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Cutmark systematics: Analyzing morphometrics and spatial patterning at Palangana

Ashley K. Lemke *

University of Michigan, Museum of Anthropological Archaeology, 1109 Geddes Avenue, Ann Arbor, MI 48109-1079, United States

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ABSTRACT

Cutmarks have played an important role in addressing whether our hominid ancestors were hunters or scavengers, describing ritual modification of human bone, defining the origin of metallurgy, and highlighting the diversity of prehistoric butchering behavior. The widespread occurrence of cutmarks on animal bones and their variability allows archaeologists to use this kind of evidence to address a broad range of questions. One goal in examining cutmark diversity is to identify diagnostic cutmarks of prehistoric butchering, processing, and consuming behaviors. Linking cutmarks to specific activities allows us to test fine-grained hypotheses concerning the nature of an archaeological site, and to do this a systematic method for addressing variability in both the appearance and anatomical position of cutmarks is essential. An analysis of caribou bones collected by Lewis Binford from the Palangana site in Alaska is used to build and test a diagnostic cutmark classification using their morphometric and spatial properties. This case study demonstrates that cutmarks can be used to simultaneously address large-scale anthropological questions and reveal intra-site behavioral variability in the archaeological record.

Introduction

Cutmarks have the potential to tell us a great deal about prehistoric behavior. Important topics include addressing whether early humans were hunting or scavenging their meat as well as sharing it, defining when metal tools were first used as butchering implements, characterizing ritual modification of human bone, and understanding how prehistoric butchering practices varied (e.g. Andrushko et al., 2000; Blom, 2001; Braun et al., 2008; Cáceres et al., 2007; Degusta, 2000; Domínguez-Rodrigo, 1997; Domínguez-Rodrigo et al., 2005; Frayer et al., 2006; Greenfield, 2006; Haverkort and Lubell, 1999; Lozano-Ruiz et al., 2004; Lupo, 1994; Lyman, 1987, 1992, 1995, 2005; Mafart et al., 2007; Mariotti et al., 2009; McPherron et al., 2010; Monks, 2001; Navas et al., 2008; Perez, 2006; Perez and Martin, 1999; Pickering et al., 2004; Pickering and Hensley-Marschand, 2008; Pobiner and Braun, 2005; Potts and Shipman, 1981; Rabinovich et al., 2008; Selvaggio, 1994; Smith and Brickley, 2004; Stiner et al., 2009). The widespread occurrence of cutmarks on animal bones and their variability allow archaeologists to use this single kind of evidence to address such a broad range of questions. While we know that both the appearance and anatomical position of cutmarks are variable (e.g. Binford, 1981, 1984a; Bunn, 1981; Eickhoff and Hermann, 1985; Guilday et al., 1962; Lagenwalter, 1980; Lyman, 1987; Miller, 1975; Potts, 1982; Potts and Shipman, 1981; Shipman, 1981; Shipman and Rose, 1983; Walker and Long, 1977), what is needed is a systematic way to address both of these issues. This study is intended to make a small contribution in this area, showing how the identification of morphological categories of cutmarks, the analysis of their position on bones, and their spatial distributions over a site can advance our ability to make sense of cutmark variability and, through that, to reconstruct past behavior.

Many analyses have focused on determining which bone modifications are in fact cutmarks, since cutmark identification can still be debatable (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Blumenschine et al., 1996; Bunn, 1981, 1983; Fisher, 1995; Fiorillo, 1984; Potts and Shipman, 1981; Shipman, 1981; Shipman et al., 1984; Shipman and Rose, 1983, 1984). While not the focus of this paper, this is the first critical step for using cutmarks as evidence to test archaeological hypotheses since it isolates the message from the "noise". Secondarily, tabulating the frequency of cutmarks is important for the determining the intensity and nature of bone modification. This may be problematic due to several taphonomic factors which influence the number of cutmarks in any given assemblage, including differential skeletal representation, the preservation of bone surfaces, bone fragmentation, butcher's skill, site functionality, the raw material of the tool used, and the carcass size of the animal being butchered (Bunn, 2001; Dewbury and Russell, 2007; Dominguez-Rodrigo and Yravedra, 2009; Egeland, 2003; Frison, 1989; Lupo and O'Connell, 2002; Lyman, 1992; Padilla, 2008). Despite these factors, the percentage of limb bones with cutmarks on them has been demonstrated to be the best estimator of

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* Fax: +1 734 763 7783.
E-mail address: aklemke@umich.edu

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cutmark frequency in any given assemblage (Dominguez-Rodrigo and Yravedra, 2009; see also Otarola-Castillo, 2010).

Given the confidence archaeologists have acquired in their ability to identify and tabulate cutmarks, the emphasis may be shifted to individual cutmark variability in order to link these traces to prehistoric behaviors. This includes differentiating between cutmarks created with different tools and raw materials (e.g. Bunn, 1982; Dewbury, 2009; Greenfield, 2006; Hannus, 1990; Potter, 2005; Potts, 1982; Stone, 2006; Walker and Long, 1977; Walker, 1978) as well as linking cutmarks to specific butchering, processing, and consuming activities (e.g. Binford, 1984b; Frison, 1970, 1973, 1974; Frison et al., 1976; Guilday et al., 1962; Johnson, 1978, 1980; Thomas and Mayer, 1983; Speth, 1983; Wheat, 1967, 1979; Wilson, 1982).

Lewis Binford provided a formal categorization of cutmark types to document their connection with human behavior, analyzing both the anatomical position and characteristics of cutmarks on caribou bone. Different types of Nunamiut butchering behaviors witnessed by Binford were described and linked with their associated cutmarks, resulting in his ‘‘filleting,’’ ‘‘skinning,’’ and ‘‘dismemberment’’ functional typology (1981). While this typology was innovative, it has limitations. First, Binford's analysis is qualitative; thus, his detailed descriptions of particular cutmarks do not lead directly to comparative analyses or to generalizations. Second, Binford focuses on the articular ends of bones, leaving the cutmarks on bone shafts unaccounted for. Third, the terms used in the classification carry functional implications, suggesting for example, that any cut resembling a ‘‘filleting’’ mark must be the result of a filleting behavior. Fourth, Binford notes that placement and orientation of cutmarks can vary even if their function is the same (1984a). And finally, Binford's illustrations of cutmarks do not account for the full range of cutmark variability on particular elements (e.g. additional types of marks on distal metapodials were illustrated by Lyman (1979), Wheat (1979, pp. 63–66) and Lyman, 1987). Due to these limitations, the application of this typology to archaeological assemblages has met with limited success (Costamagno and David, 2009). Despite the critiques of Binford's analysis, we should not abandon the goal of identifying cutmark categories which are readily distinguished from one another and may be diagnostic of specific behaviors.

Taking additional steps to meet this goal, the study presented here creates a generalizable, qualitative definition of distinct cutmark types, makes a quantitative analysis of the patterns of cutmark distributions on bones, makes a quantitative analysis of spatial patterning of cutmarks over a site, and combines these results with ethnoarchaeological information to infer the links between cutmark types and human activities.

The study context

The sample of caribou bones used for this case study is from Palangana, one of the many protohistoric Nunamiut sites located by native informants and excavated by Binford in the late 1960s and early 1970s (e.g. 1978, 1983). The Nunamiut are a group of Eskimos living near the Brooks Range in interior Alaska and are arctic foragers who subsist largely on fresh and stored caribou. Palangana is a winter residence located near Tulugak Lake and is named after a hunter that wintered there with his family around 1880 (see Maps 3 and 4 in Binford (1991a)). Palangana's house and three other winter residences were identified, and two of them were excavated, along with a dog yard and work tent (Binford, 1978). Faunal remains recovered from Palangana include caribou (*Rangifer tarandus*), Dall sheep (*Ovis dalli*), ptarmigan (*Lagopus lagopus*), and indeterminate canid (*Canis spp.*). Artifactual remains recovered from the site include wood, chipped stone, and rock (Enloe, 1993, p. 85; Waguespack, 2002, p. 403).

Palangana is an ideal assemblage for examining cutmark variability since it is an archaeological site excavated in the larger context of an extensive ethnoarchaeological project. As an archaeological site, Palangana was affected by a range of post-depositional modifications which are difficult to replicate in ethnoarchaeological or experimental studies (Dominguez-Rodrigo and Yravedra, 2009, p. 892), making it an effective dataset for building archaeological methods. Indeed, previous archaeological work has demonstrated that extensive bone processing such as grease rendering and marrow consumption, as well as meat sharing, took place at the site (Binford, 1984a; Enloe, 1993; Todd et al., 1985; Waguespack, 2002). While the Palangana collection is not ethnoarchaeological in the sense that neither Binford nor I witnessed the creation of the assemblage, the ethnographic data collected concerning Nunamuit Eskimos and Palangana specifically (e.g. Binford, 1978, 1991a, 1991b) can be used to understand the full range of subsistence behaviors practiced by this group of people and to explore the occurrence of other activities at Palangana. Therefore, many of the variables which influence whether or not bones will be marked with cuts, such as the technology, season, number of butchers, condition of carcasses and so forth (Lyman, 2005, p. 1729), are controlled in this case.

Methods

Methods for quantifying and tallying cutmarks are vast and varied (Lyman, 1992, 2005, 2008). In the following analysis, when comparing cutmark frequency across and between different elements or portion of bone, (i.e., the ends versus the shafts), the percentage of bone fragments with cutmarks on them was used. Bone fragment size was estimated by multiplying the maximum length by the maximum width of all bone fragments including cylindrical shafts following the methodology in Stiner et al. (2009, p. 13210). The number of individual striae on each bone fragment was counted, and this number divided by the calculated estimate of fragment size was used as an estimate of the relative frequency of cutmarks on each fragment, referred to as the cut coefficient. For this analysis, only an estimate of surface area was needed in order to observe patterns in the number of individual cutmarks relative to the size of the bone fragment.

In this study, bone fragments were divided into two groups in order to detect broad scale patterns, (1) shaft fragments, hereafter referred to as diaphyses, and (2) fragments with all or a part of the articular end of the bone remaining, referred to as epiphyses throughout this analysis. While more sophisticated methods of recording cutmark location have been used (e.g. Abe et al., 2002), in this analysis, cutmarks were coded as being on either an epiphysis or diaphysis.

Materials

This analysis concerns only the identifiable caribou long limb bones form Palangana. While a complete zooarchaeological analysis of Palangana has not been done, previous studies have quantified the MNI of caribou from different areas of the site (e.g. Binford, 1978, Table 8.4) with the limb bones representing a total MNI of 75 (Waguespack, 2002, p. 407) the majority of which are adult caribou.

Limb bones

Only caribou long limb bones identifiable to element from Palangana were analyzed ($n = 1453$, Table 1). This sample was

Table 1
Analyzed caribou bones from Palangana.

Element	Uncut	Cutmarked	% Cut	Total
Femur	149	22	12.87	171
Humerus	268	29	9.76	297
Radio-Ulna	329	28	7.84	357
Tibia	77	8	9.41	85
Metacarpal	226	23	9.24	249
Metatarsal	268	26	8.84	294
Total	1317	136	9.36	1453

selected for a number of reasons: (1) long bones are central "hot spots" of butchering activity (particularly for caribou, see Patou-Mathis, 1997: Fig. 5), (2) whole limbs are a common butchering unit for storing and food sharing, (3) the similar shape of long bones (i.e., cylindrical shafts) allowed for the statistical control of the size of bone fragments by estimating surface area (length × width), (4) the high density of most long bones causes them preserve better than other elements (e.g. see Lyman, 1994 discussion on density mediated attrition; Lam et al.,1998; Lam et al., 1999), (5) the percentage of cutmaked long bone specimens is considered to be the best estimator of cutmark frequency (Dominguez-Rodrigo and Yravedra, 2009), and (6) targeting specific elements such as long bones is argued to be the most useful for addressing research questions about butchering (Domínguez-Rodrigo et al., 2007).

Overall, bone preservation at Palangana is excellent with little post-depositional weathering or density-mediated attrition. The assemblage in general and the limbs specifically are highly fragmented. Previous analyses of the Palangana limbs reveal that over 93% of bone fragments demonstrate green breaks (Waguespack, 2002, p. 406). Less than 1% of long limb bones displayed carnivore-gnawing modification including the articular ends suggesting that dogs at the site had limited access to bone, or completely destroyed bone that they had gnawed (Waguespack 2002, p. 407). A high percentage of identifiable limb bones lacked cutmarks ($n = 1317$, 90.6%), and these fragments are on average smaller than bone fragments with cutmarks (ANOVA, $F = 12.349$, $p = .001$). It is difficult to determine if cutmarked bones are more likely to be eroded, weathered, scavenged, or otherwise modified (Lyman 2005, p. 1726), and likewise difficult to determine if these factors are responsible for the difference in the size of cut and uncut bone fragments at Palangana.

Considering only the subsample of cutmarked bones from Palangana ($n = 136$; *Epiphyses*, $n = 54$; *Diaphyses*, $n = 82$) (Table 1), tests for significant difference in the number of individual cutmark striae between elements, portions (diaphyses vs. epiphyses), and limbs (forelimb vs. hindlimb) were undertaken. ANOVA tests on the number of cuts on bone fragments in each of these categories were not significant (*Elements* $F = 2.085$, $p = .071$; *Portions* $F = 3.037$, $p = .084$; *Limbs* $F = .592$, $p = .443$), suggesting that no particular element, portion, or limb was cut significantly more often than others (mean number of cuts is 3.6 per fragment), including tibia fragments which were the least common element in the assemblage.[1]

Fragmentation of bone can drastically affect the frequency of cutmarks and the analyst's ability to determine the orientation of a mark since bone fragments may be too small to determine a cutmark's long axis/orientation relative to the anatomy (Abe et al., 2002; Dominguez-Rodrigo and Yravedra, 2009, p. 888; Rapson, 1990), therefore, controlling for the size of the bone fragment was necessary. A cut coefficient, or the ratio of the number of individual striae to surface area, for each bone was calculated by dividing the number of observed cutmarks by the bone surface area (cm^2) (similar to Rapson's measure of cutmark density (1990, p. 287)). While there was no significant difference in cut coefficient across elements or limbs, there was a significant difference between epiphyses and diaphyses (ANOVA, $F = 5.057$, $p = .026$; mean cut coefficient for epiphyses = 0.12, diaphyses = 0.17). Cuts tend to occur in similar numbers relative to the size of the bone across elements and limbs but tend to be denser on shaft fragments.

Cutmarks

Upon reviewing all bone modification on the limb bone fragments, 390 separate striae were interpreted as cutmarks. Four classes of cutmarks were defined based on their macromorphology and inferred direction of force during manufacture: wedge, gash, nick, and slice (Fig. 1). Wedges are broad, v-shaped incisions that look as though they are the result of two intersecting cuts, although microscopic examination would be required to determine exactly how they were created. A gash is a large, ragged, substantial mark cutting deep (i.e., qualitatively compared to other cuts) into, or all the way through, a bone. Striations in the cross-section of gash cuts are indicative of saws and seem to represent a back-and-forth sawing motion, indicating that this type of cut is most likely made with a different tool than the other cutmark classes. The majority of Palangana cutmarks are clean, angled cuts made by a single stroke and intuitively there seem to be two distinct classes: those that grouped together, are shorter, and tend to be perpendicular to the long axis of the bone; and others that are alone or paired, longer, and parallel to the long axis. Length of cuts was the attribute chosen to differentiate between the two classes; a histogram displaying length of nick and slice cutmarks revealed a break in the distribution at 3.1 mm and this point was used to separate these two classes. Therefore, a nick is an angled clean cut less than 3.1 mm in length and a slice is an angled clean cut greater than 3.1 mm in length. This analysis results in four qualitatively differentiated, empirically derived, and quantitatively supported cutmark classes that permit comparison (individual striae by category: *Nick*, $n = 283$; *Slice*, $n = 139$; *Wedge*, $n = 43$; *Gash*, $n = 25$). This typology is first and foremost an analytical tool for organizing the variability apparent in the cutmark morphometrics (i.e., their shape and size attributes). These analytical categories will be evaluated in terms of their spatial patterning in relation to each other, across bone elements and portions, and across the archaeological site to determine if any of these independent lines of evidence suggest that the analytical categories are indicative of different butchering, processing, and consuming behaviors.

Cutmark distribution

Using the four-part classification, variability across cutmark classes was assessed. There is a significant difference in the distribution of cutmark classes across elements (Table 2). In terms of each cutmark class, (1) gashes are significantly overrepresented on metacarpals and 56% of them occur on metapodials as a group, (2) 77% of wedges are on metapodials and are significantly overrepresented on metacarpals and underrepresented on radio-ulnae, (3) slices have an opposite distribution than wedges since they are significantly underrepresented on metacarpals and overrepresented on radio-ulnae, and (4) nicks are evenly distributed across all elements. Lastly, all cutmark classes occur on all elements with just one exception – no wedge marks occur on tibiae (perhaps a

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[1] Tibia was the element that was least common in the Palangana assemblage most likely due to the fact that only identifiable bone fragments were used in this analysis. Tibias were perhaps highly fragmented resulting in fewer identifiable specimens than the other elements. Despite this small sample size, the cutmark frequencies and distributions on tibia fragments still provide robust patterning.

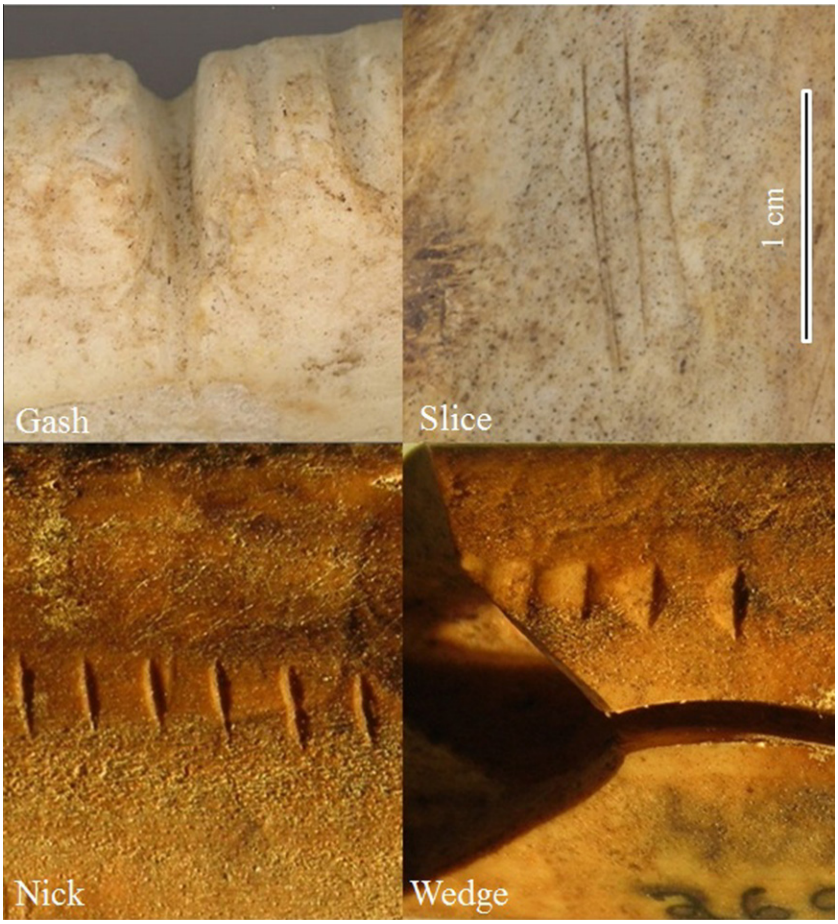

Fig. 1. Cutmark classes. Gash $n = 3$, slice $n = 4$, nick $n = 6$, wedge $n = 4$.

Table 2
Cutmark classes, number by element. Significant cell contribution to x^2 (determined by using the square root of cell x^2 as an approximate standard score) is indicated by bold text.

Cutmark class		Element						
		Femur	Humerus	Metacarpal	Metatarsal	Radio-Ulna	Tibia	Total
Gash	Observed	3	1	11	3	2	5	*25*
	Expected	2.81	3.93	5.38	6.58	4.59	1.79	
	Cell x^2	0.0134	2.1831	**6.11**	1.9491	1.4629	5.785[a]	
Nick	Observed	27	50	51	81	52	22	*283*
	Expected	37.77	44.47	60.07	74.5	51.98	20.21	
	Cell x^2	0.7149	0.6873	1.3682	0.5664	0	0.1577	
Slice	Observed	22	20	19	35	35	8	*139*
	Expected	15.6	21.84	29.5	36.59	25.53	9.93	
	Cell x^2	2.6236	0.1555	**3.7385**	0.0694	**3.5122**	0.3746	
Wedge	Observed	3	6	23	10	1	0	*43*
	Expected	4.83	6.76	9.13	11.32	7.9	3.07	
	Cell x^2	0.6912	0.0848	**21.0894**	0.154	**6.0246**	3.0714	
Total		55	*77*	*104*	*129*	*90*	*35*	*490*

($x^2 = 61.530$, df = 15, $p < .001$).
[a] Cell x^2 is suspect, expected value is too small.

function of the small sample size of tibae). Distributions of cutmark classes across portions (epiphyses vs. diaphyses) and limbs (forelimb vs. hind limb) were not significant (*Portions* $x^2 = 4.742$, $p > 0.192$; *Limbs* $x^2 = 4.186$, $p = 0.242$). This suggests a fairly even distribution of the cutmark classes along these lines.

Cutmark associations

While there are no physically overlapping cutmarks in the sample, 40% of Palangana's cutmarked bones have more than one cutmark class on them ($n = 54/136$). In order to further analyze the relationship between cutmarks on a single bone, a series of spatial analyses were performed comparing distances between cutmarks on individual bone fragments.

The proximity and diversity of cutmarks on a single bone fragment can be assessed using both qualitative and quantitative measures. Qualitatively, for each bone fragment, every cutmark was sequentially assigned position one (as "ego") and its nearest five neighboring cutmarks were recorded, e.g. Ego is a Nick, with neighbors Nick, Nick, Slice, Slice, Slice.

Table 3
Cutmark nearest neighbors of any class.

Cutmark class		Nearest neighbor class					
		No neighbor	Gash	Nick	Slice	Wedge	Total
Gash	Observed	1	12	5	5	2	25
	Expected	1.58	0.77	14.64	5.81	2.19	
	Cell x^2	0.2139	**164.925**	6.3502	0.1146	0.0171	
Nick	Observed	10	1	234	35	3	283
	Expected	17.9	8.66	165.76	65.84	24.83	
	Cell x^2	3.4894	6.7787	**28.0958**	14.4463	**19.1971**	
Slice	Observed	17	2	45	67	8	139
	Expected	8.79	4.26	81.41	32.34	12.2	
	Cell x^2	7.6577	1.1952	16.2871	**37.1505**	1.4447	
Wedge	Observed	3	0	3	7	30	43
	Expected	2.72	1.32	25.19	10	3.77	
	Cell x^2	0.0287	1.3163	**19.5431**	0.9021	**182.281**	
Total		30	*15*	*287*	*114*	*43*	*490*

$x^2 = 511.434$, df = 12, $p < .001$.

Table 4
Mean distance to nearest neighbor of any class.

Class	Mean distance (mm)	Std. deviation
Nick	4.31	11.92
Slice	9.95	16.86
Wedge	8.52	15.21
Gash	16.85	27.68

Table 5a
If the cutmark is a nick, e.g. nick to first nick, nick to first slice, etc.

1st Neighbor	*N*	Mean distance (mm)	Std. deviation
Nick	287	5.22	13.07
Slice	113	8.59	15.84
Wedge	43	9.99	17.91
Gash	15	15.35	29.09
Total	458	6.83	15.16

ANOVA, $F = 3.868$, df = 3, $p = .009$.

First, the class of each cutmark (rows in Table 3) was compared to the class of its first nearest neighbor (columns in Table 3). This demonstrates a highly significant tendency for cutmarks of the same class to occur together. Additionally, wedges and nicks occur next to each other significantly less often than expected.

A quantitative approach was also taken. The distance (mm) between each cutmark and its nearest neighbor was measured. The mean distance to the first neighbor between each cutmark class was tested. Results from an ANOVA were significant ($F = 8.285$, $p < .001$), revealing that wedges and slices are similarly close to other cutmarks, nicks are closest to other cutmarks, and gashes are the farthest away from other cutmarks (Table 4).

When the average nearest neighbor distances are calculated between classes, a complex picture emerges. Distances between each class and its nearest neighbor of the same class, i.e., measurements from a mark of a given class to the first mark of each class, e.g. nick to first nick, nick to first slice, nick to first gash, nick to wedge, etc. were significant for nicks and slices, revealing that nicks are significantly closer to other nicks than to cutmarks from any other class (Table 5a), and slices are significantly closer to other slices than to any other class (Table 5b). Wedges, although not at a level of statistical significance, are much closer to other wedges than to any other cutmark class (Table 5c). For the relatively infrequently occurring gashes, the distance to the nearest cutmark was not statistically significant (Table 5d).

Table 5b
If the cutmark is a slice, e.g. slice to first nick, slice to first slice, etc.

1st Neighbor	*N*	Mean distance (mm)	Std. deviation
Nick	45	11.25	18.36
Slice	66	6.18	10.01
Wedge	8	26.54	27.95
Gash	2	38.51	48.67
Total	121	9.95	16.86

ANOVA, $F = 6.458$, df = 3, $p < .001$.

Table 5c
If the cutmark is a wedge, e.g. wedge to first nick, wedge to first slice, etc.

1st Neighbor	*N*	Mean distance (mm)	Std. deviation
Nick	3	8.98	4.54
Slice	7	19.87	22.27
Wedge	30	5.82	12.98
Gash	0	–	–
Total	40	8.52	15.21

Table 5d
If the cutmark is a gash, e.g. gash to first nick, gash to first slice, etc.

1st Neighbor	*N*	Mean distance (mm)	Std. deviation
Nick	5	16.47	13.21
Slice	5	28.45	43.59
Wedge	2	14.03	17.21
Gash	12	12.64	27.18
Total	24	16.85	27.68

Spatial properties

The spatial information for bones in the Palangana assemblage was recorded using the north and east measurements of each excavation unit (3 × 3 m square). Excavation squares have occurrences of identifiable limb bone fragments anywhere from 1 to 224 bones and the overall distribution across the site is therefore strongly influenced by excavation units with numerous bones. In order to recognize spatially distinct clusters, a *k*-means cluster analysis of the north and east measurements of each bone fragment was conducted (following the methods developed in Kintigh, 1982). Bones with provenience information that did not match excavation re-

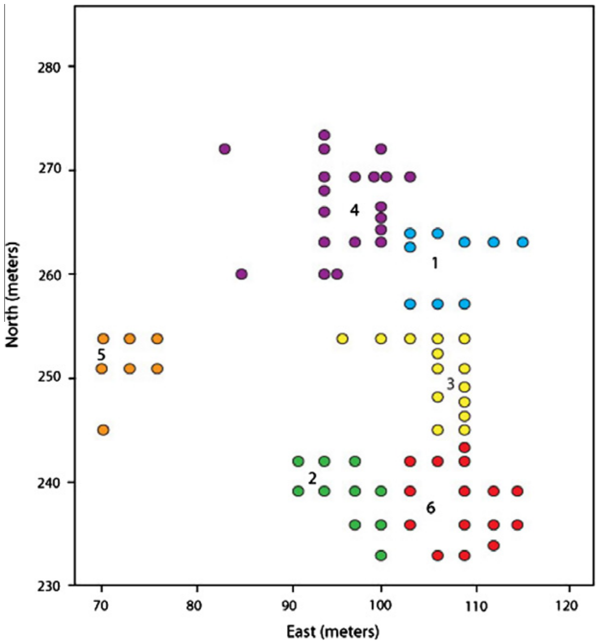

Fig. 2. Palangana site map displaying *k*-means derived clusters.

cords were considered spatial outliers and removed ($n = 20$ bone fragments, one with cutmarks, range used is E70–115 m, N230–275 m). Separate runs of the *k*-means were completed selecting five, six, and seven clusters and compared in terms of individual cluster attributes and statistics. The six cluster solution had the lowest intra-cluster variance and best represented the patterning of the Palangana limb bones. Fig. 2 displays a site map of Palangana showing the six *k*-means derived clusters. The circles on this figure represent the unit squares that contained the identifiable limb bones ($n = 1433$ bones).

Palangana limb bones without cutmarks are distributed differently than those with cutmarks, revealing that Cluster 5 has the *highest* frequency of cutmarked bones while Cluster 6 has the *lowest* (Table 6). There is also a significant difference in the mean size of bone fragments by cluster, with Cluster 5 having the largest bone fragments, and Cluster 6 having the smallest (Table 7). Elements and portions (diaphyses vs. epiphyses) are also distributed differently between clusters (Tables 8 and 9 respectively). In terms of specific elements, metacarpals are significantly overrepresented in Clusters 2 (63% of Cluster 2 is metapodials) and 4, and underrepresented in Cluster 3. Most notably for the portions, epiphyses are significantly overrepresented in Clusters 2 and 4 and are underrepresented in Cluster 3; in fact 90% of Cluster 3 is shaft fragments. Clusters 1 and 5 have nearly equal representation of epiphyses and diaphyses.

Considering just the cutmarked bones at Palangana, these fragments are distributed quite differently across portions (diaphyses vs. epiphyses). Cluster 3 has the highest proportion of cutmarked diaphyses which is not surprising given that 90% of the cluster is shaft fragments.

Table 6
Percentage of cutmarked limb bones by cluster.

Cluster	*N*	Cut	Non-cut	% Cut
1	24	2	22	8.33
2	79	7	72	8.86
3	327	28	299	8.56
4	305	37	268	12.13
5	21	7	14	33.33
6	677	54	623	7.98

$x^2 = 13.628$, df = 5, $p = .018$.

Table 7
Mean bone fragment size by cluster.

Cluster	*N*	Bone fragment surface area (mm^2)
1	24	1875.25
2	79	2194.59
3	327	2103.75
4	305	2192.49
5	21	3657.05
6	677	1651.76

ANOVA $F = 14.434$, $p < .001$.

Cluster 5 has the highest portion of cutmarked epiphyses. While the distribution of cutmarked elements was not significantly different across clusters, the percentage of cutmarked elements by cluster (displayed in Table 10) further highlights the high frequency of cuts in Cluster 5. Specifically the femur, humerus, metatarsal, and radio-ulna have a higher frequency of being cut in this cluster than in any of the other. Although Cluster 6 has the lowest frequency of cutmarked bones overall, it has the highest frequency of cuts on two limb bone elements, metacarpals and tibiae.

Considering cutmark classes specifically, there is a significant difference in the distribution of slices, nicks, wedges, and gashes (Table 11). Cluster 1 lacked gashes, Cluster 5 lacked both gashes and wedges. Additionally, Cluster 3 has a significant overrepresentation of slices, and an underrepresentation of gashes, and Cluster 5 has an overrepresentation of nicks. Due to the size of Cluster 6 ($n = 677$ bones), it is to be expected that it has the majority of all the cutmark classes including 36% of slices, 38% of nicks, 47% of wedges, and 48% of gashes.

These characteristics distinguish the six *k*-means derived clusters as distinct spatial groups with unique traits. These clusters reveal that not all cutmark classes occur in all clusters and that wedges and gashes are lacking from some areas of the site. Additionally, each spatial cluster has a unique set of characteristics concerning the distribution of elements and portions of bones across the site, as well as varying frequencies of cutmarked bones.

Results

An interpretation of Palangana – using empirical results of the assemblage combined with the cutmark classification, cutmark associations, and the spatial properties of limb bones and their cutmarks – is given below. The overall nature and distribution of subsistence behavior at Palangana is partly given by Binford's ethnoarchaeological observations and is partly inferred from a combination of those observations and the quantitative analyses from this study. Cutmark types are then inferentially linked to various subsistence behaviors using both Binford's observations and my analytical results.

Inferring behavior from cutmark classes and their distributions

Three general conclusions about Palangana's cutmark classes can be inferred from the formal and spatial nature of the assemblage: (1) a range of activities generated the cutmarks, (2) the activities targeted different portions and body parts of caribou, (3) cutmarks are differentially distributed across the site. But are these analytical cutmark categories diagnostic of different butchering, processing, and consuming behaviors? The relevant ethnographic and ethnoarchaeological information concerning the Nunamiut provides a theoretical picture of the butchering, processing, and consumption behaviors that are likely to have taken place during the winter occupation at Palangana. This

Table 8
Distribution of elements by cluster.

Cluster		Element						
		Femur	Humerus	Metacarpal	Metatarsal	Radio-Ulna	Tibia	Total
1	Observed	6	3	3	4	5	3	*24*
	Expected	2.8	4.87	4.14	4.86	5.94	1.39	
	Cell x^2	3.6682	0.7203	0.3124	0.1512	0.1504	1.8645	
2	Observed	7	7	24	26	10	5	*79*
	Expected	9.21	16.04	13.62	15.99	19.57	4.58	
	Cell x^2	0.5289	**5.0969**	**7.9173**	**6.2706**	**4.6805**	0.0393	
3	Observed	37	82	35	84	74	15	*327*
	Expected	38.11	66.4	56.36	66.18	81.01	18.94	
	Cell x^2	0.0322	3.6629	**8.0975**	**4.8008**	0.6063	0.8196	
4	Observed	21	55	82	61	69	17	*305*
	Expected	35.54	61.94	52.57	61.72	75.56	17.67	
	Cell x^2	5.9514	0.7768	**16.4735**	0.0085	0.5692	0.0251	
5	Observed	4	7	5	2	3	0	*21*
	Expected	2.45	4.26	3.62	4.25	5.2	1.22	
	Cell x^2	0.9851	1.7547	0.5264	1.191	0.9324	1.2163	
6	Observed	92	137	98	113	194	43	*677*
	Expected	78.9	137.48	116.69	137.01	167.71	39.21	
	Cell x^2	2.1762	0.0017	2.994	**4.2064**	**4.1196**	0.3659	
Total		*167*	*291*	*247*	*290*	*355*	*83*	*1433*

$x^2 = 93.694$, df = 25, $p < .001$.

Table 9
Distribution of portions by cluster.

Cluster		Portion		
		Diaphysis	Epiphysis	Total
1	Observed	11	13	*24*
	Expected	19.56	4.43	
	Cell x^2	3.7473	**16.5164**	
	% in Cluster	45.80	54.20	
2	Observed	48	31	*79*
	Expected	64.39	14.61	
	Cell x^2	4.1723	**18.3896**	
	% in Cluster	60.80	39.20	
3	Observed	298	29	*327*
	Expected	266.53	60.47	
	Cell x^2	3.716	**16.3785**	
	% in Cluster	91.10	8.90	
4	Observed	217	88	*305*
	Expected	248.6	56.4	
	Cell x^2	4.0161	**17.7012**	
	% in Cluster	71.10	28.90	
5	Observed	10	11	*21*
	Expected	17.12	3.88	
	Cell x^2	2.9588	**13.0412**	
	% in Cluster	47.60	52.40	
6	Observed	584	93	*677*
	Expected	551.81	125.2	
	Cell x^2	1.8785	**8.2794**	
	% in Cluster	86.30	13.70	
Total		1168	265	*1433*

$x^2 = 110.795$, df = 5, $p < .001$.

information combined with the results of the cutmark distributions can be used to infer the behaviors potentially responsible for generating the cutmarks.

The majority of cutmarks are nicks and slices, which may suggest a wide range of generative processes for these types of marks, or the repetition of one or few behaviors leaving the same type of marks, e.g. dismemberment, skinning, cleaning, processing, etc. The majority of nicks in the Palangana collection may suggest many generative processes, or that they are the result of a single common activity, such as the fine cutting of meat from bone. At least some of the slices on the other hand, which tend to be parallel to the long axis of the bone as opposed to nicks which tend to be perpendicular to it, may be associated with marrow-processing, perhaps produced by slicing and peeling the periosteum off before the bone is broken open, a common behavior done to control bone fracture during marrow-processing:

> Cleaning the bones of segments of meat and tendon is not all that is done prior to cracking. The secret to controlled breakage of marrow bones is the removal of the periosteum in the area to be impacted. . .This means that longitudinal scratches and striations along the shafts of long bones are commonly produced when bones are prepared for cracking during marrow processing (Binford, 1981, p. 134).

The other two classes of Palangana cutmarks are much more distinct and reveal unique behaviors. Given the nature of gash cross-sections this is the only cutmark class that is likely to have resulted from the use of saws and/or axes, and therefore the most likely activity producing these cuts would be removing meat from caches. Since the meat and bones in caches are frozen, a heavy-duty tool is needed to remove them, as Binford explains:

> Different butchering methods are therefore used for initial and secondary butchering during seasons characterized by freezing temperatures. During all season of the year the hunter generally initially butchers before the body of the animal is frozen. A sharp cutting instrument is the butchering tool and dismembering is accomplished by cutting between the articular ends of bones, thereby leaving the bones intact. During seasons characterized by freezing temperatures, an animal cached overnight will be frozen, so secondary field butchering must be accomplished on a frozen body. A knife or small sharp butchering instrument is inefficient and an ax or a saw is used (Binford, 1978, p. 50).

Thus, gashes are probably an indicator of delayed consumption and the transport of meat from the kill, to a cache, and then to a consumption site. The nature of wedges on the other hand, i.e., two corresponding cuts making a v-shape, suggests a degree of intentionality which certainly plays into their function. One

Table 10
Percent of elements cutmarked by cluster.

Cluster		Element						
		Femur (%)	Humerus (%)	Metacarpal (%)	Metatarsal (%)	Radio-Ulna (%)	Tibia (%)	Total (%)
1	% Cutmarked	0.00	0.00	0.00	25.00	20.00	0.00	8.33
2	% Cutmarked	0.00	0.00	8.33	19.23	0.00	0.00	8.86
3	% Cutmarked	13.51	8.70	5.71	5.95	8.11	6.67	8.56
4	% Cutmarked	23.81	14.55	7.32	11.48	14.49	5.88	12.13
5	% Cutmarked	50.00	28.57	0.00	50.00	66.67	0.00	33.33
6	% Cutmarked	10.87	6.57	13.27	6.19	5.00	13.95	7.98
Total		13.17	9.62	9.31	8.97	7.89	9.64	9.42

Table 11
Cutmark classes by cluster.

Cluster		Cutmark class				
		Gash	Nick	Slice	Wedge	Total
1	Observed	0	4	2	3	*9*
	Expected	0.46	5.2	2.55	0.79	
	Cell x^2	0.4611	0.2773	0.1167	6.1419 [a]	
	% in Class	0.0	1.4	1.5	7.0	
2	Observed	7	12	7	2	*28*
	Expected	1.43	16.18	7.92	2.47	
	Cell x^2	21.594	1.08	0.1064	0.0885	
	% in Class	28.0	4.3	5.1	4.7	
3	Observed	1	40	33	4	*78*
	Expected	3.99	45.07	22.06	6.87	
	Cell x^2	**2.2462**	0.5711	**5.4286**	1.2009	
	% in Class	4.0	14.2	24.0	9.3	
4	Observed	5	97	43	14	*159*
	Expected	8.15	91.88	44.97	14.01	
	Cell x^2	1.2147	0.2852	0.0857	0	
	% in Class	20.0	34.4	31.2	32.6	
5	Observed	0	21	3	0	*24*
	Expected	1.12	13.87	6.79	2.11	
	Cell x^2	1.2295	**3.6667**	2.113	2.1148	
	% in Class	0.0	7.5	2.2	0.0	
6	Observed	12	108	50	20	*190*
	Expected	9.73	109.8	53.73	16.74	
	Cell x^2	0.5277	0.0293	0.2589	0.6341	
	% in Class	48.0	38.3	36.2	47.0	
Total		25	282	138	43	*488* [b]

$x^2 = 51.473$, df = 15, $p < .001$.
[a] Cell x^2 is suspect, expected value is too small.
[b] $n = 488$ since one cutmarked bone with two cutmarks was a spatial outlier and removed.

possibility is that wedges were created to serve as a lashing point for hanging or transporting meat. Neither gashes nor wedges occur in every spatial cluster like nicks and slices, further implying that unique and specific generative behaviors were producing these marks, behaviors which were either less common or spatially restricted. Both wedges and gashes are most common on the metapodials which suggest that these elements are commonly cached and transported.

Additionally, wedges have interesting relationships with both nicks and slices. First, nicks and wedges occur next to each other significantly less often than expected, which suggests that the behaviors generating these classes are distinct. Second, slices and wedges have opposite distribution patterns since wedges are significantly overrepresented on metacarpals but underrepresented on radio-ulnae, and slices have the reverse pattern. While radio-ulnae and metacarpals are comparable in terms of marrow utility, metacarpals are the lowest ranking element in terms of overall food utility (see Fig. 6 in Waguespack, 2002). This provides additional evidence that slices are more likely than wedges to be associated with consumption.

Archaeology

Given the interpretation of the cutmark classes combined with the specific attributes of each spatial cluster, an archaeological interpretation of Palangana is possible. Five lines of evidence will be utilized in the interpretation of each cluster: (1) cutmark class presence/absence, (2) the representation of epiphyses and diaphyses, (3) the representation of specific elements, (4) the frequency of cut bone, and (5) the size of bone fragments. The unique character of each cluster provides evidence of the economic activities performed in these areas of the site, for instance, since gashes are evidence of delayed consumption, their presence or absence will be used to interpret types of consumption patterns at Palangana.

Cluster 1 is most likely an area of *immediate consumption* due to the lack of gashes combined with the nearly equal representation of epiphyses to diaphyses, suggesting that the entire bone was present. In addition, this cluster has a similar cutmark class distribution to Cluster 5; they are the only two clusters that lack gashes.

Cluster 2, given its high proportion of marrow bones (e.g. metapodials) and the highest presence of gashes, is likely a *marrow-processing* area with many bone fragments further processed after *delayed consumption.* The fact that epiphyses are significantly overrepresented supports this interpretation since marrow-processing differentially targets bone shafts, leaving few identifiable diaphysis fragments.

Ninety percent of the bones in Cluster 3 are diaphyses, and all classes of cutmarks including gashes are present and it is therefore an area of where consumption and/or cleaning refuse, again with at least some bones demonstrating evidence for *delayed consumption*. This area was most likely not one where extensive processing, such as grease rendering took place due to the large number of identifiable shaft fragments and limited bone fragmentation.

Cluster 4 also has gashes indicating an area of *delayed consumption*. The distribution of cutmark classes is most *similar* to Cluster 6, and this cluster (like Cluster 2) had a significant overrepresentation of epiphyses suggesting that the processing of shafts either for marrow extraction or tool manufacture was practiced.

Cluster 5 has the largest bone fragments, the highest frequency of cutmarks overall, as well as for epiphyses specifically and the following elements: femur, humerus, metatarsal, and radio-ulna. This cluster, which lacked gashes like Cluster 1, is the only group lacking wedges. The combination of these different lines of empirical evidence suggest that Cluster 5 represents an area of *immediate consumption*, where the entire or the majority of the carcass was butchered and consumed; this can be inferred because so many epiphyses and lower-utility marrow bones are present. Lastly, Cluster 5 has a significant overrepresentation of nicks providing further evidence that nicks are created during meat consumption; this can be inferred because there is no evidence for post-consumption processing in this cluster.

Cluster 6 has the lowest frequency of cutmarked bones overall and has the highest occurrence of cutmarked metacarpals and tibiae, both high-utility marrow elements. This cluster also has the majority of all the cutmark classes compared to the other clusters. Additionally, the smallest bone fragments are found in this cluster. This evidence suggests that Cluster 6 was an area of *delayed consumption* and extensive *post-consumption processing*.

Ethnoarchaeology

Binford provides a description of Palangana based on his excavation and information from his Nunamiut informants (see Binford, 1978, pp. 431–435). His description of House 1 and an additional structure are as follows:

> House 1 was large, a rough circle 6.5 m in diameter. In the center was a substantial inside hearth with a rock lining. The house was an *invulik*, or moss-covered, willow-framed house…The entry was to the west. Approximately 4 m west and slightly north of the entryway was a large dump of marrow-bone splinters. Beyond this dump, in an arc along a small ditch approximately 11 m from the entryway, was the dog yard…Approximately 9.5 m southwest of the entryway was a number of fire-cracked rocks and bone meal deposits from the manufacture of bone grease…Sixteen meters directly west of the entry to the house, and located in a low area, were the remains of a small *itchelik*, or skin tent. There was an oval distribution (roughly 4 × 5 m) of stone tent weights…This structure has been identified as the tent occupied by the male work party that built the winter house (1978, p. 431).

In addition to these two structures, a second house was located north of House 1 and was partially excavated. This residence had similar features to House 1 and was occupied contemporaneously (Binford, 1978, p. 434). A site map of Palangana was reconstructed (Fig. 3) (see also map in Binford, 1983, p. 183).

Comparing ethnographic and archaeological data

Binford's ethnographic descriptions correspond remarkably well with the archaeological interpretation of Palangana. When the maps are placed one above the other, the *k*-means derived clusters used for the archaeological analysis match the structures identified by Binford (Fig. 4). House 1 (Cluster 6) was surely an area of delayed consumption and post-consumption processing as the family ate meat removed from caches over the winter and processed the bones for grease and marrow. This interpretation is supported by Enloe's previous work on caribou remains from a cooking dump inside Palangana's house. Enloe concluded that both meat and marrow were consumed inside the house (1993, p. 85). The archaeological interpretation of Cluster 5 as an area of immediate consumption corresponds with a brief occupation of males hunting caribou while residing in the *itchelik*. The area of Cluster 2 corresponds to the dump-site of marrow bone splinters outside House 1 identified by Binford which supports the archaeological interpretation of a marrow-processing area with evidence of delayed consumption. Given these ethnographic descriptions of Clusters 2, 5, and 6 we can hypothesize what the other clusters may represent, given the archaeological evidence and Binford's ethnographic descriptions.

Cluster 3 is most likely a bone refuse dump associated with Palangana's house. Cluster 4, given its location, size, and similarity to Cluster 6, is most likely the second house excavated by Binford. Cluster 1, given its archaeological similarity to Cluster 5, may be the site of another male work tent, perhaps the party responsible for building the other winter homes. Additionally, according to Binford's description, the empty area between the *k*-means Cluster 3 and 5 was a dog yard, and the empty area southwest of Cluster 2 was a bone grease manufacturing site. These activities easily explain why there are no identifiable limb bone fragments recovered from these areas due to the severe fragmentation that results from dogs and grease rendering (Fig. 2).

Discussion

The number and density of cutmarks on bone shafts at Palangana are higher than might be assumed. The assumption might have been that epiphyses would have denser concentrations of cutmarks from dismembering activities since epiphyses are the loci for muscle and tendon attachments. The Palangana data suggest

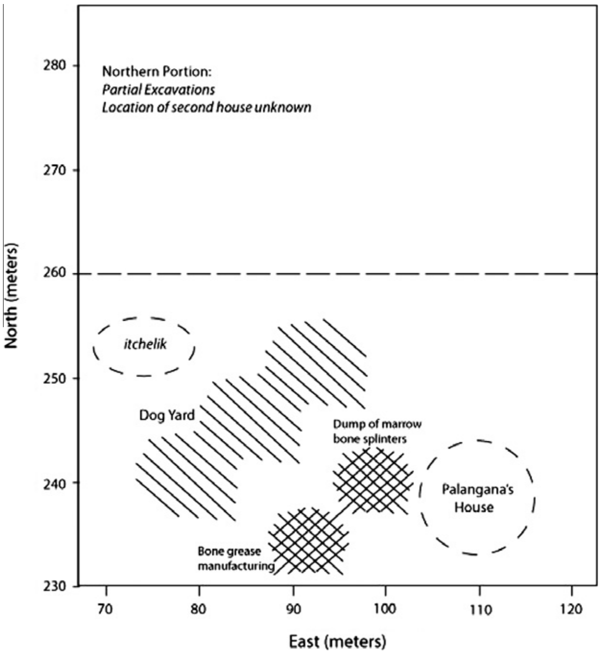

Fig. 3. Reconstructed site map with Binford's identified features.

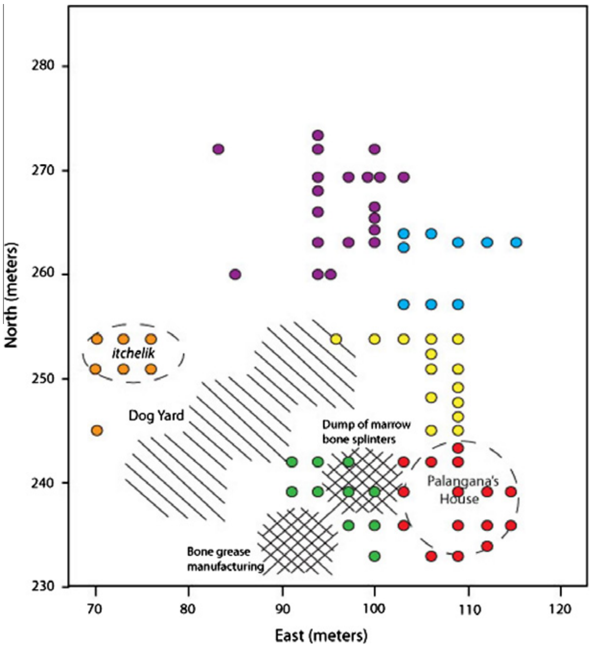

Fig. 4. Reconstructed site map overlaid with the *k*-means derived clusters.

that subsistence activities produced a noteworthy number of cutmarks on bone shafts as well as the ends.

While the focus of this study was on cutmarks systematics, a complete zooarchaeological and specifically taphonomic study of the Palangana assemblage would likely lend additional support to the inferences made in this research connecting specific types of cutmarks to different subsistence behaviors. A detailed understanding of fragmentation, burning, gnawing, and utility measures for each element would provide independent and testable expectations for specific subsistence behaviors including marrow extraction, grease rendering, and meat consumption. A complete zooarchaeological analysis will also help to confirm that the cutmark distributions described here are the result of human behavior rather than the physical properties of the bones or bone portions themselves.

Whereas limb bones were chosen since they represent butchering "hot spots," the incorporation of the axial skeleton and additional appendicular elements in future analyses would be important in order to address the topic of cutmark variability on the entire animal, and to address the possibility that different portions of the animal were butchering and consumed differently. Additionally, cutmarks on caribou and Dall sheep remains at Palangana would be beneficial to compare in order to address variability across species. This may be especially interesting since patterns of consumption and meat sharing are thought to differ between these animals (Binford, 1984a). The inclusion of the all the faunal remains and artifacts would also provide additional details for the overall reconstruction of the site.

The major strength and limitation of the Palangana sample is the site's brief occupation. Since habitation at the site was short, this analysis did not have to deal with temporal change which often masks or blurs some of the patterning. However, due to the short occupation, the sample is inadequate to address change through time. Future investigations considering the longer term effects of formation processes or behavioral change will need a different kind of archaeological sample. Importantly, although the Palangana site is not suitable for these research questions, the cutmark methodology developed in this study can be used to address the changing nature of cutmarks and their associated behaviors, revealing diversity in butchering, processing, and consumption patterns over time and space.

Conclusion

Using only caribou limb bones and their cutmarks for these analyses effectively allowed an inferential reconstruction of the Palangana site as ethnographically described to Binford. The rigorous analysis of Palangana cutmarks not only provided a detailed picture of subsistence behavior but also one that extended aspects of this behavior that were not ethnographically identified by native informants. This archaeological analysis identified specific areas and different types of consumption and processing behavior. The identification of other areas of the site not specifically mentioned by ethnographic informants demonstrates the predictive value of the methods developed in this case study.

Combining quantified cutmark classification with spatial analysis is a method that can be used to compare and evaluate cutmarks, isolate diagnostic traces of prehistoric behavior, and illuminate intra-site variability. Despite their susceptibility to modification by humans and post-depositional processes, cutmarks are an important line of archaeological evidence. Their widespread occurrence can be used to address anthropological questions at various temporal and spatial scales, from long-term trends over a large geographic area, such as a comparison of human and Neanderthal butchering techniques, to revealing diverse contemporaneous behaviors at a single site like Palangana.

This study revealed that while individual striae are important to identify, the relationships between cutmarks on a single bone may also be revealing of prehistoric behaviors. Refining our methods for addressing variability regarding individual cutmarks, their relationships, anatomical position, and spatial relationships can move us towards more detailed and meaningful behavioral interpretations of faunal remains so that we can infer patterns of consumption and sharing and may in some instances extend even to certain inferences of social organization and other behaviors. I believe that the approach of classification and analysis of the Palangana cutmarks attempted in this study may be fruitfully extended to and compared with studies of cutmarks in other archaeological assemblages.

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