Friendly Fire: Investigating the Effects of Regular Fire Use on the Social Organisation of Mid- to Late Pleistocene Hominins in Eurasia

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1. Introduction

Human life today is unimaginable without fire. From the simple act of cooking to the enormous feat of sending rockets into space, fire has always been a driving force of change. While automatisation may have rendered the presence of fire less visible in our everyday tasks, its potency remains evident in the flame as symbol (e.g. the Olympic torch, war memorials) and the campfire as relaxation and a return to nature. No known human society lacks the ability to manipulate fire, and no other animal possesses this ability. As such an integral part of the human behavioural repertoire, it is not surprising that research into the origins of fire use by hominins receives much attention.

Research into early fire use has been ongoing for decades and covers many different aspects. Within archaeology, a continuous debate is the timing and geographic appearance of 'regular' or 'habitual' fire use (definitions in section 2.4) as well as the consequences this had on hominin lives. While there is a general consensus that regular fire use appears in Eurasia around 400-300 ka, there is significant variation in the presence and absence of fire at different sites, the types of traces and fire structures found, and the uses of fire. As a result, research has considered features such as identifying fire traces and their alterations in the archaeological record (Aldeias 2017; Mallol *et al.* 2013), spatial organisation around fire structures (Barkai *et al.* 2017; Vallverdú *et al.* 2010), explaining absences of fire (Dibble *et al.* 2017; MacDonald 2017), and the use of fire for cooking (Stiner *et al.* 2011; Wrangham 2017). All these different approaches result in a broader, better understanding of the contexts in which fire might be expected, how it can be recognised archaeologically and what it might have been used for. A fuller review of previous and ongoing research is given in Chapter 3.

The majority of studies further consider it likely that fires acted as a focus for social activities. Sometimes archaeological sites may provide evidence for this, as at Qesem Cave, where it is suggested that meat was shared within the group around a central hearth (Stiner *et al.* 2011). Generally, however, not much discussion is devoted to what these social activities would entail. This is relatively understandable, as it is difficult to infer characteristics of social lives from material traces in the Palaeolithic archaeological record. However, sociality is crucial to hominin lives and intimately linked with fire; neglecting it results in an incomplete archaeology. There are researchers who discuss explicit links between fire use and sociality (Gowlett 2010; *et al.* 2012) and aspects of social development, such as language (Dunbar and Gowlett 2014) and cognition

(Twomey 2014). Cooperation and strong social networks are further discussed as requirements for regular fire use, especially if hominins were unable to create their own fire (Gowlett 2016; Twomey 2013). Nevertheless, with the exception of Twomey (2013, 2014), there is no detailed discussion of the demands this cooperation placed on hominin individuals or groups, and whether this might have necessitated changes in social structures and social behaviours. This would have been especially pertinent at the point that hominins started regularly using fire, because this would introduce costs associated with fuel collection and fire maintenance. Consequently, questions about the social structure and forms of cooperation that surrounded fire use are essential to understanding the full impact that fire had on hominin lives.

The topic of social structure and cooperation is not only interesting within an archaeological framework but contributes to wider debates about the evolution of cooperation. Human cooperation is often considered a paradox because people cooperate even when this is not to their personal benefit. Theories frequently used to explain cooperation, such as kin selection, do not fully explain the types of cooperation actually observed. Humans also cooperate in groups larger than those of any other animal (e.g. Henrich and Henrich 2007:35-74), suggesting significant changes occurred throughout human evolution to enable effective cooperative networks. Certain behavioural developments, such as collaborative foraging and hunting (Tomasello *et al.* 2012) and the use of personal ornaments (Sterelny 2014), alongside changes in physiology and brain size (Gowlett *et al.* 2012), are possible indicators of social changes that encouraged novel forms of interaction and cooperation in hominin groups. The controlled, regular use of fire may well be another, stimulating changes in social behaviour to deal with maintaining a new technology. Alternatively, the manipulation of fire may only have occurred once appropriate cooperative structures were in place. Unlike communal hunting or personal ornamentation, fire use has not yet benefited from being investigated as something that influenced social behaviour. Doing so might elucidate the archaeological record and provide more insight into the evolution of cooperation. Accordingly, this thesis will make a start at filling this research gap by demonstrating how regular fire use may have influenced the social structure of early hominins, the demands this may have placed on hominin cooperation, and the further social consequences this might have had.

1.1. Approaching social behaviour

The key aim will be to determine whether regular fire use required hominins to alter their social structure to one that facilitated cooperation. Since maintaining a fire is costly to one individual, cooperation could have alleviated this cost. However, cooperation can bring its own costs, and so it is worth considering the demands cooperation placed on hominin groups and how this affected their overall social structure. Two different models of how regular fire use may have affected hominin social structure will be discussed, a public good model and a contrived commodity (exchange) model. They will predominantly rely on research from evolutionary game theory and human behavioural ecology (HBE), with supplementary information from other disciplines relating to the evolution of cooperation. A broader range of evidence from archaeology, ethnography, primatology, and evolutionary psychology will be provided on top of this, to support or refute the proposed models.

A primarily evolutionary approach will be taken because this allows the examination of social behaviour at a basic level, without disregarding variation in behaviour. Hypotheses can initially be kept simple by examining general trends in social behaviour as responses to certain environments or pressures. This can reveal similarities between species and/or environments faced with similar pressures and conditions, which is useful in the current context as we cannot observe the behaviour of extinct hominins. A major benefit of relying on evolutionary disciplines is that they generate testable hypotheses as well as opportunities for testing them. Game theory builds models of 'rational' behaviour which are tested through experimental games, either as computer simulations or with human participants. This indicates whether behaviour conforms to rationality (it usually does not) and which factors influence human behaviour. The adaptability of models means that behavioural variability is not neglected and that models can easily be changed to test new predictions. Experimental games are also reproducible, meaning they can be replicated cross-culturally and in varying settings to examine the validity of results or understand differences in results (e.g. Gintis 2009).

Human behavioural ecology uses a similar methodology, creating models of 'optimal' behaviour and comparing these to observations of real-life behaviour, usually in extant foraging societies. Again, these models can reveal when, if ever, humans behave optimally in their environments and what factors influence behaviour. HBE also has the advantage of keeping models relatively simple while acknowledging how diverse human behaviour is, the assumption being that human behaviour is adaptive (e.g. Brown *et al.* 2011). Unlike game theory, which is currently less applied to non-Western societies

(although see Henrich *et al.* 2004), HBE relies on ethnographic observations from foraging societies. Although this has limitations (see section 7.4.1) and foraging societies today are not analogies for past societies, they are less affected by the rapid changes that industrialisation brought to other societies, making them better suited for testing hypotheses about human behavioural tendencies. Their smaller group sizes, reliance upon the natural environment for resources, and egalitarianism suggest that they should reveal human behavioural tendencies more clearly than large-scale societies removed from natural environments. This makes HBE relevant as supporting evidence, as it enables assumptions in the proposed models to be checked against real behaviours. Cross-cultural comparisons of observations from HBE and results from experimental games further provide insight into whether behaviours are universal or specific to certain cultures and environments. Because I am considering a non-modern hominin species, it may be argued that evidence from modern human groups is irrelevant. For this reason, I will also include some evidence from primatology demonstrating the existence of certain social behaviours relevant to cooperation in nonhuman primates. Both observation and experimental games or tasks can be used to test predictions about social behaviour and support the presence of these behaviours in extinct hominins.

Additionally, this approach does not neglect the influence of culture. The models proposed will be grounded in evolutionary disciplines because it is helpful to start examining behaviour at its origins, and because these disciplines provide ways of testing predictions, even when considering extinct hominins. The aim is furthermore to produce general hypotheses based on widespread behavioural tendencies. However, culture is not separate from biology, and interactions between social structure and cultural developments will be explored in Chapter 7.

1.2 Conclusions

Despite the attention that early fire use has received in Palaeolithic research, mention of the social impacts of fire use has remained fairly limited to language and general statements about sociality. There is not much discussion of how fire use may have affected social behaviours more specifically or what form of cooperation was necessary to make regular fire use feasible. Consequently, I hope to start filling this gap in the literature by discussing how regular fire use may have changed hominin social structures and the further consequences this had on hominin cooperation and social behaviour. Various lines of evidence will be used to construct two theoretical models about social

structure, and the results of these models will be discussed in the context of the types of cooperation required and the impact this had on hominin social groups. The benefit of an interdisciplinary and theoretical approach is that it initially sidesteps the problems of relying solely on the archaeological evidence or requiring empirical data. Instead, it can build up a hypothesis about the framework of sociality that may be expected in groups beginning to control fire, the demands this placed on social groups, and the types of evidence that can support this. The inclusion of several disciplines can furthermore contribute to discussions about the utility of interdisciplinary approaches in archaeology. While not necessarily providing new answers, the approach taken is novel and should result in new hypotheses, highlight gaps in the current state of research, and indicate new ways of considering fire use and sociality in the Palaeolithic.

2. Aims and Methods

This thesis has multiple aims, each of which will be framed as a question. The overarching aim is to provide a model that may explain the social structure and associated mechanisms that are required in groups of mid-Pleistocene hominins to make regular fire use a feasible behaviour. This model will rely mainly on concepts from evolutionary game theory, supplemented by studies in behavioural ecology, evolutionary psychology, and ethnography. However, a second important aim is to stimulate a wider discussion about interdisciplinary approaches within archaeology and the often-problematic nature of studying sociality in the past.

2.1 Aims

1. What effect would regular fire use have had on the social structure of a group?

This is the main question this thesis aims to answer. At some point, hominins became able to maintain and control fire, using it and manipulating it for different purposes. Unlike opportunistic use, this requires planning and investment, suggesting that a group would have to organise its continuing access to fire. My aim is to consider what this organisation would have looked like and how significant it would have been for hominin sociality. The focus will be on the type of cooperation that investment in fire necessitated based on the costs and benefits of cooperating versus defecting, and how this cooperation could be maintained.

2. *Can a modified public goods model explain how cooperation surrounding fire use would have formed and consequently been maintained? Alternatively, does a model framing fire as a contrived commodity work better?*

Other cooperative evolutionary behaviours, such as cooperative breeding and meat-sharing, have benefited from being treated as a public good. Fire use has not, so my aim is to produce a simple model showing how cooperation would form surrounding fire as a public good. The model is modified because the addition of sanctions and/or rewards is necessary to maintain cooperation. The problems associated with public goods, such as free-riding, will be dealt with. To provide an alternate possibility, a model where fire is treated as a contrived commodity, with access to fire being exchanged for other goods, will also be discussed. Both models converge into similar results, and the discussion will use supplementary evidence to examine which model seems more likely.

3. *What would the social requirements have been for maintaining these models? Can we infer the presence of certain social mechanisms and what are the implications of this?*

This overlaps to some extent with the above since the requirements will be a consequence of the models. However, this aim is meant to investigate what type of social mechanisms would need to be in place for cooperation surrounding either a public or contrived commodity to be feasible. These mechanisms include various forms of sanctions (punishment) as well as rewards, and some may be more effective in small groups than others. Moreover, the presence of these mechanisms could signify that certain other behavioural capacities were in place as well.

4. *Which other lines of evidence broadly support the theoretical models?*

This aim mainly refers to material reviewed in the discussion section, where I will attempt to bring in evidence from a relatively broad array of disciplines that support or refute the models. This evidence will focus on how extant small-scale human societies deal with the problems of cooperation and what methods are effective for them. It will also discuss social behaviours in nonhuman primate societies. The wider implications of the presence of social norms, how they are maintained and how this relates back to fire use will be covered. Archaeological evidence for social changes will further be discussed, to examine whether the hypothesis forwarded can be reapplied to the archaeological record.

5. *What are the limitations of this approach, looking both at interdisciplinarity and the assumptions inherent when discussing sociality in the deep past? Does this stimulate new approaches to Pleistocene fire use, or does it vastly overreach the evidence?*

Because several different disciplines are combined within this approach, I will review the potential limitations of such a theoretical approach (including discipline-specific limitations). I will also discuss more broadly whether this direction is useful. The aim is both to acknowledge the shortcomings of my approach and to encourage discussion surrounding approaches in archaeology that rely less on the archaeological evidence and more on other disciplines and theory.

6. *If useful, how can these models be tested? Is ABM appropriate or do future approaches need to revisit how social behaviour is studied?*

A last aim, related to the notion of utility of such an approach, is to discuss whether agent-based modelling may provide a useful way to test theoretical (game) models.

Here I will provide a brief overview of some of the positives and negatives of using ABM and whether social behaviour can be modelled within the constraints of the parameters required for ABM simulations. Other potential avenues for future research relating to cooperation and social structure that could inform the current hypothesis will also be examined.

2.2 Methods

The main method employed is a literature review. Most of the research used was obtained through the Leiden University library catalogue, either as online media or in print, by searching key words and phrases or specific authors. Other studies were found using article references and through recommendations by faculty members. Various types of journals and books were used, and no effort was made to stay within the conventional boundaries of any discipline. Some effort was made to use more recent studies (+/- 10 years) and studies that remain relevant and/or unchallenged despite being older (e.g. the cross-cultural economic experiments by Henrich *et al.* 2004). The last few decades saw rapid changes in the way human social behaviour is approached, suggesting a focus on recent literature is especially relevant. Exceptions to this are the much older studies referenced to provide some brief background to the research history of both fire use and the study of social behaviour in animals and humans.

The inferences and conclusions drawn from each model are not novel in the sense that they generally correspond to the results of experimental games or other studies, but my own input is to apply these results to the context of fire use. Consequently, my methodology here relies on placing the existing literature on evolutionary game theory onto a novel context. To illustrate the models, simple diagrams are utilised, created within Microsoft Word. No external application was deemed necessary because Microsoft Word has the required functions for these simple diagrams.

2.3 Structure

The next two chapters (3 and 4) contain literature reviews, the first focusing on research into early fire use, the second providing an overview of several relevant disciplines looking into cooperation and social behaviour. These reviews provide the basis for the two subsequent chapters (5 and 6), which each contain a model discussing how regular fire use may have necessitated a change in social structure. The first model sees fire use as a public good and explains how the problems associated with public goods would

have been solved. The second model places fire use within an exchange network and discusses the consequences of this for the social structure of a group.

The discussion (Chapter 7) is based on an extensive further literature review. I first focus on the widespread nature of sharing, especially of uncertain resources, to demonstrate that the public good model appears likelier. This includes insights from ethnography, human behavioural ecology, and primatology. Next, I discuss possible archaeological correlates for changes in hominin social structure that reflect increased cooperation. More detail is then provided on the consequences a change in social structure would have had, focusing on the stabilisation and maintenance of social norms and the reinforcing effect fire use has on cooperative structures. The last section is devoted to the limitations and benefits of the approach taken. The limitations put emphasis on the two disciplines most heavily relied on, game theory and ethnography, as well as the theoretical nature of this thesis. The benefits and validity of interdisciplinarity are discussed generally and within archaeology. The aim is not to cover all the limitations and benefits, but to stimulate discussion on the utility of interdisciplinary and theoretical research.

Finally, a short review of future possibilities will be given. This includes a discussion of whether agent-based modelling could test the public good model, as well as mentioning several areas of research that would benefit research into the origins of fire use and Palaeolithic social organisation. These include the ethnoarchaeology of fire and social organisation, experimental and ethnographic work on the costs and benefits of fire maintenance, and more focus on creating a framework for investigation sociality in Palaeolithic archaeology.

2.4 Definitions and abbreviations

Conformity: imitating the most common or most commonly seen behaviour, action, or belief.

Cooperation: the act of two or more individuals working together to achieve a common goal.

Cultural group selection: a framework within cultural evolution explaining how norms are maintained and spread through intergroup competition at the group level (see Chapter 7).

Exclusive (or contrived) commodity: a good or service which is non-rivalrous, meaning everybody can benefit the same amount, but which is excludable, meaning an individual or group can prevent others from benefiting.

Free-rider: an individual who 'cheats' by benefiting from a service or good without contributing (enough) to the maintenance of that service or good, when it is expected that they do contribute.

Hominins: this term will be used to refer to at least all members of the *Homo* lineage, excepting *Homo sapiens*, who will be called 'modern humans'. For the purpose of this paper, 'hominins' can also include the *Australopithecus* lineage, if appropriate to the beginning of controlled fire use.

Modern humans: refers to *Homo sapiens* only.

Public good: a service or good from which everybody can benefit equally, but which usually relies on contributions from the public to function. Modern-day examples are services freely provided by governments, such as street lighting, which rely on taxes.

Public goods games: an *n*-player game where individuals can contribute however much they want to the public pool, the contents of which will usually be doubled or tripled and then distributed equally to everyone (see Chapter 4).

Reciprocity: returning an action or good with another of similar value. Reciprocity does not have to take the same form both ways, but the notion of a 'favour' being returned is inherent. Negative reciprocity is when a harmful action is returned in kind.

Regular fire use: 'regular', 'controlled' and 'habitual' are used interchangeably and refer to the point at which hominins could maintain a fire in a preferred way through fuel choice/fire location and could use fire in different ways (technology, cooking, warmth/light). They were aware of the qualities of fire and could manipulate these but were not necessarily able to create fire.

Second- and third-party punishment: second-party punishment refers to a harmed individual directly punishing the individual or group that harmed them. Third-party punishment is when an external individual or group punishes the harmful behaviour of an individual or group against another, despite not being personally affected.

Social emotions: emotions which are related to the behaviour of others or the effect of your behaviour on others, such as pride, shame, and guilt.

Social mechanism: a social or regulating mechanism means any rule or other method of ensuring that expected behaviours are adhered to by the group. This may include social sanctions and rewards. These mechanisms will often be or become norms (see below), and social 'rule' is used interchangeably with 'mechanism'.

Social norm: a socio-cultural rule or ingrained expectation regarding appropriate (often context-dependent) individual and group behaviour. Norms can be self-enforcing but are also enforced by the group.

Social structure: the demography of a group, the way in-group relationships are organised, the presence/absence of hierarchies or inequalities, the presence/absence of labour divisions, and the use of social mechanisms to influence relationships within the group.

ABM = agent-based modelling

DG = dictator game

HBE = human behavioural ecology

ka = thousand years ago (e.g. 100 ka = 100,000 years ago)

Ma = million years ago (e.g. 1.8 Ma = 1.8 million years ago)

PGG = public goods game

UG = ultimatum game

3. Review of Palaeolithic Research into Fire Use

The aim of this literature review is to provide a background to existing research into Palaeolithic fire use to make clear what the problems are and how the approach of this thesis fits into wider debates. The focus will be on the problematic nature of recognising fire traces in the archaeological record, the phases by which hominins are assumed to have incorporated fire into their behavioural repertoire, and several areas of research which are prominent in debates about the role fire use played in hominin lives. A brief overview of the nature of early evidence for regular fire use will also be given. The chapter will end with a discussion about the social aspects of fire use and its relation to cooperation, in order to set the stage for the rest of the thesis.

Although research into early fire use has been occurring seriously for at least several decades, the focus will mostly be on more recent work. The notion that hominin fire use is a highly significant event in human evolution is prominent in earlier publications, with the domestication of fire being discussed as a 'civilising process' (Goudsblom 1987), a component of language evolution (Goudsblom 1989; Ronen 1998), and as offering adaptive advantages to early hominins (Clark and Harris 1985). Some of the more recent literature places emphasis on understanding the stages by which hominins came to control fire and when these stages occurred, as well as looking more in-depth at aspects such as archaeological alteration of hearths (Mallol *et al.* 2013), fuel choice and properties (Aldeias 2017; Bentsen 2014), and spatial organisation of hearths at specific sites (Gabucio *et al.* 2014). Some of these topics will be discussed in more detail.

3.1 Prevalent issues in detecting fire traces

Several difficulties exist in identifying the use of fire in the Palaeolithic record, which can complicate the debates surrounding early fire use. A first problem is determining the anthropogenic nature of fire traces. Hearths or clear ash concentrations provide more or less straightforward evidence of structured fire use, but there is often only indirect evidence. This includes fire-altered artefacts and sediments, whose alterations can mimic other taphonomic processes, and which can be found outside their primary context, making it harder to confidently associate these with anthropogenic fire (Aldeias 2017). Since a natural fire may have altered sediments and artefacts, context and spatial correlations are key to interpreting fire traces. The site of Gesher Benot Ya'aqov in Israel is an example where no direct evidence of hearths or fire structures was found; Alperson-Afil *et al.* (2017) instead use concentrations of burned micro-artefacts to

suggest repeated fire use. The British site of Beeches Pit has a similar problem, using the defined areas of coloured sediment and associated heated artefacts as indirect evidence, among other aspects (Preece *et al.* 2006). Mapping out artefacts altered by fire using geospatial applications can help determine whether the artefact distribution is spatially restricted, and if so, this strengthens the chance of an anthropogenic fire (Bentsen 2014). There is often some ambiguity regarding traces of anthropogenic fire which needs to be kept in mind when interpreting these traces. Aldeias (2017) provides further discussion of the issues associated with discerning anthropogenic fire use, especially when fire traces are indirect.

Even with an accepted hearth or fire structure, interpretation issues remain. It is usually difficult to determine how long and for what a hearth was used, especially as hearths may have been relit multiple times or have another hearth built on top. This is considered the 'palimpsest problem', as multiple episodes of use can fuse into one (Bailey and Galanidou 2009). Interpretations of hearths and their associated scatters are therefore problematic, as they may reflect multiple occupation episodes. An experimental study by Mallol *et al.* (2013) demonstrated that unless hearths are covered by a deposit between relighting events, it is not possible to differentiate between uses. The same study indicated that human activities such as trampling can rework the structure of the hearth, leading to potential difficulties in identifying its original characteristics. Other human activities, such as cleaning out the hearth or dumping the ash elsewhere, have also been attested to at Eurasian sites (Goldberg *et al.* 2012; Speth *et al.* 2012). For these reasons, experimental approaches to hearth formation, how specific environments affect their preservation, and how different fuel types, uses and forms of human intervention affect their structure are highly relevant. While the study by Mallol *et al.* (2013) was conducted over a short-term period, a more comprehensive study by March *et al.* (2014) demonstrates the necessity of long-term experiments. The authors created different types of hearths in various climates (humid, temperate, and arid) and checked them over several years, resulting in valuable information regarding how human intervention affects preservation and how environmental processes may change the structure of a hearth. Such experimental work can lead to a much better understanding of what kind of fire traces are being encountered in the archaeological record, as well as when hearths may not leave any trace.

In addition to experimental work and macroscopic observation, potential indicators of fire use can be assessed using micromorphological and micro-archaeological

approaches. Micromorphology investigates sediment characteristics at a microscopic level, which can reveal traces of fire that are not visible otherwise. In general, micromorphological analysis can reveal whether combustion features were used once or multiple times, whether they are intact or reworked, and whether they were the subject of ash dumping (Mentzer 2014). This can obviously strengthen (or weaken) ambiguous fire structures at archaeological sites and reveals hearth-related behaviours, such as cleaning and relighting. Microscopic analysis of sediments can furthermore result in the identification of charcoal particles, burnt micro-debitage, burnt bone or shell, and rubified sediments (ibid). Such indirect evidence can support the use of fire at sites without clear fire structures, although their presence cannot automatically be correlated with human activity. Microscopic plant remains (phytoliths) can provide an insight into fuel use (Albert *et al.* 2012), bedding in relation to combustion features (Cabanes *et al.* 2010) and the cooking of plants (Henry *et al*. 2004). Alongside micromorphology, other microscopic techniques can yield information about fire structures and their uses. Isotope analyses can reveal the composition of ashes, FTIR analysis of bone or clay can highlight molecular changes that result from heating, and luminescence measurements of sediments and flint can demonstrate heating and the age of the heated substance (Goldberg *et al*. 2017). These methods will not always be applicable, but they can provide a wealth of information about fire use at a site. Goldberg *et al.* (2017) do caution that the association of such information within a wider framework and with its depositional (micro)context is essential, and that some cases will still remain ambiguous. Nevertheless, this is another area of research which will likely advance our understanding fire use and fire structures.

Another prominent area of research involves analysing the artefact distribution surrounding hearths to identify activity areas and site organisation. This is usually done at a macroscopic level and therefore encounters the problem of potentially reflecting multiple occupation episodes; but as Bailey and Galanidou (2009:221) suggest, different occupants of the site may have copied the site structure based on visible signs of previous occupations. In this sense, the analysis still provides valuable information. For example, at Abric Romaní, most of the layers seem to demonstrate that the densest accumulations are associated with domestic hearths where faunal processing and knapping occurred (Vaquero and Pastó 2001). Differences between layers can provide information about occupation lengths, mobility patterns and activities conducted by different groups of inhabitants (Vallverdú *et al.* 2005, 2010; Vaquero *et al.* 2001). The

repeated use of a central hearth at Qesem Cave is associated with specific activities, such as carcase-processing (Stiner *et al.* 2011) and lithic remains being densest in the hearth area (Barkai *et al.* 2017). It is also possible to attempt to 'disentangle' the palimpsest into its original episodes. Gabucio *et al.* (2018) do this for Level O at Abric Romaní, separating the level into three sublayers and comparing the patterns they find to ethnographic evidence. Gowlett *et al.* (2005) instead describe a single phase of a knapping activity they assume lasted only a few minutes: based on a lithic refit at Beeches Pit, they reconstruct the position of an individual knapping a biface sitting close to a hearth, with three debitage pieces entering the fire. Regardless of the 'better' approach, the spatial analysis of artefacts around a hearth can provide information as to its associated activities, potential site organisation, and an insight into occupation lengths and group sizes.

While relevant to research into early fire use, a complete review of all the work being done to improve understanding of fire structures does not fall into the scope of this paper. Instead, a brief overview of the record of early fire use in Eurasia will be given to demonstrate the problems with dating the appearance of regular fire use.

3.2 Early evidence for regular fire use

This section aims to review the current evidence for regular fire use in Eurasia, highlighting a few specific examples and showing that evidence for fire use as well as fire-related behaviours becomes clearer in younger periods. It should also demonstrate that the few early examples of purported regular fire use do not provide a clear or representative view of how regular fire use arose, what its purposes were or why it is not visible at all sites.

There is a general agreement that regular fire use appears in the Eurasian archaeological record around 300-400 ka. The reason for this date is that this period sees the appearance of recognisable hearths at several Eurasian sites, and from this point onwards the frequency of hearths and associated evidence mainly increases. Roebroeks and Villa (2011) provide an overview of this evidence. A different proposed date for the beginning of regular fire use comes from Wrangham's (*et al.* 1999; 2009; 2017) cooking hypothesis, which suggests that the increase in brain size in *Homo erectus* can be explained by a shift to consuming cooked meat. This shift would have occurred around 1.8 Ma and clearly implies *Homo erectus* was capable of cooking their food, meaning

they must have been using fire regularly as well. Direct evidence for regular fire use or cooking around this time period is relatively lacking, however.

Early evidence for hearths comes from several noteworthy sites in Eurasia. Qesem cave is a site in Israel with evidence for recurring fire use between 400-240 ka, including the repeated use of a central hearth (Barkai *et al.* 2017). Spatial organisation of activities such as butchering and other tool use appear focused on the central hearth, but fire use is predominantly seen as an adaptation adopted for dietary purposes (Barkai *et al.* 2017). The cutmarks on faunal remains suggest a haphazard form of meat-sharing with multiple people cutting and taking a share rather than a formalised process of sharing (Stiner *et al.* 2011), providing an interesting insight into the social context of cooking. Beeches Pit is a site in the UK dated to around 400 ka (Preece *et al.* 2006). Although there is some ambiguity as to the anthropogenic nature of the fire traces at this site, the defined areas of discoloured sediment, the temperatures reached, heated flint, and refit patterns argue against natural forest fires causing (all) the traces (Gowlett *et al.* 2005; Preece *et al.* 2006). A third example is Bolomor cave, which has evidence for fire use starting from 350 ka (Vidal-Matutano *et al.* 2017). Charcoal remains show a preference for the black pine as fuel source (ibid) and there is evidence for both structured hearths and organised activities around hearths (Peris *et al.* 2012). As these few sites demonstrate, different conclusions are drawn from different sites: at Qesem, fire was clearly used for cooking, while at Beeches Pit there is no real sign of any use; yet such geographically separated sites are both using fire around the same time period. Whether we can draw widespread conclusions about how regular fire use was or what it was used for based on these sites is debatable.

Evidence for regular fire use becomes clearer after 200 ka, with sites like Kebara cave in Israel and Abric Romaní in Spain showing intensive and repeated use of hearths. Kebara has yielded many charred plant remains, suggesting occupants cooked plant foods at least some of the time (Lev *et al.* 2005), while phytoliths also provide an insight into fuel types used (Albert *et al.* 2012). Moreover, there is evidence that hearths were cleaned out and the ash deposited in a 'dumping zone' (Speth *et al.* 2012). Abric Romaní has an enormous number of hearths, spanning 27 archaeological layers. Studies focusing on different layers have used hearths to find evidence for potential sleeping areas and sleeping hearths in layer N (Vallverdú *et al.* 2010), specific activity areas, occupation layers and roasting of meat in level O (Gabucio *et al.* 2014; 2018), and short occupation patterns in level I (Vallverdú *et al.* 2005). While this later period still sees sites without

fire use, it becomes easier to identify its regular and/or repeated use for specific purposes.

This brief review demonstrates that it is difficult to draw widespread conclusions about the start of regular fire use. This becomes easier, but not necessarily easy, once more sites show prolonged use of fire for specific purposes. Whether this is a preservation issue or not is unclear. What does seem clear is that despite the many aspects covered, even in the small selection of research mentioned above, the inconsistency of the early fire record raises questions about the nature of regular fire use.

3.3. Modelling the emergence of fire use

Because fire use is considered one of the most important steps in human evolution, much attention has focused on the origins of fire use in hominins, what behavioural changes this required, and how hominins eventually progressed towards control and creation of fire. I will outline the different proposed phases of early fire use and discuss why the step from opportunistic to controlled fire use is most significant for the current discussion.

Numerous studies describe a pathway including the steps they assume hominins would have taken toward controlling and being able to create fire. Most of these start with an 'opportunistic use' stage, or earlier with a habituation stage (e.g. Chazan 2017; Sandgathe 2017). Research on other extant primates has shown that they have a certain familiarity with fire. Pruetz and Herzog (2017), for example, demonstrate that chimpanzees in Senegal are able to predict wildfire movement and take advantage of recently burned areas to travel and feed. Herzog *et al.* (2014) show that vervet monkeys also realise the potential of burned areas for traveling to new territories and foraging more efficiently. Based on chimpanzee behaviour towards fire, Pruetz and LaDuke (2010) conclude that chimpanzees likely reached what they consider the first stage in fire manipulation, namely the conceptualisation of fire. If this is considered a prerequisite to fire use, the next steps of opportunistic and controlled use might have occurred earlier than the archaeological record suggests (ibid). It is highly likely that early hominins living in environments with wildfires had reached this same stage of conceptualisation and potential opportunistic use.

The next step in fire use models is controlled or regular use of fire, and the last is usually the ability to create fire. As mentioned, it is currently difficult to discern when controlled

fire became part of hominin behaviour due to a relatively patchy record. It is likely that this step (re)occurred multiple times in different or even the same places (Sandgathe 2017). Due to the lack of evidence of clear fire-making tools before the Upper Palaeolithic, there is also no consensus on whether earlier hominins were able to create fire. The lack of fire traces at many sites where fire use might be expected seems to challenge the hypothesis that hominins could create fire. However, there may have been reasons not to use fire at all sites – Henry (2017) places the use of fire for cooking into an economic framework, suggesting that costs such as time and fuel availability may have made fire use less appealing in some environments. The lack of correlation between cold periods or environments and fire use among Neanderthals (Dibble *et al.* 2017) also seems to argue against the creation of fire. The consideration that fire was not actually necessary during glacial periods has therefore received discussion (Dibble *et al.* 2017; MacDonald 2017). On the other hand, Sorensen *et al.* (2018) have shown there is evidence for Neanderthals potentially creating fire using bifaces, and future research might further clarify this issue. Interestingly, a recent study of on-site fire use among extant hunter-gatherer groups revealed that of the 40 groups for which there was data available on rates of fire creation, only three groups made new fires when they moved camp. The other 37 transported preserved fire by means of embers or a firebrand (McCauley *et al.* 2020). This raises the possibility that even if the hominins in question could create fire, they may have preferred to maintain it. For the purpose of this thesis, however, it is unnecessary to debate this. I will instead be concerned with the step from opportunistic to controlled use of fire maintaining the assumption that hominins were unable to (or unwilling to) start a fire themselves.

The reason for this focus is that controlled, regular fire use has many more demands than opportunistic use. A hominin that encounters a natural fire can benefit from its warmth, the charred food it leaves behind, and the new territory left in its wake, without too much effort on his or her own part. A hominin wishing to keep and maintain a fire, however, has to possibly transport the fire, keep the fire fuelled, maintain the fire, and protect the fire from natural elements and maybe from other hominins (Twomey 2013). There are also more complex cognitive abilities involved, as the provisioning and maintenance of fire requires collectively planning for a future need, inhibiting immediate gratification, imagining a currently inexistent end-product such as cooked food, and potentially understanding the properties of fuel and fire (Ronen 1998; Twomey 2013). Time needs to be allocated to gathering fuel, which may be easy or

difficult depending on the environment, and the gathering may require a division of labour or form of cooperation. All of these aspects suggest that both the cognitive and behavioural shift from opportunistic to controlled fire use were substantial and likely had consequences on other aspects of hominin lives. Before going into more detail, the existing research on the relationship between fire and sociality will be reviewed, as this is significant for discussions about the step to controlled fire use.

3.4 "Fire is more a social reality than a natural reality" (Bachelard 1964:9)

Despite the large amount of research into fire use, the social aspect of fire use has not received much attention in Palaeolithic archaeology. Although many of the studies investigating early fire use do mention the hearth as a social focus, there is largely no detailed discussion of what this implies or what effect the use of fire had on social groups. This may partly be down to a general reluctance within Palaeolithic archaeology to address early social lives because it is difficult to find direct evidence for social behaviour in the archaeological record (e.g. Spikins *et al.* 2018). Answering questions of when and where fire use appeared, what fuels were used, what was cooked and how fires were obtained or started may also seem more relevant, as such research can provide tangible (and functional) answers. Yet if archaeology aims to understand individuals in the past, discussions about sociality are essential. I will review some of the research that has been done on the links between fire and sociality, before placing my approach into the current framework of fire research.

3.4.1 Fire and the social brain

The social brain hypothesis stipulates that the increased demands of living in larger social groups placed increased demands upon the brain to develop ways to deal with the complexity of these groups. This link was demonstrated by Dunbar (1993), who showed that the neocortex ratio is directly correlated with group size in primates. He proposed language as a way to deal with the demands associated with larger, more complex social groups, as grooming (the main way of maintaining social bonds among primates) would take up too much time to be feasible (ibid). Gowlett (2006) links early fire use to the social brain by hypothesising that the increased demands from the brain could be met through cooked meat, requiring fire – this is like Wrangham's hypothesis, although Gowlett (2006) envisions this occurring around 500-300 ka rather than 1.8 Ma. Gowlett (2006) consequently suggests the need for strong local social networks to maintain the fire and potential wider social links to replenish the fire in case it went out. Later,

Gowlett (2010) discusses the likely connection between an extended day made possible by fire light, and the difference in human circadian cycles compared to other primates, namely that our peak activity occurs in the early evening when other primates are preparing to sleep. He suggests that this extra time would have increased social interactions and that we might see a move to multiple, smaller, hearths throughout the Middle Pleistocene which facilitated sharing and conversation. The association of fire and the social brain is restated by Gowlett *et al.* (2012), who propose that the investment required by large hearths implies cooperation and the organisation of labour. They also state that hearths act as a proxy for social behaviour, as they drew people together in novel situations and provided an environment in which to focus on each other. Finally, Gowlett (2016) emphasises the increased time for socialising that fire provided by extending the day and suggests a "re-organisation of human sociality focused on fire and the hearth" (2016:7).

3.4.2 Fire and language

There are several authors who focus specifically on the link between language and fire use. Goudsblom (1989) already suggested that the need for social coordination and planning in maintaining a fire would have benefited from 'symbolic communication', or language. This would be reinforced by groups in possession of fire having an advantage over others, while the focal setting for social interactions created by fire could further stimulate language development. Dunbar and Gowlett (2014) return to the extended day provided by fire to argue for a social purpose for the extra +/- four hours. They suggest that this time could not have been used for foraging, instead being used for cooking and socialising. This allowed social interactions to be moved to the evening hours and would imply evening conversation is predominantly social in nature (Dunbar and Gowlett 2014). Turning to ethnography, Wiessner (2014) actually finds that 81% of lengthy conversations around the fire among the Ju/'hoansi bushmen are concerned with storytelling. This contrasts with daytime conversations, which are dominated by complaints and economic matters. She explains that the stories connect people to larger, imagined communities as they tell of absent or past individuals, and elicit trust and other positive emotions between the group. While only one example, it suits a relationship between fire use and language, and Wiessner (2014:14033) does suggest a deeper past for 'expanding the imagination by night', 200-300,000 years ago.

3.4.3 Fire and cooperation

Most of the mentioned studies also assume that fire use would have required social coordination or cooperation. Twomey (2013, 2014) discusses this in more detail, suggesting that the high levels of investment required by regular fire use encouraged the evolution of cooperation, assuming hominins could not create fire. He further suggests that hominins needed a strong social network to replenish their fire, should it go out (similar to Gowlett 2006). Twomey (2013) links this need for cooperation with complex cognitive abilities, such as collective intentionality, planning for future needs, trust, and language. He elaborates on this with the need for incentives to cooperate to prevent free-riding or cheating (Twomey 2014). These incentives could be related to punishment of cheaters, social emotions, or social norms. According to him, these types of social regulations are cognitively complex and would have required intersubjective communication, capable of expressing displacement and future intentionality, to be effective, which may have stimulated the evolution of language (Twomey 2013). A different approach is taken by Lynn (2014), who demonstrates that seeing and hearing a fire can decrease blood pressure and increase levels of relaxation. In turn, this would increase prosocial feelings and contribute to a willingness to cooperate. It is therefore possible that the physiological effects of early fire use also encouraged social cohesion. In general, there seems a consensus that fire use would have mandated cooperation, at least to some extent. This requirement consequently has implications for how hominins regularly started investing in fire use.

3.4.5 The costs of fire

The existing literature on fire and sociality places emphasis on the cooperation required for fire use and the subsequent cohesive effect fire had on social groups (abovementioned authors; also Kuhn and Stiner 2019). This notion is crucial to the ideas developed within this thesis. Cooperation is deemed necessary because it ensured that regular fire use was not too costly. But how costly is using fire? As previously mentioned, Henry (2017) looks at the fuel costs and cooking benefits of using fire in different environments. The availability of appropriate fuel determines the cost of gathering fuel, and in certain environments this cost (and others, including defense and time lost cooking) may outweigh the benefits gained from fire (ibid). Henry *et al.* (2018) provide an experimental study demonstrating that fuel collection is indeed more costly in certain environments and that the wood collected is not of the same quality. However, the authors also suggest that these costs could be offset by spreading them between individuals, since the costs could not be met by one individual for any fuel and meal type

(ibid). Consequently, fuel collection is likely to (often) have been costly enough to benefit from cooperation. According to Matthews (2016), fuel choice is also influenced by ecological and social strategies, associations between fuel collection and other tasks, and socio-cultural perceptions of resource properties. These may be factors to consider when testing whether cost-benefit analyses of fuel collection apply to archaeological evidence or extant foraging groups.

There are other costs beyond fuel collection. If groups were unable to start fires, they needed to ensure the fire did not die, and this may have required someone there to watch it. If groups instead relied on neighbouring groups to replenish their fire as Twomey (2013, 2014) and Gowlett (2006) suggest, this would imply numerous other costs: travel, transportation of fire, maintenance of relationships, constant awareness of where friendly groups are located, and reciprocation. Conversely, fire and its outcomes, such as cooked food, may have needed defending against others, also requiring at least one person to watch the fire and warn others. To ensure a stable fire, it may have needed stoking or replenishing with fuel regularly; if not, the costs of maintenance would have been less, since embers stay warm a while. Finally, when moving camp, transportation of the fire or embers would also have been necessary.

No studies measuring the actual costs of maintaining a fire in different environments, with different fuels and/or for different purposes, appear to exist. A review of historic cooking hearths discusses the tremendous increase in efficiency (for many aspects of life) the change from open fires to enclosed, indoor hearths brought, but does not detail the specific costs associated with the former (Nowakowski 2011). Factors influencing efficiency of fires for cooking in developing countries (thereby influencing fuel consumption) are considered by Wood and Baldwin (1985). This is not fully relevant to Palaeolithic fires, but they do mention that a larger pot/cooking for larger groups uses less fuel and that simply having the cook pay close attention to the cooking can reduce fuel consumption by up to 25% (ibid). Both studies suggest costs of fire maintenance can be considerable since effort is devoted to reducing them. References to the amount of time it takes individuals in modern societies to collect fuel are also found in the literature, but usually in the context of increasing fuel scarcity (e.g. Wood and Baldwin 1985). According to Hill (2002:123), the Aché will collect fuel, light, and tend to someone else's fire as a helpful action, suggesting the cost is at least high enough that help is appreciated. As mentioned, McCauley *et al.* (2020) demonstrate that some extant and recent hunter-gatherer groups preserve fire when moving camps and/or rarely start new

fires. Investigating the cost of maintenance could therefore start by examining how extant foraging groups maintain fires.

While measuring the costs of fire maintenance is difficult considering there are no proper studies on this, I believe it can be said that the costs of fuel collection and maintenance would be high enough for cooperation to be desirable, especially in smaller groups. We might further expect that even in environments favourable for fuel, individuals would feel cheated if they were always the ones collecting fuel or tending to the fire. Social coordination of fire use would therefore be beneficial in most cases, and essential in some.

The probable need for cooperation implies that the problems associated with cooperating to achieve a communal resource (fire) would need to be overcome – since individuals would benefit from the fire more if they did not need to invest in it, the temptation to 'cheat' and let others provide the effort of maintaining the fire is always present. While Twomey (2013) suggests the importance of fire might have induced individuals to cooperate, he also mentions there were probably mechanisms in place to prevent free-riding. These mechanisms include punishment and reward, and eventually the establishment of social norms (as will be discussed in detail later). Consequently, the step towards controlled fire was not simple, potentially requiring novel cognitive abilities and definitely requiring a social structure that encouraged cooperation without enabling individuals to take advantage. It is therefore significant to investigate what kind of social structure would be necessary for hominins to be able to maintain fire within groups, or what kind of social structure they would have to adapt to if they wanted to continue regularly using fire.

3.5 Concluding thoughts

This brief overview demonstrates how active research into Palaeolithic fire use is. It takes many approaches, from examining the role of fire in cooking and diet, to analysing spatial patterns in relation to the hearth, to identifying the kinds of fuel used. Understanding patterns of fire use can increase our understanding of past diets, technological applications, the organisation of domestic space, environmental adaptations and even hominin cognitive abilities, as the ability to manipulate and control fire requires the capacity to plan ahead, cooperate, and visualise a currently inexistent end-product. The hearth is often discussed as a central focus for social interactions, with a consequent link to language and social cohesion. The timing of the

appearance of controlled fire in the archaeological record remains debated, but the demands of maintaining fire would clearly have required a cognitive shift and some form of cooperation (if another cooperative behaviour had not already caused this), making it an important change to investigate in more detail. The next section will focus on theories of cooperation.

4. Review of Approaches to Human Social Behaviour

This review will provide some background on the relevant disciplines looking into social behaviour (specifically cooperation) in humans and explain in more detail the concept of game theory. Because this is such a large area, the reader is directed to the mentioned references for more information. A discussion of how fire use can be framed in the context of a public good ends this review in order to provide the basis for the first model.

4.1 The beginning of evolutionary behavioural studies

Investigating the social behaviour of animals (including humans) leads to a need to explain cooperative behaviour and altruism. The simple rule we tend to have in the back of our minds, that behaviours must have been selected for and therefore advantageous to the survival and reproduction of the individual, does not usually explain the observed behaviours. An easy example is a colony of ants – the worker ants do not fight for their own survival or reproduction, instead ensuring their queen survives and reproduces. A human example is our tendency to follow bad norms as well as good ones. Smoking is not an evolutionarily advantageous behaviour and yet many people smoke. Why do animals sometimes behave in ways that seem to go against their instinct to survive and reproduce? This question has motivated different (sub)disciplines to explore animal behaviour from multiple angles, and a brief overview of these will follow.

Sociobiology was a discipline coined in the 1940s which gained publicity in the 1970s. It aimed to explain social behaviour using evolutionary processes such as natural selection and focused on behaviour being explained by genetics (Brown *et al.* 2011). Commonly found behaviours among animals were seen as the result of selective pressures and could therefore be explained in an evolutionary sense. The field was controversial, with critics claiming that it ignored the complexity of social behaviour and some arguing that sociobiology advocated genetic determinism. For a review of this debate, see Laland and Brown (2002). The outcome of this debate was the formation of several subfields that sought to explain social behaviour, including behavioural ecology, evolutionary psychology, and gene-culture co-evolution.

Behavioural ecology, or human behavioural ecology (HBE) for the purpose of this paper, is a discipline which studies the environmental pressures leading to behavioural variation between human groups. It is important to distinguish between two concepts

here. *Adaptive* behaviour is any behaviour currently contributing to survival or reproductive fitness. An *adaptation* is a behaviour selected for because of its efficiency in fulfilling a role in relation to its environment, but this role may no longer be relevant today, in which case the behaviour or trait is not adaptive (Brown *et al.* 2011; Laland and Brown 2002). HBE is concerned with adaptive behaviour, seeking to answer why a certain behaviour exists today but being less concerned with the cognitive and genetic mechanisms behind this behaviour (or whether it is an adaptation or not). Emphasis is placed on external influences, and variation in behaviour is explained as human adaptive responses to variations in the environment (Brown *et al.* 2011). It is assumed that individuals will still display 'optimal' adaptive behaviours that maximise their reproductive success, but the highly flexible nature of human and animal behaviour is acknowledged. Furthermore, humans and other animals often face trade-offs that need to be considered when looking at optimal behaviour, such as the best feeding spot also having a high risk of predators (Laland and Brown 2002:117). A common discussion point in HBE is optimal foraging theory, which tries to construct a model outlining the decisions and trade-offs involved in foraging (or hunting) with the assumption that individuals will choose the decision that provides the largest payoff or the least cost. Such predictions, once formulated into a mathematical model, are compared to real scenarios to see if optimality holds true (ibid:116, 145). Related to this is the phenomenon of food sharing in hunter-gatherer groups, which often occurs with large game and seems counter-productive as meat is given to those not involved in the hunt. Explanations for this behaviour are sought in kin selection, costly signalling and tolerated theft (Gurven 2004; Hawkes *et al.* 1993), which include the idea that behaviour involves some form of maximising reproductive success or limiting costs to yourself.

Evolutionary psychology concerns itself with identifying the fundamental cognitive processes and instincts of a behaviour, often assuming these underlie a universal human nature (Brown *et al.* 2011:316). Thus, it might identify a certain cognitive pathway explaining why humans will act one way when confronted with a specific situation, but it is less interested in the display of this behaviour in real environments. These cognitive pathways are assumed to have originated during the Pleistocene and to have remained relatively unchanged since then (Laland and Brown 2002:159). They essentially underlie behavioural adaptations which evolved in humans in their ancestral environment (known as the *environment of evolutionary adaptedness*), but which may sometimes result in a 'mismatch' in our current, modern environments. Behavioural diversity

between cultures can then be explained by pre-existing behavioural variants being selected for expression in differing contexts (Brown *et al.* 2011:316). An example of a theory from evolutionary psychology is the 'Big Mistake Theory', which states that altruistic tendencies are a remnant of when humans lived in small, mostly kin-based groups (Tomasello *et al.* 2012). Altruistic behaviour in modern societies is therefore explained by inherent proximate mechanisms which react as if we still lived in such groups, even though modern societies involve one-off interactions and interactions with strangers (ibid). Because more emphasis is placed on genes compared to external and environmental factors, this discipline often conflicts with HBE.

Gene-culture coevolution (or dual inheritance theory) sees a more equal influence of both genetics and external, cultural factors. A famous example of gene-culture coevolution is the development of lactose tolerance in humans when the domestication of animals and agriculture began. The culture influenced a change in the gene rather than a genetic change occurring first, as is usually assumed. This discipline sees culture as evolving and suggests that the selection acting upon genes can be influenced by the spread of cultural information (Laland and Brown 2002:243). Something that begins as a socially learnt behaviour may therefore eventually become or affect a genetic tendency, which is relevant to social norms and their stabilisation within a group. Group selection theory further focuses on this idea by assuming that behaviours can be selected for at the group level, resulting in cultural evolution which may then affect genetic evolution as well (e.g. Henrich and Henrich 2007:134). For example, groups that cooperate more successfully (possibly due to norms or other cultural traits) might outcompete less cooperative groups, resulting in genes aiding this cooperative tendency. Thus, gene-culture coevolution sees genetic and cultural evolution both having a strong potential to influence human behaviour, with cultural evolution acting faster.

Because each of these fields focuses on a different cause and consequence of behavioural changes (see Table 1), they do not easily work together. However, they are essentially addressing the same question of why certain behaviours exist, and they all acknowledge that genetic, environmental, and socially learnt differences affect behaviour (Brown *et al.* 2011). While it may be difficult for some researchers within these fields to accept the different directions, there is no reason why evidence from all these subdisciplines cannot be used together to form a fuller picture of the diversity of human behaviour. It appears highly likely that both genetic and environmental factors

influence social behaviour, and that sometimes one may have a stronger influence than the other.

Table 1: The relevant disciplines focusing on social behaviour

Field	Explanation
Sociobiology	Explaining social behaviour using evolutionary processes such as natural selection; assumed large role of genetics but criticised for genetic determinism and reducing complexity of social behaviour.
Human behavioural ecology	Explaining behaviours based on environmental influences; assumes humans will optimise behaviour to maximise reproductive success but acknowledges high flexibility of human behaviour and allows for wide range of adaptive trade-offs that influence behaviour.
Evolutionary psychology	Explaining behaviours based on underlying cognitive (and genetic) mechanisms that evolved during the Pleistocene and have mostly stayed the same; assumes universal basis of human behaviours and culture.
Gene-culture coevolution	Explaining behaviour as give-and-take between genetics and culture; sees culture as able to evolve and influence genes dependent on transmission of social knowledge; behaviour may be selected for at group level.
(Evolutionary) game theory	Predicting behaviour using mathematical models of rationality; assumes optimal strategies will be chosen and then seeks to explain deviations from the optimal by adapting models. Applied to evolutionary behaviours to help understand why they evolved in favour of other behaviours.

After: Brown *et al.* (2011); Laland and Brown (2002); Stanish (2017).

4.2 What about game theory?

A fourth approach to human social behaviour that will be emphasised throughout this thesis is (evolutionary) game theory. Considering game theory comes from economic studies, the link to social behaviour may not seem immediately obvious. However, it can support and test observations made within behavioural ecology and evolutionary psychology. Conversely, hypotheses from game theory can also be applied to HBE and other disciplines. I will provide a background to game theory and briefly explain how it works, before demonstrating why it relates well to the study of human social behaviour.

The concept of evolutionary game theory comes from classic game theory, which determines what the optimal strategies are for players in competition based on rational choice. Each player will seek to optimise their payoff by making certain choices based on the rules of the competition and the choices of other players (Stanish 2017:36-7). Game theory may use games consisting of one round, making the interaction one-off, or of several rounds. These games are based on mathematical models played out using computer simulations, but game theory has widespread applications in the social sciences, biology, and economics, where human actors are often used. Because there are a variety of different games which can be further adapted to suit specific contexts, a

wide range of human behaviour can be explored (Gintis 2009:45). Table 2 explains several games but see Camerer and Fehr (2004) and other chapters within Henrich *et al.* (2004) for a more comprehensive overview and examples of how these games are applied. A quick note about '*Homo economicus*' might be useful: this is the idea that individuals act out of self-interest to maximise their own benefits, thus acting rationally. For example, if I received ten euros and could give however much I wanted to a second individual, I would give the lowest amount possible (i.e. the dictator game). However, it is now acknowledged that this is (almost) never the case. Even without repercussions for acting selfishly, individuals will often give or cooperate more than expected (Gintis *et al.* 2003; Henrich *et al.* 2005). Consequently, game theory can test predictions of optimal behaviours and determine whether they hold true. If not, game theory can alter its parameters to determine the factors influencing behaviour.

Evolutionary game theory is simply game theory applied to evolutionary behaviours. It attempts to explain how humans, or other animals, evolved certain behaviours in the past and why other behaviours may not have worked. Behaviours are assumed to 'compete' within a population, with the most successful behaviour(s) eventually dominating and stabilising (Wilson 2000). This can be simulated mathematically, but the focus in this thesis is on the results of its application in simulations and on human participants, meaning the mathematics will not be shown (see Gintis 2009 for a relatively accessible review of the mathematics). The evolution of cooperation is a human behaviour that can be examined using evolutionary game theory: different games, payoffs and parameters can model contexts where certain forms of cooperation would stabilise as beneficial behaviours and contexts where cooperation does not evolve. To examine human cooperation, games are set up with human actors to identify their choices when faced with certain conditions. These conditions may relate to the amount of payoff, anonymity concerning other players, group size, amount of choices, number of playing rounds and social mechanisms involved. Social mechanisms are rules within a group that act to govern social behaviour, such as status acquisition or punishment (Bowles and Gintis 2011). Their addition can determine whether humans inherently act in a certain way or are influenced by social sanctions and rewards.

4.2.1 Compatibility of game theory and evolutionary approaches

Evolutionary game theory is another approach to studying human social behaviour. It is especially well-suited to the study of cooperation and altruistic behaviour because it can

utilise different games with differing conditions to predict the motivations behind cooperative and noncooperative behaviours. For example, if individuals vary greatly in their actions when they are anonymous as opposed to when they are public, we can infer that these individuals care about what others think (i.e. their reputation). The ability of game theory to add choices and consequences, such as punishing other players, and of altering the context, as when the game is public or anonymous, allows the motivations underlying behaviours to be isolated. With repeated games across varying groups, games can contribute to hypotheses surrounding innate, socially learnt, and universal behaviours. Moreover, games can be played in controlled, unfamiliar lab settings, but it can also mimic real-life settings (for examples see Henrich *et al.* 2004). Like HBE, game theory creates predictive models and tests those in various settings to see when, and if, individuals act as expected by the model. Based on the outcomes of theoretical games, the same questions can be asked as in other approaches to human behaviour: Why do individuals not always act optimally? What are the main external influences on behaviour? Why did certain behavioural tendencies evolve and are they universal?

Consequently, game theory is a beneficial addition to other evolutionary approaches because it allows for empirical data which can be tested both in a lab setting and in a field setting, and which can either form the basis of hypotheses about human behaviour or be used to test hypotheses from other disciplines. Results from game theory can supplement theories from evolutionary psychology by demonstrating the likelihood of universal tendencies, or they could supplement theories in HBE which point toward environmental factors affecting behaviour. Alternatively, results from game theory could be tested using another evolutionary approach to behaviour. The main benefits of incorporating game theory include the replicability and therefore testability of the used games. Results can be validated through repeated rounds with different groups and cross-cultural comparisons (Gintis 2009). This is highly relevant if inferences are to be made about universal behaviours and socially learnt norms. While the lab setting is also seen as a limitation (Levitt and List 2007; section 7.4.2), it can provide useful information regarding the compatibility of lab and 'field' settings as well as providing more insight into what factors influence behaviour. Results can be corroborated by post-game interviews with participants and by bringing in evidence from other disciplines, including HBE, ethnography and evolutionary psychology.

Table 2: Several games used in evolutionary game theory

Game	Explanation	Common outcomes	This can reveal…
Tit-for-Tat	Game between two players where the second player simply copies the action of the first, after initial cooperation. If the first player remains cooperative, so will the second player.	This game usually leads to mutual cooperation if played over repeated rounds.	That cooperation is favoured if players have a high chance of meeting again.
Prisoner's Dilemma	Game between two players with the option to cooperate or defect. If both players cooperate, they receive 10 points each; if player A defects but player B cooperates, player A gets 15; if both defect, each player gets 5; and if player A cooperates and player B defects, both receive nothing.	The safest option for player A is to defect because they will always gain something, but mutual cooperation is beneficial for both players. Cooperation is a common outcome when players have a high chance of meeting again, defection is more common in one-off situations.	Whether players have social preferences to cooperate or take future encounters into consideration.
Ultimatum	Game between two players where player A receives a sum of money, of which they can offer any amount to player B. Player B can either accept or reject this amount, and if they reject it, neither player receives anything.	In a purely rational context, player B would accept any offer so player A would offer the smallest amount possible. In real life, player A tends to offer higher offers than expected and player B often rejects low amounts.	Whether player B is willing to sacrifice their gain to punish player A, and how initial offers by player A and rejections by player B may be influenced by notions of 'fairness'.
Dictator	The same as the ultimatum game, except that player B is unable to reject an offer.	Even though player A can offer the smallest amount to player B without fear of rejection, player A still tends to offer more than necessary.	Whether player A was governed by fear of rejection in the ultimatum game, or whether other mechanisms are involved in the decision to offer more than the lowest possible amount.
Public Good	A social dilemma game: *n* players each have a given amount of money and choose how much they want to contribute to a common pool, if anything. At the end of the round,	The highest payoff comes from not contributing at all. However, players usually start by contributing relatively large amounts, but cooperation	How cooperation to a public good may be sustained over time. Most studies show that cooperation is not sustainable without additional mechanisms

	the pool is doubled, and the contents distributed equally among all players. This game usually has multiple rounds. *This game knows several variations, such as including an option to punish other players after each round.	decreases quite quickly over subsequent rounds. *When additional mechanisms are added, such as punishment of other players, contributions are likely to be sustained over multiple rounds.	in place, so this game tests which mechanisms have the most effect on players' contribution levels.
Third-party punishment	Player A receives a certain amount of money, of which they can transfer any amount to Player B, who cannot reject it. Player C also receives a certain amount of money (usually less than player A) and can choose to punish player A at their own cost – this punishment also incurs a cost to player A.	Despite costing them money, Player C is likely to punish player A if they believe player A has transferred an 'unfair' amount to Player B. The amount at which player C chooses to punish can differ per context.	Whether individuals are willing to punish others who they believe are acting unfairly or against social norms, even at a cost to themselves, despite not being directly affected.

After: Bowles and Gintis (2011); Boyd and Richerson (2005); Camerer and Fehr (2004); Henrich *et al.* (2006); Rockenbach and Milinski (2006).

4.3 Why cooperation might occur (in groups)

Cooperation is one of the main 'problems' when discussing human social behaviour because it appears to defy any one explanation, and yet it is crucial to the way we evolved and developed our societies. This is especially pertinent to explaining characteristics specific to human cooperation, such as cooperating with individuals infrequently encountered or when there is no possibility of future encounters. As a result, cooperative behaviours are examined extensively in many disciplines and considered in both current and ancient contexts. Many of the concepts associated with cooperation are tied to both biological and economic sciences, such as direct reciprocity, which originated in biology but is widely used in economics and game theory as well. This section will review some general theories of cooperation, drawing more heavily on concepts from HBE and evolutionary game theory but also including related disciplines. Theories of cooperation are often applied to extant hunter-gatherer groups because they are assumed to maintain a lifestyle and group size closest to that of the context in which cooperation is likely to have evolved (see section 7.4.1 for limitations). Thus, ethnographic evidence is also brought in to support some of the ideas discussed.

It is generally assumed that direct reciprocity cannot sustain cooperation in groups of more than two individuals (Kurokawa and Ihara 2017). Direct reciprocity is technically the 'tit-for-tat' game described above – I help you, you help me, and so on over time. In larger groups, this may be discouraged by imperfect information, decreased chance of future interactions and the fact that the only retaliation for defection is defection itself, which is detrimental to cooperation (ibid). Instead, possibilities such as kin selection, reciprocal altruism and indirect reciprocity have been invoked to explain cooperation in groups. Kin selection assumes a bias toward cooperating with kin, which would still indirectly benefit individual survival and passing on of genes depending on level of genetic relatedness (Laland and Brown 2002:75-6). However, the problem with kin selection is that most cooperative groups today, including modern foraging societies, are not primarily composed of kin (Hill *et al.* 2011). While kinship remains important, it cannot explain cooperative tendencies on its own. Reciprocal altruism suggests that when one individual helps another, they expect this act to be returned in the future. This mechanism is relatively successful in small, stable groups, but when the chance of future interactions decreases (through mobility or uncertain, risky situations) or when the group becomes too large to successfully keep track of reciprocal acts, cooperation can collapse (Gintis *et al.* 2003). Indirect reciprocity refers to an indirect benefit from a cooperative act – a cooperative individual may gain reputation rather than a direct return on their cooperative act. Indirect reciprocity is quite successful at promoting cooperation, as reputation provides both an incentive to act cooperatively and a deterrent from acting uncooperatively, since this could ruin reputation (Rockenbach and Milinski 2006). However, cooperation can also evolve in situations without reputation-building as a result of indirect reciprocity (Henrich *et al.* 2006), implying it cannot answer for all forms of cooperation.

An evolutionary behaviour often examined from the perspective of cooperation is food-sharing in hunter-gatherer societies, specifically meat-sharing. One reason it attracts attention is because the hunters are taking on a risk and subsequently sharing the meat with individuals who were not involved in the hunt. Moreover, in some societies the hunters actually receive less meat for themselves and their families (Hawkes *et al.* 1993). Several explanations are proposed to explain patterns of food-sharing: kin-based sharing, reciprocal altruism, tolerated theft and costly signalling (Gurven 2004). The first two are explained above. Tolerated theft assumes the cost of defending food is higher than the potential gain from consuming all the food, meaning it is less costly to allow

others to take some food. Costly signalling sees food-sharing as a way to gain reputation and to signal prosocial intent. Marlowe (2004) used experimental games to investigate the motivations behind food sharing among the Hadza, finding that tolerated theft represented the results the best. Bliege Bird and Power (2015) explain patterns of food sharing among Martu hunters as reflecting costly signalling intended to signal honest prosociality, which leads to other social benefits. Sharing is also often structured by social rules or expectations (Marlowe 2004; Marshall 1961) accompanied by social sanctions when these rules are not followed. Consequently, cooperation might be viewed as a combination of altruistic and self-interested tendencies, where several forms of cooperation operate simultaneously.

4.3.1 Social mechanisms

This leads into another important aspect of human cooperation in groups: the use of social mechanisms and norms to maintain general social stability. These mechanisms might involve punishment, reputation and verbal encouragement or discouragement, and have the function of ensuring individuals stick to the agreed ways of behaving within a group. Norms are the 'unwritten rules' by which a group operates and are often culturally dependent, although certain norms may be (almost) universal. There is no single answer as to what mechanisms work best or are used most often, however, and this is likely to depend on the cultural and economic context in which individuals find themselves. For example, Henrich *et al.* (2005) suggest that the level of market integration present in societies influences how cooperation does or does not work. It can be difficult to study norms because they are sometimes so ingrained that individuals do not realise they are adhering to any norms. By investigating the use of social mechanisms, however, it can be possible to determine what mechanisms are enforcing what type of norm. This is often studied in extant foraging societies and/or by using historical ethnographic evidence. Wiessner (2005), for example, examines norm enforcement and societal rules among the Ju/'hoansi Bushmen. Based on analysis of hundreds of conversations, she found that most punishment begins with talking, which starts with jokingly putting the individual down but can lead to harsh criticism if the warning is not heeded. The notion of using verbal sanctioning or gossip as a low-cost punishment is also discussed by other scholars (Guala 2012; Marshall 1961).

Studies on norms and their enforcement in industrialised societies exist as well. Henrich and Henrich (2007) provide examples from the Chaldeans, a Christian-Iraqi population

living in Detroit. They describe that donations are given at funerals, where the amount signifies not only the donor's generosity but also their other qualities and how much they cared about the deceased (Henrich and Henrich 2007:130). Gossip is widespread and the reputation of an individual reflects on the whole family, so the consequences of not conforming to expected donation sizes can be great (ibid:147). The way norms are created and maintained within societies and why also receives attention, relying on group selection theory (Henrich *et al.* 2006; Guzmán *et al.* 2007).

Game theory can further examine how norms are influenced by social mechanisms. Shimao and Nakamaru (2013) investigate whether the strictness of punishment affects how cooperation evolves during continuous PGGs; Henrich *et al.* (2006) discuss the use of costly punishment across human societies in various games; Sally (1995) uses Prisoner's Dilemma games with discussion before rounds to demonstrate that language increases cooperation in repeated games; and Rockenbach and Milinski (2006) use adapted PGGs to examine the relationship between indirect reciprocity (reputation) and costly punishment in increasing cooperation. These games occur both as controlled lab experiments and as 'real life' games, the latter notably done by Henrich *et al.* (2004) in fifteen small-scale societies across the world. The use of game theory can also occur alongside the use of ethnographic evidence – Wiessner (2009) compares the results of experimental games conducted among the Ju/'hoansi to their behaviour in real-life situations, linking observation with experimental work.

No society studied so far conforms completely to the selfishness axiom, and most groups use some form of sanctioning, from criticism to institutionalised punishment. A significance of social norms is that they are also an adaptation against invasive behaviours. While norms do change, individuals are likely to conform to the expected pattern of behaviour, meaning a strong social norm will do well in regulating whatever behaviour it is aimed at (Guzmán *et al.* 2007). For this reason, investigating how social norms are utilised to maintain certain forms of cooperation, or cooperation in certain contexts, is crucial to understanding the overall maintenance of prosocial behaviours, especially when costly.

4.4 Game theory and cooperation: fire as a public good

The application of game theory to cooperation is relatively widespread. While not all the games discussed before are specific to understanding cooperation, almost all of them provide an insight into how individuals choose to act and react to the behaviour of

others and whether they are likely to act 'fair' or helpful toward others. A willingness to behave fairly or to the advantage of others is part of cooperating. When groups are cooperating for the purpose of achieving a collective goal, they might face a social dilemma: they are better off not aiding the collective goal and still benefiting from the result, but if everybody thinks this way, the collective goal will not be achieved, and everybody will be worse off. This is exemplified by the public goods game. A PGG will often result in sustained cooperation if the option for punishing free-riders is added or some form of reputation is present over repeated rounds. In an evolutionary context, a behaviour such as cooperative hunting (and associated food sharing) may be viewed as a social dilemma: individuals may gain a larger food package by hunting together, but this means risking all solo alternatives and trusting that the individuals involved will cooperate (Tomasello *et al.* 2012). In many instances, as described with food sharing (see 4.3), those not hunting will still end up consuming the meat, meaning there is an incentive to avoid hunting and just consume. However, if nobody wants to hunt or forage, there will be no food to share, leading to an evolutionary PGG (Dubreuil 2010b).

Looking at the development of regular fire use specifically, it is worth restating that the maintenance of fire use as a behaviour would have required some form of cooperation between hominins. As with cooperative hunting and food sharing, everybody can benefit from a maintained fire, but everybody is better off avoiding the effort of gathering fuel and maintaining the fire. However, if nobody contributes, the fire will go out and nobody will benefit. Regular fire use can therefore be considered another evolutionary public good, although excepting Dubreuil (2010b), it has not been phrased as such. Twomey (2013, 2014) does consider the need for cooperation and potential social mechanisms surrounding fire use, while Ofek (2001:138-52) discusses fire as a contrived commodity that would have acted as an impetus for trade. However, no detailed investigation of the nature of cooperation and its maintenance surrounding the regular use of fire has been undertaken, despite its similarity to cooperative behaviours that are frequently investigated, such as cooperative hunting, food sharing and cooperative breeding. Regular fire use can be viewed as a social dilemma where fire is a public good and individuals need to choose between contributing to the public good or free-riding. Game theory could provide an interesting new angle to exploring the social structure necessary for regular fire use to be a sustainable evolutionary behaviour through cooperative efforts. Moreover, it may contribute to discussions about the evolution of cooperation more generally – Kurokawa and Ihara (2017) conclude that

group-wise cooperation could have played a key role in early hominin survival, if the non-rivalrous benefits of cooperation were significant for survival and reproduction. It seems likely that regular access to fire definitely was a significant component.

4.5 Conclusions

A huge array of literature exists on the evolution of cooperation that goes far beyond the few points discussed here. Cooperation is a phenomenon that interests so many disciplines that it would be impossible to provide a comprehensive background to its study. However, I have tried to briefly explain the different disciplines that focus on animal social behaviour and their main directions, and the relevance and use of game theory to explain cooperation in humans. Moreover, the need for additional social mechanisms to maintain cooperation in most cases has been highlighted. I ended with an overview of why fire use works as a public good – the next chapter focuses on creating a model based on the concept of a public good, explaining cooperation surrounding fire use.

5. Model 1: Fire as a Public Good

The previous chapter ended on a brief description of how fire use can be framed as a public good. A public good as referred to here is non-rivalrous, meaning that one individual benefiting does not diminish the benefits a second individual can gain. However, this means that individuals contributing to the public good pay a higher cost than individuals who only enjoy the benefits without contributing. Assuming hominins were unable to start a fire, instead relying on natural sources, there would be several investments required to acquire and maintain fire. These include finding a source of fire (or borrowing it from a neighbouring group; Twomey (2013)), transporting the fire while keeping it alight, gathering fuel, and keeping the fire fuelled. In the case of replenishing a fire source from a neighbouring group, some form of cooperative relationship would need maintaining between the two groups. This might only include reciprocity regarding access to fire but could include the sharing or giving and receiving of other resources and would require possible 'score-keeping' and knowledge of where the other group is located. Moreover, all of these requirements come at the expense of other activities, while individuals are able to benefit the same way regardless of whether they contributed. Individuals are therefore faced with the dilemma of whether to contribute – they are better off not contributing but if nobody contributes, there will be no fire access. Consequently, the first problem is ensuring individuals will contribute to maintaining fire access in a cooperative manner.

A likely second problem is that of free-riding individuals. Even if most individuals within a group regularly contribute to fuel gathering or keeping the fire going, there tend to always be individuals who do not contribute. In large groups this can often be tolerated, as the overall stability of the group is not necessarily threatened and the cost to contributing individuals is not significantly increased. However, in evolutionary terms, we are likely dealing with small residential groups of hominins. Hayden (2012:3-4) proposes a range of 12-28 individuals based on floor space and sleeping hearths at several Middle Palaeolithic sites, which corresponds to the range of 10-20 people in modern foraging groups in harsh environments. A residential group size averaging 28 individuals for contemporary hunter-gatherers is given by Hill *et al.* (2011), while a range from 8-30 individuals in Martu bands is given by Bird *et al.* (2019). The boundaries of residential group sizes during the Middle Pleistocene are not well-established, and may have varied, especially in different environments (see Marlowe 2005 for varying ethnographic group sizes). However, based on approximate site sizes and the sizes of

residential groups of hunter-gatherers today, it will be assumed that residential groups in the Middle Pleistocene were not significantly larger than the numbers mentioned (although overall social networks will have been larger). In these small residential group settings, free-riders may threaten social cohesion and increase the costs of contributing, meaning tolerance toward free-riding is potentially detrimental to group stability (Stanish 2017; Twomey 2014). Thus, the second problem involves dealing with free-riders or preventing free-riding from occurring.

A third problem may be introduced as a result. If free-riders are punished for their lack of contribution, this punishment may involve a cost to the punisher. However, the whole group benefits from the punishment of this free-rider because they are likely to contribute in the future. This is termed a 'second-order social dilemma' (Guala 2012; Marlowe *et al.* 2008) because everybody would like the free-riding individual to be punished, but everybody benefits more if someone else bears the cost of punishing. The punishment itself may be seen as a public good. Consequently, deterring free-riders also relies on a willingness to enforce a method of deterrence, even if it incurs a cost.

Early fire use thus required a group willing to cooperate and willing to maintain that cooperation in some way. This can be seen in two ways: the start of regular fire use may have come as a result of a social structure that enabled successful cooperative behaviours surrounding public goods, or the need to regularly use fire stimulated the development of a social structure that could support this. I will highlight the steps that may have been needed to achieve this below.

5.1 A cooperative model for early fire use

As mentioned, the first step is ensuring cooperation occurs and is maintained. Experimental PGGs demonstrate that cooperation is not sustained over multiple rounds of contributions, despite initial contributions frequently being quite high (Fehr and Gächter 2000; Henrich *et al.* 2005; Kümmerli *et al.* 2010). Several studies suggest one reason for initial high contributions is that some individuals are conditional cooperators: they cooperate when others do or when they expect others to do so (Fehr and Gächter 2000; Smith *et al.* 2018; Twomey 2014). When these conditional cooperators realise others are not contributing as much, however, they will scale down their contributions accordingly. This suggests that unless early hominin groups were made up only of optimistic conditional cooperators, they would be unable to sustain cooperation without additional incentives or regulating mechanisms. Even if we assume such cooperative

groups did exist, the introduction of one defector would break down cooperation rapidly, making the social stability of the group very fragile. This problem is depicted in Diagram 1.

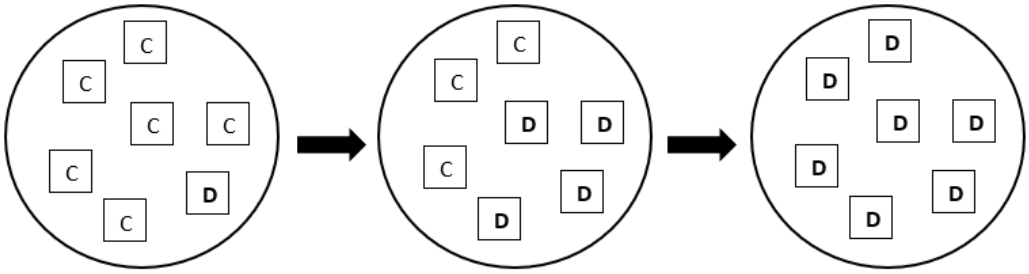

Diagram 1: *The problem of maintaining cooperation in a population when defectors exist. C = conditional cooperator, D = defector. The bold letter represents an example individual (in subsequent models as well).*

The problem of maintaining cooperation thus needs to deal with the problem of low contributors and free-riders. There are many ways that a group might do so. The simplest form of retaliation would be to withhold cooperation, but in the context of a public good this is not feasible as this would either induce more defection (Boyd and Richerson 2005) or, if everybody withholds cooperation, just lead to lack of access to the public good. Instead, punishment can be effective. In PGGs, the introduction of an option to punish those individuals who did not contribute in the previous round, or who contributed less than expected, helps maintain high levels of cooperation. Fehr and Gächter (2000) demonstrate that individuals will contribute 2-4 times more when punishment is possible relative to a PGG without punishment. They furthermore show that over repeated rounds with the same players and the option of punishment, contributions converge toward full cooperation. This holds true even when the punishment option also inflicts a cost on the punisher (termed costly punishment), as Gintis *et al.* (2003) describe. In experimental games, the punishment is a fee or reduction in monetary payoff, and the cost of meting out the punishment is expressed likewise. In our evolutionary setting of early fire use, we could imagine punishment taking the form of exclusion from certain activities or benefits. The cost would come from enforcing this exclusion.

An alternative method of sustaining cooperation is to add an incentive. Experimental games demonstrate that reputation (or indirect reciprocity) can have a similar effect to punishment on cooperation rates in PGGs (Panchanathan and Boyd 2004; Rockenbach

and Milinski 2006). Humans generally seem concerned about their reputation (Tomasello *et al.* 2012), potentially because reputation can signal the willingness of an individual to act cooperatively and therefore their appeal as a partner in a cooperative venture. However, in many settings there may be further social benefits to having a good reputation that are not immediately visible: preferential partner choice, influential positions within the community, or increased chances of offspring survival (Gurven 2004). The idea is further that reputation allows the avoidance of non-cooperators because individuals can refuse to cooperate with those known for not cooperating in the past (McElreath *et al.* 2003). Consequently, a reputation for being willing to cooperate may have been crucial for survival, as the alternative would be exclusion from activities or even from the group itself.

An interesting point demonstrated by Milinski and Rockenbach (2006) is that when individuals participating in PGGs could choose between a game with only indirect reciprocity and a game with indirect reciprocity and punishment, most preferred the latter. The interaction between reputation and punishment furthermore ensured that punishment had to be given less often (ibid). This suggests having multiple enforcing mechanisms in place may be most useful in sustaining cooperation. The necessary framework for ensuring sanctions and rewards actually encourage cooperation will be detailed in Chapter 7 – for now it is enough to conclude that punishment or incentives to contribute usually allow cooperation surrounding a public good to be maintained. This implies that for hominins regularly using fire, a regulating mechanism was likely needed to ensure fire maintenance was feasible within a group. Diagram 2 demonstrates this.

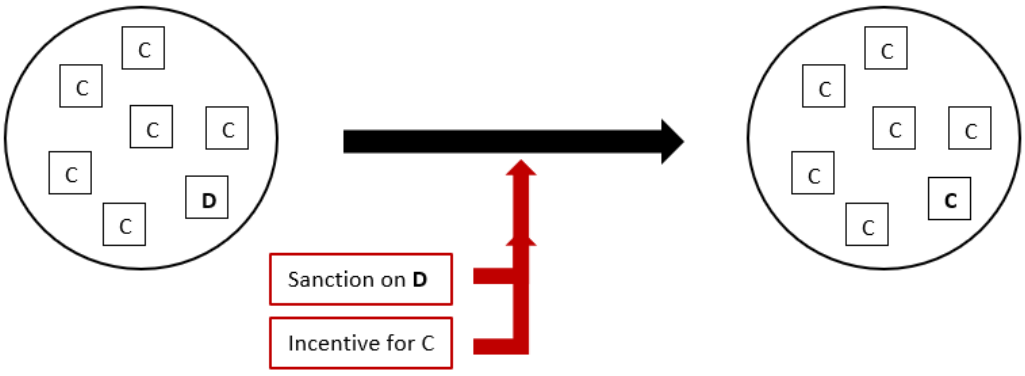

Diagram 2: *The effect of a regulating mechanism on the presence of defectors in a population. C = conditional cooperator, D = defector.*

However, there is the potential third problem. If punishment is used to deter free-riders, there may be a cost to the individual doing the punishing, not just to the punished individual. This cost may occur as a direct result of the form of punishment: for example, if punishment in our fire use setting means the free-riding individual is prohibited from cooking their food, someone else has to ensure that they actually do not cook their food and that nobody else gives them cooked food. This requires effort on the part of the punisher. Another indirect cost may be that the punisher acquires a reputation for punishing behaviour, which is generally seen as a negative trait (Guala 2012). Consequently, the cost of punishment could deter individuals from being punishers, despite the benefits it conveys on the group as a whole. Experimental games do show a surprising willingness to punish non- or low contributors (Fehr and Gächter 2000), while brain imaging studies have demonstrated that costly punishment is motivated in part by an impulsive negative reaction to unfairness, but also partly by the pleasure of punishing those who break social rules (Guala 2012). Punishment may therefore be an inherent aspect of the way humans deal with social expectations and cooperative ventures. However, ethnographic studies tend to show that the form of punishment initially used in small-scale societies is low-cost, such as gossip or mocking the individual (e.g. Marshall 1961; Wiessner 2005). This will be discussed more later, but it may suggest that in order to deal with the second-order social dilemma punishment brings, low-cost punishment mechanisms became widespread. Costly punishment might only have been necessary or desirable in larger groups where the cost of punishing could be shared such that individual cost remains low, or where third parties are in charge of meting out punishment. Marlowe *et al.* (2008) likewise suggest that cooperation in large groups might rely on third-party punishment (see 2.4), whereas second-party punishment is sufficient in smaller groups.

5.2 The resulting model

Our resulting model is therefore as follows. For cooperation surrounding regular fire use to be sustainable, a group of hominins would have had to incorporate social regulating mechanisms to ensure individuals continued cooperating. These mechanisms may have taken the form of punishments or incentives, but a combination is likely. To offset the potential cost involved in punishing another individual, it is probable that low-cost punishments were widespread, and that costly punishment, if present, only occurred in cases where the cost could be shared; otherwise the cost would result in nobody being

willing to punish defectors, and therefore to a breakdown in cooperation. Diagram 3 shows this process.

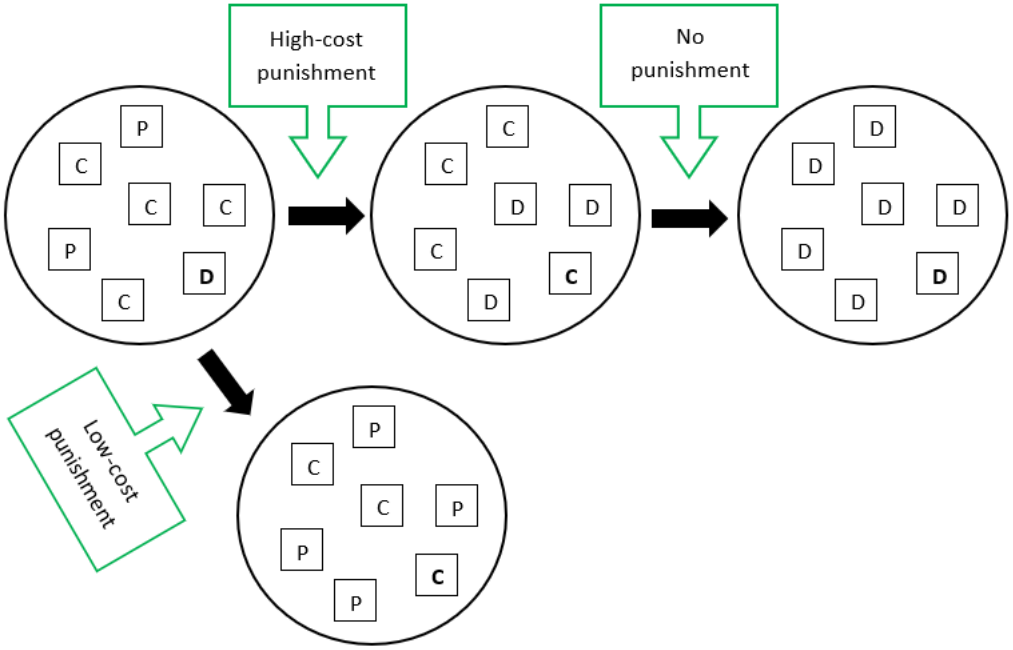

Diagram 3: *The effect of low-cost punishment on cooperation in a population. If punishment is costly, even a population with some individuals willing to punish (P) will not maintain cooperation, since the punishers will not continue punishing. If punishment is low-cost, the defectors will cooperate to avoid punishment and the cooperators might also become punishers, since it proves effective, reducing the cost further. C = conditional cooperator, D = defector, P = punisher/conditional cooperator.*

Importantly, this process results in a specific social structure that governs the way a group cooperates and interacts with each other. It does not necessarily relate only to the regular use of fire – earlier cooperative ventures may have similarly stimulated the need for a social structure that promotes cooperation. In that case, this model presents the type of social structure that needed to exist already when hominins started regularly using fire. Alternatively, the desire to 'keep' fire rather than opportunistically coming across it may have motivated a change in social structure. It can work both as a cause and consequence, but it does imply that with the start of regular or controlled fire use, we can assume a particular social structure that induces cooperation and punishes non-cooperation was present. The inevitable reliance on some form of regulating mechanism to maintain this cooperative structure suggests that certain cognitive abilities related to planning for the future and prosocial emotions accompanied this social change, as will be further discussed in Chapter 7.

5.3 A further consequence

Consequently, we have a group of hominins who have developed certain mechanisms to ensure they can continue using fire regularly in a way that benefits everybody, although this may also apply to other cooperative ventures in the past. Once certain mechanisms promoting cooperative behaviour are present, the stabilisation of these mechanisms can result in the formation of social norms. For example, if those continuously contributing little to the maintenance of fire are mocked or excluded by others, this will likely be copied by the next generation as the way to react to low contributors. The notion that low contributions result in negative reactions from other group members will become internalised, and over time become a 'rule' that prevents most individuals from being low contributors because they want to avoid the known consequences. Of course, these mechanisms may have differed per group, implying that varying norms may exist for similar reasons in different groups.

Social norms, then, are rules that govern social behaviour, interactions, and cooperative ventures. Norms provide a standard of behaviour for different situations as well as a framework against which behaviour can be judged (Silk and House 2016). The threat of punishment in cases of non-conformity renders established social norms quite effective; often they reduce the need for punishment as the threat of it is enough to encourage individuals to follow the norm. Sterelny (2014) further suggests that norms can reduce the costs of conflict and negotiation between individuals as norms already specify the general expectations. Bowles and Gintis (2003:439-40) propose that norms become internalised because they increase individual fitness when sociality is too complex to continuously analyse social actions and their meanings. Conformity to norms is also effective because it facilitates within-group coordination, consolidates group identity in opposition to groups that may have other norms, and reduces the risk of punishment (Tomasello *et al.* 2012). Consequently, the development of a social structure promoting cooperative behaviour with the aid of regulating social mechanisms, if stabilised, almost certainly resulted in the establishment of social norms and rules. Chapter 7 will further examine the importance of norms and conformity.

5.4 Conclusions

This model has attempted to depict a scenario where the development of regular, controlled fire use relies on a specific social structure being in place already or developing as a result. This social structure would necessarily have been one promoting

cooperation, and it has been shown that regulating mechanisms appear essential to maintaining ongoing cooperative behaviour. These regulating mechanisms can include punishments, such as social exclusion or mocking, and incentives, such as reputation. The problem of enforcing punishment was most likely 'solved' by utilising low-cost punishments, at least initially, and only resorting to costly punishments when the whole group was willing to share the costs or when groups became large enough to have third parties administering punishment. The social mechanisms regulating cooperation would have become the norm over time, leading to the establishment of social norms that further consolidated the existing social structure.

6. Model 2: Fire as a Contrived Commodity

The context of maintaining regular fire use was detailed in Chapter 5. For this model, free-riding is again a problem. Instead of finding ways to induce free-riders to cooperate, however, another situation could evolve. Individuals able to acquire the resources for a fire and maintain it might exclude others from accessing it. I believe this is less probable in small residential groups of early hominins, but it is worth examining as an alternative to the public good model.

A contrived commodity is a resource that others do not have automatic access to (it is exclusive), but which others can be granted access to at no additional costs to the owner (non-rivalrous). Just like public goods, consumption by one individual does not usually limit the amount available to another. A modern example is WiFi at home – you pay to receive this service, and those who do not pay cannot access it, but if they choose to pay, they have the same amount of access you do. The notion of fire as a contrived commodity is discussed by Ofek (2001:150), who considers contrived commodities to provide the largest impetus for trade out of all types of goods. He characterises fire as a contrived commodity based on the requirement of activation energy, allowing for exclusion, and the ability of fire (given fuel) to proliferate indefinitely, making it non-rivalrous (2001:151). Ofek (2001) visualises an 'incendiary hub' with a central fire being continuously maintained from which family units can take fire as needed. Those responsible for maintaining the fire would receive something in exchange for their effort, thus forming an exchange system. I will discuss this as an alternative social structure facilitating the move to controlled fire use and examine the social consequences this would have had. A brief further explanation of Ofek's proposal will be given along with some of its limitations, which will be addressed.

6.1 The 'incendiary hub'

It is possible to imagine a scenario where an individual or a few individuals maintain their own private fire, especially if groups were comprised of family units who generally conducted their daily activities independently. Ofek (2001) assumes that borrowing fire from neighbours would become an easy way of putting less effort into maintaining your own fire, meaning those giving fire bear more costs. This problem is similar to free-riding with public goods. Instead of countering with punishment, exchange arises: if one unit wants to take fire, they will have to give something in return. However, Ofek (2001) rightly suggests that individual fires that need constant maintenance would be costly

and require more fuel than a more optimally sized fire, which is why he proposes a central fire with specialised fire-keepers (reiterated by Sterelny 2014:69). Although not explicitly stated, I assume these specialised individuals would also be in charge of gathering fuel.

Technically, the problem of free-riding is overcome because fire maintenance is allocated to a few individuals, meaning others are unable to cheat by contributing less. However, an individual may still offer something less valuable, promise something and never deliver, or fake the value of a good. Ofek (2001:153-167) offers no explanation of how cheating would be avoided nor what the initial form of exchange would involve. Are individuals exchanging goods, services or both, and who decides what a 'fair' exchange entails? If free-riders existed in the public good and individual fire scenarios, they would also exist in this context, either trying to limit the costs of exchange or, as a fire-keeper, maybe demanding more than the maintenance costs involved. Ofek (2001) does not explain how to regulate this exchange system. He further mentions that the emergence of exchange is accompanied by the conditions for specialisation and division of labour (Ofek 2001:167). Again, nothing is said about what this specialisation or labour division would mean in practice. Consequently, the plausibility of an exchange system surrounding regular fire use remains unclear without more explanation of what this early form of exchange would involve. I will therefore attempt a discussion about the aspects Ofek (2001) disregards, starting with what specialisation and division of labour imply before outlining the types of rules that might govern exchange. This chapter will further highlight the problems of exchange in small groups.

6.2 Division of labour and specialisation

The fire-specialists would have less time to invest in other tasks. Simultaneously, their investment in fire maintenance would likely lead to a better understanding of fuel choice, effective fire size and fire properties. This promotes two things: exchange and specialised knowledge. Both are often inherent in labour division systems. The initial focus of certain individuals on fire maintenance could lead to others also specialising in specific tasks, such as units that collect gatherable foods versus units that focus on hunting. I will discuss how division of labour and associated specialisation would operate in small groups, factors influencing its development, and its archaeological visibility.

Task division can lead to higher efficiency in producing the desired outcomes, while the cost of task-switching further favours division of labour (Goldsby *et al.* 2012). This

implies that if the conditions of early regular use of fire were such that it was time consuming or otherwise costly to change tasks, labour division and specialisation could stabilise. For example, two individuals may initially have been in charge of gathering fuel and maintaining a central fire. They would learn where to find specific types of fuel and what they are suited for, but if two new individuals replaced them, this information would have to be taught or shown. Consequently, it is less costly if the initial individuals remain in charge. This is put simply for the argument – it seems unlikely small hominin groups would divide useful knowledge so rigidly – but it can explain the appeal of labour division. Moreover, as technical knowledge of fire properties increased, the efficiency of keeping tasks separate would also increase. Jaeggi *et al.* (2016) suggest that in contemporary foraging societies, the slow life history of humans increases the payoffs of specialisation. They also propose that trade is one of the forces governing cooperation in small-scale societies (their example being the Tsimane), as it creates interdependence between and within generations. If individuals depend on each other for commodities (and knowledge), this promotes social cohesion, as each individual's contribution is necessary for group survival. However, because contributions likely fluctuated with seasonal and environmental conditions, with increased specialisation, or with exploitation of new environments (Sterelny 2014:72), maintaining social cohesion through reciprocal exchange was probably not that simple. It also seems probable that interdependence based on specialisation in small groups could put the group at risk if any individual is unable to produce their specialism at any point (see Diagram 4).

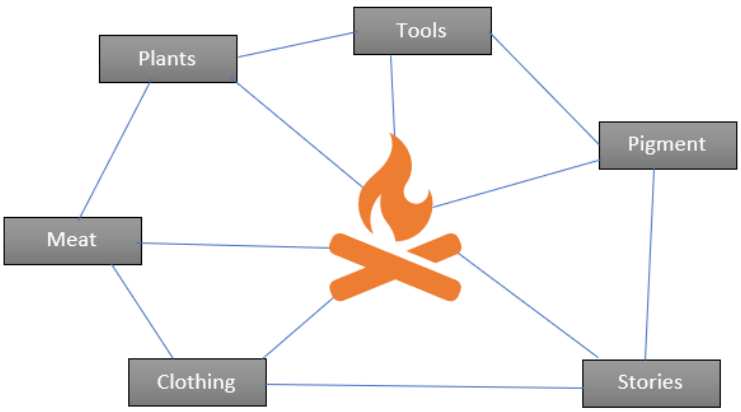

Diagram 4: *Interdependence based on specialisation. Even without connecting all the different actors, it is clear that specialisation can be risky in small groups. If one actor disappears in this diagram, nobody has access to the product they specialised in.*

6.2.1 Dividing labour

Division of labour is traditionally gender-based. In foraging societies (and not only), men tend to focus on high-risk high-gain resources (i.e. meat) and women on reliable resources (Marlowe 2007). This is usually linked to differing reproductive roles, with women less inclined to undertake risky ventures due to childcare responsibilities. Men and women might also divide other tasks, such as the making of specific tools or the acquisition of non-food items. While Boismier (1991) describes quite a rigid gendered division of labour among historic subarctic foragers in Alaska, including differential tool-making between sexes, gender roles in some foraging societies are very fluid (Kuhn and Stiner 2006; Marlowe 2007). Age is another way to divide labour, with elderly individuals, adults and children performing different tasks. Fuel-collecting might be something which children were well-equipped to do, as there is little risk and it requires no sophisticated skills. This would remove some of the costs associated with fire maintenance. Maintaining a fire might not be suitable for children given the risk of being burnt, but it may be something that elderly individuals were suited for as it does not require intensive labour. However, finding evidence for any labour divisions is difficult, especially since there are various possibilities. It therefore suffices to say that division of labour may have occurred, but not necessarily following modern assumptions.

6.2.2. Demography and environmental factors

Demography may have impacted specialisation. Sterelny (2014), for example, sees specialisation and division of labour as a probable result of demographic growth, and argues that specialisation is more easily supported by larger groups (also Kuhn and Stiner 2006). Ofek (2001:161) mentions around a dozen family units using an incendiary hub. If we assume family units comprised at least four individuals, this means a group of at least 48 individuals. It would be useful to investigate whether there is a threshold size at which specialisation becomes (more) effective for groups to regularly acquire the resources they need. Distinguishing between the effects on specialisation of an increase in residential group size versus an increase in social network size would also be helpful – it would seem likely that an increase in social network size would allow specialisation in non-essentials, but not of essential resources, since this would require daily or otherwise frequent contact. The literature supports a link between group size and increased division of labour and specialisation in general social systems (e.g. Bonner 2004; Jeanson *et al.* 2007). Nakahashi and Feldman (2014) discuss this for hominins,

pointing out that small groups are less likely to specialise because knowing every task is important in case somebody is absent, and it is also less advantageous to specialise if others do not. This seems to support that an increase specifically in residential group size is more likely to lead to specialisation than increases in wider group networks.

Another potential factor is environmental productivity. Marlowe (2007) emphasises that in contemporary foraging societies, sexual division of labour varies considerably in rigidity based on environmental conditions, with warmer climates showing the highest overlap in male and female foraging behaviour. Food security reduces the necessity of specialising, but simultaneously allows more freedom to specialise. One of the models of labour division discussed by Nakahashi and Feldman (2014) suggests that labour division would develop only when gathered foods were abundant relative to hunted foods. The choice of resources in an environment and their acquisition risks could therefore also limit or encourage division of labour and specialised tasks, along with group size.

6.2.3 Archaeological visibility

Archaeological evidence for the division of labour during the Middle Pleistocene is scarce. An issue might be not knowing what the archaeological correlates are: looking for 'female activities' based on ethnographic analogy does not prove that females were actually conducting those activities. Yet Kuhn and Stiner (2006) assume that the high-latitude, game-rich environment of Neanderthals would lead to females investing in specialised technology, as seen in recent foraging groups in similar environments. While they state that ethnography cannot 'fill gaps' in the archaeological record, they also appear to use the absence of expected female activities to argue for a lack of gendered labour division without considering potential differences in the past. Adopting modern and/or gender-traditional expectations about task division is not helpful unless supported by other evidence. This may be especially important in differing environments. To give an Upper Palaeolithic example, cave art was supposedly the domain of male adults, and yet there is now evidence that art production involved women and children as well (van Gelder and Sharpe 2009; Snow 2013).

However, human remains could reveal whether certain age- or gender-groups were conducting different activities. Estalrrich and Rosas (2015) find potential evidence for distinct activities between Neanderthal males and females based on differential tooth wear, while Sparacello *et al.* (2017) find similar humeral asymmetries in both Neanderthals and modern humans possibly indicating similar sexual division of labour.

Such research could reveal differences in labour by age or gender and support hypotheses about specialisation and labour division. It may further be possible to theorise that spatial segregation of activities or specific off-site activities reflects division of tasks, but it would have to be shown that the activities were conducted by different individuals.

6.2.4 Conclusions

Labour could have been divided in several ways to minimise the costs associated with fire maintenance. This division did not have to be gender-based but could have involved children or elderly individuals. It is likely that demography and environmental conditions need considering when discussing labour division and specialisation, as larger groups are likelier to specialise, and resource availability can influence task division. Since archaeological evidence is currently quite limited, no confident conclusions can be made about labour division and specialisation in the Middle Pleistocene.

6.3 Regulating exchange

With labour division and the beginnings of specialisation in place, exchange or trade would be the next step to ensure everyone acquires the resources they need. I will explain why exchange needs regulating and how this might be done.

To ensure that an exchange system works, there needs to be agreement on how exchange is characterised. Exchange is a form of direct reciprocity, where one individual gives another an item, and the other returns it with a different item of similar value. This may be an immediate or delayed return. Direct reciprocity is usually maintained successfully in pairs, especially with the chance of future interactions, because it is worth helping your partner if you need their cooperation in the future (Kurokawa and Ihara 2017). It is also easy to remember their actions. If they fail to cooperate, you can end the partnership. In groups, however, direct reciprocity is less successful (Boyd *et al.* 2003), possibly because it becomes harder to track your partners' actions, and because certain ventures require group cooperation. Cooperating with several others to hunt a large mammal, for example, makes it difficult to determine what type of reciprocation one individual owes the others. If group-level cooperative efforts continue, direct reciprocity would require too much tracking of obligations and their respective value, especially over longer durations (Hawkes *et al.* 1993).

However, this just suggests that direct reciprocity was not the only form of exchange. Fire specialists may have had direct reciprocal exchange relationships with specific individuals, but it is unlikely that every individual had such partnerships with everyone else. Instead, an exchange system can incorporate indirect reciprocity. This implies that fire specialists enjoyed indirect benefits like social support or partner choice in return for their provision of fire. Moreover, this could help circumvent periods of resource uncertainty for other specialised individuals – if meat is scarce, hunters can still access fire without hostility arising. The fire specialist, in turn, is assured of future assistance because they are 'good' exchange partners. A reputation for being a good collaborator is beneficial in a group setting because others will appreciate this reputation, leading to positive social partnerships (Bliege Bird *et al.* 2012; Tomasello *et al.* 2012).

Altruism is vulnerable to exploitation, however. If individuals realise that they can gain fire by pretending to have nothing in exchange, they might free-ride on the goodwill of the fire specialist. To avoid this behaviour, which undermines cooperation and group cohesion, social rules governing exchange are necessary. In modern settings, exchange is always regulated: if I buy something, I pay the standardised value immediately; if I receive a birthday present, I know the giver expects a present on their birthday. Exchange rules might govern the value of goods and the period of reciprocity, who can conduct exchanges, or the appropriate exchange setting. If early exchange was part of a system of division of labour and specialisation, it seems likely that rules were in place to assure 'fair' exchanges, focusing mainly on value and expected reciprocation, as otherwise the system might collapse. These rules are similar to the social mechanisms discussed for public goods, as a reward for fair exchanges could encourage reciprocal exchanges while punishment for unfair exchanges could likewise do so. As will be explained, reputation is a likely reward for exchange, while the punishment is initially low-cost.

6.3.1 Ultimatum and dictator games

To demonstrate how reward and punishment mechanisms may operate in exchange settings, examples from the outcomes of ultimatum and dictator games will be given, as these can reveal whether individuals are concerned with their reputation and/or fear of punishment (see 4.2.1). The ultimatum game is played between pairs, where player A receives an amount of money and can give any proportion to player B, who can accept or reject the offer. If rejected, neither player receives anything. The dictator game is the

same, except that player B is unable to reject the offer. In theory, player A should always offer the smallest amount, and in the ultimatum game, player B should accept any offer because it is better than receiving nothing. In practice, player A in the ultimatum game often offers more than the lowest amount and player B routinely rejects what they consider low or unequal offers, effectively punishing player A (Gintis *et al.* 2003; Guala 2012; Henrich *et al.* 2005). In the dictator game, the offers are less variable, but players still routinely offer more than the lowest amount (Camerer and Fehr 2004). There is also considerable cross-cultural variation in the amounts offered and rejected in these games (Henrich *et al.* 2004), suggesting that cultural norms and expectations significantly influence behaviour in these contexts.

The outcomes suggest that players expect more than the lowest amount, and in some cases, expect that low offers should be punished, even at a personal cost. This seemingly demonstrates that reputation (for offering more) and punishment (for not offering enough) are important mechanisms regulating social behaviour. Interestingly, Boesch (2012) mentions that in a DG where player B was unaware of the game or what they might receive, player A gave nothing almost half of the rounds. This highlights the importance of *known* reputation specifically. Acting in accordance with social expectations is only beneficial if others know you did so. Engelmann and Fischbacher (2009) likewise find that in a game where half the participants had public 'scores' for helping and half did not, those with public scores helped substantially more. The UG and DG are not analogous to exchange, but they reveal the importance of societal expectations for behaviour. Deceiving an exchange partner might be the 'economic' way to act, but social mechanisms often prevent this from occurring.

6.3.2 Social norms

Subsequently, an exchange system surrounding regular fire use would need regulating mechanisms to function effectively. These mechanisms are likely to have been reputation and/or low-cost punishment. Reputation is beneficial to exchange settings because it promotes fair exchange and allows individuals to avoid unfair exchange partners. Moreover, it provides an incentive to conform to social expectations. Because having a 'bad' reputation means less chances to engage in exchange, this is a low-cost punishment on its own. However, if reputations are difficult to advertise or easy to manipulate, another form of low-cost punishment may also exist. As with public goods, the maintenance of social mechanisms would lead to transmission of these mechanisms

to offspring and newcomers. Over time, such expectations become internalised and can be considered social norms.

The presence of social norms regulating exchange should also increase levels of trust. Knowing the reputation of your partner and having a punishment option should increase social cohesion, while the threat of punishment should decrease its actual use, if the threat is credible (Frey and Rusch 2012). An increase in trust allows an increase in specialisation as well, since individuals will only feel confident specialising in a specific task (at the cost of others) if they are sure they will be able to acquire the other resources they need for survival (Marlowe 2007).

6.3.3 Conclusions

An exchange setting surrounding regular fire use and access would likely utilise both direct and indirect reciprocity, where the specialist fire keepers might benefit either from a direct return or from reputational benefits. Both forms of exchange would require regulating to ensure that individuals do not cheat by offering low-value goods or by not returning anything at all. It is likely that these regulating mechanisms involved reputation and low-cost punishment and, if effective, would stabilise over time. What constitutes a 'fair' exchange would likely differ per group, leading to different exchange systems, but the need for regulation would remain.

6.4 Hierarchy?

Trade and exclusive resources are precursors to hierarchy (Mark 2018), suggesting a social structure based on exchange could promote hierarchy. This undermines group-level cooperation because notions of power, ownership, and rank create inequality between individuals, leading to within-group conflicts and difficulties organising cooperative ventures. If early social structures were centred on exchange, they needed to avoid hierarchy formation to be successful.

Exchange regulated by reputation might result in a 'social hierarchy'. Generous and fair individuals would gain a reputation for being good exchange partners, which would likely extend to other aspects of life, resulting in certain individuals being more trusted than others. Mark (2018) discusses status as organising cooperative behaviour in social interactions, suggesting that status functions as an incentive to cooperate and can create status hierarchies in groups that order the way decisions are undertaken. In an exchange setting, those with a better reputation may have more influence in group

decisions, temporarily rendering them 'higher status'. This is possibly a foundation for later hierarchical societies based on exchange and excludable resources. Yet permanent status differences would be detrimental to the social cohesion necessary to survive in small groups. As mentioned, exchange centred on specialised items can increase cooperation by ensuring individuals are dependent upon each other (Jaeggi *et al.* 2016), and it is probably this interdependence which could maintain a cooperative exchange setting in early hominin groups. It is acknowledged by several recent/contemporary hunter-gatherer groups that interdependence influences levels of, or lack of, tolerance to certain actions (e.g. the Batek and the Moriori – Endicott (2013); Ju/'hoansi – Marshall (1961)). This explains why strong social norms promoting cooperation, 'fairness' and the levelling of would-be dominant individuals could develop even in exchange settings with a strong hierarchical potential. An increase in (residential) group size, thereby lessening interdependence and increasing coordination problems, would increase the potential for hierarchy (Perret *et al.* 2020).

The risk of hierarchy needs considering when assuming that early groups of hominins developed an exchange-based social structure. Interdependence generated by exchange is likely to prevent hierarchy and encourage rules for levelling individuals acting hierarchically or cheating in exchanges, meaning strong social mechanisms are essential for early exchange settings. However, the tendency toward hierarchy may render an exchange system less stable as a cooperative social structure.

6.5 Conclusions

To summarise, a model has been described where exchange regulates access to fire. A few individuals are in charge of maintaining a central fire which is available to all in exchange for direct or indirect benefits. These individuals would invest time in gathering fuel and fire maintenance, leading to a better understanding of fire and fuel properties and therefore to possible specialisation and labour division. Ofek (2001) sees this as signifying the beginning of trade. For trade to be effective, it needs to be regulated so individuals do not cheat their partner. Punishment and reward mechanisms are likely to have developed to maintain an exchange system. I have given more weight to a combination of direct and indirect reciprocity, with reputation as a mechanism playing a large role. This is because the addition of reputation can easily accommodate low-cost punishment in the form of exclusion, gossip, and 'bad' reputation. Over time (if effective), the notion of what makes a good or bad reputation would be instilled in

individuals and transmitted, resulting in the stabilisation of social norms. This is very simplified and does not discuss exchange with other social groups, instead providing a broad outline of how an exchange system might have worked.

There are clear similarities to the public good setting discussed. Both potential social structures lead to the implementation of regulating mechanisms to ensure that interactions between individuals are beneficial to both sides. These mechanisms are likely to be low-cost punishment and/or reputation. Their use would eventually cause specific social norms to develop dictating appropriate behaviour in exchange interactions defining 'good' actions and character. In theory, both social structures would lead to a system where social norms are in place to encourage prosocial behaviour and to prevent free-riding, although exact norms would differ between groups. In practice, the risk associated with specialisation in small groups and the tendency toward hierarchy in exchange settings make this a less likely social structure for early fire-using hominins.

7. Discussion

Two models demonstrating how regular fire use might have influenced hominin social structure have been described. This chapter will provide evidence supporting the public good model, before considering the effects of a change in social structure on hominin social organisation. I start by discussing the widespread sharing of uncertain resources in small-scale societies and the use of social mechanisms to maintain cooperation. Evidence is drawn from ethnography and HBE with additional support from primatology, showing that certain social behaviours are not limited to modern humans. Next, changes in the archaeological record are shown to potentially support, or result from, changes in hominin social structure. The further consequences of a change in social structure is then discussed with regard to conformity, social emotions, and cultural group selection. Mention is also made of linguistic and cognitive capacities. Finally, limitations and benefits of the approach taken are discussed, focusing on the problems of a theoretical approach, the issues with certain disciplines, and the benefits of interdisciplinary research. Emphasis is placed on the need for broader discussions about sociality in the Palaeolithic to advance ongoing debates.

7.1 Sharing is caring

Widespread sharing of food, often meat, is common among small-scale foraging groups today and is frequently investigated in HBE studies (e.g. Gurven 2004; Hawkes *et al.* 2001). It is often framed as a public good, with sharing motivations receiving a lot of attention. I want to demonstrate the similarities between meat and fire as public goods, explaining why we might expect fire use to initially be treated as a public good. Ethnographic evidence will be used to portray what types of social rules surrounding sharing and cooperation we could expect in small residential groups.

Meat-sharing in foraging societies is considered a public good because individuals often receive a share regardless of whether they contributed to acquiring the resource (Dubreuil 2010b; Hawkes *et al*. 1993). It can be framed in terms of reciprocal altruism (see 4.3), where individuals who share meat with another expect that meat is likewise shared with them at a later period. This acts as a form of risk-reduction (Kameda *et al.* 2005) since sharing individuals are assured of meat when they did not catch anything. It can also be framed as indirect reciprocity, where individuals who share more receive more indirect benefits, such as more influence within the community and more cooperative partnerships (see 6.3). This would be considered a form of costly signalling

(Bliege Bird and Power 2015). These explanations can be viewed as complementary because both may explain meat-sharing at the same time: sharing can reduce risk while simultaneously offering individuals the opportunity to signal their cooperative intent. As a result, (meat-)sharing is attractive because it increases access to resources, thereby benefiting individual and group survival, and because it allows individuals to broadcast their generosity or other attractive qualities, thereby increasing their social reputation. Other reasons for food-sharing were mentioned in previous chapters, including kin-based sharing and tolerated theft. Kin-based sharing often influences sharing behaviours (e.g. among the Ju/'hoansi, see 7.1.1), but kinship does not actually predict sharing patterns (Smith *et al.* 2016). Moreover, it has been demonstrated that residential groups in foraging societies are not based on close kinship (Hill *et al.* 2011), making this explanation for sharing less likely. Tolerated theft is not considered here because it does not seem supported, with the possible exception of Marlowe's (2004) analysis of Hadza sharing behaviour. This does not assume that kin-based sharing and tolerated theft never play a role in sharing, but they appear unlikely as major explanations for sharing surrounding public goods. Consequently, I will provide more detail on risk-reduction reciprocity and costly signalling as explanations for food-sharing, before relating them back to early fire use.

When resources are uncertain because they are difficult to acquire, sharing might emerge as a buffer – if I share my catch now, I will receive a share when I have not caught anything. This is beneficial for the individual and the group. In many modern hunter-gatherer societies, sharing is expected, possibly for this reason. Marshall (1961) mentions that for the Ju/'hoansi, keeping meat without sharing is just not done. Uncertainty generates interdependence, so when survival depends upon other group members (and their sharing), any behaviour potentially resulting in decreased cooperation is actively discouraged. For the Batek, the recognition of being dependent upon the group for survival prevents harmful behaviour (Endicott 2013). Since meat-sharing prevents individuals from feeling excluded and lacking resources, it helps maintain group cohesion. Kameda *et al*. (2003) demonstrate that a 'communal-sharing norm' can evolve and stabilise when resource acquisition is uncertain, providing some support for widespread sharing being risk-reducing. In a simulation modelling cooperation around food storage in hunter-gatherer societies, Angourakis *et al.* (2015) found that environmental stress induced cooperation, also implying cooperative food-sharing reduces risk.

Simultaneously, when resources are difficult to acquire, they might represent a signal of (hunting) skill. Sharing the meat enhances that signal by demonstrating that the individual is also generous and therefore a desirable cooperative partner. Gurven *et al.* (2002) discuss this as costly signalling, where any food which requires time and effort to produce, if shared, can signal cooperative intent. Examples of hunters distancing themselves from their catch in extant hunter-gatherer societies (Bliege Bird and Power 2015; Hill 2002) suggests this signal should be costly and modest to be perceived as genuine. Modest (and repeated) sharing behaviours indicate that individuals are not being generous for personal gain since they do not need their generosity advertised. Hill (2002) mentions that Aché hunters do not even eat their own catch, providing support for costly signalling. Consequently, food-sharing not only ensures all group members have sufficient food when resources are uncertain, but also enables individuals to signal cooperative intent.

Fire as a public good can be characterised by the same explanations. While hominins were unable to create fire, it was an uncertain resource: they either depended upon natural wildfires or, once they had acquired fire from this source, depended upon keeping the fire going and obtaining sufficient fuel for this. Even if Twomey's (2014) assumption that hominins obtained fire from social networks is correct, this implies a dependence upon a mobile and potentially unstable network. Access to fire would remain unpredictable since the generally low population density and small groups of the Middle Pleistocene do not suggest one group was always close to another. Being someone who contributes to maintaining this uncertain resource could therefore be a signal of cooperative intent. Spending time gathering fuel for the fire instead of gathering food could function like sharing meat, establishing that you are willing to bear costs in order to contribute to group wellbeing. Likewise, maintaining the fire reduces the time for other tasks, again signalling prosociality. Early fire use may therefore be viewed as an activity that stimulates sharing, due to its uncertainty and its potential for costly signalling. However, we run into the problem of free-riding almost immediately unless every member of a group is an unconditional sharer, so rules are needed that govern this sharing.

7.1.1 Ethnographic examples of 'sharing rules'

To demonstrate how sharing is regulated in small-scale societies, several ethnographic examples will be given. These highlight the expectations surrounding meat-sharing but

also provide an insight into the social mechanisms used to maintain cooperative behaviour, with social reputation and low-cost punishment being especially relevant.

The Martu hunt sand monitors cooperatively and bring the catch back to a 'dinner camp' of 4-20 people to share (Bliege Bird and Power 2015). This sharing has a first round between the hunters, each receiving an even share, and a second round at the camp where each hunter shares their portion with others (Bliege Bird *et al*. 2012). In the second round, giving and receiving of meat typically occurs until everybody has a more or less even share, with the hunters aiming to end up with less of their own catch than anybody else (Bliege Bird and Power 2015). This is when individuals can build a reputation for being generous, which is important because the Martu respect individuals who 'hunt to share' and who share with individuals they have no obligation to share with. However, generosity signals must be repeated and consistent to be considered genuine. Social reputation is a reward: generous individuals might be given trusted ritual positions, while generous hunters tend to have more cooperative partners and social support (Bliege Bird and Power 2015). Stingy individuals may be excluded from cooperative ventures and have less social support (Bliege Bird *et al.* 2012).

The Ju/'hoansi also share big game in two distributions. The first distribution occurs between the owner of the arrow, the hunter(s), and if applicable, the giver of the arrow. This is because the game is initially considered the property of the owner of the arrow, not the shooter (Marshall 1961). The owner is responsible for this distribution. The second round of sharing involves the people who already received meat further dividing their shares, and this is governed by certain kinship obligations first. All those who receive meat also share their portions again, but at this point it has the quality of a gift (*xharo*), meaning the favour should be returned. If sharing obligations are frequently neglected, this can result in public criticism (Marshall 1961). This is seconded by Wiessner (2009), who mentions that the Ju/'hoansi constantly monitor who gives what and to whom. In her analysis of over 300 conversations, Wiessner (2005) found that the majority involve verbal criticism, often aimed at behaviours disrupting social cohesion (such as big-shot behaviour). The criticism ranges from joking and mocking to serious complaints. Free-riders were not often targeted, instead losing social regard and having fewer social opportunities (ibid). Praise was infrequent because it could threaten egalitarian relations and create social inequality (Wiessner 2005). Non-cooperative behaviour thus affects reputation and might include public criticism, a low-cost punishment especially when shared across a group.

The Hadza share meat widely, and often honey as well, although this may also be restricted to the household (Marlowe 2009). Honey is considered a valuable resource, which could explain why it is shared. There are no proper 'rules' regarding shared resources, and yet in most distributions everyone receives a more or less equal share. When someone receives a share of meat and they do not think it is enough, they simply ask for more (Marlowe 2004). Individuals who do not share are viewed as bad people, and the Hadza tend to avoid them (ibid). Again, this implies that a reputation for being cooperative and generous is important (Hawkes *et al.* 2001), while avoidance is a low-cost punishment tactic to evade non-cooperative individuals. Anonymous ultimatum and dictator games (see Table 2, pg. 37 for definitions) played with the Hadza resulted in low offers (Marlowe 2004). Since both games can reveal whether individual offers are governed by social expectations about appropriate amounts, and therefore affect individual reputations for being generous or stingy, the results support the idea that *known* reputation matters.

A last example comes from the Aché. Hunters leave their catch at the camp edge as a form of distancing themselves from their catch, thereby renouncing any ownership. The meat is cooked by a woman and then divided and distributed by an older man, who is not a hunter (Hill 2002). The meat is distributed equally, but the hunter does not eat his own catch, and his wife and children receive no more than others. Other (smaller) resources are shared in various ways, with the producer keeping more and a significant relationship between giving and receiving families, which is not the case for meat provision (ibid). This also confirms that uncertain resources are more likely to be widely shared. The Aché also appear concerned with social reputation. In UGs played among them, Hill and Gurven (2004) found that there were many offers over 50% and no rejections. They suggest this reflects the habit of sharing meat widely but also individual concerns about social approval, resulting in high offers to dissuade disapproval. The lack of rejections may reflect the tendency not to confront individuals directly, as the Aché gossip about others instead. In PGGs played among them, everyone contributed something even in the anonymous round, but verbal encouragement in the public round significantly increased contributions (Hill and Gurven 2004). The authors mention that those who contributed more appeared more satisfied and were mentioned repeatedly by others after the game. These games demonstrate the importance of reputation, and the use of low-cost punishment in the form of gossip and reputation loss.

The ultimate reasons for food-sharing are likely often a combination of underlying motives. To re-emphasise, however, meat is an uncertain (risky) resource and one that provides opportunities for costly signalling, possibly explaining why meat is widely shared. The same may have applied to early fire use, suggesting that the potential for similar sharing behaviours was present. Importantly, the qualities preferred in food-sharing, such as generosity and modesty, reflect what are considered desirable qualities for an individual in all areas of life. These are closely linked to maintaining egalitarian relations and preventing conflict within the group, to avoid detrimental impacts on group cohesion and cooperation. The use of social reputation and low-cost forms of punishment, such as avoidance and gossip, also support the importance of social cohesion in small-scale groups. These characteristics generally suit the public good model better than an exchange model, mainly due to the focus on social cohesion and egalitarianism. It is worth noting that the abovementioned groups do participate in forms of exchange, like reciprocal gift exchange or trade with neighbouring groups (Marshall 1961). However, gifts do not seem take the form of shared or uncertain resources – secondary meat distributions in some societies can be gifts, but this might only be the case because everyone already has a share of meat. This could suggest that goods are only suitable for exchange when they are not crucial resources.

This limited overview provides evidence for widespread sharing behaviour surrounding meat alongside general expectations of cooperative behaviour. This tends to be enforced through social reputation and its associated benefits on the one hand, and low-cost punishment on the other. Moreover, the focus is predominantly on generosity and sharing because this is crucial to group survival, while inequalities are avoided. This seems to refute the idea that exchange was likely as an initial scenario surrounding fire use, given small group size and probable interdependence within groups.

7.1.2 Primate cooperation and conflict reduction

So far, evidence from modern humans has been applied to an undefined extinct hominin species without much consideration of whether this is appropriate. However, the presence of social mechanisms to encourage cooperation is not unique to humans; it is also found in other primates. When studying nonhuman primates, a general assumption is that any behaviour we currently share with them can be expected in our last common ancestor, and therefore also in extinct hominin species (e.g. Boehm 2018). This is a vague statement, and for further explanation on this in relation to a Palaeolithic context,

see Boehm (1999:149-96) and Dubreuil (2010a). Nevertheless, it will suffice for the purpose of providing a basis for social mechanisms in Pleistocene hominins. I will briefly discuss evidence of primate behaviours that encourage cooperation and/or reduce threats to cooperation, alongside other evidence for the significance of cooperative behaviours. While deducing the exact motivations for behaviour in nonhuman primates is difficult, it is possible to identify cooperative behaviours and social mechanisms. This is done by observation in the wild and through experimental studies or 'games' to determine how primates act given certain situations and payoffs. Such information can lend support to certain capabilities being present in earlier hominin species.

Reciprocal food-sharing in chimpanzees and capuchin monkeys is examined by de Waal and Brosnan (2006), who found that food possessors shared more with those who had groomed them earlier. Moreover, capuchin monkeys reacted negatively when receiving lesser rewards than their partner in experimental games, suggesting that capuchins (and other non-hierarchical species) have "emotionally-charged expectations about reward distribution and social exchange that lead them to dislike inequity" (de Waal and Brosnan 2006:102). This implies that certain primate species can measure their own effort and reward against those of others and react to asymmetry in relationships (ibid). Lakshminarayanan and Santos (2010) confirm this by also demonstrating inequity aversion in chimpanzees and capuchins. These observations suggest some nonhuman primates have social expectations about the behaviours of others and recognise unfair outcomes.

Intergroup aggression among vervet monkeys often leads to a public good, such as territory or resources (Arseneau-Robar *et al.* 2018). However, fighting can be costly and therefore some individuals prefer limiting intergroup aggression. Arseneau-Robar *et al.* (2018) reveal that male vervet monkeys use aggression to coerce others into decreasing their participation in intergroup fights and target individuals who recently escalated fights as punishment. These individuals are less likely to engage in future intergroup aggression (ibid). Conversely, females are likelier to escalate intergroup aggression when valuable resources are at stake. Arseneau-Robar *et al*. (2016) show that females direct aggression at male defectors and groom fight participants, with both actions resulting in increased effort by these males in future fights. While grooming seems a small reward for the risk of fighting, it may have longer-term consequences on male fitness through access to females (Arseneau-Robar *et al.* 2016). This implies that reward and

punishment influence contributions to a potential public good, although males and females have different motivations.

Reconciliation behaviour after aggressive conflicts occurs in 30+ primate species, including chimpanzees (Aureli and Schaffner 2006). This can re-establish pre-conflict relationships, which is significant for reducing the uncertainty and anxiety associated with losing the relationship benefits. The latter is a strong incentive for reconciliation, as individuals with more cooperative (beneficial) relationships indeed reconcile at higher rates (ibid). Additionally, Flack and de Waal (2000) mention that more reconciliatory behaviours in a species may reflect their level of social cohesion, since more tolerant and egalitarian species have higher reconciliation rates. The widespread nature of reconciling behaviour suggests that maintaining cooperative relationships and social cohesion is significant enough to encourage behaviours that minimise damage done by conflicts. According to Flack and de Waal (2000), reconciling behaviours might be necessary when groups are not despotic, as dominance relationships usually manage conflict effectively. This could imply that social mechanisms that maintain social cohesion can be expected in less- and non-hierarchical primate species.

Finally, Sussman *et al.* (2005) comprehensively review primate social relations, concluding that the majority of social interactions are affiliative. They emphasize that if a primate depends on their group for survival, their ability to maintain affiliative behaviours and minimise aggression is crucial, providing insight into the evolution of group-living and sociality (Sussman *et al.* 2005:92). That most social interactions among nonhuman primates are cooperative does support the significance of cooperative behaviour in primates more generally. Platt *et al.* (2016) confirm this, discussing the positive fitness consequences of social bonds and cooperation in primates, and the possibility that differences in cooperative behaviours between humans and other primates are only a matter of degree. Rosati *et al.* (2018) further demonstrate that chimpanzees make prosocial choices faster than selfish ones, a bias which presumably emerges only when cooperation is highly successful, and which is linked to the development of stable human cooperation (ibid). Somewhat related is Boehm's (2018) discussion of collective intentionality among chimpanzees. Collective intentionality is a shared intention between two or more individuals, requiring at least joint attention to a common goal or outcome and (the realisation of) a shared belief in desiring that outcome. It may also include collective emotions. Boehm (2018) finds evidence of collective intentionality in chimpanzee hunting, patrolling and dominance-levelling

behaviour. He considers this a first step in moral evolution, where morality is partly why social sanctions and rewards succeed in human groups. The presence of collective intentionality in chimpanzees, bonobos, and humans is, according to Boehm (2018), suggestive of this capacity existing in our last common ancestor, implying that one of the main requirements of cooperative behaviour was present in all hominin species.

This section aimed to highlight that cooperative, conflict-reducing behaviours are present in many nonhuman primate species. Their nature suggests they are significant in ensuring groups remain socially cohesive and reciprocal relationships remain beneficial to both parties. Inequity-aversion and the use of social mechanisms to influence behaviour are present in some species, suggesting an ability to measure effort and rewards relative to that of others. There are obviously differences, but there appears to be a basis for cooperation and for using social mechanisms to encourage prosocial behaviour, indicating that we can expect these tendencies in extinct hominin species. While the nonhuman primate examples mentioned focus largely on interactions between pairs or within small, temporary groups, the introduction of regular fire use led to the recurring provisioning of a public good and group-wide cooperation. The scale and duration of this type of cooperation therefore sets hominin social structures apart.

7.1.3 Conclusions

It has been illustrated that uncertain resources are often shared, that this sharing is regulated by social mechanisms, and that these mechanisms generally apply to social behaviour, often including reputation and low-cost punishment. Examples were given from several extant foraging societies and some reasons why sharing occurs were also discussed. To counter problems with using modern human data to understand the past, I included evidence from nonhuman primates. This was not a direct comparison of hominins and other primates but aimed to demonstrate that the foundations of several cooperative, prosocial tendencies are present in nonhuman primates. This makes it harder to assume that Mid-Pleistocene hominins were incapable of using social mechanisms to regulate social behaviour. The emphasis on affiliative and reconciling behaviour furthermore suggests a focus on social cohesion as crucial to effective group living, something which applied to past hominins.

The evidence cited supports a social structure dealing with regular fire use as a public good, rather than as part of an exchange system. Relatively small hominin groups were vulnerable to changes in resource availability and dependent upon fellow group

members for support. In such uncertain settings, cooperation and sharing of hard-to-acquire resources were crucial to survival. The costs of not cooperating, losing a group member, or cheating are hard to bear for a small group (Wiessner 2005). It is therefore logical to have mechanisms in place that encourage cooperative and prosocial behaviour while discouraging detrimental behaviour. Other problems associated with an exchange system were already mentioned in Chapter 6. There need to be exchangeable resources. If valuable resources are scarce, exchange becomes difficult to achieve, especially if these valuable resources also rely on cooperative ventures. Exchange is often a feature of larger, settled groups. Large groups mean more individuals will be acquiring or producing the same item, reducing the risk of relying on only one individual for this item and allowing room for specialisation. Exchange also requires ownership of essential goods (Hawkes 2001), while it is noticeable that at least with meat sharing, many small-scale societies attempt to disassociate notions of ownership from the meat. Maybe most significantly, exchange promotes hierarchy and ownership of resources is linked to inequality (Bird and O'Connell 2006). Hierarchy can be detrimental to small groups because it reduces cooperation and increases conflicts. The Ju/'hoansi, for example, trade with their Bantu neighbours but do not trade amongst themselves as this causes bad feelings (Marshall 1961). The complete egalitarianism of many extant hunter-gatherer societies provides further support, as does the emphasis on levelling behaviour directed toward individuals with hierarchical tendencies (Wiessner 2005). In small groups, exchange is likely to be harmful to group cohesion and survival.

Consequently, I suggest that in small groups in uncertain conditions, cooperative behaviour relies on interdependence supplemented by social mechanisms that encourage cooperation and prosociality. The public good model exemplifies this by relying on the inherent willingness of prosocial individuals to contribute and on the strength of social rules to induce reluctant individuals to contribute anyway. The exchange model, while plausible in larger groups with relative resource stability, is less likely mostly because it undermines cooperation by promoting resource accumulation, encouraging hierarchy and inequality.

7.2 Social changes in the archaeological record

Up to now, the supporting evidence has come mostly from ethnography. While this is certainly insightful, it remains indirect evidence, since it covers modern humans with varying lifestyles and offers no way of determining whether any aspect of those

lifestyles is applicable to the past, let alone to another hominin species. Although the archaeological record can be ambiguous in terms of fire traces and social behaviour, it provides direct evidence about past behaviours. As such, it is necessary to correlate the archaeological record and the proposed social changes to advance beyond the hypothetical. A candidate period for making such a correlation is MIS 13 – MIS 11, which sees the convergence of several behaviours that may relate to a cooperative social structure: colonisation of northern latitudes, potential preferred habitat choices (in NW Europe – Ashton 2015; Brown *et al.* 2013), novel human-environment interactions (Brown *et al.* 2013; Davis and Ashton 2019; Moncel *et al*. 2015), 'home bases' and resource pooling (Kuhn and Stiner 2019; Rolland 2004) and slightly later, increased use of caves (Davis and Ashton 2019), evidence of regular fire use (Roebroeks and Villa 2011) and increased encephalisation (Gowlett 2006). I will begin by discussing the earliest archaeological record of the colonisation of northern latitudes in Europe, before moving into habitat choice, niche construction, and home bases, in order to highlight roughly contemporaneous behavioural changes which have important implications for hominin cooperation. These latter changes are based mostly on evidence from Europe and the Near East because these regions are currently better understood, but a few studies will be mentioned demonstrating that similar changes may also be present in Africa and Asia.

Early evidence of hominins colonising the northern (above 45°) latitudes comes from Happisburgh (UK), dated to over 800 ka, and Pakefield (UK), from around 700 ka (Moncel *et al.* 2015). More regular occupation occurs postdating MIS 12, with sites like Beeches Pit, Barnham and Hoxne (Gowlet *et al*. 2005). The occupation of these sites is significant because hominins would have had to deal with considerable environmental challenges, including seasonal extremes, long, cold winters and subsistence stress (Rolland 2014). Fluvial sites, often near the coast (Ashton 2015), are preferred locations, possibly due to greater year-round biodiversity and resource availability (Brown *et al.* 2013). The milder temperatures along coastal regions could have facilitated occupation of these sites (Cohen *et al*. 2012). Later sites in northwest Europe, like Bilzingsleben and Schöningen, are also often near to sources of water. The early UK sites do not reveal much about whether occupations were year-round, seasonal, long-term, or short-term. Based on faunal associations, mean winter temperatures at Happisburgh reached -11° to -3° Celsius, while those at Pakefield were slightly warmer at -6° to 4° (Coope 2006). Without direct evidence for fire use, it is unclear how hominins coped, although

suggestions include retention of body hair (Ashton 2015), seasonal migrations or occupation only during interglacials (Cohen *et al*. 2012) and use of clothing (Hosfield 2016). Additionally, northern sites in other parts of Eurasia, such as the Nihewan Basin in China (Dennell 2013), were being inhabited even earlier. While some of these sites appear predominantly occupied during temperate phases, as well as there being potential gaps in the occupation record during cold periods (Yang *et al.* 2019), other sites would likewise have required strategies to deal with extreme seasonality and overwintering (Dennell 2013; Rolland 2014). Consequently, the occupation of northern latitudes, potentially focused on specific habitat choice, suggests a change in hominin behaviour, which would have been facilitated by a cooperative social structure reducing the risks of inhabiting new (and harsh) environments.

From ca. 500 ka, more northern sites, as well as sites in central Europe, are occupied. This is accompanied by other behavioural changes, such as niche construction (Brown *et al*. 2013; Davis and Ashton 2019; Kuhn and Stiner 2019). Niche construction theory, put simply, is the concept of organisms altering their environment. When these alterations modify natural selection pressures, evolution via niche construction can occur (Laland *et al*. 2016), potentially creating a reciprocal relationship between niche construction and hominin evolution. Davis and Ashton (2019) suggest that during stable climatic periods in the Middle Pleistocene, hominins created recognisable 'landscapes of habit' through distinctive material culture (focusing on Acheulean handaxes). Brown *et al*. (2013) posit that the high nutrient diversity in river valleys prompted behavioural changes in hominins, such as increased consumption of marine resources, while repeated or prolonged occupation of such sites altered them and created adaptive responses in the flora and fauna. Kuhn and Stiner (2019) see the increase in 'hearth-centred base camps' as niche-constructing behaviour, since these were novel spaces created within the environment and could have acted as concentrated resource patches to which hominins repeatedly returned. Their arguments focus on changes in the Levant from 450-250ka because this region includes well-dated and studied sites, but similar changes are seen in the rest of Eurasia and Africa (e.g. Rolland 2004). Consequently, new environments were not only occupied but also altered. The use of material culture 'habituated' these environments and created novel notions of space partitioning, hominins created feedback loops with resource acquisition and new behaviours in response to resource availability, and they constructed home bases. New ways of engaging with the environment could mirror novel social interactions.

The term home base signifies sites which are characterised mainly by the organisation of activities within and around the home base (evidenced by artefact concentrations), and the transporting of meat back to the home base for sharing (Isaac 1975). Initially, home bases were recognised in the archaeological record during the Lower Pleistocene, with sites such as Olduvai Bed I and II and Koobi Fora (FxJj1 and FxJj3) fitting some of the home base requirements (Isaac 1971). However, an increase in the concentration of home bases was already acknowledged for the early Mid-Pleistocene (Isaac 1975), and more recent research sees them as additionally characterised by fire traces and highly structured activity patterns (Rolland 2004), resulting in home bases appearing from around 400 ka onward. Consequently, there is an intimate link between fire use and home bases, which Rolland (2004) discusses in relation to the occupation of caves. He suggests that fire use is a relatively punctuated event in the archaeological record, and that caves could not be inhabited until fire use was possible, as the damp and dark environment makes caves undesirable living spaces. Fire use allowed for fixed-site locations where all activities, including meat-sharing, took place, freeing hominins from the day/night constraints that existed before fire was controlled (Rolland 2004). These home bases would be identifiable in the archaeological record through fire traces, spatial organisation, and structured activity locations (ibid).

Importantly, Kuhn and Stiner (2019) indicate that a central gathering space (i.e. home base) is the material correlate for cooperative activities, since effective cooperation requires individuals to engage in the same place. They likewise see a niche shift towards increased cave use and partitioning of space at sites after 500 ka, accompanied by fire use and central hearths, but also by changes in resource acquisition and carcase transport. Meat starts being brought back and shared at these central places, while the hunting focus lies on prime adult game (Kuhn and Stiner 2019). Recently, Grotte des Rhinocéros in Morocco, dated to ca. 700 ka, has yielded evidence for meat transportation back to a cave site and subsistence activities within the cave, in association with a rich Acheulean industry (Daujeard *et al.* 2020). This is one of the earliest direct associations of meat consumption with tool manufacture in a cave context (ibid). Another early example comes from Caune de l'Arago, France, around 600 ka, which is likewise a cave site with evidence of tool-making, subsistence activities, and transportation of meat back to the site (de Lumley *et al.* 2004). Both sites may suggest that the home base was an outcome of socio-behavioural changes, including meat-sharing and cooperative activities.

Ashton (2015) includes the appearance of home bases within a 'package' of innovations involving fire use, shelter and Acheulean bifaces all structuring the landscape such that home bases become visible places. The significance of Acheulean bifaces is also discussed by Moncel *et al.* (2015), who likewise attach it to fire use, shelters, shifts in meat acquisition and transportation, and notions of cultural identity. Clearly, sometime after 500 ka, the archaeological record shows a convergence of new behaviours often related to hominin niche construction, where hominins start inhabiting new environments in the form of caves, adapting these environments through fire, and structuring them through new patterns of resource acquisition, processing and sharing, as well as through spatial organisation of activities and through material culture. These changes could result from novel within-group interactions changing the way hominins viewed their world and structured their activities.

In addition to these changes, a period of hominin encephalisation seems to have occurred in the early Middle Pleistocene (Rightmire 2004). Although it is difficult to find explicit evidence for this, the Sima de los Huesos fossils show encephalisation quotients which are higher than those of *Homo erectus* and lower than those of Neanderthals, thereby showing an increase from *H. erectus* which is not due to the increase in body size (Arsuaga *et al.* 2015; Poza-Rey *et al.* 2019). Several studies suggest there was an increase in endocranial volume after 600 ka (Neubauer and Hublin 2012; Hublin *et al.* 2015), or between 800-200 ka (Antón *et al.* 2014), independent of body size, although care needs to be taken when comparing different measures of brain size/volume (Shultz *et al.* 2012). While nothing definite can be inferred about behavioural changes, Gowlett (2006) associates a Middle Pleistocene brain size increase with the exploitation of marginal environments and the resulting need for increased social networks. As larger brains have higher energy requirements, the use of fire to process foods and/or changes in resource focus and acquisition would accompany the increase in brain size (ibid). Finally, it has been shown across various mammals that encephalisation is linked to sociality, especially to stable social groups (Shultz and Dunbar 2010). This may suggest that the phase of encephalisation triggered, or resulted from, changes in social network structure or size and can be linked to the abovementioned behavioural changes.

7.2.1 Conclusions

Changes in hominin social structure could be reflected in several archaeological patterns during the Middle Pleistocene. These start with the colonisation of northwest Europe (as

well as northern sites in other parts of Eurasia), implying that hominins could adapt to new environments and exploit them successfully. This initial shift is gradually accompanied by an increased emphasis on hominin-environment interactions, or niche construction, signifying new ways of engaging with the landscape. The archaeological correlates include home bases, spatial partitioning and distinct activity zones, the controlled use of fire, cave occupation, and changes to resource acquisition, transportation, and processing. Finally, an increase in brain size might be relevant in explaining the behavioural and social changes mentioned. A move towards modern human-like cooperation is mentioned in relation to most of the behaviours discussed, but the mechanisms this requires are not specified (Ashton 2015; Davis and Ashton 2019; Gowlett 2006; Kuhn and Stiner 2019; Moncel *et al.* 2015; Rolland 2004). Occupying new environments would encourage strong social networks that reduce risk, while home bases are tied to sharing of resources and communal activities; thus, a change in social structure that includes a public good-type cooperative system is conceivable. Whether this change acted as a trigger or a consequence, future research should explore how archaeological traces can reflect important changes in social organisation.

7.3 Further impacts on social structure

Several factors have been discussed that support an early cooperative structure treating fire as a public good. The archaeological record provides tentative agreement with this. However, as both proposed models require social mechanisms, it is unnecessary to definitely assert one is correct in order to discuss further consequences of a change in social structure. I will therefore consider how social mechanisms are stabilised and maintained, how they survive in a multi-group setting, and how this relates back to early fire use. I will only generally review social norms – for fuller discussions, see the literature cited.

7.3.1 Stabilising social norms

If a group developed a cooperative structure where social reputation induced individuals to act in a prosocial manner (e.g. by gathering fuel) and loss of reputation prevented free-riding, this could be transmitted to each new generation. Put simply, individuals recognise that being generous or helpful is beneficial to their social position, and make sure their offspring also know this. However, what keeps individuals adhering to the 'rules' defining prosocial behaviour? Rules only work if everybody agrees on their

content, their applicability, and their enforcement. At least two (related) concepts are relevant in this regard: conformity and social emotions.

Conformity is the tendency to imitate the most common behaviour (Guzmán *et al.* 2007), or the behaviour individuals have most frequently witnessed (Claidière and Whiten 2012). If individuals are unsure of the most beneficial way to act, it is easiest to 'follow the crowd' (Guzmán *et al.* 2007). In new environments or information-poor situations, conforming is a much faster way for individuals to successfully adapt their behaviour than individual learning. This is *informational* conformity and indicates gaining non-social information and adapting to non-social environments (Claidière and Whiten 2012). With *normative conformity*, individuals gain information to adapt to their social environment (ibid). Individuals might disagree with the belief or behaviour, but they realise that conforming facilitates coordination with others, encourages group acceptance, leads to social rewards, or allows avoidance of punishment (Richerson and Henrich 2012). Both informational and normative conformity are risk-reducing and some behaviours may be informational and normative or start by being informational only and become normative (Claidière and Whiten 2012).

It may be expected that larger groups induce more conformity. However, early studies found that conformity only increases up to about three individuals (reviewed in Claidière and Whiten 2012; Wilder 1977), while more recent work still suggests social influence reaches its maximum at 4-6 people (Walther *et al.* 2002). Instead, conformity strength may be dependent upon the number of different entities trying to exercise influence (Wilder 1977), the level of environmental uncertainty (Walther *et al.* 2002), or the frequency of a behaviour (Claidière and Whiten 2012). At the same time, Claidière and Whiten (2012) also propose that there may be marginal effects of group size increases in small groups when dealing with normative conformity. Therefore, although conformity evidently does affect small groups, it is currently unclear if, and to what extent, the effect increases with group size.

Conforming is useful because it increases the (social) survival of an individual within a group. Accordingly, when social 'rules' are adhered to by the majority and deviance from these rules is punished, these rules may stabilise into social norms. Any newcomers to the group will tend to conform to avoid the negative consequences of not conforming. This suggests that as hominins introduced rules to ensure cooperation and reduce free-riding, anyone not following these rules was sanctioned. The negative

consequences of being sanctioned would prevent others from free-riding, meaning even unwilling individuals would (reluctantly) cooperate (Frey and Rusch 2012:829). This explains why punishment would become a stable strategy as well and could remain low-cost – if the threat of punishment is enough to deter individuals from free-riding, the cost rarely has to be paid, and when it does, general group agreement on appropriate behaviours would ensure the cost is spread over many punishers.

Experimental PGGs have shown that conformity and social norms influence human decision-making. For example, participants of a PGG with punishment will punish individuals with increased deviation from the group average contribution more (Fehr and Gächter 2000). This suggests that the average contribution becomes a behavioural standard, which is dependent upon the group in question and their preconceptions about the 'right' amount. Moreover, individuals adjust their contribution to the majority behaviour in the group, indicating a tendency to conform (Dong *et al*. 2015). There are degrees of conformism, with not everyone being a strong conformist, since complete conformism would prevent any change within groups (Claidière and Whiten 2012). Yet studies show that a significant proportion of individuals will conform to majority behaviour even if they believe it is incorrect (see Claidière and Whiten 2012 for a review; Henrich and Henrich 2007 for a case study on Chaldeans).

Humans also appear primed to recognise and internalise social norms. Experimental work with young children revealed that they instinctively recognise social norms and react negatively to deviation by others to the perceived norm (Richerson and Henrich 2012:46). Humans generally react negatively to norm deviation by third parties even when not directly affected and will sanction these third parties at a personal cost (Henrich and Henrich 2007). Interestingly, reward circuits are activated within the brain when humans follow relevant norms and when they punish others who did not (Richerson and Henrich 2012:47). fMRI data indicate that the reward effect of punishing holds regardless of punishment effectiveness or personal involvement (Strobel *et al*. 2011), suggesting that solely the notion of social conformity makes punishment rewarding. Accordingly, our cognitive and social frameworks seem prepared to internalise social norms and to punish norm deviation. Smith *et al.* (2018) demonstrated that Hadza cooperation levels are best predicted by the cooperativeness of their current social group, not by individual past behaviour. The authors conclude that this is consistent with social learning of local norms, suggesting the Hadza easily adapt to

differing norms when they move groups. This supports the importance of social norms in 'surviving' new social settings.

The stabilisation of social norms is aided by social emotions. The definition of emotion is debated (e.g. Karnaze 2013), but social emotions generally refer to feelings such as guilt, pride, and shame – emotions relating to others, their behaviours, and the effect of your behaviour on others. Although no formal framework exists demonstrating how social emotions 'work' (Bowles and Gintis 2003:433), they are widely thought to be related to cooperation and norm enforcement (Henrich and Henrich 2007:65; Mesoudi and Jensen 2012). For example, free-riding causes an individual to feel guilty, which acts as a punishment and a deterrent for future cheating, while contributing generously and receiving social approval causes an individual to feel proud, which encourages future cooperation. Norms, accompanied by prosocial emotions, can therefore be self-enforcing.

7.3.2 Maintaining social norms

Social norms could be maintained within a residential group through conformity and social emotions alone. However, this would not explain why we tend to see similar forms of widespread cooperation across the world in groups that do not interact with each other. It is therefore necessary to determine why social norms would persist, which will be briefly discussed in the framework of cultural group selection.

The types of norms that stabilise depend on factors like group context and ecology. This means that different groups develop different norms, not always equally beneficial (Henrich and Henrich 2007). The difference allows members of a group to distinguish between insiders and outsiders, while the enforcement of group norms increases in-group homogeneity, thereby exacerbating between-group differences (Claidière and Whiten 2012). In any environment, there will be potential group competition, where groups with 'better' norms are more successful. This success can take multiple forms: one group might conquer another, one group might have more offspring, or one group might attract many newcomers who spread the norms back to their groups. Alternatively, a group might go extinct because another group has norms better adapted to the (social) environment. Whatever the reason, cultural group selection provides a framework explaining how social norms survive and spread. This theory posits that intergroup competition (not necessarily warfare) allows the spread of prosocial and cooperative norms, assuming cooperative behaviour is more successful than

noncooperative behaviour, which it appears to be (Boyd *et al*. 2003). Any neutral or maladaptive norms might be contained within a group but will not spread, since they are not selected for (Henrich and Henrich 2007:66). Moreover, as cultural group selection favours cooperative norms and the punishment of norm-violators, it will also select for individuals capable of rapidly acquiring norms to avoid punishment (Henrich and Henrich 2007:69). The frequency of individuals willing to punish within a group is linked to the maintenance of cooperation, so when cooperation is selected for, punishment often is as well (Boyd *et al*. 2003). Thus, the spread of group-beneficial cooperative norms changes the social environment facing individuals, encouraging selection of genes capable of dealing with that environment, such as genes related to norm acquisition and prosocial behaviour (Henrich and Henrich 2007:134), or to social emotions (Mesoudi and Jensen 2012).

Cultural group selection is a multi-level theory, meaning that selection can operate (simultaneously) at multiple levels within a population, such as at the 'band' level as well as at a nation level (Richerson *et al.* 2016). However, these authors also suggest that the competition resulting in cultural group selection occurred between ethnolinguistic groups, and that the more groups differed, the likelier this type of selection is (ibid). While they apply it to the human past, possibly 'as far back as symbolic marking is evident' (Richerson *et al.* 2016:11), this poses a problem because we do not know enough about Middle Pleistocene demography and group differences. Consequently, cultural group selection provides a plausible theory for explaining the spread of norms once groups reached a certain size and level of organisation, but the threshold of residential or network size needs investigating. Agent-based modelling (see Chapter 8) may provide one way this could be examined.

A full discussion of cultural group selection (and its criticisms – see Boyd 2017) is beyond the current scope. However, it provides one way of explaining the prevalence of cooperative norms and sanctions, and why we might expect that conformity and prosocial emotions helped enforce initial cooperative norms. To make an extremely broad point, it could even help explain the patchy fire record. If a novel cooperative structure was necessary for regular fire use to be feasible, it would take time for groups to successfully alter their social structure. Some groups will not have (socially) survived, while others will have thrived. The persistence of cooperation today reflects the success of cooperative norms, although it cannot tell us when and why they emerged.

7.3.3. Fire as social reinforcement

Fire itself may have reinforced a cooperative social structure, firstly because it provides a focus for socialisation. When a group gathers around a fire, the cooperative nature of fire maintenance may be reinforced by people communally benefiting from it. This is less pertinent if fire maintenance resulted from exchange. Moreover, early fire use is presumably related to socialising in the evening, as the firelight was insufficient for other tasks (Dunbar and Gowlett 2014). Fire reduces blood pressure and relaxes individuals, which makes them more socially inclined and thereby strengthens group cohesion (Lynn 2014). The visual effect of fire possibly produces meditative feelings in humans, also suggesting fire is relaxing (Rossano 2007). Fire as a phenomenon is thus effectively tuned toward increasing feelings of sociality while simultaneously providing the focus for socialising. These feelings of cohesion would only increase if individuals ate together around the fire (suggested for Qesem, Stiner *et al.* 2011), which is likely because cooperatively maintained hearths make processing carcases easier as well as making it near impossible not to share and interact (Kuhn and Stiner 2019). The 'fire time' might also have been used to share social information or engage in activities that bonded individuals (Dunbar and Gowlett 2014). Regular fire use and maintenance necessitated a cooperative structure, but it also enforced that cooperative structure by being a focus for socialisation and strengthening group cohesion. Additionally, Gowlett *et al*. (2012) assert that the brain size increase (see 7.2) during the Middle Pleistocene represents developed social capabilities, which "are both required for communal fire use and reinforced by its existence" (2012:705). If fire use was crucial to survival in some environments, groups which effectively cooperated to maintain fire held an advantage over non-cooperative groups (Twomey 2014), again consolidating the cooperative nature of fire use.

The sociality of fire is attested to in ethnographic and ethnoarchaeological work (not always explicitly). Among the Selk'nam of Tierra del Fuego, fuel collecting was a family affair, people gathered around fires throughout the day, and fire is what made a settlement a home (Spikins *et al.* 2018). Campfires form the focus of many activities, including socialising, for the Efe (Fisher and Strickland 1989), while McCauley *et al.* (2020) list 74 hunter-gatherer groups (out of 93) that use fire for ritual purposes and 56 that use it to facilitate activities such as gossiping, playing games and dancing in the evening. An analysis of Ju/'hoansi campfire conversations (Wiessner 2014) found the majority (81%) focused on storytelling, and storytelling around the campfire on an

evening is a vital part of life for Aboriginal Australians (Stasiuk and Kinnane 2010). Fire clearly occupies a central place in human social lives, the origins of which might be found with its initial manipulation by hominins. The cooperation required to regularly use fire may well have added to its importance in social life.

7.3.4 Language and cognition

Language has not yet been explicitly discussed in relation to fire or cooperation. It is definitely relevant, as the addition of communication between players in PGGs increases cooperation, sometimes even maintaining it until the last round (Sally 1995). It can therefore help organise social coordination without additional mechanisms. Fire is also linked to the evolution of language (Dunbar and Gowlett 2014; Gowlett 2010), which is supported by the relationship between language and fire-focused activities today, such as story-telling (e.g. Dunbar 2014). However, assuming language was present in any hominin except modern humans is currently problematic. Language, with emphasis on *verbal* language, is also not required for cooperation, nor for rewards and sanctions to play a role in maintaining cooperation. Section 7.1.2 reveals that primates engage in cooperative behaviours and use social mechanisms to influence behaviour, while mechanisms such as avoidance, reputation and exclusion can be non-verbal. Gossip or criticism, however, would not be possible, meaning that while the overall picture does not change, the specifics of maintaining cooperation are unclear without considering the role of language. Smith (2010) further proposes that language would reduce the costs of enforcing sanctions and help solve coordination problems arising from collective endeavours, suggesting that language would both diminish the costs of cooperation and increase the scope of cooperation. While both models could likely arise without language and a cooperative social structure could be maintained using nonverbal sanctions and rewards, language will have influenced cooperation and norm enforcement considerably whenever it emerged.

Cognition is another aspect not yet addressed. Cooperation is not necessarily linked to intelligence, considering that eusocial insects are the next most cooperative species after humans (Henrich and Henrich 2007:41-2). However, human cooperation is unique for several reasons, including interaction with unrelated individuals and the large scale on which it occurs. The motivations behind cooperative behaviours are still not always understood, as they never fit into one theory. This might suggest unique cognitive capacities. Twomey (2013) argues that planning ahead, response inhibition and

collective intentionality were some of the cognitive prerequisites of using fire habitually. These prerequisites are likely, considering that planning ahead and response inhibition can be linked to provisioning a fire and sharing cooked food, while collective intentionality is necessary to cooperate. Furthermore, a change in social structure almost certainly required new ways of thinking about social interactions and relationships. Novel socio-cognitive abilities may have developed as a result of needing to adapt to social norms and sustain multiple relationships. As Shultz *et al.* (2012) indicate, maintaining cohesive social groups places cognitive demands on the group, as they need to solve social dilemmas within a socially organised environment. The wishes of all members need acknowledging, which necessitates theory of mind and empathy (ibid), both of which have their basis in collective intentionality. As social norms increased the complexity of the social environment, additional pressures might have further enhanced cognitive capacities. Debating when these cognitive abilities appeared is challenging, however, and in-depth discussion of potentially required cognitive abilities does not add to my argument. Nevertheless, it is relevant to emphasise that novel or increased social pressures leading to or resulting from changes in social organisation would have stimulated novel or increased cognitive capacities. It may be possible to link this to changes in brain size during the Middle Pleistocene, although it is currently problematic to infer cognitive abilities from brain endocasts (e.g. Poza-Rey *et al.* 2020). Alternatively, these cognitive abilities might already have existed, resulting from dealing with complex social problems in a different context. Investigating specific cognitive abilities necessary to deal with cooperation dilemmas and social interactions would aid understanding about the full impact of social changes in the past.

7.3.5 Conclusions

Once a cooperative social structure arises where behaviour needs regulating, social norms can be expected. The stabilisation of norms is aided by a tendency toward conformity and reinforced by prosocial emotions, which act as an internal punishment and reward system: norm deviation produces negative emotions and norm adherence produces positive emotions. These emotional reactions extend to third-party behaviour, explaining the prevalence of punishment and how the threat of punishment may be enough to induce norm adherence. Cultural group selection was used to describe how norms might survive over time. Successful norms spread or replaced less successful norms, and the prevalence of cooperative norms suggests cooperative groups were more successful. The nature of fire consolidates norms and social cohesion with the

cooperation required for fire use being strengthened by the effects of fire. This suggests a permanent change in social behaviour can be expected once a cooperative social structure was present. The roles of language and cognition have only briefly been mentioned, but their investigation will provide valuable insights.

7.4 Limitations

Given the broad scope and theoretical nature of this thesis, there are several limitations to consider. Firstly, various factors influencing cooperation were ignored. Group size and composition, environmental conditions, and resource availability are all significant aspects that could affect group interactions. In a predictable environment or one where fire was not a necessity, the pressure to cooperate would be diminished. This could produce a relaxed social structure where cooperation is less urgent and free-riding is taken less seriously (e.g. Angourakis *et al.* 2015). In the reverse, a more rigid social structure with stricter sanctions might arise because the costs of fire are higher. These factors are crucial to fully understanding fire use, its costs, and its benefits (see Henry 2017; Henry *et al*. 2018), and its effect on social structure. Various lines of evidence did not receive full consideration despite their relevance, including primatology and psychological studies on cooperation and norm enforcement. This is due to the scope of this thesis focusing specifically on the link between fire use and cooperation, but also the desire to provide a broad discussion that covers multiple aspects related to this link. The ability to provide definite conclusions is therefore limited, and further research would ideally investigate specific factors influencing cooperation surrounding fire use, such as group size or the costs of maintaining a fire.

Another issue is the application of evidence from modern-day humans to extinct hominins. I tried not to directly apply behaviours to the past by discussing general behavioural tendencies instead, but it is a limitation when considering social capacities in extinct hominins. It hopefully does not detract too much from the overall arguments since modern forms of cooperation and social mechanisms had to start somewhere in the past. That specific forms of cooperation were necessary before modern humans appeared seems well-founded; the main problem is determining when they emerged. Multiple behavioural developments could have entailed social changes, but since direct archaeological evidence for sociality is scarce, research on (Palaeolithic) sociality necessarily relies on evidence from other disciplines. This results in more potential limitations, as I will discuss for ethnography and game theory.

7.4.1 Ethnography

Using ethnography is common within archaeology, with limitations usually being acknowledged. Clearly, modern foraging societies are not analogous to those in the past, while most historic foraging societies had contact with colonial powers and neighbouring agricultural societies already when documented (Haas and Piscitelli 2013). Modern hunter-gatherer societies also have highly diverse lifestyles which are not solely down to environmental pressures (Endicott 2013). General tendencies of small-scale societies can be relevant to the past, but only with careful consideration of specific contexts. Determining whether a behaviour appears designed to aid survival and reproduction in the evolutionary ancestral environment is one way this is attempted. If it does not, it is much less likely to be a 'human universal' or evolutionary behaviour (Fry 2013:2), possibly helping to separate evolutionary from culturally evolved tendencies. Another problem is that hunter-gatherer means different things across the literature and is not always defined (Fry 2013:8). Technically, only nomadic, egalitarian foragers should be used to infer anything about past hunter-gatherers, but evidence from pastoralists or agriculturalists is often included (Fry 2013:8-10). This suggests some of the studies used in this paper may refer to a broader range of small-scale societies than is useful when studying the past.

I used ethnographic evidence to exemplify how small-scale societies might manage shared resources and enforce cooperation. The examples should be understood within a wider range of evidence demonstrating certain cooperative mechanisms are more common than others in small, public good contexts. A major limitation is that environmental and other pressures were not considered for each society, nor was their reliance on certain resources or methods of acquisition. I did not take differing group sizes or social/kin structures into account, and the sample size was extremely small. Further research into cooperative structures surrounding shared resources would need to consider environmental contexts and other factors to properly discuss sharing behaviours and norm enforcement, ideally compared across many small-scale societies.

7.4.2 Game theory

Applying game theory to human behaviour receives some criticism. Many studies use controlled lab settings with anonymity and/or one-off interactions, which do not represent real life. Wiessner (2009) found that the Ju/'hoansi were 'selfish' and did not punish in anonymous games, while they were generous and willing to punish in real life.

Anonymous games played among the Hadza found similar results (Marlowe 2004). Anonymity is a shortcoming for studying cooperation in the past because anonymous, one-shot interactions were assumedly rare (Gurven and Winking 2008; Patton 2004). When games instead reflect real-life situations, the game and real-life behaviours are frequently comparable (Henrich *et al.* 2005; Hill and Gurven 2004). It is therefore relevant to the reliability of results whether game contexts are familiar to participants. Another issue is that most studies use only (American) undergraduate students, meaning results are unrepresentative. Research such as the cross-cultural study by Henrich *et al.* (2004) is essential to understand cultural variation in results. Although more studies look at non-undergraduate groups, they remain a minor section of game participants (Frey and Rusch 2012). Consequently, more cross-cultural work is needed for game theory to better reflect human behavioural tendencies.

Levitt and List (2007) discuss other limitations of games in lab settings. For example, individuals act more prosocial when they know they are being observed (Ohtsuki *et al.* 2015). Terms such as 'opponents' or 'partners' in the game context influence individual behaviour (Levitt and List 2007; Ostrom 2000). Games have limited options, while individuals in real life have almost unlimited choices (Levitt and List 2007). The defect or cooperate distinction in games almost never applies to real life, and game duration is not representative either, given that real interactions can continue beyond 10 rounds and interaction with the same individuals can occur in different contexts (Frey and Rusch 2012; Guala 2012). The majority of game results used in this thesis are supported by multiple studies, but I do not mention potential biases or comparisons between field and lab experiments. This may limit the validity of some studies used.

7.5 Benefits

The approach taken has benefits as well. The advantages of game theory will first be discussed, before reviewing the benefits of theoretical and interdisciplinary research and their utility in archaeology.

7.5.1 Game theory again

Despite criticisms, lab settings offer the advantage of being able to control factors that might influence behaviour, potentially revealing what influences behaviour the most. An example is playing ultimatum and dictator games within the same group, as this indicates whether the fear of rejection motivates individual offers (Henrich *et al.* 2006).

Introducing and removing anonymity can further reveal individual concern about reputation (Engelmann and Fischbacher 2009; Ohtsuki *et al*. 2015). Another benefit is the reproducibility of controlled lab games, increasing the validity of comparing results across studies (Camerer and Fehr 2004). Using game results alongside observations from HBE and ethnography can determine if game theory offers valid insights into human behaviour. The finding from PGGs that cooperation is not maintained without sanctions or rewards can be compared to public good settings in actual societies. As section 7.1 discusses, small-scale societies do incorporate such mechanisms. This lends credence to theoretical results. In case of discrepancies, a benefit of games is that they are easily adjusted.

7.5.2 Theoretical and interdisciplinary approaches in archaeology

Due to the theoretical nature of my approach, the discussion could focus on more aspects of sociality than testing every hypothetical scenario would have allowed, resulting in a broad overview covering several significant points. This permits various hypotheses about fire use, cooperation, and sociality to be drawn from this paper, while simultaneously highlighting numerous potential directions for future research. It also emphasises gaps in the research, such as the lack of literature on the costs of fire maintenance.

Furthermore, the interdisciplinary approach has advantages. The archaeological record can be vague or difficult to interpret, meaning sole reliance on archaeology is not always practical. Insights from other disciplines are useful, as when reviewing the social consequences of fire use. By examining cooperation through HBE, game theory and related disciplines, a novel discussion about the social changes that regular fire use might have stimulated was initiated. This also permits a move beyond the constraints of the record, and thereby beyond repetitive discussions about the limitations of investigating social lives in the Palaeolithic. Moreover, possible archaeological correlates for social change could be identified (section 7.2). While this thesis is not necessarily the correct approach, it has demonstrated that interdisciplinarity can produce novel hypotheses, which in turn may emphasise directions for future research (Chapter 8) or provide new takes on known information.

Nevertheless, taking the best parts of multiple disciplines does not by default produce reliable research. It is difficult to cross over into a subject with different methodologies and successfully integrate it into the original subject (McBee and Leahey 2016). The

supposed boundaries of many disciplines complicates things further. Supporters of interdisciplinarity assume crossing these boundaries allows problems to be solved, while opponents believe these boundaries organise research effectively (Light and Adams 2016). Both have a point. In looking at something as broad as human behaviour, however, it seems ineffective to limit research within rigid boundaries rather than combining the available knowledge. Being confronted with disciplines doing research differently can produce new ideas, especially because individuals can enter the second discipline without being constrained by discipline-specific frameworks. Results obtained using different methods but answering similar questions can furthermore be compared. I am not arguing for interdisciplinarity always being optimal, but it can be valuable in giving recurrent debates a new twist, highlighting new research directions, and in pointing out neglected aspects of research. In terms of archaeology, it gives a voice to those facets of past lives that leave no material traces, while providing ways of tracing sociality and other 'invisible' aspects within the archaeological record.

7.5.3 Conclusions

A few limitations have been highlighted, focusing on the lack of contextual information applied, the use of ethnography, and the reliance on game theory. I emphasised the limitations of ethnography and game theory specifically because they often receive criticism. However, both have benefits as well, with those of game theory discussed to emphasise why it is a useful subject for studying social behaviour. Using several lines of supporting evidence has hopefully demonstrated how related disciplines can inform and supplement archaeological questions. I discussed the benefits of interdisciplinary and theoretical research, arguing that it produces novel hypotheses and insights into ongoing debates. This is especially relevant for a broad topic such as human evolution and behaviour. Specific to archaeology, interdisciplinarity is important in giving due consideration to the parts of past lives that leave little trace. Moreover, the broad and theoretical approach highlighted several relevant directions for future research into social structure and fire use, which will be detailed in the next chapter.

8. Future Research Directions

Given the broad focus of this thesis, many directions for future research could be identified. I will review four topics that seem most pertinent to answering questions about cooperation and fire use, specifically from an archaeological point of view. These are agent-based modelling, ethnoarchaeology, the costs of fire maintenance, and a framework for research into Palaeolithic sociality.

8.1 Agent-based modelling

Considering we cannot go back in time to check if current hypotheses about social behaviour in extinct hominins hold true, other testing methods are needed. One possibility is agent-based modelling (ABM), which entails a simulation of actors within a complex system constrained by specific parameters and sets of choices. An advantage of ABM is that it includes individual agency and simultaneously models the emergence of population-level patterns, based on individual behaviours and interactions (Romanowska *et al.* 2019). A criticism of social simulations is the lack of data derived from experimental observation and the difficulties with reducing complex social phenomena to empirical data (Silverman 2018).

Using ABM to model the public good scenario would mean deciding which aspect of the model should be investigated. Romanowska *et al.* (2019) list five main purposes of ABM, of which three could apply: simulations as a heuristic tool, as a substitute for experiments, and as a technique to understand system dynamics. Consequently, the overall purpose needs determining – a simulation including the feasibility of cooperation surrounding a public good, the costs of fire use and cooperation, and the effect of social norms on group structure would be far too complicated. Next, relevant parameters would need identifying, which would include environmental conditions, resource availability, and group size, but also individual options when faced with certain situations. Moreover, setting parameters for individual behaviour means re-engaging with questions of language and cognition. Simulations are more understandable when simplified to key aspects, but this introduces ambiguity about the influence of excluded factors (Davies *et al.* 2019) and the representativity of the simulation.

There are examples of agent-based models of social structure and cooperation. Angourakis *et al.* (2015) investigate how cooperation surrounding food storage evolved. Their simulation demonstrates that a norm punishing free-riders can transform an

individualistic society into a cooperative one, if punishment is not too harsh, and that cooperation is more likely to evolve under environmental stress. This lends support to the public good model and indicates that ABM is useful in uncovering which factors are necessary for certain cooperative structures to emerge. Lewis *et al.* (2014) create an agent-based model to simulate hunter-gatherer populations living in unstable environments, concluding that demand-sharing of food and mobility is crucial in conditions of high unpredictability. They further show that free-riders can be avoided and kept minimal through free movement of family units, indicating to them that punishment is not necessary (ibid). This demonstrates the utility of ABM in providing alternative ways for groups to survive in specific environments and revealing when certain behaviours are successful.

Consequently, ABM could determine in which environments aspects of the public good model would (not) work, and how individuals would interact given certain choices and payoffs. This may give insight into early fire use and the development of cooperation. As concluded by Romanowska *et al.* (2019), ABM is a useful 'testing tool' in that it allows researchers to simulate plausible hypotheses and discard them if the simulation results prove incompatible with the archaeological record. The two abovementioned examples likewise indicate its utility in revealing environmental and social influences on individual or group behaviour. However, the specific purpose of the simulation and the relevant parameters would need careful consideration.

8.2 Ethnoarchaeology and spatial analysis

Spatial analysis of sites can reveal patterns in how activities were structured and identify artefact clusters. Hearths or fire traces are significant because they are often associated with specific activities or located in distinct areas of the site (e.g. centrally or at the peripheries). Finding correlations between activities, site areas and fire use can reveal the purpose of the fires and their importance in different parts of life, from technological to social. Consistent changes in hearth position, orientation and size might also point to changes in the way social groups were structured. For example, some sites show central, larger hearths while others have many smaller hearths. Determining whether this relates to social structure, as Gowlett (2010) suggests, would be interesting. Ethnoarchaeology could be useful in supporting archaeological analyses by looking at how and when social activities leave traces and whether different types of fires are used for socially-oriented activities. For example, McCauley *et al.* (2020) report

that ritual fires are sometimes lit especially for the ritual purpose and then left to burn out. This is different from hearths used for warmth, which are kept burning through the nights and die out in the morning or burn indefinitely. Ethnoarchaeological work on the traces left behind by distinct fires in extant small-scale groups could provide new ways of hypothesising about traces in the archaeological record.

Additionally, more enquiry into relationships between social activities and fire use in extant foraging groups is needed. Wiessner (2014) demonstrated that conversations in the evening around the fire are predominantly social in nature, while McCauley *et al.* (2020) indicate that the majority of ethnographic groups they reviewed spend time around the fire gossiping, dancing, and playing games. Such work might reveal overlooked aspects of why fire is socially important and could investigate how individuals view fire in these settings. For example, is a fire for warmth purely functional or does its purpose include creating a specific atmosphere? While this will not allow any definite conclusions to be drawn about past hominins, it could indicate new research directions that are pertinent to understanding the social role of fire. Moreover, investigating *who* and how many people are involved in maintaining a fire and benefiting from it could be useful for discussions about the amount and size of hearths found in the archaeological record and what this might suggest about group size and structure.

8.3 Costs of fire use

Fire use will have depended on environmental conditions, including both resource availability and how necessary fire was for survival. These factors are important for cooperation since they affect the costs that cooperation needs to overcome. If fire is not essential, the need for cooperation is reduced. More research into the costs of fire use in different environments is therefore crucial to understanding the appearance of regular fire use and the social changes that may have followed. As mentioned, Henry (2017; *et al.* 2018) provide comprehensive discussions and experimental work on the costs of fuel collection versus the benefits of cooking. Following this, future research should focus on the costs of fuel collection in various environments and potential payoffs between fuel choice and distance that may have been made. More emphasis should be placed on investigating how much fuel different-sized fires require, as this also influences the costs and impacts how often fuel had to be gathered. This may depend on the purpose of the fire, suggesting that experimental comparisons between different

types of fires would help. Fire maintenance outside of fuel collecting has not been studied either, although such research could seriously influence ideas about early fire use requiring cooperation. McCauley *et al.* (2020) mention that most groups they considered prefer to maintain fire rather than light it but offer no information on how much effort this maintenance requires.

Consequently, there seem to be two main ways forward in looking at the costs of fire use: experimental work and observation of historical or extant foraging groups. Experimental studies looking at fuel collection, the fuel requirements of different types of fire, and maintaining different types of fire would greatly inform hypotheses about the costs of fire use, elucidating how likely the need for cooperation was. Moreover, this could highlight that fire use was not practical in all environments (Henry *et al.* 2018), explaining the absence of fire traces at some sites. Ethnographic observation can provide examples of the logistics of fuel collection and fire maintenance in various environments, which can further inform hypotheses about cooperation surrounding fire use and its presence/absence in the archaeological record. It is possible that regular use of fire was not feasible if the social structure of a group could not support the level of cooperation needed. Currently, such aspects are not often documented in ethnographic studies, and when they are, they are not aimed at understanding the costs of fire use. Attempting to change this might provide new useful information.

8.4 Finding Palaeolithic sociality

Although certain aspects of sociality, such as symbolic behaviour, are considered within Palaeolithic research, social interactions and organisation are less discussed. Interdisciplinary approaches are useful here because they can provide insight into behaviours that may be 'invisible' in the archaeological record. Research like that of Gamble (e.g. 1998; *et al.* 2010; 2012), Gowlett (e.g. 2010), d'Errico (e.g. *et al.* 2003; and Colagè 2018) and Spikins (*et al.* 2014; *et al.* 2018) is important in this respect, because they use evidence from several disciplines to discuss archaeological queries. Sociality and emotion are not neglected, instead benefiting from conclusions drawn in other fields, like cognitive sciences, behavioural ecology, or psychology. This results in a fuller picture of hominin lives and a wider range of hypotheses and ideas that can stimulate further research.

Future work should therefore develop a framework for investigating sociality, including interdisciplinarity, to enable archaeologists to approach topics which do not leave

material traces. Other disciplines have much to contribute to archaeological debates about human evolution and behaviour, and they can provide hypotheses for filling in the gaps that the archaeological record has or provide alternative explanations for ambiguous archaeological traces. However, this means allowing theoretical assumptions to be made and explored so the benefits and limitations can properly be identified and reliable ways of integrating non-archaeological information can be established. A positive note by Silverman and Bryden on social simulations, but relevant here as well, is that "more generalised models of society may provide a means for investigating aspects of society which elude the empirical data-collector…" (2018:95). An initial focus on possibilities rather than proven theories of sociality does not have to be detrimental, but an emphasis on establishing 'best practice' methods in theoretical and interdisciplinary research will help validate conclusions.

9. Conclusions

Although a variety of topics was discussed, the overarching aim was to provide two pathways by which hominin groups could have organised cooperation surrounding habitual fire use. The first pathway portrayed fire as a public good, resulting in a cooperative structure where sharing is common and social mechanisms emphasise prosocial behaviour. The second modelled fire as a commodity to be exchanged (following Ofek 2001), resulting in a social structure centred on division of labour and specialisation requiring social mechanisms to regulate exchange. The discussion provided additional lines of evidence which supported the public good model as a likelier form of cooperation in small-scale hominin groups. I will summarise my findings in line with the original aims of this thesis, before closing with some final thoughts.

9.1 The effect of fire on social structure

The first two aims asked what effects fire use would have had on hominin social structure, and whether a modified public good model or an exchange model could explain how cooperation surrounding fire use may have worked. Unlike opportunistic use of fire, regular fire use would have required an active engagement with fire. This meant an investment of effort and time into fuel gathering and fire maintenance, meaning less time for other activities. Cooperation would have alleviated the costs placed on each individual, but would also have presented a social dilemma for hominin groups: to contribute, or not to contribute? Everyone benefits more by not contributing, but if nobody does, there is no fire. To overcome this dilemma, I suggested that hominins would have changed their social structure to one regulating cooperation through use of social mechanisms.

As early fire use has the qualities of a public good, being non-rivalrous and non-excludable (Dubreuil 2010b; Twomey 2014), the first model detailed how cooperation surrounding fire as a public good would form. Game results demonstrated that the public good model could explain cooperation surrounding fire use if social mechanisms are introduced, resulting in a cooperative structure where reputation and/or low-cost punishment maintained contributions to the public good. The second model depicted fire as centrally maintained by a few individuals, who allowed access in exchange for other commodities or benefits. This would have stimulated division of labour and specialisation, creating an interdependency that is feasible in larger groups but risky in small groups. Exchange further encourages hierarchy, threating cooperation and group

cohesion. With emphasis on interdependency and strong social mechanisms in place to regulate exchange, I concluded that an exchange system is not impossible. However, the public good model explains much better how cooperation around fire use may have arisen.

The third aim considered whether we can infer the presence of social mechanisms based on the requirements of the proposed models. Since contributions to a public good are not maintained without such mechanisms, and exchange would be open to cheating, social mechanisms needed to be present. Experimental games established that reputation and low-cost punishment are the most effective at sustaining cooperation. Reputation encourages cooperation because individuals can use it to determine who they want to interact with. Individuals with a good reputation will therefore have more cooperative partners and increased social opportunities. Over time, the individual qualities that lead to a good reputation will regulate appropriate social behaviour. Low-cost punishment encourages cooperation because individuals want to avoid the costs of being punished, which might include exclusion or reputation loss. The behaviours that are sanctioned will likewise come to regulate behavioural expectations. The result is that social mechanisms become social norms which guide interactions and reinforce the social organisation of the group.

Social emotions were demonstrated to reinforce social norms, since norm adherence and deviation can produce strong emotional reactions which influence behaviour. Because norms differ per group, the ability to adapt to new norms quickly is crucial to integration and avoiding punishment. This suggests the emergence of norms and social emotions stimulated further social (and genetic) changes, enabling individuals to successfully navigate increasingly complex social environments and leading to permanent changes in hominin sociality.

9.2 Supporting evidence

The next aim considered whether there is evidence supporting the proposed models. Chapter 7 discussed several lines of evidence indicating support for the public good model rather than an exchange model. Widespread meat-sharing in extant foraging societies was considered in the context of risk-reduction and costly signalling. The similarity between meat and fire as public goods was used to argue for fire likely being subject to similar sharing behaviours as meat. Ethnographic examples further confirmed that reputation and low-cost punishments are significant in regulating cooperative

behaviour and maintaining egalitarianism, suggesting these social mechanisms are indeed probable in small groups. The importance of egalitarianism argues against an exchange system being likely in small residential groups. To counter the issue of applying evidence from modern humans to extinct hominins, evidence from primatology was used to demonstrate that we can clearly expect an emphasis on cooperation and the use of social mechanisms in extinct hominins. Inequity aversion, reconciliation behaviour, using rewards/punishment to influence behaviour, and a tendency toward prosocial interactions were all observed in nonhuman primates, providing a basis for these behaviours in hominin species.

Various archaeological developments were furthermore identified that could indicate a social change focused on increased cooperation. From ca. 500 ka onward, the colonisation of northern latitudes, specific habitat choice, niche construction, the appearance of home bases and space partitioning, and regular use of fire all suggest organised, cooperative groups. The concurrent increase in brain size possibly strengthens the hypothesis that social change resulted from or triggered behavioural changes. Moreover, no conclusive evidence exists for specialisation and division of labour during the Middle Pleistocene.

The significance of the emergence of social norms was reinforced with evidence from various disciplines indicating a human inclination toward conformity, punishment of norm deviation, and being influenced by social emotions. Cultural group selection was invoked to explain the prevalence of cooperative norms, possibly supporting the public good model more. The properties of fire were discussed as reinforcing social structure by acting as a focus for socialisation and inducing social cohesion. Ethnographic evidence for socially bonding activities occurring around the fire was used in support (McCauley *et al.* 2020; Wiessner 2014). The socially cohesive nature of fire and its associated activities argue against it being an exchangeable commodity. Consequently, regular fire use necessitated cooperation and reinforced cooperative behaviour by bringing individuals together.

9.3 Benefits and limitations

Another aim questioned the validity of the overall approach. It is clearly a limitation that the models are hypothetical and untested, and this would be a necessary next step. The broad scope taken meant that while the limitations of ethnography and game theory were explicitly addressed, other shortcomings were not. Many factors influencing

cooperation were disregarded, which might limit the reliability of conclusions drawn, while the current lack of research into the costs of fire maintenance comprises a further limitation.

Nevertheless, I suggested that the approach is generally beneficial as it demonstrates that interdisciplinarity is useful in approaching topics from new angles. It has been shown that fire use likely impacted social structure and cooperation, highlighting the need for further research in this direction and identifying specific gaps that need considering. The theoretical nature of this thesis allowed for a broad consideration of a variety of social aspects related to fire use that could aid our understanding of early fire use as well as hominin sociality. It further demonstrated that these aspects can be approached without direct archaeological evidence, and that other disciplines might inform interpretations of the record.

9.4 Future research

My last aim considered how the models might be tested or reviewed. Several research possibilities were identified that could contribute to advancing (or discarding) the models. Agent-based modelling was discussed as a method of testing the public good model. Specific environmental and individual parameters could demonstrate when such a social structure might be feasible, resulting in more conclusive hypothesis about the need for cooperation and the costs of fire in specific conditions. Differential weighting of parameters or their exclusion might limit the representativity of the model, but it would provide a beneficial test of the assumptions made in this hypothesis.

Using ethnoarchaeological approaches to identify the traces that different types of fires and possibly social activities leave behind was proposed as a way of informing archaeological interpretations of site organisation. Supplementary ethnographic evidence on fire maintenance and its place in social activities could further highlight relevant aspects that need considering. This includes the costs of fire maintenance, for which more experimental work (following Henry *et al.* 2018) is crucial. Such research could provide insight into why fire was (not) used at specific sites and what its impact was on cooperation and social structure.

Lastly, research into Palaeolithic sociality would benefit from a framework emphasising the integration of multiple disciplines and seeing theoretical research as useful. This can

sidestep problems of archaeological visibility, highlight new ideas, and reveal disregarded aspects of hominin sociality.

9.5 Final thoughts

The start of regular fire use is significant for many reasons, including the effects it had on social organisation and interactions. I hope to have demonstrated that these effects are not inaccessible within archaeology, but that various disciplines need to be incorporated and different approaches need taking to the usual reliance on the archaeological record. Accordingly, it has been shown that the social organisation surrounding regular fire use can be modelled by viewing fire as a public good. To maintain cooperation toward a public good, social mechanisms were necessary, which could have stabilised into social norms and permanently changed how social interactions and cooperation within a group were structured. As this suggests that fire use put pressure on social groups, it is worth considering whether social requirements and costs can contribute to debates about the presence and absence of fire. Moreover, the social consequences of regular fire use clearly need integrating into debates about hearth and site organisation, hominin social development, and the evolution of cooperation. The full effect that fire use had on human evolution remains understated if social changes are not included in discussions about the emergence of controlled fire use.

Abstract

Despite the large amount of research focused on early fire use during the Palaeolithic, not much attention is given to the ways in which the shift from opportunistic to regular fire use may have affected hominin social organisation. Regular fire use involves several costs, including fuel collection and fire maintenance, which could be alleviated by cooperating. However, cooperation is open to free-riding, meaning further social mechanisms are required to maintain cooperation. The demands that regular fire use placed on hominin residential groups may therefore have altered the social organisation of Pleistocene hominins, possibly resulting in permanent changes to sociality.

Two models are discussed predicting how regular fire use may have affected the social organisation of hominin groups. The first sees fire as a public good, resulting in a cooperative structure where sharing is widespread, social mechanisms to maintain cooperation include reputation and low-cost punishment, and social norms eventually arise. The second model places fire within an exchange system, resulting in an interdependent group where reputation and low-cost punishment regulate exchange, but where group stability is more fragile, and hierarchy threatens social cohesion. Evidence supporting the public good scenario is found in multiple disciplines, including game theory, human behavioural ecology, ethnography, and primatology. The implications of such a cooperative structure are discussed with regard to the archaeological record, social norms, and the links between fire use and sociality. Given the reliance upon multiple disciplines, the limitations and benefits of a theoretical, interdisciplinary approach are also reviewed.

This thesis concludes the following: 1) Regular fire use necessitated a cooperative structure, possibly with fire as a public good, where cooperation is maintained through social mechanisms. 2) The development of such a cooperative structure is likely to lead to the development of social norms, which may be reinforced by fire use itself. 3) Theoretical, interdisciplinary approaches can stimulate new approaches by sidestepping conventional disciplinary boundaries and removing the constraints of not being able to test hypotheses, which is important for advancing research into Palaeolithic sociality. 4) ABM may be able to test the proposed models, but future research needs to focus on the costs of maintaining different types of fires in different environments, in order to determine the extent to which cooperation was necessary for regular fire use.

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