Journal of Paleolithic Archaeology
https://doi.org/10.1007/s41982-020-00052-7

A Cross-cultural Survey of On-site Fire Use by Recent Hunter-gatherers: Implications for Research on Palaeolithic Pyrotechnology

Brea McCauley[1] · Mark Collard[1] · Dennis Sandgathe[1,2]

Published online: 12 March 2020

Abstract

The ability to control fire clearly had a significant impact on human evolution, but when and how hominins developed this ability remains poorly understood. Improving our understanding of the history of hominin fire use will require not only additional fieldwork but also comparative analyses of fire use by ethnographically-documented hunter-gatherer groups. Here, we report a study that focused on the second of these tasks. In the study, we consulted ethnographic texts for a sample of 93 hunter-gatherer groups and collected data pertaining to fire use in settlements. We focused on the groups' methods of making fire, the ways in which they used fire, and when and where they created fires. While many of the observations were in line with expectations, some were surprising. Perhaps most notably, we found that several groups did not know how to make fire and that even within some of the groups who were able to make fire, the relevant knowledge was restricted to a very small number of individuals. Another surprising finding was that many groups preferred to preserve fire rather than creating it anew, to the point that they would carry it between camps. In the final section of the paper, we discuss the implications of the survey's findings for understanding the early archaeological record of fire use.

Keywords Fire · Hunter-gatherer · Ethnography · Ethnology · Cross-cultural analysis · Cooking

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s41982-020-00052-7) contains supplementary material, which is available to authorized users.

✉ Dennis Sandgathe
dms@sfu.ca

1 Department of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6, Canada

2 Museum of Archaeology and Anthropology, University of Pennsylvania, 3260 South Street, Philadelphia, PA 19104, USA

Introduction

It is widely accepted that the development of the ability to control fire was a key event in human evolutionary history (Clark and Harris 1985; Goudsblom 1986; James 1989). Numerous benefits of being able to create and use fire have been recognized. In addition to the obvious ones of providing heat and light and enabling food to be cooked, the ability to control fire would have allowed individuals to manufacture a range of new artifacts, protect themselves against pests and predators, and increase hunting returns via landscape burning (Brown et al. 2009; Gilligan 2010; Mazza et al. 2006; Oakley 1956). According to a number of scholars, the advantages of fire use were so great that it influenced the evolution of both our digestive system and our nervous system (Gowlett 2006; Twomey 2014; Wrangham 2006, 2017). It has even been suggested that modern humans are so dependent on fire that they could not survive without it (Wrangham 2017).

While it is obvious that developing the ability to control fire had major impacts on human evolution, a number of issues concerning the history of hominin fire use remain poorly understood. Most obviously, we have little idea when hominins discovered how to create fire or even when they first started using fire. Currently, the earliest putative evidence for fire use comes from sites in Kenya and South Africa that date to ca. 1.5 and 1.0 million years ago (Mya), respectively (Berna et al. 2012; Hlubik et al. 2017). However, Wrangham and colleagues have argued that hominins started using fire as early as two million years ago (e.g. Wrangham et al. 1999; Wrangham 2009; Wrangham and Carmody 2010). This is based on the fact that *Homo erectus*, which first appeared around this time, had relatively small teeth and jaws, a rib cage indicative of a short gut, and a relatively large brain. According to Wrangham and his colleagues, these traits indicate dependence on cooked food and therefore on fire. Complicating the debate further, Dibble et al. (2018) have proposed that some populations of our closest relatives, the Neanderthals, who likely did not appear until after 0.5 Mya, may have lacked the ability to make fire at will. Other important issues are even less well understood than these timing-related ones. For example, we have only recently begun to consider the costs of acquiring fuel (Henry 2017; Henry et al. 2018) and the impact of the greater number of productive hours that firelight makes possible (Dunbar and Gowlett 2014; Wiessner 2014).

Improving our understanding of the history of hominin fire use will obviously require further fieldwork. However, recovering additional archaeological evidence will not be sufficient. We also need data on fire use by ethnographically documented hunter-gatherer groups. Such data are crucial for making sense of the early archaeological record of fire use. Recently, Scherjon et al. (2015) reported a cross-cultural study that shed some light on off-site fire use by recent hunter-gatherer groups, but our knowledge of the ways in which such groups used fire in their settlements is limited to observations of just a few well-known cases. Here, we report a study that was designed to improve this situation. In the study, we consulted ethnographic texts for a large sample of hunter-gatherer groups and collected data on their methods of making fire, the ways in which they used fire, and when and where they created fires. As we will show, the results of this survey have a number of implications for research on early pyrotechnology.

Materials and Methods

Our main data source was the World Cultures Ethnography Database, which is a keyword-searchable online database of ethnographies (Human Relations Area Files 2008). We used the 36 keywords listed in Table 1 to search for mentions of fire-related activities in the categories “hunter-gatherers” and “primarily hunter-gatherers.” As the resulting sample of groups was heavily biased towards the Americas, we also searched hard-copy ethnographies for information on fire use by hunter-gatherers from Africa, Asia, and Australia.

From the sections of text highlighted in the search, we extracted information on three sets of variables. The first concerned the ways in which fire was created. Where possible, we recorded the method(s) of fire production, how often new fires were made, and how long it took to create a fire. We also recorded whether or not fire-making was restricted to particular individuals within the group. In addition, we noted whether the group preserved fire and, if they did, how they accomplished this. The second set of variables related to the ways in which fire was utilized. In addition to the obvious uses of providing heat and light and preparing cooked food, we noted whether fire was employed for protection from predators and insects, food preservation, and/or craft manufacture. We also recorded whether the groups used fire for ritual purposes. The final set of variables pertained to the spatial and temporal dimensions of fire creation and use. We recorded where in settlements fires were located, and when in the year and at what time of day they were created. Whenever possible, we also recorded how long fires were tended.

Needless to say, it is necessary to be careful when using ethnographic sources to assess the presence/absence of a given practice. This is especially the case for early written reports which were often more casually done, typically by untrained observers (see, for example, Gott 2002 and Taylor 2008 on early European claims that Indigenous Tasmanians lacked the ability to make fire). In an effort to minimize potential inconsistencies between the reported and actual practices of the groups in our sample, we avoided using the simple absence of mentions of a practice as evidence that it was absent. Instead, a practice was deemed to be absent only when the ethnographic record(s) for a group specifically stated that the group did not engage in the practice.

Table 1 Keywords used to search the World Cultures Ethnography Database (Human Relations Area Files 2008). Adding an asterisk allowed variants of a given term to be included in the search (e.g. burn, burns, burnt, burning)

Adhesive	Cook*	Heat	Roast*
Ash	Ember	Hollow	Smok*
Blaze	Fire	Insect*	Soften
Boil	Firewood	Light	Spark
Bonfire	Flame	Melt	Steam
Broil	Fuel	Pigment	Thermal
Burn*	Glue	Preserv*	Tinder
Coal	Harden	Predator*	Torch
Combust*	Hearth	Raw	Warm

Results

We obtained data for a total of 93 groups—43 from North America, 21 from South America, 13 from Oceania, ten from Asia, and six from Africa. Information about the groups is given in Table 2 and their locations are shown in Fig. 1. The group names used in Table 1 are the same as those listed in the World Cultures Ethnography Database (Human Relations Area Files 2008) to assist the reader who wishes to check our results. A list of alternative ethnonyms is provided in Online Resource 1. The data were drawn from 480 ethnographic sources, details of which are presented in Online Resource 2. To save space, when outlining the results of the survey, we will use examples rather than discuss all of the groups that engaged in a given practice. The latter information can be found in Online Resource 3. It should be noted that sample size is not consistent among the variables. This is because we found that there is considerable variability in the types and quantity of data available for the 93 groups.

Fire Creation and Preservation

At the time the ethnographic data were collected, the vast majority of the 93 groups ($n = 88$) knew how to make fire using traditional methods, such as wood friction or percussion, but several did not. These were the Onges, Yuquí, Warlpiri, Sirionó, and northern Aché. To reiterate, we only recorded a practice as absent when the relevant ethnographic report(s) specifically stated that the group did not engage in the practice, so the absence of fire-making technology in these cases is reliable. The Onges and Yuquí collected natural fire and then conserved it for as long as possible (Cipriani and Tayler Cox 1966: p. 25; Stearman 1984: p. 637). If an individual's fire went out, they borrowed a firebrand from a neighbour. The Warlpiri relied on matches to make fire (Meggitt 1965: p. 263). The Sirionó explained to ethnographers that they used to know how to create fire with the wood friction method but no longer possessed that knowledge (Holmberg 1950: p. 11[2]; Holmberg 1969: p. 17). Stearman (1984): p. 643–644) argued that this loss of knowledge was due to the Sirionó having to relocate to a new area that was wetter and more humid than their previous territory, and therefore, the environment made it harder to create fire leading to the loss of knowledge over time. Because of this loss of knowledge, if all of their fires were extinguished, the Sirionó raided nearby agricultural settlements for fire (Rydén 1941: p. 35–36; Isaac 1977: p. 142). Not all Aché groups were able to make fire with traditional methods at the time of contact. Hill et al. (2011) reported that the Southern Aché were able to do so, but the Northern Aché were no longer able to create fire with traditional methods by the time they were contacted in the 1970s and they were only able to remember some of the details of the methods. A further two groups, the Mbuti and Twa, had very few members capable of creating fire with traditional methods (Gusinde 1955: p. 22; Turnbull 1965: p. 35). In the case of the Mbuti, the few individuals who could make fire without matches learned how to do so from neighbouring farmers (Turnbull 1965: p. 35), which suggests that traditional fire-making methods had effectively been lost by the Mbuti by the time they were studied by ethnographers.

Fire-making and maintenance were sex-specific tasks in some of the groups. Five groups specified that fire starting was exclusively the domain of males, whereas no

Table 2 Groups included in the sample. Group names are the same as those listed in the World Cultures Ethnography Database (Human Relations Area Files 2008). See Supplementary Table 1 for a list of ethnonyms

No.	Name	Region	No.	Name	Region
1	Hadza	Africa	48	Pomo	North America
2	Mbuti	Africa	49	Quinault	North America
3	Nharo	Africa	50	Stoney	North America
4	Okiek	Africa	51	Tlingit	North America
5	San	Africa	52	Tubatulabal	North America
6	Twa	Africa	53	Ute	North America
7	Agta	Asia	54	Western Apache	North America
8	Ainu	Asia	55	Western Woods Cree	North America
9	Andamans	Asia	56	Winnebago/Ho-Chunk	North America
10	Koryaks	Asia	57	Yokuts	North America
11	Mlabri	Asia	58	Yuki	North America
12	Nenets	Asia	59	Yurok	North America
13	Nivkh	Asia	60	Alyawara	Oceania
14	Samoyed	Asia	61	Aranda	Oceania
15	Semang	Asia	62	Kaurna	Oceania
16	Vedda	Asia	63	Luritja	Oceania
17	Aleut	North America	64	Manus	Oceania
18	Alutiiq	North America	65	Mardu	Oceania
19	Assiniboine	North America	66	Māori	Oceania
20	Blackfoot	North America	67	Ooldea	Oceania
21	Chinook	North America	68	Pila Nguru	Oceania
22	Chipewyan	North America	69	Tiwi	Oceania
23	Comanche	North America	70	Warlpiri	Oceania
24	Copper Inuit	North America	71	Yiwara	Oceania
25	Creek	North America	72	Tasmanians	Oceania
26	Crow	North America	73	Abipón	South America
27	Delaware	North America	74	Aché North	South America
28	Eastern Apache	North America	75	Aché South	South America
29	Greenland Inuit	North America	76	Barama River Carib	South America
30	Gros Ventre	North America	77	Bororo	South America
31	Haida	North America	78	Canela	South America
32	Ingalik	North America	79	Chorote	South America
33	Innu	North America	80	Mataco	South America
34	Island Carib	North America	81	Mudurucu	South America
35	Kaska	North America	82	Nambicuara	South America
36	Klamath	North America	83	Ona	South America
37	Maricopa	North America	84	Sirionó	South America
38	Mescalero Apache	North America	85	Tehuelche	South America
39	Miskito	North America	86	Terena	South America
40	Mi’kmaq	North America	87	Ticuna	South America
41	Northern Paiute	North America	88	Trumai	South America

Table 2 (continued)

No.	Name	Region	No.	Name	Region
42	Nuu-chah-nulth	North America	89	Tupinamba	South America
43	Nuxalk	North America	90	Warao	South America
44	Ojibwa	North America	91	Xokleng	South America
45	Omaha	North America	92	Yahgan	South America
46	Osage	North America	93	Yuquí	South America
47	Pawnee	North America			

groups stated the same for females. In contrast, in ten groups, females were primarily responsible for preserving the fire. No group specified the same for males.

Data on methods of fire manufacture were available for 74 of the groups who knew how to make fire with at least one traditional method (Table 3). Thirty-three groups used only wood friction methods such as a bow drill or fire saw, and ten used only percussion methods like flint and pyrite. The other 31 groups employed more than one method. Twenty-one used wood friction and percussion; three used wood friction and matches; one used percussion and matches; and six used wood friction, percussion, and matches. In total, 64 groups used wood friction, 38 used percussion, and 11 used matches.

Data on the fuel used for fires were available for 69 groups. Not surprisingly, the vast majority of groups ($n = 62$) employed wood. The type of wood utilized was not specified for 34 of the groups, but it was for the rest. For ease of analysis, we divided the wood into "hardwood," "softwood," and "palm wood" (palm trees are listed separately because their cellular structure is such that they are not considered to be hardwood or softwood [Parthsarathy and Klotz Parthsarathy and Klotz 1976]). It should be kept in mind that these categories do not necessarily reflect emic concepts. Fifteen of the 28 groups used only hardwood; seven employed only softwood; five utilized a mixture of hardwood and softwood; and one employed palm wood. Of the nine groups that did not use wood, seven utilized animal dung and two employed grass. There were no reports of bone being used as fuel.

Fifty-six groups had information on the tinder they used when creating fire. The most common tinder was dry wood ($n = 17$), followed by grass ($n = 12$), dry fungus

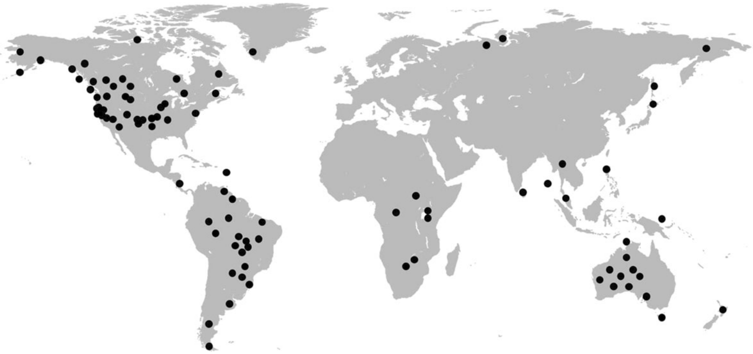

Fig. 1 Geographic locations of groups in sample

Table 3 Fire manufacture techniques employed by the groups in our sample

Manufacture type(s)	Number of groups
Wood friction	33
Percussion	10
Wood friction and percussion	21
Wood friction and matches	3
Percussion and matches	1
Wood friction and percussion and matches	6
Total wood friction	63
Total percussion	38
Total matches	10

($n = 10$), dry leaves ($n = 8$), rotten wood ($n = 8$), moss ($n = 6$), the down of birds ($n = 5$), animal dung ($n = 4$), cotton ($n = 3$), dry straw ($n = 2$), dry roots ($n = 2$), cacti ($n = 1$), thistles ($n = 1$), and crude rubber ($n = 1$).

Data on the methods used when a fire went out were available for 28 groups. Only two groups reported starting a new fire. Eight groups raked their earlier embers in an effort to re-ignite fires from previous days, while another 18 took embers from their neighbours' fire or from a communal fire.

Some groups often would not make new fires when moving camp. Instead, they preserved their fire in portable form (i.e. a firebrand, slow match, or smouldering embers). Rates of fire creation or preservation when moving camp were available for 40 groups. Only three of these groups started a fresh fire at their new camp. The other 37 preserved their fires by carrying a firebrand, slow match, or smouldering embers with them.

Uses of Fire

There was considerable inter-group variability in the amount and quality of data pertaining to the uses of fire. As such, the fire uses may be more common than reported.

Not surprisingly, cooking was the most commonly reported use of fire. All 93 groups employed fire to cook at least some of their foods. Data on the consumption of cooked food was available for 64 of the groups. Interestingly, the types of food they cooked differed. Thirty groups cooked animal foods but ate some plant foods raw, while seven groups cooked plant foods but ate some animal foods raw. The remaining 27 ate some plant and animal foods raw and some plant and animal foods cooked. Methods of cooking differed among the 64 groups as well. Boiling was the most common method ($n = 64$), followed by roasting ($n = 58$), broiling ($n = 19$), and steaming ($n = 14$). Most of the 64 groups used multiple cooking methods, but six groups only boiled their food.

Equally unsurprisingly, providing warmth was the second most prevalent on-site fire use reported. It was mentioned in ethnographic reports pertaining to 81 of the groups.

Ritual was the third most commonly reported use of fire. Seventy-four groups employed fire in rituals, with death rites being the most common of these ($n = 43$). For 26 of these groups, either the deceased, their dwelling, or their possessions were burned. Fire was also used regularly in rituals involving medicine ($n = 29$), sweat lodges ($n = 25$), dances ($n = 24$), birth ($n = 17$), communing with the spirit world ($n = 14$), and initiation ($n = 11$). Rarer ritual uses of fire included hunting ($n = 7$), war ($n = 6$), marriage ($n = 5$), to predict or influence the weather ($n = 4$), and feasting ($n = 2$). For these ritual purposes, 19 groups lit new fires rather than used those that were already burning.

Raw material processing and manufacture was the fourth most commonly reported use of fire. We found it mentioned in reports relating to 71 groups. Among these groups, 53 used fire to process wood, including to harden it ($n = 33$), shape it ($n = 26$), and hollow it out ($n = 23$). Some groups used fire to cut materials such as wood and hair ($n = 16$), and to aid in the creation of adhesives ($n = 23$), pigments ($n = 28$), and poisons ($n = 3$). Fire was also used by certain groups to process hides ($n = 22$), to fire ceramics ($n = 17$), and to soften materials such as bark, wood, stone, and iron ($n = 15$).

The next most frequently reported on-site use of fire was producing light in the evenings. This use of fire was mentioned for 56 groups. Among the activities that were facilitated by firelight were gossiping, playing games, telling stories, weaving, sewing, dancing, and communing with the spirits. Of these 56 groups, 32 reported relying on more than just a campfire. Seventeen used lamps as well as a campfire and 21 used torches as well as a campfire. Interestingly, torches were also used for warmth and lamps were also used for warmth and cooking.

A large number of groups were reported to preserve their food using smoke from their on-site fires. Forty-one groups in the sample were reported to engage in this practice.

The final two on-site fire uses relate to protection from animals. Twenty-nine groups were reported to create especially smoky fires to protect against insects, while seven groups used fire to keep predators away from their camp.

Data on whether an on-site fire was used for multiple purposes or just one were available for 64 groups. All of these groups were reported to have employed fires for multiple purposes, but thirty-three of them were also reported to have used single-purpose fires. One of the more commonly reported functions for single-use fires was cooking certain types of food, especially tubers, which were baked, and big-game meat, which was roasted ($n = 18$). Another common function for single-use fires was ritual ($n = 19$).

Temporal and Spatial Dimensions of Fire Creation and Use

Fifteen groups had data for how long it took them to make fire using wood friction methods. Four groups took less than one minute to produce a flame; eight took between one and five minutes; and three took more than five minutes. We only located data for one group on how long it took them to make fire using percussion methods. This group reported producing a flame in less than one minute.

Some of the sources we consulted had information pertaining to how frequently groups created on-site fires. Data were available for a total of 35 groups. Three of them made new fires often; ten did so occasionally; and 21 rarely started new fires. Most often, when a new fire was lit, it was for ritual purposes ($n = 19$).

Unfortunately, data on the temporal and spatial dimensions of on-site fire uses were limited. We located some information about the use of fires for cooking and warmth but not for any of the other uses. The ethnographers who produced the accounts we relied on simply did not record such information.

We found data pertaining to the temporal aspects of cooking fires for 28 groups. For these groups, we obtained information on how long cooking fires were kept alight. Such fires either burned continuously ($n = 23$) or were kept burning all day but extinguished at night ($n = 5$). Sometimes a fire was created to cook a particular item of food. For example, a large fire might be built to cook meat from a large animal or a pit might be dug to roast tubers. Typically, these specialized fires were only kept going long enough to cook the food item in question.

The sources we consulted provided information about the temporal dimensions of the use of fire for warmth for 42 groups. For 33 of these groups, we were able to obtain data on when in the year fires for warmth were used. Twenty-three groups always had a fire lit for warmth no matter the weather; nine groups only used fire for warmth in the winter or during poor weather; and one group used fire for warmth only in the summer. The last group warmed themselves with lamps during the winter months. We were also able to compile data concerning how long fires were kept alight for warmth for 35 of these 42 groups. The fires either burned indefinitely ($n = 25$) or burned all night but were allowed to die out in the morning ($n = 10$).

Information on the location of fires that were used for cooking and/or warmth were available for 68 groups (Table 4). Forty-two groups used the same fire for warmth as they did for cooking and we have location data for 35 of them. Twenty-two of the 35 located the fire in the centre of their dwellings; six placed the fire such that it was close to the centre of the dwellings but also close to their sleeping places; five groups located it in front of their dwellings; and two groups located the cooking/warmth fire in the centre of their dwellings but also created an additional cooking fire in the centre of their camp. The situation with the remaining group, the Twa, is more complicated. During the day, they cooked on the fire in front of their dwellings. At night, they pushed the fire structure inside the dwellings and used it for warmth.

Eight of the 68 groups seem not to have used the same fire for warmth and cooking. In these cases, the reported locations of the cooking and warmth fires were different. These fires could also be employed for other uses, such as light or protection from animals. Four of the groups located cooking fires in front of their dwellings and warmth fires by their sleeping places; two groups placed cooking fires in the centre of their dwellings and warmth fires near their sleeping places; one group positioned cooking fires in front of their dwellings and warmth fires in the centre of their dwellings; and one group built cooking fires in front of their dwellings and at the centre of the camp and created warmth fires by their sleeping places.

For the remaining 25 groups, it is unknown whether the fire structures used for cooking or warmth were the same or not, as the location of only one of these two purposes was reported. Ten of these groups had data for the location of their cooking fires. Four groups placed the fires in the centre of the dwellings, three located them in front of their dwellings, one kept the cooking fire at the back of their dwellings, one placed the cooking fire at the opening of their dwellings, and one group had cooking fires in the centre and in front of their dwellings. The remaining 15 groups had location information for their warmth fires. Ten of these groups kept the fires by their sleeping places, two groups located the fires in the centre of their dwellings, one group had their warmth fire centrally located in the camp, another group had warmth fires in their

Table 4 Locations of different types of fires. Data on fire location were available for a total of 68 groups

Types of fire	Location	Groups
Same fire used for cooking and warmth ($n = 35$)	Centre of dwelling	22
	Centre of dwelling and by sleeping places	6
	In front of dwelling	5
	Centre of dwelling and centre of camp	2
Separate fires for cooking and warmth ($n = 8$)	Cooking fire in front of dwelling; warmth fire by sleeping places	4
	Cooking fire at centre of dwelling; warmth fire by sleeping places	2
	Cooking fire in front of dwelling; warmth fire at centre of dwelling	1
	Cooking fire at centre of camp and in front of dwelling; warmth fire by sleeping places	1
Unknown if fires for cooking and warmth were the same ($n = 25$)	Cooking fire at centre of dwelling; no data on warmth fire	4
	Cooking fire in front of dwelling; no data on warmth fire	3
	Cooking fire in opening of dwelling; no data on warmth fire	1
	Cooking fire at back of dwelling; no data on warmth fire	1
	Cooking fire at centre of dwelling and in front of dwelling; no data on warmth fire	1
	No data on cooking fire; warmth fire by sleeping places	10
	No data on cooking fire; warmth fire at centre of dwelling	2
	No data on cooking fire; warmth fire at centre of camp	1
	No data on cooking fire; warmth fire at centre of camp and by sleeping places	1
	No data on cooking fire; warmth fire in front of dwelling and at centre of dwelling	1

dwellings by their sleeping places as well as a centrally located fire for warmth, and one group had warmth fires in the centre and in front of their dwellings.

Discussion

Limitations

One problem we encountered repeatedly was the failure of a group's ethnographer to provide data on the uses of fire. For example, data on activities that were facilitated by firelight (e.g. weaving, playing games, dancing) were only available for approximately half of our sample. Similarly, repelling insects and predators with fire was rarely mentioned in the ethnographies we consulted, even though they seem like obvious benefits of fire in many regions. It is possible that these uses of fire were not as common as is typically assumed. However, we suspect that such activities, and how the availability of fire influenced them, may just have been so obvious to ethnographers that they often did not think to report on them. Unfortunately, the evident inconsistencies in data collection mean that we are not in a position to determine which of these possibilities is correct.

A second problem we encountered was a lack of detail concerning particular uses of fire. Often an ethnographer would mention a fire use but provide very little information. For instance, there is reason to think that different types of raw material manufacture and processing would have required fires that had distinct characteristics or behaved in specific ways (e.g. Mallol and Henry 2017). But the majority of entries pertaining to raw material processing did not describe the fire used in any detail. Another example is the use of fire in rituals. As we noted earlier, ritual fires were the most common type of newly constructed fire. Accordingly, it would have been very useful to have data on the properties of these fires. Unfortunately, however, ethnographers usually did not provide any information on these fires. Instead, they focused on the details of the actors and contexts of the rites. While this is understandable, it is unfortunate for those of us interested in the evolution of hominin fire use.

A third problem was that the information on the location of fires was less than ideal. We obtained data pertaining to fires used for cooking and warmth, but not for fires used for other purposes. There are a couple of potential reasons for this. One is that ethnographers simply did not think to document the location of fires in the settlement. Another possibility stems from the fact that fires were often multi-functional. It is feasible that fires used for raw material processing, light, and animal protection may have been the same fires used for cooking and warmth. Unfortunately, however, this was not often specified. This means that we cannot be sure if there were specific locations for these fires, or if one or two fires were used for all purposes.

Lastly, it is important to keep in mind that there are issues with using recent hunter-gatherers as models for extinct hominin species. Most notably for present purposes, the latter may not have been subject to the same physiological constraints as modern humans and therefore may not have been as dependent on fire as we appear to be, or used it in the same way. Given this, we recommend viewing the present study as a source of hypotheses that need to be tested with archaeological data rather than as a source of ethnographic analogies for interpreting fire residues at Palaeolithic sites.

Implications for Interpreting the Early Archaeological Record

There are a number of findings from our cross-cultural survey that have implications for the interpretation of the archaeological record of early pyrotechnology. One is that fires intended for a single use were relatively uncommon among historic hunter-gatherers. Most fires are used for multiple functions, which means that fewer fires are constructed than we might have anticipated. An obvious implication of this concerns the number of individual fire structures discovered at archaeological sites. In general, finding only small numbers of fires associated with individual occupations might not be a reflection of group size or be a product of taphonomic factors. It might be an accurate reflection of the number of fires present at the site when it was in use. Furthermore, if a low number of fires per occupation were typical in the Palaeolithic, then this could have implications for excavation strategies. If only a small portion of a site is excavated, we could miss the few fire remains that might be present. Furthermore, if constructing a small number of fires per occupation was the norm, then in situations where preservation conditions are not ideal, having a very small quantity of remains to begin with could mean that certain types of fire residues do not survive at all. Therefore, it is important that we focus on those residues less affected by taphonomy, both at the macroscopic level (i.e. burned flints and burned bone [e.g. Dibble et al. 2009]) and at the microscopic and chemical levels (i.e. sediment micromorphology and geophysical and geochemical analyses [e.g. Goldberg et al. 2012]).

A second implication relates to the lifespan of individual fires. There is some evidence for the use of small, short-duration fires. For example, Mallol et al. (2007) note that the Hadza will occasionally make a small fire and keep it going only for a minute or two in order to light their cigarettes. But most groups in our sample kept their fires burning for extended periods of time. Of course, it is possible that the ethnographers missed quick fires, and that they were much more common than the data suggest. Even if this were the case, however, the prevalence of long-lasting fires among the 93 groups still underscores the need for care in interpreting concentrations of fire residues at Palaeolithic sites. Thick concentrations could reflect either longer occupation of the site with intermittent fire construction, or shorter occupations with fires that were kept alight constantly. While fires of any reasonable size and duration will tend to leave residues (Aldeias et al. 2016; Dibble et al. 2018), longer duration fires are more likely to leave obvious remains. It seems reasonable to expect that maintaining and extending the life of a single fire that is used periodically will leave a different signature in the archaeological record than building a new fire or restarting an old fire each time it is needed and letting it die between uses. Determining whether this is indeed the case would make an excellent focus for an experimental study.

Extending the life of a fire also has implications for fuel use. Shackleton and Prins (1992) have argued that the preferred fuel type, dry standing wood, can quickly become depleted, even in areas of low population density. In line with this, Pryor et al. (2016) have proposed that Gravettian groups in the Pavlov Hills in the Czech Republic would have rapidly eliminated the available dry standing wood, and that it would have taken 40–120 years for the fuel source to regenerate. Even among modern groups, fuel collection can involve a substantial cost. For instance, fuel collection trips in rural Mexico have been found to require as much as four person-hours (Manning and Taylor 2014). The high cost of fuel collection could have had important consequences for Palaeolithic populations. Henry (2017) has highlighted one of these. She has argued that the costs of fuel collection may not have been offset by the benefits of fire for Neanderthals living in certain environments, leading them to not use fire in those instances. Thus, when we encounter a large quantity of fire remains at an archaeological site, we should take into account the different ways they could have been produced and the impact these practices could have had on other behaviours.

Staying with fuel, it is worth reflecting on the fact that we found no reports of the use of bone as a fuel source. While we did not include "bone" among our search terms, instances of bone being used as fuel should have been captured by the search term "fuel." So, we suspect that our failure to locate mentions of the practice reflects its absence among the societies in our sample. This is intriguing because it has been argued that bone was utilized for fuel in Palaeolithic Europe (e.g. Théry-Parisot and Costamagno 2005) and there is archaeological evidence that seal hunters used seal bones for fuel in Antarctica in the nineteenth century (Villagran et al. 2013). The most obvious potential explanation for the difference between the ethnographic period groups and the archaeological cases is limited availability of dry standing wood in the Palaeolithic and nineteenth century Antarctica. However, this hypothesis is difficult to square with the fact that none of the Arctic groups in our sample employed bone as a fuel. Developing and testing other hypotheses for why bone was used for fuel in some contexts but not in others would be a useful undertaking.

That several groups in our sample did not employ traditional methods to create fire also has implications. Once again, we only recorded practices as absent when the ethnographies explicitly indicated that they were not present, so the absence of traditional methods of making fire in these cases can be treated as a real absence. The existence of recent hunter-gatherers who did not have knowledge of traditional fire manufacturing techniques indicates that we should avoid treating fire manufacture as an on/off skill even for recent modern humans, never mind for extinct hominins. As Dibble et al. (2017), Chazan (2017), and Sandgathe (2017) have argued, we should resist the assumption that once we find fire in the archaeological record it means that fire was an essential part of the hominin behavioural repertoire (e.g. Daniau et al. 2010; Barkai et al. 2017).

The ethnographic data also make it clear that the presence of fire in the archaeological record, even the long-term presence of fire in Upper Palaeolithic/Late Stone Age contexts, cannot be taken as evidence that all group members knew how to make fire, or even all adult members of a group (e.g. Barkai et al. 2017; Alperson-Afil et al. 2017; Alperson-Afil 2008). In line with some researchers' suggestions about the Neanderthals' use of fire (e.g. Sandgathe et al. 2011a, 2011b; Aldeias et al. 2012; Dibble et al. 2017; Dibble et al. 2018), fire remains at a Palaeolithic site could be the result of individuals simply collecting naturally occurring fire and successfully maintaining it for long periods. It is clear from the ethnographic data that curating fire, rather than making it, was a reliable approach to regular, long-term fire use.

A corollary of the foregoing is that for us to be confident that members of a particular hominin group manufactured fire, we need to find fire-making implements. Unfortunately, there are some issues with this. First, our data reveal that, of the groups that used traditional fire-starting methods, a large portion used wood friction methods. Evidence for such methods is unlikely to be encountered in the archaeological record because wood is rarely preserved. In addition, we have not yet identified an archaeological signature of percussion methods of creating fire, at least for Palaeolithic contexts (see below). Therefore, in certain contexts, we may not be able to say for certain whether members of a hominin group manufactured fire or collected it from their environment and should consider both options when interpreting fire remains.

On a more positive note, with improved data on recent hunter-gatherer fire use and the continued development and application of geochemical analyses in archaeology (e.g. Leierer et al. 2019; Lejay et al. 2016), we may yet be able to identify specific fire use signatures. For example, if the ethnographic data indicate that certain plant-based tinders are typically associated with specific fire-making methods and certain wood species are commonly used for specific fire functions, then the identification of molecular markers for these plants in association with Palaeolithic fire residues may tell us if, and how, Palaeolithic groups were creating fire and what the fire was being used for. Furthermore, improved ethnographic data on the relationship between fire function and fire placement (e.g. Galanidou 2000) might also improve our ability to use the location of fire features within Palaeolithic sites to interpret their potential functions.

Implications for Our Understanding of the Role of Fire in Human Evolution

Our cross-cultural survey underscores that creating fire using traditional methods is a technology and, like any technology, for someone to have it, they must have discovered it or learned it from another individual. Like many technologies, manufacturing fire also requires both theoretical knowledge (e.g. that, done correctly, fire can be made by striking flint and pyrite together or by rubbing wood together) and practical skills. Just having the theoretical knowledge is not enough, as anyone trying to make fire for the first time using traditional methods can attest. And, like any technology, under certain circumstances, both the theoretical knowledge and practical skills can be lost from the collective repertoire of a group and even if the theoretical knowledge survives, the required practical skills can be lost either through the loss of skilled individuals (they die or a group fissions) or from simple lack of practice. This is highlighted by the fact that several groups in our sample did not have the ability to manufacture fire with traditional methods. A further important implication of this concerns the evolution of hominin cognition. It means that the lack of knowledge of a specific technology cannot be considered evidence of inferior cognitive abilities. If there are recent modern human groups who lack the ability to make fire, then evidence that archaic *Homo* species lacked this ability (e.g. Dibble et al. 2017; Goldberg et al. 2012; Sandgathe et al. 2011a, b) is not, on its own, evidence that they lacked the cognitive ability to master such a technology.

Furthermore, we cannot assume that once a group comes to realize the advantages of fire that fire use would spread quickly within or between populations (Dibble et al. 2017). As per Henry (2017), Henry et al. (2018)), we believe that discussions about the manufacture and use of fire would benefit from applying the framework of behavioural ecology. Instead of envisaging fire manufacture as just an either/or skill—either hominins at a certain time had the ability to make fire or they did not—we should investigate both the potential benefits and the potential costs of fire manufacture and maintenance. The costs and benefits will differ based on the environment and group needs. Thus, groups may have been able to produce fire and yet choose not to under certain circumstances because of a particular cost, such as limitations on fuel availability or moisture levels. Contemporary hunter-gatherer groups are a particularly good option for developing a behavioural ecology approach to fire use, as they are constrained by features of their local ecology and thus adapted to their environment through behavioural trade-offs. These observed relationships between environmental constraints, trade-offs, and variable solutions to these factors should provide a basis for hypotheses concerning early fire use (cf, Hawkes et al. 1997).

A significant point in relation to developing a theoretical framework for understanding Palaeolithic fire use is the commonness of fire preservation and transportation in our sample. Groups that knew how to make fire did not do it frequently; they often stated that fire-making was strenuous and therefore tried to avoid doing it regularly (e.g. Zeisberger et al. 1910: p. 19; Gusinde and Schütze 1937: p. 42; Smith 1982: p. 11; Opler 1941: p. 395; Murdock 1934: p. 24). In addition, there was a strong tendency for groups to carry fire from camp to camp as opposed to creating new fires when they settled. It occurred to us that there could be some patterning to this, with groups that generally stayed longer in one place and moved less frequently developing a stronger habit of preserving fire because they experienced longer periods of easy access to fires in fixed locations. It seemed reasonable to suppose that these groups would have had a greater tendency to carry their fires when they relocated. However, this does not appear to be the case. Binford (2001) provides data on the average number of moves per year for 17 of the groups in our sample that preserved fire when relocating camp. The average number of moves per year was 14 and the maximum was 38, both of which are high for recent hunter-gatherers (Binford 2001). This suggests that it was often less costly for groups to transport fire when they moved locations than it was to create a fire from scratch when they reached their destination, even when they moved frequently. An obvious corollary of this is that fire preservation and transportation may have been frequent in the Palaeolithic.

Our survey makes it clear that it was common for recent hunter-gatherer groups to maintain campfires past dusk. It is easy to overlook the importance of this practice for human evolution. It has been estimated that firelight would have added approximately four hours of socializing time to an individual's daily time budget (Dunbar and Gowlett 2014). Opening up increased time for important socializing activities after twilight would have allowed groups to devote more of their daylight hours to foraging and collecting raw materials for tool manufacture, which would have had obvious benefits (Burton 2011). In addition, it has been argued that group size and time devoted to social interaction correlate in primates because social interaction reduces the probability of group fissioning (Dunbar 1992; Lehmann et al. 2007). Thus, maintaining campfires past dusk could have contributed to hominins' ability to live in larger groups. Firelight may have had other impacts on human evolution. For example, Gowlett (2010) has hypothesized that firelight resulted in selection for changes in the circadian rhythms of hominins who used fire. In a similar vein, Dunbar et al. (2012) have proposed that the use of fire to extend the day into the reduced light levels of the evening may have created selection pressure for a larger visual system in fire-using hominins.

Possible Future Research Directions

In addition to trying to shed more light on the use of bone as fuel (see "Implications for Interpreting the Early Archaeological Record"), there are two obvious possibilities for future research. First, given that several historic hunter-gatherer groups in our sample did not have traditional fire-starting techniques, we cannot assume that in archaeological contexts the evidence of the use of fire is evidence for fire manufacture. Instead, to say with any certainty that groups were manufacturing fire, we need to find evidence of fire-starting implements. Unfortunately, we are unlikely to find friction-based fire-making implements in the archaeological record due to the poor preservation of wood materials. It is possible that percussion-based fire-starting methods (e.g. flint and pyrite) left behind evidence, but this has yet to be convincingly demonstrated in relation to the Palaeolithic archaeological record (Sorensen et al. 2014). Sorensen et al. (2018) reported finding evidence that Mousterian bifaces were used as strike-a-light. However, their study was limited to comparing use-wear on a sample of bifaces to use-wear generated in replicative experiments without quantification or blind testing. Thus, their findings were no more than suggestive. To conclusively demonstrate that Palaeolithic hominins used flint and pyrite to start fires, it will be necessary to develop methods for identifying pyrite residues on stone tools or in archaeological sites in association with fire residues.

We also think that the question of fire preservation should be investigated in more detail. Instead of regularly lighting new fires, a surprisingly large percentage of the groups with available data (49 out of 53) preserved their fires not only for the duration of their stay at a residential camp (26 out of 28) but also when they moved to another camp (37 out of 40). This has important implications for fuel use and for acquiring or maintaining access to fire. However, we do not know the full range of this behaviour as we lacked data for a number of the groups in our sample. Better data on recent hunter-gatherer fire preservation practices could improve our understanding of the role of fire in the lives of Palaeolithic groups that relied on access to natural fire sources. If a group lacked the ability to make fire and relied on fire preservation techniques, what impact would this have had on their subsistence, settlement, and mobility?

Conclusions

Cross-cultural analyses of fire use by ethnographically documented hunter-gatherer groups have an important role to play in the ongoing attempt to understand the history of hominin fire use. Recently, Scherjon et al. (2015) reported the results of a survey of off-site fire use by recent hunter-gatherer groups. In this paper, we have outlined the results of a complementary study in which we surveyed ethnographies pertaining to a sample of 93 recent hunter-gatherer groups and extracted information about the ways they created and used fire in their settlements. Many of the findings of the survey were unsurprising. For example, all of the groups used fire to cook and most fires were employed for multiple purposes. However, several of the findings were unexpected. Most notably, we found that several groups either did not know how to make fire using traditional methods or had very few members who knew how to use such methods. Another unexpected finding was that many groups preferred to preserve fire than to create it anew, even to the point of carrying it between camps. These surprising results have implications for our understanding of early pyrotechnology. That some groups in our sample did not know how to make fire strongly supports the argument that we cannot view the manufacture of fire as a skill that once learned will inevitably spread among populations (Dibble et al. 2017). It clearly has the potential to be learned and then lost, which means that an absence of fire residues at a Palaeolithic site may indicate the absence of fire-making knowledge and skills rather than simply the effects of taphonomic processes. The prevalence of the practice of preserving fire in our sample also has an important implication. It means that the presence of fire residues at a Palaeolithic site is not necessarily evidence of the ability to manufacture fire. To identify the latter, it is necessary to identify fire-making artifacts or other evidence of fire starting. Needless to say, this makes it considerably more challenging to distinguish fire collection from the manufacture of fire at a Palaeolithic site.

Acknowledgements We would like to thank the two anonymous reviewers for their feedback and suggestions which significantly improved the final paper.

Funding Information Our work was supported by the Social Sciences and Humanities Research Council of Canada (766-2017-1115 and 895-2011-1009), the Canada Research Chairs Program (228117 and 231256), the

Canada Foundation for Innovation (203808 and 36801), the British Columbia Knowledge Development Fund (862-804231 and 962-805808), and Simon Fraser University (14518).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Aldeias, V., Goldberg, P., Sandgathe, D., Berna, F., Dibble, H. L., McPherron, S. P., Turq, A., & Rezek, Z. (2012). Evidence for Neanderthal use of fire at Roc de Marsal (France). *Journal of Archaeological Science, 39*(7), 2414–2423.

Aldeias, V., Dibble, H. L., Sandgathe, D., Goldberg, P., & McPherron, S. J. (2016). How heat alters underlying deposits and implications for archaeological fire features: a controlled experiment. *Journal of Archaeological Science, 67*, 64–79.

Alperson-Afil, N. (2008). Continual fire-making by hominins at Gesher Benot Ya'aqov, Israel. *Quaternary Science Reviews, 27*(17–18), 1733–1739.

Alperson-Afil, N., Richter, D., & Goren-Inbar, N. (2017). Evaluating the intensity of fire at the Acheulian site of Gesher Benot Ya'aqov—spatial and thermoluminescence analyses. *PLoS One, 12*(11), e0188091.

Barkai, R., Rosell, J., Blasco, R., & Gopher, A. (2017). Fire for a reason: barbecue at Middle Pleistocene Qesem Cave, Israel. *Current Anthropology, 58*(S16), S314–S328.

Berna, F., Goldberg, P., Horwitz, L. K., Brink, J., Holt, S., Bamford, M., & Chazan, M. (2012). Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave, Northern Cape province, South Africa. *Proceedings of the National Academy of Sciences USA, 109*(20), E1215–E1220.

Binford, L. R. (2001). *Constructing frames of reference: an analytical method for archaeological theory building using ethnographic and environmental data sets*. Oakland: University of California Press.

Brown, K. S., Marean, C. W., Herries, A. I. R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D. L., Meyer, M. C., & Bernatchez, J. (2009). Fire as an engineering tool of early modern humans. *Science, 325*, 859–862.

Burton, F. D. (2011). *Fire: the spark that ignited human evolution*. Albuquerque: UNM Press.

Chazan, M. (2017). Toward a long prehistory of fire. *Current Anthropology, 58*(S16), S351–S359.

Cipriani, L., & Tayler Cox, D. L. (1966). *Andaman Islanders*. New York: Frederick A. Praeger, Inc..

Clark, J. D., & Harris, J. W. (1985). Fire and its roles in early hominid lifeways. *African Archaeological Review, 3*(1), 3–27.

Daniau, A. L., d'Errico, F., & Goñi, M. F. S. (2010). Testing the hypothesis of fire use for ecosystem management by Neanderthal and Upper Palaeolithic modern human populations. *PLoS One, 5*(2), e9157.

Dibble, H. L., Berna, F., Goldberg, P., McPherron, S. P., Mentzer, S., Niven, L., Richter, D., Sandgathe, D., Théry-Parisot, I., & Turq, A. (2009). A preliminary report on Pech de l'Azé IV, layer 8 (Middle Paleolithic, France). *PaleoAnthropology, 2009*, 182–219.

Dibble, H. L., Abodolahzadeh, A., Aldeias, V., Goldberg, P., McPherron, S. P., & Sandgathe, D. M. (2017). How did hominins adapt to ice age Europe without fire? *Current Anthropology, 58*(S16), S278–S287.

Dibble, H. L., Sandgathe, D., Goldberg, P., McPherron, S., & Aldeias, V. (2018). Were Western European Neandertals able to make fire? *Journal of Paleolithic Archaeology, 1*(1), 54–79.

Dunbar, R. I. M. (1992). Time: a hidden constraint on the behavioural ecology of baboons. *Behavioural Ecology and Sociobiology, 31*, 35–49.

Dunbar, R. I., & Gowlett, J. A. (2014). Fireside chat: the impact of fire on hominin socioecology. In R. Dunbar, C. Gamble, & J. Gowlett (Eds.), *Lucy to language: the Benchmark Papers* (pp. 277–296). Oxford: Oxford University Press.

Dunbar, R. I. M., Baron, R., Frangou, A., Pearce, E., Van Leeuwen, E. J. C., Stow, J., Partridge, G., MacDonald, I., Barra, V., & Van Vugt, M. (2012). "Social laughter is correlated with an elevated pain threshold." *Proceedings of the Royal Society B: Biological Sciences, 279*(1731), 1161–1167.

Galanidou, N. (2000). Patterns in caves: foragers, horticulturists, and the use of space. *Journal of Anthropological Archaeology, 19*(3), 243–275.

Gilligan, I. (2010). The prehistoric development of clothing: archaeological implications of a thermal model. *Journal of Archaeological Method and Theory, 17*(1), 15–80.

Goldberg, P., Dibble, H., Berna, F., Sandgathe, D., McPherron, S. J., & Turq, A. (2012). New evidence on Neandertal use of fire: examples from Roc de Marsal and Pech de l'Azé IV. *Quaternary International, 247*, 325–340.

Gott, B. (2002). Fire-making in Tasmania: absence of evidence is not evidence of absence. *Current Anthropology, 43*(4), 65.
Goudsblom, J. (1986). The human monopoly on the use of fire: its origins and conditions. *Human Evolution, 1*(6), 517–523.
Gowlett, J. A. (2006). The early settlement of northern Europe: fire history in the context of climate change and the social brain. *Comptes Rendus Palevol, 5*(1–2), 299–310.
Gowlett, J. A. J. (2010). Firing up the social brain. In R. I. M. Dunbar, C. Gamble, & J. A. J. Gowlett (Eds.), *Social brain, distributed mind* (pp. 345–370). Oxford: Oxford University Press.
Gusinde, M. (1955). Pygmies and pygmoids: Twides of tropical Africa. *Anthropological Quarterly, 28*(1), 3–61.
Gusinde, M., & Schütze, F. (1937). *Yahgan: the life and thought of the water nomads of Cape Horn*. Mödling Bei Wein: Anthropos-Bibliothek.
Hawkes, K., O'Connell, J. F., & Rogers, L. (1997). The behavioral ecology of modern hunter-gatherers, and human evolution. *Trends in Ecology & Evolution, 12*(1), 29–32.
Henry, A. G. (2017). Neanderthal cooking and the costs of fire. *Current Anthropology, 58*(S16), S329–S336.
Henry, A. G., Büdel, T., & Bazin, P. L. (2018). Towards an understanding of the costs of fire. *Quaternary International, 493*, 96–105.
Hill, K., Walker, R. S., Božičević, M., Eder, J., Headland, T., Hewlett, B., Hurtado, A. M., Marlowe, F., Wiessner, P., & Wood, B. (2011). Co-residence patterns in hunter-gatherer societies show unique human social structure. *Science, 331*(6022), 1286–1289.
Hlubik, S., Berna, F., Feibel, C., Braun, D., & Harris, J. W. (2017). Researching the nature of fire at 1.5 Mya on the site of FxJj20 AB, Koobi Fora, Kenya, using high-resolution spatial analysis and FTIR spectrometry. *Current Anthropology, 58*(S16), S243–S257.
Holmberg, A. R. (1950). *Nomads of the long bow: the Sirionó of eastern Bolivia*. Washington, DC: Smithsonian Institution.
Holmberg, A. R. (1969). *Nomads of the long bow: the Sirionó of eastern Bolivia*. New York: American Museum of Natural History.
Human Relations Area Files, Inc. (2008) World Cultures Ethnography Database. http://ehrafWorldCultures.yale.edu. Accessed 20 November 2017.
Isaac, B. L. (1977). The Sirionó of eastern Bolivia: a reexamination. *Human Ecology, 5*(2), 137–154.
James, S. R. (1989). Hominid use of fire in the Lower and Middle Pleistocene: a review of the evidence. *Current Anthropology, 30*(1), 1–26.
Lehmann, J., Korstjens, A. H., & Dunbar, R. I. M. (2007). Group size, grooming, and social cohesion in primates. *Animal Behaviour, 74*, 1617–1629.
Leierer, L., Jambrina-Enríquez, M., Herrera-Herrera, A. V., Connolly, R., Hernández, C. M., Galván, B., & Mallol, C. (2019). Insights into the timing, intensity and natural setting of Neanderthal occupation from the geoarchaeological study of combustion structures: a micromorphological and biomarker investigation of El Salt, unit Xb, Alcoy, Spain. *PLoS One, 14*(4), e0214955.
Lejay, M., Alexis, M., Quénéa, K., Sellami, F., & Bon, F. (2016). Organic signatures of fireplaces: experimental references for archaeological interpretations. *Organic Geochemistry, 99*, 67–77.
Mallol, C., & Henry, A. (2017). Ethnoarchaeology of Paleolithic fire: methodological considerations. *Current Anthropology, 58*(S16), S217–S229.
Mallol, C., Marlowe, F. W., Wood, B. M., & Porter, C. C. (2007). Earth, wind, and fire: ethnoarchaeological signals of Hadza fires. *Journal of Archaeological Science, 34*(12), 2035–2052.
Manning, D. T., & Taylor, J. E. (2014). Migration and fuel use in rural Mexico. *Ecological Economics, 102*, 126–136.
Mazza, P. P. A., Martini, F., Sala, B., Magi, M., Colombini, M. P., Giachi, G., Landucci, F., Lemorini, C., Modugno, F., & Ribechini, E. (2006). A new Palaeolithic discovery: tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. *Journal of Archaeological Science, 33*(9), 1310–1318.
Meggitt, M. J. (1965). *Desert people: a study of the Walbiri aborigines of Central Australia*. Chicago: University of Chicago Press.
Murdock, G. P. (1934). *Crows of the western plains. Our primitive contemporaries*. New York: The Macmillan Company.
Oakley, K. (1956). Fire as Palaeolithic tool and weapon. *Proceedings of the Prehistoric Society, 21*, 36–48.
Opler, M. E. (1941). *Apache life-way: the economic, social, and religious institutions of the Chiricahua Indians*. Chicago: University of Chicago Press.
Parthsarathy, M. V., & Klotz, L. H. (1976). Palm “wood” I. Anatomical aspects. *Wood Science and Technology, 10*(3), 215–229.

Pearce, E., & Dunbar, R. (2011). Latitudinal variation in light levels drives human visual system size. *Biology Letters, 8*(1), 90–93.

Pryor, A. J. E., Pullen, A., Beresford-Jones, D. G., Svoboda, J. A., & Gamble, C. S. (2016). Reflections on Gravettian firewood procurement near the Pavlov Hills, Czech Republic. *Journal of Anthropological Archaeology, 43*, 1–12.

Rydén, S. (1941). *A study of the Siriono Indians*. Gothenburg: Elanders Boktyckeri Aktiebolag.

Sandgathe, D. M. (2017). Identifying and describing pattern and process in the evolution of hominin use of fire. *Current Anthropology, 58*(S16), S360–S370.

Sandgathe, D. M., Dibble, H. L., Goldberg, P., McPherron, S. P., Turq, A., Niven, L., & Hodgkins, J. (2011a). On the role of fire in Neandertal adaptations in Western Europe: evidence from Pech de l'Azé IV and Roc de Marsal, France. *PaleoAnthropology, 2011*, 216–242.

Sandgathe, D. M., Dibble, H. L., Goldberg, P., McPherron, S. P., Turq, A., Niven, L., & Hodgkins, J. (2011b). Timing of the appearance of habitual fire use. *Proceedings of the National Academy of Sciences USA, 108*(29), E298–E298.

Scherjon, F., Bakels, C., MacDonald, K., & Roebroeks, W. (2015). Burning the land: an ethnographic study of off-site fire use by current and historically documented foragers and implications for the interpretation of past fire practices in the landscape. *Current Anthropology, 56*(3), 314–315.

Shackleton, C. M., & Prins, F. (1992). Charcoal analysis and the "principle of least effort"—a conceptual model. *Journal of Archaeological Science, 19*(6), 631–637.

Smith, D. M. (1982). *Moose-deer island house people: a history of the native people of Fort Resolution* (Vol. 81, pp. 1–185). Dossier Ottawa: Musée National de l'Homme. Collection Mercure. Division d'Ethnologie. Service Canadien d'Ethnologie.

Sorensen, A., Roebroeks, W., & Van Gijn, A. (2014). Fire production in the deep past? The expedient strike-a-light model. *Journal of Archaeological Science, 42*, 476–486.

Sorensen, A. C., Claud, E., & Soressi, M. (2018). Neandertal fire-making technology inferred from microwear analysis. *Scientific Reports, 8*(1), 10065.

Stearman, A. M. (1984). The Yuquí connection: another look at Sirionó deculturation. *American Anthropologist, 86*(3), 630–650.

Taylor, R. (2008). The polemics of making fire in Tasmania: the historical evidence revisited. *Aboriginal History, 32*(2008),1–26.

Théry-Parisot, I., & Costamagno, S. (2005). Propriétés combustibles des ossements : données expérimentales et réflexions archéologiques sur leur emploi dans les sites paléolithiques. *Gallia Préhistoire – Archéologie de la France préhistorique, CNRS Éditions, 47*, 235–254.

Turnbull, C. M. (1965). *Mbuti pygmies: an ethnographic survey*. New York: American Museum of Natural History.

Twomey, T. (2014). How domesticating fire facilitated the evolution of human cooperation. *Biology and Philosophy, 29*(1), 89–99.

Villagran, X. S., Schaefer, C. E. G. R., & Ligouis, B. (2013). Living in the cold: geoarchaeology of sealing sites from Byers Peninsula (Livingston Island, Antarctica). *Quaternary International, 315*, 184–199.

Wiessner, P. W. (2014). Embers of society: firelight talk among the Ju/'hoansi Bushmen. *Proceedings of the National Academy of Sciences USA, 111*(39), 14027–14035.

Wrangham, R. W. (2006). The cooking enigma. In P. Ungar (Ed.), *Evolution of the human diet: the known, the unknown, and the unknowable* (pp. 308–323). Oxford: Oxford University Press.

Wrangham, R. (2009). *Catching fire: how cooking made us human*. New York: Basic Books.

Wrangham, R. (2017). Control of fire in the Paleolithic: evaluating the cooking hypothesis. *Current Anthropology, 58*(S16), S303–S313.

Wrangham, R., & Carmody, R. (2010). Human adaptation to the control of fire. *Evolutionary Anthropology, 19*(5), 187–199.

Wrangham, R. W., Jones, J. H., Laden, G., Pilbeam, D., Conklin-Brittain, N., Brace, C. L., Roura, E. C., Hawkes, K., O'Connell, J. F., & Blurton Jones, N. G. (1999). The raw and the stolen: cooking and the ecology of human origins. *Current Anthropology, 40*(5), 567–594.

Zeisberger, D., Hulbert, A. B., & Schwarze, W. N. (1910). *David Zeisberger's history of Northern American Indians*. Columbus: Ohio Archaeological and Historical Publications.