Paleoindian Bison Hunting on the North American Great Plains—Two Critical Nutritional Constraints

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ABSTRACT

Post-Clovis Paleoindians living on the North American Great Plains are often thought to have been dedicated bison hunters, fulfilling most of their food needs from this one large herbivore. The archaeological record seems compatible with this view, as it is dominated by kill sites, many containing the remains of dozens to hundreds of animals. Campsites often produce remains of a broader range of animals, but these sites too are overwhelmingly dominated by bison, both in numbers of bones and in terms of meat weight. Bison are also the most obvious food source that would have been available to Plains-dwelling Paleoindians, providing an abundance of protein, fat, and hides. However, largely on the basis of nutritional grounds, this paper challenges the viability of a subsistence system based heavily on bison, or even one that relies to a similar extent on other animals. Building from the assumption that humans cannot subsist for extended periods on a diet in which protein intake exceeds ~35% of total calories, I present data to show that bison, even in peak condition, are unlikely to yield sufficient fat. The shortage of fat in bison, and in most other wild ungulates, would have been exacerbated by the fact that Plains Paleoindians made little effort to maximize the yield of skeletal fat from their kills. They often ignored major marrow bones, and apparently made little or no effort to boil grease from the bones. As a consequence, in order to maintain a viable diet, post-Clovis Paleoindians in the Plains may have had to hunt bison and/or other animals in excess of their lean meat needs, primarily for the purpose of obtaining additional fat. The number of kills they would have had to make beyond their lean meat needs depended on the size of the group that had to be fed and the condition of the animals. Unused lean meat could have been fed to dogs, or simply abandoned and left to rot. Plains Paleoindians also may have made greater use than archaeologists currently assume of oily and starchy plant foods, although to do this they may have had to leave the Plains proper, at least seasonally, to forage in adjacent areas such as the foothills of the Rockies. Finally, drawing on Binford's conception of embedded toolstone procurement, archaeologists use the location of "high-quality" flint sources to determine Paleoindian hunting ranges. I suggest here that the lithics will probably tell us little about the food-related mobility of Plains Paleoindians. In addition to bison, the seasonal availability of foods rich in fats, oils, and starches almost certainly played a far more important role than flint in determining when, where to, and how often groups moved. More likely, what the flint-based distribution maps offer us are insights into the spatial arrangement of peoples who had ties to the same ancestral landscapes and shared broadly similar belief systems. Although the focus of this paper is on Paleoindian bison hunters, many of the same nutritional arguments likely apply to Eurasian Paleolithic hunting peoples who at times also relied heavily on the naturally lean meat of wild ungulates.

INTRODUCTION

This paper is concerned with post-Clovis Paleoindian bison hunters on the North American Great Plains (Figure 1). Its primary goal is to show that a Paleoindian lifeway, whether based heavily on hunting bison, or on hunting a broader range of prey taxa, would have been subject to two critical nutritional constraints in order to remain viable—an upper limit to the amount of protein (i.e., lean meat) the hunters could safely consume on a daily basis, and the inadequate quantities of fat (i.e., non-protein calories) provided by their prey. For a Plains Paleoindian band whose livelihood was heavily dependent on the meat of wild game, when hunters made successful kills they would typically acquire more lean meat (i.e., more protein) than they could safely consume, but insufficient fat. To cope with this likely shortfall of non-protein calories, Plains Paleoindians had two options open to them. One was to preferentially target and selectively butcher the fattest animals available to them, while continuing to hunt additional animals beyond their lean meat needs with the primary goal of obtaining more fat. The other option was to procure supplementary oil-rich or carbohydrate-rich plant foods in order to maintain the needed intake of non-protein calories. These options need not have been mutually exclusive, although the spatial and temporal availability and abundance of their prey and plant resources had to be factored into their

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Figure 1. Major habitat types of North America, including the mid-continent grasslands of the Great Plains. The location of the Olsen-Chubbuck Site (OC) is denoted by a triangle. The image was modified from the file "Major habitat type CAN USA.svg" which is available online from the Wikimedia Commons at https://commons.wikimedia.org/wiki/File:Major_habitat_type_CAN_USA.svg

overall mobility system. The excess lean meat that would result from a hunting-dependent economy could have been fed to dogs, if dogs were part of the system, but much of it probably was abandoned and left to rot. What follows is an attempt to justify the various threads of this argument and to explore a few of its more interesting implications. Many of the same nutritional arguments likely apply to Eurasian Paleolithic hunting peoples who at times also relied heavily on the naturally lean meat of wild ungulates.

Bison hunting figures prominently in any depiction of how Paleoindians earned their living on the North American Great Plains. Communal kills, some containing hundreds of animals, have become iconic of the subsistence practices and lifeways of these early inhabitants of the continent's vast interior grasslands. In so far as we know, bison first became targets of Paleoindian hunters, albeit in modest numbers, in Clovis times. Our best evidence comes from sites such as Blackwater Draw (NM), Jake Bluff (OK), Lubbock Lake (TX), and Murray Springs (AZ). With major climatic and environmental changes toward the end of the Pleistocene and the disappearance of mammoths and other megafauna, bison became the principal economic focus of Paleoindian hunters on the Plains (e.g., Bement and Carter 2010: 930; Bement et al. 2012: 54). By Goshen and Folsom times, at sites such as Agate Basin (WY), Carter/Kerr-McGee (WY), Cooper (OK), Folsom (NM), Lipscomb (TX), and Mill Iron (MT), communal kills, commonly utilizing steep-sided arroyos as traps, became somewhat larger, and more numerous, than their Clovis antecedents. And by the latter stages of the Paleoindian period, during Plano or Cody Complex times, the number and scale of communal kills seemingly exploded. Numerous kill sites are known from this period, a few of the more famous among them being Agate Basin (WY), Carter/Kerr-McGee (WY), Casper (WY), Finley (WY), Horner (WY), Jones-Miller (CO), Milnesand (NM), Plainview (TX), and Scottsbluff (NE). Not only were the numbers of animals killed in these events much greater than in preceding periods, but the strategies Paleoindians used to entrap them were also much more varied, with animals being driven into arroyos (steep-sided gullies), parabolic dunes, snowdrifts, and marshy or ponded areas (see, for example, Bamforth 1988, 2011; Bement 1999; Bement and Carter 2010; Bement and Carter 2016; Carlson and Bement 2018; Fawcett 1987; Haynes and Huckell 2007; Matthew E. Hill 2002, 2007b, 2008; Hofman et al. 1991; Holliday et al. 2016; Kornfeld et al. 2010; Larson et al. 2009; Meltzer 2006; Moss 1951; Sellards 1955; Sellards et al. 1947; Speth 2017; Stanford 1978; Todd 1987; Todd et al. 1990; Todd and Rapson 1999). Though virtually invisible in the archaeological record, it is quite possible that Paleoindians, like early historic Plains groups, also took bison communally by a technique known as a "foot surround," a difficult and quite dangerous way to hunt bison, in which the hunters slowly encircled a small herd of grazing animals and killed as many of them as possible before the frightened animals broke through the human circle and fled (Kelsey 1994: 8).

Curiously, cliff jumps, the technique that most often comes to mind when one thinks about communal bison hunting on the Plains, did not come into common use until fairly late in the Archaic and especially during the subsequent Late Prehistoric period (Kornfeld et al. 2010; Speth 2017; see also Byerly et al. 2005). Massive cliff jumps, together with intensive marrow and bone-grease production, reflect something akin to the "industrialization" of communal bison hunting, with an unknown but substantial amount of their prodigious yield in meat, fat, and hides probably destined for trade with contemporary farming communities that sprang up along many of the region's major river systems (Bamforth 2011; Bethke et al. 2018; Cooper 2008; Zedeño et al. 2014). Thus, communal bison hunting during Late Prehistoric times, especially in the Northern Plains, was quite different, both quantitatively and qualitatively, from what came before. Yet, reinforced by the rich ethnographic and ethnohistoric record documenting the central role of bison in protohistoric and historic Plains lifeways (Arthur 1975; Bamforth 1988; Brink 2008; Verbicky-Todd 1984; Wheat 1972), many in the profession remain committed to the view, some explicitly, many implicitly, that post-Clovis Paleoindian economies in the mid-continent grasslands were heavily, if not overwhelmingly, committed to, and dependent upon, the communal hunting of bison (e.g., Bamforth 2007: 2–3; Carlson and Bement 2013: 83; Jennings 2012: 8; Knell and Hill 2012: 50-51; LaBelle 2012: 146-147; Waguespack 2012: 93; Widga 2013: 73–75).

Remains of ungulates other than bison, particularly deer and antelope, as well as the bones of medium- and small-sized mammals, birds, reptiles, and amphibians, do occur at a number of post-Clovis Paleoindian Plains sites (e.g., Allen, Lime Creek, Wilson-Leonard), most notably at campsites, (Bamforth 2007: 3–4; Collins 1998; Hudson 2007; Jones 1999; Kornfeld 2007; LaBelle 2005). However, despite the presence of these other animals, much of the scholarly focus remains squarely on bison and bison kills. This is not particularly surprising. When the zooarchaeologist translates the recovered animal remains into the likely contribution of each taxon to the overall diet expressed in terms of meat weights, bison generally overshadows everything else, often by a huge margin. And as Bamforth (2007: 4) notes, bias on the part of the archaeologist often enters into the picture as well: "The overwhelming emphasis on bison in well-studied post-Clovis Paleoindian sites probably results as much, and perhaps more, from the choices archaeologists make about where to dig as it does about the choices Paleoindians made about what to eat." But the predominance of bison is very real, nonetheless, as shown for example by the work of Knell and Hill (2012: 50–51, and their Table 7). In their synthesis of the faunal assemblages from 33 Northern Plains Cody Complex components (campsites and kills combined), out of the 20 taxa represented bison and bison-sized bones made up 99% of the total sample of 72,474 identified specimens (NISP). Looking only at the assemblages from campsites, bison still comprised 91% of the total NISP.

There has been considerable, often quite contentious, debate in recent years about whether or not Paleoindians were big-game-hunting "specialists" (Cannon and Meltzer 2004, 2008; DeAngelis and Lyman 2018; Lyman 2013; Surovell and Waguespack 2009). Much of this debate has been focused on Clovis and the role these early Paleoindians may have played in the extinction of proboscideans and other Late Pleistocene megafauna. This is not a debate I wish to become embroiled in here. Suffice it to say that the data provided by Knell and Hill (2012: 50–51) and many others clearly show that post-Clovis Paleoindian hunters on the Plains devoted a substantial part of their hunting effort to the procurement of bison. For our purposes, it matters little whether or not one calls this pattern of hunting a form of "specialization." What does matter here are the nutritional constraints that such heavy reliance on meat, whether from bison or from other wild animals, imposes on Paleoindian lifeways.

When it comes to plant remains in post-Clovis Paleoindian sites on the Plains, with a very few notable exceptions (e.g., Wilson-Leonard; Collins 1998), there are hardly any to speak of aside from charcoal and occasional hearths and patches or lenses of ash. One has to look to the Paleoindian record in regions surrounding the Plains (e.g., LaBelle 2005: 205), or farther afield in the Great Basin and in Eastern North America to find a reasonably informative paleoethnobotanical record (Dent 2007; Gingerich 2011; Hollenbach 2007). It is no secret that plant foods generally do not preserve well. And even if flotation together with phytolith and starch grain analyses were to reveal the presence of seeds or other potentially edible vegetal matter, how does one move from such limited hit-or-miss kinds of evidence to quantitative statements about the actual contribution of plant foods to Paleoindian diet, expressed as kcal or grams per person per unit time? Without that sort of concrete nutritional information, ethnobotanical data, while unquestionably valuable and interesting, remain largely anecdotal. The net result is that they are generally ignored altogether in reconstructions of Plains Paleoindian subsistence systems, aside from the occasional *pro forma* lip service.

There is another factor, one less often made explicit, that very likely colors our perception of the role of bison in Plains subsistence economies. When one drives across the heart of the Plains today, it seems almost a given that there would not have been much out there other than bison for a forager to eat. Sure, during Paleoindian times the riparian zones along the major river valleys and the widely scattered upland areas might have been likely places to find a greater variety of edible plants than out in the open expanses of grassland, but such landscapes are a minority in the vastness of the Plains and could hardly have provided highly mobile bands with more than a fraction of their requisite annual fare. One would have to leave the Plains to find more suitable habitats, such as in the foothills of the Rockies or along the margins of the Southern Plains, and perhaps that is precisely what at least some Plains hunting peoples did on a fairly regular, even seasonal, basis (see, for example, Andrews et al. 2008: 486; Bever and Meltzer 2007: 79; Kornfeld 2007; and LaBelle 2005: 205). Intuitively, then, in the heart of the mid-continent grasslands bison would seem to be the resource of choice, the only one available in sufficient numbers to be capable of supporting Paleoindian groups year-round on the Plains. Equally important, meat is widely seen as a uniquely "high-quality" resource. Thus, the view that Plains Paleoindians were dedicated bison hunters has seemed "intuitively obvious" to archaeologists for decades, a view bolstered by the archaeological evidence itself, and by the testimony of the rich ethnohistoric and ethnographic literature. Despite a handful of dissenters, that view still remains commonplace in the Paleoindian literature of the last decade (e.g., Carlson and Bement 2013: 83; Jennings 2012: 8; Knell and Hill 2012: 50–51; LaBelle 2012: 146–147; Waguespack 2012: 93; Widga 2013: 73–75).

The facts seem undeniable—bison are big; they likely numbered in the millions; they were a walking larder of high-quality protein, as well as a source of valuable fat and hides; and, if you knew how to manipulate them, as Native Americans clearly did, they could be killed on a regular basis in numbers large enough to sustain a group, not only through the milder parts of the year, but over the long cold months as well. This view is at the heart of George Frison's classic "overwintering" model, the idea that Paleoindians focused a lot of their hunting effort on procuring cows during the fall and early winter, a strategy that allowed the hunters to build up a surplus of meat, fat, and hides to tide them over the long harsh months that lay ahead (Frison 1978). Bison, taken both singly and in massive communal drives, provided just about everything a band of Paleoindians needed—food; hides for clothing, shelter, and vital equipment; and, an ideal resource upon which to base periodic social gatherings.

PROBLEMS WITH THE CONVENTIONAL PICTURE

So, what makes me think there might be something amiss with this picture of the bison-dependent Paleoindian on the Plains? For one thing, both scholarly and popular descriptions often give one the impression that communal kills not only took place every year but, more importantly, that they generally succeeded in producing the surpluses the hunters needed to make it through the winter (for interesting exceptions, see Kornfeld et al. 2010: 287–288; Reher and Frison 1980). I am sure that most archaeologists, if asked, would agree that failure must have occurred, but almost no one has made a concerted effort to model either the likelihood of such failure or its real-life consequences. Admittedly, this would not be an easy task, but it could be done by combining ethnohistoric research with information from fields such as wildlife biology, paleoenvironmental studies, and computer modeling. The ethnohistoric record frequently mentions cases of unsuccessful communal hunts (e.g., Cocking 1908: 109–111, 113, 116), but it will be difficult from such evidence to ferret out the impact on these hunting ventures of extrinsic factors and forces such as the displacement and decimation of Native populations as a result of European diseases and colonial expansion, and their involvement in the competitive milieu created by the fur trade and Capitalist economies more generally. Unfortunately, because of these and other difficulties, most archaeologists simply ignore the issue—in other words, the Paleoindian literature remains virtually silent on the topic of failure. We have no idea what Plains Paleoindians did, or where they went, when things went wrong. However, by not attempting to model failure in any sort of systematic or rigorous fashion, one ends up, by default, with the (perhaps unintended) impression that communal bison hunting was just about as predictable and productive as going to the neighborhood supermarket, getting a big shopping cart, wheeling it over to the meat counter, and loading up with the winter's supply of steaks and roasts.

There were many reasons why a communal drive might not produce the needed return or might fail altogether. An inadequate yield meant not only getting too few animals into a trap, but also getting too few of the right sex and body condition (i.e., fat levels). Bison kills also failed for many reasons—the herds did not materialize in the right place at the right time; the animals did arrive as expected, but were subsequently spooked for one reason or another, often as they were being "moved" from the "catchment" or grazing area toward the trap; the prevailing winds blew from the wrong direction, sometimes for days on end, making it impossible for the hunters to approach the animals undetected; the herds may have been driven out of the area by wolves, wild fires ignited by lightning, intolerable insect infestations, deep snow, hail storms, impenetrable ice blocking access to underlying forage, or even by a competing hunting band that got to the area first. Failure could be costly, forcing the band to relocate, sometimes to distant hunting grounds. Or, instead, the band may have had to overwinter on a far more meager supply of food. The bottom line, while communal kills could be highly productive when successful, they were far from a sure thing.

There is another reason why a Paleoindian lifestyle heavily based on bison hunting, whether just for the cold months of winter and spring, or for the entire year, would have been anything but straightforward. Making such an adaptation nutritionally viable involved more than just success at killing animals. Even when communal drives went off as planned, Plains bison simply would not have produced enough fat for the hunters to have been able to make full use of the lean meat these kills would have generated. Inuit (Eskimos) could live for months on end on a diet that for all practical purposes was 100% meat (i.e., animal protein and fat), but Paleoindian bison hunters could not. To avoid the syndrome known as "rabbit starvation," the negative and potentially lethal consequences of a diet in which protein exceeded about 35% of total calories, Inuit, northern Athabaskans, Siberian hunter-gatherers, and others living in northern environments consumed prodigious amounts of fat—typically from 65% to 70% or even 75% of their daily caloric intake (Cordain et al. 2000; Draper 1977: 311, his Table 1; Speth 2010). They had blubber, fat, and oil galore from whales, walruses, seals, salmon and salmon roe, beaver tails, and waterfowl; Paleoindians did not, especially if their focus was squarely on bison. Bison in the best of condition are pretty lean animals, strikingly so when stacked up against a seal or walrus (Marchello et al. 1989; Meagher 1986: 4; Speth and Spielmann 1983).

Both coastal Inuit and subarctic groups living in the interior of Alaska and Canada, as well as in Siberia, also invested many hours of quite strenuous labor to thoroughly break up and boil the grease from caribou (reindeer), moose, muskox, and sheep bones. Many Plains groups also routinely rendered grease from bison bones (Bethke et al. 2018; Binford 1978; Brink and Dawe 2003; Chapdelaine 2012; Gramly 1982, 2010; O'Shea et al. 2013; Pasda 2013; Pelletier and Robinson 2005; Saint-Germain 1997: 155). Curiously, however, when it comes to Paleoindians in the Great Plains, there is virtually no evidence of boiling technology (e.g., LaBelle 2005: 212). Subsurface features that might have served as boiling pits are noteworthy for their scarcity in Plains Paleoindian sites. Perhaps more telling is the fact that heated stones (a.k.a. fire-cracked rock), whether the result of stone-boiling or pit-baking, are virtually absent in the Paleoindian record—not just on the Plains, but across the entire continent—and they do not make their appearance in any appreciable quantity until the transitional stage marking the very end of the Paleoindian period and the beginning of the Archaic (Bousman and Oksanen 2012: 216; Chatters et al. 2012: 41; Ferring 2001: 124; Gramly 2008: not paginated; Matthew E. Hill 2007a: 299; Jodry and Stanford 1992: 154; Kornfeld 2007: 42; Miller and Kenmotsu 2004: 221; Thoms 2008: 121).

While hundreds of ethnohistorical accounts from the 19th century allude to the production of bone grease, and a number of studies have observed or replicated the process experimentally (e.g., Binford 1978; Church and Lyman 2003; Janzen et al. 2014; Leechman 1951; Lupo and Schmitt 1997; Vehik 1977), there is very little solid quantitative information about the amount of time that had to be invested to break up the bones, or the actual yield, by weight or calories, of such labor. That the labor may have been substantial is suggested by the interesting exchange between Church and Lyman (2003) and Janzen et al. (2014). The former showed experimentally that breaking up bones beyond a certain size threshold into progressively smaller fragment sizes (i.e., 4cm, 2cm, 1cm) did not significantly increase the total yield of grease produced by boiling. The experiments conducted by the latter authors concurred with Church and Lyman's basic findings, but they also observed that less fuel was needed to extract grease from the smaller fragment sizes. Since fuel may well have been in short supply in many areas of the Plains, one might surmise that Paleoindians in such environments would have invested whatever labor was needed to break up the bones into sizes small enough to minimize, or at least reduce, their use of fuel.

That grease-rendering would have been a laborious process is also suggested by a set of experiments carried out by Claire Saint-Germain (1997, 2005). Working with the femurs and tibias of four moose and two caribou, it took her 20 hours to clean, break into fragments, boil, and recover the resulting grease from these bones, netting a total of 160g or about 1,440kcal of fat. She emphasized her inexperience at replicating the process and suggested that someone who had done this activity their entire life would have been far more efficient. Data provided by both Abe (2005: 138–139) and Lupo and Schmitt (1997: 139, Table 1) underscore Saint-Germain's concerns about experience. Abe's Evenki informants were able to break up broadly comparable quantities of bones much more quickly. Lupo and Schmitt's processing times were also much faster. Ideally, one would also like to know how much fuel would have been expended under field rather than laboratory conditions, and the time foragers would have needed to gather the wood or dung (Henry et al. 2018; Hornaday 1889: 451; Miller and Smart 1984). Given these and other uncertainties, it would be unwise to draw any firm conclusions from Saint-Germain's study, but the results do suggest that a forager, by processing not just the limb bones, but all of the grease-producing elements in a carcass, would have been able to generate a valuable supplement to his or her lean meat diet, but one that Plains Paleoindians seem to have largely if not entirely forgone.

Equally striking is the fact that many post-Clovis Paleoindian kill sites yield surprising numbers of bison that were only partially utilized, not just in terms of meat removal, but right down to the processing of the most valuable marrow bones (Bement 1997; Bement et al. 2012; Matthew G. Hill 2001: 247; Todd 1987; Wheat 1972; but see Byers 2002 for a case where marrow does seem to have been heavily exploited). Interestingly, similar underutilization of proboscidean carcasses may have been the norm in Clovis times as well (Haynes and Hutson 2014: 302–303). Matthew G. Hill (2001: 247) sums it up very succinctly: "To date, an assembly of these [grease-rendering] features has not been excavated at a Paleoindian site and greasing is reasonably inferred to *not* have played a role in the organization of their subsistence…" [emphasis added]. Many of these precious lipid reservoirs were simply left behind, unprocessed, at the kill. This sort of evidence, evincing what would seem to be a casual or haphazard approach to important sources of fat, is a radical departure from what we know about arctic and subarctic peoples, whose traditional diets came closest to 100% dependence on meat (and fish). This evidence alone is already enough, in my opinion, to indicate that post-Clovis Paleoindian subsistence systems in the Great Plains were more complex than archaeologists commonly assume, and that we may well be underestimating, perhaps by a considerable margin, the importance of plant foods in their annual diet.

An especially curious facet of the ethnohistoric record of Native Americans on the Great Plains (and elsewhere) is the apparent frequency with which they used bison brains to soften hides, often after first allowing them to thoroughly rot, instead of eating them (e.g., Peale 1872). Brains are certainly edible (Abramson 2007), and they provide a rich source of lipids (e.g., DHA and AA, or Docosahexaenoic acid and Arachidonic acid; see Cordain et al. 2002). The average bison brain (N=6; 4 subadult males and 2 adult females) weighs about 458g, a value broadly similar to the average weight of the brains (~480g) in a much larger sample (N=150) of domestic cows (Ballarin et al. 2016: 3; Meagher 1986: 4). Using "beef brain" as an analog for bison, the fat content is about 10.3% by weight (data for composition of beef brain, extracted from *Axxya Systems Nutritionist Pro*™, and provided to me by Loren Cordain, November 26, 2019). Assuming that full-grown adult male bison brains would be somewhat heavier than the value provided by Meagher, I will use the average cow value of 480g to estimate the fat yield of a bison brain—about 49g or 445kcal, clearly a significant amount of non-protein calories. The amount of DHA is also substantial (0.85% by weight). To put this figure in perspective, the DHA content of human milk ranges from 0.01% to 0.56% by weight (Jensen et al. 1992: 427, their Table 5).

So, why does the Plains ethnohistoric record seem to suggest that historically documented foragers in the grasslands often were more inclined to bypass the dietary potential of brains in favor of their hideworking benefits? I should note that this is my impression from the literature, not a hard-and-fast conclusion drawn from a rigorously selected sample. I do not know the answer to this (but for a possible explanation, see Speth 2018: 226), nor do I know how widely this pattern may have held in Paleoindian times. Nevertheless, there are a number of archaeological cases from the Plains that point to the underuse of brains, a behavior that, if further substantiated, would fit well with the incomplete marrow and grease processing that seems to have been common, if not prevalent, in Paleoindian times (e.g., Frison 1974: 48; Meltzer 2006: 240; Wheat 1967: 51). If Paleoindian peoples often did in fact ignore the brains of their prey, or instead used many of those they did take primarily for hideworking rather than as a source of non-protein calories, it would raise yet another issue concerning the nutritional viability of a life based largely on bison (or equally dependent on the meat of other animals).

One could, of course, argue that the underutilization of marrow seen in many Paleoindian sites simply reflects the poor or stressed condition of the animals that were taken in those particular kills (see discussion in Speth 1983). Such an explanation is definitely within the realm of possibility, though its widespread and frequent occurrence is not what one would expect. More troubling is the near-universal absence of grease-rendering at Paleoindian sites, although I have been unable to find any literature that explicitly discusses how these lipids respond when an animal is stressed, so it is possible that they end up being mobilized much like the marrow fat (Loren Cordain, personal communication, February 2020). Also troubling is the apparent underutilization of the lipids in the brains of the kills, since those fats are not mobilized, not even under very stressful conditions (Dulloo and Jacquet 1999: 346). So, the fact that heavily meat-dependent hunting peoples on the Plains underutilized or even ignored these valuable sources of fat is curious, to say the least.

In short, Paleoindians had nowhere near the fat resources that Inuit had. Without such resources, could bison-dependent hunters on the Plains have acquired enough fat from their kills to avoid the deleterious consequences of excess protein intake or "rabbit starvation"? As I will attempt to show in what follows, I seriously doubt they could, at least not year in and year out on any reliable basis. Perhaps, as already suggested, Paleoindian diet was not as heavily bison- or meat-focused as archaeologists have commonly assumed. In fact, many are beginning to question the traditional "bison-hunting-specialist" view of post-Clovis Plains Paleoindian lifeways in favor of a more "generalist" perspective (e.g., Bamforth 2007: 4; DeAngelis and Lyman 2018; Cannon and Meltzer 2004, 2008; Matthew E. Hill 2007b; Knell and Hill 2012: 50–51; Knell and Muñiz 2013: 16–17; Kornfeld 2007: 56; LaBelle 2012: 151–152). Up till now, much of this debate has centered on the extent to which Clovis peoples focused their hunting efforts primarily on proboscideans and other megafauna. But archaeologists are also beginning to recognize that a fair number of later Paleoindian sites, especially campsites, also contain more than just bison, sometimes far more. In this more generalist view, post-Clovis Plains Paleoindians are thought to have had a more eclectic diet, one which included an array of animal taxa, from ungulates like deer and antelope, to smaller animals such as beaver, rabbits, a variety of terrestrial and aquatic birds, and turtles and tortoises.

Interesting as this shift in view might be, it does not necessarily get us out of the nutritional quagmire. "Rabbit starvation" means too much animal protein in one's diet. It does not really matter whether the protein comes from bison or from bunnies, the problem is still the same. Treating Paleoindians as generalists simply shifts the perspective from bison-focused to meat-focused. Unless the newly envisioned diet was made up largely of fatty fish like salmon (esp. those caught downstream before they burned up their fat reserves in the spawning run), catfish, beaver (especially their tails; see Hudson 2007: 215 and Jones 1999 regarding the beaver remains at Lime Creek in Nebraska), or geese and other fat-rich waterfowl, we still are unlikely to be talking about a nutritionally viable diet over the long haul (Aleksiuk 1970; Aleksiuk and Cowan 1969: 480; Belinsky 1998; Mainguy and Thomas 1985; Schoolcraft 1821: 67; Soprovich 1994).

Despite periodic failures, Plains Paleoindians were probably reasonably successful at killing enough bison to supply themselves with adequate amounts of lean meat (i.e., protein); but, as I will show below in more concrete terms, they would almost invariably have fallen short of the amount of fat they needed to maintain an appropriate ratio of protein-to-non-protein calories (as a rule of thumb, roughly 35%:65%). To obtain enough fat, they would have had to kill many more bison than their protein needs would demand, and simply discard the excess lean meat (or use it to feed their dogs). One might argue that is precisely what Paleoindians did, given all the unbutchered and partially butchered animals encountered in many Paleoindian sites (Bement 1997; Bement et al. 2012; Matthew G. Hill 2001: 247; Todd 1987; Wheat 1972). However, if the hunters' livelihood depended on killing excess numbers of animals *on a regular and predictable basis* in order to get enough fat, their risk of failure would have increased, perhaps significantly so. As already noted, communal bison kills, productive as they might have been, were prone to failure. Moreover, the total amount of fat on male and female animals was neither abundant nor was it entirely predictable (see Speth 1983, 2010). Fat levels varied in response to a host of intrinsic and extrinsic factors, among them time of year, quality and abundance of forage, weather conditions, predator pressure, the sex and reproductive state of the animals, their age and health, and so forth.

Given these and other sources of uncertainty and risk, it is very likely that a Paleoindian lifeway heavily dependent on bison also, of necessity, involved substantial reliance upon sources of *non-protein* calories above and beyond those provided by bison fat, particularly the carbohydrates and oils from plants (Bement 1999: 6; Kornfeld 2007: 56; Kornfeld et al. 2010: 287–288). In light of the highly perishable nature of most plant remains, the problem of course will be to develop productive and reliable ways to quantitatively test this assertion. But that can only begin when Paleoindianists explicitly recognize that a sustained bison-focused lifestyle, or even a more generalist but still meat-focused lifestyle, would have been very difficult and costly to maintain, and may not, in fact, have been nutritionally viable.

EXCESSIVE PROTEIN INTAKE AND "RABBIT STARVATION"

Let us look more directly now at whether a Paleoindian economy based heavily on bison is likely to have been nutritionally viable. To do this I will first briefly review the nutritional problems posed by a sustained diet that is comprised almost entirely of meat from wild ungulates, and then use these insights to evaluate the evidence presented by the archaeological record itself and as projected from the fat levels in living bison.

Vihljalmur Stefansson (1945: 234), an arctic explorer and ethnologist, wrote extensively on the deleterious and potentially lethal effects of a diet that contained excessive levels of protein. Commonly referred to as "rabbit starvation," the consequences of consuming too much protein were widely known in the 18th and 19th century (e.g., Henry 1812: 48; Lawrie 1948: not paginated, p. 43 in document; Marcy 1863: 16; Speth 2010, and references therein), and that knowledge persisted into the first third or so of the 20th century. However, if one were to judge by much of the nutritional and medical literature from the 1940s onward into the 1970s and 1980s, one would have to conclude that medical and nutritional experts could not imagine a situation in which protein intakes above the recommended daily allowance could ever pose a health risk. Any excess would simply have been converted into body fat. In fact, most experts were convinced that there was far too little protein in human diets the world over and began devising all sorts of clever schemes to increase the global supply. The politics of the "Cold War" played no small part in these schemes (McLaren 1974: 95; Newman 1995: 239; United Nations 1968). It is perhaps not surprising, then, that when I approached nutritionists as recently as 1980 with ethnohistoric accounts of "rabbit starvation," they simply dismissed them as anecdotal, ill-informed, or just plain "nonsense." Protein scarcity even entered the anthropological literature in a big way, with Marvin Harris (1979: 32) unquestionably as its most prolific and ardent champion (see also Gross 1975).

A sea-change in views about protein began in the late 1970s and 1980s, when nutritionists started to look more closely at human protein requirements. Cannon (2005: 704) nicely summed up the situation this way: "Also demoralising to the profession was the 'great protein fiasco': the massive recalculation of human protein requirements in the 1970s which 'at the stroke of a pen' closed the 'protein gap' and destroyed the theory of pandemic 'protein malnutrition'." From that point onward, a steadily increasing number of nutritionists, medical professionals, social workers, historians, and others began to recognize that too much protein, not just too little, could pose serious health risks. David Rush's (1989; see also Rush et al. 1980) studies of the negative impact of high-protein supplements on the birth outcomes of pregnant inner-city women are particularly enlightening in this regard. In the process, this shift in perspective restored the credibility of the countless 18th- and 19th-century accounts that told of the severe hardships Native Americans, explorers, fur-trappers, missionaries, and others had to endure when they were reduced to daily rations of lean meat that contained too little fat.

Not surprisingly, 18th- and 19th-century Native Americans, explorers, and fur-trappers also knew precisely what the ratio of protein to fat had to be in order to avoid "rabbit starvation." True, they did not express things in terms of protein, amino acids, urea synthesis, ammonia toxicity, or calories, but they knew exactly how much lean meat and fat they had to eat each day in order to remain vigorous and healthy. Nothing illustrates this knowledge better than the numerous surprisingly explicit "recipes" for how to make pemmican (pemican, pimmican, or pimican in older spellings), a mixture of pounded dried lean meat ("beat meat") and rendered fat (Allen 1877: 567–568; Back 1836: 501–502; Baldwin 1896: 10; Colpitts 2015; Cowie 1913: 415; Dawson 1859: not paginated, p. 11 in document; Dennett 1835: 420; Dunn 1844: 75; Farnham 1843: 60; Godman 1836: 134; Hall 1865: 347; Hanson 1938: 138–139; Hargrave 1871: 168–169; Hind 1860: 312; Hooper 1853: 393; Keating 1824: 428–429; King 1836: 154; Lewis 1809: 147–148; Mair 1891: 104; Mc-

Clintock 1859: 9; M'Gillivray 1929: 45; Parry 1824: 415; Richardson 1829: 245; Robinson 1879: 163; Simpson 1843: 404; Snelling 1831: 370–371; Speth 2010: 52–59; Stefansson 1960: 212; Tyrrell 1916: 434–435). I have cited quite a few examples here to show that the appropriate ratio of fat to protein was absolutely common knowledge to anyone venturing into the "bush," whether that happened to be in arctic Alaska, Siberia, or in the central desert of Australia (Leichhardt 1847: 168-169; Stefansson 1960: 212). It was equally common knowledge what would happen to someone if he or she strayed too far afield from the right mixture. Until Stefansson popularized the term "rabbit starvation," it was not the standard descriptor of a diet comprised of too much lean meat (or too little fat), but many of these early explorers and adventurers provided vivid details of their sufferings when reduced to eating little else than the naturally lean meat of wild game or the fat-depleted carcasses of their starving horses, camels, or other pack animals.

Sadly, that knowledge vanished more or less hand-in-hand with the disappearance of the buffalo, the end of the fur trade, and the expansion of the railroads at the close of the 19th century. During the following decades, world hunger and poverty came to be seen as closely tied to shortages of protein, and efforts were begun on a global scale to supplement the world's food supply with high-protein foods, often in the form of soy products and skim milk. In many instances, the heath outcomes of such elevated protein intakes were diametrically opposite to what nutritionists, policy makers, and politicians anticipated, at times devastatingly so. Unfortunately, few during this period actually bothered to look at what was happening (McLaren 1974: 95; Newman 1995: 239; United Nations 1968). The deleterious consequences of consuming excessive amounts of protein were not "rediscovered" by nutritionists and health practitioners until the mid-1970s and 1980s. But hand-in-hand with this "rediscovery" came room for confusion as well, confusion that many archaeologists seem not to have fully come to grips with as yet. Nutritionally, the naturally lean meat of most wild ungulates presents us with a kind of "double edged sword," clearly healthy to today's overfed Westerner whose access to saturated fats and highly processed starch is virtually unlimited, but potentially problematic, at times dangerous, even lethal, for traditional and prehistoric foragers whose livelihood, like that of Paleoindian bison hunters on the Plains, was heavily dependent on the naturally lean meat of wild ungulates (see, for example, the data and references in Speth and Spielmann 1983: 10–11, Table 2; see also Cordain et al. 2002: 188–189).

From the early descriptions of how to make pemmican, one can easily calculate the percentage of total calories contributed by protein. To do this, we have to assume that the thoroughly dried or jerked and pulverized "lean" meat described in the accounts can be roughly equated with protein, and which therefore would have contributed about 4kcal per gram to the final product (Food Standards Agency 2002: 9). The rendered fat that was mixed together with the lean would have contributed another 9kcal per gram. The traditional recipes specify mixtures that range from about one-third fat/two-thirds lean to roughly equal proportions of the two. The latter, however, is by far the most common mixture advocated in the 18th- and 19th-century accounts (i.e., in over 80% of the examples cited above). As Stefansson (1960: 212) put it: "It was a standard calculation of the fur trade that one pound of jerky had the food value of six pounds of lean meat, and they knew from experience that in order to remain healthy and strong indefinitely they needed a pound of suet to go with each six pounds of fresh lean, meaning they would have to have a pound of suet for each pound of jerky." I should point out that these were rule-of-thumb recipes; the actual product often deviated somewhat from the stated ideal. Moreover, a number of the expeditions described in these citations had provisions with them other than pemmican, often including hardtack, sugar, rice, flour, potatoes, and other sources of non-protein calories. With these supplemental "luxuries," they could afford to consume smaller daily amounts of pemmican, and blends that contained somewhat higher proportions of lean meat (i.e., protein).

So, what actually is "rabbit starvation"? The amino acids from ingested proteins are catabolized (deaminized) in the liver, and the nitrogenous wastes that result from this process are converted to urea and largely excreted in the urine (Morris, Jr. 1992, 2002; Powers-Lee and Meister 1988; Saheki et al. 1977, 1980). Donna Dimski (1994) provides a concise description of how the urea cycle works; she also outlines the major differences between obligate carnivores, such as cats, and non-carnivorous mammals, such as rats, domestic dogs, and humans, in the way they synthesize urea (see also James G. Morris 2002; Nuzum and Snodgrass 1971; Schimke 1962). According to Rudman et al. (1973; see also Cordain et al. 2000; Jackson 1999; Mann 2000; Bilsborough and Mann 2006), the ability of the liver to upregulate one or more of the five key enzymes involved in the synthesis of urea (*carbamyl phosphate synthetase-I*, *ornithine transcarbamylase*, *argininosuccinate synthetase*, *argininosuccinate lyase*, *arginase*) is rate limited, such that at protein intakes above this limit the liver can no longer effectively deaminize the amino acids, leading to a build-up of ammonia (*hyperammonemia*) and excess amino acids (*hyperaminoacidemia*) in the blood (Dimski 1994; Husson et al. 2003; Morris, Jr. 1992, 2002; Powers-Lee and Meister 1988; Ratner 1977; Ratner and Petrack 1951). Presumably these are the conditions, exacerbated by low carbohydrate intake, ketosis, and concomitant impairment of kidney function (Denke 2001), that Stefansson (1945: 234) and others (e.g., Hunter 1907: 66) recognized as "protein poisoning" or "rabbit starvation." The mean maximum rate of urea synthesis (MRUS) observed in experiments conducted by Rudman et al. (1973) is about 65mg of nitrogen (N) per hour per kg body weight (commonly written as 65mg N h−1 kg−1 ($BW^{0.75}$)), where BW is the metabolic body weight or $BW^{0.75}$; range 55–76mg N h−1 kg−1 ($BW^{0.75}$). These rates can be used to estimate the approximate upper limit to the amount of protein that an individual can safely consume on a daily (i.e., 24-h) basis.

Before proceeding, however, we need to determine what value we should use as an estimate of the average body weight of our Paleoindian hunters. Most modern hunter-gatherers are fairly small, with adult female and male weights falling between about 40kg and 60kg (Jenike 2001: 223, 226; Walker et al. 2006: 300). In noteworthy contrast, 19th-century equestrian Native Americans on the Great Plains were unusually tall (Cordain 2016; Prince and Steckel 2003: 372; Steckel and Prince 2001), especially in comparison to Euroamericans during the same period of time. Plains females averaged about 159cm (63in or 5′3″), while males averaged about 172cm (68in or 5′8″). In offering these stature estimates, I in no way mean to imply any sort of direct connection between these 19th-century bison hunters and their Paleoindian predecessors. Interestingly, however, the Arch Lake (NM) skeleton, an adult female whose remains probably date to some point within the late Paleoindian or Plano period, is estimated to have been 166.5cm (5′5.5 in) tall, which "places her approximately equal to modern American whites" (Owsley et al. 2010: 52). Nitrogen stable isotope data indicate that her diet may have been rich in meat, very likely bison (Owsley et al. 2010: 28–29,78). This result dovetails well with Prince and Steckel's (2003: 375–376) suggestion that the tall stature of historic Plains hunters was in large measure a reflection of their protein-rich diet of bison meat. Thus, to be conservative in my estimates, I will assume that Paleoindian bison hunters, also largely because of their meat diet, were generally quite tall, and select a weight figure that is commensurate with fairly large individuals. This choice, of course, will raise the estimated value for the safe upper limit to total protein intake, but for the arguments that follow I feel it is better to work with a value that overshoots the mark rather than one that is too low.

While there is a surprising wealth of stature data for 19th-century Native Americans living on the Great Plains, thanks largely to the efforts of anthropologist Franz Boaz (Steckel and Prince 2001), measures of body weight from the same period are noteworthy for their scarcity. One small dataset is available, however, collected in 1906–1907 by James R. Walker among the Oglala Sioux on the Pine Ridge Reservation in South Dakota (Prince 1995: 398). Prince groups Walker's weight values according to decade of birth (1830–1880). Given the traumatic and detrimental impact of reservation life on the participants in Walker's study, these data are far from ideal. Nevertheless, they clearly show that the Sioux were tall (males averaged about 172cm or 5′8″), closely paralleling Boas's observations. One would expect, therefore, that Sioux body weights to also be elevated, commensurate with their stature. And this is precisely what Walker's data show. The average weight of adult females is 69.7kg (154lb) and 73.9kg (163lb) for adult males. The value for women seems rather high when compared to the corresponding male figure, very likely a consequence of reservation life. Nevertheless, the average weight for males, approximately 70kg (154lb), offers a reasonable value to use as an estimate for the *maximum* weight of tall Paleoindian peoples on the Plains. Interestingly, Willett et al. (1999: 428), in a paper in the *New England Journal of Medicine*, suggest that Euroamerican men with a height similar to that of the Sioux (i.e., 172cm or 5′8″) should weigh less than about 164lb (74kg). Given that our Paleoindian bison hunters included, not just men, but women and children as well, an average body weight of 70kg (154lb) gives us a conservative *maximum* value for estimating the safe upper limit to total protein intake.

Now, assuming that protein averages about 16% nitrogen, a widely used value to estimate total or "crude" protein (see, for example, Conklin-Brittain et al. 1999), a 70kg (154lb) adult can consume approximately 236g of protein per day (range 200–276 g; see Speth 2010: 78). If we further assume that an average active adult requires about 2,500kcal per day (see Jenike 2001: 212), and that each gram of protein provides roughly 4kcal, the average upper limit (and range) to daily protein intake for our hypothetical 70kg Paleoindian individual would fall around 38% (range 32%–44%) of total calories (Speth 2010: 78; see also Cordain et al. 2000; Mann 2000; Bilsborough and Mann 2006). If our Paleoindian people were somewhat smaller and lighter weight, the safe upper limit to total daily protein intake would, of course, be lower.

Though estimates vary, nutritionists nowadays typically set the limit at about 35% (Cordain et al. 2000). It should not come as a surprise that this value falls remarkably close to the ideal mixture of rendered fat and dried lean meat in the pemmican described in 18th- and 19th-century ethnohistoric accounts (see above). In other words, although Native Americans, explorers, fur trappers, and others lacked the detailed biochemical and physiological knowledge available to modern medicine and nutrition, they nevertheless knew all too well from hard won experience what their daily rations had to include in order to remain active and healthy.

It is important to point out that expressing the safe upper limit to total protein intake as a *percentage* of total energy is somewhat misleading. It implies that a forager will be fine so long as he or she keeps adding fat or carbohydrate to the diet in order to keep the concentration of protein below the 35% threshold. But that threshold—whatever the current uncertainties about its actual value might be—is an absolute amount of protein, expressed in grams per kilogram of body weight, that the body can safely deaminize and excrete within a 24-h period. As noted earlier, that amount is constrained by the liver's ability to upregulate the enzymes involved in the synthesis of urea. Allowing for a certain (but unknown) degree of adaptation, once that amount has been exceeded, further augmenting one's intake of fat or carbohydrate is not likely to result in a significant upward displacement of the protein limit. In other words, merely increasing one's intake of non-protein calories in order to stay abreast of the amount of lean meat one is consuming will not do the trick; one's intake of lean meat has to be regulated to keep it in line with the amount of fat, plant oils, or carbohydrates that are available. If non-protein calories are in limited supply, successful hunters may produce more lean meat than they can safely use.

AN ARCHAEOLOGICAL CASE STUDY: OLSEN-CHUBBUCK

Let us take a look now at an actual Paleoindian communal bison kill—the classic (and beautifully documented) late Paleoindian (Cody Complex) Olsen-Chubbuck Site in Colorado (Wheat 1967, 1972). At Olsen-Chubbuck about 190 animals were driven into a steep-sided arroyo and dispatched, many probably crushed to death by the sheer mass of animals that piled into the trap. According to Wheat (1967: 49, 1972: 90), the kill was a single large-scale event that took place in the spring, probably in late May or early June. Frison (1991: 179, 2007: 346; see also Kornfeld et al. 2010: 163) re-evaluated Wheat's seasonality assessment and concluded that the kill actually took place later in the year, probably in late summer or early fall. Killed at the site were 46 adult bulls and 27 immature ones, 63 adult and 38 immature cows, and 16 calves (Wheat 1967: 49). Of the 190 animals, 10% were not butchered at all, 16% were only partly utilized, and about 74% were completely butchered (Wheat 1972: 114).

To convert the Olsen-Chubbuck data into a form that will allow us to determine the ratio of protein to fat calories in the estimated food yield of the kill, we need to make several assumptions. As already done earlier, we assume that protein and carbohydrate each yield about 4kcal per gram, while fat is energetically more dense and yields about 9kcal per gram. We also assume that bison muscle, like that of other wild ungulates, is not marbled and is therefore largely separable from the fat, and that fresh fat-free meat is approximately 21% protein (Cordain et al. 2002: 186–187; Speth and Spielmann 1983: 12). Wheat pioneered a new standard of analysis by thoroughly mining the wildlife and ethnohistoric literature to arrive at concrete estimates of the total amount (by weight) of meat (muscle), offal or organ meat, tallow, and marrow fat generated by the animals that were killed and butchered at the site. In his calculations, he took into account the degree to which the various carcasses had been processed, as well as their age and sex. He also adjusted the values to factor in the larger body size of Paleoindian bison. From Wheat's (1972: 114–116) data, we arrive at the following values:

a. Weight of fresh meat + offal (with 25% increase for fossil bison)=31,323kg
b. Weight of tallow + marrow (with 25% increase for fossil bison)=2,552kg
c. Total protein yield=26,040,000kcal (53.1% of total calories)
d. Total fat yield=22,968,000kcal
e. Total calorie yield=49,008,000kcal

Assuming that Wheat's estimated yields are reasonable approximations of reality, the protein provided by the partial to complete butchery of the 190 animals adds up to about 53% of the total calories that were generated by the event. This estimated protein level clearly exceeds the 35% safe upper limit by about 18%. In order for Wheat's estimated yield of protein to constitute only 35% of the total, nearly 25,400,000 additional kcal of fat would be needed, somewhat more than double the amount produced by the original event, and roughly equivalent to another 2,821kg of fat. Not even the fat remaining on the unbutchered and partly butchered animals would have been enough to provide the missing non-protein calories. The shortfall is substantial, to say the least! Wheat may well have been right in suggesting that the Olsen-Chubbuck hunters fed a fair amount of the lean meat to their dogs, and it is also possible that they simply discarded a lot of the meat and left it to rot. And, of course, there is the possibility that Wheat's estimates, as careful as he was in developing them, may have missed the mark by a considerable margin. Nevertheless, these data suggest that the kill at Olsen-Chubbuck produced far more lean meat (i.e., protein) than the hunters could safely consume without guaranteed access, more or less simultaneously, to a reliable source of non-protein calories, most likely plant foods of one sort or another, either stored nearby or harvested somewhere in the vicinity.

NUTRITIONAL INSIGHTS FROM LIVING BISON

We can look at this issue from a slightly different angle, one that does not require all the assumptions that Wheat had to make to arrive at his estimates of total meat and fat yields. If hunters were limited to about 236g of protein per day, a value based on a 70kg forager (see above), that amount would translate into roughly 1.1kg (1,124g) of meat per day. Total body fat in wild ungulates (ignoring differences in age, sex, and reproductive state) commonly ranges from a low of under 2% (by weight) when the animal is in average to poor condition, to around 10% or so when in peak condition (Marchello et al. 1989; McClenahan and Driskell 2002; Meagher 1986: 4; Medeiros et al. 2002; Morris et al. 1981: 214; Speth and Spielmann 1983). Emerson (1990: 513) provides a similar range (roughly 6% to 10% by weight) for four range-fed bison in reasonably good condition. For comparison, the summary data generated from the Olsen-Chubbuck calculations yielded a total fat value of 7.5% (by weight), an entirely reasonable figure for a wild ungulate such as bison. In the present example I will use a range, with 3% for an animal in fair condition, but definitely not starving, and 10% for an animal in excellent condition. Looking first at bison at the leaner end of the condition spectrum (3% total body fat), 1.1kg of meat would yield, on average, only 34g of fat, or roughly 303kcal (~12% of the hunter's daily energy intake of 2,500kcal). The combined calories from the protein (944kcal) and the fat (303kcal) contained in the meat add up to 1,247kcal, or only about 50% of the hunter's average daily energy needs. The remaining 50% of the calories would have to come from other non-protein sources.

If we now look at bison in excellent condition (10% total body fat), meat from these animals would yield, on average, approximately 87g of fat, or roughly 783kcal. In these animals, the combined calories from the protein (944kcal) and the fat (783kcal) add up to 1,727kcal, or just under 70% of the hunter's total energy requirement. This still leaves a shortfall of roughly 30% that has to be filled by other means.

These calculations, despite the many assumptions that went into them, suggest that the Olsen-Chubbuck results are actually quite realistic. Looked at from both archaeological data and from projections based on the body condition of living bison, there simply is not enough fat on these animals for a band of hunting peoples to achieve the necessary ratio of protein to non-protein calories on a sustained basis, whether that be seasonal or year-round. This unfortunate reality was clearly underscored by Isaac Cowie (1913: 415), writing in the latter half of the 19th century, when he bemoaned the fact that "the supply of fat was always too small to enable us to convert all the lean pounded or powdered meat into pemmican, for which equal weights were required." Communal bison kills are almost certain to yield an excess of lean meat that hunters will have difficulty fully utilizing unless they have to feed a large contingent of dogs, or if they have access to non-protein calories from sources other than the kill itself, including, for example, the fat from waterfowl or beaver tails, or the oils and carbohydrates from plants.

DISCUSSION

One conclusion seems pretty clear from the information presented thus far—fat, not lean, was likely a serious limiting factor for Great Plains Paleoindians who relied heavily on bison. Adding deer, antelope, or most other wild mammals to their daily fare would have done little to alleviate the problem. Hunters could usually fulfill their protein needs long before they obtained sufficient non-protein calories. The implication is that their hunting, because of the inherent excess of lean relative to fat in wild ungulates, would almost inevitably be accompanied by some degree of "waste," the amount depending on the size of the group relative to the number of animals killed, the condition of the animals, and how heavily the participants relied on meat for their sustenance. Perhaps they dried and cached some of the excess lean meat for later use when greater quantities of non-protein foods became available. But storage of that sort has to fit into their overall mobility system. Such reserves would be of little use if the hunters were not able to get at them at precisely those times when non-protein calories were most needed. The sheer immensity of the territories that archaeologists often postulate for bison-hunting Paleoindians, most strikingly those of the Folsom period in the Southern Plains, would make regular use of storage seem rather unlikely (e.g., Amick 1996; Hofman 1999). Nor is there much in the way of archaeological evidence for storage in Plains Paleoindian sites. Such evidence, when it does occur, is more common in sites located around the margins of the Plains, as pointed out, for example, by LaBelle (2005). Alternatively, the hunters could have schlepped processed plant foods with them, but the bulk implied by such a strategy would have created significant logistical problems for highly mobile peoples. More likely, the hunters fed some of the excess lean to their dogs, assuming of course that dogs were part of the system. But, more often than not, much of the excess meat was probably abandoned and simply left to rot, a common scenario in the ethnohistoric record (Coues 1893: 233; Morgan 1953: 262; Pike 1892: 48; Tindale 1972: 248)

Archaeologists have not really come to grips with the likelihood that "wastefulness," for reasons that turn out nutritionally to be quite sound, may have been built into the hunting way of life. This is apparent, for example, in the way zooarchaeologists construct "utility indices." While fat enters squarely into the calculus when modeling bone marrow and grease, weight is the only parameter considered when it comes to meat. Meat utility indices and their derivatives ignore the quantity and distribution of intra- and intermuscular fat associated with different muscle masses. Thus, regardless of whether one uses Binford's (1978) Modified General Utility Index (MGUI) or Metcalfe and Jones's (1988) standardized Food Utility Index (FUI), femurs invariably rise to the top of the utility scale, in large part because of the sheer weight of their associated muscles—i.e., the hams, thighs, or haunches. Yet, in the ethnohistoric accounts, particularly those dating to the days of the fur trade, the haunches were valued primarily for making pemmican, precisely because they contained almost no fat and therefore could be easily dried or jerked and pounded into powder or "beat meat." They might also be looked upon favorably if the hunters were well supplied with agricultural foods such as maize or wheat flour. Otherwise, the haunches stand out as being one of the least desirable parts, one that was often simply discarded or set aside as "White Man's food" or "dog food" (in the parlance of the time, thigh meat was dry or coarse; see Anderson 1918: 61; Gubser 1965: 301; Pike 1892: 51; Russell 1898: 90–91; Wilson 1924: 201–202). Moreover, in accounts that simply note the parts that hunters preferred, meat from the haunches was not just low on most lists, it was seldom even mentioned (Wheat 1972: 101). Instead, in those instances where the thighs or haunches were explicitly noted in favorable terms, it was commonly in reference, not to the meat, but to the marrow contained within the femurs (e.g., Dodge 1883: 273–274).

In sum, Great Plains Paleoindian sites present archaeologists with an unusual conundrum. Not only is there a fair amount of evidence of "waste" in the form of unbutchered and partially butchered animals, but there is a decided underuse of skeletal fats, and possibly also of the brains. Also telling is the near total absence of boiling pits and fire-cracked rock, critical pieces of evidence if grease-rendering had been a major activity. In other words, there seems to have been only limited effort by Paleoindian bison hunters to maximize the fat yield of their kills. Truly intensive processing of the skeletal fats does not emerge on the Great Plains until the latter part of the Archaic and especially during the subsequent Late Prehistoric period—that is, not until the last 2,000 years or so (e.g., Bamforth 2011; Bethke et al. 2018; Brink and Dawe 2003; Cooper 2008; Zedeño et al. 2014).

How dedicated Paleoindian bison hunters managed to gain access to sufficient quantities of non-protein calories on a regular and reliable basis remains, in my view, one of the million dollar questions in Great Plains Paleoindian studies. However, as already noted, when it comes to reconstructing post-Clovis subsistence-settlement systems on the Plains, most archaeologists pay, at best, only limited attention to food resources other than bison; and, of the few that do, only a handful seriously consider the possible role of oily or starchy plant foods (e.g., Andrews et al. 2008; Kornfeld 2007). Most archaeologists proceed with their model-building as though foods other than bison were, for all practical purposes, inconsequential. Of course, in the absence of actual paleobotanical evidence, determining the contribution of plants to Paleoindian diet may seem like a hopeless task. However, even if we cannot get decent samples of the botanical remains themselves, and we are precluded from conducting isotopic and trace element studies of human remains, both because such remains are scarce and because current NAGPRA regulations discourage or forbid it, we can nonetheless get much further than we currently are by a number of indirect means: 1) studying the extant ethnobotanical literature from both historic and contemporary Plains peoples, and through interviews with knowledgeable elders about the role of plants in their traditional foodways; 2) studying the botanical resources available in modern analog environments; 3) recovering and analyzing starch grains, phytoliths, and biomolecular residues from the sites themselves; and, 4) developing computer models and simulations. These approaches are not ideal, but they certainly are better than throwing up our hands and doing nothing.

NON-PROTEIN CALORIES, MOBILITY, AND EMBEDDED TOOLSTONE PROCUREMENT

Judging from the literature, most understandings today about post-Clovis Paleoindian mobility in the Great Plains are based on five underlying assumptions (and the necessity of acquiring non-protein calories is definitely *not* one of them): 1) hunters spent much of their subsistence effort in the pursuit of bison; 2) bison hunting necessitated large annual ranges; 3) high-quality flint was needed for the manufacture of the hunters' projectile points; 4) procurement of these flints was embedded within the hunters' annual subsistence rounds; and, 5) the region, often a very large one, that simultaneously encapsulates the hunters' kills, campsites, and principal flint quarries reflects the geographic location and spatial scale of a group's annual subsistence (i.e., hunting) range.

Plains hunters clearly needed bison to survive, I do not question that. And, as the previous arguments have suggested, they also needed reliable sources of non-protein calories, a lot of them—in fact, quite possibly as much as a third or more of their total energy input. Thus, meat and non-protein calories—whether from additional animal fat, or from plant oils and carbohydrates—must, in combination, have formed the cornerstone of Plains Paleoindian subsistence systems and, I would surmise, must have been paramount among the factors that determined their annual mobility strategies (setting aside social, religious, political, and demographic reasons for moving about; see Whallon 2006, 2011).

But why assume that toolstone procurement should necessarily be embedded in one's subsistence pursuits? Put another way, why should the locations of a group's flint quarries bear any direct relationship to the places where they went to get their food? Flint and food are radically different types of resources, each with its own unique set of spatial and temporal characteristics and constraints. Flint is absolutely stationary and completely predictable—in other words, it is always there and always in the same place. Not so with food. The abundance of most plant and animal resources varies seasonally, and where one finds any particular food may change from one year to the next. Humans obviously must have food and water to survive; both are absolutely vital to life. On the other hand, flint, and especially the high-quality flints that Paleoindians so highly prized for their projectile points, were definitely not biological necessities. In fact, as the archaeological record from across the Plains amply demonstrates, one could fashion one's projectile points from a panoply of much lesser-quality materials and still successfully kill large game or wage war on one's enemies (e.g., Ahler 1977; Speth 2018: 168–169; Wyckoff 2005).

More to the point, what is the likelihood that flint quarries just happened to be conveniently located in the same place, or anywhere near, or even en route to or from the place where Paleoindians had to be in order to intercept a bison herd, or pick ripe berries, or dig camas bulbs, or harvest pine nuts, or capture waterfowl when and as they were needed? Flint at many quarry locales is abundant, in fact often superabundant. It also does not rot if it is not harvested at the right time; it does not hide or run away when someone comes to collect it; and it does not have the seasonal booms and busts that most plant and animal resources do. And given its sheer abundance and utter lack of value as a comestible, flint from most major quarries is unlikely to be used up by a competitor. In other words, hunters could go and get flint whenever it was convenient, a flexibility seldom possible with plant or animal foods.

Quarries may be owned by a local corporate group of one sort or another but, given flint's abundance, predictability, non-perishable nature, and its often widely shared spiritual and symbolic meanings, it is unlikely to be defended to the total exclusion of outsiders (Speth 2018; Speth et al. 2013; Spielmann 1982, 1986). Instead, in order to gain access, visitors may have to perform a ceremony with or for the local owners, bring them gifts, make payments or offerings, or participate in celebratory feasts. Sometimes visitors were given unrestricted access to a quarry, but often the quarries were seen as so laden with potentially dangerous spiritual powers that only qualified locals were permitted to do the actual extraction. Once the flint had been quarried, these individuals brought the partially worked blocks or pieces of raw material to a nearby "workshop area" where the visitors tested them and "negotiated" for suitable pieces in exchange for various goods or services (e.g., Brumm 2010; Dillian 2002; Jones and White 1988; McBryde 1987: 265; Paton 1994; Ross et al. 2003; Speth 2018; Speth et al. 2013; Wright 1967: 183–184).

So, where did the idea of embedded toolstone procurement come from; and, more importantly, how did it come to be so inextricably enmeshed with subsistence-related mobility? The concept, of course, was introduced by Lewis Binford (1979) more than forty years ago, and in classic fashion he presented it in the form of a rigid "law-like" generalization. Over the years, Bamforth (2002, 2006, 2009, 2013) has examined the concept in considerable detail, and provided a thorough critique of its many empirical and theoretical shortcomings. Despite this, the steady stream of articles appearing each year that continue to rely on the idea, most with little or no consideration or even recognition of these shortcomings, indicates that for many in the profession embedded procurement is not an interesting hypothesis in need of further thought and testing, but an established and unassailable fact. Given the considerable importance of this issue for our understanding of Paleoindian food-related mobility, it is worth quoting Binford's law-like generalization in full:

> …raw materials used in the manufacture of implements are normally obtained incidentally to the execution of basic subsistence tasks. Put another way, procurement of raw materials is embedded in basic subsistence schedules. Very rarely, *and then only when things have gone wrong*, does one go out into the environment for the express and exclusive purpose of obtaining raw material for tools. (Binford 1979: 259; emphasis added)

Given the absolute certitude with which Binford proclaimed the idea of embeddedness, one might get the impression that it was based on an overwhelming amount of evidence culled from his vast knowledge of the ethnographic and ethnohistoric record of hunters and gatherers, and from his own firsthand field observations among extant foraging peoples. As it turns out, however, the idea was based largely on a mere two-week "visit" to the Alyawara in Australia in 1974, which James O'Connell humorously characterized as "parachute" ethnography (O'Connell, personal communication, 2016). Just two weeks! He fleshed out the idea with a few very sketchy recollections about 19th-century Nunamiut toolstone procurement provided by a few of his Inuit informants (see discussion in Bamforth 2006: 522). This is not much upon which to base such a sweeping generalization, one that he offered as an explanation of hunter-gatherer toolstone procurement the world over and throughout all of prehistory.

Binford's law-like pronouncement is all the more curious given that he said nothing about the comparatively recent introduction of dog sleds into the New World arctic, an event that apparently occurred less than 1,000 years ago with the Thule expansion and began to transform mobility patterns throughout the northern latitudes of the New World (Friesen 2016: 680). And even though dog sled technology was present by Thule times, its impact on northern modes of transport actually remained relatively minor until the emergence of the fur trade in the 18th and 19th centuries. In order to encourage the Inuit, Athabaskans, and others to bring their furs from distant hunting grounds to remote and widely scattered trading posts, the Hudson's Bay Company (HBC) undertook efforts to upgrade Native modes of transport by introducing innovations in sled technology, as well as new breeds of dogs big enough to pull the sleds (Ameen et al. 2019; Gubser 1965: 293–294; Loovers 2015; McCormack 2014; Morey and Aaris-Sørensen 2002; Savelle and Dyke 2014; Savishinsky 1975; Sharp 1976: 26; Sheppard 2004). The new transport technology had a huge impact on the way of life of these northern peoples, significantly altering their mobility patterns, and almost certainly changing the way they procured their foods and other resources. Thus, given the upheavals and transformations wrought, first by the Thule migration, then by HBC and the fur trade, Binford's Nunamiut are an unlikely basis for any sort of law-like generalizations about embedded toolstone procurement in the arctic or, for that matter, anywhere else.

Nor did the idea of embedded procurement come from the global ethnohistoric or ethnographic literature, both of which are virtually silent when it comes to mentions of anything akin to embedded procurement. In striking contrast, there are a remarkable number of accounts that document the direct procurement of a whole host of important resources, including flint and obsidian, but also red ocher and other pigments, stone for grinding slabs, and many other raw materials and items. Such direct procurement trips were regularly undertaken by both individuals and small task groups, who in their quests often traversed distances of hundreds of kilometers and crossed through the territories of other groups, including those of enemies (Speth 2018; Speth et al. 2013). Binford's reduction of flint procurement to an utterly mundane economic pursuit, one that was embedded entirely within the food quest, flew in the face of numerous Australian ethnographic and ethnohistoric accounts and, not surprisingly, was rapidly and resoundingly rejected by many Australian scholars (e.g., Gould and Saggers 1985; for clear expositions of the noneconomic significance attached by Australian Aborigines to flint and flint quarries, see Brumm 2010; Jones and White 1988; McBryde 1987: 265; Paton 1994; Ross et al. 2003). Yet, judging by the literature, the overwhelming majority of Paleoindianists swallowed the idea hook, line, and sinker, and for the next forty plus years have continued to operate as though embedded procurement were an established fact no longer in need of closer scrutiny. There are obviously a number of exceptions (e.g., Bamforth 2002, 2006, 2009, 2013; Curran and Grimes 1989; Ellis 1984, 1989; Meltzer 1989; Newlander 2015, 2018), but one has to look long and hard to find papers or chapters in edited volumes, particularly recent ones, that seriously vet the original idea.

Of course, none of what I am suggesting here means that embedded procurement never occurred in the past; it very likely did. And in certain contexts embedded procurement may have been an effective and important way of obtaining flint. But for the many reasons enumerated above, I seriously doubt the idea warrants the status of anything even remotely approximating a universal "law." Granted, it was a brilliant idea, in large part because it seemed so logical, but only if one is willing to assume 1) that food resources were predictably available each year near or en route to or from flint sources at precisely the time when foragers also happened to be in the area, and 2) that flint sources, or the tools made from those raw materials, had no symbolic or spiritual meanings to the people who made and used them. I have already commented on the problems with the first point. With regard to the second one—the symbolic aspect—I think Binford made another very unfortunate mistake. In his classic article "Archaeology as Anthropology," Binford (1962: 219–220) defined what he called "ideotechnic artifacts" and described them as follows:

> "The third major class of items which archaeologists frequently recover can be termed ideotechnic artifacts. Items of this class have their primary functional context in the ideological component of the social system. These are the items which signify and symbolize the ideological rationalizations for the social system and further provide the symbolic milieu in which individuals are enculturated, a necessity if they are to take their place as functional participants in the social system. Such items as figures of deities, clan symbols, symbols of natural agencies, etc., fall into this general category."

What Binford seems to be saying, or at least implying, in this curiously misguided and anthropologically naïve statement, is that an object is either utilitarian in some way (i.e., you can do something of obvious practical value with it) or it is symbolic, but it cannot serve in both contexts at the same time. This dichotomy is strangely reminiscent of the debates among archaeologists that went on in the 1980s about how to distinguish style and function in artifact form (see, for example, the discussions and citations in Sackett 1977, 1986 and Wiessner 1983). Robb (1998: 331) nicely captured the essence of what was amiss with Binford's ideotechnic way of thinking: "In many ways, the question is not whether we can find symbols archaeologically, but whether we can find anything cultural that is not symbolic. Many powerful symbols in any culture are the commonest things: bread, water, houses, the river, and the hills beyond" (see also Keane 2010: 190–191 for a more recent take on this same issue).

It is clear that Binford saw flint, and artifacts made from flint, not as ideotechnic objects, but as purely utilitarian entities, certainly not in the same class as statues of deities or clan symbols. Hence, he had no qualms about reducing the procurement of flint to an incidental activity embedded within another one that he felt was of far greater importance—getting food (see discussion in Bamforth 2006). Unfortunately, I think Binford missed the boat here. Think about the nature of Paleoindian projectile points. Many of them are absolutely gorgeous—long, thin, beautifully flaked—in short, masterpieces of craftsmanship and skill. Some are very large, even "hypertrophic" (Anderson 2014). Some are fashioned from single large quartz crystals, a beautiful but very difficult material to flake (Speth et al. 2013: 116). Moreover, quartz crystals, at least among contemporary Native Americans, are almost invariably thought to be imbued with all sorts of spiritual power and meaning (Zedeño 2009). To acquire the special high-quality flints that Paleoindians needed to make these points, they had to travel vast distances to the sources, not uncommonly covering hundreds of kilometers in the process. Moreover, on these trips the participants often bypassed much closer sources that would have served equally well (functionally) to make effective killing weapons. These facts alone suggest that the points, or the raw materials, or the quarries themselves, had symbolic importance to their makers—they almost certainly were "ideotechnic" objects to use Binford's rather awkward terminology.

But one need not stop there. It seems very likely that these points were made and used by men and, given their beauty and craftsmanship, they may well have symbolized an individual's status as a man, perhaps as an adult man, perhaps even as an initiated man, as well as a hunter and warrior. That would make them "ideotechnic artifacts" in my book, without in the least diminishing their simultaneous functional value as potentially lethal weapon tips. How could tools and materials acquired and used under those sorts of circumstances not have important symbolic meanings? Those are precisely the kinds of items and materials that men would go to great lengths to procure and display in whatever contexts were deemed socially and politically appropriate. In other words, rather than being *embedded* within the subsistence pursuits of Plains Paleoindians, I think it far more likely that these high-quality flints were procured by individual men or small groups of men who made special trips to distant quarries whose symbolic meanings were shared by a number of Paleoindian bands in the region, perhaps members of a single language group, or perhaps less closely related or unrelated bands with spiritual ties to the same ancestral landscape or that simply participated in the same overarching religious system.

Whatever the case, I seriously doubt the locations of these exotic lithic sources necessarily tell us much about the subsistence-related mobility of Paleoindian bands on the Great Plains. Those movements are far more likely to have been guided by the seasonal distribution and condition of the bison, together with the availability and abundance of plant foods, waterfowl, and other key sources of non-protein calories, both on the Plains and in surrounding regions adjacent to the grasslands (see Andrews et al. 2008: 486; Bever and Meltzer 2007: 79; Kornfeld 2007; LaBelle 2005: 205). I would expect the particular combination of resources that created a viable diet for Plains Paleoindians to have been variable over both space and time, keyed to local topography, elevation, microclimate, water, and soils, and to the evolving social and political landscape. But in all of this, I suspect the acquisition of high-quality ("exotic") flint seldom had much or anything to do with a group's annual foraging rounds. For the most part, the lithics are a distraction. If archaeologists are genuinely interested in subsistence, they need to take a more holistic look at what sorts of diets and foodways would have been nutritionally viable on the Plains. Bison, and wild game more generally, were definitely an important part of the story, but they were far from being the whole story.

CONCLUDING REMARKS: FLINT AND ANCESTRAL LANDSCAPES

In closing, it might be worth returning briefly to the intriguing question of why Paleoindians placed such great importance on high-quality, often remarkably beautiful flints that they felt compelled to procure from sources often located hundreds of kilometers from where they ultimately used and discarded the tools. While these exotic flints were most often fashioned into projectile points, they clearly were not needed for that purpose, at least not in a purely utilitarian or functional sense (Speth 2018). Paleoindian big-game hunting could have been carried out, arguably with equal success, using spear or atlatl points made from any number of other materials, many not requiring anywhere near the same amount of time and effort to procure or to shape into objects of such extraordinary beauty and craftsmanship. The great variety of raw materials used to make points for functionally comparable purposes by later hunting peoples in the same regions amply testify to that.

So, if these "costly" exotic flints were not functional necessities of the hunting enterprise, why were they so important to Plains Paleoindians? Drawing insight from the rich ethnographic and ethnohistoric record, my suspicion is that Paleoindian sites with large amounts of exotic flint from the same source or sources are telling us about peoples who also shared broadly similar or overlapping belief systems. More specifically, these would have been hunting bands who shared similar beliefs about how their ancestral landscape came into being, and the mythological significance of its sacred places, including springs, lakes, rivers, caves, unusual rock formations, hills, mountains, and shrines, as well as sources of spiritually potent fossils, minerals, flint, obsidian, and pigments such as red ocher. Such materials and objects, including special flints, probably moved around the landscape, and from group to group, in large part as a result of both direct procurement and through gift-giving and exchange. The resulting patterns of distribution very likely tell us about social networks and shared systems of belief, not annual movements of groups driven by their food needs (e.g., Oetelaar 2014: 11).

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