK31	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17603	37,000	> than	-22.71	n/a	37,000	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK22	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17613	37,200	> than	-21.60	n/a	37,200	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK29	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17611	37,500	> than	-22.69	n/a	37,500	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK36	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17604	37,600	> than	-21.89	n/a	37,600	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK15	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17617	37,600	> than	-22.07	n/a	37,600	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK32	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17609	38,100	> than	-20.76	n/a	38,100	> than	n/a
<i>Mammuthus</i>	Guthrie, 2004	IK26	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17608	39,000	> than	-21.78	n/a	39,000	> than	n/a

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Mammuthus</i>	Guthrie, 2004	AK72-4	28848	Titaluk R.	n.r. <sup>a</sup>	AA-14959*	39,400	> than	-21.70	n/a	39,400	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK34	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17607	39,500	> than	-22.02	n/a	39,500	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK30	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17606	40,000	> than	-21.85	n/a	40,000	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	AKV-72-5	29356	Titaluk R.	n.r. <sup>a</sup>	AA-14961	40,700	> than	-22.00	n/a	40,700	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	Tusk	n/a	Umiat	tusk	AA-22617	40,800	> than	-21.90	n/a	40,800	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK5	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17625	41,000	> than	-21.98	n/a	41,000	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	V-30-76	23334	Meade R.	molar	AA-22620	41,000	> than	-21.80	n/a	41,000	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	My Ikpiapu,	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-14946	41,100	> than	-20.90	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	A-5	n/a	Meade R.	n.r. <sup>a</sup>	AA-14953	41,100	> than	-22.30	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	AK119-V-1	28789	Colville R.	n.r. <sup>a</sup>	AA-14959*	41,100	> than	-21.80	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK7	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17618	41,100	> than	-22.41	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK1	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17621	41,100	> than	-22.33	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	Guthrie, 2004	IK2	n/a	Ikpikpuk R.	n.r. <sup>a</sup>	AA-17624	41,100	> than	-22.62	n/a	41,100	> than	n/a	
<i>Mammuthus</i>	this study	IK09-07	n/a	Ikpikpuk R.	tusk	Beta-263032	42,000	> than	-21.20	n/a	42,000	> than	n/a	
<i>Mammuthus</i>	this study	KIK10-TT	n/a	Kikiakrorak R.	tusk	Beta-283247	43,500	> than	-20.60	n/a	43,500	> than	n/a	
<i>Mammuthus</i>	this study	IK98-CWB	n/a	Ikpikpuk R.	tusk	Beta-283241	43,500	> than	-20.90	n/a	43,500	> than	n/a	
<i>Mammuthus</i>	this study	Pelvis	n/a	Ikpikpuk R.	pelvis	Beta-111034	46,450	> than	-21.60	n/a	46,450	> than	n/a	
<i>Mammuthus</i>	this study	IK98-0957	n/a	Ikpikpuk R.	long bone	CAMS-120662	48,900	> than	-20.74	8.06	48,900	> than	n/a	
<i>Mammuthus</i>	this study	IK99-236	11111	Ikpikpuk R.	molar	CAMS-91804	49,000	> than	-21.84	8.10	49,000	> than	n/a	
<i>Mammuthus</i>	this study	T02-038	8617	Titaluk R.	scapula	CAMS-91960	49,200	> than	-22.44	6.64	49,200	> than	n/a	
<i>Mammuthus</i>	this study	IK01-256	11972	Ikpikpuk R.	molar	CAMS-92086	49,200	> than	-21.36	8.18	49,200	> than	n/a	
<i>Mammuthus</i>	this study	IK02-121	10523	Ikpikpuk R.	radius	CAMS-120652	49,300	> than	-21.85	n/a	49,300	> than	n/a	
<i>Mammuthus</i>	this study	IK01-200	11684	Ikpikpuk R.	molar	CAMS-92084	50,000	> than	-22.29	n/a	50,000	> than	n/a	
<i>Mammuthus</i>	this study	IK98-1312	9853	Ikpikpuk R.	femur	CAMS-120672	50,100	> than	-22.04	6.86	50,100	> than	n/a	
<i>Mammuthus</i>	this study	IK99-588	10941	Ikpikpuk R.	pelvis	CAMS-120723	50,400	> than	-22.03	n/a	50,400	> than	n/a	
<i>Mammuthus</i>	this study	IK01-079	11646	Ikpikpuk R.	rib	CAMS-120638 <sup>#</sup>	49,100	> than	-23.18	8.36	49,100	> than	n/a	
<i>Mammuthus</i>	this study	IK01-079	11646	Ikpikpuk R.	rib	CAMS-120713 <sup>#</sup>	52,000	> than	-23.18	8.36	52,000	> than	n/a	
<i>Mammuthus</i>	this study	IK98-0298	8889	Ikpikpuk R.	radius	CAMS-120657	50,600	> than	-22.09	7.80	50,600	> than	n/a	



Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Mammuthus</i>	this study	IK99-366	11180	Ikpikpuk R.	tusk	CAMS-120678	51,000	> than	-21.59	8.50	51,000	> than	n/a	
<i>Mammuthus</i>	this study	IK01-255	11971	Ikpikpuk R.	femur	CAMS-120644 <sup>#</sup>	50,000	> than	-21.98	7.67	50,000	> than	n/a	
<i>Mammuthus</i>	this study	IK01-255	11971	Ikpikpuk R.	femur	CAMS-120719 <sup>#</sup>	52,100	> than	-21.98	7.67	52,100	> than	n/a	
<i>Mammuthus</i>	this study	IK98-1281	9996	Ikpikpuk R.	tibia	CAMS-120671	51,100	> than	-21.42	7.19	51,100	> than	n/a	
<i>Mammuthus</i>	this study	IK98-1000	9773	Ikpikpuk R.	tusk	CAMS-120663	51,300	> than	-21.58	7.63	51,300	> than	n/a	
<i>Mammuthus</i>	this study	IK98-1274	10079	Ikpikpuk R.	radius	CAMS-120669	51,300	> than	-21.72	7.18	51,300	> than	n/a	
<i>Mammuthus</i>	this study	IK99-130	11120	Ikpikpuk R.	femur	CAMS-120674	51,500	> than	-21.35	6.77	51,500	> than	n/a	
<i>Mammuthus</i>	this study	IK01-132	12035	Ikpikpuk R.	radius	CAMS-120640 <sup>#</sup>	49,100	> than	-21.46	6.64	49,100	> than	n/a	
<i>Mammuthus</i>	this study	IK01-132	12035	Ikpikpuk R.	radius	CAMS-120715 <sup>#</sup>	54,500	> than	-21.46	6.64	54,500	> than	n/a	
<i>Mammuthus</i>	this study	IK99-322	10561	Ikpikpuk R.	molar	CAMS-91807	52,000	> than	-21.88	9.35	52,000	> than	n/a	
<i>Mammuthus</i>	this study	IK98-0759	9541	Ikpikpuk R.	scapula	CAMS-121743	52,200	> than	-21.20	9.31	52,200	> than	n/a	
<i>Mammuthus</i>	this study	IK99-5000b	7954	Ikpikpuk R.	tusk	CAMS-92095	52,500	> than	-21.60	7.35	52,500	> than	n/a	
<i>Mammuthus</i>	this study	IK01-082	n/a	Ikpikpuk R.	leg bone	CAMS-120639 <sup>#</sup>	51,000	> than	-20.80	5.07	51,000	> than	n/a	
<i>Mammuthus</i>	this study	IK01-082	n/a	Ikpikpuk R.	leg bone	CAMS-120714 <sup>#</sup>	55,100	> than	-20.80	5.07	55,100	> than	n/a	
<i>Mammuthus</i>	this study	IK98-0761	9543	Ikpikpuk R.	ulna	CAMS-121744	53,400	> than	-20.80	7.68	53,400	> than	n/a	
<i>Mammuthus</i>	this study	IK98-1087	9813	Ikpikpuk R.	molar	CAMS-91795	54,000	> than	-21.76	8.65	54,000	> than	n/a	
<i>Mammuthus</i>	this study	IK02-042	n/a	Ikpikpuk R.	pelvis	CAMS-91961	54,000	> than	-21.40	6.37	54,000	> than	n/a	
<i>Mammuthus</i>	this study	IK01-359	12008	Ikpikpuk R.	molar	CAMS-92092	54,000	> than	-21.69	8.41	54,000	> than	n/a	
<i>Mammuthus</i>	this study	IK98-0801	9424	Ikpikpuk R.	metapodial	CAMS-121746	55,500	> than	-20.80	7.88	55,500	> than	n/a	
<i>Ovibos</i>	this study	ING-99-1001	8638	NPRA	cranium	AA-48776	226	59	-19.80	3.76	226	59	212	
<i>Ovibos</i>	this study	Sing12-2	30202	tundra	cranium	Beta-339445	250	30	-20.00	3.60	250	30	295	
<i>Ovibos</i>	this study	TUN12-1	30203	tundra	cranium	Beta-339278	340	30	-18.50	4.80	340	30	390	
<i>Ovibos</i>	this study	NIG09-1	n/a	Nigliq	cranium	Beta-283248	350	40	-19.20	n/a	350	40	399	
<i>Ovibos</i>	this study	KEA1	29498	Kealok Cr.	cranium	Beta-244761	900	40	-19.00	n/a	900	40	825	
<i>Ovibos</i>	this study	KEA2	29499	Kealok Cr.	cranium	Beta-223266	1,140	40	-21.00	n/a	1,070	40	980	
<i>Ovibos</i>	this study	KEA3	29500	Kealok Cr.	cranium	Beta-244762	1,080	40	-20.30	n/a	1,080	40	991	
<i>Ovibos</i>	this study	ING-99-1002	8639	NPRA	cranium	AA-48283	1,148	42	-20.00	5.56	1,148	42	1,059	
<i>Ovibos</i>	this study	IK99-353	29501	Ikpikpuk R.	cranium	AA-48263	7,127	59	-19.60	6.81	7,127	59	7,953	
<i>Ovibos</i>	this study	IK98-1032	10098	Ikpikpuk R.	cranium	AA-48757	10,180	110	-19.80	3.71	10,180	110	11,846	

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Ovibos</i>	this study	TIT05-08	29502	Titaluk R.	tibia	Beta-223267	21,050	90	-20.80	n/a	21,050	90	25,112	
<i>Ovibos</i>	this study	IK98-0819	9673	Ikpikpuk R.	metatarsal	AA-48753	21,670	370	-19.40	9.26	21,670	370	25,982	
<i>Ovibos</i>	this study	IK98-0871	9753	Ikpikpuk R.	metatarsal	AA-48239	27,580	750	-19.60	9.31	27,580	750	32,133	
<i>Ovibos</i>	this study	IK11-28	29503	Ikpikpuk R.	scapula	Beta-306116	27,640	150	-21.00	n/a	27,640	150	31,711	
<i>Ovibos</i>	this study	TIT09-01	29504	Titaluk R.	cranium	Beta-263036	30,950	240	-19.70	n/a	30,950	240	35,500	
<i>Ovibos</i>	this study	TIT08-17	29505	Titaluk R.	metatarsal	Beta-258464	31,430	240	-20.60	n/a	31,430	240	35,830	
<i>Ovibos</i>	this study	TIT10-04	n/a	Titaluk R.	cranium	Beta-283251	33,960	240	-18.80	n/a	33,960	240	38,872	
<i>Ovibos</i>	this study	IK01-159	11886	Ikpikpuk R.	metatarsal	Beta-286418	34,570	250	-20.20	8.58	34,570	250	39,586	
<i>Ovibos</i>	this study	IK01-313	11685	Ikpikpuk R.	metatarsal	AA-48277	35,920	930	-19.60	7.43	35,920	930	40,972	
<i>Ovibos</i>	this study	IK01-294	11628	Ikpikpuk R.	metatarsal	AA-48276	36,400	770	-20.00	7.27	36,400	770	41,444	
<i>Ovibos</i>	this study	IK99-179	10709	Ikpikpuk R.	mandible	Beta-286425	40,080	340	-20.00	n/a	40,080	340	44,067	
<i>Ovibos</i>	this study	TIT08-13	29506	Titaluk R.	cranium	Beta-258463	40,410	780	-21.20	n/a	40,410	780	44,313	
<i>Ovibos</i>	this study	IK99-047	10573	Ikpikpuk R.	mandible	Beta-286423	40,950	570	-20.10	n/a	40,950	570	44,710	
<i>Ovibos</i>	this study	IK97-501	29507	Ikpikpuk R.	cranium	Beta-117141	41,470	1,050	-23.80	n/a	41,470	1,050	45,133	
<i>Ovibos</i>	this study	IK98-1173	n/a	Ikpikpuk R.	axis	CAMS-53908	43,000	1,800	-19.90	4.25	43,000	1,800	46,736	
<i>Ovibos</i>	this study	IK98-0393	8813	Ikpikpuk R.	metacarpal	AA-48748	35,500	> than	-19.10	8.20	35,500	> than	n/a	
<i>Ovibos</i>	this study	IK98-0673	9641	Ikpikpuk R.	metatarsal	Beta-286422	36,200	> than	-20.70	5.25	36,200	> than	n/a	
<i>Ovibos</i>	this study	IK98-0654	9439	Ikpikpuk R.	metacarpal	AA-48750	37,100	> than	-18.70	2.40	37,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0469	9259	Ikpikpuk R.	metacarpal	Beta-286421	37,300	> than	-20.20	7.28	37,300	> than	n/a	
<i>Ovibos</i>	this study	IK98-0387	8786	Ikpikpuk R.	cranium	Beta-286420	39,500	> than	-20.50	7.24	39,500	> than	n/a	
<i>Ovibos</i>	this study	IK98-1221	9875	Ikpikpuk R.	metacarpal	AA-48258	39,800	> than	-20.10	5.32	39,800	> than	n/a	
<i>Ovibos</i>	this study	IK98-1324	9890	Ikpikpuk R.	horn core	AA-48260	39,900	> than	-19.20	2.73	39,900	> than	n/a	
<i>Ovibos</i>	this study	IK01-086	11674	Ikpikpuk R.	metatarsal	AA-48771	40,000	> than	-20.40	3.17	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK09-05	29508	Ikpikpuk R.	femur	Beta-263030	40,000	> than	-19.50	n/a	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK09-06	29509	Ikpikpuk R.	femur	Beta-263031	40,000	> than	-21.00	n/a	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-1028	9959	Ikpikpuk R.	cranium	AA-48756	40,000	> than	-19.90	8.84	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-1309	9834	Ikpikpuk R.	metacarpal	AA-48761	40,000	> than	-19.20	8.36	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK99-142	10682	Ikpikpuk R.	cranium	AA-48764	40,000	> than	-19.40	3.51	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK99-731	10845	Ikpikpuk R.	metatarsal	AA-48768	40,000	> than	-19.60	9.17	40,000	> than	n/a	

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Ovibos</i>	this study	IK99-754	10936	Ikpikpuk R.	metatarsal	AA-48769	40,000	> than	-18.90	8.75	40,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-0028	9068	Ikpikpuk R.	metacarpal	AA-48252	40,100	> than	-19.30	4.21	40,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0818	9677	Ikpikpuk R.	metatarsal	AA-48238	40,100	> than	-19.70	7.96	40,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1288	10017	Ikpikpuk R.	metacarpal	AA-48259	40,200	> than	-19.40	6.89	40,200	> than	n/a	
<i>Ovibos</i>	this study	IK98-0441	8926	Ikpikpuk R.	metacarpal	AA-48254	40,300	> than	-19.90	5.52	40,300	> than	n/a	
<i>Ovibos</i>	this study	IK01-311	11662	Ikpikpuk R.	metacarpal	AA-48250	40,700	> than	-20.00	6.96	40,700	> than	n/a	
<i>Ovibos</i>	this study	IK01-398	11840	Ikpikpuk R.	metacarpal	AA-48279	40,900	> than	-20.20	5.75	40,900	> than	n/a	
<i>Ovibos</i>	this study	IK01-136	11888	Ikpikpuk R.	metatarsal	AA-48272	41,000	> than	-19.90	5.54	41,000	> than	n/a	
<i>Ovibos</i>	this study	IK01-160	11887	Ikpikpuk R.	metatarsal	AA-48249	41,000	> than	-20.00	7.10	41,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-0849	9336	Ikpikpuk R.	metacarpal	AA-48257	41,000	> than	-19.60	5.53	41,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-0980	9740	Ikpikpuk R.	metatarsal	AA-48755	41,000	> than	-20.40	n/a	41,000	> than	n/a	
<i>Ovibos</i>	this study	IK99-729	10843	Ikpikpuk R.	metacarpal	AA-48265	41,000	> than	-19.70	9.17	41,000	> than	n/a	
<i>Ovibos</i>	this study	IK01-073	11862	Ikpikpuk R.	cranium	AA-48267	41,100	> than	-19.80	5.62	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0029	9069	Ikpikpuk R.	metacarpal	AA-48744	41,100	> than	-19.30	3.43	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0049	8911	Ikpikpuk R.	metacarpal	AA-48745	41,100	> than	-19.20	10.71	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0089	9095	Ikpikpuk R.	metacarpal	AA-48746	41,100	> than	-19.70	8.85	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0133	9122	Ikpikpuk R.	metacarpal	AA-48747	41,100	> than	-20.20	7.69	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0286	8836	Ikpikpuk R.	metacarpal	AA-48236	41,100	> than	-19.80	2.25	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0461	9251	Ikpikpuk R.	metacarpal	AA-48237	41,100	> than	-19.90	6.01	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0513	9610	Ikpikpuk R.	metatarsal	AA-48255	41,100	> than	-20.10	6.62	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0653	9438	Ikpikpuk R.	metacarpal	AA-48256	41,100	> than	-19.60	5.97	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0742	9471	Ikpikpuk R.	metatarsal	AA-48752	41,100	> than	-19.70	2.64	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-0930	9504	Ikpikpuk R.	metacarpal	AA-48754	41,100	> than	-20.10	6.57	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1027	9958	Ikpikpuk R.	cranium	AA-48240	41,100	> than	-19.60	3.07	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1044	10044	Ikpikpuk R.	metacarpal	AA-48241	41,100	> than	-19.00	7.37	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1124	9918	Ikpikpuk R.	metacarpal	AA-48242	41,100	> than	-19.40	6.10	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-143	10683	Ikpikpuk R.	cranium	AA-48244	41,100	> than	-20.40	4.66	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-320	10559	Ikpikpuk R.	metacarpal	AA-48245	41,100	> than	-20.10	3.80	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-504	10883	Ikpikpuk R.	metatarsal	AA-48264	41,100	> than	-20.00	8.79	41,100	> than	n/a	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Ovibos</i>	this study	IK98-1123	9922	Ikpikpuk R.	metacarpal	AA-48758	41,100	> than	-19.90	6.46	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1289	10018	Ikpikpuk R.	metacarpal	AA-48760	41,100	> than	-20.60	7.30	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK98-1267	10058	Ikpikpuk R.	cranium	AA-48759	41,100	> than	-20.50	6.41	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-045	11130	Ikpikpuk R.	cranium	AA-48762	41,100	> than	-19.60	n/a	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-096	10729	Ikpikpuk R.	metatarsal	AA-48763	41,100	> than	-20.60	n/a	41,100	> than	n/a	
<i>Ovibos</i>	this study	IK99-255	10645	Ikpikpuk R.	metacarpal	AA-48765	41,100	> than	-19.50	9.14	41,100	> than	n/a	
<i>Ovibos</i>	this study	KIK09-01	29510	Kikiakrorak R.	cranium	Beta-263034	41,500	> than	-20.60	n/a	41,500	> than	n/a	
<i>Ovibos</i>	this study	IK09-08	29511	Ikpikpuk R.	mandible	Beta-263033	42,000	> than	-18.60	n/a	42,000	> than	n/a	
<i>Ovibos</i>	this study	IK10-04	29512	Ikpikpuk R.	cranium	Beta-283245	43,500	> than	-19.70	n/a	43,500	> than	n/a	
<i>Ovibos</i>	this study	IK99-133	10832	Ikpikpuk R.	mandible	Beta-286424	43,500	> than	-19.70	n/a	43,500	> than	n/a	
<i>Ovibos</i>	this study	IK08-17	29514	Ikpikpuk R.	mandible	Beta-258459	44,000	> than	-20.20	n/a	44,000	> than	n/a	
<i>Ovibos</i>	this study	IK08-33	29515	Ikpikpuk R.	cranium	Beta-258460	44,000	> than	-20.20	n/a	44,000	> than	n/a	
<i>Ovibos</i>	this study	IK98-1220	9874	Ikpikpuk R.	phalange	Beta-175459	45,720	> than	-20.50	6.41	45,720	> than	n/a	
<i>Ovibos</i>	this study	IK99-142	10682	Ikpikpuk R.	cranium	Beta-175460	48,420	> than	-19.90	3.51	48,420	> than	n/a	
<i>Ovibos</i>	this study	TIT05-06.1	29516	Titaluk R.	cranium	Beta-223269	49,800	> than	-20.70	n/a	49,800	> than	n/a	
<i>Panthera</i>	this study	IK98-278	8807	Ikpikpuk R.	mandible	CAMS-53909	11,290	50	-18.60	4.89	11,290	50	13,187	
<i>Panthera</i>	this study	IK01-409	12041	Ikpikpuk R.	humerus	AA-48280 <sup>#</sup>	12,930	130	-18.40	8.03	12,930	130	15,551	
<i>Panthera</i>	Barnett, 2009	IK01-409	12041	Ikpikpuk R.	humerus	OxA-13473 <sup>#</sup>	12,630	60	-18.50	8.03	12,630	60	14,928	
<i>Panthera</i>	this study	MAY12-24	29517	Maybe Cr.	humerus	Beta-331881	15,990	60	-18.50	8.80	15,990	60	19,148	
<i>Panthera</i>	this study	TIT12-07	30204	Titaluk R.	calcaneus	Beta-339277	30,520	180	-18.70	9.20	30,520	180	34,965	
<i>Panthera</i>	this study	IK06-18	29518	Ikpikpuk R.	humerus	Beta-286419	33,260	230	-18.60	n/a	33,260	230	38,083	
<i>Panthera</i>	this study	IK97-1001	11013	Ikpikpuk R.	humerus	Beta-117142	35,710	1,180	-22.50	8.53	35,670	1,180	40,659	
<i>Panthera</i>	this study	IK98-436	8983	Ikpikpuk R.	phalanx	CAMS-53910	40,900	1,140	-18.10	8.78	40,900	1,140	44,689	
<i>Panthera</i>	this study	IK02-164	10389	Ikpikpuk R.	humerus	CAMS-91784	48,300	2,100	-19.47	10.97	48,300	2,100	48,637	
<i>Panthera</i>	this study	IK01-112	12045	Ikpikpuk R.	humerus	AA-48271	41,100	> than	-18.80	7.79	41,100	> than	n/a	
<i>Rangifer</i>	this study	IK98-0804	9426	Ikpikpuk R.	mandible	CAMS-64413	160	40	-19.19	3.80	150	40	151	
<i>Rangifer</i>	this study	IK98-0589	9283	Ikpikpuk R.	humerus	CAMS-64409	200	50	-18.26	2.14	190	50	176	
<i>Rangifer</i>	this study	IK98-0875	9496	Ikpikpuk R.	mandible	CAMS-64416	220	40	-18.66	2.91	210	40	183	
<i>Rangifer</i>	this study	IK99-421	10579	Ikpikpuk R.	humerus	CAMS-64465	350	30	-18.67	2.30	340	40	394	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Rangifer</i>	this study	IK98-0385	8784	Ikpikpuk R.	humerus	CAMS-64403	390	40	-18.15	2.74	370	40	426	
<i>Rangifer</i>	this study	IK98-0155	n/a	Ikpikpuk R.	metapodial	CAMS-64397	1,120	40	-18.11	2.49	1,100	40	1,007	
<i>Rangifer</i>	this study	IK99-314	10766	Ikpikpuk R.	mandible	CAMS-64462	1,190	30	-18.18	2.29	1,170	40	1,093	
<i>Rangifer</i>	Gal, 1982 <sup>j</sup>	XCL-010	n/a	Avingak	n.r. <sup>a</sup>	GaK-2304	<b>1,470</b>	<b>80</b>	<b>-18.7</b>	n/a	573	80	590	
<i>Rangifer</i>	Gal, 1982 <sup>j</sup>	XPB-003	n/a	Pt. Hope	n.r. <sup>a</sup>	P-98	<b>1,619</b>	<b>210</b>	<b>-18.7</b>	n/a	1,722	210	1,659	
<i>Rangifer</i>	Gal, 1982 <sup>j</sup>	XBP-007	n/a	Putuligayuk, R.	n.r. <sup>a</sup>	Uga-3719	<b>2,075</b>	<b>70</b>	<b>-18.7</b>	n/a	2,178	70	2,188	
<i>Rangifer</i>	this study	IK98-1284	10013	Ikpikpuk R.	humerus	CAMS-64453	2,140	40	-18.52	2.65	2,130	40	2,112	
<i>Rangifer</i>	this study	IK98-888	n/a	Ikpikpuk R.	n.r. PM <sup>b</sup>	CAMS-64418	2,540	50	-20.60	-0.49	2,540	50	2,611	
<i>Rangifer</i>	this study	IK98-1038	9983	Ikpikpuk R.	metatarsal	CAMS-64420	2,600	40	-17.59	2.36	2,580	50	2,704	
<i>Rangifer</i>	Gal, 1982 <sup>j</sup>	XCL-002	n/a	Tuktu-Naiyuk	n.r. <sup>a</sup>	SM-917	<b>3,042</b>	<b>188</b>	<b>-18.7</b>	n/a	3,145	188	3,353	
<i>Rangifer</i>	this study	IK98-0083	8988	Ikpikpuk R.	mandible	CAMS-64395	7,830	40	-19.11	2.42	7,820	50	8,600	
<i>Rangifer</i>	this study	IK99-397	10740	Ikpikpuk R.	humerus	CAMS-64463	8,830	40	-18.10	1.74	8,810	40	9,845	
<i>Rangifer</i>	this study	IK99-044	10571	Ikpikpuk R.	metatarsal	CAMS-64454	8,890	50	-17.81	1.36	8,870	50	10,003	
<i>Rangifer</i>	this study	IK98-0627	9601	Ikpikpuk R.	metapodial	CAMS-64410	12,370	50	-18.79	2.80	12,360	50	14,391	
<i>Rangifer</i>	this study	IK97-601	n/a	Ikpikpuk R.	n.r. PM <sup>b</sup>	Beta-117140	12,710	100	-23.30	n/a	12,680	100	14,990	
<i>Rangifer</i>	this study	IK99-594	11000	Ikpikpuk R.	metacarpal	CAMS-64470	13,250	50	-18.94	3.06	13,240	50	16,209	
<i>Rangifer</i>	this study	IK98-0585	9704	Ikpikpuk R.	metacarpal	CAMS-64408	14,380	50	-19.25	3.00	14,370	50	17,478	
<i>Rangifer</i>	this study	IK98-0879	3296	Ikpikpuk R.	metacarpal	CAMS-64417	16,950	50	-18.88	9.17	16,940	60	20,137	
<i>Rangifer</i>	this study	IK98-0846	9325	Ikpikpuk R.	humerus	CAMS-64415	17,610	60	-19.16	7.56	17,600	60	20,989	
<i>Rangifer</i>	this study	IK99-089	10654	Ikpikpuk R.	metatarsal	CAMS-64456	18,410	60	-18.88	5.90	18,400	60	21,962	
<i>Rangifer</i>	this study	IK98-0265	9186	Ikpikpuk R.	humerus	CAMS-64398	20,480	80	-18.95	7.15	20,470	80	24,422	
<i>Rangifer</i>	this study	IK98-0031	9089	Ikpikpuk R.	metacarpal	CAMS-64392	24,750	110	-19.87	8.70	24,750	110	29,572	
<i>Rangifer</i>	this study	M-98-064	9110	Meade R.	mandible	CAMS-64475	24,940	110	-19.17	6.23	24,940	110	29,826	
<i>Rangifer</i>	this study	IK97-402	n/a	Ikpikpuk R.	n.r. PM <sup>b</sup>	Beta-117139	25,190	190	-22.70	n/a	25,190	190	29,987	
<i>Rangifer</i>	this study	IK98-0690	9598	Ikpikpuk R.	humerus	CAMS-64412	27,420	190	-17.86	6.27	27,400	190	31,516	
<i>Rangifer</i>	this study	IK98-0311	8944	Ikpikpuk R.	humerus	CAMS-64400	28,760	160	-18.36	3.73	28,740	170	33,214	
<i>Rangifer</i>	this study	IK98-0833	9300	Ikpikpuk R.	humerus	CAMS-64414	28,930	170	-18.51	7.02	28,920	170	33,502	
<i>Rangifer</i>	this study	IK98-0079	8900	Ikpikpuk R.	metacarpal	CAMS-64394	30,050	210	-18.34	3.34	30,040	210	34,725	

Genus	source	FIELD ID	JAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>			$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>				14C date	1 std dev <sup>e</sup>	
<i>Rangifer</i>	this study	IK98-1207	9831	Ikpikpuk R.	mandible	CAMS-64471	30,270	200	-18.21	3.75	30,250	200	34,831	
<i>Rangifer</i>	this study	IK99-171	10994	Ikpikpuk R.	metacarpal	CAMS-64457	30,820	200	-19.00	3.92	30,810	200	35,281	
<i>Rangifer</i>	this study	IK99-570	10847	Ikpikpuk R.	cranium	CAMS-64468	31,830	330	-17.73	2.26	31,820	330	36,340	
<i>Rangifer</i>	this study	IK99-409	3281	Ikpikpuk R.	humerus	CAMS-64464	31,920	240	-18.16	3.95	31,900	240	36,462	
<i>Rangifer</i>	this study	IK98-0983	9743	Ikpikpuk R.	humerus	CAMS-64419	32,570	250	-18.64	2.59	32,550	250	37,058	
<i>Rangifer</i>	this study	IK98-0479	9270	Ikpikpuk R.	metapodial	CAMS-64406	37,570	580	-17.65	1.61	37,570	580	42,275	
<i>Rangifer</i>	this study	IK99-543	10919	Ikpikpuk R.	metacarpal	CAMS-64466	38,830	540	-18.12	3.77	38,810	540	43,129	
<i>Rangifer</i>	this study	IK99-066	10547	Ikpikpuk R.	humerus	CAMS-64455	40,840	950	-18.11	5.40	40,820	950	44,634	
<i>Rangifer</i>	this study	IK98-0350	9107	Ikpikpuk R.	metatarsal	CAMS-64401	41,100	1,100	-18.03	0.95	41,100	1,100	44,871	
<i>Rangifer</i>	this study	IK98-0450	9032	Ikpikpuk R.	metatarsal	CAMS-64404	42,040	800	-19.38	2.39	42,030	800	45,455	
<i>Rangifer</i>	this study	IK99-764	11016	Ikpikpuk R.	humerus	CAMS-64473	42,500	1,200	-18.50	1.82	42,500	1,200	46,042	
<i>Rangifer</i>	this study	IK98-0478	9269	Ikpikpuk R.	metapodial	CAMS-64405	44,200	1,000	-17.30	2.99	44,200	1,000	47,520	
<i>Rangifer</i>	this study	IK98-0041	9204	Ikpikpuk R.	metacarpal	CAMS-64393	44,300	1,100	-17.76	1.16	44,300	1,100	47,623	
<i>Rangifer</i>	this study	IK98-0687	9596	Ikpikpuk R.	metapodial	CAMS-64411	45,500	1,200	-17.22	1.88	45,460	1,210	48,436	
<i>Rangifer</i>	this study	IK98-1051	10065	Ikpikpuk R.	metatarsal	CAMS-64421	46,300	1,400	-18.72	3.85	46,300	1,400	48,837	
<i>Rangifer</i>	this study	IK98-1108	9867	Ikpikpuk R.	metapodial	CAMS-64422	46,500	1,600	-18.09	3.32	46,500	1,600	46,850	
<i>Rangifer</i>	this study	IK98-0153	9045	Ikpikpuk R.	humerus	CAMS-64396	48,300	1,700	-18.11	1.65	48,300	1,700	48,701	
<i>Rangifer</i>	this study	IK98-0351	9108	Ikpikpuk R.	metatarsal	CAMS-64402	48,000	2,600	-18.87	4.32	48,000	2,600	49,087	
<i>Rangifer</i>	this study	IK99-247	10566	Ikpikpuk R.	humerus	CAMS-64460	52,000	2,700	-18.51	4.60	52,000	2,700	53,195	
<i>Rangifer</i>	this study	IK99-199	12288	Ikpikpuk R.	metapodial	CAMS-64458	52,600	3,500	-17.61	1.75	52,600	3,500	54,935	
<i>Rangifer</i>	this study	IK99-740	10876	Ikpikpuk R.	humerus	CAMS-64472	53,300	3,800	-16.97	2.91	53,200	3,800	56,103	
<i>Rangifer</i>	this study	IK98-0310	8943	Ikpikpuk R.	humerus	CAMS-64399	46,900	> than	-19.71	5.03	46,900	> than	n/a	
<i>Rangifer</i>	this study	IK98-1227	9903	Ikpikpuk R.	humerus	CAMS-64424	47,200	> than	-18.50	1.73	47,200	> than	n/a	
<i>Rangifer</i>	this study	TIT05-09	29519	Titaluk R.	tibia	Beta-223268	49,800	> than	-18.50	n/a	49,800	> than	n/a	
<i>Rangifer</i>	this study	IK98-1228	9876	Ikpikpuk R.	humerus	CAMS-64425	49,900	> than	-18.03	4.34	49,900	> than	n/a	
<i>Rangifer</i>	this study	IK99-286	10726	Ikpikpuk R.	humerus	CAMS-64461	49,900	> than	-17.51	2.01	49,900	> than	n/a	
<i>Rangifer</i>	this study	IK98-1158	10053	Ikpikpuk R.	tibia	CAMS-64423	51,200	> than	-17.45	0.14	51,200	> than	n/a	
<i>Rangifer</i>	this study	IK99-585	10938	Ikpikpuk R.	mandible	CAMS-64469	51,700	> than	-17.17	2.28	51,700	> than	n/a	
<i>Rangifer</i>	this study	IK98-0573	9457	Ikpikpuk R.	mandible	CAMS-64407	52,800	> than	-19.71	3.10	52,800	> than	n/a	

Genus	source	FIELD ID	UAMES number <sup>c</sup>	Location	Dated Bone	<sup>14</sup> C Laboratory number	<sup>14</sup> C Age reported <sup>d</sup>		$\delta^{13}\text{C}^f$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$ -normalized age used for calibration		Median prob. (cal yr before 1950) <sup>g</sup>
							14C date	1 std dev <sup>e</sup>			14C date	1 std dev <sup>e</sup>	
<i>Rangifer</i>	this study	IK98-1230	9921	Ikpihpuk R.	metatarsal	CAMS-64426	54,000	> than	-17.84	1.52	54,000	> than	n/a
<i>Saiga</i>	Guthrie et al., 2001	n/a	n/a	Bronx Cr.	cranium	AA-3073	28,930	560	n/a	n/a	28,930	560	33,712
<i>Saiga</i>	Harington, 2003 <sup>i</sup>	USGS M1 422	n/a	Usutuk R.	cranium	GSC-3050	37,000	990	n/a	n/a	37,000	990	41,913
<i>Ursus</i>	this study	IK98-1065	10003	Ikpihpuk R.	radius	CAMS-53913	36,310	780	-18.40	n/a	36,310	780	41,399
<i>Ursus</i>	Barnes et al., 2002	PM collected	n/a	Colville R.	n.r. <sup>a</sup>	AA-17510	48,164	3,224	n/a	n/a	48,164	3,224	49,262
<i>Ursus maritimus</i>	this study	Coast09-1	29513	Arctic Ocean	cranium	Beta-283240	43,500	> than	-11.70	n/a	43,500	> than	n/a

<sup>a</sup> Dated bone type not recorded by source

<sup>b</sup> Dated bone type not recorded by Matheus

<sup>c</sup> University of Alaska Museum of the North, Earth Sciences collection accession number

<sup>d</sup> <sup>14</sup>C age from dating laboratory; bold-italicized ages not normalized for  $\delta^{13}\text{C}$

<sup>e</sup> 1 Std Dev reported as > than indicates an infinite date reported by laboratory

<sup>f</sup>  $\delta^{13}\text{C}$  values from dating laboratory except bold-italicized values that were estimated using mean of measured  $\delta^{13}\text{C}$  values for that genus

<sup>g</sup> Median probability calculated using Oxcal 4.1 and the Intcal09 calibration curve

<sup>h</sup> This sample was reported as problematic by the laboratory and is likely to be infinite in age (G. Zazula, pers. comm.)

<sup>i</sup> Harington, C.R., 2003. Annotated Bibliography of Quaternary Vertebrates of Northern North America. University of Toronto Press Inc., Toronto.

<sup>j</sup> Gal, R., 1982. An Annotated and Indexed Roster of Archaeological Radiocarbon Dates from Alaska, North of 68° Latitude. In: Archaeological Investigations in the National Petroleum Reserve in Alaska, vol. 20, pp. 159-180.

\* These laboratory numbers appear twice in Guthrie (2004) and are probably transcription errors. Because the rest of each record is distinct, we include all dates here.

# Duplicate dates were obtained and both dates are reported. The mean of both dates was used in any analyses.