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Ancient Alaskan Fuel Selectivity Strategies

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ABSTRACT. In ancient Alaska, people allocated wood, bone, and oil for both fuel and non-fuel purposes, which required careful management. By examining these resources through the lens of human behavioral ecology (HBE) and the principle of least effort (PLE), we can understand fuel use—especially woody fuel use—from the standpoint of selectivity, wherein ancient people considered energetic output, handling costs, and state when choosing fuel sources. At any given site, some degree of firewood selectivity, ranging from complete indifference to marked discrimination, would have been most advantageous. Accordingly, ancient Alaskans at Cape Espenberg, Gerstle River, Hungry Fox, and Walakpa would have employed different fuel management strategies tailored according to their evolving needs. Results suggest that firewood indifference was more common, and that selectivity was advantageous only at longer-term occupations where fuel was abundant. Otherwise, proximity and handling costs trumped the benefits of taxon-specific selectivity, which is a strategy meant to confer desired combustion outcomes. Detecting when and where it was beneficial for ancient Alaskans to be selective grants insight into how they categorized fuel and adapted their fuel selection behaviors to fit particular circumstances. Moreover, the restrictions imposed by finite fuel availability have general implications for settlement patterns and mobility that may help trace ancient migration routes as hunter-gatherers leap-frogged from one fuel patch to another.

Keywords: Alaska; Birnirk; Denali; firewood; fuel; human behavioral ecology; Nuñamiut; principle of least effort; selectivity; Thule

RÉSUMÉ. Dans l'Alaska ancien, les peuples se servaient de bois, d'os et d'huile comme combustibles et à d'autres fins, ce qui nécessitait la gestion soigneuse des ressources. L'examen de ces ressources en fonction de l'écologie comportementale humaine et du principe du moindre effort nous permet de comprendre l'usage des combustibles – surtout l'usage des combustibles à base de bois – du point de vue de la sélectivité, les peuples anciens faisant leurs choix en tenant compte de l'énergie produite, des coûts de manutention et de l'état des sources de combustibles. À n'importe quel endroit, un certain degré de sélectivité à l'égard du bois à brûler, allant d'une indifférence complète à une discrimination marquée, aurait été des plus bénéfiques. Par conséquent, les anciens Alaskiens de Cape Espenberg, de Gerstle River, de Hungry Fox et de Walakpa auraient employé des stratégies différentes de gestion des combustibles en fonction de leurs besoins évolutifs. Les résultats suggèrent que l'indifférence du bois à brûler était plus courante et que la sélectivité n'était avantageuse qu'aux occupations de plus longue durée où se trouvaient des combustibles en abondance. Sinon, la proximité et les coûts de manutention éclipsaient les avantages de la sélectivité propre au taxon, une stratégie servant à produire les résultats de combustion désirés. Le fait de détecter à quel moment et à quel endroit il était bénéfique pour les anciens Alaskiens de faire preuve de sélectivité permet de voir comment ils catégorisaient les combustibles et comment ils adaptaient leurs comportements de sélection des combustibles en fonction des circonstances. De plus, les restrictions découlant de la disponibilité limitée de combustibles avaient des incidences générales sur les tendances de peuplement et la mobilité, ce qui pourrait aider à tracer les anciennes voies migratoires des chasseurs-cueilleurs qui passaient d'un lieu de combustible à l'autre.

Mots-clés : Alaska; Birnirk; Denali; bois à brûler; combustible; écologie comportementale humaine; Nuñamiut; principe du moindre effort; sélectivité; Thulé

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INTRODUCTION

Long, dark, and frigid Alaskan winters make fuel as important to survival as food and fresh water (Burch, 2006). To thrive in their harsh environment, ancient Alaskans would have needed to effectively procure and manage fuel stores. Bone, oil, and wood were multi-purpose resources needed not only for heat and light, but also for various other critical economic activities, like building, making tools, and more. Alaskans would have selected these resources with such ends in mind while considering and operating within given environmental and energetic restrictions.

While this research examines the role of bone and oil, it is mostly concerned with firewood. There are two main ways archaeologists have understood firewood selectivity. Most commonly, archaeologists have employed the

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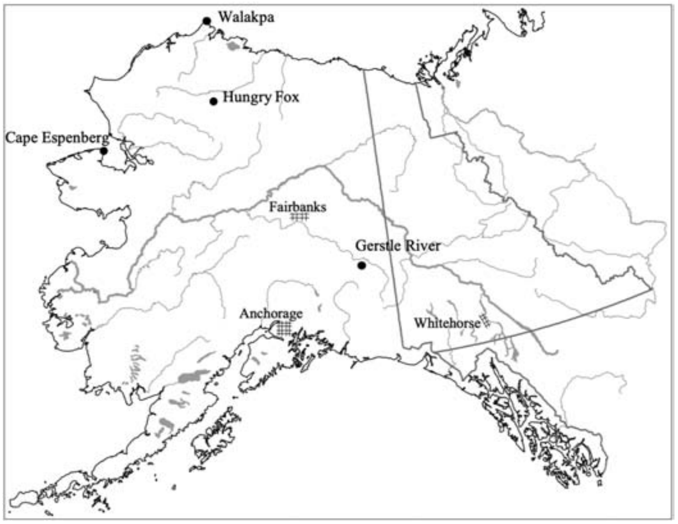

FIG. 1. Map of site locations.

principle of least effort (PLE), which proposes that people collected firewood more or less indiscriminately (see Marquer et al., 2010; Miszaniec, 2014; Joly et al., 2017). For the PLE, the main selection criterion is proximity, which minimizes the energy expended in gathering firewood. Only when firewood is abundant do foragers take state into account as well (i.e., moisture content) (Shackleton and Prins, 1992).

Less commonly, archaeologists have explored firewood selectivity using human behavioral ecology (HBE) models like the diet breadth method (DBM) (see Deo Shaw, 2008; Marston, 2009). Adapted from prey models, the DBM ranks firewood taxa according to their net energetic yield. The DBM predicts that foragers will select the most energetic taxa available, switching over to less energetic taxa as they exhaust more energetic ones (Kelly, 2013). Alongside energetic output, foragers will consider the amount of time and energy it took to procure and handle (i.e., cut and haul) firewood. Despite the wide gap between these two understandings, the evidence in support of both suggests that firewood selectivity porbably existed along a continuum, from DBM-like taxon-specific selectivity, to a complete disregard for both taxon- and state-specific properties akin to the PLE.

Selectivity can be measured as the divergence between archaeological taxon ratios and paleoenvironmental reconstructions, with greater divergences related to greater selectivity and vice versa. Where inhabitants adhered to the PLE, the proportions of woody taxa recovered from charcoal assemblages should closely match the proportion of locally available woody taxa. Alternatively, DBM-type selectivity should result in charcoal assemblages where there are disproportionately more highly ranked woody taxa and lesser quantities of low-ranked fuel wood, when compared to what was locally available.

Firewood gathering behavior would have necessarily been flexible, and Alaskans would have adjusted their fuel management strategies in keeping with changing conditions. Determining the nature of these conditions helps establish when and where a given fuel selectivity strategies would be the most advantageous. By identifying wood charcoal at four sites, Cape Espenberg, Hungry Fox, Gerstle River, and Walakpa (Fig. 1), this exploratory research attempts to uncover what firewood preferences, if any, existed in antiquity, and how those preferences were related to adaptive challenges.

Because of their differences, the Cape Espenberg, Hungry Fox, Gerstle River, and Walakpa sites were useful for studying fuel management and selectivity. These sites were occupied at different times by people with distinct cultures and technologies who experienced diverging climates, availability of resources, and other factors (Table 1). By comparing these sites, we may begin to understand how such variables influenced behaviors related to fuel.

BACKGROUND

Firewood Selectivity: The Diet Breadth Model

Undoubtedly, ancient Alaskan foragers had extensive knowledge about their landscapes and resources, including taxon-specific firewood properties. Certain properties would have increased or decreased the perceived value of any given firewood species, including energetics. As per the DBM, I approximate firewood energetics here as the relationship between caloric output (heat) and how difficult it is to cut and haul wood (density). I measure calories in kj/g and density as specific gravity (g/cm^3). Theoretically, whenever the DBM applies, the most desirable firewood should be highly energetic, low-density wood, which would maximize energetic output and minimize energetic expenditure. In reality, however, density is positively correlated with energetics, so harder woods are typically more energetic than softer woods. Foragers would also want to minimize energetic costs by targeting nearby firewood, although they might travel longer distances for firewood needed for a specific purpose.

To understand how ancient Alaskans ranked and selected firewood we must consider the properties of different woody taxa. Unfortunately, in Alaska, it is nearly impossible to identify wood charcoal to the species level, and identifications are typically limited to the genus level. In this paper, when I refer to a tree by its common name, I am including all Alaskan species within that genus. Within a genus, however, different species may have different densities or variable heat outputs. As such, the net energetic gain of any woody taxon must be averaged across species within genera.

Woody Taxa Profiles: I recovered six taxa: alder (*Alnus* sp.), aspen/cottonwood/poplar (*Populus* sp.), birch (*Betula* sp.), spruce (*Picea* sp.), tamarack/larch (*Larix* sp.) and willow (*Salix* sp.) (Fig. 2). On average, birch species burn hottest, followed by spruce, alder, larch, willow, and *Populus* species. Birch is the densest genus, then larch,

TABLE 1. Site, culture/complex, date of occupation, landform, and available fuel types.

Site	Culture/Complex	Date	Landform	Available fuel
Cape Espenberg	Late Thule	300–500 BP	Treeless coastal dune complex	Driftwood, shrubs, bone, sea mammal oil
Hungry Fox	Nuñamiut	480–550 BP	North Slope riparian	Shrubs, bone, tallow, maybe sea mammal oil (through trade)
Gerstle River	Denali	11,250–9700 BP	South facing bedrock knob	Standing and dead wood, shrubs, bone
Walakpa	Birnirk, Thule	1200–900 BP	Treeless coastal bluff	Driftwood, bone, sea mammal oil

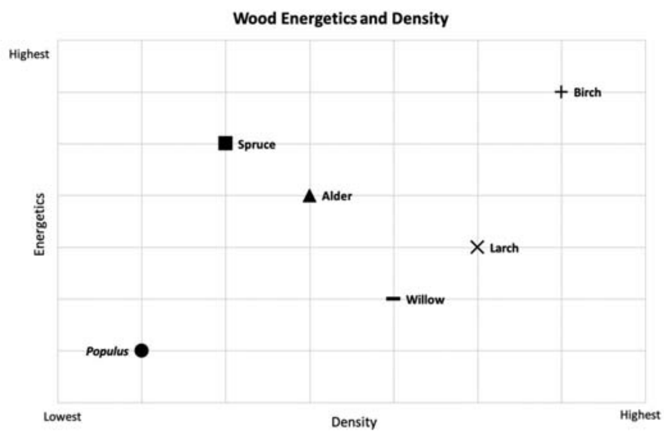

FIG. 2. Comparing density and energetics of Alaskan woody taxa (values averaged from Alaska Department of Natural Resources, 1996; Deo Shaw, 2008; Brackley et al., 2010; Wilson et al., 2010).

willow, alder, spruce, and the *Populus* sp. genus (values averaged from Alaska Department of Natural Resources, 1996; Deo Shaw, 2008; Brackley et al., 2010; Wilson et al., 2010). Ethnographic accounts show that Alaska Natives considered many variables when selecting firewood, not just density and energetic output, although these were important considerations.

Alaska Natives generally consider birch, alder, and spruce to be good firewood. Birch burns slow and hot, but its density makes it challenging to fell, even with modern tools (Anderson et al., 1988; Alix and Brewster, 2004; Deo Shaw, 2012; Steelandt et al., 2013). Alder is also preferred because it is hot and slow burning (Anderson et al., 1988; Burch, 2006; Deo Shaw, 2008). Spruce is widely desirable because it burns hot and is only moderately dense (Osgood, 1958; Shinkwin and Case, 1984; Nelson, 1986; Anderson et al., 1988). It is also the most common genus in Alaska's boreal forest and in driftwood assemblages in the north and northwest (Eggertson, 1994; Alix, 2004, 2005, 2008). Larch, despite being moderately energetic, is scarce as both driftwood and timber, and thus infrequently burned. Willow is often a staple firewood due to its abundance. It is less dense than some other taxa, which makes it easier to handle. It also burns cooler than most taxa, making it a better choice of fuel during warmer months (Smart and Hoffman, 1988).

There is no single common name for the multi-species *Populus* sp. genus. On average, this genus has the lowest densities and energetic outputs of any other recovered genera, though these values vary by species. *Populus* sp. wood is soft and easy to manipulate, but its cool burning temperatures are most desirable in warmer weather (Smart and Hoffman, 1988). Some *Populus* species are very ashy, making them a poor choice for burning indoors, but good for mosquito smudging (Burch, 2006) and smoking fish (Alix and Brewster, 2004; Wheeler and Alix, 2004; Deo Shaw, 2008). For some groups, past and present, *Populus* was the last or near-last firewood option considered, and this wood would more often be put to other non-fuel uses (Anderson et al., 1988; Burch, 2006; Alix, 2009a, Crawford, 2020).

Bone and Oil: Firewood was not the only fuel source available to ancient Alaskans. Animal-derived oil (especially sea mammal oil) and bones were critical components of the fuel economy (de Laguna, 1940; Ford, 1959; Anderson, 1984; Bigelow and Powers, 2001; Mason et al., 2001; Hoffecker and Elias, 2003; Lee and Reinhardt, 2003; Burch, 2006; Hoffecker and Elias, 2007). These fuels could be burned in various proportions and combinations, creating fires with different combustion properties that could be tailored for specific uses. Moreover, Alaskans could manage their fuel stores through the preferential consumption or conservation of certain fuel types. Like firewood, bone and oil likely existed within a shifting, ranked hierarchy. Because bone, oil, and wood all have non-fuel purposes, their importance as fuel would have waxed and waned according to the quantity of other fuel types and the needs of the group.

Sites

Cape Espenberg, The Rising Whale Site: The first site I considered was the Rising Whale site at Cape Espenberg. There are multiple house sites within the Rising Whale site, two of which mentioned here are KTZ-087 and KTZ-088. Cape Espenberg is the northernmost extension of the Seward Peninsula (Mason et al., 1997), just above the Arctic Circle. The spit is comprised of storm deposited late-Holocene beach berms under low dunes, interspersed with marshy swales and thaw ponds and is surrounded on three sides by Kotzebue Sound and Chukchi Sea (Mason, 1990; Mason et al., 1997). People inhabited the area intermittently for over 4000 years (Harritt, 1994; Tremayne, 2015), and at about AD 1200 a dense Thule occupation appears to have been established there. Features 68A and 33 are two Thule occupation houses within the Rising Whale sites KTZ-087 and KTZ-088 respectively.

Two radiocarbon dates from a caribou rib bone and the outer ring of a spruce tunnel post (2σ 1729–1920 cal AD and 1730–1926 cal AD, respectively), paired with the absence of European trade goods, suggest that Feature 33 is a precontact, late Western Thule–era dwelling dating to the late seventeenth or early eighteenth century. Feature 68A is slightly older than Feature 33, dating to the Intermediate Kotzebue period between AD 1495 and AD 1614 (on caribou bone: 140 ± 40 RCYBP; 260 ± 40 RCYBP; 355 ± 27 RCYBP and 395 ± 15 RCYBP). Both houses are typical late–Western Thule winter dwellings: they are semi-subterranean sod structures with robust wooden frames, sunken entrance tunnels, and rear sleeping platforms in the main living spaces. Note that this latter feature is implied for 68A, which was not fully excavated. There are also two burned features (F33-1 and F68A-1), one near each of the houses. Both features contained dense concentrations of charcoal; small, burned bones; and hard, cement-like clinker, which is a mixture of hardened sea mammal oil and sand.

F33-1 was part of a potentially attached, covered kitchen area (Hoffecker and Mason, 2010). F68A-1 is more obviously disconnected from its associated house structure, and there are no apparent associated architectural elements. It has been interpreted as an open-air summer cooking or ceramic firing feature, a conclusion drawn from the presence of a reddish, possibly burned, clay-covered area (Darwent et al., 2013).

The inhabitants of Features 68A and 33 had access to three main types of fuel: wood, bone, and sea mammal oil. In western Alaska, plentiful driftwood deposits are typically replenished annually (Alix, 2005, 2009a), and this was likely true for Cape Espenberg as well (Crawford, 2020). Moreover, Thule people relied heavily on oil lamps for light, heat, and cooking, and Feature 33's living area yielded an in situ oil lamp (Crawford, 2012).

If the occupants of Features 68A and 33 adhered to the PLE, wood charcoal assemblages should closely resemble local driftwood accumulations, as approximated by contemporary driftwood accumulations surveyed nearby. However, if the DBM prevailed, charcoal assemblages at these houses should be dominated by highly ranked firewood taxa (i.e., alder, birch, and spruce) because foragers could afford to ignore lower ranked taxa (i.e., willow and *Populus* sp.).

Gerstle River: Gerstle River is a multi-component Denali tradition site located in eastern Alaska near the town of Delta Junction, 1.6 km east of the Gerstle River in the Tanana Valley. It consists of an upper and lower locus and sits atop a southern facing bedrock knob overlooking an outwash plain. The site is long-lived and ancient, with the earliest human occupation dating to 11,250 BP, and the latest dating to 9700 BP (Potter, 2005).

Component 3, which is in the site's lower locus, is the focus of this study. This short, fall occupation lasted less than a day to a few days at most and seemingly served to process large mammals killed nearby (Potter, 2005). Dating to around 10,000 BP, it has a rich, undisturbed collection of well-preserved archaeological remains, an intact living floor, and 10 likely-contemporaneous, unlined hearths containing ample wood charcoal (Potter and Reuther, 2012). The lack of paleosol formation suggested that the site was buried quickly (Potter, 2005; Potter et al., 2011; Potter and Reuther, 2012).

Component 3 was occupied during a time in which birch and willow dominated pollen assemblages in the Tanana Valley, with increasing amounts of poplar (Bigelow, 1997). Contemporary pollen assemblages recovered specifically from Tanana Valley lake cores (Bigelow and Powers, 2001) show the predominance of birch in the region, followed by spruce, willow, *Populus* sp., and finally alder. Palynological records, however, can be problematic when trying to recreate local paleoenvironments (Birks and Birks, 2006; Jørgensen et al., 2012).

If the inhabitants of Gerstle River adhered to the PLE, charcoal assemblages should closely resemble the composition of locally growing woody vegetation, as approximated by pollen records. Otherwise, if DBM-like selectivity prevailed, anthracological assemblages should contain greater proportions of higher ranked taxa (i.e., birch) and lesser proportions of lower ranked taxa (i.e., *Populus* sp.).

Hungry Fox: Hungry Fox is located in Gates of the Arctic National Park and Preserve. It overlooks a shallow side channel of the Killik River, directly opposite a large, willow-covered island in the southern mouth of Toguyuk Creek. Site investigations over the years have revealed the presence of a single, dense midden layer containing ample stone, slate, bone, antler, wood, and charcoal remains (Rasic, 2006). Bone is the most numerous artifact class (Scheidt, 2013), but the site also contains extremely large quantities of charcoal. The zoological remains suggest people occupied Hungry Fox during the winter and spring, pursuing caribou, ptarmigan, and ground squirrel (Scheidt, 2013). Radiocarbon dates, paired with diagnostic artifacts (e.g., pottery, semi lunar–shaped slate knives), show that Hungry Fox was a late prehistoric Nuñamiut site dated to 480–550 BP (Spearman, 1992; Scheidt, 2013).

If the inhabitants of Hungry Fox adhered to the PLE, the charcoal assemblage should closely resemble the composition of locally growing woody vegetation (mostly willow and some birch). Greater degrees of taxon-specific selectivity would be evidenced by larger quantities of wood charcoal from nearby, highly-ranked taxa (i.e., birch), and perhaps quantities of highly-ranked taxa that grew farther away (i.e., alder and spruce).

Walakpa: The Walakpa site is situated atop a bluff overlooking the Chukchi Sea, 19.3 km southwest of Utqiagvik. It is deeply stratified, containing Arctic Small Tool tradition (ASTt) remains as old as 3450 BP, though most research at the site has focused on the Birnirk- and Thule-era occupations dating to ~1500–500 BP (Stanford, 1976). Unfortunately, Walakpa is highly endangered due to climate change. Permafrost thaw has destabilized its bluff face, and ever stronger, more frequent storms have led to its severe and rapid erosion. Bluff face erosion exposed a deep, unbroken profile rich in archaeological remains, which made it possible to take soil samples from the entire height

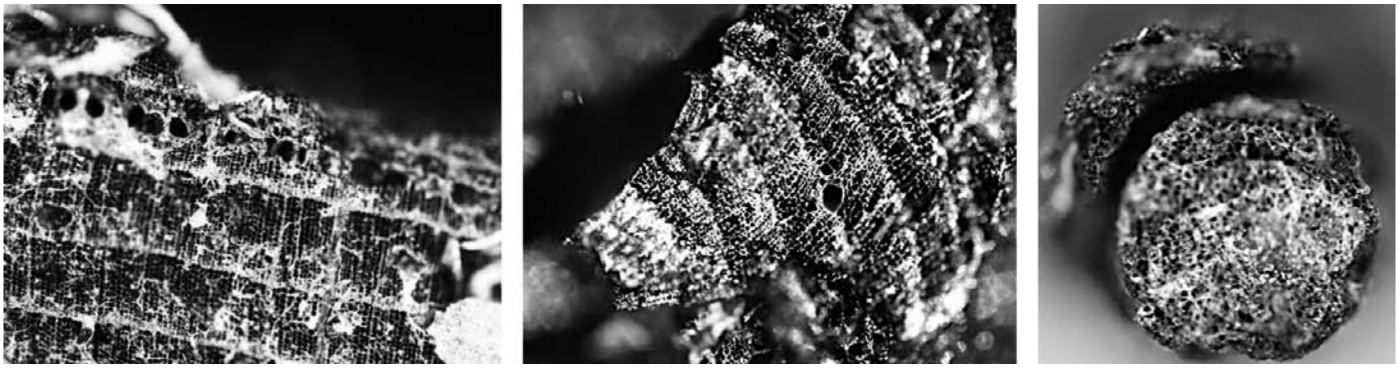

FIG. 3. Weak, moderate, and tight growth curvature.

of the bluff. The charcoal analyzed for this study comes from these deep and extensive midden deposits.

Like earlier archaeologists at Walakpa (see Stanford, 1976), I examined Northern Maritime tradition deposits. I chose to focus on Birnirk- and Thule-era deposits at Walakpa because I wanted to compare my findings against those from Cape Espenberg. Though the samples from Walakpa are older (~1200–900 BP) than those at the Rising Whale site (480–550 BP), they belong to the same broader cultural tradition.

Like at Cape Espenberg, the Birnirk and Thule inhabitants at Walakpa apparently burned driftwood, bone, and sea mammal oil. Driftwood here was typically renewed annually (Alix 2005, 2009a), and oil lamps were important for cooking, heat, and lighting. Evidence from Walakpa suggests that inhabitants often had access to all three fuel types in considerable quantities. If Walakpa's inhabitants adhered to the PLE, wood charcoal assemblages should closely resemble local driftwood accumulations, as approximated by contemporary driftwood accumulations. Otherwise, if they adhered to the DBM, highly ranked taxa (i.e., birch, alder, and spruce) should be overrepresented in the anthracological record, with lesser amounts of lower ranked taxa (i.e., willow and *Populus* sp.) when compared to contemporary driftwood accumulations.

METHODS

Anthracology

Charcoal fragments at a site originate from wood collected and burned as fuel, discarded wooden tools, construction materials. Identifying these charcoal fragments provides information about how different woody taxa were used and what woody species were locally available (Pearsall, 1988; Smart and Hoffman, 1988; Hastorf, 1999; Dufraisse, 2006; Marguerie and Hunot, 2007; Byrne et al., 2013). Charcoal found spread throughout occupation layers represents burning over a longer time period than charcoal concentrated in burned features (Heinz and Thiébault, 1998). Anthracologists identify numerous charcoal fragments to the highest taxonomic level possible, which in Alaska is almost always to the genus level. Using an incident light microscope, anthracologists observe microscopic structures in wood under 10–400x magnification, then compare those features against modern reference specimens or manuals.

In total I examined 3973 charcoal specimens for this research. However, the number of observations per context was invariably small due to the poor quality of anthracological samples. This, unfortunately, is typical for Arctic and sub-Arctic assemblages. Identifying many charcoal fragments and lumping categories and proveniences helped mitigate these limitations somewhat.

Growth Curvature

I examined growth curvature to estimate the original diameter of the trunk or branch from which charcoal fragments originated. Weaker growth curvature originates from a larger-diameter branch or trunk, whereas moderate or tight growth curvature charcoal fragments originate from smaller elements (Fig. 3). Because moderate and tight growth–curvature charcoal can also originate from the interior of large conifer trees, growth curvature estimates are imprecise. There are methods that allow for more precise wood diameter estimates (see Paradis-Grenouillet et al., 2010), but I did not need this level of precision. My aim was to discern whether there were general preferences for larger- or smaller-diameter tree or shrub sections, which helps to understand the energetic needs of ancient Alaskans. Larger wood sections may provide more energy overall than smaller sections, but they are more energetically expensive to handle. Small-diameter wood is often less energetically expensive to handle but may not provide as much energy. What diameter of wood Alaskans chose indicates the importance of handling costs versus energetic output. Diameter estimates may also give an idea of the size of available woody shrubs and trees.

Paleoenvironmental Comparisons

Paleoenvironmental reconstructions are crucial for detecting anthropogenic firewood selectivity. Discrepancies between the relative quantity of charcoal taxa at a site versus

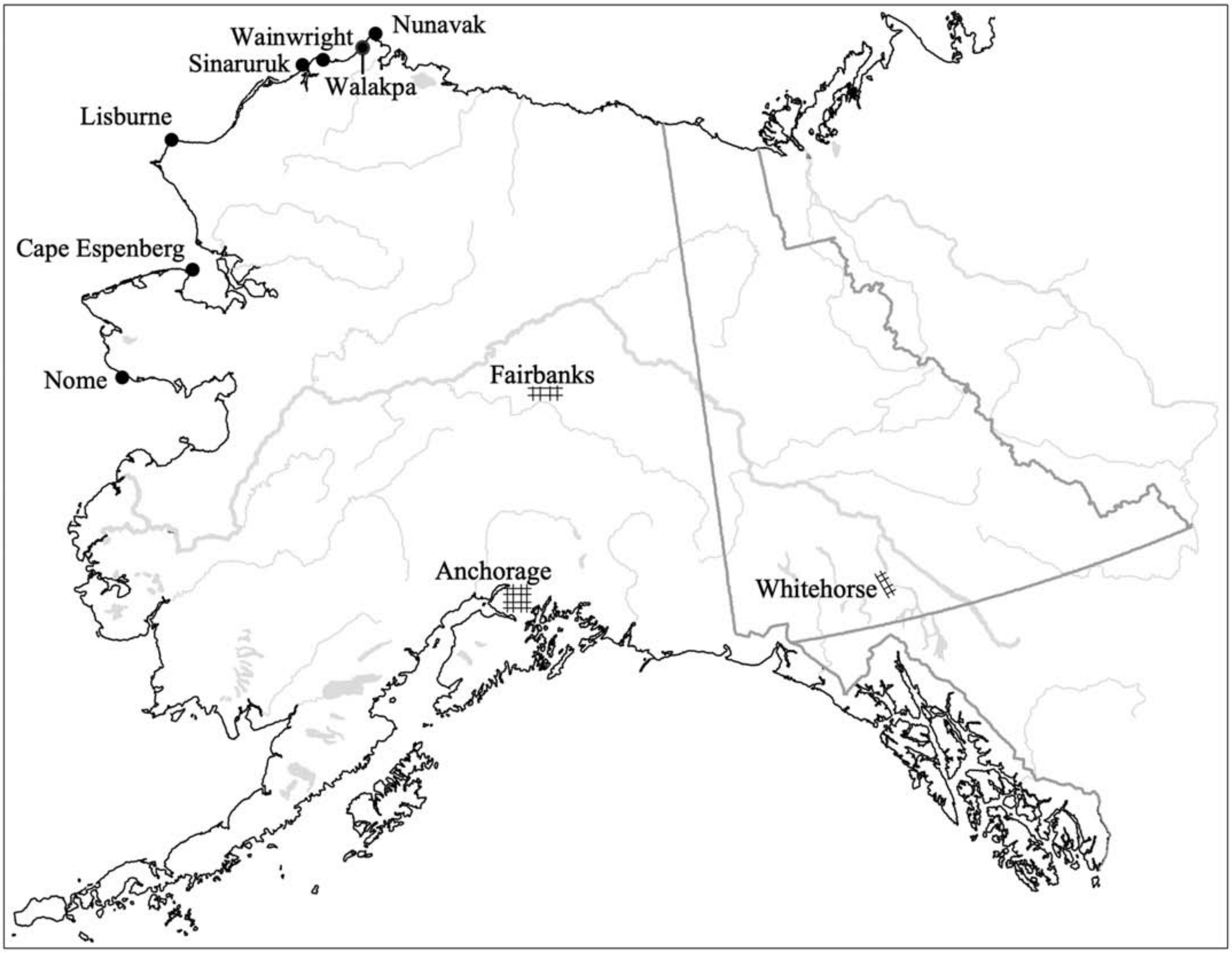

FIG. 4. Map of Cape Espenberg and Walakpa in relation to driftwood accumulation sites surveyed by Alix (2005).

their abundance on the landscape may indicate firewood preferences. To make these comparisons, anthracologists must always consider the natural and cultural forces that work in tandem to distort the anthracological record (Théry-Parisot et al., 2010). In practice, this often means working from insufficient, poorly preserved, or heavily biased samples. However, as long as anthracologists understand the limitations of our data, this does not preclude us from generating meaningful conclusions.

For all but Gerstle River, the modern environment is likely similar enough for comparison. At Hungry Fox, modern vegetation is likely similar to what existed during the site's occupation ~500 years ago (Anderson et al., 1988; Oswald et al., 1999). If so, Hungry Fox would have been overgrown with willow shrubs, as it is today. As such, the Nuñamiut at Hungry Fox had easy access only to birch and (mostly) willow shrubs. Other taxa like spruce, alder, and *Populus* might have grown too far away for regular use as firewood.

For Cape Espenberg and Walakpa, modern driftwood accumulations are very similar to those that existed during the occupation of these sites. The composition of Alaska's boreal forest, which is the origin of most driftwood in northwest Alaska, has changed little in the last 4000–6000 years (Alix, 2009b; Higuera et al., 2009). Moreover, the gyres that direct the flow and direction of driftwood have not changed significantly since Thule times (Alix, 2001, 2005). Alix (2005) surveyed driftwood accumulations at Cape Lisburne, Nome, Nunavak, Sinaruruk, and Wainwright (Fig. 4), and her study serves as the basis of comparison for Cape Espenberg and Walakpa.

Gerstle River, however, is so ancient that pollen records are the only basis for comparison. Yet, pollen records have limitations, and interpreting pollen assemblages is difficult. They cannot serve as an exact record of paleovegetation around the site due to biasing factors: pollen from different taxa may be overrepresented, underrepresented, or even absent (Jørgensen et al., 2012) because of pollen dispersal methods, the amount of pollen a plant produces, and differential preservation. Pollen is best understood as a measure of larger, more general trends rather than as the basis for fine-resolution reconstructions; the latter is what is ideally needed here.

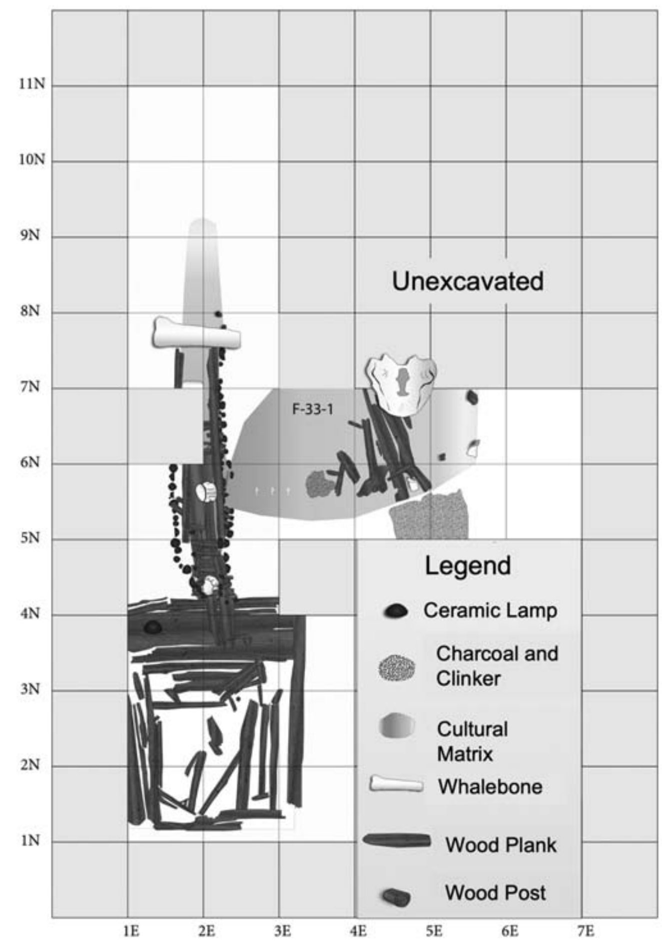

FIG. 5. Site KTZ-088, house Feature 33 showing all levels. Each square represents 1 m^2. Used with permission from John Darwent.

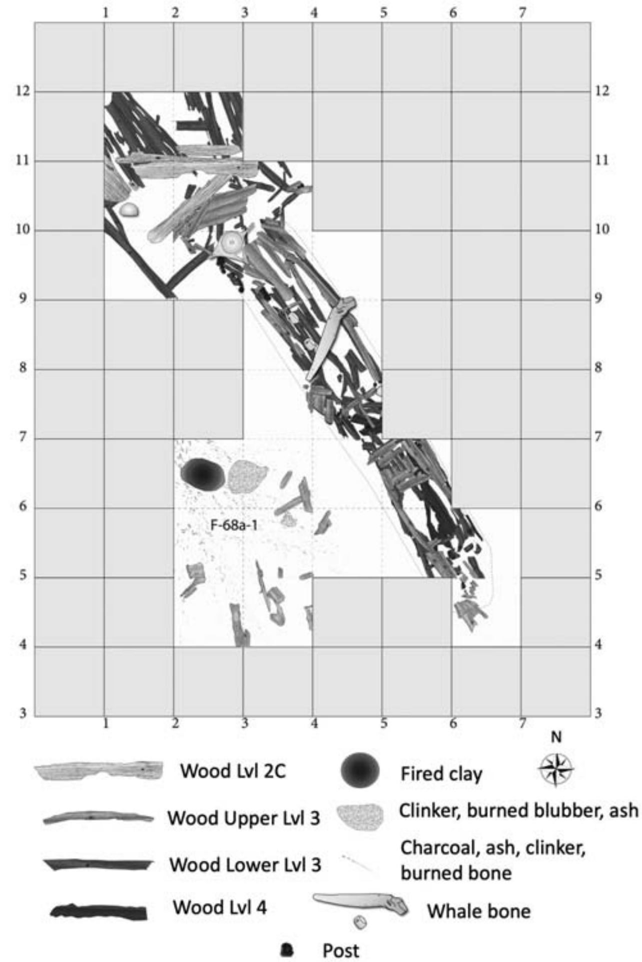

FIG. 6. Site KTZ-087, house Feature 68A showing all levels. Each square represents 1 m^2. Used with permission from John Darwent.

Sampling, Subsampling, and Identification

Cape Espenberg: Following the removal of overburden and fill layers, excavators took soil samples using a blanket scatter method, collecting one liter of sediment for each 10 cm layer in every 1 m^2 unit. We took 100% of the burned feature at Feature 33 (F33-1) but did not take bulk samples from the burned feature at Feature 68A (F68A-1) because it was not immediately recognized in the field. In total we took 237 soil samples from the cultural layers of Features 33 and 68A (Figs 5, 6), most of which were a liter in size. We floated these soil samples on site using a flotation system designed by Shelton and White (2010).

I selected 37 cultural samples (a total of 22.5 L of soil) for analysis from the tunnel, burned features, and main living areas. Each of these samples contained large quantities of well-preserved paleobotanical remains, often containing hundreds, if not thousands, of macrofossils and charcoal pieces per sample. I analyzed at least one sample from most 1 m^2 units of the occupation layer directly atop the houses' wooden floors. To reduce bias, I randomly selected 50 pieces of charcoal to identify per sample. Biodiversity is low enough in the Arctic and sub-Arctic so that identifying 50 pieces is typically sufficient to ensure data redundancy (Mooney, 2013). In total, I examined 1617 charcoal fragments from cultural units.

After sorting samples under low (10x) magnification, I counted the number of charcoal specimens, then identified sub-samples using a high-powered reflected light microscope (100 to 500×). To examine the microscopic anatomy needed for identification, I broke charcoal pieces to view the cross, tangential, and radial sections. I used reference collections, the InsideWood website (InsideWood, 2004–onwards; Wheeler, 2011; Wheeler et al., 2020), and written manuals (Panshin and de Zeeuw, 1980; Hoadley, 1990) to aid identification.

Gerstle River: Threatened by erosion, Gerstle River was a salvage project. Excavation occurred in both natural and arbitrary layers. After removing the overburden in natural layers, the team excavated the site in 10 cm levels until reaching sand. Upon reaching sand, the team excavated the site in 20 cm levels, and then again in natural levels once they encountered gray sand. They took charcoal samples from every stratigraphic unit. Excavators did not screen or wash the samples, but gently cleaned them in the field with a soft brush. I later sorted samples from screens in the lab following procedures described by Potter (2005). Because of the large amount of charcoal recovered from the site, I chose to examine Component 3, Y4 levels 2 and 3, primarily because it appeared to have 10 contemporaneous hearths. This suggests Component 3 was a single occupation that was, as mentioned earlier, very short-term in nature. This provides a good comparison against the longer-term occupations at Walakpa and Cape Espenberg.

Charcoal samples at Gerstle River were small, and few contained more than a handful of specimens, in part because excavators handpicked them using three-point provenience sampling rather than collecting them as soil samples. Preservation was poorer at Gerstle River than at any other site considered, perhaps due to its great antiquity. Of the 689 specimens examined, only 311 were identifiable to the genus level. I identified charcoal using the same methods discussed previously, but because samples were handpicked in the field, the assemblage is subject to additional biases. Small samples often contained a few specimens from the same taxon, likely originating from a single, once-intact piece, introducing an unknown degree of redundancy. Larger samples, however, often did contain multiple taxa.

Hungry Fox: All the analyzed charcoal from Hungry Fox comes from the 2004 excavation season. Excavators chose to focus on Locality 3 because it was the richest area of the site, but also because it was eroding downslope. Archaeologists divided Locality 3 into four blocks (A, B, C, D), all of which had intact matrices. They called anything outside of these blocks "slump." Since Hungry Fox is a single occupation site, excavators uncovered these blocks in a single level following a 1m × 1m excavation grid. This midden-like cultural layer contained dense concentrations of fauna, lithics, and botanical remains. The 2004 team screened 14 bulk samples through ⅛" mesh, after which they sorted them by material type (Scheidt, 2013). They water screened the rest together with miscellaneous site debris.

Hungry Fox, too, yielded enormous amounts of charcoal. As such, subsampling was necessary. Initially I identified 100 randomly selected specimens per bulk sample to ensure data redundancy, but because I only ever found two taxa (willow and birch), I reduced sampling to 50 and then to just 25 identifications. I followed the same identification procedures outlined above.

Walakpa: In 2015 our team had planned to take two 100% column samples from the entire depth of the eroding bluff face, but Column A collapsed soon into excavation due to relatively warm weather that had thawed the permafrost and destabilized the bluff. We quickly excavated Column B the following day before it too collapsed. Column A only reached 18 cm below surface. We excavated Column B in arbitrary 10 cm levels starting with level B at 50 – 60 cmbs. I processed the 2015 soil samples at The Ohio State University using a Flote-Tech machine. I then sorted the samples under low magnification (8 – 35×) to remove charcoal. I identified 50 specimens per sample whenever possible, but not all samples were this charcoal rich, while others contained much more.

RESULTS

Cape Espenberg

Features 33 and 68A contained plentiful, well-preserved organic remains, among which are the 1617 charcoal specimens I examined for this study. Of these 1617, I identified 1288 to the genus level. Of these, 2 (0.2%) were alder, 14 (1.1%) were birch, 2 (0.2%) were crowberry (*Empetrum nigrum*), 40 (3.1%) were likely larch, 971 (75.4%) were spruce, 29 (2.3%) were poplar, and 230 (17.9%) were willow (Fig. 7). Of the 1416 specimens with discernible growth curvature, weak growth curvature was the most common by a significant margin (93.2%, 1320), followed by tight growth curvature (4.2%, 60), and moderate growth curvature (2.5%, 36, Fig. 8).

To measure the divergence of cultural assemblages from natural driftwood assemblages, I compared the composition of charcoal taxa at Cape Espenberg to modern driftwood accumulations in northwest Alaska at Lisburne, Nome, Nunavak, Sinaruruk, and Wainwright, which were surveyed by Alix (2005). At present, there are no modern driftwood studies at Cape Espenberg, so these nearby sites serve as proxies. Compared to these sites, there was more spruce charcoal (76.6%) at Cape Espenberg than anywhere else (Fig. 9). Moreover, the amount of charcoal from the *Populus* sp. genus (2.3%) was much lower than its natural abundance. The remaining taxa (alder, birch, larch and willow) all occur in keeping with their natural abundance.

Gerstle River

The charcoal from Gerstle River is poorly preserved. Of all 689 specimens I examined, 54.8% could not be

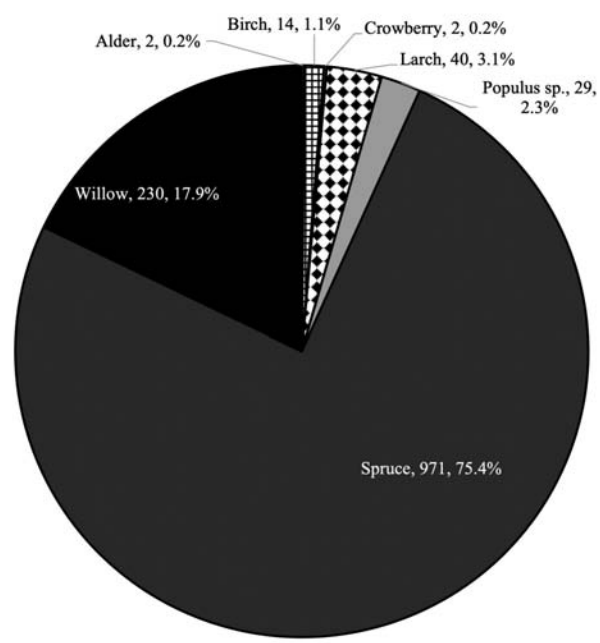

FIG. 7. Woody taxa found at Cape Espenberg.

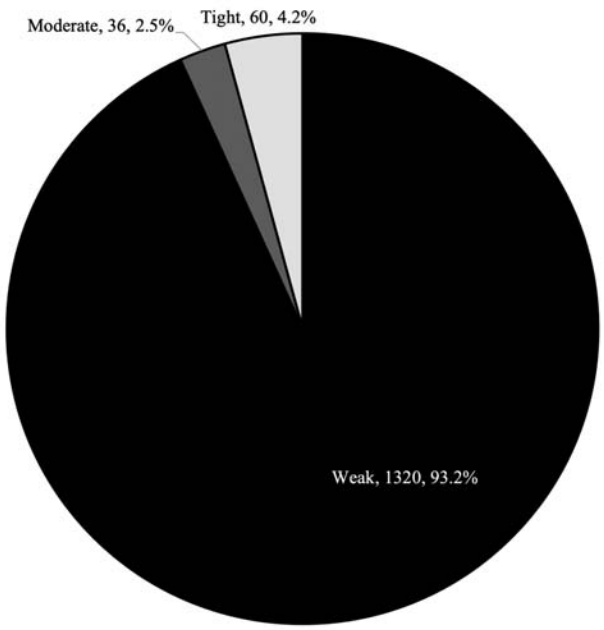

FIG. 8. Cape Espenberg charcoal growth curvature percentages.

identified to the genus level, and a total of 7.3% of the total sample was completely unidentifiable. Of the 311 identified specimens, willow was the most common at 80.4% (250) of the total. Charcoal from the *Populus* sp. genus comprised 16.7% (52) of the total. There were small amounts of spruce (2.6%, 8) and alder (0.3%, 1) as well (Fig. 10). Of the 471 charcoal specimens with identifiable growth curvature, 416 (88.3%) had weak growth curvature. The number of specimens with moderate (38, 8.1%) and tight (17, 3.6%) curvature is very small in comparison (Fig. 11).

To recreate the paleoenvironment surrounding Gerstle River, I examined contemporaneous (10,000 ± 250 BP) pollen assemblages averaged from several Tanana Valley lake sites sampled by Bigelow and Powers (2001) (Fig. 12). Using palynological data alone makes it difficult to reconstruct the vegetation growing in the area immediately around Gerstle River, wherein the ancient inhabitants would have confined their firewood gathering efforts. The charcoal assemblage at Gerstle River, however, does not closely resemble the contemporary pollen signature from the surrounding area. Birch, which is completely lacking in the anthracological record at Gerstle River, dominates the Tanana Valley palynological record (78%). Gerstle River also has much higher levels of charcoal from the *Populus* sp.

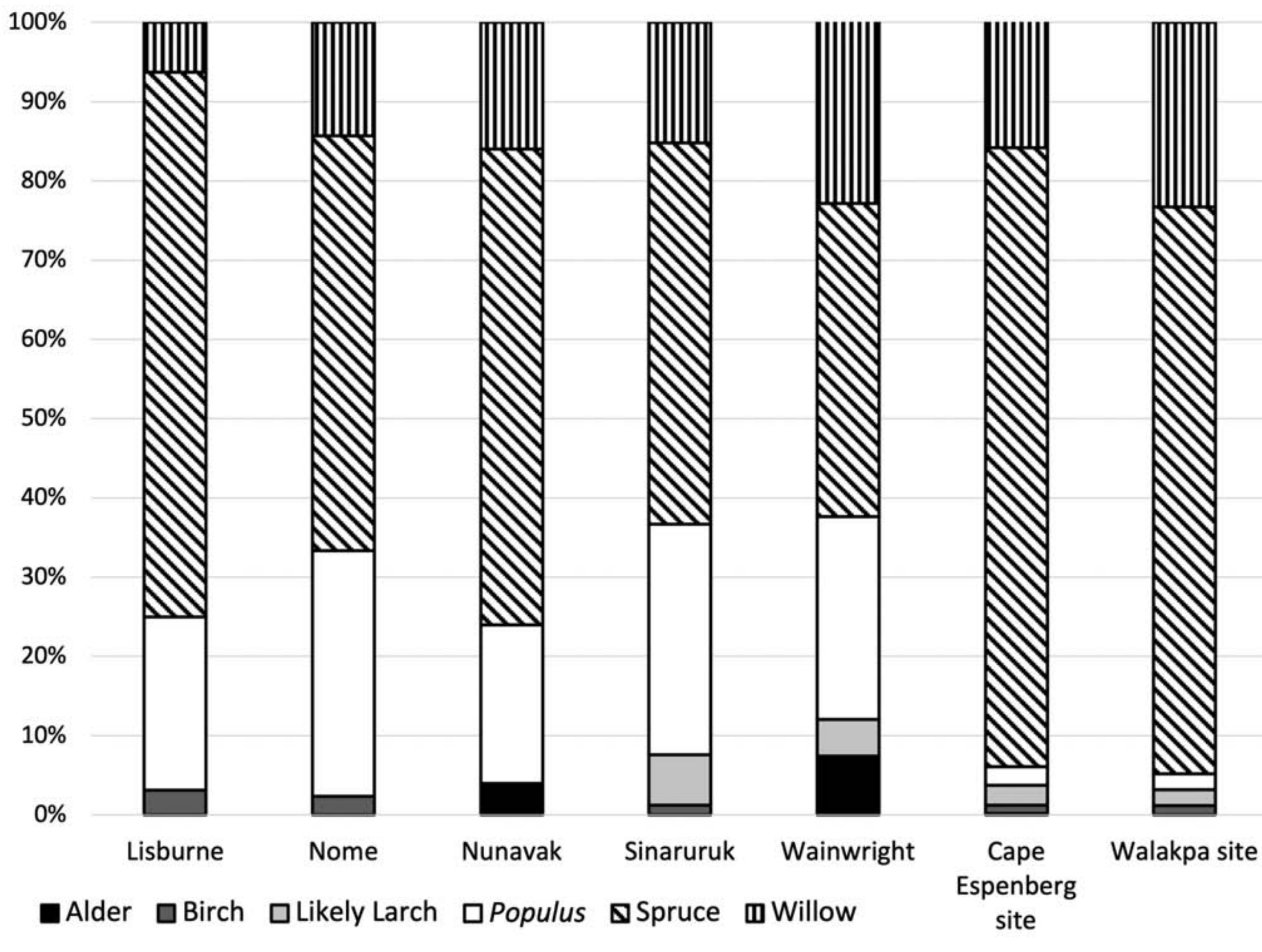

FIG. 9. Comparing driftwood sites surveyed by Alix (2005) to woody taxa found at Cape Espenberg and Walakpa.

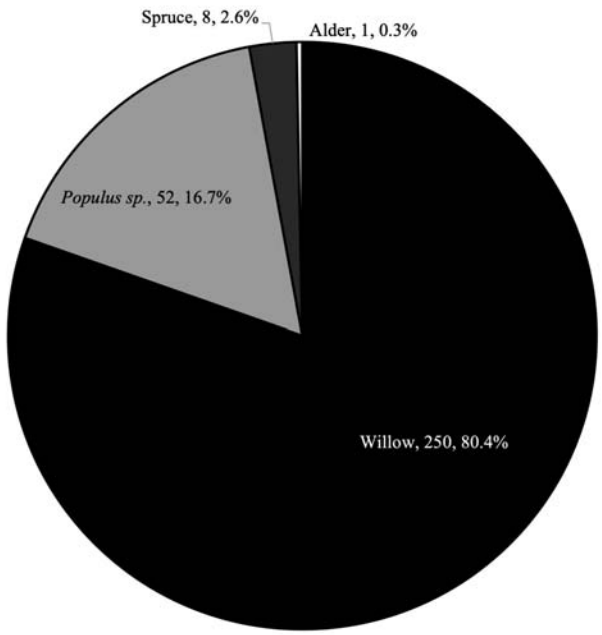

FIG. 10. Woody taxa found at Gerstle River.

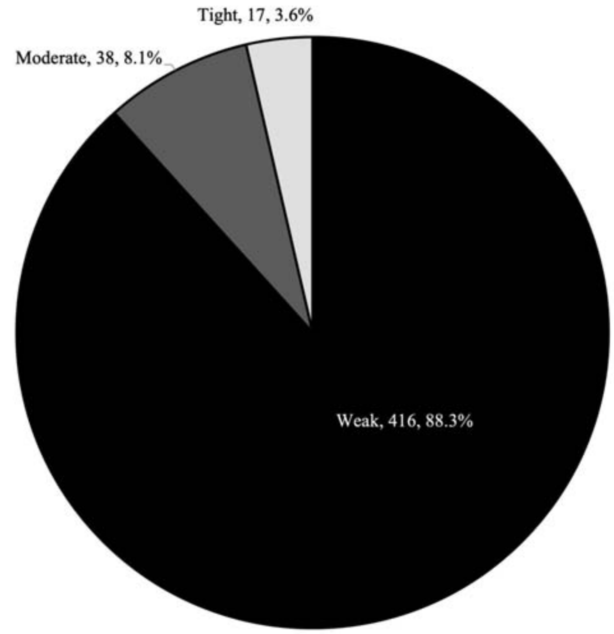

FIG. 11. Gerstle River charcoal growth curvature percentages.

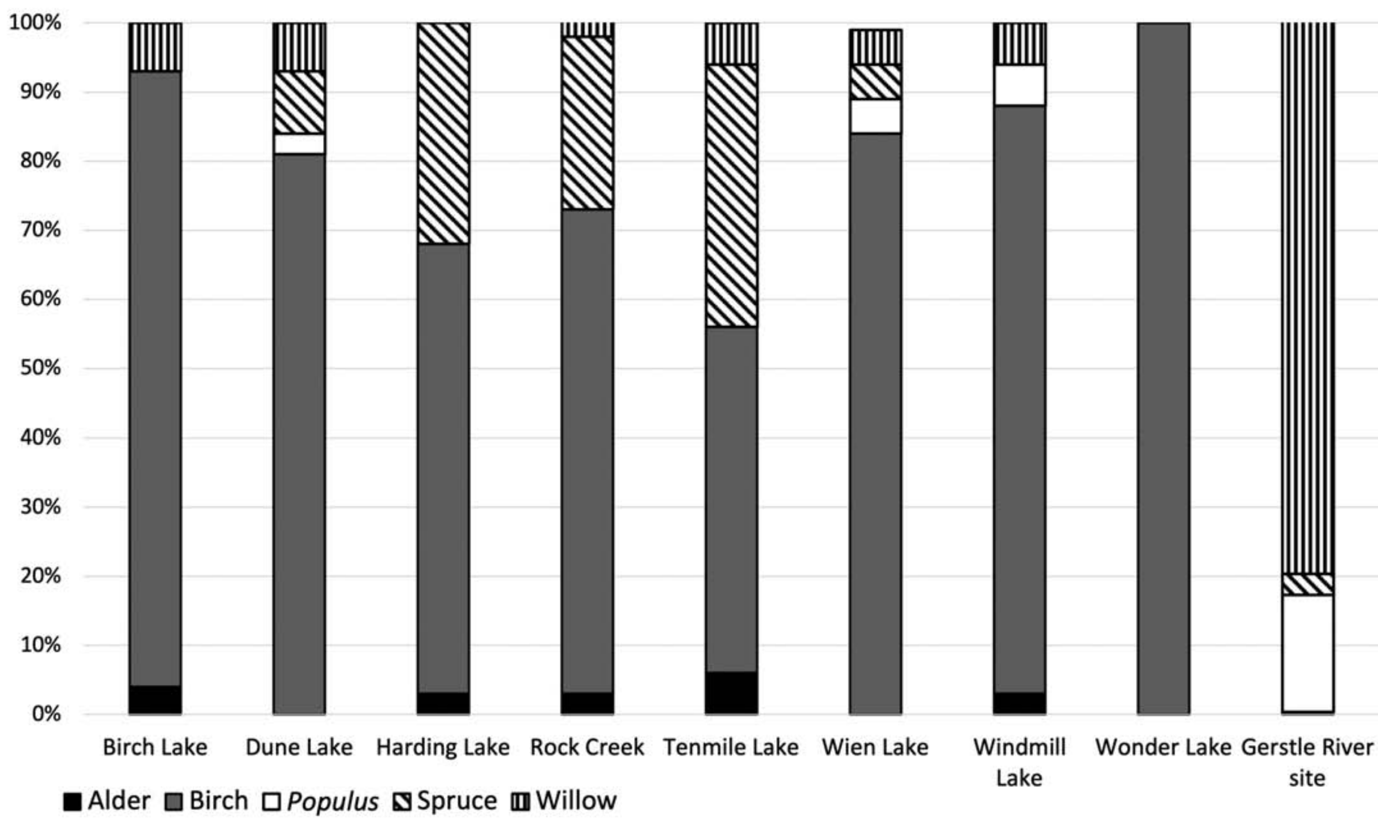

FIG.12. Approximated pollen percentages in the Tanana Valley ~10,000 yr BP compared to woody taxa found at Gerstle River.

genus (16.7% at Gerstle River versus ~2% at Tanana River Valley) and willow (80.4% versus ~4%). Alder percentages are both similarly low (0.3% and ~2%), and there is less spruce charcoal at Gerstle River than spruce pollen in the Tanana River Valley samples (2.6% versus ~14%).

Hungry Fox

Thanks to excellent preservation, I was able to examine 975 charcoal specimens from Hungry Fox and identify 950 of those to the genus level. The only genera I found were

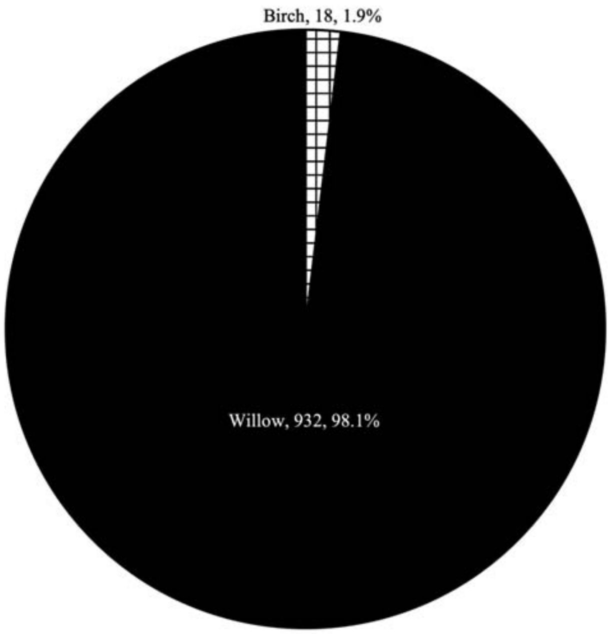

FIG. 13. Woody taxa found at Hungry Fox.

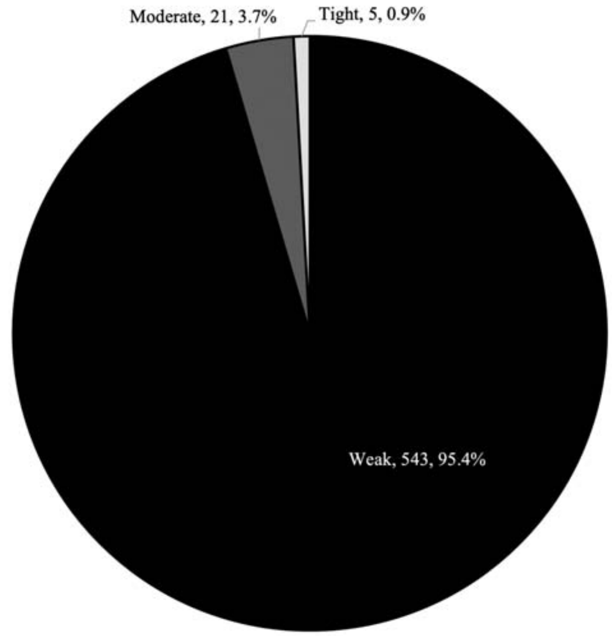

FIG. 14. Hungry Fox charcoal growth curvature percentages.

willow and birch, of which 932 (98.1%) were willow and 18 (1.9%) were birch (Fig. 13). Of the 845 specimens with discernible growth curvature, weak growth curvature was most common (47.9%), although a significant proportion of specimens had moderate growth curvature (43.2%), and a smaller amount (8.9%) had tight growth curvature (Fig. 14). While still dominated by charcoal with weak growth curvature, Hungry Fox had the most charcoal with moderate and tight growth curvature compared to the other sites.

Given the young age of the site, it is reasonable to use the modern vegetation as a proxy. Today, the site's slumped, eroding embankment face is overgrown by scattered *Artemisia* spp. (mugwort genus), grasses, and low herbaceous- to tree-sized willow (Spearman, 1992). The dominance of willow charcoal at Hungry Fox makes sense in this context.

Walakpa

At Walakpa I was able to identify 692 charcoal fragments to the genus level. Of these identifiable charcoal specimens, spruce was the most common taxon (71.5%, 495) followed by willow (23.3%, 161). The remaining taxa (birch, larch, and *Populus* sp.) occurred in small amounts. Birch constituted 1.2% of the total, with 8 specimens, larch was 2.0% of the total, with 14 specimens, and *Populus* sp. made up 2.0% of the total, with 14 specimens (Fig. 15).

At Walakpa there were 569 charcoal specimens with preserved growth curvature, 95.4% (543) of which had weak growth curvature (Fig. 16). There were very few specimens with moderate growth curvature (3.7%, 21) and even fewer with tight growth curvature (0.9%, 5).

SITE INTERPRETATIONS

Cape Espenberg

Taxon-specific Selectivity: The firewood selection strategy at Cape Espenberg was more akin to the DBM than the PLE. The mismatch between the quantities of spruce and *Populus* sp. charcoal in both houses, and the quantities of these taxa in northwestern Alaskan driftwood accumulations, constitute evidence of taxon-specific firewood selectivity. Spruce charcoal occurs in amounts greater than does spruce driftwood, and the disparity between *Populus* sp. charcoal and driftwood is even more pronounced. This suggests that the inhabitants of these houses preferentially selected spruce and intentionally ignored *Populus* sp. driftwood.

Spruce is the most common driftwood taxon in northwestern Alaska, on average comprising about 55% of accumulations. Yet it comprises 75.4% of Cape Espenberg's charcoal assemblage. The overabundance of spruce could be the result of repeated stockpiling. Inhabitants may have trolled driftwood accumulations preferentially for spruce and then stored it for later use. Driftwood could be replenished faster than people could use existing stores, leading to its superabundance as charcoal in the Cape Eisenberg occupation.

Spruce was likely an attractive firewood because it was abundant, relatively energetic, clean burning, and not too dense. The quantity of spruce driftwood along the coast would have reduced search time, and it would not have required great effort to cut. Burning spruce may have granted a favorable energetic net gain, and it could have been used for many purposes, including heating, firing pottery, and cooking.

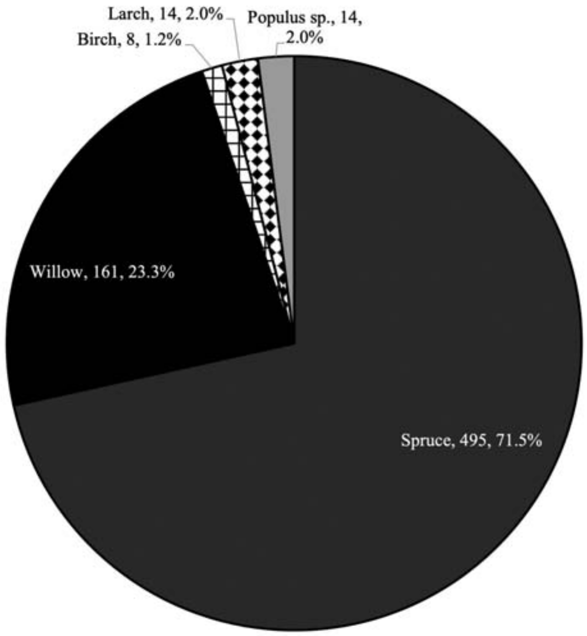

FIG. 15. Woody taxa found at Walakpa.

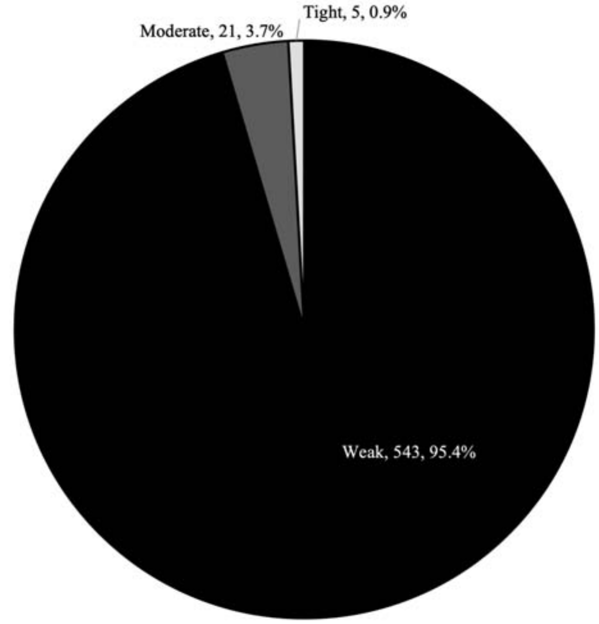

FIG. 16. Walakpa charcoal growth curvature percentages.

In contrast, *Populus* sp. wood was not often selected as firewood. On average, *Populus* sp. driftwood makes up about 26% of northwestern Alaskan accumulations but only makes up 2.3% of charcoal at Cape Espenberg. Even so, *Populus* sp. wood was not absent from Northern Maritime sites where it was used in construction and made into tools (Alix, 2003, 2009a; Méreuze, 2015). Like the modern Iñupiat, Thule people primarily selected *Populus* sp. wood for non-fuel purposes. Besides certain specialized tasks like smoking fish and repelling mosquitoes, the Iñupiat do not typically burn the excessively smoky and cool-burning *Populus* sp. wood as fuel (Alix and Brewster, 2004; Alix, 2005; Burch, 2006; Deo Shaw, 2008).

Growth Curvature: Most of the charcoal from Cape Espenberg had weak growth curvature, in part because most driftwood has weak growth curvature. The driftwood cycle is tumultuous and typically destroys smaller-diameter wood. As such, much of the charcoal with moderate and tight growth curvatures likely originated from woody shrubs growing on the landscape. Thule inhabitants would have used short, shrubby vegetation to obtain smaller-diameter wood. Smaller-diameter wood could have been used for kindling and controlling flame height, heat output, ember brightness, and cinder expulsion (Dufraisse, 2006; Dufraisse and Garcia Martinez, 2011). Even though small-diameter wood played an important role in fire management, large-diameter driftwood was available in greater quantities and provided a larger energetic package overall, although transportation and handling costs would have been higher.

Bone and Oil: F33-1 and F68A-1 contained large quantities of burned bone fragments, suggesting that bone was added purposely. Bone is an excellent fuel source; dry bone is about as energetic as green wood, and fresh, greasy bones burn at about twice the temperature of most woods (Deo Shaw, 2008; Beresford-Jones et al., 2010). Bone fuel, however, has several shortcomings, one being that it requires high temperatures (350˚C – 380˚C) to ignite, thus requiring kindling (Beresford-Jones et al., 2010). Moreover, bone conducts heat poorly and does not produce embers. It is better suited for lighting, drying, or curing rather than indirect cooking or heating. Further, burning wood and bone together results in slightly lower burning temperatures. These cooler burning fires, however, may have been safer (Théry-Parisot, 2002; Marquer et al., 2010). Also, adding bone to wood fires helps to conserve fuel because the correct ratio of bone to wood (80% bone and 20% wood is ideal) increases burn time (Théry-Parisot, 2002).

The addition of bone fuel does not necessarily imply firewood scarcity (Cook, 1969; Hoffecker, 2005; Marquer et al., 2010). This widespread notion is based on the apparent scarcity of wood charcoal at a given site. Charcoal, however, is more susceptible to taphonomic processes (e.g., freeze and thaw cycles, bioturbation) than bones (Marquer et al., 2010, 2012), and it is difficult to accurately estimate the original proportion of bone to wood in a fire. Thus, the large quantities of burned bone in F68A-1 and F33-1 do not necessarily indicate wood scarcity at Cape Espenberg.

Finally, the large quantities of clinker, especially in F33-1, suggest that oil may have been added to these fires intentionally. If the inhabitants of Features 68A and 33 purposely added oil to their fires, it may have been to conserve fuel, control temperatures, extend burn time, and control combustion properties, such as flame height and cinder output (Yravedra et al., 2017). De Laguna (1940) reported that the Iñupiat would fire pots using firewood soaked in seal oil. Alternatively, the oil could have been introduced from cooking. Though the Iñupiat typically boiled their food, they did occasionally roast their meat (Burch, 2006). Greasy bones added to the fire also could have released liquid fat.

Gerstle River

Adhering to the PLE?: The charcoal taxa profile at Gerstle River is a poor match for the paleoenvironmental profile of the contemporary Tanana Valley. Palynological records show that at about 10,000 BP, birch was the dominant taxon by a wide margin, followed distantly by willow, poplar, spruce, and alder (Bigelow and Powers, 2001). Pollen, however, is a problematic proxy for studying firewood selectivity because the catchment area for pollen is much larger than the small distance foragers are willing to travel for firewood. Moreover, palynological samples can be misleading, as certain species may produce more pollen than others (e.g., spruce, poplar, alder), or pollen may be especially buoyant (e.g., birch), traveling long distances from the source (Bryant and Holloway, 1983; Traverse, 2007), among other obfuscating factors. The pollen profiles seen in Tanana Valley lake cores may not be representative of what was growing around the Gerstle River site. Birch, for example, though abundant in the palynological record, may not have been present in the catchment area.

As a result of these distortions, results at Gerstle River are difficult to interpret. The lack of birch charcoal at Gerstle River could be due to its absence in the catchment area, or it could reflect taxon-specific selectivity. Birch, though hot burning, is dense, tough to process, and can be smoky (Deo Shaw, 2012). It could have also been set aside for other, non-fuel related purposes, but would not have been stockpiled. Due to their highly mobile lifestyles, Gerstle River inhabitants would have incurred high transportation costs if stockpiling wood for later use.

Birch aside, there is reason to believe that fuel management strategies at Gerstle River more closely resembled the PLE than the DBM. Gerstle River was a brief occupation in the autumn, a season wherein temperatures drop and nights lengthen. Upon arriving on site, occupants would have needed copious firewood fast. They may not have benefitted much from taxon-specific selectivity. Instead, state-specific properties would have been more important. Inhabitants targeted dead, dry wood that did not need to be cut to size, favoring larger-caliber wood and, most importantly, whatever was closest to their camp.

Bone: By weight, only 14% of the bones recovered from Component 3 were burned. These were found directly in hearth Features 1, 3, 5, 10, and 14, and there were almost no burned bones in other areas, perhaps reflecting intrasite differences in faunal remains processing, though different areas of the site were likely subject to different taphonomic processes (Potter, 2005). Like the charcoal assemblage, the faunal assemblage at Gerstle River is poorly preserved, making it difficult to arrive at interpretations about the role of bone fuel. While it is possible that bone may have been burned intentionally, it is also possible that bone was simply discarded into fires. There is no conclusive evidence of oil in the hearths of Component 3.

Hungry Fox

Limited Options: The inhabitants of Hungry Fox adhered to the PLE by default, even though they had access to two different taxa. Though birch is highly energetic, the birch shrubs available at Hungry Fox were likely too small to grant an energetic advantage. Search and handling costs would have been elevated excessively by searching for and gathering dwarf birch shrubs preferentially, and ultimately there may not have been enough birch biomass to satisfy the fuel needs of Hungry Fox's occupants. Thus, although dwarf birch may have been harvested upon encounter, the area's comparatively large willow shrubs may have realistically been the only serviceable firewood in the surrounding catchment area.

Given the impracticality of taxon-specific selectivity, size, state-specific qualities, and proximity may have been more important than taxon-specific properties. Because shrubby willow is a smaller energetic package than tree-sized taxa, and because willow is not very energetic, the Nuñamiut at Hungry Fox may have chosen a strategy that minimized search, travel, and handling costs to maintain a positive net energetic yield. This is especially important given that winters in the Brooks Range are the harshest in Alaska. The people of Hungry Fox would have burned enormous quantities of willow. As such, willow patches in the Brooks Range must have been a powerful draw, dictating where people chose to settle and how often they had to move as they exhausted their woody resources.

Compared to the other sites, Hungry Fox has more charcoal with moderate and tight growth curvature, which indicates the selection of smaller-diameter wood. In this manner, shrubby willow, with its smaller-diameter trunks and branches, would have helped keep handling costs low. These could be cut easily, or even broken into usable-sized pieces (Burch, 2006). Better yet, dead, dry willow branches could have been collected off the ground. Still, a total of 91.1% of charcoal specimens with visible growth curvatures remaining have weak or moderate growth curvature. This is a result of both selection and taphonomy, because smaller charcoal fragments do not survive as well as larger ones.

Yet, the mobile Nuñamiut had access to other woody taxa during their annual rounds, as evidenced by the presence of a poplar fishing float in Hungry Fox's midden (Rasic, 2006). While it may have been worthwhile to travel and trade for wood, it was probably not energetically efficient to do so for firewood. Any wood other than willow would have needed to be conserved for special, non-fuel related activities.

Bone and Oil: At Hungry Fox, inhabitants extensively processed bones to extract grease and marrow for consumption (Spearman and Vinson, 2000; Rasic, 2006). Large quantities of bones were found in features identified as hearths (Spearman and Vinson, 2000), some of which were calcined (Spearman, 1992). Like at Gerstle River, bones at Hungry Fox may or may not have been burned intentionally. And while the Nuñamiut relied on tallow for lamps (Larsen, 1958; Gubser, 1961), no lamps were found at Hungry Fox. Moreover, ethnographic sources report that the Nuñamiut traded heavily with coastal groups because of the scarcity of food and other resources in the Brooks Range (Gubser, 1961) and may have traded for sea mammal oil. While it seems likely that the inhabitants at Hungry Fox burned both bone and oil, there is no conclusive evidence.

Walakpa

Selectivity: The conditions at Walakpa made taxon-specific selectivity advantageous. Unlike Gerstle River and Hungry Fox, Walakpa supported repeated seasonal occupations year after year. Abundant coastal resources, including wood, allowed for such long-term occupations. Taxon-specific firewood selectivity was possible here because driftwood was renewed annually, making it impossible to deplete firewood supplies for long. Moreover, bone and sea mammal oil supplemented woody fuel stores. As such, inhabitants infrequently needed to burn undesirable wood. Taxon-specific selectivity was also made possible by low search costs. Today, there is a concentrated driftwood patch a short distance away from the site, which meant that it cost foragers little energy to find or ignore certain driftwood taxa. It appears that fuel supplies either met or exceeded the needs of inhabitants, allowing foragers to secure sufficient fuel stores even when being selective.

Growth Curvature: Like at Cape Espenberg, the growth curvature of charcoal at Walakpa is overwhelmingly weak (95.4%), with only very small amounts of charcoal showing moderate and tight growth curvature. This is because the vast majority of Walakpa's firewood comes from the nearby driftwood assemblage rather than the locally prostrate, small, and creeping woody plants, which are too small to constitute any significant biomass. As mentioned previously, the tumultuous driftwood cycle typically strips logs of small branches and twigs. As such, the lack of charcoal with moderate and tight growth curvature at Walakpa reflects a lack of choice, rather than selectivity: the only significant source of wood at this site arrives in the form of driftwood.

Bone and Oil: Stanford (1976) recovered ceramic lamp sherds at Walakpa that were encrusted with soot and grease, attesting to their use (Stanford, 1976). Inhabitants at Walakpa likely burned highly energetic sea mammal oil, which was the primary fuel source of coastal northwestern Alaskans. Sea mammal oil is significantly more energetic than wood, and its handling costs, embedded in hunting efforts, are low. Like at Cape Espenberg, oil may have been added to firewood and other fuels to stretch fuel supplies (Saario and Kessel, 1966). Sea mammal oil, however, was also an important food source, and during lean times, the post-contact Iñupiat would sacrifice both heat and light to consume their oil instead (Burch, 2006). This example demonstrates that the choice to burn wood, bone, and sea mammal oil alike allowed Walakpa's inhabitants adaptive flexibility; any one of these resources could be allocated to either fuel and non-fuel purposes depending on short-term needs and resource availability.

CONCLUSION

The fuel management strategies at Cape Espenberg, Hungry Fox, Gerstle River, and Walakpa are perhaps too complicated to be explained entirely using optimal foraging models alone, especially given the many variables in play. Fuel sources like bone, oil, and wood were multi-purpose, used for both fuel and non-fuel ends. These economic systems are irrevocably intertwined, and foragers would not have regarded and procured bone, wood, and oil strictly as and for fuel. Thus, it is difficult to rank fuel types without reference to other resource management systems. Even so, these different fuel categories appear to have been ranked against each other, and there seem to have been rankings within fuel types that are only sometimes based on taxon-specific combustion properties. It is important to be aware that Western taxonomic systems are not universal, and that foragers would not necessarily have categorized different trees or wood by species. Even so, applying an HBE framework to fuel use is useful for understanding fuel selectivity and management.

This exploratory research suggests that PLE-adjacent strategies were more common, largely because greater degrees of taxon-specific selectivity were advantageous only under particular circumstances. For one, there must be a fuel surplus. Otherwise, foragers cannot afford to ignore any reasonably energetic fuel. Furthermore, occupation length must be long enough to allow foragers sufficient time to preferentially select desired fuels, which could entail stockpiling wood for future use. Longer occupations, however, result in the depletion of woody resources, which may be slow growing and thus slow to renew. With fuel depletion, DBM-type selectivity becomes increasingly less advantageous. In places where fuel and firewood are replenished reliably and regularly, however, taxon-specific selectivity can endure indefinitely.

Cape Espenberg and Walakpa differ from Gerstle River and Hungry Fox because their inhabitants enjoyed reliably renewable surpluses of driftwood, sea mammal oil, and bone. They also inhabited repeated, long-term winter occupations, whereas Gerstle River and Hungry Fox were shorter-term, single occupations. For these reasons, foragers at Cape Espenberg and Walakpa expressed taxon-specific preferences for firewood, overselecting spruce and underselecting *Populus* sp. firewood compared to natural abundance. Presumably, foragers avoided *Populus* sp. wood for general use because of its lackluster combustion properties, and employed it only for special purposes, like smoking meat and repelling mosquitos. Spruce was preferentially selected and burned because of its abundance, relative ease of handling, and reasonably energetic combustion properties.

The inhabitants of Hungry Fox had little choice but to mostly burn willow shrubs for fuel. Local dwarf birch shrubs were too small to contribute much fuel, and other woody taxa grew too far away and only intermittently on the landscape. At Gerstle River, foragers may have selected dead, dry wood, with more regard for handling costs and less regard for taxon-specific combustion properties. The question of birch remains ambiguous at Gerstle River, however: if it was present in the catchment area, its absence in the anthracological record could suggest some degree of taxon-specific selectivity. At both sites there was insufficient time for stockpiling and curing. Moreover, growing woody trees and shrubs were renewed much more slowly here than on the coast, where driftwood deposition was essentially an annual occurrence. Once wood supplies were exhausted, foragers at these sites would have necessarily moved on to the next resource patch.

Ultimately, if these observed patterns are more widely applicable, foragers should tend towards indifference most of the time. The PLE should apply anywhere without a fuel surplus and in places where fuel stores are restored more slowly (i.e., woody re-growth). Otherwise, any sort of selectivity would be a sort of self-imposed fuel scarcity. Places populated by growing woody shrubs and trees, or any fuel supply that is slow to replenish, may be more commonplace than areas with reliably and regularly renewable fuel supplies (e.g., driftwood, sea mammal oil).

Future fuel selectivity research should focus on fuel more generally, not just firewood, because all fuel selectivity and management systems are intertwined. Moreover, fuel needs to be studied as part of the entire foraging economy. The emphasis of these studies should be on adaptive flexibility and the shifting choices foragers make in response to changing economic, environmental, and social factors. Also, there must be more research into those seemingly uncommon conditions that allow for greater selectivity, how much fuel is necessary to allow for selectivity, and how foragers ranked different fuel types. Further, there are many other variables, like climate, mobility, site function, and much more, that influence selectivity in ways that are, as of now, poorly understood. Ultimately, the answers to these questions will come into sharper focus by widening the number and array of study sites.

Finally, fuel management studies have important implications for human migration. In part, the availability and types of fuel on a landscape would have influenced the movement of mobile peoples, who likely leapfrogged from one fuel patch to another, pending exhaustion. How these ancient people moved across the landscape has implications for how archaeologists understand mobility on a larger scale. For instance, the distribution of firewood in eastern Beringia may elucidate the migration and settlement patterns of the earliest Americans.

It is difficult to generate far-reaching conclusions from just four archaeological sites, but the wealth of novel information gleaned from each demonstrates that fuel selectivity and management studies are rich in research potential. Given the centrality of fuel to human survival, studying fuel management systems promises new insights into many aspects of ancient life. As such, fuel management studies should be regarded as of equal importance to ceramic, lithic or zoological inquiries and performed at sites whenever charcoal and other fuel remains are preserved.

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