Neanderthal Cooking and the Costs of Fire

by Amanda G. Henry

While it is clear that Neanderthals used fire for cooking their foods in some times and places, the record of their use of fire is somewhat patchy. We should not assume that Neanderthals had the same relationship with fire that we do; as a technological/cultural behavior, fire may be better understood as a tool that was used only when the costs of manufacture and maintenance were outweighed by the benefits.

Use of fire, particularly to transform food, is widely recognized as a major step in human evolution, allowing us increased access to refractive foods (Stahl 1984), lowered cost of digestion (Carmody and Wrangham 2009), and decreased exposure to food-borne bacteria (Smith et al. 2015). Just when this process was first adopted by human ancestors is highly debated, with the earliest evidence for fire being very unevenly distributed in time and space. Burned materials are found in association with hominin activity at a variety of archaeological sites, dating from 1.5 Ma at Koobi Fora (Hlubik et al. 2017), 1.4 Ma at Chesowanja (Gowlett et al. 1981), and 1 Ma at Wonderwerk Cave (Berna et al. 2012). However, as Pruetz and Herzog (2017) and Gowlett et al. (2017) indicate, naturally occurring fire is nearly ubiquitous, and it is extremely challenging to show that the hominins who created the archaeological scatters at these sites were coeval with, or even directly interacted with, the fire. To use the terminology developed by Sandgathe (2017), hominins may have been habituated to fire, but discerning their use, maintenance, or manufacture of fire is extremely difficult in the early record. In fact, regular use of fire does not appear to be widespread among northern-latitude hominins until much later (Roebroeks and Villa 2011; Stahlschmidt et al. 2015). Some have even argued that as late as the Middle Paleolithic, Neanderthals may have been able to maintain fires but were not able to manufacture them (Sandgathe et al. 2011). The benefits of cooking have been well documented (Wrangham 2009), and this has been argued to be a driving factor in promoting human use, maintenance, and manufacture of fire, such that once hominins first used fire, it quickly became an obligatory part of their niche. The disconnect between the very sparse archaeological record of fire and the potentially strong benefits of using fire begs the question, Is the absence of fire evidence a result of processes that erased the record of fire, or is fire use perhaps more variable in human history than we have previously assumed?

In this paper I address the question of Neanderthal use of fire, in particular for cooking their food. The fossil and archaeological record of Neanderthals is the most complete among our hominin relatives, and there is clear evidence at many sites that Neanderthals used fire and cooked their food. Despite this wealth of data, many questions about Neanderthal use of fire remain unanswered, and some have even suggested that fundamental differences between Neanderthal and Early Modern Human (EMH) use of fire may have contributed to the disappearance of the former. By exploring the factors that may have influenced how, when, and why Neanderthals used fire, we may begin to build a more nuanced model of the influence of fire in human evolution.

Evidence for and against Neanderthal Use of Fire

Several European and Levantine Middle Paleolithic sites have ample evidence for the presence of fire, in the form of discrete hearths of charcoal, ash, and fire-altered sediments, charred and calcined bone, and heated stone. These sites are found in the Levant at Tabun, Kebara, and Hayonim (Goldberg 2003); in France at St. Cesaire (Morin 2004), La Quina (Chase 1999), Pech de l'Azé IV, and Roc de Marsal (Goldberg et al. 2012); and in Spain at Abric Romani (Vallverdú et al. 2012) and El Salt (Gómez de la Rua et al. 2010). Evidence for the use of fire includes the discovery of birch tar hafting, which would have required intentional heating (Mazza et al. 2006), found on several Middle Pleistocene flakes from Italy. The study of charcoal and other fire remains, though initially used to document the local tree species, has become increasingly used as a means to document Neanderthal and EMH fire behavior, in large part due to the extensive experimental works of Isabelle Théry-Parisot. She has shown that it is possible to differentiate among the burning of green, dry, and rotten woods, and that each of these fuels burns for a different amount of time with different heating properties (e.g., convection, conduction, and illumination; Théry-Parisot 2001). Applying these methods to ar-

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chaeological sites, she has demonstrated that Paleolithic hominins (Neanderthals and EMH) generally burned dry standing wood and did not appear to choose particular tree species. However, she and others have also shown that in certain cases, Neanderthals burned coal or bone in addition to wood because of their preferred burning properties (Dibble et al. 2009; Théry-Parisot and Costamagno 2005; Théry-Parisot and Meignen 2000). Coal does not produce flames, but it is better than wood at conduction, so it is good for heating opaque, solid objects (e.g., food placed on the fire to cook or flint and other raw materials to improve their flaking characteristics; Théry-Parisot and Meignen 2000). Mixes of bone and wood achieve longer burning times and better conduction of heat than wood alone (Théry-Parisot and Costamagno 2005). These results strongly indicate that Neanderthals not only knew how to maintain a fire but had sufficiently experimented with different fuels to be able to choose among them to create fires with particular burning properties.

In contrast to the above data, there is also an increasing emphasis on the evidence that suggests that Neanderthals perhaps were able to use and maintain fire but were not able to manufacture it. Sandgathe et al. (2011) point to the fact that, once fire appears in the archaeological record, it is seen only at a small percentage of sites at any one particular time period and often only within a small percentage of occupation layers within each site. Based on the record at two French sites, they reject taphonomic processes, sampling biases, changes in function of the site, or seasonality of use as causes for the apparent disappearance of direct and indirect evidence of fire. They argue instead that the absence of fire reflects that the use of fire was "not an essential part of [Neanderthal] behavior" (Sandgathe et al. 2011:217). They emphasize that modern or recent historical foragers should not be taken as direct analogues for Neanderthals; instead, we must recognize that Neanderthals had a deep time history in Europe that may have provided ample opportunity to physiologically adapt to colder temperatures and to acquire enough calories from uncooked food. They conclude that Neanderthals used and probably maintained fire when it was convenient and available on the landscape—for example, in warmer periods when fuel was abundant and natural fires from lightning strikes were frequent—but that Neanderthals did not have the ability to manufacture fire.

Neanderthal Use of Fire for Cooking

In the same manner that Neanderthal use of fire has a variable record, evidence for cooking is inconstant and debated. The cooking of animal foods such as meat and fat is mostly evidenced by heat-damaged bones. Blackened bones are frequently found in sites, but discerning whether they have actually been charred or just stained requires a level of analysis that was not commonly done during the excavation of many Middle Paleolithic sites (Shahack-Gross, Bar-Yosef, and Weiner 1997). Even for bones that have been conclusively charred or calcined, there can be some question about whether they were damaged during cooking, burned as a way of disposing refuse, or simply heated after burial when a fire occurred in the sediments above them. While some have developed metrics to help discern between cooked and otherwise fire-damaged bones (e.g., Costamagno et al. 2008; Speth and Tchernov 2001), these methods have been applied only to a very small number of Neanderthal sites. At Kebara, it seems the charred bones were the result of cooking (Speth and Tchernov 2001), while at Pech de l'Azé IV, the evidence is inconclusive and could indicate cooking, refuse disposal, or both (Dibble et al. 2009).

Direct evidence for cooking of plant foods is extremely rare in the Neanderthal record. Charred seed remains have only been reported from a handful of sites, including Kebara (Lev, Kislev, and Bar-Yosef 2005) and Douara Cave (Matsutani 1987) in the Levant, Franchthi Cave in Greece (Hansen 1991), and Gorham's and Vanguard Caves in Gibraltar (Gale and Carruthers 2000). Most of these assemblages are very small, but the Kebara assemblage consists of more than 4,000 charred seeds, mostly from legumes (Fabaceae) and nuts (*Pistacia* and *Quercus*). A range of other plants, including members of the Boraginaceae family, were also common at several sites. Though these have been interpreted as food, even charred seeds may not be an accurate record of cooking. Miller (1984, 1996) has strongly argued that the primary mechanism by which whole seeds become charred is by the burning of animal dung as fuel, rather than direct cooking of plant foods, since there is little benefit to be had by cooking whole seeds on an open-flame fire. Even if Neanderthals did not collect and burn dung, it is possible that the seeds were accidentally burned rather than intentionally cooked. Shallowly buried seeds may be inadvertently charred when a fire is burned above them (Aldeias et al. 2016), calling into question the relationship between the fire and the seeds. New sources of information about cooking and the consumption of cooked plant foods are clearly needed.

In the last 10 years, dental calculus has been increasingly explored as a source of new information about diet and health. This biological material is created through the proliferation of oral bacteria on the teeth and the subsequent mineralization of this biofilm due to the supersaturation of calcium phosphate in the saliva (Jin and Yip 2002; Lieverse 1999). The mineralized surface is recolonized by bacteria, and calculus builds up in successive layers throughout the lifetime of the individual, though the trigger of the mineralization process and the rate of formation are generally unknown and likely vary among individuals. As calculus forms, many of the organic residues found in the mouth, including human and bacterial proteins and DNA, food lipids, and plant microremains, are trapped in the mineral matrix and can be preserved over archaeological time spans (Buckley et al. 2014; Henry and Piperno 2008; Warinner, Speller, and Collins 2015). There are two types of plant microremains that are particularly useful in reconstructing diets—phytoliths and starch grains. Phytoliths are particles of amorphous silica that form within and between the cells of a plant (Piperno 2006) and are generally regarded as a form of mechanical defense against herbivory (Massey and Hartley 2006).

Starch grains are structures that a plant produces from long-chain carbohydrates as a means of energy storage (BeMiller and Whistler 2009). Both microremain types can have taxon-specific morphology that can be used to identify the plant species and/or plant part in which they were formed. Furthermore, plant microremains can often record changes due to processing, such as grinding and heating. Exposure to extremely high temperatures can change the refractive index of phytoliths (Elbaum et al. 2003), while starches can undergo a variety of diagnostic changes, including gelatinization, cracking, and loss of organization, which indicate heating in the presence of water (Babot 2003; Henry, Hudson, and Piperno 2009; Messner and Schindler 2010).

To date, over 70 Neanderthal dental calculus specimens from more than 40 individuals have been sampled for plant microremains and other residues, providing us a new glimpse into their dietary behavior (Hardy et al. 2012, 2016; Henry 2010; Henry, Brooks, and Piperno 2011; Salazar-García et al. 2013). These samples include material from the Levant (Shanidar, Qesem Cave), the Mediterranean (Sima de las Palomas, Kalamakia), and more "classic" areas in western Europe (Spy, La Quina, La Ferrassie). Some of the earliest work demonstrated that Neanderthals from a variety of environments consumed plant foods, including several of the resources, like grass seeds and tubers, that became important in later agricultural societies (Henry 2010; Henry, Brooks, and Piperno 2014). In rare occasions, gelatinized starch grains were found, indicating that the plants had been cooked prior to consumption (Henry, Brooks, and Piperno 2011). In the cases where the partially gelatinized starches could be identified to taxon, they seem to be all from grass seeds or other plants with hard, starchy endosperm in their seeds, lending support to the interpretation that the charred macrobotanical remains found in other sites do indeed represent cooking of seeds. However, this interpretation must be tempered by some of the unresolved issues relating to differential survival of starches from different plants.

Furthermore, it is interesting to note that many of the Neanderthal samples did not preserve any plant microremains. This pattern, with some specimens showing heavy use of plants while others seem to preserve none, has been found in every subsequent study of calculus, across the entire geographic range of sampled specimens. In fact, there has been to date no coherent pattern of plant use across the sampled specimens. Neither age nor geographic region influences the number of recovered plant microremains, nor the number of different types of plants represented (Henry, Brooks, and Piperno 2014). A study currently under way (Power et al., forthcoming) aims to explore whether a finer-grained geographical analysis that includes information about average temperature and tree cover at a site might better explain the number of plants that Neanderthals consumed. Particularly relevant to the discussion of cooking, however, is the observation that gelatinized starches are extremely rare and appear only in a small handful of specimens. While this may indicate even lower frequencies of cooking, again, we must be careful with the problem of absence of evidence—gelatinized starches are particularly vulnerable to removal from the archaeological record. Other calculus inclusions, including smoke residues, charcoal, and altered fats found in several individuals from El Sidrón and Qesem Cave, also suggest cooking by these individuals (Hardy et al. 2012, 2016).

There is much work to be done to assess the taphonomic biases that may affect the record of plant microremains and other residues in dental calculus. Based on studies matching the diets of modern groups with their calculus microremains (Leonard et al. 2015; Power et al. 2015), we know that our results likely underrepresent the true number of plant foods consumed by Neanderthals. Furthermore, there are many taphonomic factors that potentially remove starches from the archaeological record (Henry 2015), and we have seen that gelatinized starches are very quickly removed from buried stone tools (Debono Spiteri et al. 2014) and thus might also be strongly underrepresented in the calculus record. Residue analysis using mass spectroscopy–based methods is still in its infancy, as no analysis on populations with known diets has been performed. However, given the increasingly large number of Neanderthal calculus samples studied to date, it is likely that the apparent pattern of variability in Neanderthal use of cooked plant foods is a real one.

Applying a Behavioral Ecology Framework to the Discussion of Fire

When combined with the data that suggest inconsistencies in Neanderthal control of fire, the pattern of cooking variability raises the question of why Neanderthals would have fire and cook with it in some places and times and not in others. Some have argued that Neanderthals did not possess the capacity to manufacture fire (Dibble et al. 2017; Sandgathe et al. 2011), while others have invoked a more taphonomic explanation (Gowlett and Wrangham 2013). However, in most studies so far, researchers have considered only the possibility of an "either/or" situation—either Neanderthals had the ability to manufacture fire and therefore did so in all times and all places, or they did not. I propose that the use of fire needs to be examined using an explicitly economic framework to understand the benefits but also the potential costs of manufacturing and maintaining a fire. The relative costs to benefits in different environments could explain the variability in Neanderthal fire use. Neanderthals may have had the ability to manufacture fire but in some cases may have chosen not to do so, and it is in exploring their choices that we gain a better understanding of their behaviors.

Like other technologies, the use of fire for cooking is something that can be explained by using models derived from human behavioral ecology (Bird and O'Connell 2006). In these models, it is possible to predict an individual's response to its current environment. The basic premise is that an individual attempts to achieve some goal that will increase its fitness, but in order to do so, it has to choose between a variety of potential behaviors. Each of these behaviors has costs and benefits that are measured in a certain currency. In some cases, the individual is prevented from using one of its potential behaviors. When using behavioral ecology models to examine real-world data, the researcher makes a prediction about the exact goals, choices, costs and benefits, currencies, and constraints that influence the organism in order to predict the most optimal behavior. When the hypothesis matches the actual behavior, the researcher chose the correct variables; when the actual behavior differs from the predicted, then either the predicted variables were incorrectly chosen or the model was in some way inappropriate. This framework makes it possible to test whether certain environmental restrictions or behavioral limitations strongly influenced human use of fire, or we need instead to invoke another explanation (e.g., taphonomic bias, cultural pressure sensu Wiessner [2014]) for the presence or absence of fire in the archaeological record.

Specifically, in the case of using fire for cooking, most of the benefits come in the form of caloric savings. Several experiments have documented that some tubers, meat, and even oil-rich seeds become more easily digestible once cooked (Boback et al. 2007; Carmody and Wrangham 2009; Groopman, Carmody, and Wrangham 2015). The risk of food-borne illnesses drops once foods are cooked (Smith et al. 2015). Some plant foods are only accessible to digestion after cooking, due to the reduction in toxins and other antifeedants (Stahl 1984). All of these benefits can be measured as an increase in calories available to the consumer through a reduction in the caloric costs of the food, a reduction in costs related to illness, or an increase in the number of potentially calorie-rich food sources, all of which would then allow more calories to be spent on other tasks (Aiello and Wheeler 1995).

Despite these rather significant benefits, there may be occasions or environments where the costs of creating a fire outweigh the benefits of having one. The most obvious cost is that of collecting fuel (Ofek 2001). Dry standing wood is the preferred fuel for cooking, because rotten wood burns poorly and fresh wood requires significant time investment (6–36 months) to properly dry (Théry-Parisot 2001), which limits its use by mobile foraging groups. Dry standing wood is common in many forested areas, and Théry-Parisot and Meignen (2000) have calculated that there is enough deadwood within less than a kilometer radius of a site to burn four fires 24 hours a day for 6 months. However, these calculations were done for the site of Les Canalettes in France, which would have been surrounded by thick forest during the period the authors were analyzing. In other environments, wood may not be so abundant (Elton 2008). Some of the earliest analyses of human choice of fuel have argued that preferred dry standing wood can quickly become depleted, even in areas of relatively low population density (Shackleton and Prins 1992). A recent paper on fuel use in the Pavlov Hills region of the Czech Republic proposed that the Gravettian hunter-gatherers in the region would have quickly eliminated the naturally occurring deadwood, and it may have taken several generations (40–120 years) for the deadwood to regenerate (Pryor et al. 2016). Clearly, securing preferred fuel would have required some sort of behavioral shift. In the case of the Gravettian groups, the authors proposed intentional management strategies, such as geographic mobility and the deliberate killing of trees in advance, but for groups less dependent on fire than modern humans, it is possible that other adaptive strategies may have been used.

Many studies have documented how increasing the cost of fuel can change behavior. Among people living today, fuel collection requires a significant time and energy investment, with some households in rural Mexico spending nearly 4 person-hours per trip to collect fuel (Manning and Taylor 2014). Small decreases in forest cover are connected with large increases in the amount of time collecting fuel, with one study linking a 1% increase in deforestation to a 0.3% decrease in fuel consumption and a 0.6% increase in fuel collection (Kumar and Hotchkiss 1988). This may sound small, but it represents an extra 1.13 hours per day spent on fuel collection (Kumar and Hotchkiss 1988). Recent Kenyan agripastoralists chose to prepare more quickly cooked foods in times of fuel scarcity (van Wijngaarden 1984). Furthermore, while these agripastoralists often collected fuel in conjunction with other tasks (such as herding cattle), they recognized the costs of carrying the wood, preferentially leaving cut green wood to dry in public areas, thus potentially risking its loss, rather than carrying the heavy fresh wood back to the farm to cure (van Wijngaarden 1984). Patterns of fuel use are less well studied in foraging populations than among developing societies. Women and children are the primary fuel gatherers in most societies (Murdock and Provost 1973), but there is a clear environmental variation in the value of and attitude toward fuel. Lee (1979:148) noted that for the !Kung San, "in the dry Kalahari firewood is rarely a problem. Dead wood is plentiful and even living wood is dry enough to burn instantly if put into a fire." In contrast, the Mbendjele foragers in Congo-Brazzaville complain about having to cook beans, because they take too long and require too much wood (K. Janmaat, personal communication); despite the abundance of trees, good fuel is limited in a rainforest.

In the archaeological record, it has also been possible to recognize behavioral shifts resulting from the costs of fuel. A series of elegant studies have indicated that, as local wood resources were depleted by smelting, Bronze Age inhabitants of the Levant shifted to using more tin in their bronze because of its significantly lower melting temperature, which reduced their overall fuel needs (Kaufman 2013; Kaufman and Scott 2014). Even earlier in history, in the semiarid savanna of southwest Texas and Coahuila, Mexico, Archaic period inhabitants relied on lechuguilla and sotol, two extremely refractive starchy plant resources that required intensive processing, mostly roasting in an earth oven for long periods of time. To create enough food for 1 day for a small group of four to five individuals required a minimum of 250 kg of wood (Dering 1999). This quickly depleted local fuel sources, and Dering argued that fuel and food scarcity, not water availability, led to increasing mobility among these foragers. Charcoal analyses at Mousterian sites have already shown that Neanderthals were aware of the qualities of their fires and probably also were aware of the availability of various fuel sources. Théry-Parisot and colleagues (Théry-Parisot 2002; Théry-Parisot and Meignen 2000) have argued that the introduction of coal and bone to wood fires significantly reduces the amount of wood that is needed to burn for the same amount of time, suggesting a need to reduce wood consumption perhaps due to a decreased availability of wood. Furthermore, the charcoal fragments at a Spanish Neanderthal MIS 5–4 site showed signs of radial cracking and fungal infestation of wood (Vidal-Matutano et al. 2015). The former indicates the burning of green wood and the latter of rotten wood, neither of which is a preferred fuel source (Théry-Parisot 2001), suggesting that perhaps the local environment had become depleted in standing dry deadwood. These lines of evidence suggest that there may have been ample reasons for Neanderthals to consider the amount of fuel they consumed. Though there would have been wood in sheltered places around Neanderthal sites even during cold, dry periods, it is possible that the time and energetic costs of collecting this limited resource may not have been offset by the benefits of fire.

Though fuel collection is the major cost associated with fire, there are other potential costs to consider. These include the time spent curating a fire to cook the food, the potential loss of food to conspecific competitors, the removal of potentially beneficial bacteria, and the health risks associated with fire itself. Time allocation is a major aspect of energy allocation. For example, sitting around a fire while cooking food is a relatively low-energy activity, and it is time that cannot be spent on other, perhaps more fitness-enhancing, behaviors such as collecting additional food items. The cooked food also needs to be guarded from theft. Wrangham and colleagues (Wrangham et al. 1999) noted that cooked food is of increased value because it is more digestible; also, it has been collected and gathered to a central place and is therefore at risk to be taken by "scroungers." The potential loss of food items should be considered when weighing the benefits of cooking. Not only are cooked items vulnerable, but the fire itself is a shared good that is at risk of freeloaders (Twomey 2013) who might use the benefits of the fire but not contribute to its maintenance. Furthermore, the process of cooking itself may produce harmful physical reactions. Cooking destroys bacteria, which can reduce foodborne illnesses. However, we are increasingly aware that humans can acquire adaptive genes from exogenous bacteria and assimilate them within functional members of the complex system of gut microbiota (GM; Smillie et al. 2011). One potent example comes from a group of Japanese people who have gained the ability to digest a type of refractive seaweed by incorporating genes from naturally occurring bacteria into their GM (Hehemann et al. 2010). Studies of non-Western rural and forager groups further indicate that the adoption of genes from environmental bacteria into the GM confers digestive benefits (De Filippo et al. 2010; Rampelli et al. 2015; Schnorr et al. 2014). Finally, the process of creating a fire and cooking carries intrinsic health risks. These range from the nutrient-reducing and potentially carcinogenic effects of the Mailliard reaction, which occurs when food is browned or burned over a fire (Ledl and Schleicher 1990; Mottram, Wedzicha, and Dodson 2002), to the actual risks of injury or death from burning and the long-term health risks of smoke inhalation (Bruce, Perez-Padilla, and Albalak 2000; Smith et al. 2000). Recent genetic studies have shown that modern humans, and not Neanderthals, Denisovans, or living African apes, have a fixed derived variant of a gene (*AHR*) that reduces the deleterious effect of polycyclic aromatic hydrocarbons, a group of chemicals released in smoke and found on charred foods (Hubbard et al. 2016). This suggests that there was strong selective pressure among modern humans to avoid some of the negative health effects of fire. Another study found no evidence in Neanderthals for selection among a large number of detoxification genes toward alleles that were more protective against the ill effects of smoke (Aarts et al. 2016). It is unlikely that Neanderthals had an understanding of microbial horizontal gene transfer or of linking cancer risks to browned food. However, these invisible costs of cooking may have had a noticeable effect on longevity and disease state, leading to a decrease in fitness of groups who regularly cooked.

Finally, and perhaps most importantly, the costs and benefits of cooking vary among environments, so that the value of cooking would not be the same across the entire geographic and temporal spread of the Neanderthals. As mentioned above, the amount of available fuel depended heavily on the degree of tree cover and on the local distribution of other resources, such as coal. For example, the cost to access standing deadwood in a steppe environment may have been very high, while other fuels might not have been an option if the foragers were mobile (it requires a significant time investment to create and dry dung cakes or to cure fresh-cut wood). Furthermore, the kinds of foods available in different environments have different responses to cooking. Within a single food type, plant underground storage organs, there is large variation among taxa in their nutritional qualities and their changes in digestibility when cooked. One study of the glucose digestibility of tubers consumed by the Hadza foragers showed that of four species, one had improved digestibility when cooked, two had negligible changes, and one was actually less digestible after cooking (Schnorr et al. 2015). The Hadza can and do consume these plants when raw, and when they cook them, they do so for short (ca. 5 min) periods (Marlowe 2010). It seems that the Hadza cook the tubers to make them easier to peel, but not to predigest the starch inside them. This is in contrast to the tubers available in rainforest environments, which often contain harmful toxins that must be denatured by cooking (and sometimes more elaborate processing like leaching in lye) prior to consumption (Tanno 1981). Clearly, ascribing the value of cooking to one single factor can lead to misunderstandings of its use in human history.

Fire is so embedded in the way present-day humans live that it is hard for us to consider life without its benefits, including cooking, light, heat, and protection. However, given the immense time periods and significant environmental shifts in which Neanderthals lived, we must realize that using our present, or even the recent historical past, as a reference may not be appropriate. When the data suggest interpretations for Neanderthal interactions with fire that do not mimic our own, we must be open to the possibility that they had a different mode of living. Instead, models developed for studies of all living species, such as those derived from behavioral ecology, allow us to better understand Neanderthal behavior in terms of costs and benefits rather than social or cognitive abilities. Behavioral ecology models have been successfully used to explore Neanderthal decision-making in other areas (e.g., that the choice of lithic raw material depends in no small part on the distance to the quarry and the difficulty of terrain to reach it [Browne and Wilson 2011; Wilson 2007*a*, 2007*b*]). A new comprehensive view of the costs of fire must be undertaken. While many of the potential costs cannot be directly compared to the potential gains of cooking, we can at least begin by exploring the caloric costs of fuel collection in different environments and exploring how much time and energy it requires to access different fuels (e.g., dry standing wood, green wood, etc.). A study that incorporates the various caloric costs of fuel collection in different environments and compares this to the relative caloric benefits of cooking local foods could illuminate why, or why not, Neanderthals chose to cook their dinners.

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