Carrying on with Neanderthal mobility: a GIS-based approach to group movement in Northern Spain

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PhD
University of York
Archaeology
September 2019

Abstract

The composition of a social group will undoubtedly influence everyday decisions, including how tasks are divided and how a group moves. We know that 40-60% of Palaeolithic societies consisted of children, yet we rarely consider their presence in our interpretations. Carrying infants is a universal task for humans and ethnographic accounts demonstrate how this behaviour is intricately intertwined with subsistence activities and the division of labour, as well as key social behaviours such as cooperation and sharing. It is also a considerable investment and it is this energetic cost that provides a tangible route to looking at its impact in the past. This study develops a GIS-based approach to understanding how group composition, specifically carrying infants, could impact Neanderthal mobility. This is explored through a Middle Palaeolithic case study, using sites in northern Spain. It is argued that a reassessment of Neanderthal social organisation is needed, with group mobility and the social division of labour varying within a local and regional context.

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Acknowledgements

First and foremost, I would like to thank my husband Matt, whose support and encouragement has meant everything throughout this PhD. I cannot thank you enough. I am also very grateful for the love and support of my family, including my parents (Margaret and David), nan (Eileen), sister and brother-in-law (Becky and Gareth), and Lucy the dog.

I would also like to thank Helen Goodchild, who has provided enthusiasm and discussion as part of my Thesis Advisory Panel, as well as GIS training courses and further technical guidance. Additional thanks go to Aleks McClain, who chaired my thesis panel, and whose outside perspective always provided interesting ideas and questions. I am also grateful for the wonderful PhD community at York.

Finally, I am very grateful to my PhD supervisor, Penny Spikins. I feel very lucky to have been supervised by someone so kind, understanding, knowledgeable and enthusiastic throughout this research process. Penny inspired my love of prehistory in my undergraduate degree and I would have never had gotten this far without her belief in me.

This work was supported by the Arts & Humanities Research Council (grant number AH/L503848/1) through the White Rose College of the Arts & Humanities. WRoCAH has also provided many training and developmental opportunities, as well as support for conference attendance, which have been of great benefit during my research degree.

Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

CHAPTER ONE

Introduction

1.1 Carrying in human evolution

> *"Every time you watch fellow airplane passengers struggle to cram their enormous carry-on luggage into the overhead bins on an airplane, you are witnessing two consequences of our ancestor's logistical mobility. Humans habitually carry things, and we often carry more than we need"* (Shea 2016, 56).

In comparison to non-human primates, humans are notable for the distance, quantities and duration of their carrying, as well as the creation and modification of objects to enhance portability (Figure 1.1; Hilton and Meldrum 2004; Key 2016; Shea 2016). This difference is seen early in human evolution, with evidence of raw materials being transported 10-13 km by Oldowan hominins, in comparison to less than 1km by extant non-human primates (Braun et al. 2008; Shea 2016; Wynn et al. 2011). Carrying has also long been considered an important factor in the evolution of bipedalism, argued both as part of the initial selective pressure and as an exaptive behaviour (e.g. Hewes 1961; Lancaster 1978; Lovejoy 1988). Regardless of the debate over cause or consequence, this change allowed the hands to be freed, making it possible to carry whilst moving with ease. There is also an increasing number of studies which suggest that this need to carry continued to influence modern body proportions. This includes shorter upper limbs (Vidal-Cordasco et al. 2015), longer legs in relation to the trunk (Wang and Crompton 2004) and specific changes in the hand (Key 2016). It is clear that carrying has long been a habitual activity in our evolutionary history and has helped shape our physical form. However, it is the profound implications for behaviour which need further exploration within archaeological method and theory.

Figure 1.1: A Yanomamo woman in Venezuela returning home from a distant village (from Lancaster 1978, 88). She carries children, palm leaves, gourds, baskets, and food collected along the way. "Her world is based on the distinctly human ability to carry" (Lancaster 1978, 89).

When non-human primates carry food, it is largely focused on collection, processing and consumption for the individual, with no larger social dimension (Lancaster 1978, 86; Shea 2016, 58). For humans however, transport facilitates key aspects of social behaviour such as sharing and cooperation (Lancaster 1978). Ethnographic accounts of recent hunter-gatherers demonstrate how carrying is intricately intertwined with reproduction and childcare, environment and subsistence activities, as well as division of labour (Figure 1.2-1.4; e.g. Hilton and Greaves 2004; Hurtado et al. 1985; 1992; Meehan et al. 2013). Put simply, humans can transport beyond individual needs and sharing these surplus resources means that childcare can become a collective responsibility. This in turn opens opportunities for dividing tasks and more risky forays for resources (Shea 2016, 59). Mobility and group organisation are shaped by these social and ecological factors, and raises the question of how we might be able to see this through the archaeological record.

Figure 1.2: Moving with children. A Selk'nam family group cross a beach in Tierra del Fuego. Tools and young children are carried, whilst the older children walk independently (from EDLB 2018).

Figure 1.3: A Penan family walking through the Sarawak forest in 1985, moving their campsite to a better salo palm foraging area, about a three or four hour walk from their last camp. The men had gone out the day before to locate a camp and blaze a trail. Resources and young children are transported using carrying devices on the back (from Kelly 2013, 89).

Figure 1.4: San hunter-gatherers walking across the Kalahari Desert in southern Africa, tools are carried by hand and infants are carried on their mother's side (from Wallace et al. 2018, 5).

There are already some ways in which we implicitly explore carrying in the Palaeolithic. For example, we often relate the distance that raw materials were transported to trade and territory (e.g. Féblot-Augustins 1999). We also discuss the movement of tools to infer levels of forward planning and the provisioning of places or individuals (e.g. Kuhn 1992). It is also considered in terms of food resources, where faunal analysis can indicate whether prey was transported whole or in parts to a site (e.g. Pike-Tay et al. 1999). It is far rarer however, for carrying to be considered directly, and among the few existing examples, stone tools and lithic raw materials have remained the sole focus (see Close 1996; Shea 2016; Vidal-Cordasco et al. 2015). Although the survival of these materials in the archaeological record makes them an obvious choice for investigation, we need to expand our knowledge to other forms of carrying behaviour. Carrying infants, for example, is ubiquitous for humans, but has received little attention in our interpretations of the Palaeolithic, despite children forming 40-60% of past societies (Baxter 2005). This likely reflects a wider neglect of children in archaeological studies (see Baxter 2005; Spikins et al. 2014 for summary). Childcare was undoubtedly part of group decisions over mobility and subsistence activities. Without considering the influence of social factors, such as the presence of children, our understanding of the past remains incomplete.

This study will therefore develop a new approach for evaluating how group composition, specifically carrying children, could have influenced mobility in the Palaeolithic. The next section will outline the research aim, questions and objectives of the study. In order to provide context, this will then be followed by a discussion of the evolution and energetics of infant carrying. This will highlight the importance of this factor in shaping reproduction, mobility and subsistence strategies, and how energetics could provide a tangible route to understanding this behaviour. Following these background reviews, the choice of Middle Palaeolithic northern Spain as a case study will be discussed. Finally, the structure of the thesis will be outlined.

1.2 Research aim, questions and objectives

The fundamental aim of this study is to evaluate the impact of infant carrying on the mobility of Palaeolithic groups, using archaeological sites in Middle Palaeolithic northern Spain as a case study. The research will specifically address the following questions:

1. To what extent did the energetic cost of infant carrying impact movement?
2. What can the consideration of children add to the current understanding of mobility and social organisation in the Palaeolithic?

In order to address the research aim and questions, the following objectives are set out:

- To use fossil and energetics data to inform the development of a GIS-based methodology for studying the role of infant carrying in past mobility.
- To analyse how the cost of carrying children interacts with other key variables such as terrain and body mass.

- To model different scenarios in order to interpret the contexts in which carrying behaviour is more likely versus other options, such as children walking independently or a group dividing tasks.
- To critically assess current Neanderthal energetics data by modelling it in a regional context, using real terrain and archaeological data.
- To evaluate the feasibility of current interpretations of Neanderthal mobility, social organisation, and energetics when infant carrying is included.
- To appraise the impact of specific Neanderthal morphology (body mass) on the energetic cost of transport.

The study aims to test the hypothesis that infant carrying had a notable effect on how past hunter-gatherers chose to move. It is also hypothesised that differences in morphology through human evolution would have helped shape how this movement was managed. The study will use a GIS-based cost distance modelling approach. To the author's knowledge, there have been no previous attempts to model infant carrying, so a full methodology chapter has been included to discuss how this will be implemented. The next section will first provide the evolutionary context for infant carrying.

1.3 The evolution of infant carrying

Non-human primate infants are typically carried on their mother's front or back, often relying on the infant's ability to cling and grasp their mother's fur (Altmann and Samuels 1992; Amaral 2008). In humans however, this transport is dependent on the adult and likely emerged with the upright posture of bipedalism, which reduced the opportunities for infants to cling (Amaral 2008; Watson et al. 2008). This need to actively carry infants was further necessitated by the loss of body hair (Reed et al. 2007) and reduction in the foot's grasping capacity, signs of which can be seen in *Australopithecus afarensis* (Alemseged et al. 2006). It has also been argued that early hominins were unlikely to 'park' infants, given the limited evidence for setting offspring down among primates (Wall-Scheffler et al. 2007, 841). The benefits of carrying similarly support this view. Carrying allows a child to be simultaneously kept warm and soothed by the close proximity to a body, whilst also being kept clean, fed and in safety (Lancy 2014, 126). For modern humans, it has also been linked to healthy hip development (Schön and Silvén 2007, 118), mother-child attachment (Anisfield 1990), as well as social and learning opportunities (Henry et al. 2005, 194; Konner 1977). For early hominins, carrying young children would have therefore been vital for survival, but with little direct evidence, it has remained difficult to understand its role.

In many recent hunter-gatherer societies, babies are attached to their mother with a sling, woven bag, or length of cloth and ride on the chest, back or hip (Figure 1.5; Lancy 2014, 126). There are also very culturally specific examples of carrying technology, influenced by factors such as climate and environment. Inuit mothers, for example, wear complexly tailored parkas called *amauti*, which have built-in pouches for babies just below the hood (Figure 1.6; Issenman 1985, 105). The wide range of organic carrying implements seen in recent hunter-gatherer groups are unlikely to survive in the archaeological record and leaves us with a gap in our understanding (Ehrenberg 1989; Lancaster 1978; Wall-Scheffler et al. 2007). This study therefore argues that we need to develop new methods for understanding this behaviour. Taking an energetics approach could provide a solution.

A study by Wall-Scheffler et al. (2007) investigated the caloric cost of carrying an infant in the arms versus using a sling to support the baby's weight. It was found that costs were increased by 13-25% when no support device was used and had the potential to require more energy than lactation (Wall-Scheffler et al. 2007). As the research team asked: "Would any biped be able to travel far enough and fast enough to gather resources, escape from predators, and keep up with her group while incurring an average of a 16% increase in cost above the cost of the baby's mass alone?" (Wall-Scheffler et al. 2007, 845). It was concluded that some form of carrying support was far more likely and this technology would have been necessary after the emergence of bipedalism, 1.8 million years ago (Wall-Scheffler et al. 2007). This research demonstrates that despite the lack of direct material evidence of carrying technology, the energetic cost of carrying is a testable factor and opens up a potential route of research. It translates the influence of child carrying on everyday activities into tangible terms that can be tested against the archaeological record.

Figure 1.5: Work activities and childcare combined. Hadza women and young girls using digging sticks to forage for tubers. Babies accompany the women in a cloth sling (from Marlowe 2010, 74).

Figure 1.6: An Inuit woman chewing sealskin to soften it for making boots, whilst a child sits within an in-built parka pouch (Photo by Wilfred Doucette. Canada. National Film Board of Canada. Photothèque. Library and Archives Canada, R-002167).

1.4 The energetic cost of carrying infants

Research with recent hunter-gatherers demonstrates the extent to which young children are carried in everyday life. From a cross-cultural perspective, being held or carried more than half the day appears to be typical (Lozoff and Brittenham 1979, 480). !Kung infants for example, are held or carried 80-90% of the time in the early months of their life and 60% by the age of nine months (Konner 1976, 223). Hadza women meanwhile carry infants using a sling or kaross about 7 or 8 hours per day (Marlowe 2010, 87). As well as this frequency on a daily basis, carrying is also a long-term activity. It is well known that human infants are born highly dependent and vulnerable, to the extent that babies are initially unable to support their own head. Human females therefore carry frontal loads continuously during pregnancy and initial breastfeeding, usually followed by carrying a child to the side or the back for another few years, at which point the cycle can begin again (Wall-Scheffler 2014, 177). Carrying is therefore a fundamental part of life and also a considerable investment of energy.

There are surprisingly few studies that have considered the cost of infant carrying, despite being the second most costly form of postpartum childcare (Kramer 1998, 72). Among the existing studies, it is agreed that carrying significantly increases the cost of mobility (Figure 1.8; Kramer 1998; Wall-Scheffler et al. 2007; Wall-Scheffler and Myers 2013; Watson et al. 2008). Additional mass and different postural costs both contribute to this increase (Gruss et al. 2009), which can be further enhanced by incline (Kramer 2010) and the mode of carrying (Abe et al. 2004; Watson et al. 2008). As an infant grows, carrying becomes an increasingly costly behaviour and there is a “theoretical break-even point”, beyond which mothers will stop (Watson et al. 2008, 677). Kramer (1998) investigated this energetic limit and argued that the decision to carry versus having a child walk independently can be predicted from the body mass of the mother and child, and the child’s age. Using predictive equations of energy expenditure, the study concluded that the heavier the mother, the longer she is able to carry an infant efficiently (Kramer 1998). On the other hand, “In some cases, especially for the lightest mothers, it is never in the mother’s best energetic interest to carry her child” (Kramer 1998, 71). From an evolutionary perspective, this could be significant, since morphology and average body mass have altered through time, meaning that the nature of these maternal investments have likely also differed.

These costs have profound implications for reproduction and survival, with both the fertility of females and the health of existing infants being sensitively tuned to a mother's energy stores (French 2019; Kaplan 1996; Wall-Scheffler and Myers 2013; Snodgrass and Leonard 2009). A depletion in maternal energy can lead to longer interbirth intervals (Kramer 1998, 72), meaning that the energetic relationship between birth, carrying, mobility and subsistence activities becomes a fine balance. Among recent foragers, a birth spacing of around 3 to 4 years is common (Ehrenberg 1990, 60; Hrdy 2011, 106; Kaplan et al. 2000, 158). Some have suggested this is a natural result of dependence on breast milk, whilst others have suggested it is a 'deliberate policy', as it is unlikely that mothers could constantly carry more than one child, whilst keeping up with the demands of a foraging lifestyle (Ehrenberg 1990, 60; Richerson et al. 2001, 51). This idea of competing demands between childcare and work activities has been well explored in anthropology (e.g. Hilton and Greaves 2014; Meehan et al. 2013). Some have argued that the cooperative economy between men and women is key, whilst others have emphasised intrasex cooperation, which has led to evolutionary theories such as the 'grandmother hypothesis' (Hawkes et al. 1997; Hawkes 2003). The need to carry children therefore has significant individual costs for the carrier, which could impact their movement and work activities, as well the ability to have further children. It may also have wider ramifications for the group, especially if group members need to travel together.

In one of the few studies to consider the broader implications of female loads, Wall-Scheffler and Myers (2013) investigated the extent of these costs and how this may shape the mobility of a group. The study found that a female with a frontal load equal to 16% of her body mass has an increase of 12% in transport costs at or near her optimal speed, which is 5% slower than when unloaded (Wall-Scheffler and Myers 2013, 453). Furthermore, the cost of transport curve for burdened travel is more acute, meaning that the energetic penalty is progressively greater for walking at suboptimal speeds (Figure 1.7-1.8). In short, the cost of moving is significantly higher for females carrying an infant and slower walking is preferred. This has important implications for group mobility, as

Figure 1.7 (left): An example of how the cost of infant carrying can be assessed. Oxygen consumption was measured by having participants walk on a treadmill carrying a mannequin (from Watson et al. 2008, 678).

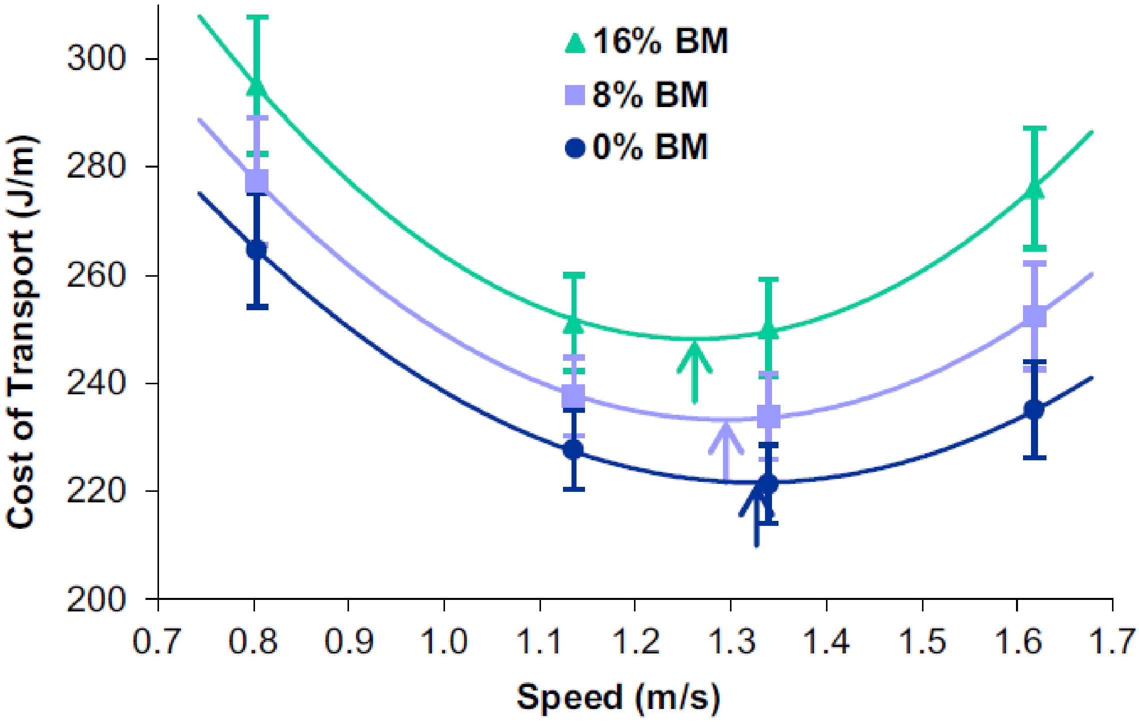


Figure 1.8: Average cost of transport as a function of walking speed systematically shifted as frontal loads (equal to 0, 8, and 16% of body mass) increased (from Wall-Scheffler and Myer 2013, 451).

the locomotion of individuals could impact the whole group. For example, if females attempt to maintain the speed of other group members when carrying loads, they will incur high costs (Wall-Scheffler and Myers 2013, 454). Conversely if males, who already have higher optimal speeds, choose to walk at the slower preferred pace of burdened females, they also could incur significant energetic penalties (Wall-Scheffler 2012b, 5). The way a group chooses to move and potentially divide is therefore dependent on its composition. In order to consider all these factors, this study will take a new methodological approach which allows these energetic considerations to be modelled on the terrain surrounding archaeological sites. A specific case study has been chosen to test the influence of infant carrying, with the next section providing context for this choice.

1.5 Case study: Neanderthals and Middle Palaeolithic northern Spain

In order to test the impact of infant carrying on past mobility, this study will focus on Neanderthals and Middle Palaeolithic sites in northern Spain. Neanderthal infants, like modern humans, were born in a highly altricial state and required a long development period before being capable of moving independently in their environment (Spikins 2014, 112). Added to this were the risks of cold and environmental dangers, which means it was unlikely that very young children would be set down for long periods and were probably carried for several years (Wall-Scheffler 2012a, 75). Transporting children was therefore likely to be an everyday part of Neanderthal life and inevitably formed part of the decision-making process for group movement, whether consciously or not. In a rare acknowledgment of this, Shaw et al. (2016, 1449) point out that “Social composition would have had an impact on travelling time, with young children carried, if not moving more slowly than adults”. Other than this fleeting mention however, there have been no attempts to consider children in our archaeological interpretations of Neanderthal mobility. Beyond this lack of research, the reasons for choosing Neanderthals as a case study are twofold. Firstly, there is the availability of data to make this a feasible option, and secondly, the implications of this topic are particularly relevant to current key debates in Neanderthal studies.

Whilst many early hominins might only be represented by a few individuals, there is evidence for at least 500 Neanderthals (Pettitt 2002, 2). This includes a broad spectrum of ages, from the newborn buried at La Ferrassie (Heim 1976), to the ‘old man’ of Shanidar (Solecki 1972). This fossil record has allowed Neanderthal morphology, growth and development to be explored in depth, which means data such as body mass are accessible for an energetics approach. As a result, a wealth of literature already exists for Neanderthal energetics and whilst there is disagreement over exact values, there is a consensus that daily energy requirements were particularly high (e.g. Churchill 2014; Sorensen and Leonard 2001; Steegmann et al. 2012). These high requirements are frequently cited and often given as an explanation for aspects of Neanderthal behaviour, or even as a factor in their extinction (e.g. Froehle and Churchill 2009). Hockett (2012) however, warns of the overinterpretation of Neanderthal energetic expenditure, arguing that current models would have been nutritionally unsustainable for pregnant women. This raises the question of how feasible these energetic interpretations are if the costly behaviour of infant carrying has also not been considered. These values have also had little in depth testing against archaeological data. Of the few energetic models which exist (Byrd et al. 2016; Heasley 2015), none have tested existing estimates for Neanderthal daily energy expenditure. Modelling how these energy requirements are expressed against real terrain and archaeological sites will therefore add to current understanding.

As previously discussed, ethnographic accounts suggest that the need to carry children also has implications for how group tasks are divided and how group members are organised. However, these patterns cannot be applied directly to Neanderthals. Firstly, there are fundamental issues with using direct analogy, which is compounded by use beyond modern humans (see Spikins et al. 2017). Furthermore, current interpretations suggest distinct characteristics in both the size and composition of Neanderthal social groups (Churchill 2014; Spikins et al. 2014), as well as a potential lack of division of labour (Kuhn and Stiner 2006). Under this current understanding, Neanderthals are assumed to have moved together as whole groups. If correct, the costly influence of infant carrying could have significant implications for mobility patterns.

The focus region for this study is Middle Palaeolithic northern Spain, encompassing archaeological sites from the Navarre, Asturias, Cantabria and Basque Country provinces

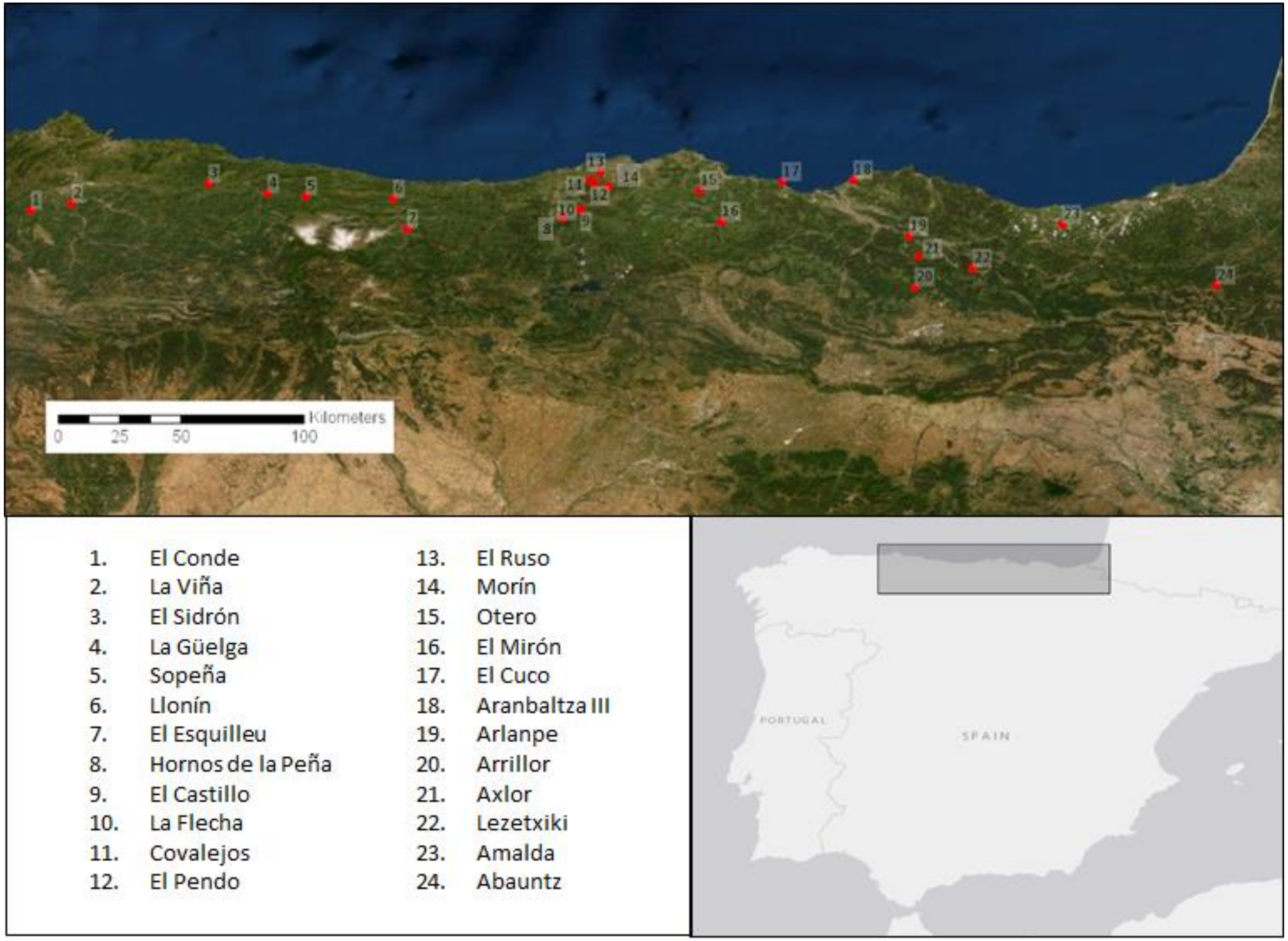


Figure 1.9: The study region with Middle Palaeolithic sites labelled (Basemaps: ESRI). Coordinates were collated from NESPOS and site literature (see Appendix 1).

(Figure 1.9). Beyond simply the level of data available, this region was selected for a number of reasons. Firstly, the 13 individuals recovered from El Sidrón in Asturias remains the best evidence for the typical composition of a Neanderthal 'family' group. The mixed topography of undulating and abrupt mountainous environments, coastal bays and open valleys also provides a unique opportunity to explore the influence of terrain. In addition, northern Spain is a particularly interesting region for Neanderthal and modern human occupation, with the chronology of potential overlaps and the last survival of Neanderthals still under much debate. This region therefore presents great potential for future studies comparing Upper Palaeolithic evidence.

1.6 Thesis structure

Figure 1.10 provides a summary of the thesis structure. This demonstrates the overall shape of the study, from a broader evolutionary viewpoint, to a specific Neanderthal case study, before expanding back out into broader implications.

Following on from the evolutionary and energetic context for infant carrying, Chapter 2 will review the current evidence for Neanderthal mobility, social organisation and energetics. This will provide important context and points of comparison for assessing the implications of infant carrying. Current understanding of the size and composition of Neanderthal groups is discussed, in order to inform modelling scenarios. Current estimates for daily energy expenditure and cost of transport in Neanderthals are also reviewed, in order to demonstrate the sources of energetic data for the methodology, as well as point of comparison for the resulting models.

Chapter 3 will provide an overview of the sites used in this study, including a detailed table of how Neanderthal occupations have been interpreted. Evidence for mobility patterns will be summarised on a local and regional scale, which will again inform the discussion of the results.

Figure 1.10: Thesis structure and breakdown of chapter content.

C1 Introduction: Broader evolutionary context of carrying and why it is important. Infant carrying has profound behavioural implications in terms of reproduction, social organisation and cooperation, but has remained unexplored in archaeological approaches. Energetics provides a tangible method but has never been applied directly to archaeological data. This study aims to address this, using Middle Palaeolithic northern Spain as a case study.	**Key content:** Carrying in human evolution; Energetics of infant carrying; Aims and objectives
C2 Literature review: What is our current understanding of Neanderthal mobility, social organisation and energetics? Neanderthal mobility is currently interpreted as frequent and largely local, with small groups moving together and no sexual division of labour. High energetic requirements are estimated, but the impact of carrying and group composition has not been considered. Key evidence of the 'El Sidron' family.	**Key content:** Mobility (raw materials, isotopes and anatomy); Social organisation (group size, composition, division of labour); Energetics (cost of locomotion, daily energy estimations)
C3: How has MP northern Spain specifically been interpreted? Mobility is largely local and occupations often short-term and repeated, with possible seasonal movements and regional connections. Social influences remain unexplored.	**Key content:** Table of archaeological sites; Interpretations of mobility (local, regional, individual level)
C4 Method: Cost distance modelling (CDM) This study uses an established CDM approach but introduces previously unexplored variables, relating to infant carrying. This incorporates energetics, fossil and archaeological data in order to create cost catchments.	**Key content:** Background to least cost analysis; Method flowchart, Explanation and justification of variables
C5 Analysis: Cost catchments in MP northern Spain The overall method and each variable are evaluated (carrying versus terrain, body mass, walking speed). Different values for adult and child body are explore to analyse contexts in which carrying is likely (versus independent walking by children).	**Key content:** Validity tests; Carrying vs. body mass; Child body mass values; Adult body mass; Comparing terrain across region
C6 Discussion and conclusions: Broader implications for Neanderthals and future directions. Results indicate that Neanderthal mobility and social organisation was more complex than existing interpretations suggest, but dependent on regional and local context. Expansion to other regions and different carrying behaviours are key next steps, as well as further energetics experiments.	**Key content:** Reinterpreting Neanderthal mobility and division of labour; Future directions

Chapter 4 details the methodological approach. Cost distance modelling is an established approach in archaeology, but no previous study has attempted to model infant carrying costs. This chapter will therefore explain the process in depth, with justification for the data sources and calculation of energetic costs.

Chapter 5 analyses the modelling results, including the validity tests for the method and different scenarios of carrying. This will assess the impact of different variables such as terrain and body mass on carrying behaviour, and how the costs of carrying may have influenced mobility ranges.

Chapter 6 will discuss the wider implications of the results in interpreting Neanderthal mobility, energetics and social organisation. It will also assess the utility of modelling infant carrying through a GIS-based approach. Finally, recommendations for future research will be explored.

CHAPTER TWO

Neanderthal context

2.1 Introduction

Within this study, mobility encompasses the way in which individuals locomote (e.g. with or without burdens) across a landscape (e.g. with variable terrain) to gain access to necessary resources (Wall-Scheffler 2014, 174). Interpreting these movements, however, remains far from simple. Hunter-gatherers movements are known to be very diverse and complex, given the broad range of economic and socio-cultural factors involved (Kelly 2013). Added to this, in our evolutionary past, there are specific morphological traits which likely influenced energetic considerations. This study aims to draw out some of these nuances by considering the impact of social behaviours, specifically carrying children, on Neanderthal mobility. In order to inform the models produced in this study, this chapter will discuss current interpretations of Neanderthal mobility, social organisation, and energetics. This will evaluate key factors intertwined with childcare costs (Figure 2.1).

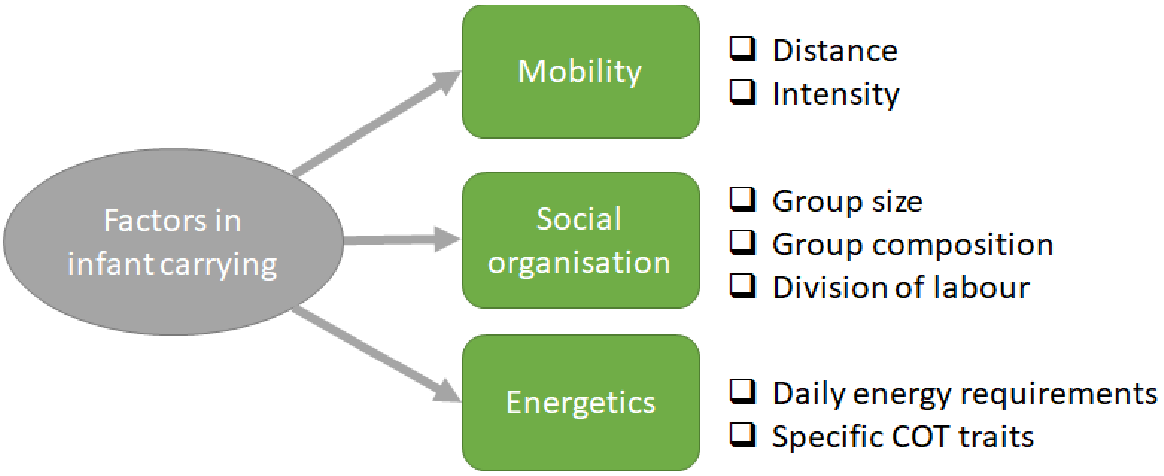


Figure 2.1: Factors that likely had an impact on Neanderthal infant carrying, or in turn, may have been influenced by this behaviour. COT stands for the cost of transport and refers to specific morphological traits which could impact the energetic cost of mobility.

2.2 What is the current understanding of Neanderthal mobility?

The mobility of Neanderthal groups has been well studied through a broad variety of archaeological and anatomical approaches. This section with evaluate current interpretations, exploring evidence of raw material transfers, and from strontium isotope analysis, and biomechanical approaches. This will provide the typical distances and intensity of Neanderthal mobility, whilst highlighting the need to consider evidence within its local and regional context.

2.2.1 Raw material transfers

The largest and best studied archaeological evidence for Neanderthal mobility comes from lithic tools and the study of raw material transfers. In short, this approach infers movement between the geological source of a raw material, to the archaeological site where the tool was found. Whilst this method has long been in use (e.g. Geneste 1988), raw material transport patterns have not been extensively studied across the Neanderthal range and much of the work has centred on a few, specific locations in Central and Western Europe (e.g. Féblot-Augustins 1993; 1999). It is beyond the scope of this study to provide a full collation of transfers data, but this section will evaluate broad interpretations. Specific raw material transfers in northern Spain will also be explored as part of the regional review in Chapter 3.

Raw material transfers are often divided into categories of distance. Whilst the terminology and exact ranges have varied, they are generally divided into local (<5 km), semi-local (5-20 km), non-local (20-100 km) and 'exotic' resources (>100 km)(Figure 2.2). It is this final category of longer distance transport which could provide evidence of connectivity between different social groups (Sykes 2012). However, it remains very difficult to determine whether they represent exchange or simply the result of multiple movements (Churchill 2014; Spikins et al. 2017).

Overall for the Middle Palaeolithic, a dominance of local and semi-local raw materials has

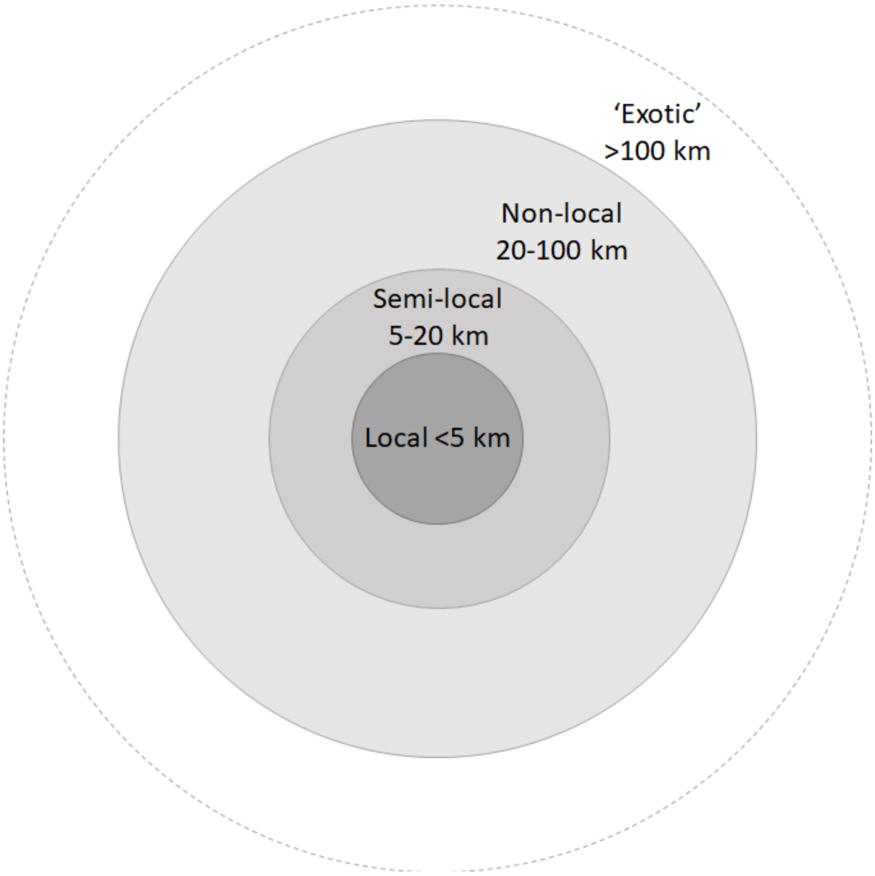


Figure 2.2: Typical categories of raw material transfers. Transport of materials beyond >100 km is often linked to social connectivity between groups, but this remains difficult to interpret.

been reported for many sites in Western Europe, including specific regions of Germany (Conard et al. 2012), France (Daujeard and Moncel 2010; Fernandes et al. 2008; Meignen et al. 2009; Slimak and Giraud 2007), and Spain (Fernândez-Laso et al. 2011; Picin and Carbonell 2016). This pattern is also reported in research outside of Europe, including Tor Faraj in southern Jordan (Henry 2012) and some sites in the Caucasus (Burke 2006; Doronicheva et al. 2016) and the Levant (Hovers 1990; 2009). Examples of exotic (>100 km) resources are present, but in very low percentages (Doronicheva et al. 2016; Fernandes et al. 2008; Slimak and Giraud 2007) and technological analysis indicates these are typically tools with a long lifecycle of use (Meignen et al. 2009; Slimak and Giraud 2007). A largely local focus for Neanderthal group movement therefore appears to be common, but there is some variability.

The unique characteristics of a local environment has been shown to influence resource transport. In the Salento region in Italy for example, there is a notable absence of good quality local resources (Spinapolice 2012). Consequently, 50% of the raw materials used by Neanderthals at Grotta dei Giganti were sourced 100-150 km away, in comparison to 5-6% at other Italian sites (Spinapolice 2012, 687). Similarly, at the open-air site Rozhok-1, the overwhelming majority of artefacts come from two high quality flint sources located 90 and 101 km away (Doronicheva et al. 2017).

The quality of raw materials may not be the only factor in determining where they are sourced. At Amud Cave, 30-40% of the raw materials are non-local and highly diverse, despite local, good quality raw materials being available (Ekshtain et al. 2016, 19). This has been interpreted as the result of how the site has been used by Neanderthal groups, with Amud representing a focal point in the settlement systems for two separate occupation periods (Ekshtain et al. 2016, 20). These examples emphasise that, whilst broad patterns can be inferred, mobility patterns still need to be understood within the local landscape and regional context (e.g. Burke 2012).

In addition to specific site occupations, there also appears to be nuances between different types of raw material. Obsidian, for example, is consistently transported for further distances in the Middle Palaeolithic (Pearce and Moutsiou 2014), including >300km in Central and South-Eastern Europe (Moutsiou 2012) and >200km in the Caucasus (Doronicheva and Shackley 2014). Whilst this suggests possible connectivity between Neanderthal groups, these transfers are still much less frequent than in the Upper Palaeolithic (Pearce and Moutsiou 2014), where considerably longer distances have also been reported (e.g. Frahm and Hauck 2017).

Raw material transfers therefore remain complex to interpret in the Middle Palaeolithic. Technological analysis detailing the use and manufacture of tools adds to this complexity (e.g. Picin and Carbonell 2016), as well as the regional context of a site (e.g. Ekshtain et al. 2016), and specific characteristics of the local environment (e.g. Spinapolice 2012). Nevertheless, a high percentage of local lithic resources appears to be common for many Neanderthal groups, sourced from distances well within a regional scale movement. Aspects of social interaction within groups have been possibly inferred, but the influence of intergroup factors require alternative methods, as explored by this study.

2.2.2 Strontium isotope studies

During the last decade, strontium isotope analysis has emerged as a new source of evidence for past human mobility. The method is based on the ratio of two isotopes of strontium in dental remains, which reflect the average isotopic values in plants and soils in the region where an individual lived during tooth formation (Bentley 2006; Lugli et al. 2017). Strontium isotopes can therefore serve as geochemical signatures to 'source' dental remains to a geologic area (Bentley 2006) and reflects childhood residence area (Moncel et al. 2019).

The first application of this method for a Neanderthal sample came from the site of Lakonis, Greece (Richards et al. 2008). The study indicated that the LHK 1 individual grew up at least 20 km away, and possibly further (Richards et al. 2008, 1254). This figure is unsurprising in terms of hunter-gatherer mobility, so likely simply represents a minimum level of movement (Churchill 2014, 316). It did however demonstrate the potential of the method, although concerns about the results do exist (see Nowell and Horstwood et al. 2009; Richards et al. 2009).

More recent approaches have sought to combine strontium isotope analysis with other forms of evidence. For example, Moncel et al. (2019) investigated Neanderthal mobility at the site of Payre, France, using a combination of lithic procurement analysis and isotopic evidence. The strontium results were broadly in agreement with the lithic analysis and suggested food procurement occurred in a local to semi-local area (Moncel et al. 2019, 22). This approach has also been applied to the closely located sites of Spy and Goyet cave in Belgium (Wißing et al. 2019). The study found that the two Spy individuals, an adult and 1.5 year old child, had very similar values and fall within the local signal (Figure 2.3). The Goyet Neanderthals, on the other hand, yielded high δ34S values, indicating an origin outside of the local ecosystem (Wißing et al. 2019, 8). The individuals from Goyet also show evidence of cannibalism, which led the researchers to

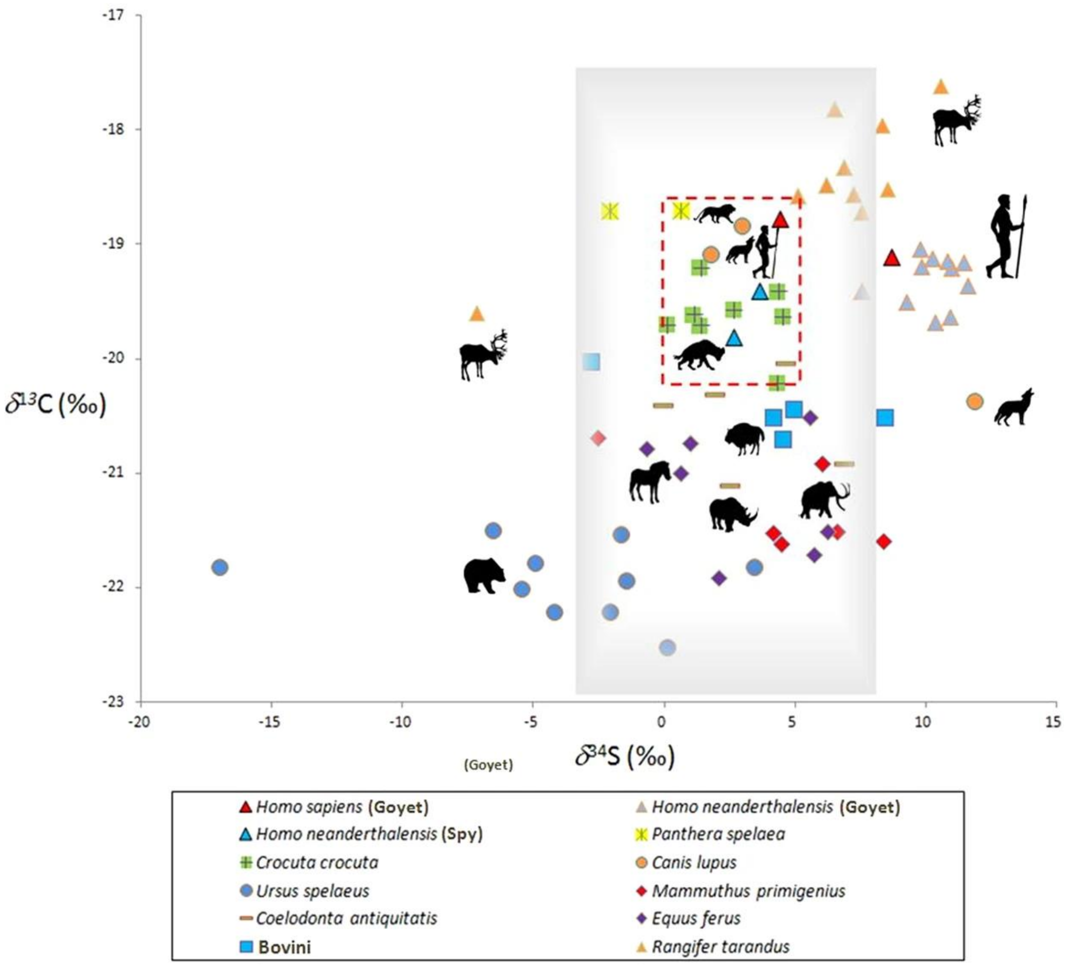


Figure 2.3: Strontium isotope analysis for the Late Pleistocene ecosystem in Belgium, including Neanderthals from Goyet and Spy. The shaded grey rectangle represents the local sulphur signal, the red dashed line encompasses most of the carnivorous species. Results suggest the Spy Neanderthals are local and the Goyet Neanderthals are non-local in origin (from Wißing et al. 2019, 4).

suggest their movement into the area could have been a factor in their death (Wißing et al. 2019, 8). Unfortunately, the catchment area for the Goyet individuals has not yet been identified, so the extent of the group's mobility is currently unknown. It could be that the group is simply at the outer limits of their mobility range so appear 'non-local'. This is a reminder that we need to see these resource movements within the context of wider settlement systems.

These existing strontium isotope studies only represent a very small sample of sites but do indicate evidence of local to semi-local mobility (Lakonis, Payre and Spy), as well as more extensive movement (Goyet). The distances and regional variability of movement therefore currently corroborate patterns from raw material movements. However, caution needs to be taken in interpreting this evidence. For example, as migrating herbivores were an important food source in the Middle Palaeolithic, a change in ratios may simply reflect a change in the mobility patterns of prey (Moncel et al. 2019, 22). Nevertheless, this approach does provide insights into mobility on an individual scale and with increasing analytical advances and expansion to further sites, will likely add important contributions to our understanding of Neanderthal mobility in the future.

2.2.3 Biomechanical evidence

An additional source of evidence for Neanderthal mobility comes from fossils and the use of biomechanical approaches. Walking and running impacts the size and shape of bones in various ways, as the skeleton responds to the loading from these activities (Davies et al. 2014; Ruff et al. 2006). These skeletal responses include differences in long bone curvature (e.g. De Groote 2011), long bone robusticity (e.g. Shaw and Stock 2013), and areas of muscle attachment (e.g. Churchill and Rhodes 2006). Through examining these indicators of loading, it is possible to gain insights into patterns of mobility and the influence of different activity levels, subsistence modes and ways of dividing labour (Davies et al. 2014).

There have been decades of biomechanical research which suggest Neanderthals led highly active and mobile lifestyles. Early studies concluded that these were particularly strenuous in comparison to early modern humans (e.g. Lovejoy and Trinkaus 1980; Trinkaus 1989), but this was later reassessed through improved methodology (e.g. Trinkaus 1997). Further sampling and extended comparisons to Holocene and modern populations support this reinterpretation of comparably high mobility for Middle and Upper Palaeolithic groups (Shaw and Stock 2013).

Current studies suggest that this highly active lifestyle extended across age and sex (Churchill 1998; 2006; 2014), although further research is needed in understanding the processes that result in adult postcranial robusticity (see Cowgill et al. 2010). This raises the question of when this high mobility emerged in childhood, and how these energetic costs were balanced for Neanderthal mothers. It has been suggested elsewhere that these activity levels left reduced time for childcare for Neanderthals, in comparison to early modern humans (Rossano 2010, 146). However, this interpretation assumes that Neanderthals had unusually elevated levels of mobility, which now seems unlikely (see Shaw and Stock 2013). This factor should also not be interpreted in isolation, as aspects of social life such as group size and composition also represent crucial influences in childcare provisioning.

2.3 What is the current understanding of Neanderthal social organisation?

The interpretation of Neanderthal social life has long been intertwined with broader perceptions of this hominin group. In the past, this often led to a simple versus complex dichotomy, where traits of 'modern human behaviour' were shown to be absent for Neanderthals (see Ames et al. 2013 for critique). There has been a clear shift from seeing Neanderthal life as simple, solitary and shaped by physical stress (e.g. Pettitt 1997; 2000), to one of cooperative, closely bonded social units (e.g. Spikins 2014; 2018a; 2018b). The lines between Neanderthals and early modern humans have blurred, and we remain in the early stages of trying to unpick the nuances within social behaviour.

From an energetics perspective, it seems likely that cooperative childcare would have emerged at least in early *Homo* (Aiello and Key 2002), or possibly even earlier (DeSilva 2011), as the result of body form changes. It is therefore highly likely that Neanderthals were also dependent on non-maternal provisioning for children (Churchill 2014, 336). Evidence for cooperative behaviour is also clear in hunting strategies (e.g. Smith 2015), intrasite activities (e.g. Henry 2012), and healthcare provisioning (Spikins et al. 2018a; 2018b), and shared childcare was likely another part of these social relationships (Spikins et al. 2018a, 12). Infant carrying was undoubtedly influenced by aspects of social organisation and this section will therefore evaluate current evidence for group size, group composition and the division of labour in Neanderthal groups.

2.3.1 Neanderthal group size

Estimations for Neanderthal demography exist on different scales from overall population (e.g. Bocquet-Appel and Degioanni 2013), to regional community size (e.g.

Aiello and Dunbar 1993), and local group size (e.g. Hayden 2012). This study is concerned with the local scale of social groups, defined as the number of people travelling and living together on an everyday basis. The size of a local group has significant implications for childcare and infant carrying, as it influences the options for allocare and the feasibility of dividing group tasks. Given the limited direct evidence of Neanderthal group size, a broad range of approaches based on archaeological and fossil evidence have been developed in order to estimate it (Figure 2.4). This section will evaluate and compare current estimates, in order to inform the scenarios and discussion of infant carrying costs.

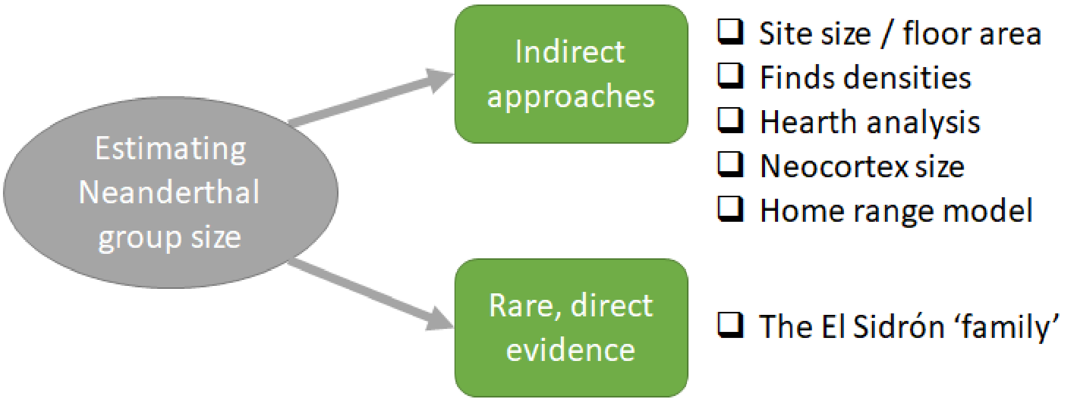


Figure 2.4: Summary of methods for estimating Neanderthal social group size.

One of the most common methods for predicting group size is the overall size of a site. This assumes there is a positive correlation between the extent of the site and the number of people who inhabited it (French 2016, 168). For example, in a study of Neanderthal settlement patterns in Crimea, Burke (2006, 518) notes that many Middle Palaeolithic sites in the region are around 35-50 m^2, "suggesting small group sizes". Similarly, for Palaeolithic Southwestern France, Mellars and French (2011, 626) note markedly smaller average site sizes for Mousterian versus Aurignacian occupations and argue for smaller living groups. Hayden (2012) took this approach a step further by using estimates of floor space per person derived from winter habitations of recent hunter-gatherers. Based on one person for every 2.5–3.0 m^2 of floor area, occupation surfaces for six different Middle Palaeolithic sites resulted in group sizes of 12-28 people (see Table 1 in Hayden 2012). Churchill (2014, 338-9) has since applied the same occupant density to a broader range of sites and produced somewhat lower estimates primarily in the 11-16 individual range. However, this approach does not come without fundamental issues, not least in the difficulty of actually defining the limits of a site, particularly when multiple and repeated occupations add complexity (French 2016, 169). Given these issues, any estimates must therefore be placed in the context of other sources of evidence.

Hearth analysis has provided another approach to understanding Neanderthal group sizes. One method has been to investigate the spatial relationship between combustion activities and sleeping areas, as documented within ethnography (Figure 2.5). At Abric Romaní, Spain, an occupation surface in level N yielded a well-preserved set of aligned hearths in the inner zone of the living floor (Vallverdú et al. 2010). Given the few archaeological remains and regular 1.3 m spacing, it was interpreted as a resting area (Figure 2.6; Vallverdú et al. 2010, 142). Based on a density of 1.5-2 m^2 per individual, the inner zone could accommodate 8-10 hominins, with 4-6 individuals in the sleeping spaces (Vallverdú et al. 2010, 143). Hayden (2012, 5) expanded this estimate to 13-18 people by extending to the frontal and central zones of the site (see Figure 2 in Hayden 2012). However, these areas demonstrate clear evidence of knapping and food consumption activities (Vallverdú et al. 2010, 143), suggesting the original, smaller estimates are more likely.

A detailed study of hearth arrangement was also undertaken at Tor Faraj in Southern Jordan (Henry 2012). This included standard analysis of the size and spacing of combustion activities, as well as ring and sector analysis. These methods interpret the frequency and distribution of artefacts around a hearth in order to infer the movement and activity of its occupants (Henry 2012). Based on this approach, an estimate of 11-24 people was given for the principal and largest occupation of each living floor, which supports within the 15-19 person range predicted from the floor area (Henry 2012, 262). The site area of 136 m^2 is high in comparison to most Middle Palaeolithic occupations (see Burke 2006; Churchill 2014, 338; Daujeard and Moncel 2010, 371; Hayden 2012), but consistent with some examples (e.g. Mellars and French 2011). This suggests there were some variability in site size and potentially group size. A full comparison of reported floor areas within different regions could be a useful future investigation.

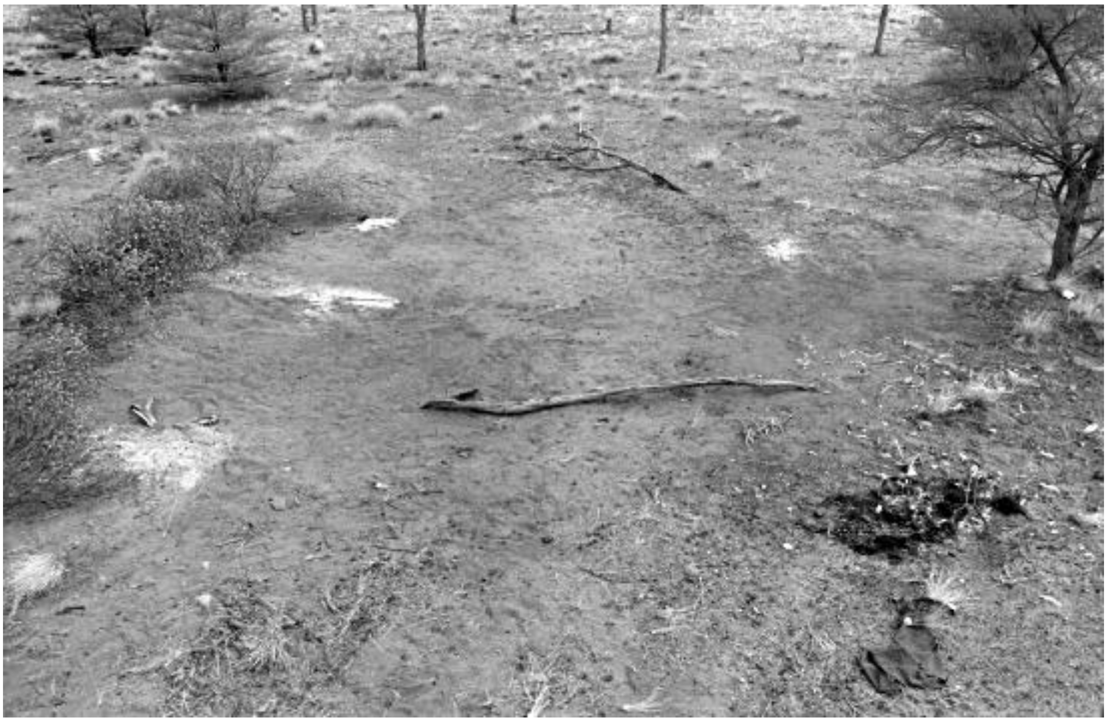


Figure 2.5: Ethnographic example of the spatial patterning of hearths and sleeping areas (from Hayden 2012, 5). Sleeping hearths (whitish areas near the brush windbreak) and a cooking hearth (centrally located) used by two Pintupi men in the Western Desert. Hayden (2012) draws similarities to hearth patterns seen at Middle Palaeolithic sites.

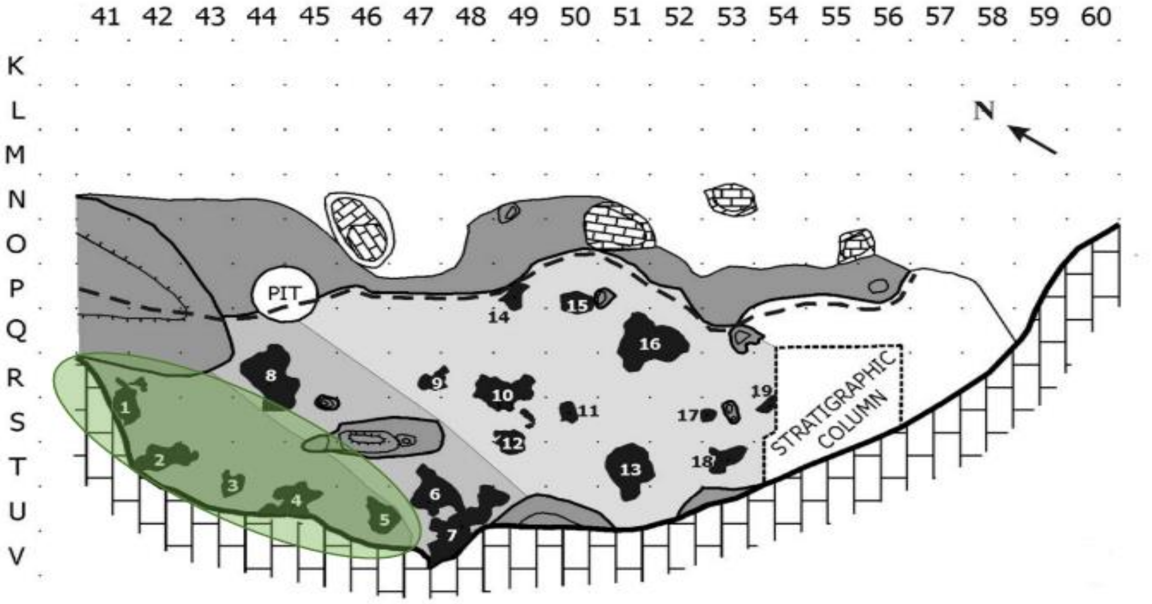


Figure 2.6: Floor plan of Level N at Abric Romaní showing the location of hearths 1 to 5 and postulated sleeping areas (added by author in green). Interpretation based on the regular 1.3 m spacing, limited lithic/faunal remains, and evidence for long-term, repeated fire use. Key: 1. Distribution and number of combustion activity areas; 2. Inner zone. 3. Frontal zone; 4. Central zone; 5. External zone (from Vallverdú et al. 2010, 138).

Group size can also be inferred from finds densities research. This assumes that the amount of cultural material deposited reflects the number of inhabitants at a site (French 2016, 164). Conard et al. (2012), for example, compares finds from Middle and Upper Palaeolithic sites in the Swabian Jura, Germany. The study collates data for major classes of archaeological materials, including lithics, burnt bone, and modified faunal remains (Conard et al. 2012). It was found that across all the categories of artefacts, the average find densities for Aurignacian sites was roughly ten to fifteen times higher than in the Middle Palaeolithic (Conard et al. 2012, 240). It was argued that this indicated lower occupation intensities and population densities for Neanderthals, as well as smaller social units (Conard et al. 2012, 244). The difficulties associated with this approach are well documented (see French 2016, 171-173 for full discussion), with the palimpsest nature of most Palaeolithic sites again becoming an issue. The amount of material recovered is also greatly affected by excavation techniques (Conard et al. 2012, 240).

The final source of evidence explored here is predictive models. These are based on correlations to group sizes observed in the animal world. Dunbar (2003), for example, analyses the relationship between relative neocortex size and group size, as observed among extant primates. Neocortex volume is not available directly from fossils, but it can be estimated from total cranial volume (Aiello and Dunbar 1993; Dunbar 2003). Using a regression equation, the study found that the size of Neanderthal regional groups falls just below that of modern humans, suggesting that local group sizes were also smaller as a result (Figure 2.7). Whilst the accuracy of predicting neocortex size from total brain volume has been questioned (e.g. Steele 1996), this result is consistent with archaeological comparisons.

In another predictive model approach, Steele (1996) uses the positive correlation between home range and total group mass, as observed among mammals. The study uses body mass estimates based on fossil data and assumes a group composition ratio of one male : one female : two juveniles (Steele 1996, 249). For a group size of 25 Neanderthals, the model predicts 1,049 kg of group mass, which calculates a home range of 32.6 km (Table 2.1). This can then be compared to archaeological indicators of home range, such as raw material transport. For example, Burke (2006, 518) uses these estimates to

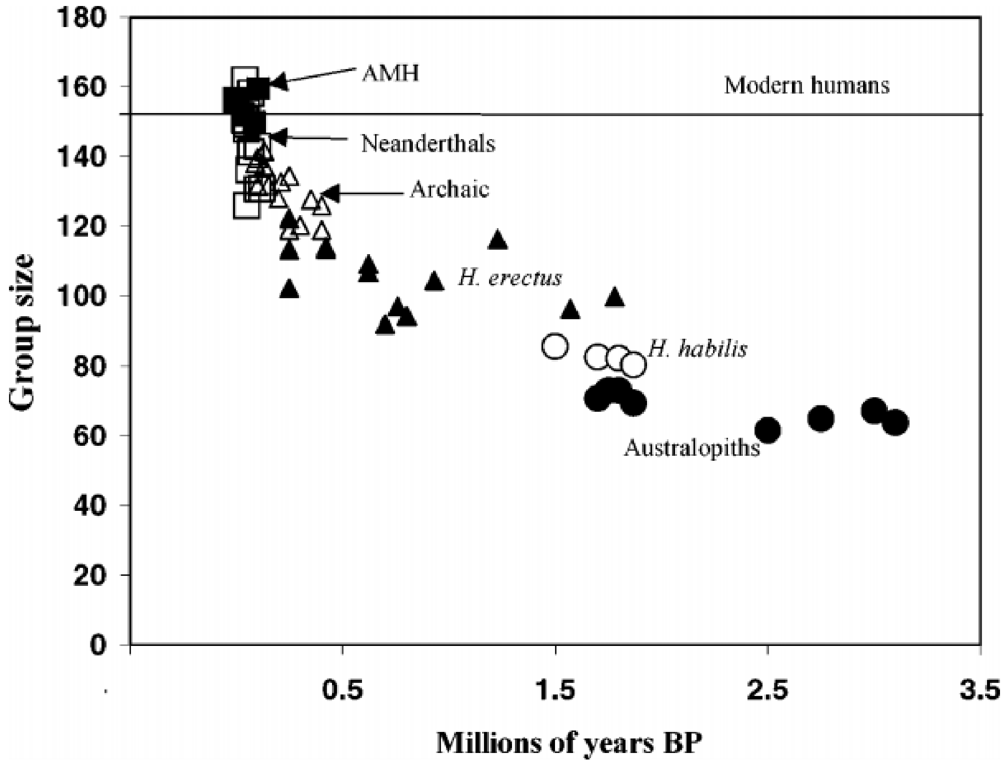
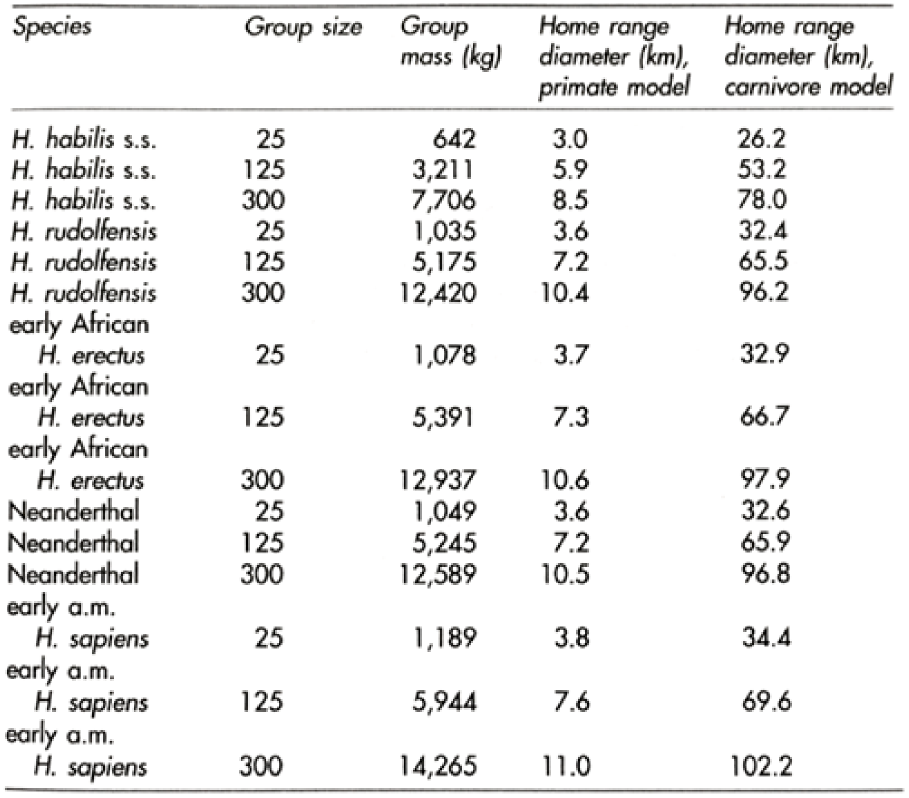


Figure 2.7: Regional group size predictions using a regression equation based on neocortex ratio, estimated from cranial volume. The horizontal line represents the value of 150 predicted for (and found in) modern human populations (from Dunbar 2003, 273). Neanderthals are predicted to have smaller regional groups, and likely smaller local groups as a result.



Species	Group size	Group mass (kg)	Home range diameter (km), primate model	Home range diameter (km), carnivore model
H. habilis s.s.	25	642	3.0	26.2
H. habilis s.s.	125	3,211	5.9	53.2
H. habilis s.s.	300	7,706	8.5	78.0
H. rudolfensis	25	1,035	3.6	32.4
H. rudolfensis	125	5,175	7.2	65.5
H. rudolfensis	300	12,420	10.4	96.2
early African *H. erectus*	25	1,078	3.7	32.9
early African *H. erectus*	125	5,391	7.3	66.7
early African *H. erectus*	300	12,937	10.6	97.9
Neanderthal	25	1,049	3.6	32.6
Neanderthal	125	5,245	7.2	65.9
Neanderthal	300	12,589	10.5	96.8
early a.m. *H. sapiens*	25	1,189	3.8	34.4
early a.m. *H. sapiens*	125	5,944	7.6	69.6
early a.m. *H. sapiens*	300	14,265	11.0	102.2

Table 2.1: Group size predicted from group mass and home range diameter (from Steele 1996, 249).

suggest that the maximum group size for Neanderthal groups in Crimea is 25, based on average raw material transfers. Whilst it is useful to have an approach which incorporates both archaeological and fossil evidence, the chain of inference may again pose problems. This chapter will later discuss the difficulties in accurately estimating body mass from hominin fossils. Small variances could have significant knock on effects for the model.

Despite the many difficulties in these approaches, there is some consensus that Neanderthals social groups were relatively small on average. Estimates from indirect approaches have centred on 8-16 individuals, with hints of larger groups at certain points in space and time (e.g. Tor Faraj). This range agrees with rare, direct evidence from El Sidrón, Spain, where the remains of 13 individuals from the same social group have been recovered (Rosas 2006). These estimates are also in agreement with growing genetic evidence of small, closely related kin groups (Sánchez-Quinto and Lalueza-Fox 2015). In addition to the size of a social group, its composition will also have had important implications for childcare and carrying. This will be discussed in the next section, with key evidence from northern Spain.

2.3.2 Neanderthal group composition and the El Sidrón 'family'

Our best evidence for Neanderthal group composition comes from the unique assemblage at El Sidrón cave in northern Spain, and forms part of the reasoning for selecting this region as a case study.

The El Sidrón site is a 3,700 m long karst system located in Asturias, Spain, formed of a main gallery and several small transverse galleries (Figure 2.8). In 1994, a Neanderthal assemblage was discovered in one of these areas, which led to further investigation between 2000 and 2014 (Rosas et al. 2006). To date, these excavations have recovered 2556 hominin skeletal remains (Ríos et al. 2019), 415 lithic tools (Santamaría et al. 2010), and 51 faunal remains, all from the same archaeological unit (Estalrrich et al. 2017). This unit comprises of a massive debris flow deposit, likely caused by a major flooding event, which caused the collapse of an upper gallery and dragged the archaeological and skeletal material down from a higher level (Estalrrich et al. 2017; Lalueza-Fox et al. 2011a;

2012b). Given that ~18% of the lithic materials can be refitted and several skeletal regions were found in correct anatomical articulation, it has been suggested that they result from a single and brief cultural activity (Lalueza-Fox et al. 2011, 250). The remains therefore appear to represent all or part of a contemporaneous social group, dating to around 49,000 years ago (Wood et al. 2013). This provides us with a unique insight into the size and composition of a Neanderthal group.

Many of the recovered hominin bones show signs of anthropic activity, such as cut marks, percussion pitting and inner conchoidal scars, which have been associated with cannibalistic activity (Lalueza-Fox et al. 2012b, 134). The current most plausible scenario is therefore that a whole Neanderthal family group was killed and cannibalised by another group (Lalueza-Fox et al. 2012b, 134) and their remains were shortly afterwards buried together as a result of the karst collapse (Rosas 2006; Lalueza-Fox et al. 2011a). The skeletal remains are therefore in secondary position, but due to the preservation conditions of this site, palaeogenetic studies have been possible on all the individuals. This has revealed unique information on possible kinship and internal genetic diversity (Lalueza-Fox et al. 2011; 2012b).

To date, there have been 13 individuals identified among the hominin remains (Table 2.2). This group consists of seven adults (three males and four females), three adolescents, two juveniles, and one infant (Figure 2.9 and 2.10; Rosas et al. 2013). Mitochondrial DNA (mtDNA) analysis has identified the presence of three distinct lineages, of which all the adult males share one, but among each adult female differs. This could be an indication of patrilocal mating behaviour (Lalueza-Fox et al. 2011a, 252) and a rare glimpse at individual mobility. Strontium isotope analysis could be used for testing higher female mobility, but this has yet to be studied (Lalueza-Fox et al. 2011b). This would also provide an interesting comparison to the Goyet Neanderthals (see Wißing et al. 2019, also discussed earlier in chapter).

The mtDNA analysis also hints at potential familial relationships, with juvenile 2 possibly the offspring of female adult 5, and juvenile 1 and the infant possibly the offspring of female adult 4 (Table 2.2; Lalueza-Fox et al. 2011a, 252). This could have important implications for infant carrying, as it suggests an interbirth interval of around 4.5 years

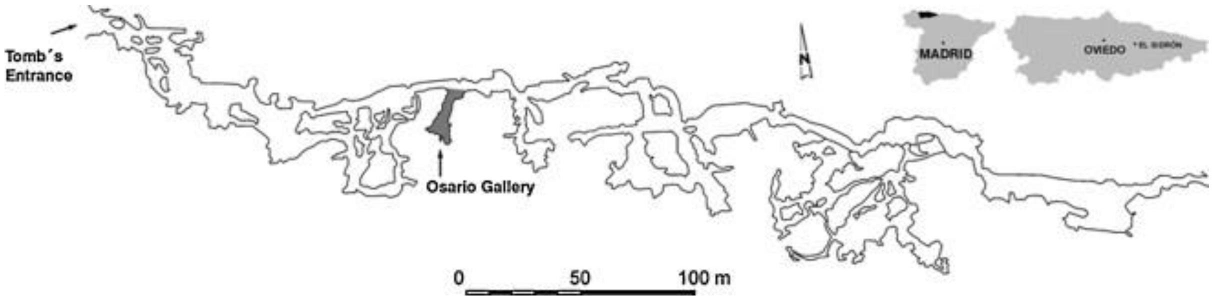


Figure 2.8: Map of El Sidrón karst system. Tomb's entrance: main entrance into the system; Osario Gallery (Ossuary Gallery): lateral galley where the Neanderthal remains have accumulated (from Lalueza-Fox et al. 2012b, 134).

Specimen	Age	Sex	mtDNA lineage
Adult 1	Young adult	Male	A
Adult 2	Young adult	Male	A
Adult 3	Adult	Female	B
Adult 4	Young adult	Female	C
Adult 5	Adult	Female	A
Adult 6	Adult	Male	A
Adult 7	Adult	Female	?
Adolescent 1	11-12 years	Male	C
Adolescent 2	12–13 years	Female	A
Adolescent 3	12-13 years	Male	A
Juvenile 1	7.5 years	?	C
Juvenile 2	9-10 years	?	A
Infant	2-3 years	?	C

Table 2.2: Age, sex and mitochondrial DNA lineage for the 13 Neandertal individuals present at the El Sidrón site (mtDNA data from Lalueza-Fox et al. 2011; Adult 7 sex from Estalrrich et al. 2017; ages from Rosas et al. 2013). mtDNA analysis currently unpublished for El Sidron Adult 7.

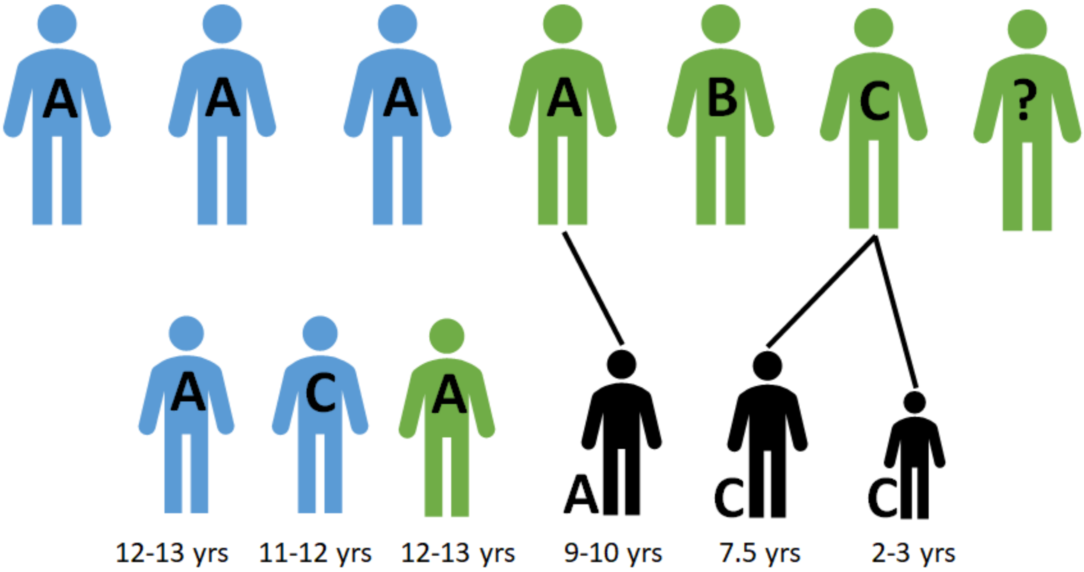


Figure 2.9: The size and composition of the El Sidrón 'family'. Males are represented in blue, females in green, and undetermined in black. Each individual is labelled with their attributed mtDNA lineage (A, B or C), where available. All the females belong to different lineages, which could indicate patrilocal movement. Familial relationships have been inferred between some of the women and children.

Figure 2.10: Reconstruction of the El Sidrón 'family'. The infant has been depicted being carried. Whilst this behaviour might therefore seem obvious in popular representations of Palaeolithic life, it is still yet to be considered in depth in our interpretations (Image courtesy of Cristina López Tascón, University of Oviedo).

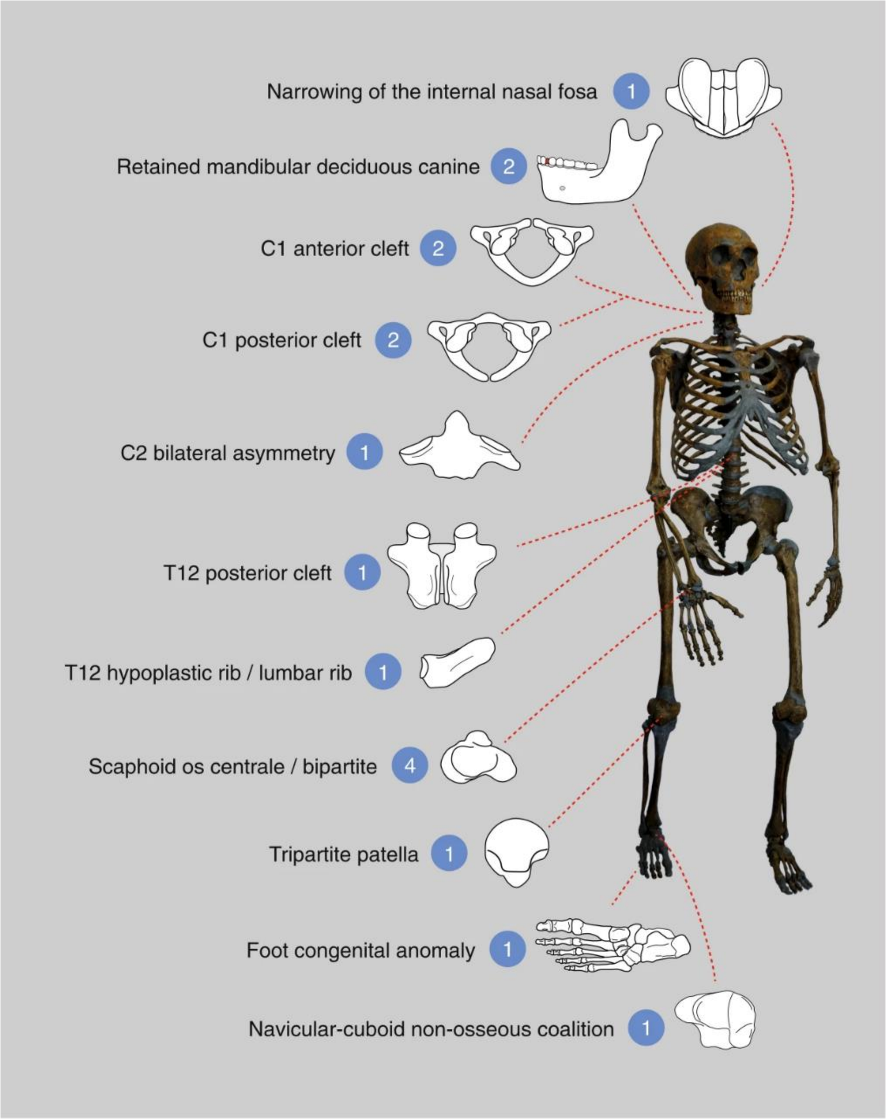


Figure 2.11: Summary of the 17 congenital anomalies observed within the El Sidrón Neanderthal family group. The number of observations for each condition is shown in the blue circles, together with a schematic representation of the condition. At least four Neanderthal individuals have a cleft in the arch of the first cervical vertebra (from Ríos et al. 2019, 5).

for Neanderthals and a possible end point for this behaviour. This falls within the upper birth ranges reported for modern hunter-gatherers (see Table 1 in Kaplan et al. 2000).

The size of the El Sidrón 'family' therefore fits within indirect estimates of Neanderthal group size, although additional, missing members of the group cannot be ruled out. In terms of group composition, this is of course only one example, and it cannot be expected to be applicable to the whole Neanderthal range. This is emphasised by genetic and skeletal evidence of demographic pressures.

As well as close kin relationships, mtDNA analysis suggests a particularly low genetic diversity among the El Sidrón group (Lalueza-Fox et al. 2011; 2012b). This is consistent with wider analysis of mtDNA genomes, which suggests that genetic diversity among Neanderthals living 70-38,000 years ago was approximately one third of that in contemporary modern humans (Briggs et al. 2009). The particularly high frequency of congenital conditions at El Sidrón however, suggests this site might represent an extreme example. Ríos et al. (2019) identified 17 congenital anomalies among the identified skeletal remains, with at least four individuals affected by the same condition (Figure 2.11). The skeletal evidence therefore supports the emerging genetic scenario of small, isolated groups, with high levels of intragroup mating (Lalueza-Fox et al. 2012a). El Sidrón could represent the point at which this becomes a demographic collapse (Ríos et al. 2019).

The El Sidrón 'family' could therefore be seen as specifically representative of late Neanderthal groups in this region. If this is the whole group represented, it might be that the number of children is different to earlier periods due to demographic strains. This site still remains our best evidence of Neanderthal group size and composition, and until recently, our only direct evidence.

A recent discovery of Neanderthal footprints in France however, has brought an additional example and suggests a more significant presence of children in some Neanderthal social groups. The site of Le Rozel (Manche, France) includes a rich Mousterian lithic industry and around 8000 faunal remains, as well as evidence of hearths and lithic-knapping areas (Duveau et al. 2019, 2). Since 2012, renewed excavations of the occupation site have also yielded hundreds of hominin footprints dating to around 80,000 years ago (Figure 2.12; Duveau et al. 2019, 1). These tracks have been attributed to Neanderthals based on their consistency with known morphological traits, as well as their association with Mousterian artefacts (Duveau et al. 2019, 3). The dating also falls in a period where Neanderthals were the only hominin species known in Western Europe. The research team investigated the size and composition of the group by developing a morphometric method based on experimental footprints. The metric analysis revealed a group size of around 10-13 individuals, of which the majority were children and adolescents (Duveau et al. 2019). This includes the presence of very young

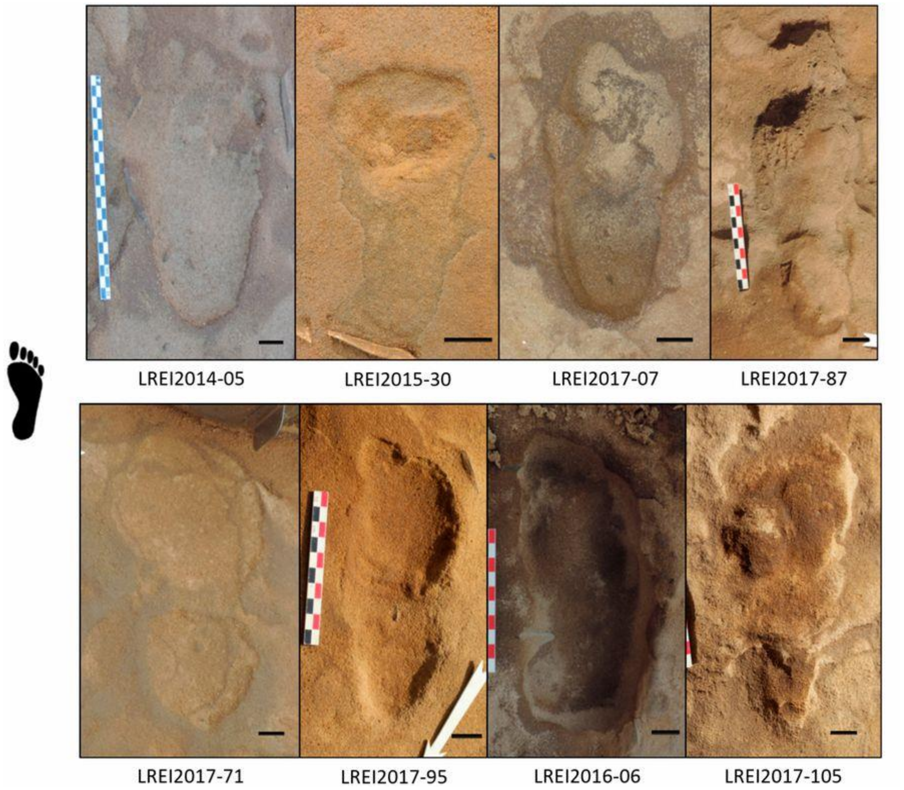


Figure 2.12: Some of the 257 hominin footprints discovered at Le Rozel, reflecting a single, brief occupation event. Three sources of evidence supports the attribution to Neanderthals: morphometric analysis, the dating of the site, and association with Mousterian lithics (from Duveau et al. 2019, 3).

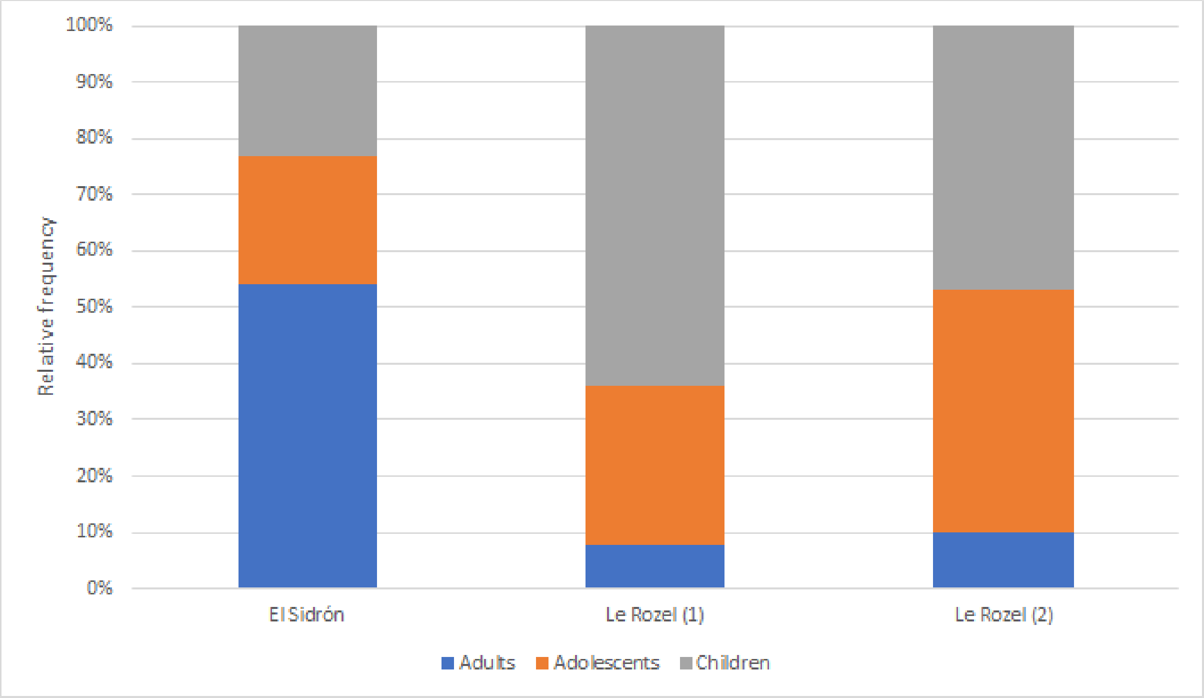


Figure 2.13: Relative frequencies per age class compared at El Sidrón and Le Rozel. Le Rozel (1) used estimated stature from footprint length, versus footprint width (Le Rozel 2).

children, with the smallest footprint corresponding to an age of 2 years (Duveau et al. 2019, 5). Similar to El Sidrón, it is difficult to prove that these footprints represent the entire composition of the group. It is also questionable how reliably we can match foot dimension with Neanderthal age ranges, particularly as it must rely on comparative modern data. Regardless of the exact age estimates, this site still suggests that there was a high frequency of children. This reinforces the fact that we cannot make assumptions about the entirety of Neanderthal behaviour from one example and unsurprisingly suggests there was diversity in the composition of social groups (Figure 2.13).

2.3.3 Division of labour

As discussed in Chapter 1, the division of labour within social groups has clear connections to childcare. For recent hunter-gatherers, the nature of work activities and mobility is influenced by whether children need to be carried, or can be left behind in camp, and whether resources can be supplemented by other group members (e.g. Hurtado et al. 1992; Meehan et al. 2013). Some have argued that the gender-based division of tasks only emerged with modern humans and may have even provided a competitive advantage over Neanderthals (Kuhn et al. 2006; Balme and Bowdler 2006; Soffer 1994; Stiner and Kuhn 2009). This section will discuss the main existing interpretation of Neanderthal social organisation (Kuhn and Stiner 2006), as well as the impact of new evidence (Estalrrich and Rosas 2015). This will provide important context for assessing the role of infant carrying in later stages of this thesis.

Kuhn and Stiner (2006, 957) argue that the Middle Palaeolithic record provides little evidence of the subsistence roles typically filled by women and children in recent foraging societies. The study emphasises the narrow range of Neanderthal economic activities, where large terrestrial game hunting dominates and evidence of clothing production or technological specialism is lacking, both of which are suggested to point to gender roles in the ethnographic record (Kuhn and Stiner 2006, 958). It is therefore argued that Neanderthals do not fit into the 'typical' pattern of labour division in recent foragers and leaves three possible scenarios for Middle Palaeolithic women and children:

1. Women and children were doing little beyond having babies and growing up.
2. Women and children were collecting small game and vegetable foods but consuming them ‘in the field’ rather than on site.
3. Women, children, and men all participated in the acquisition of large animals (Kuhn and Stiner 2006, 958).

The first option is suggested to be unlikely given the skeletal evidence for high levels of activity across age and sex, as summarised earlier in this chapter. The second hypothesis was also argued unlikely, with the researchers pointing to isotopic evidence of a low plant food diet, as well as limited direct evidence for small game or vegetable foods. This leaves hypothesis three, which points to women and children engaging in hunting more extensively and directly than seen in the ethnographic record. Kuhn and Stiner (2006, 959) suggest this was most likely in the form of lower risk roles, such as beaters or game drivers. This is potentially supported by trauma patterns in Neanderthals, where females exhibit comparable but slightly less trauma than males (Estabrook 2009, 337).

In response to the study, Macdonald and Roebroeks (2006, 966) warned against simply applying a “new black-and-white characterisation” of Neanderthals versus modern humans, that of narrow versus broad foraging activities. This binary framework for interpreting Neanderthals has had a long history in archaeological studies but has become an increasingly defunct approach (see Ames et al. 2013 for summary). Like any research, the evidence used by Kuhn and Stiner (2006) is also a product of its time. For example, the discussion of division of labour needs to be reassessed in light of increasing evidence for diverse diets among Neanderthals, such as marine resources (e.g. Brown et al. 2011; Cortés-Sánchez et al. 2012), plant foods (e.g. Henry et al. 2014; Power et al. 2018), and small game (e.g. Carvalho et al. 2018; Cochard et al. 2012). The view of Neanderthal diet being universally dominated by large game can no longer be sustained (Hardy and Moncel 2011; Hardy et al. 2012). Similarly, the argued low level of technological elaboration is disputed by new evidence of the use of bone tools, mastics, and stone tipped hunting weapons (e.g. Soressi et al. 2003; Villa et al. 2009). Since there was variability across time and space, we should expect the organisation of social groups to reflect this. In addition, new analysis has brought direct evidence of age and gender

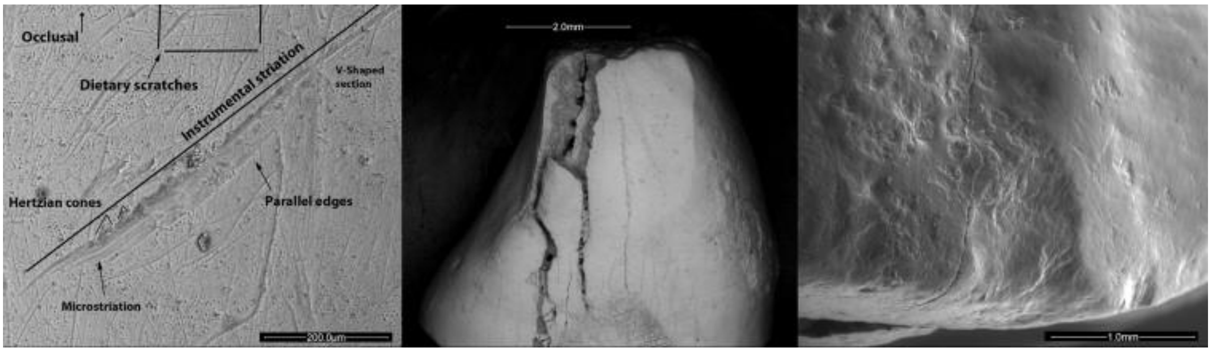


Figure 2.14: Examples of activity-related dental wear features on Neanderthal teeth. Left: a cultural striation on a lateral lower incisor from El Sidron cave with the characteristic cut-mark morphology. Middle: post-mortem fracture (not considered in study) on a mandibular central incisor. Right: ante-mortem crack or dental chipping on a maxillary canine (from Estalrrich and Rosas 2015, 53).

differences in Neanderthal processing behaviour, through the analysis of activity-related dental wear.

Neanderthals are known to have used their teeth extensively as a 'third hand' for food preparation, tool production, and preparation of skins, all of which leave characteristic signatures of wear (Clement et al. 2012; Volpato et al. 2012). Examples of this wear were investigated in a study by Estalrrich and Rosas (2015), who focused on the evidence of cultural striations and dental chipping among 19 Neanderthal individuals (Figure 2.14). The researchers found that Neanderthal females had more striations, and the striations were longer. This suggests differences in the frequency of this activity, as well as differences in the nature of the material they were cutting (Estalrrich and Rosas 2015, 59-60). Narrower striations were also more frequent in non-adults, suggesting that young individuals may have been using tools with a smaller edge. Clear differences were also found in the positioning of dental chipping, with 89% of male teeth affected on their maxillary dentition and 93% of female teeth on the mandibular teeth (Estalrrich and Rosas 2015, 57). Surprisingly, chipped teeth were more frequent for non-adults than adults and, like females, were focused on the mandibular dentition (Estalrrich and Rosas 2015, 57).

All of the individuals studied by Estalrrich and Rosas (2015) had evidence of dental striations and chipping, which suggests similar behaviour across age and sex. However, task processing, the nature of the material they were cutting, and the repetition of this behaviour was dependent on gender (Estalrrich and Rosas 2015). In short, females appeared to have used their teeth to process different materials, possibly hides, more often than males. Evidence of dental chipping similarly suggests a division of activity, with Neanderthal males following the pattern seen in ethnography, but females not (Estalrrich and Rosas 2015, 61).

It is important to acknowledge that this study is based on samples from three sites, namely El Sidrón (Spain), L'Hortus (France), and Spy cave (Belgium), so cannot be assumed to be representative for all Neanderthals. For example, evidence from two individuals at Saccopastore, Italy, display no gender differentiation in dental wear (Fiorenza 2015). However, we have argued elsewhere (Spikins et al. 2018, 4) that a division of roles in Neanderthal groups is likely to be culturally determined. The local or regional context must have an impact, which is why taking a regional focus could provide particular insights in this study.

These interpretations of labour division also raise the question of what this might mean for child carrying. If all members of Neanderthal groups were involved in hunting, albeit possibly in different capacities (e.g. Kuhn and Stiner 2006), children were present and depending on their age, may have needed to be carried. If there was some level of social or gendered division however, young children may have remained at 'home' for safety reasons and to avoid this costly behaviour. Whilst it is of course very difficult to provide a definitive answer, this study can explore different scenarios and what behaviour might be more likely in certain contexts.

2.4 What is the current understanding of Neanderthal energetics?

This chapter has evaluated the evidence for Neanderthal mobility, group size and composition to inform scenarios of infant carrying. The overall approach in this study is based on calculating energetic costs and therefore current interpretations of Neanderthal energy requirements also need to be assessed. Whilst there have been many studies calculating estimates of Neanderthal energy requirements, none have considered the role of infant carrying, despite this being a fundamental cost in hunter-gatherer life. An important objective of this research is therefore to assess the feasibility of current interpretations.

2.4.1 Energetics and human evolution

Bioenergetics is the study of the transfer and use of energy in organisms. It is concerned with how individuals and populations extract energy from their environments, and in turn, how this energy is allocated to different biological functions (Leonard and Robertson 1997, 266). These dynamics have important ramifications for survival and reproduction, and major transitions within our evolutionary past impacted how energy is transformed (Leonard et al. 2007, 345).

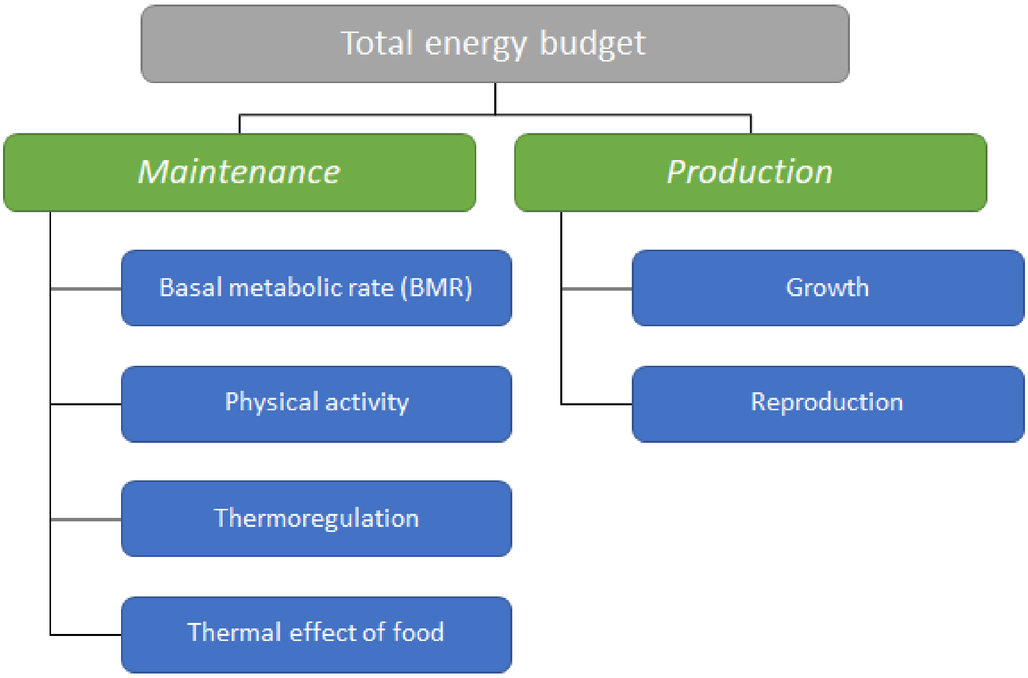


Figure 2.15: The key components for the energy budget of an animal, adapted from Snodgrass and Leonard (2009, 221). Maintenance costs encompass the energy necessary for daily survival, and production includes growth until maturity and the costs of dependent offspring.

Since the 1990s, an energetics perspective has increasingly contributed to debates within human evolution, including the origins of bipedalism (e.g. Leonard and Robertson 1995; Sockol et al. 2007), brain growth and development in *Homo* (e.g. Aiello and Wheeler 1995; Leonard and Robertson 1996), and the evolution of life history (e.g. Aiello and Key 2002). Within this research domain, a specific focus on Neanderthals has also emerged, likely reflecting the extensive fossil record available in comparison to other past hominins. This has provided insights into levels of cold tolerance (e.g. Steegmann et al. 2002; Churchill 2006), use of space (Macdonald et al. 2009; Verpoorte 2006), foraging and locomotor efficiency (e.g. Sorensen and Leonard 2001; Steudel-Numbers and Tilkens 2004), and ultimately the replacement of Neanderthals by modern humans (e.g. Sorensen and Leonard 2009; Froehle and Churchill 2009; Froehle et al. 2013). It is becoming clear that even subtle differences in terms of body size, shape, and development would have important implications for energy budgets and knock-on consequences for Neanderthal life (Froehle et al. 2013, 285).

The energy budget for an animal is typically divided into maintenance and production costs (Figure 2.15). Maintenance refers to the energy needed to keep an animal alive on a daily basis, including metabolic processes, heat production and physical activity (Leonard et al. 2009, 344). Production encompasses the energy required for growth from infancy to adulthood and the direct costs of dependent offspring. In order to understand the energetic cost of mobility in Neanderthals, it is important to explore the broader context of the daily energy budget.

2.4.2 Estimating daily energy expenditure (DEE) in Neanderthals

Daily energy expenditure (DEE; kcal/d), also known as total energy expenditure, is the amount of energy that an individual uses across a typical, active day (Leonard et al. 2005, 458). Whilst it cannot be directly measured in Neanderthals, it is possible to estimate by combining measurable factors from the fossil record with data and insights from modern populations. Studies to date have used a variety of methodological approaches and together provide important insights into Neanderthal energetics.

One approach is to use the correlation between body mass (M) and DEE (see Aiello and Wells 2002). Leonard and Robertson (1997, 275) for example, produced a predictive equation based on a mixed sample of human and nonhuman primates, whereby:

$$DEE = 86.0M^{0.793}$$

Whilst Neanderthals were not included in the original study, Churchill (2006, 121) used the equation to produce DEE estimates of 2258 - 2532 kcal/d for females and 2586 - 2835 kcal/d for males. In comparison to the reported ranges of 3000 - 4000 kcal/d for arctic foragers (Steegmann et al. 2002, 577), these values appear to be low. This could partly be due to energetic costs such as thermoregulation and food digestion not being included (Leonard and Robertson 1997, 270), but is most likely the influence of nonhuman primates within the sample. Nonhuman primates have lower daily energy needs per unit body mass than human foragers in general and would therefore lead to the values for Neanderthals being underestimated (Churchill 2006, 121). All other studies of Neanderthal energetics have used only modern human data and whilst their materials and methods have varied, have consistently produced higher estimates.

One such model incorporated fat-free mass (FFM) and calorie consumption in modern circumpolar populations to estimate daily Neanderthal costs. The study by Steegmann et al. (2002, 577) suggested that Neanderthal males would have averaged 67.3 kg of FFM (extrapolated from body mass), compared to an average of 60 kg in Inuit males. This suggested that Neanderthal FFM is around 1.1 times higher than Inuit averages and if daily energy consumption is adjusted accordingly, produces DEE ranges of 3360 - 4480 kcal/d (Steegmann et al. 2002, 577). Whilst modern forager data is likely to provide more reliable ranges than general primate models, this approach relies solely on direct analogy with the Inuit. It therefore assumes no difference in climatic conditions and could mask species-specific characteristics of locomotion, both of which could impact energetic costs. Increasingly researchers have attempted to account for the complexity of variables involved, and have focused on estimates of basal metabolic rate to further improve reliability.

Basal metabolic rate (BMR) is the minimum energy required to keep the body functioning when at rest, including processes such as breathing, blood circulation, and cell growth. In most modern human populations, BMR is the largest component of energy expenditure (FAO/WHO/UNO 1985), and has thus become the standard measure for comparing energetic needs between different groups (Leonard et al. 2005; Snodgrass and Leonard 2009). The basic approach for estimating daily energy requirements is to estimate basal metabolic rate (BMR) and then multiply that number by an assumed level of physical activity (PAL):

$$DEE = BMR * PAL$$

Within this basic framework, the methods for estimating Neanderthal BMR have varied, as well as the extent of additions to account for factors such as climate during the Middle Palaeolithic (Table 2.3). In summary, whilst most Neanderthal research has used the correlation between body mass and BMR (e.g. Sorensen and Leonard 2001; Froehle and Churchill 2009), others have used additional or entirely separate methods such as fat-free mass (Snodgrass and Leonard 2009) or skin surface area (Churchill 2006). When compared, the results from these different equations appear to vary by around 200 kcal (Macdonald et al. 2009, 214). As these methods are based on modern humans within modern climates, several studies have also included adjustments to reflect Neanderthal environment. This has ranged from simply applying a percentage increase to reflect seasonal cold stress (e.g. Snodgrass and Leonard 2009), to more complex methods of incorporating annual mean temperature within the BMR equation itself (Froehle and Churchill 2009).

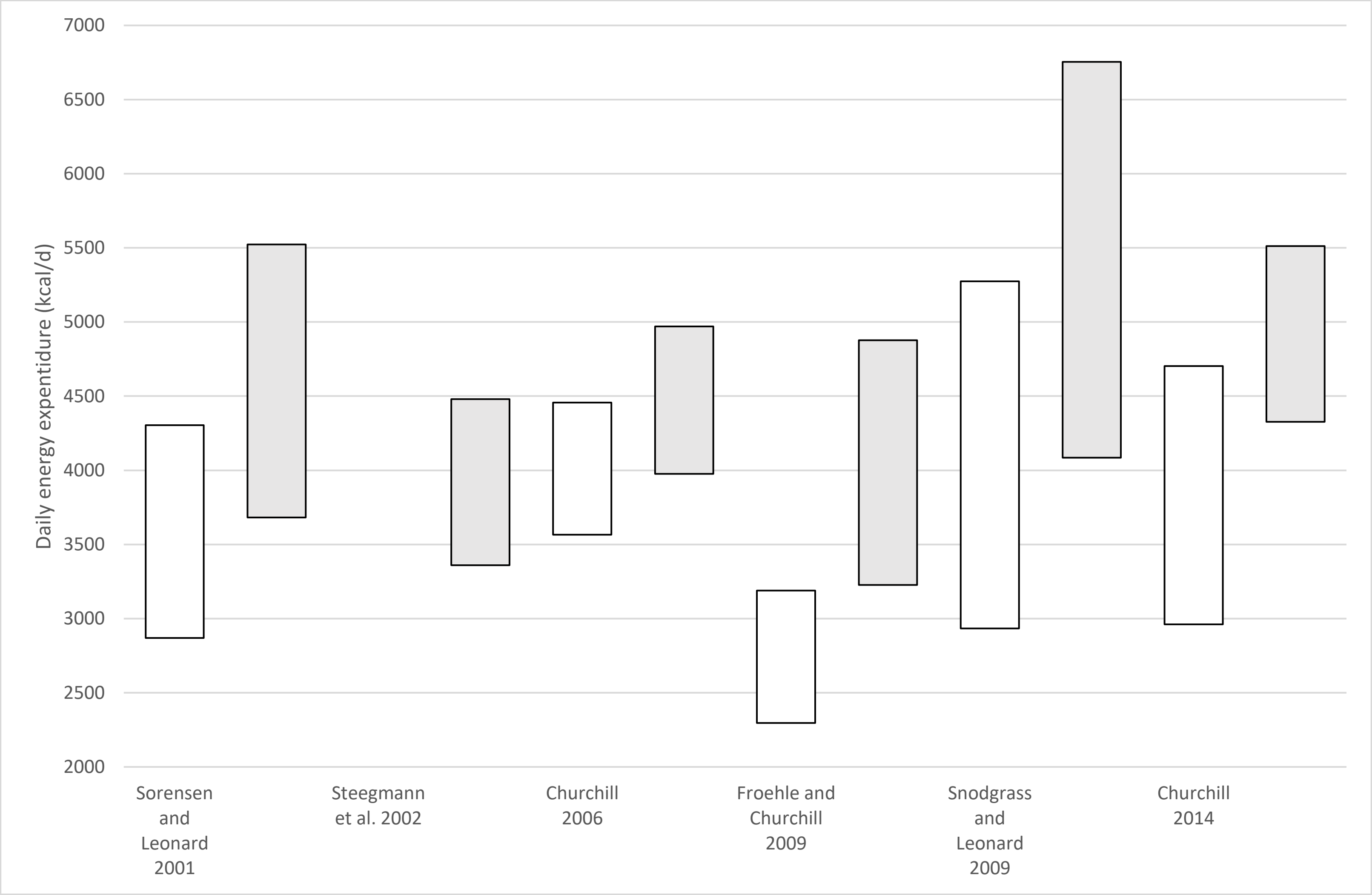
Variation between the assumed physical activity level (PAL) for Neanderthals will also have consequences for daily energy results. PAL provides a measure of the relative amount of energy that is expended above basal needs across a typical day (Leonard et al. 2005, 458). For human groups, daily activity levels are generally assessed using the PAL index developed by the World Health Organisation (FAO/WHO/UNU 1985). This system ranges from 'light' workloads, typical of sedentary urban occupations, to 'heavy' workloads found among manual labourers and subsistence farmers during harvest (Leonard et al. 2007, 459). Most researchers agree that Neanderthals would fall at the upper end of this scale, but to varying degrees. Sorensen and Leonard (2001) directly applied the 'heavy' levels of the WHO system, whilst other studies have relied on empirical data from modern arctic foragers (Churchill 2006), a combination of temperate and cold living hunter-gatherers (Froehle and Churchill 2009), or averages from a range of subsistence populations (Snodgrass and Leonard 2009). This has produced a PAL multiplier ranging from 1.7 to 3.0 (Table 2.3). Churchill (2014) sought to evaluate how appropriate these levels are by separately calculating the activity costs of Neanderthals based on the current understanding of archaeological evidence. Interestingly, the results were consistent with the ranges used by previous studies. However, given that a PAL of 2.5 is likely to be the maximum for a sustainable lifestyle among humans (Shetty 2005),

Table 2.3: Estimated energy expenditure for adult Neanderthals based on recent studies using BMR as a measure. Each column contains the materials and methods used to calculate basal metabolic rate (BMR; kcal/d), physical activity level (PAL), and total energy expenditure (TEE; kcal/d).

Study	**BMR (kcal/d)**	**PAL**	**TEE (kcal/d)**
Sorensen and Leonard 2001			
Female	1435	2.00 – 3.00	2870 – 4305
Male	1841	2.00 – 3.00	3682 – 5523
	Female BMR = 14.7 (M) + 496 Male BMR = 15.3 (M) + 679 Following FAO/WHO/UNU (1985), which uses body mass (M) and regression equations based on young adult humans aged 18-29 years. Neanderthal body mass values are 55 kg (female) and 65 kg (male) based on data by Hartwig-Scherer (1994). BMR results increased by 10% due to costs of living in a glacial environment, based on circumpolar population data.	Assumes heavy to very-heavy activity levels as defined by World Health organisation criteria (FAO/WHO/UNU 1985).	TEE = BMR * PAL No additional adjustments.
Churchill 2006			
Female	1783	2.00 – 2.50	3566 – 4458
Male	1988	2.00 – 2.50	3976 – 4970
	BMR = 1042 * SA Following Winslow and Herrington (1949) which uses skin surface area (SA). Estimates of SA based on clinical equations by Gehan and George (1970). To assess the validity of using modern clinical data for Neanderthals, study creates and anatomical reconstruction to compare SA estimates.	Based on empirical data for the Inuit (Shepherd and Rode 1996).	TEE = BMR * PAL No additional adjustments.
Froehle and Churchill 2009			
Female	1351 – 1498 (temperate) 1446 – 1450 (cold)	1.70 (temperate) 2.2 (cold)	2297 – 2547 (temperate) 3180 – 3190 (cold)
Male	1672 – 1851 (temperate) 1788 – 1951 (cold)	1.93 (temperate) 2.5 (cold)	3227 – 3527 (temperate) 4469 – 4877 (cold)
	Female BMR = (9.2*M) - (3.8*TMEAN) + 852 Male BMR =(14.7*M) - (5.6*TMEAN) + 735	Values based on modern forager averages in Panter-Brick (2002). Temperate values use Ache and !Kung	TEE = BMR * PAL No additional adjustments.

	Following Froehle (2008) which incorporates mean annual temperature (TMEAN), as well as physiological factors of body mass (M), age, and sex. Majority (55/65) of Neanderthal M values from Ruff et al. (1997), and remaining estimates (10/65) use methods based on femoral head diameter, stature or orbital area (Froehle and Churchill 2009, 101).	data, and cold based on the Igloolik but increased given "sedentary nature" of study population (Froehle and Churchill 2009, 103). Values assigned depending on local climate of each site and assumes a difference in activity based on sex.	
Snodgrass and Leonard 2009			
Female	1465 (summer) 1758 (winter)	1.82 – 2.50	2933 – 4029 (summer) 3840 – 5274 (winter)
Male	1876 (summer) 2251 (winter)	1.98 – 2.50	4085 – 5159 (summer) 5348 – 6754 (winter)
	Following Leonard et al. (2005), which uses 1) body mass (BM) and 2) fat-free mass and regression equations based on indigenous Siberian populations. Neanderthal BM averages of 66.4 kg (female) and 77.6 kg (male) from Ruff et al. (1997). FFM assumed similar body fat as Inuit adults. Winter values include 20% seasonal increase accounting for acute cold stress. This is based on metabolic studies of industrial populations and hormone profiles of northern populations (Snodgrass and Leonard 2009, 225).	Lower activity values based on averages for contemporary subsistence populations in Leonard (2008). Higher values are reported as the upper bounds of sustainable population level energy expenditure (e.g. Shetty 2005).	TEE = BMR * PAL + TEF Addition of thermal effect of food (TEF) based on Alaskan Inuit data. Adjustments of an additional 10% in summer and 20% in winter (Snodgrass and Leonard 2009, 225).
Churchill 2014			
Female	1400 – 1950	1.80 – 2.50	2962 – 4703
Male	1800 – 2300	2.10 – 2.50	4327 – 5512
		$PAL = TEE / BMR_T$ Unlike previous studies, this study used a different method to estimate TEE, so the results could be used to estimate new PALs. Higher values are reported as the upper bounds of sustainable population level energy expenditure (Shetty 2005).	$TEE = (BMR_T + AC - BMR_A)(1 + SDA)$ Does not use PAL, instead incorporates total basal metabolic rate (BMR_T), activity costs (AC = mobility costs + domestic activity), and metabolic rate while active (BMR_A). An adjustment of 10% for specific dynamic action (SDA), or thermal effect of food, is included.

Figure 2.16: Estimates of daily energy expenditure (DEE; kcal/d) in Neanderthals.



Churchill (2014, 326) suggests that range of 1.8-2.5 for females and 2.1-2.5 for males is most reliable.

In comparison to Steegmann et al. (2002), studies using BMR and a physical activity multiplier generally result in higher daily energy expenditure (DEE) ranges (Table 2.3). The female range produced by Snodgrass and Leonard (2009) is the exception and explainable by being the only study to assume a sexual division of labour. Nevertheless, whilst methodological approaches have varied, all the studies are within a reasonably consistent range (Figure 2.16), and produce an overall average of 2926 - 4386 kcal/d for females and 3859 - 5527 kcal/d for males. The emerging picture is that Neanderthal adults had particularly high energy expenditure but caution still needs to be taken.

Using a nutritional approach, Hockett (2012) argues that very high estimates are potentially unsustainable, especially when the additional costs incurred during pregnancy are included. Based on a modelled diet of 5500 calories per day derived exclusively from large, terrestrial herbivores, the study found both an over and under-consumption of key nutrients, some to toxic levels (Hockett 2012, 80). This could mean that factors such as thermoregulation or sexual division of labour have previously been underappreciated (Hockett 2012, 81). It could also be that the role of marine resources and plants have been underestimated within Neanderthal diet (Hockett 2012, 81), which is consistent with increasing archaeological evidence of a broader range of foods (e.g Hardy et al. 2012). Whilst the estimates for Neanderthal DEE ranges should not be completely dismissed, it does throw caution to some of the higher values which have been produced. This study could add to this caution by exploring the costs of infant carrying.

As discussed above, nearly all Neanderthal DEE studies have accounted for the cost of physical activity by assuming abnormally high levels relative to modern populations. However, there have also been attempts to specifically calculate the cost of Neanderthal mobility. Among extant hunter-gatherers, activity energy expenditure constitutes a significant proportion of daily costs, within which locomotion is a major part (Froehle et al. 2013, 296). Whilst walking is not the only activity that contributes to daily costs, the skeletal indicators of locomotion provide a tangible link to the fossil record and create the opportunity for estimations to be made.

2.4.3 Understanding Neanderthal locomotor energetics

Hunter-gatherers and other small-scale societies spend a considerable amount of energy on movement across the landscape (Froehle et al. 2013; Churchill 2014). Among the Ju'/hoansi and Ache for example, daily travel accounts for around half of the total energy spent on activity (Froehle et al 2013, 296). It is within this context, that minimising locomotor related costs becomes significant, and some have argued that this has been a major driver of anatomical changes throughout human evolution (e.g. Sorensen and Leonard 2001).

Assessing locomotion costs within past hominins relies on a combination of evidence from modern exercise physiology and fossil anatomy. Body size is one of the major determinants, but variation in other anatomical traits such as limb length also create important modifications in cost. This is where the unique postcranial morphology of Neanderthals could be significant. As well as being at least 10% heavier than modern day humans (Ruff et al. 1997, 171), Neanderthals had a short stature, broad trunks, 'barrel-shaped' chests, short extremities relative to trunk height, and particularly foreshortened distal elements (e.g. Holliday 1997; Ruff et al. 1997). There is much debate over whether this morphology was shaped by climate (e.g. Holliday 1997; Steegmann et al. 2002) or mobility (e.g. Higgins and Ruff 2011), but irrespective of the selective pressure behind it, these differences create ramifications for locomotion. The next section will focus on the potential impact of lower limb length on the cost of transport for Neanderthals.

2.4.4 Terrain and lower limb length

It is well established that lower limb length has differed throughout human evolution, both between *Australopithecus* and *Homo*, and within *Homo* itself (Figure 2.17). Neanderthals, for example, are known to have had shorter lower limbs than modern humans, particularly in the distal elements (e.g. Holliday 1997). This is significant in the context of mobility, as biomechanical arguments suggest that longer limbs result in fewer strides per distance, leading to lower costs (e.g. Polk 2004). This has been further specifically assessed the effect of variable lower limb length within a modern human sample. The reasoning follows that if longer lower limbs result in lower energetic costs

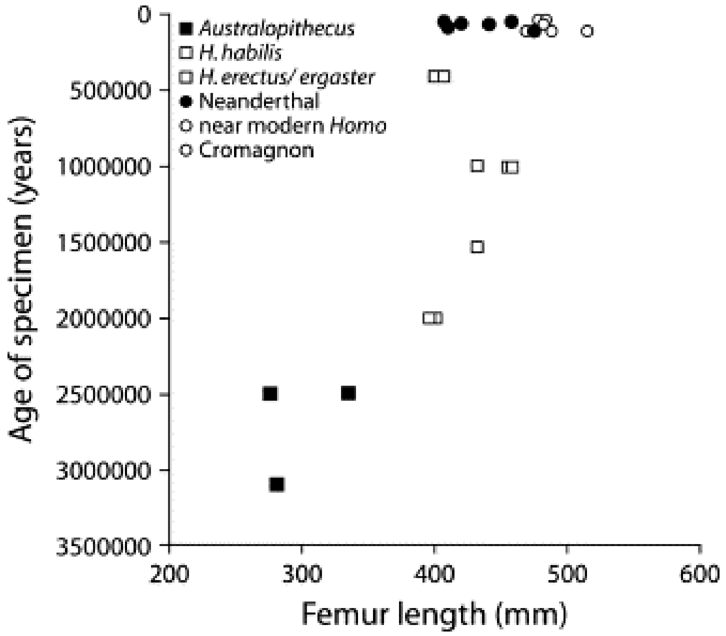


Figure 2.17: The increase in femur length through time in the hominin clade (from Steudel-Numbers and Tilkens 2004, 102).

within modern humans, it will have a similar effect between hominins in the fossil record (Steudel-Numbers and Tilkens 2004). This suggests it would have cost more energy for Neanderthals to travel the same distance as longer limbed AMHs (Steudel-Numbers and Tilkens 2004).

Whilst there is consensus over the effect of shorter lower limbs, the proportion of the effect within the overall cost of transport remains debated. For example, in comparison to Steudel-Numbers and Tilkens (2004, 104) who report that lower limb length accounts for 14% of additional costs, Hora and Sladek (2014, 26) suggest it may be less than 1%. Experiments investigating the impact of lower limb proportions have also largely relied on the use of flat treadmills, but this is of course not representative of natural terrain, particularly of the Palaeolithic. Neanderthals occupied sloped and rugged landscapes across Eurasia, with archaeological sites dominated by rock shelters and caves. Walking over variable and irregular terrain would therefore have been a necessary part of Palaeolithic life. Studies show that even moderate slopes can greatly enhance the cost of transport (Minetti et al. 2002), but it is the different biomechanics of uphill locomotion that are particularly significant for Neanderthal mobility. In order to walk over sloped terrain, postural adjustments are needed to both propel the body upward and to raise the swing leg (Higgins and Ruff 2011, 337). This is where differences in lower limb proportions, especially the ratio of tibia length to femur length (the crural index), could be significant.

Using mathematical simulations, Higgins and Ruff (2011, 342) suggested that the stride advantage for modern humans exhibited on flat terrain does not extend to rugged terrain. For example, on mountainous land, the advantage is drastically reduced by 91% in the case of modern European humans and 71% for Upper Palaeolithic samples (Higgins and Ruff 2011, 342). Any additional energetic costs therefore appear to diminish as grade increases and suggest that Neanderthals could travel the same distance on sloped terrain (Higgins and Ruff 2011, 342). A consideration of variable terrain therefore must be factored into any understanding of Neanderthal mobility.

2.5 Chapter 2 conclusions

In order to understand the role of infant carrying in Neanderthal life, this study brings together current interpretations of mobility, social organisation, and energetics for the Middle Palaeolithic. Typical patterns suggest Neanderthal groups were small (8-16 individuals), with a significance presence of children, and moved within largely local and semi-local distances. A social division of labour is unclear based on existing interpretations and will form an important consideration in this study. These patterns, however, are variable and dependent on the local environment and regional context. It is therefore important that this study is framing models of infant carrying within a specific case study (see Chapter 3). Finally, interpretations of energetics have yet to consider the cost of infant carrying or how intragroup differences would influence mobility costs. This study will therefore add to this understanding through the development of a new approach (see Chapter 4).

CHAPTER THREE

Northern Spain case study

3.1 Introduction

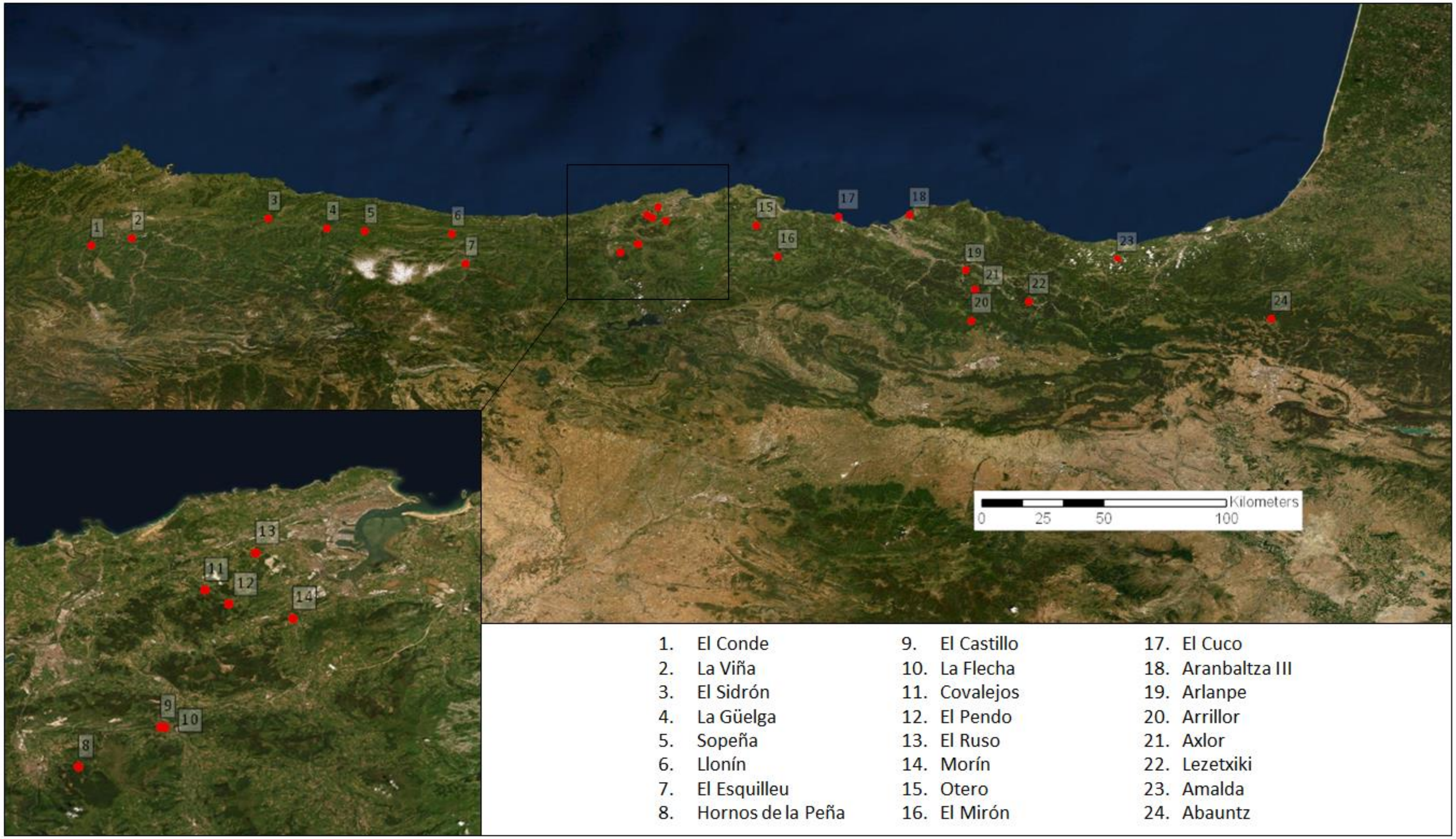
The northern Spain region is rich in Palaeolithic sites and archaeological evidence, representing thousands of years of occupation throughout the Middle and Upper Palaeolithic. This region is of particular use in this study of infant carrying, due to the discovery of the Neanderthal social group at El Sidrón in Asturias (see Chapter 2). The mixed topography of undulating and abrupt mountainous environments, coastal bays and open valleys also provides a unique opportunity to explore the influence of terrain on carrying. Finally, renewed and additional excavations have brought crucial new data, sequences and reassessments of Palaeolithic occupation in this region, adding to debates surrounding chronology and transitions within this period (e.g. Garcia Garriga et al. 2012; Marín-Arroyo et al. 2018; Maroto et al. 2012),

This study is focused on the Middle Palaeolithic, encompassing archaeological sites from the Navarre, Asturias, Cantabria and Basque Country (Figure 3.1). Table 3.1 provides a review of the current understanding of the sites used in this study. This includes details on chronology, archaeological material, and current interpretations of the Neanderthal occupations. Details from this table will be interpreted further as part of the main discussion within this thesis. The rest of this chapter will evaluate current interpretations of mobility in this region. This includes evidence of raw material transport, regional use of cleaver technology, and existing models of game procurement strategies. This will again be used in later stages of the thesis, when discussing the study's results and implications.

3.2 Raw material procurement in northern Spain

The northern Spain region provides great lithological variety, with several distinct zones for procurement (Garcia Garriga 2012, 101). The western area, particularly Asturias, is

Figure 3.1: The study region with Middle Palaeolithic sites labelled (Basemaps: ESRI). Coordinates were collated from NESPOS and site literature (see Appendix 1).



largely dominated by quartzite, with flint becoming increasingly available moving eastwards towards the Basque Country, where it has predominance (Garcia Garriga 2012, 101). In general, the selection of raw materials during the Middle Palaeolithic appears to vary according to this local availability, although there is some evidence for more distant procurement. The following sections will review the evidence for raw material use from the sites included in this study, based on the current availability of data. This will be used to infer the typical mobility of groups occupying these sites during the Middle Palaeolithic.

3.2.1 Asturias

At El Sidrón, most raw materials were sourced from within 5 km (Santamaría et al. 2010, 125). Two types of local flint dominate (83%) and non-local materials are scarce (1.1%) (Santamaría et al. 2010, 126). Local raw materials also dominate at La Viña, including quartzite from the nearby river Nalón and Piedramuelle flint, both less than 10km away (Santamaría 2016, 35). Evidence for more distant movement is indicated by the presence of Piloña flint, which has also been identified at Llonín, El Sidrón (Santamaría 2016) and La Güelga (Menéndez et al. 2014; 2018). Beyond the small presence of Piloña flint at La Güelga, the assemblage mostly consists of locally sourced quartzite (Menéndez et al. 2014; 2018), which also dominates the assemblages at Sopeña. Its use steadily decreases in more recent Sopeña levels from 86% in Level XV to 53% in Level XII (Pinto Llona et al. 2012, 73). Flint is scarce in the local area and suggests more distant mobility, but quantities again decrease between levels from 14% (Level XV) to 10% (Level XII). This suggests a decrease in geographic range in later occupations (Pinto Llona et al. 2012).

3.2.2 Cantabria

At level VII at El Cuco, flint is the most dominant raw material by far (>95%), with the most common variety, Flysch, found 20 km east of the site (Gutiérrez-Zugasti et al. 2018, 49). Non-local varieties are also present, with the most used type found 50 km to the West. The presence of Treviño and some Paleocene flints, located >80 km away, also suggests extended transport (Gutiérrez-Zugasti et al. 2018, 49).

At El Esquilleu, local quartzite is the dominant raw material across the sequence (Yravedra and Gómez-Castanedo 2014, 228). The vast majority of the materials are locally sourced (99.2%) from a stream bed just 200 m from the cave (Yravedra and Gómez-Castanedo 2014, 228). This local focus is also reflected in the faunal assemblage, which is dominated by Iberian ibex and chamois, both of which are well suited to the surrounding steep relief (Yravedra et al. 2014). Differences between the levels at El Esquilleu can also be identified, with progressively greater focus on local resources through time (Figure 3.2; Baena et al. 2019). For example, in the earlier, lower levels (7-20), there is evidence for more dense occupation and more distantly obtained raw materials, suggesting movement extended to the coastline (Baena et al. 2012, 204). However, in more recent levels (3-6), the occupation appears to be more ephemeral, with a focus on local and direct exploitation of resources (Baena et al. 2012, 204). In both cases, the steep, rocky topography of the gorge likely affected the mobility of Neanderthal groups, with movement not extending much further than the Deva River and mostly staying within 5 km of the site (Baena et al 2012; Yravedra and Gómez-Castanedo 2014; Yravedra et al. 2014). This pattern of earlier, more stable occupations followed by later, more ephemeral site use in also observed in the levels at Axlor (Rios-Garaizar and García-Moreno 2015, 336), although the change in raw material use is the opposite, with more local resources being exploited in the stable levels.

In common with El Esquilleu, the raw materials used at La Flecha are again largely from the local area, with a dominance of quartzite, found only a few kilometres away (Castanedo 2001, 7). Other materials such as ophite, limestone and sandstone pebbles are also easily accessible from the nearby Pas River (Castanedo 2001, 7). Flint is present in small quantities (2.5%), with some varieties originating from longer distance sources (Castanedo 2001; Cabrera et al. 2004). Greater quantities of flint can be found at El Castillo, El Pendo, and Cueva Morín, with the latter two sites both situated closer to coastal flint outcrops, allowing for more diversity in raw material use (Cabrera et al. 2004, 439). At El Castillo, the proportion of flint also varies between levels in the sequence, with higher quantities (c. 40%) in later Mousterian levels, than earlier (7.8%)(Cabrera et al. 2004, 439). Overall, the emphasis is still on local, coarse-grained materials such as quartzite and ophite for most sites. Whilst Cantabrian flint is scarce, poor quality and

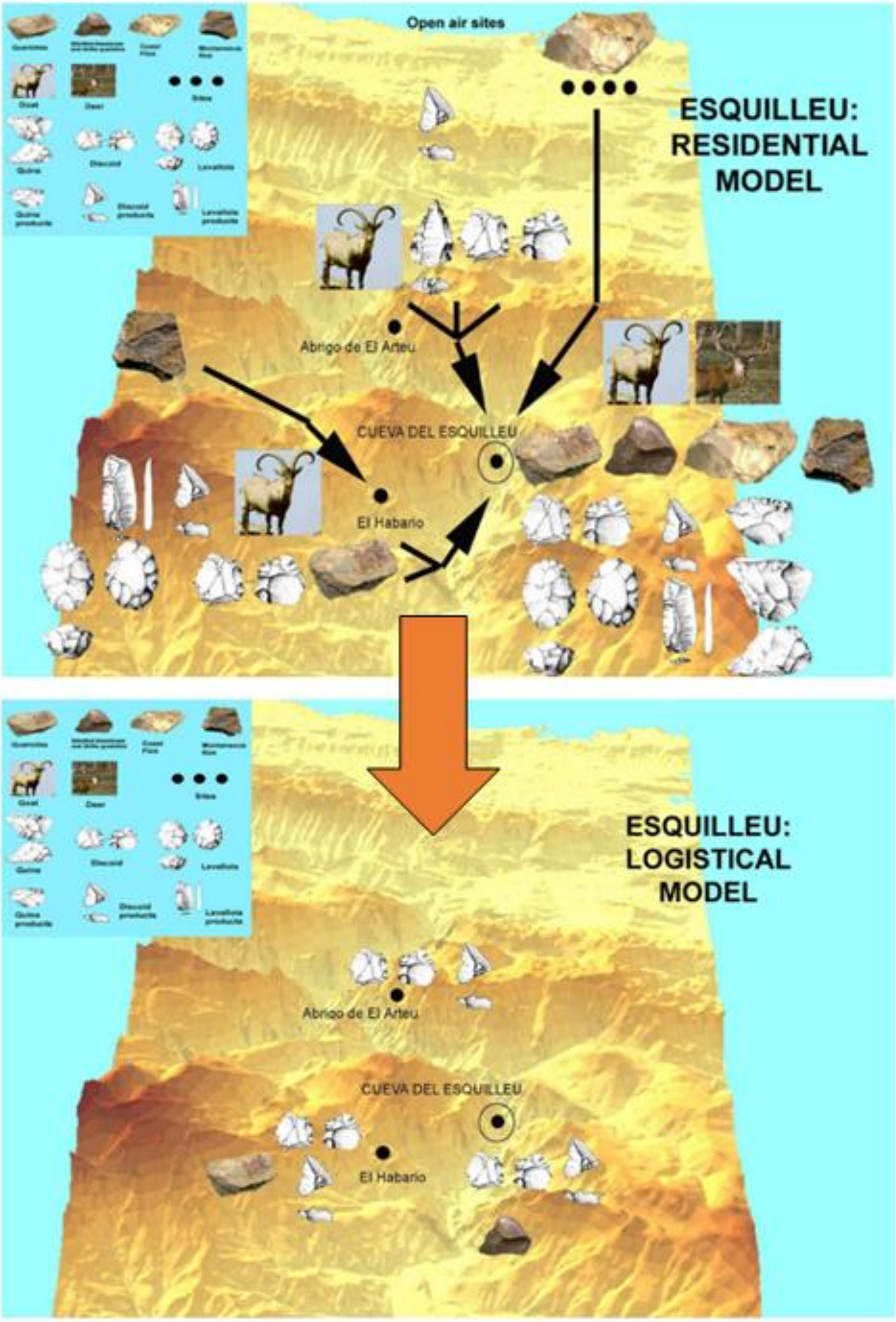


Figure 3.2: Site use changes at El Esquilleu, from longer, stable occupations using a wider variety of raw materials from further afield (levels XV–VII), to more ephemeral visits with a greater focus on local resources (levels VI–III) (from Baena et al. 2012, 205-206).

geographically concentrated (Garcia Garriga 2012, 101), quartzite is high quality and very fine grained, leading to its frequent use throughout the Palaeolithic (Cabrera et al. 2004, 440). For example, its use is high at Castillo (45%) and Hornos de la Peña, and very high at La Flecha (78%)(Cabrera et al. 2004, 440). The material is also emphasised in the manufacture of flake cleavers, which will be discussed further below. El Cuco stands out as different with its overriding focus on flint, but this is again just a reflection of local variability, where nearby flint sources are available.

3.2.3 Basque Country and Navarre

At Amalda, flint is the most dominant raw material, coming mainly from the Flysch outcrops situated on the northern coast less than 15 km away (Figure 3.3; Rios-Garaizar 2015b, 192). Two other varieties of flint located 45-75 km to the south were also used occasionally, with non-local (>40 km) sources making up 9% of the total (Rios-Garaizar and Garcia-Moreno 2015a, 334). Other less frequent materials such as mudstone, ophite, limestone and limonite are all found in the vicinity of the cave (Rios-Garaizar 2017, 57).

Local Flysch flint similarly dominates the assemblages at open-air site Aranbaltza III, with scarce use of other materials such as quartzite, trachyte and mudstone (Rios-Garaizar et al. 2018, S2). Nearby raw materials also form the focus at Arlanpe, outnumbering non-local sources by 2:1 (Rios-Garaizar et al. 2011). This includes sandstone, limonite, quartz and mudstone, with the latter found less than 1 km away (Rios-Garaizar 2015, 237). Several non-local flint varieties also appear, such as Flysch (29 km NW), Urbasa (65 km SE), Treviño (50 km S) and Loza (60 km S), suggesting movement through extensive territories (Figure 3.4). Some differences can also be seen between the sedimentary sequences, with assemblages from sequence SQ3 relying more intensively on local materials (Rios-Garaizar et al. 2015, 241).

For Arrillor, little detail is available for the lithic industry and raw material sources, but still hints at a similar pattern. Non-local flint is present throughout, with some differences in the use of local materials between levels. For example, lyddite is the most abundant raw material in level Smk-l, but local quartzite appears to be used more in level Amk and Lmc (Iriarte-Chiapusso et al. 2019, 108). Distinctions between levels can also be seen at Axlor, with assemblages in the upper part of the sequence (B-F) showing great dependence on non-local flint imported from the north and south (>30 km)(Rios-Garaizar and García-Moreno 2015, 336). Flint is used less in the lower levels (M-N), with more focus on the northern sources (Flysch) than the southern (Treviño and Urbasa). Other materials such as mudstone or quartz were also used intensively, compared to their

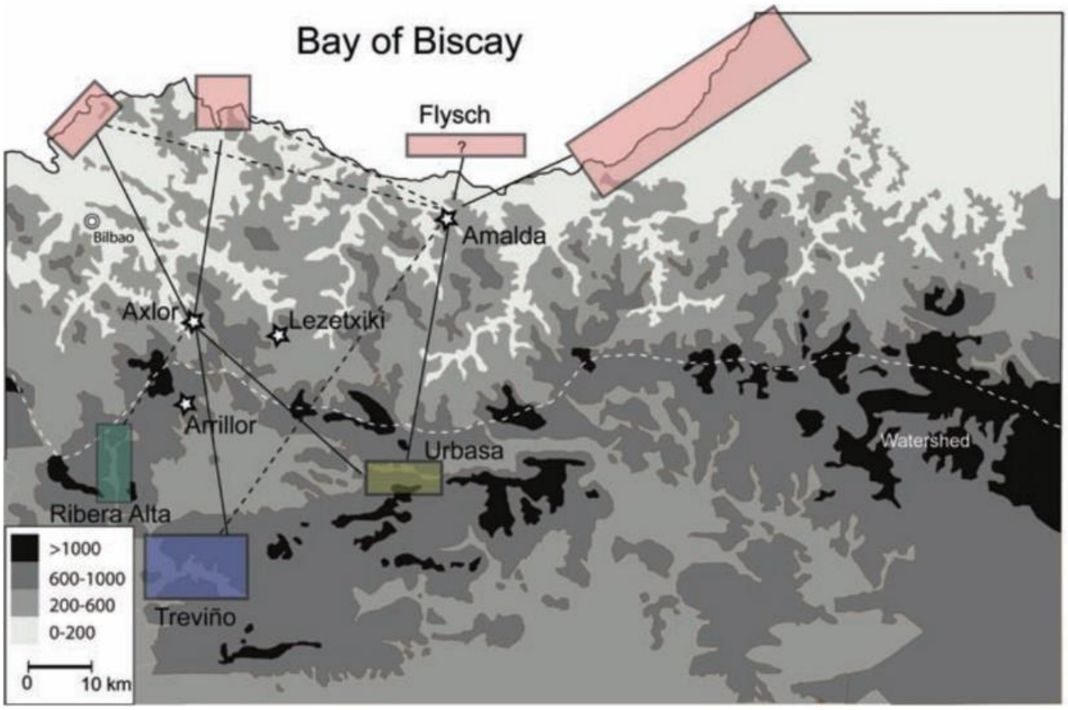


Figure 3.3: Flint sources used at Amalda and Axlor, with details in text (from Rios-Garaizar and Garcia-Moreno 2015, 335)

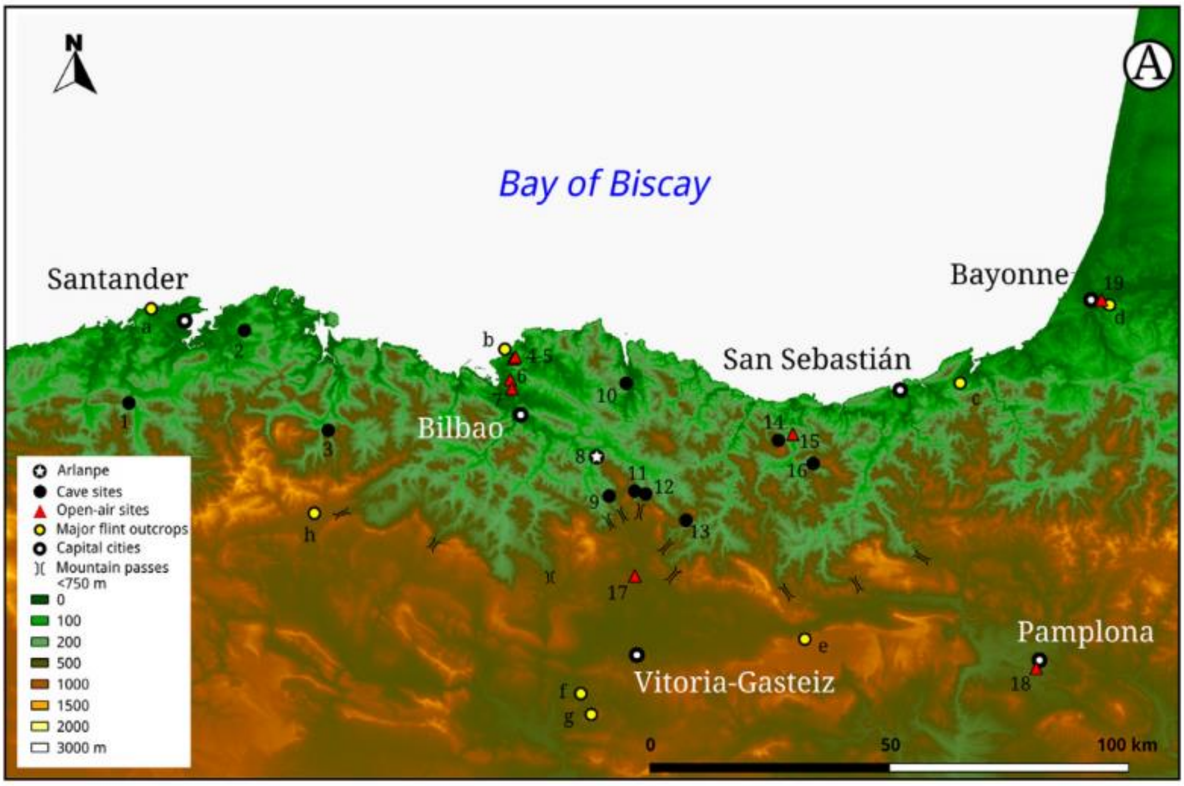


Figure 3.4: Flint sources (yellow circles) used at Arlanpe (Rios-Garaziar et al. 2015, 235). Relevant sites listed include 1: El Castillo; 8: Arlanpe; 9: Axlor; 13: Lezetxiki. Flint outcrops: a: Monte Picota; b: Kurtzia; c: Gaintxurizketa; d: Bidache; e: Urbasa; f: Trevino; g: Loza; h: Ojo Guarena.

scarce appearance in the upper levels (Rios-Garaizar and García-Moreno 2015, 336-7). Flint is the most used raw material across the levels (V, IV, III) at Lezetxiki, again coming mostly from non-local sources situated more than 30 km away (Rios-Garaizar and García-Moreno 2015, 337).

3.2.4 Summary of raw material transports

In the Middle Palaeolithic, the use of raw materials across Asturias, Cantabria and the Basque Country largely follows local patterns of resources. In general, sites further west concentrate on locally abundant quartzite, with flint use increasing towards the east, where sources are far more bountiful. This implies that mobility for most groups in this region focused on the immediate surrounding area, with hints of occasional longer distance movements at some sites. There is some evidence for particularly restricted mobility, where terrain appears to have influential factor. In particular, the rough, steep environment surrounding El Esquilleu, where movement appeared to be limited to 5 km around the site. There has yet to be a study which considers the implications of terrain on a regional scale, so the exploration of energetics here will expand understanding.

Finally, there are also some interesting relationships between changes in occupation type and the distances of raw material procurement. For example, both El Esquilleu and Axlor demonstrate a move from stable occupations, to more short-term visits through time. The impact on raw material use is opposite however, with the use of local resources increasing at Esquilleu, but decreasing at Axlor. This is a reminder that although local availability will undoubtedly be an important factor in resource procurement, factors specific to the occupants such as how the site is being used and the composition of the group using it, will also have had great influence.

3.3 Regional flake cleavers in the late Middle Palaeolithic

Flake cleavers are rare in the Middle Paleolithic, except in the late Mousterian in a limited geographic zone, which incorporates sites included in this study (Figure 3.5; Claud et al. 2015; Deschamps 2017). Whilst remaining controversial since their first proposal in the

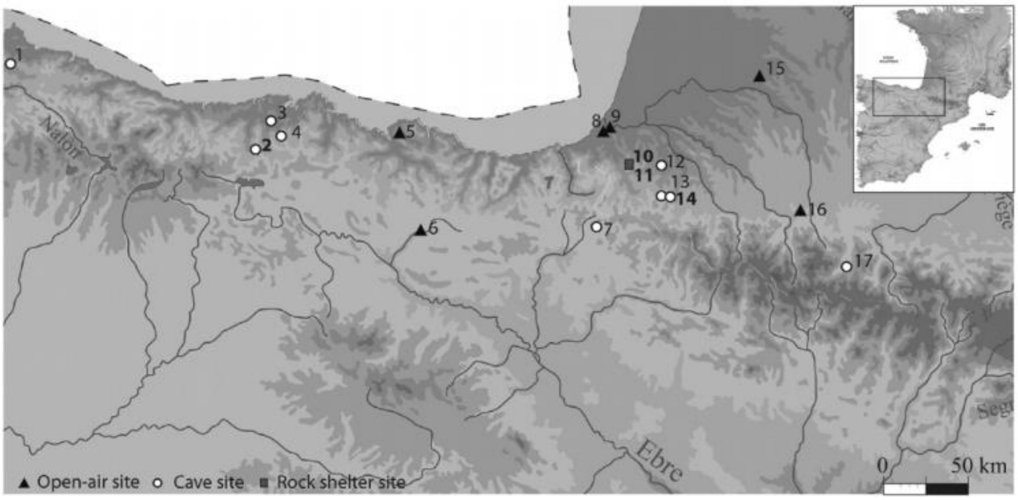


Figure 3.5: Distribution of late Middle Palaeolithic sites in the Vasco-Cantabria region that have yielded cleavers (from Claud et al 2015, 2). The location of sites used in this study: 1. La Viña, 2. El Castillo, 3. El Pendo, 4. Morín, 7. Abauntz.

1950s (Bordes 1953), this group of regional tools have often been used to infer connections and mobility between sites and have received renewed interest in recent years (e.g. Deschamps 2017; 2019). The cleavers, traditionally known as the Vasconian, are characteristically made out of coarse-grained stones such as quartzite and ophite, despite the availability of flint in the region (Cabrera et al. 2004; Claud et al. 2015). Several studies have sought to uncover the possible functions of these tools, leading some to suggest their use could be specialised. For example, a recent study by Claud et al. (2015) analysed use-wear traces at four Middle Palaeolithic sites, including Level 20 of Castillo where a particularly large number of cleavers (N=250) were recovered. The macro-traces of use were compared with an experimental reference collection, revealing similarities with pieces which were hafted and used for percussion to fell trees and divide carcasses (Figure 3.6; Claud et al. 2015). This interpretation expanded upon previous use-wear analyses which similarly suggested the cleavers were used in the initial phases of butchery, wood and hideworking, when weight and large edges were needed (Rios-Garaziar 2010; Utrillo and Mazo 1996). This possible specialised function, along with the identical manufacture and selective use of raw material, have all been used to support potential connections between site assemblages.

Researchers studying the assemblages from Abauntz have argued that the cave should be included as part of the regional cleaver group (Mazo et al. 2012; Utrillo et al. 2015). Eleven cleavers were recovered from the site, representing 26% of the lithic assemblage (Utrillo

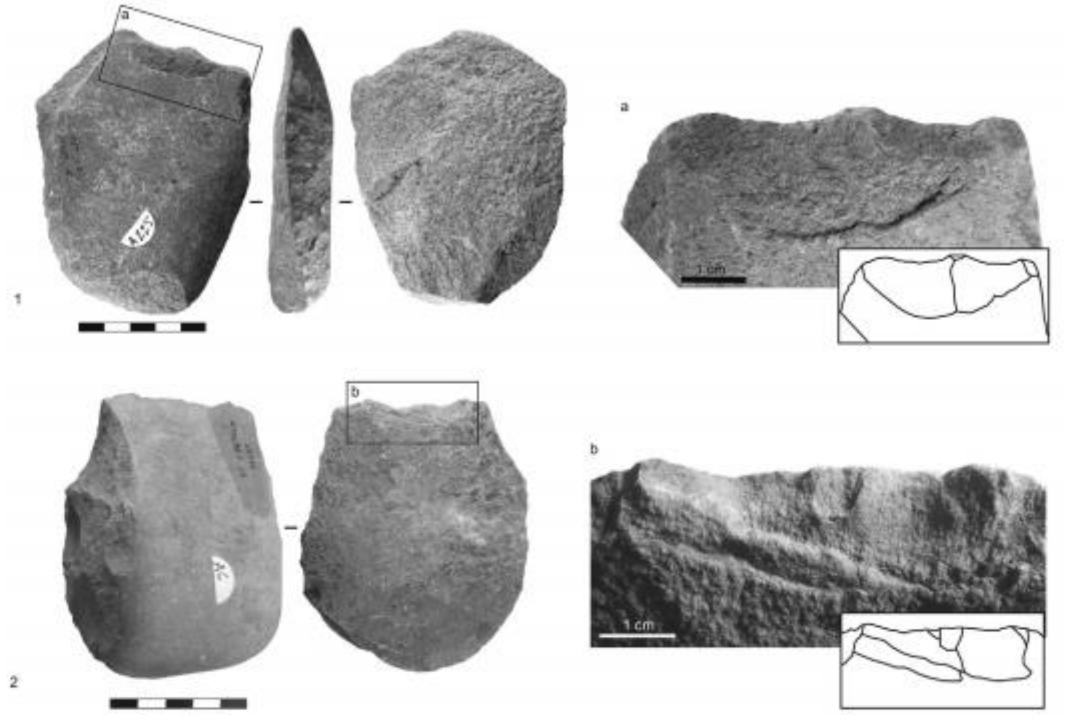


Figure 3.6: Mousterian cleavers from Castillo cave and macro-wear indicating their use with a percussion action on a medium hard material, such as wood (1) and a hard material, such as bone (2) (from Claud et al. 2015, 19).

et al. 2015, 296). All were produced from typical non-flint materials and demonstrate the same manufacture characteristics seen elsewhere. Use-wear analysis also suggest comparable functions (Utrilllo et al. 2015, 296).

In another study, Cabrera et al. (2004, 441) specifically links the sites El Castillo, El Pendo and Morín through their presence of ophite and quartzite cleavers. The three sites form a triangle between the Bay of Santander and the valley of the Pas river, with no more than 25 km between each (Figure 3.1; Cabrera et al. 2004). The researchers note the following:

"Their stylistic attributes undoubtedly result from a shared cultural knowledge among the early humans regarding their production. Also, the cleavers are associated with the selection of particular raw materials, which generally occur close to the occupations, and which, at least in the case of the area circumscribed by these three Cantabrian sites, are very rarely used for the manufacture of other kinds of tools. If the chronostratigraphic interrelationship of the three cave deposits is confirmed, then [flake cleavers] will serve as valuable microregional indicators of group mobility, exchange, and territorial extent." (Cabrera et al. 2004, 444).

If these sites did form part of the same settlement system at various times, seasonality studies have the potential to offer further insight. Pike-Tay et al. (1999) undertook dental growth mark analysis from faunal remains at El Pendo, El Castillo and Morín, revealing possible seasonal behavioural patterns. Both El Pendo and Morín could have feasibly acted as an autumn and winter camp for small groups, who then moved to Castillo in the spring (Pike-Tay et al. 1999, 312). Many of these interpretations however, come with the caveat of chronology, which remains a serious issue in the interpretation of flake cleavers and the region in general. Rios-Garaziar (2017, 59) also points to the difficulty in defining the cleaver technocomplex given the variability of assemblages in which they are found. It raises the question of whether the mere presence of these tools is enough to draw a connection between sites (Rios-Garaziar 2017, 59).

Despite these difficulties, the tools are still notable based on their sheer quantity at some sites. For example, the 250 cleavers at El Castillo suggests a repetition of specific activities (Claud et al. 2015, 20), which would likely have strong implications for how the group was organised and how they move as a consequence. In addition, it is often suggested that this group of tools implies the transfer and sharing of knowledge, but there has been little explicit study on this. Drawing inferences about group composition from lithic-based evidence of learning has been achieved elsewhere (e.g. Stapert 2007; Uthmeier 2013), so this could be a valuable next step in understanding the implications of these regional tools. Overall, the use of late Mousterian flake cleavers as an indicator of group mobility remains debatable. Existing issues are unlikely to be resolved without further direct dating and continued work on the sequencing of industries (e.g. Deschamps 2019).

3.4 Models of game procurement

The final source of mobility evidence considered here is work by Rios-Garaizar and García-Moreno (2015), who modelled game procurement strategies at Amalda, Arrillor, Axlor, and Lezetxiki. The study reconstructed the potential distribution of forest and ungulates within a two-hour walking territory of each site, under two climatic conditions (stadial and interstadial). The hypothetical distributions were then compared to archaeological evidence, including lithic industries, raw material use and faunal remains, in order to assess whether Neanderthal behaviour reflected the natural potentiality of the local surroundings.

At Amalda, there was a clear link between the local territory and chosen prey, with animals from rocky environments representing 70% of the total (Rios-Garaizar and García-Moreno 2015, 352). Similarly, at Arrillor, where the local environment is more heterogeneous, procurement strategies match the more diversified spectrum of animals available. This dependence on local resources extends throughout the levels, with variances in prey corresponding to climatic differences (Rios-Garaizar and García-Moreno 2015, 354).

On the other hand, despite the steep reliefs surrounding Axlor and Lezetxiki, game strategies were focused on non-local resources, with rugged terrain animals never exceeding 33% of the total (Rios-Garaizar and García-Moreno 2015, 353). This suggests that the groups using these sites developed planned catchment strategies within an extended territory, which allowed for the specific hunting of non-local herbivores (Rios-Garaizar and García-Moreno 2015). As already discussed, lithic analysis also supports this interpretation, with Axlor level B and Amalda level VII in particular demonstrating a great dependence on non-local flint. As the authors note, if climate or environment are not the major determinant in mobility strategies, “then we may need to start looking for satisfactory explanations in demography, territorial patching, or social changes inside Neanderthal societies, or more appropriately, in a combination of these factors” (Rios-Garaizar and García-Moreno 2015, 357). Mobility at these sites is therefore interpreted as planned and socially driven, and this study will offer a new approach to accessing how social group size and composition may have been an influence.

3.5 Chapter 3 conclusions

This chapter has demonstrated that, once a regional perspective is taken, the complexity and nuances of Neanderthal mobility can begin to be understood. Whilst local environment and resource availability is often an important factor, it is clear that the patterns seen in archaeological evidence cannot always be explained by this alone. There are differences in raw material transports inter-site, but also between levels intra-site, which hints at the variability in site use, subsistence and demography we should be expecting from hunter-gatherers. The possibility of a shared, late Middle Palaeolithic cleaver technology is also a reminder that we need to consider sites in their wider context and how they may fit within a regional settlement system. The study by Rios-Garaizar and García-Moreno (2015) is particularly relevant for this research, as it argues for socially driven mobility for a number of sites in this region. There have been no attempts to consider how variability in social organisation may have impact group movement in this region. This study can therefore add important insights into current debates.

Table 3.1: Middle Palaeolithic sites collated from NESPOS located in the northern Spain regions of Asturias, Cantabria, Basque Country and Navarre. Additional sources are cited throughout.

New abbreviations used in the table:

- *EMP - Early Middle Palaeolithic*
- *LMP - Late Middle Palaeolithic*
- *m.a.s.l. - metres above sea level*

Several sites have been excluded:

- *Coscobilo cave (Olazagutía, Navarre) - Middle/Upper Palaeolithic site that no longer exists due to a quarry being built.*
- *Covalanas cave (Ramales de la Victoria, Cantabria) - Upper Palaeolithic art site, but also listed as a Middle Palaeolithic site with evidence of Capra in Yravedra and Cobo-Sánchez (2015, 16), but no sources cited and listed as 'no data' available.*
- *El Polvorín (Carranza Valley, Biscay, Basque Country) - a possible Middle Palaeolithic occupation and a possible Neanderthal deciduous premolar have been briefly mentioned as part of new excavations (Ruiz Idarraga and d'Errico 2007), but no further details are currently published.*

Site	Site context	Archaeological material	Chronology	Sources
Abauntz cave (Arraitz, Navarre) Excavated 1976-1979; 1988-1996	Long sequence ranging from the Mousterian to the Late Roman period. Ten stratigraphic levels cover 50,000 years of seasonal visits by Neanderthals and AMH. Occupied as a domestic camp in the Mousterian, in the periods when bears abandoned their hibernation dens. Abauntz is located in a mid-range mountain area with weathered peaks, 650 m.a.s.l. and 40 km from the coast. The site is in a favourable location as it controls the pass between the southern plains and the more abrupt environs at the head of the Zaldazaín creek, covered by a dense deciduous forest.	**Level H - Mousterian** • No structures or hearths, but burnt bones present. • 42 lithic remains including 11 cleavers, 2 handaxes, 2 sidescrapers, 2 endscrapers, 3 truncations, and 4 retouched flakes. • 90% of faunal remains were deposited during the natural use of the cave by bears and other carnivores. Cut marks present on deer remains.	>45,000 BP (AMS) 47,000 ± 7000 BP (AAR)	Mazo et al. 2012; Utrilla et al. 2015

Amalda cave (Zestoa, Gipuzkoa, Basque Country) Excavated 1979-1984	Stratigraphic sequence spans from the Mousterian to the Roman period. Occupied during the Mousterian as a multi-functional site, involving both domestic and logistic activities. Amalda cave opens up onto a narrow valley subsidiary of the Urola River, 205 m.a.s.l. and 8 km from the coast. The surrounding landscape is steep and mountainous, in a region characterised by a variety of ecological niches.	**Level VII - Mousterian** • Occupation extends over a large surface (around 60 m^2) where a structured occupation pattern has been observed. • 1084 lithic remains, with spatial distribution suggesting organisation of space for different tasks. • Use-wear analysis indicates different production phases of wood tool-making, hide processing and/or carcass butchery. Cleavers present. • Faunal assemblage is mainly composed of small herbivores from rocky landscapes imported in their entirety to the site (chamois) and some other herbivores (red deer, horse, bison). Interpreted as intense hunting site of chamois, but this has been debated.	MIS 4 (but a more recent chronology has been argued)	Rios-Garaizar 2010; 2017; Rios-Garaizar and García Moreno 2015; Yravedra 2010a
Aranbaltza III open-air (Barrika, Biscay, Basque Country) Excavated 2013-present	Aranbaltza is an archaeological complex formed of at least three open-air sites (Aranbaltza I, II and III), with comparable archaeo-sedimentary sequences spanning from the Late Middle Pleistocene to the Holocene. Aranbaltza III is consistent with LMP open-air occupation. Long sequence was formed between 137–50 ka and includes several archaeological horizons, attesting to the long-term presence of Neanderthals in this area.	**Unit 1, 4 and 5 - Mousterian** • Unit 1 - abundant Mousterian lithic remains (N=901). • Unit 4 - two wooden tools (including one interpreted as a digging stick) and one flint flake. Pollen analysis suggests relatively temperate and humid conditions. • Unit 5 - rich in lithic artefacts including discoid technology, also unworked wood materials.	137-50,000 BP it 2,3,4,6 - OSL) >70,000 ± 8400 BP (minimum age of Unit 4 - OSL)	Rios-Garaizar et al. 2012; 2018a

	Aranbaltza III is located in the bottom of a small valley that runs towards the Butron river mouth. Although the current coastline is very close to the site (800 m NW), it is separated from the site by a raised cliff (90 m.a.s.l.).			
Arlanpe cave (Lemona, Biscay, Basque Country) Excavated 2006-2011	Sequence includes occupations from the Early Middle Palaeolithic to Late Roman period. EMP layers divided into two major sedimentary sequences (SQ2 and SQ3). Occupations during SQ2 interpreted as occasional and short. SQ3 corresponds to longer occupations where different resources were processed intensively, at least partially, at the site. Both represent groups moving through extensive territories. Arlanpe is located in the Arratia Valley close to its confluence with the Ibaizabal River, 25 km from the coast and <750 m.a.s.l. Environmental data suggests that the surrounding area was mixed with rocky surfaces, temperate woods with pine and riverine trees, as well as open spaces probably located in the valley. The position of the cave offers a good view of the Arratia and Ibaizabal rivers, which likely attracted herbivore herds.	Across the whole EMP sequence, the most abundant species is ibex and chamois, which is consistent with the surrounding rough terrain. **SQ2 (levels VI, 5 and 4)** • Lithic assemblage is characterised by levallois, laminar and discoid flaking systems, without bifaces. • Carnivores quite abundant. Faunal remains with anthropic marks present. Significant amount of land snails suggesting possible collection and consumption. • Environment data suggests relatively warm conditions, with a significant development of forests. **SQ3 (levels V, IV, 3 and D)** • Lithics assemblage characterised by the combination of SSDA, levallois and discoid flaking systems and the presence of poorly standardised bifacial tools, all made from local raw	MIS 6 (SQ2) MIS 5/5e (SQ3)	Rios-Garaizar et al. 2011; 2015

		materials. • Number of caprines notable. Faunal remains with anthropic marks present. • Colder conditions at the start of sequence, but then warm and humid conditions.		
Arrillor cave (Murua, Álava, Basque Country) Excavated 1989-1997	Long stratigraphic sequence divided into three sedimentary complexes (lower, middle and upper). Most of the 22 archaeological levels have yielded only a small number of artefacts. Post-depositional processes have reduced the Magdalenian occupations to residual evidence. However, level Amk, Smk-l and Lmc provide significant evidence of intermittent but repeated human occupation during the Middle Palaeolithic. Arrillor is located in the southern foothills of the Gorbea Mountains at the boundary with the Alavese Plateau, at 710 m.a.s.l. and 50 km from the coast. The cave is in a strategic position with reliable sources of water in the nearby valleys and positioned on a necessary route of passage for humans and animals.	**Middle complex (level Amk) - Mousterian** • One Neanderthal molar (AR-1740) from an individual aged 9-13 years. • Upper part contains layer with hearths. • Significant and varied assemblage of lithic implements in flint and quartzite, including typical Mousterian elements (sidescrapers, points and denticulates) and more morpho-technologically evolved artefacts (endscrapers, truncated pieces and burins). • Ungulates dominate the faunal record, particularly red deer and large bovines (*Bos bison*). • Interstadial conditions. Environmental data suggests significant woodland development. **Middle complex (level Smk-I) - Mousterian** • Assemblage relatively specialised in sidescrapers and points, and the	~48,500 BP (level Amk) ~45,600 BP (level Smk-I) ~ 44,900 BP (level Lmc)	Iriarte-Chiapusso et al. 2019; Rios-Garaizar and García Moreno 2015

		Levallois technique. Lyddite is the most abundant raw material. - Ibex remains are common, together with red deer and large bovines. **Upper complex (level Lmc) - Mousterian** - Typical Mousterian elements and some morpho-technologically evolved types (endscrapers and burins) that were made mostly in flint of acceptable quality, but also local rocks like quartzite and quartz. - Dominance of red deer over chamois and bison. Appearance of rhinoceros, roe deer and horse in small quantities. - Cold stadial conditions.		
Axlor cave (Dima, Biscay, Basque Country) Excavated 1967-74; 2000-2008	Long stratigraphic sequence with several Mousterian levels divided into two sequences (upper and lower). Upper sequence is interpreted as a palimpsest of repeated, short-term occupations dedicated to processing carcasses and animal by-products. Lower interpreted as residential occupations with a complex subsistence and tool provisioning system. Site therefore sees a major shift from stable occupations with a Levallois-based technology to shorter, repeated occupations with a Quina-based technology. Axlor is located on the northwest slope of the Urrestei mountain, close to the Indusi stream, a tributary of the Arratia river, at 320 m.a.s.l. and	**Upper sequence (levels B-F / III-V in old stratigraphy)- Quina Mousterian** - Five Neandertal dental remains and a maxilla fragment from the same young adult individual (level III-IV). - Lithics consistent with Quina Mousterian. Abundant use of non-local flint. Intensive curation, production and use of lithic tools. Bone tools also abundant. - Faunal assemblage dominated by red deer, large bovids, goats and horses, with evidence of intense carcass processing. Cut marks also present on avian and carnivore remains.	42,010 ± 1280 and >43,000 BP (Upper, level D - AMS) MIS 3 (Lower)	García-Diez et al. 2013; Gómez-Olivencia et al. 2018; Rios-Garaizar 2003; 2017

	33 km from the coast. It is near one of the lowest mountain passes linking the Cantabrian basins and the Alavese Plateau.	**Lower sequence (levels M-N / VI-VIII in old stratigraphy) - Mousterian** • Pebble with anthropic modifications (level VIII). • Presence of repeatedly used hearths. • Levallois-based technology, with complex provisioning strategy. Some bone tools and a possible bone fragment decorated with parallel incisions. • Faunal assemblage is mostly composed of red deer.		
El Castillo cave (Puente Viesgo, Cantabria) Excavated 1910-1914; 1980-2011	26 sedimentological units with archaeological assemblages ranging from the early Middle Palaeolithic to the Azilian. Consistently occupied during the Middle and Upper Palaeolithic. Seasonality analysis of Mousterian Level 20c suggests possible longer term and repeated use by groups during the cold season, with smaller scale, shorter term occupations during the warm season. El Castillo is located in the upper part of the Pas valley at 190 m.a.s.l. and 17 km from the coast. It at the southern edge of the Santander coastal plain in the first foothill range of the Cantabrian Mountains. The cave opens half-way up a steep, conical mountain of the same name, which stands out in the landscape and may have represented a visible landmark. El Castillo is located in the same river valley as Covalejos cave, about 14 km away along the River Pas. La	**Levels 20-26 - Mousterian** (most detail currently available for level 20, which is divided into 20 a/b, 20c, 20d, and 20e) • Clear evidence of Mousterian lithic technology, including a large amount of flake cleavers (N=250, level 20). • Abundant evidence for the repeated use of at least one hearth. • Temperate suite of fauna, dominated by red deer, but horse and *Bos* also abundant. Occasional fragments of roe deer and chamois. Skeletal profiles of red deer indicate transport of whole carcasses, suggesting prey hunted locally. Seasonality analysis suggests year round hunting episodes, but majority taken from late autumn through spring. • Bone collagen δ13C values are	48,700 ± 3400 49,400 ± 3700 uncal BP (Level 20c - AMS AF) 59, 100 BP (Level 22 - ESR)	Bernaldo de Quiros et al. 2014; Cabrera et al. 2004; Claud et al. 2015; Jones et al. 2019; Pike-Tay et al. 1999; Wood et al. 2018

	Flecha cave is located on the same mountain, about 200 m away.	constant through time, suggesting that there was very little change in tree cover or climate during MP/UP and a predominantly open landscape prevailed. - Level 21 - decorated quartzite pebble (5.7 cm long) with a line of four pitted points, with a fifth one above them.		
El Conde cave (Tuñón, Santo Adriano, Asturias) *a.k.a. El Fornu* Excavated 2001-2008	Sequence spans from the Mousterian to the Aurignacian. Three distinct zones have been identified: the External Zone, the Entrance Platform and Gallery A. Faunal analysis suggests the site was occupied for seasonal hunting during the Mousterian. El Conde cave is a large, northeast facing cavity located some 40 m above the River Trubia, a tributary of the River Nalón. It is located at 180 m.a.s.l. and 30 km from the coast. Small vertebrate analysis suggests a patchy landscape, dominated by humid meadows and woodland areas with the existence of water in the vicinity of the cave.	**External zone (level N103 and N104), Entrance Platform (level N20a), Gallery A (level N2a1) - Mousterian** - Mousterian lithics. - Temperate suite of fauna. Remains dominated by deer, also evidence of horse, Iberian ibex, wild boar and chamois.	MIS 3 39,110 ± 520 BP (level N104) 38,250 ± 390 BP and 37 710 ± 470 BP (level N20a)	Adán and Arsuaga 2007; López-García et al. 2011; Uzquiano et al. 2008
Covalejos cave (Velo, Piélagos, Cantabria) Excavated 1879; 1997-	Long stratigraphic sequence ranging from isotope stages 3 to 5, containing EMP to Aurignacian levels. Several Mousterian layers (D, H, I, J, K and M). Interpreted as short term occupations with carnivore inhabitation and flooding events in between. Covalejos is located close to the mouth of the river Pas in the lower part of the Pas valley, 48	**Level D, H, I, J, K and M - Mousterian** - Level J - Quina Mousterian, level D - discoid core technology. - Abundance of deer throughout suggests specialised hunting. - Taxa such as reindeer could reflect cooler conditions in levels B, C, I, J and K. Presence of animals like fallow deer	43,050 + 750 / - 550 uncal BP (Level D - AMS) >45,000 BP (Level J - AMS)	Jones et al. 2019; Maroto et al. 2012; Yravedra et al. 2016

1999; 2002	m.a.s.l. and 7 km from the current coast. The surrounding environment is characterised by a gentle landscape with low hills below 250 m. The palaeoenvironment seems to have been dominated by a wooded landscape with different taxa depending on weather conditions. The site is located in the same river valley as El Castillo, which is around 14 km along the River Pas.	in level D reveals more temperate and humid conditions. • Skeletal profiles of red deer indicate complete transport of whole carcasses to site, suggesting prey hunted locally. • Large inter-individual variations in δ15N values within Levels B and D suggests animals being procured from different isozones surrounding the site. Inter-level differences in $\delta^{34}S$ values suggests animals from different sulphur regions, indicating larger hunting ranges, possibly corresponding with periods of higher resource pressure or increased population density. • Pollen and charcoal evidence similarly suggest slightly cooler conditions in level J, but overall stability in terms of vegetation.		
El Cuco rockshelter (Castro-Urdiales, Cantabria) Excavated 2005	Long stratigraphic sequence composed of 14 archaeological levels (I-XIV). A new chronology has recently been proposed with assemblages originally attributed to the Evolved Aurignacian technocomplex (levels VI to XIII) now attributed to the regional LMP. El Cuco is located at the base of a limestone cliff on the southern slope of the Alto de San Andrés, only 350 m from the current coastline. Environmental analysis suggests a transition from low temperatures (level XIII), with few arboreal species present, to more temperate	**Levels VI - XIV - Mousterian** • Level VII has a rich lithic assemblage (N=11,282) and characterised by a ramified Levallois strategy. • Intensive use of flint (>95%), from both local and to a lesser extent, non-local sources. Other levels are similar (flint-based and Levallois technology), with a detailed re-evaluation ongoing. • Predominance of red deer. • Evidence of systematic shell collection (levels X to XIII). Most shell	42,300 and 46,200 BP (level X) >43,500 BP (level XII) 46,400 BP (level XIII)	Gutiérrez-Zugasti et al. 2013; 2018; Marín-Arroyo et al. 2018b

	conditions (level X) with a notable expansion of woods. Levels IX-VI show a decrease of woodland and some evidence of aridity.	assemblages within the oldest portion (levels X, XI and XII). Variety of taxa, although only limpets (*Patella*) found in any significant quantity. Possible collection of land snails (*C. nemoralis*).		
El Esquilleu rockshelter (Cillorigo de Liébana, Cantabria) Excavated 1997-2006	One of the most complete chronological sequences in the Cantabrian Mousterian, with 41 archaeological layers covering almost all of MIS 3. Site used for specialised hunting of Iberian ibex and chamois and the exploitation of local resources. Evidence for seasonal practices is inconclusive, but the main activity at the site occurred during the milder seasons. El Esquilleu Cave is located on the southwestern slopes of La Hermida gorge, 350 m.a.s.l. and 19 km from the coast. Highly mountainous area which consists of a corridor that connects the coastal area with the Liébana Valley, which is bounded by the Picos de Europa mountains. The rocky, steep terrain may have hindered Neanderthal mobility, although favoured ibex and chamois.	• 99.2% of the lithic materials used throughout the site are found within 200 m of the cave. Although levels 7 to 20 show a greater variability and a wider geographical range, extending to the coastline. • Dominance of Iberian ibex and chamois, which make up >85% of the assemblage of each level with the exception of levels 7, 9 and 12. Deer third most common taxon. Skeletal profiles indicate the transportation of complete ibexes to the site in all levels, together with deer in level 11F. **Levels 3 to 5 - Mousterian** • Ephemeral occupation evidence with discoid technology using local raw materials. **Levels 6 to 14 - Quina Mousterian** • Dense occupation with abundance of Quina Mousterian technology, utilising a greater diversity of raw materials.	>53,000 - 30,000 BP	Baena et al. 2012, 2019; Yravedra et al. 2014; Yravedra and Gómez-Castanedo 2014; Yravedra and Uzquiano 2013

		Levels 15 to 30 - Mousterian • Hearths identified in levels 21, 23, 25, 28 and 29. Abundant burnt and charred faunal remains of ibex found in level 21 and 23 hearths, also with evidence of repeated use (hearth 21c). Level 21 - intentional breakage and deliberate disposal of bones in fire. • More specialised occupation with Levallois, discoid and Quina technology.		
La Flecha cave (Puente Viesgo, Cantabria) Excavated 1951	Discovered during works to build a road in 1951, but not excavated systematically and with little documentation. A drawing of the stratigraphy exists, but the material was not published and not stored by level or with any contextual information. Some lithic material lost in the time between the study by Freeman and González Echegaray (1967) and reanalysis by Catenado (2001). Butzer (1981) proposes a short archaeo-sedimentary sequence, including several units with Mousterian occupation (unit 2, 4 and 5). 'Denticulate Mousterian' suggests a different, specific site function to El Castillo (Butzer 1981). La Flecha cave opens on the upper slope of Monte Castillo, a steep, conical shaped mountain of white limestone. It is located 110m above the valley of the Pas River and 175 m.a.s.l. El Castillo cave is also located on the mountain, less than 200m away.	**Unit 2, 4 and 5 - Mousterian** • Mousterian lithic industry. • Nearly all the raw materials come from the local area, largely within a few kilometres from the cave. Ophite, limestone and sandstone pebbles are easily obtainable from the nearby Pas River. Small quantities of flint are from greater distances. • Main taxon *Cervus* (data unpublished). • Unit 4 and 5 both described as light occupation and Unit 2 as moderately intensive with abundant bone, artefacts and charcoal fragments.	31,640 ± 890 BP (SI-4460)	Butzer 1981; Castenado 2001; Freeman and González Echegaray 1967; Yravedra and Cobo- Sánchez 2015

La Güelga cave (Narciandi, Cangas de Onis, Asturias) Excavated 1989-2008	Rich and complex sequence from the Middle and Upper Palaeolithic. Zone D contains archaeological levels defined as Mousterian, Châtelperronian and Early Aurignacian. Evidence for intense Mousterian occupation, suggesting a recurrent and prolonged use of the site by Neanderthal groups. La Güelga is located at the bottom of a mountain valley in the Eastern part of Asturias, at 186 m.a.s.l. and 15 km from the coast. The cave mouth is located at the base of a cliff with a strong relief and the entrance morphologically resembles a large stony rockshelter in which the river incised its course.	**Zone D (interior) level 9 - Mousterian** • Intense human occupation, with multiple combustion areas. • Local quartzite lithics, Levallois type blanks, side-scrapers, backed knives and retouched flakes. • ~8000 faunal remains, dominated by deer and chamois (75%). Anthropic marks on 25% of the roe deer remains, as well as 40% of the chamois and red deer. High levels of fire alteration. **Zone D (exterior) level 4b - Mousterian** • Four Neanderthal teeth. • Remains of combustion present. • Mostly local quartzite. Flint is scarce, but Piloña type present. High percentage of Levallois pieces. Worked bone present. • Rich faunal assemblage, dominated by red deer and chamois. Burnt bone and anthropic marks present. **Zone D (interior) level 1 and 2 - Châtelperronian** • Quartzite and flint pieces, mostly Middle Palaeolithic technologies and typical assemblages (scrapers, notches and denticulates). Some blades made of distantly sourced flint. • ~3200 faunal remains, with chamois	>45,300 cal BP (level 9 - R14) ~45,800 - 41,400 cal BP (level 2 - R14)	Menendez et al. 2014; 2018; Jordá Pardo 2013; Kehl et al. 2018

		and deer best represented. • Anthropogenic marks present in both levels, particularly high in Level 2. 11% of level 2 total show alterations by fire.		
Hornos de la Peña cave (Tarriba, San Felices de Buelna, Torrelavega, Cantabria) Excavated 1906; 1909-1912; 2016-ongoing	Sequence spanning from the Mousterian to the Neolithic. However, there is a lack of definition of the archaeological sequence, as well as bias created by old excavation methods and difficulties attributing specific artefacts to the archaeological units originally described. Reanalysis and reexcavation since 2016 has revealed several Mousterian layers (Level 8-14), including a rich and well-preserved Neanderthal occupation (Level 13, currently unpublished). Hornos de la Peña is located in the Corrales de Buelna valley, 18 km from the coast and 280 m.a.s.l. The area is characterised by a mountain landscape open to many different ecological niches. Mount Castillo and its associated Middle Palaeolithic sites are located only 6 km NE.	Mousterian level V is described by Yravedra (2010; 2013), but levels appear to have been renamed in recent reanalysis (currently unpublished, see Rios-Garaizar et al. 2018). **Level V - Mousterian** • Faunal analysis restricted by early field methodology. Chamois is well represented, but appears to be introduced by carnivore activity. Deer and horse dominant and yield evidence of human activity in the form of cut and percussion marks. Auroch remains also show anthropic activity.	> OIS 3	Yravedra 2010b, 2013; Rios-Garaizar et al. 2018b
Lezetxiki cave (Arrasate, Gipuzkoa, Basque Country)	The Lezetxiki archaeological complex consists of the 'classic' Lezetxiki deposit which was first excavated 1956–1968 and located at the southern entrance of the cave, and a small adjacent cavity known as Lezetxiki II, which was excavated as part of renewed work in 1996-2016. Lezetxiki II is located at the eastern entrance.	**Lezetxiki (classic) - level VI-V (EMP) and level IV, III (Mousterian)** • Level III - two Neandertal teeth. Levallois and Quina production. Flint imported from sources >30 km away from the site. Faunal assemblage consists of many carnivores, plus bovid, red deer and goat.	>46,500 BP (Lezetxiki - level IIIa) >55,000 BP (Lezetxiki - level V) MIS 5(e?)	Arriolabengoa et al. 2018; Baldeón 1993; Garcia-Ibaibarriaga et al. 2015, 2018; Maroto et al. 2012; Rios-Garaizar

Excavated 1928; 1956-1968; 1996-2016	The sedimentary sequence of the classic deposit is extensive and divided into eight main levels (I-VIII). Occupation interpreted as part of planned catchment strategies, involving movement around an extended territory in order to hunt specifically selected herbivores which are limited locally. Lexetxiki II is formed of 11 levels and interpreted as sporadic occupation by carnivores and human groups. The Lezetxiki complex is located on a steep hillside in an area of abrupt relief in the upper valley of the River Deba, near the end of the Bay of Biscay. The caves are well positioned over the surrounding valley area, at 380 m.a.s.l. and 30 km from the coast.	• Level IV - low density of remains. Flint again imported from >30km away. Abundant carnivores and herbivores dominated by red deer. • Level V - lithics scarce, includes Levallois technology. Main raw material is flint. Cave bear dominates, with red deer as the main ungulate species. **Lezetxiki II - Level G, H and I - Mousterian** • Small Mousterian lithic assemblages. • Faunal remains with some evidence of human activity. • Remains of *Muscardinus avellanarius* (hazel dormouse) in Level G. Presence agrees with the abundance of rodent species indicative of woodland, suggesting mild climatic conditions and a landscape formed by deciduous forest. Provisionally interpreted as warm and humid conditions related to an interstadial period in MIS 5(e?).	(Lezetxiki II - Level G)	and García Moreno 2015
Llonín cave (Peñamellera Alta, Asturias) Excavated	The archaeological sequence spans from the Mousterian to the Bronze Age, distributed through the Galería (G), the Vestíbulo (V) and the Cono Anterior (CA) and Cono Posterior (CP). Cave was occupied alternately by hyenas, leopards and canids, as well as by Neanderthals for short, sporadic phases. Subsistence activities revolved around the processing and	• No evidence of hearths. • Skeletal profiles indicate entire animals were transported to site for processing and consumption. • Mousterian evidence is scant, indicating sporadic occupation.	MIS 3 43,539 ± 2419 BP (CP level VIII)	Sanchis et al. 2019

1987-1997	consumption of deer and, to a lesser extent, caprines. Llonín is located in the basin of the rivers Cares and Deva, surrounded by a mountainous landscape. The cave entrance lies 112 m.a.s.l., 23m above the stream of La Molinuca and 18km from the coast. It is positioned in an area of transition between forest and steeper terrain. Palaeoenvironmental studies at Llonín and regional analyses of plant macroremains indicate open forests with the presence of species that thrived in mild climates.	**CP level VIII - Mousterian** • Anthropic activity, especially cut marks and some percussion notches, appear on ungulate (mainly deer) and indeterminate medium-sized remains, and on one carnivore bone. **G level VI - Mousterian** • Little evidence of anthropogenic modifications.		
El Mirón cave (Ramales de la Victoria, Cantabria) Excavated 1996-2013	Long stratigraphic sequence consisting of 50 levels, which represent frequent occupations of the cave by hominin groups from the Mousterian to the Bronze age, with differing intensities, uses and settlement type. Limited faunal remains and small lithic assemblages suggest short and sporadic occupations by Neanderthals, alternated with occupation by carnivores. Focus on ungulate prey species available in the local environment. El Mirón is located on a mountainside dominating the broad upper part of the Asón River valley. The cave is positioned at 260 m.a.s.l. and 20 km from the present coastline. The surrounding area is mountainous with peaks of ≥1000 m a.s.l. Bone collagen analysis of δ13C and δ15 N values indicate a relatively open landscape.	**Level 130 - Mousterian** • 111 lithic artefacts, including two denticulates on flint flakes, a simple flint burin, 110 items of debitage, one mudstone flake core and a sandstone hammerstone. • Iberian ibex is the most abundant taxon, followed by red deer, then chamois. Three cut marks were found in red deer, ibex and indeterminate ungulate elements. Signs of thermo-alteration present on fragments. • No evidence of hearths or living floors.	47,300 - 42,900 cal BP (Level 130 - AMS)	Cuenca-Bescós et al. 2009; González Morales and Straus 2014; Marín-Arroyo et al. 2018a

Morín cave (Villanueva de Villaescusa, Cantabria) Excavated 1912; 1917–1919; 1966-1969	Long stratigraphy consisting of 22 levels spanning from the Middle Paleolithic to the Epipaleolithic. Mousterian occupation interpreted as short-term and seasonal. Faunal analysis suggests prey were taken during the late autumn and winter. Morín is located at the base of a small, low lying hill, at 57 m.a.s.l. and 6 km from the current coastline. The site has been linked to El Pendo and El Castillo through regionally unique cleavers and may have formed part of the same settlement system. The three sites form a triangle between the Bay of Santander and the valley of the Pas river.	**Levels 11, 12, 13, 14, 15, 16 and 17 - Mousterian** • Deer most abundant across whole sequence, followed by horse and bovid. Cut marks and other anthropic traces present. Carnivore activity present. • Skeletal profiles suggest medium animals transported to site whole, but only the most nutritious parts of large animals. • Local raw material use, mainly flint. • Level 11 and 12 (denticulate Mousterian) are characterised by discoid and partly Levallois production, with a small micro-blade production. • Levels 13-17 show predominance of cleavers. • Level 17 - spatial distribution of finds and presence of a line of piled stones forming a curved area, suggests possible walled structure. No hearths detected inside.	41,800 ± 450 BP (level 11 - OxA-19083) 43,600 ± 600 BP (level 11 - OxA-19459)	Freeman 1992; Maíllo-Fernández et al. 2014; Maroto et al. 2012; Pike-Tay et al. 1999; Yravedra and Gómez-Castanedo 2011
Otero cave (Secadura, Junta de Voto, Cantabria)	Nine archaeological levels spanning from the Mousterian to the Azilian. Interpretation of Mousterian level 9 is limited by early excavation methods. Otero cave is located in the Aras valley at 60 m.a.s.l and 12 km from the coast.	**Level 9 - Mousterian** • Small number of lithics. • Early excavation methods involved selective collection, which means faunal analysis is biased and limited. Deer most dominant, followed by horse and other ungulates, such as	OIS 3	Yravedra 2013; Yravedra and Gómez-Castanedo 2010a, 2010b

Excavated 1963		chamois and ibex. No cut marks present.		
El Pendo cave (Escobedo de Camargo, Cantabria) Early C20th; 1953-1957; 1994-2000	Long stratigraphic sequence spanning from the Middle Palaeolithic to the Bronze Age. Originally interpreted as 18 archaeological levels, but recent reanalysis suggests a total of 33. Mousterian levels interpreted as repeated, small-scale occupations during late autumn and winter. However, recent work warns of contamination and mixing between levels of the 'classic' excavation area, questioning the reliability of previous analysis (Montes 2014). El Pendo is a large downward-sloping cave located at the base of a steep cliff at 90 m.a.s.l. at the northern end of a long valley. The surrounding landscape is relatively gentle and rolling. The cave is within one day of coastal, river valley, forest, and mountain resources.	**Level VIIId, IX, X, XI, XII, XIII, XIV, XV, XVI, XVII (classic) - Mousterian** • Evidence of hearths. • Across all levels, tools are most often made from flint, with the exception of Level XIII, where flint and quartzite are used in equal amounts and ophite cleavers are present. • Faunal remains generally marked by an abundance of red deer. • Seasonality study suggests kills were limited to late autumn through winter. • Regionally unique flake cleavers suggest that, at various times, El Pendo may have been part of the same settlement system as Morín and El Castillo.	MP Under review (Montes 2014)	Butzer 1981; Cabrera et al. 2004; Montes 2014; Pike-Tay et al. 1999
El Ruso (Igollo, Camargo, Cantabria) Excavated 1950; 1965; 1970s; 1984	Seven archaeological levels spanning from the Mousterian to the Bronze Age. Mousterian occupations interpreted as short-term and sporadic, with a seasonal focus (end of spring, midsummer and start of winter). The site was used by carnivores in between occupations. El Ruso is located on a small, limestone hill in the coastal plain of Santander Bay at 60 m.a.s.l. and 6 km from the current coastline. The site is very close to El Pendo cave.	**Level V - Mousterian** • Dominance of deer, followed by horse and large bovids. Skeletal profiles of deer and horse suggest transport of complete animals to site. Cut and percussion marks present.	30,200 ± 1360 uncal BP	Yravedra 2013; Yravedra and Gómez-Castanedo 2010b; Yravedra et al. 2010

El Sidrón (Borines, Piloña, Asturias) Excavated 2000-2014	El Sidrón is a 3,700 m-long karst system formed by a main gallery and several small transverse galleries. A Neanderthal assemblage has been found in one of these galleries (the Ossuary Gallery, located 220 m from the main entrance). The most plausible hypothesis for the origin of the assemblage is that a whole Neanderthal family group was killed and cannibalised by another group (Lalueza-Fox et al. 2012, 134), and later were buried together as a result of a collapse of an underground karst. Given this secondary position, little interpretation of occupation type can be made. Faunal remains and anthracological samples suggest temperate phase of MIS 3, with environmental conditions similar to the present. The landscape was covered with a mix of coniferous and deciduous forests, with associated bushes and grasslands, in addition to some open spaces and a permanent source of water.	**Unit III - Neanderthal assemblage** A single high-energy event dragged archaeological and paleoanthropological material down from an upper level, either from the surface or from an undiscovered upper gallery. Remains are therefore in a secondary position. • 2556 Neandertal bone fragments to date, including the partial remains of 13 individuals (7 adults, 3 adolescents, 2 juveniles and 1 infant). • Occlusal molar microwear suggests mixed diet of meat and vegetables. • Many bones display signs of anthropic activities that have been associated with cannibalism. • 415 lithic tools. • Scarce faunal remains (N=51). • Genetic analysis suggests small groups, characterised by low genetic diversity, with possible patrilocal mating behaviour. Congenital conditions suggest inbreeding.	~49,000 BP	Estalrrich et al. 2017; Lalueza-Fox et al. 2011, 2012; Rosas 2006; Ríos et al. 2019; Wood et al. 2013
Sopeña rockshelter (Avin, Cangas de Onis, Asturias)	Deep stratigraphic sequence, with 17 archaeological levels corresponding to the Mousterian, Early Upper Palaeolithic and Gravettian. Occupied almost continuously by humans during all of the last glacial cycle. At least seven Mousterian levels (XII-XVI) identified so far. Smaller number of finds versus UP is typical, suggesting a more ephemeral use	**Level XII-XVI - Mousterian** • High concentrations of wood ash in levels XIV, XIII and XII, but only a sublayer within Level XIII appears to be an *in situ* combustion feature. • Altogether 726 stone artefacts and 69 retouched pieces. Level totals include	~43-49,000 to ~57, 000 BP 44,421 ± 363 BP (Level XII - AMS 14C)	Pinto Llona 2014; Pinto Llona and Grandal d'Anglade 2019; Pinto Llona et al. 2012

Test excavation 2002	by Neanderthals or smaller groups. Tool size increases throughout Mousterian levels, possibly signalling a demographic contraction (Pinto Llona et al. 2012, 73). Sopeña is located on the northern slopes of the Cantabrian mountain range (450 m.a.s.l.). It overlooks the valley of the river Güeña, which is some 250 m below the rockshelter. Its small tributary, La Güesal, is some 100 m below. The site opens to the southwest and affords an unobstructed view of the adjacent valleys to the west.	187 (XII), 130 (XIII), and 319 (XIV-XV). Mousterian tools are larger and heavier than the UP collection. Average tool length rose steadily in the Mousterian Levels from XV to XII. • Use of locally abundant quartzite decreases steadily in the more recent Mousterian levels. Flint use also decreases suggesting decrease of geographic range. • Faunal remains exceed lithics throughout the sequence by a ratio of 3:1. Level totals include 842 (XII), 678 (XIII), 1042 (XIV) and 5567 (XV). Most levels are dominated by ungulates. Some cut marks and carnivore modification present.		
La Viña rockshelter (La Manzaneda, Oviedo, Asturias) Excavated 1980-1996	Extensive archaeological sequence from the Middle Palaeolithic to the Holocene. The site is divided into a central and western sector, with Mousterian levels identified in the latter. La Viña rockshelter dominates the Nalón valley and is located 290 m.a.s.l. Its prominent position allows for views across the surrounding landscape (more than 10km^2) and the large, rocky front of the rockshelter makes it a visible landmark.	**Level IB, XV/IA, XIV, XIV* and XIII basal - Mousterian** • Most raw materials come from the local area, including quartzite from the river Nalón and Piedramuelle flint, both less than 10km away. Piloña flint, a more distant source, is present. • Poor bone preservation throughout, with remaining fragments mostly <10 cm. Cut marks are rare. • Level XIII basal - quartzite dominates. Rich lithic industry, including flake cleavers. Sediment formed under temperate, interstadial conditions.	>62,000 BP (level XIII basal - OxA-19196) >39,000 BP (level XIV* - GifA-95551)	Santamaría 2016; Santamaría et al. 2014; Wood et al. 2014

CHAPTER FOUR

GIS Method

4.1 Introduction

One of the principal objectives of this study is develop a new methodology for understanding the role of infant carrying. Chapter 2 discussed current understanding of Neanderthal mobility, social groups and energetics, in order to provide a comparative framework and data for an approach to be developed. Chapter 3 provided details of the regional case study and specific archaeological sites. This chapter will outline how these materials can be brought together into a GIS-based modelling approach known as cost distance modelling (CDM).

CDM is a common method in archaeological studies of past mobility, but here it is being applied in a unique way, using variables previously unexplored. It is important to acknowledge that models are built on choices, which ultimately shape the result (Figure 4.1). It is therefore vital to justify these steps, with clear consideration of the potential limitations and assumptions within this process. There have been no previous attempts to model the infant carrying, so the method for incorporating these costs particularly need discussion. Finally, as the user-friendliness of GIS software is enhanced, there is concern that the underlying procedures in modelling can often be obscured (Kantner 2012, 225), This chapter therefore aims to provide a detailed breakdown of the chosen data and tools to allow for easy evaluation of the method and results, as well as comparison to past and future studies.

The following section will first outline the basic principles behind cost distance modelling. This will provide some background to the approach, discuss inherent assumptions in least cost analysis and highlight key decisions an analyst must make. This will be then be followed by the detailed discussion of the study-specific variables needed to understand

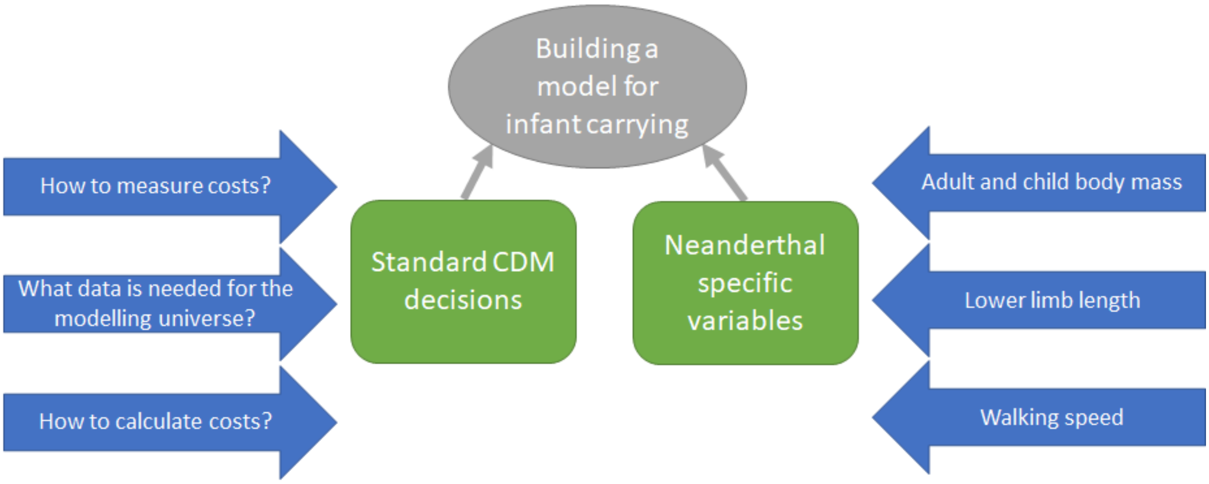


Figure 4.1: Flow diagram of the key decisions needed to build an infant carrying cost model for Neanderthals. Whilst this study includes standard CDM decisions, many of the variables are study-specific and require further explanation in this chapter.

the role of infant carrying in Neanderthal mobility. This will justify what data is used and outline any additional steps required in the modelling process.

4.2 Cost Distance Modelling

4.2.1 From Site Catchment Analysis to Cost Distance Modelling

The emergence of processual archaeology in the 1960s brought a new focus on relationships with the environment, part of which included new analytical techniques such as site catchment analysis (SCA). This method, originally derived from geography, has been used in archaeology for almost 50 years, with the term first being introduced by Vita-Finzi and Higgs (1970). Whilst encompassing a wide variety of techniques, the broad aim of this approach is to study the relationships between the occupants of archaeological sites and their local environment (Bailey and Davidson 1983, 88). A 'site catchment' can therefore be defined as the area regularly used by its inhabitants in order to exploit natural resources (Becker et al. 2017, 2).

SCA assumes there is a spatial limit for this activity, where at some point the energy required to procure resources will outweigh the energy that would be gained (Birkett 1985, 134). The method of determining this limit has varied among researchers, with early studies being largely based on two approaches. Firstly, ‘fixed-distance radii’, where circles of 5 km or 10 km radius are simply drawn around a site; and secondly, ‘time contours’, which incorporate 1 or 2 hour transect walks conducted in the field (Birkett 1985, 135). Given the practical restraints of many archaeological projects, most studies relied on the convenience of fixed 10 km radii, despite this neglecting the various costs associated with the physical characteristics of the landscape. Further assumptions and methodological issues associated with traditional SCA have been well explored (e.g. Roper 1979), often emphasising the simplistic nature of analysis, where only a limited range of variables can be considered. However, with the increasing availability of computer-aided methods and digital datasets, a resurgence and further refinement of SCA has emerged (see Hunt 1992; White and Surface-Evans 2012).

The GIS-based method which can be applied to SCA is known as cost distance modelling (CDM), though the terms ‘least-cost site catchment’ (e.g. Herzog 2014) and ‘cost catchments’ (e.g. Surface-Evans 2012) have also been used to differentiate from the traditional approach. Rather than assuming that all areas within a landscape are equally accessible or desirable, CDM can quantify the area of land that may be accessed from an archaeological site (Surface-Evans 2012, 128). For example, environment data such as terrain, vegetation, and rivers can be incorporated to assess their effect on human mobility (Surface-Evans 2012, 128). In common with traditional SCA, there is no single or correct way to perform CDM. Instead, it relies on the analyst selecting the appropriate approach and variables based on the research question in hand (Surface-Evans and White 2012). In addition, it is important to acknowledge that not all the problems associated with SCA are automatically overcome using GIS (Conolly and Lake 2006, 224) and equally, that new procedural issues emerge. These issues and assumptions will be discussed throughout this chapter.

4.2.2 Assumptions in CDM

Cost distance modelling opened up a whole new avenue of analysis and interpretation, allowing new questions to be asked of archaeological data. However, the method is not without its issues. There are several inherent assumptions that are associated with CDM. Firstly, that humans alter their behaviour in order to optimise the cost of travel, a concept known as the 'least cost assumption' (Surface-Evans 2012, 132). This extends to a further implication that the traveller has a universal knowledge of the landscape in order to make these energetic decisions (Branting 2012, 213). In reality, there are many reasons why humans will not always minimise the cost of movement, including cultural and political motivations (see Murrieta-Flores 2009). This does not however negate the potential of CDM. The outcome of a model should be seen as narrowing down the possibilities to archaeological questions, rather than reconstructing the exact reality of past life. It is a simplification of decision making, but does serve as a baseline to test archaeological data and behavioural hypotheses against (Branting 2012; Surface-Evans 2012). In addition, the relationship between environment and movement remains paramount. This is particularly true in relation to this study, which is specifically aimed at testing energetic data and the role of carrying loads on a physical landscape.

In addition to these fundamental assumptions in any least cost analysis, it is also important to acknowledge that the elements incorporated into a model are based on decisions by the analyst. Each stage of a cost distance model requires assumptions, from the chosen accuracy of data (e.g. DEM), to the values been used to represent variables (e.g. body mass), to the limits being applied (e.g. daily energetic costs). This chapter will discuss and justify these key choices.

4.2.3 Key decisions in CDM

Whilst the elements included in cost distance models are primarily based on the research question being asked, there are some universal factors to consider, all of which contribute to the reliability of CDMs:

- What variables are needed to answer the research question?

- What data is needed to create the modelling universe?
- How will costs be measured?
- What will costs be calculated?
- How will the results be validated?

  (from Herzog 2014, 223; Kantner 2012, 226; Surface-Evans and White 2012, 4)

Table 4.1: Key modelling decisions made in this study. Whilst some issues are common to archaeological CDM studies (terrain and archaeological sites), specific Neanderthal traits need to be considered here, as well as the approach to including infant carrying costs.

Input	**Selection**	**Issues discussed**
What data is needed?		
Terrain	90m SRTM-3 DEM	Accuracy Resolution Palaeoenvironment
Archaeology	Middle Palaeolithic northern Spain	Source of coordinates (see Appendix 1)
How will costs be measured?		
Cost unit	Energy	Time vs. energy
How will costs be calculated?		
Cost function	Pandolf equation	Accuracy e.g. downhill walking Validity tests Modifying for Neanderthals (see study specific variables below)
Energetic limit	Churchill 2014	Source and reliability of data
Study specific variables: Neanderthals		
Body mass	Froehle and Churchill 2009 (see Table 6)	Source and reliability of data
Carrying children	Mateos et al. 2014 (see Table 7)	Source and reliability of data
Walking speed	Hora and Sladek 2014; Wall-Scheffler 2014; Wall-Scheffler and Myers 2013	Source and reliability of data

Table 4.1 summarises the decisions made in this study, which will be discussed and justified in the rest of this chapter. First, the basic modelling process will be outlined.

4.3 The CDM process

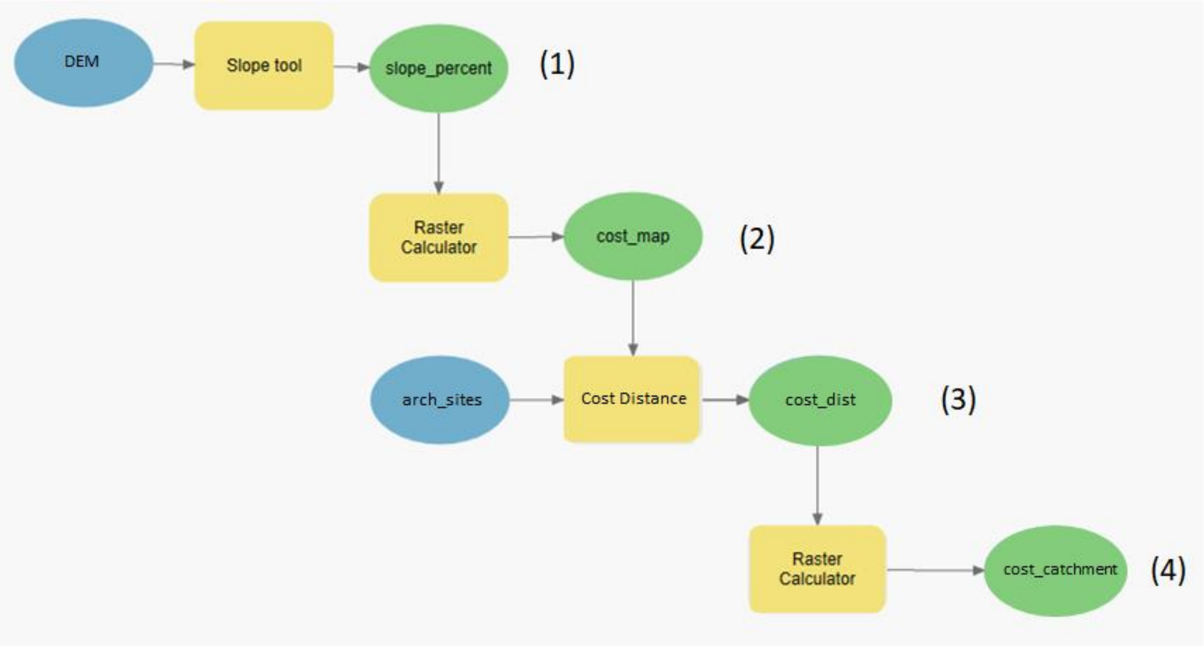


Figure 4.2: Step by step process chart of the standard approach to cost distance modelling. Data inputs are blue, GIS tools are yellow, and resulting outputs are green. In order to model infant carrying and specific Neanderthal variables, a cost equation is used in Step 2.

This study will use a standard process in a GIS-based CDM (Figure 4.2). This is performed using the software programme ArcMap, a facet of the ArcGIS desktop suite, version 10.6. Cost distance models are implemented using ArcMap's Modelbuilder, which creates a flow chart of the modelling process and allows repeated application to multiple archaeological sites. Some of the steps and input data can be modified in order to simulate different scenarios and to test the impact of different variables. The resulting cost catchments are generated from the following steps:

1. Generate a **slope map** from the DEM using the *Slope* tool.
    - *ArcToolbox > Spatial Analyst Tools > Surface > Slope*
    - Input raster: DEM of study area
    - Output measurement: PERCENT_RISE
    - Output raster: slope_percent

2. Generate a **cost map** by entering a cost equation into the *Raster Calculator*.

  - *ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator*
  - Input raster: slope_percent
  - Input: cost function
  - Output raster: cost_map

3. Generate an **accumulated cost surface** by inputting the cost map and point data (archaeological sites) into the *Cost Distance* tool.
   - ArcToolbox > Spatial analyst > Distance > Cost distance
   - Input source data: archaeological sites
   - Input raster: cost_map
   - Output raster: cost_dist

4. Set the limits of the **cost catchment** using the raster calculator and create an outline by converting to a polygon.
   - *ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator*
   - catchment = cost_dist <= maximum
   - *ArcToolbox > Conversion Tools > From Raster > Raster to Polygon*

The next sections will discuss the input and process for these steps. This includes the sources for terrain and archaeological data (step 1 and 3), how the cost of carrying will be calculated (step 2), and how costs be accumulated across a landscape and a limit set (steps 3 and 4).

4.4 Terrain and archaeological data

4.4.1 What is a digital elevation model (DEM)?

Within GIS software, terrain data is typically represented as a digital elevation model (DEM), a 3D representation of the Earth's surface (Conolly and Lake 2006, 291). The most common type of DEM is raster-based, which comprises of equally sized cells arranged into a grid. Each cell represents a square unit of area and stores a numeric value for the

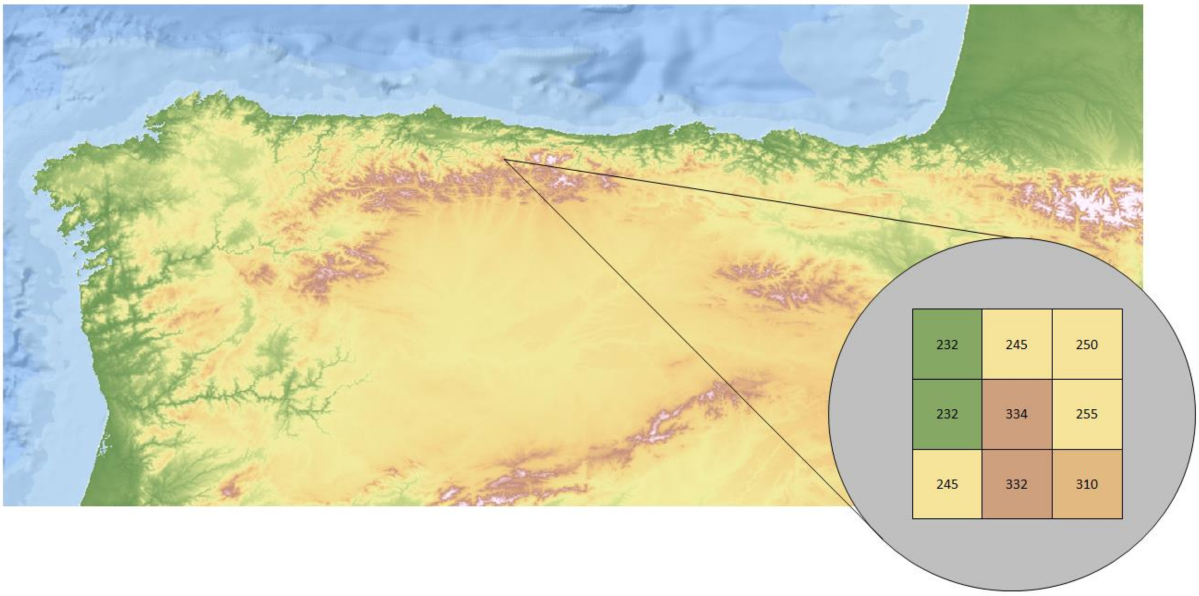


Figure 4.3: A DEM as viewed in GIS software and an example of the cell-based data.

mean elevation across that area (Figure 4.3). This allows you to quantify the characteristics of the land surface and through software tools calculate the cumulative cost of travelling across it.

Whilst studies used to be constrained by the availability of terrain data, there is now a variety of freely available DEMs with near-global coverage. Each of these have their own characteristics based on how the data was acquired and what post-processing techniques were used (Becker et al. 2017; Mukherjee et al. 2013). Although continuing advancements have done much to overcome concerns over quality, differences in the resolution and accuracy of DEMs can still impact the results of cost distance modelling (Becker et al. 2017; Herzog 2014). The danger of increasingly available DEMs is that these issues are not always addressed.

4.4.2 Resolution and accuracy: issues in selecting a DEM

The level of detail represented by a DEM is often dependent on the size of the cells, which defines the resolution of the dataset. A smaller cell size allows for "more features, smaller

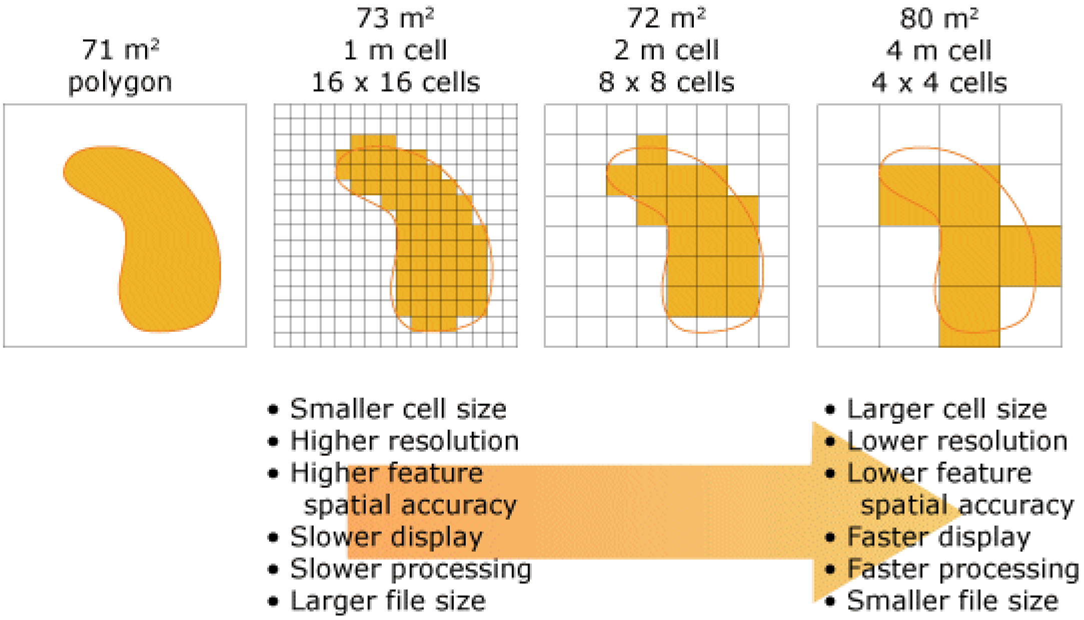


Figure 4.4: A comparison of small versus large cell sizes, and the impact upon resolution, accuracy and processing (from ESRI 2017).

features, or a greater detail in the extent of features" (Figure 4.4; ESRI 2017). As a consequence, greater storage space is needed, which often results in longer processing times. For archaeological studies, caution is also needed with very high resolutions, as DEMs with 5 m or 10 m cell sizes have been shown to include more contemporary residuals, which may not be suitable for studies of the past (Becker et al. 2017, 22).

Specific to cost distance modelling, DEM cell size has been shown to impact both the size and to a lesser extent, the shape of cost catchments (see Becker et al. 2017). In general, increasing cell size leads to a decrease in average slope values (Becker et al. 2017; Herzog and Posluschny 2011; Herzog and Yépez 2015; Zhang et al. 2016). Put simply, lower resolution DEMs are likely to result in somewhat larger catchments because travel is less restricted in hilly terrain. Becker et al. (2017, 20) also found that higher resolution DEMs produce more jagged catchments, due to small-scale landscape features being more prominent. In contrast, Herzog and Yépez (2015) tested four different DEMs for a small case study in Ecuador and found little variation in the catchment results. They suggested this was most likely due to the topography of the study area, where steep terrain created clear corridors of movement (Herzog and Yépez 2015, 16). This emphasises that the justification for DEM selection needs to be specific to the study area, as well as the overall research objective.

The second aspect in considering the quality and suitability of a DEM is accuracy. Third party DEMs provide information on data accuracy and studies are available which compare the characteristics of publicly available DEMs (see Becker et al. 2017, 4-5 for summary). This includes researchers who have specifically tested the impact of accuracy on cost catchments and least cost paths for archaeological studies (e.g. Becker et al. 2017; Herzog and Yépez 2015). It is also sometimes possible to test the accuracy of a DEM yourself (see Herzog and Posluschny 2011; Herzog and Yépez 2015 for examples), which for studies looking to create realistic catchments, such as resource patching, might be an important step to take.

4.4.3 Palaeoenvironment

GIS models are inevitably a simplification of the past landscape. For example, the further back in time models are created, the greater problems are encountered in replicating environments and environmental changes. Past landscapes were undoubtedly different to modern elevation measurements, both due to natural forces such as flooding and landslides, as well as human activities such as terracing and bulk material extraction. Accounting for these changes in models however, can be a difficult and time-consuming task. Among Palaeolithic least cost studies, Byrd et al. (2016) reconstruct sea and lake levels in the southern Levant as part of the cost distance model. This reconstruction was important to include as many of the archaeological sites were located around the lake. The decision to reconstruct palaeoenvironment therefore has to be study specific. It is dependent on data availability for the time period, the capabilities of the software being used, and the specific characteristics of the study area.

4.4.4 The study DEM: SRTM-3

The DEM used in this study is derived from the Shuttle Radar Topography Mission (SRTM) 90 m Digital Elevation Database v4.1 (Jarvis et al. 2008). The SRTM-3 DEM is freely available and was acquired from the official download interface (CGIAR-CSI 2017). The cell size is c. 90 m (3 arc-second resolution) and the vertical error is reported to be less than 16 m (CGIAR-CSI 2017).

As discussed above, the advantages of a lower resolution DEM are faster processing times and for archaeological studies, potentially less modern residuals. Some archaeologists have also suggested that a low resolution comes closer to the human perception of a landscape (Herzog and Posluschny 2011, 238). It is however acknowledged that a larger cell size introduces a level of smoothing, which will likely create somewhat larger and less jagged cost catchments (see Becker et al. 2017). This effect appears to be systematic however, and thus predictable (Becker et al. 2017, 20). The aim of this study is also not produce a set moment in time, nor the full nature of settlement patterns in a region, but instead identify contexts where certain social behaviour is most likely. If the DEM is kept constant throughout, this comparison can be made.

In terms of accuracy, several studies report that SRTM DEMs tend to overestimate valley-floor elevation and underestimate ridge elevation (e.g. Guth 2006; Hayakawa et al. 2008). However, Guth (2006, 275) notes that these issues are most acute in low slope areas like floodplains. Issues of accuracy also arguably have more of an impact on cost path analysis, where resulting routes have the potential to change completely depending on the study area, rather than have a more consistent effect on size like cost catchments (e.g. Becker et al. 2017, 20). Whilst it is important to acknowledge these influences, it is unlikely to have any effect on this study given the scale of discrepancy in comparison to the issues investigated.

As discussed above, environmental conditions would have of course varied in the Palaeolithic, but again as a comparison is currently the primary aim, rather than a completely nuanced reconstruction, this is of lesser importance than in some studies. Becker et al. (2017, 21) also notes that whilst it is possible to include data from palaeoenvironmental research such as the Stage Three Project, there is still a need for improved higher resolution environment data to improve results from models. There is also the potential to over complicate the model, with too many variables making it increasingly difficult to assess the genuine impact of the focus variable - in this case, carrying loads. This study will therefore not introduce aspects of paleoenvironment into the modelling process.

4.4.5 Archaeological data

Beyond terrain data, the other major form of data input is cultural, which is most commonly represented by archaeological sites. These form the start and end points for costs to be modelled. The focus region for this study is Middle Palaeolithic northern Spain, encompassing archaeological sites from the Navarre, Asturias, Cantabria and Basque Country provinces. Reasons for selecting this region were discussed in Chapter 1. Current understanding of the specific sites and mobility patterns in this region are discussed in Chapter 3. The sites and co-ordinates used in this study have been drawn from the NESPOS (2016) database and corresponding site literature (see Appendix 1).

4.5 Measuring and calculating cost

4.5.1 Time or energy: how will cost be measured?

Nearly all models concerned with the cost of walking rely on one of two currencies - time or energy. These measures are rarely equivalent and often chosen with little discussion of the associated advantages and disadvantages (Herzog 2014, 233). Time can become a crucial factor when it becomes a scarce resource, such as when food or water supplies are limited, or when tasks are urgent (Murrieta-Flores 2012, 253). For historical periods, it can also become the obvious choice if written accounts confirm that short journey times were the major concern (e.g. Livingood 2012). Some have argued however, that energy expenditure is a more accurate measure of the physiological costs associated with walking (e.g. Jobe and White 2009, 1100). Kantner (2012, 227) even suggests that those enculturated into busy, Western societies may be imposing an unrealistic value on time for past people. Rademaker et al. (2012, 36) also argue that time was unlikely to have been a major concern for hunter-gatherers in their study area, as there is no archaeological evidence to support a 'race' for resources. In reality, both likely played a role in how people chose to travel in the past, whether they were consciously aware of it or not (Surface-Evans and White 2002, 6). The decision is not related to which currency is better overall, but in justifying which is most appropriate for the particular culture and landscape in question (Surface-Evans and White 2002, 6). As this study is specifically concerned with testing energetics data for Neanderthals, the choice of energy expenditure as currency is fundamental to the research question.

4.5.2 How will energetic cost be calculated?

Cost distance models are generated using variables that constrain or place costs on movement. Many studies have relied exclusively on slope as the factor to determine costs, but associated limitations have led to increasing use of more complex approaches (see Kantner 2012). For example, incorporating predictive equations developed from physiological studies can yield more realistic results. In addition to slope, these equations use variables such as body mass and walking speed to calculate the cost of walking.

Within the application of GIS, this is usually known as a cost function or algorithm. These equations can be inserted within the modelling process in order to convert the topographic surface into some measure or proxy of cost (Kantner 2012). Like a DEM, this 'cost map' consists of a raster of cells, but the values represent the cost of movement across the cell (Kantner 2012, 226). The following section will discuss and justify the choice of energetic equation used in this study. Subsequently, how each variable has been selected and modified in order to calculate cost for Neanderthal mobility.

4.5.3 The Pandolf equation

There are many algorithms available for predicting the cost of adult walking (see Kantner 2012; Herzog 2014 for summaries). Among the equations which incorporate energy expenditure, Pandolf et al. (1977) is the most frequently used among GIS-based studies:

(1) $$M = 1.5W + 2.0(W + L)(L/W)^2 + \eta(W + L)[1.5V^2 + 0.35VG]$$

M = metabolic energy expenditure (watts)
W = body mass (kg)
L = load carried (kg)
V = walking speed (m/s)
η = terrain factor
G = slope (%)

This equation is particularly suited to this study, as in addition to incorporating standard variables of body mass (W), walking speed (V), and slope (G), it also allows for carrying external loads (L) and moving through different terrain types (η). Importantly, it has also been found to be a good predictor of energy expenditure, with a number of independent studies validating its estimates for certain sets of conditions (Duggan and Haisman 1992; Hall et al. 2004; Potter et al. 2013, 2017).

All predictive equations are however limited by their original data collection. For example, a number of researchers (Herzog 2014; Kramer 2010; Rue and Kramer 2017) have pointed to the limited range of test subjects, which in the case of Pandolf et al. (1977) is young, physically fit males for military research. This of course neglects females, although Rue and Kramer (2017) specifically sought to address this and found that any sex-based differences in energy expenditure remain inconclusive (see also Abadi et al. 2010). It also neglects older individuals of both sexes, although this is beyond the scope of this study. The obvious concern here is that this project is dealing with the movement of Neanderthals and not modern humans. It is not unreasonable to use clinical data of highly active individuals for mobile hunter-gatherers, but this issue will also be analysed.

In addition to the range of test subjects, it is also important to acknowledge the range of conditions tested and how this may impact predictive modelling. The Pandolf equation is suited for all walking velocities (<2.4 m/s), burdens up to 70 kg carried on the back, and gradients of 0-25% (Pandolf et al. 1977). It is not however equipped for negative grades (Pimental and Pandolf 1979, 970). Downhill movement offers little impedance, which initially causes the cost of walking to fall to a minimum, before then increasing as energy is spent on braking to maintain control (Minetti et al. 2002; Santee et al. 2001). However, in its original form, the Pandolf equation produces negative costs for downhill walking (White 2012, 194). This suggests that a walker can move 'for free' on negative slopes or worse, 'recharge' (White 2012, 194). In GIS terms, this is known as an isotropic cost function, as it does not account for the direction of travel (see Conolly and Lake 2006, 215-221).

A number of researchers argue that directionality is much less crucial for site catchment analysis, as the return trip would substantially compensate for the difference in up or downhill walking (Becker et al. 2017; Rios-Garaizar and García-Moreno 2015). Santee et al. (2001, 565) also argues that for load carrying, accurately estimating uphill and level costs are much more important. There are options available for modifying the Pandolf equation and van Leusen (2002) has proved popular in archaeological studies. However, Herzog (2014) points out several issues with this modification, including confusion over measurement units, which have since been duplicated into a number of publications (Ejstrud 2005, 137; Conolly and Lake 2006, 220), including CDMs for the Palaeolithic (e.g. Bryd et al. 2016; Heasley 2015). Tests in this study confirmed these issues (see Appendix 2), meaning the original Pandolf et al. (1977) equation was selected.

Following the selection of an appropriate cost function, it is also important to justify the data being used. A simple way to do this is varying the parameters within a cost function, which is increasingly seen as good practice in cost distance modelling (e.g. Kantner 2012; Herzog 2014). Key variables for this project, namely walking speed, body mass and load, will therefore be tested, as discussed below.

4.5.4 Creating a slope map

The Pandolf equation requires the input of slope measured in percent. This can be calculated from a digital elevation model (DEM) by using the *Slope* tool available is most GIS software packages. This is a push-button functionality and calculates the maximum

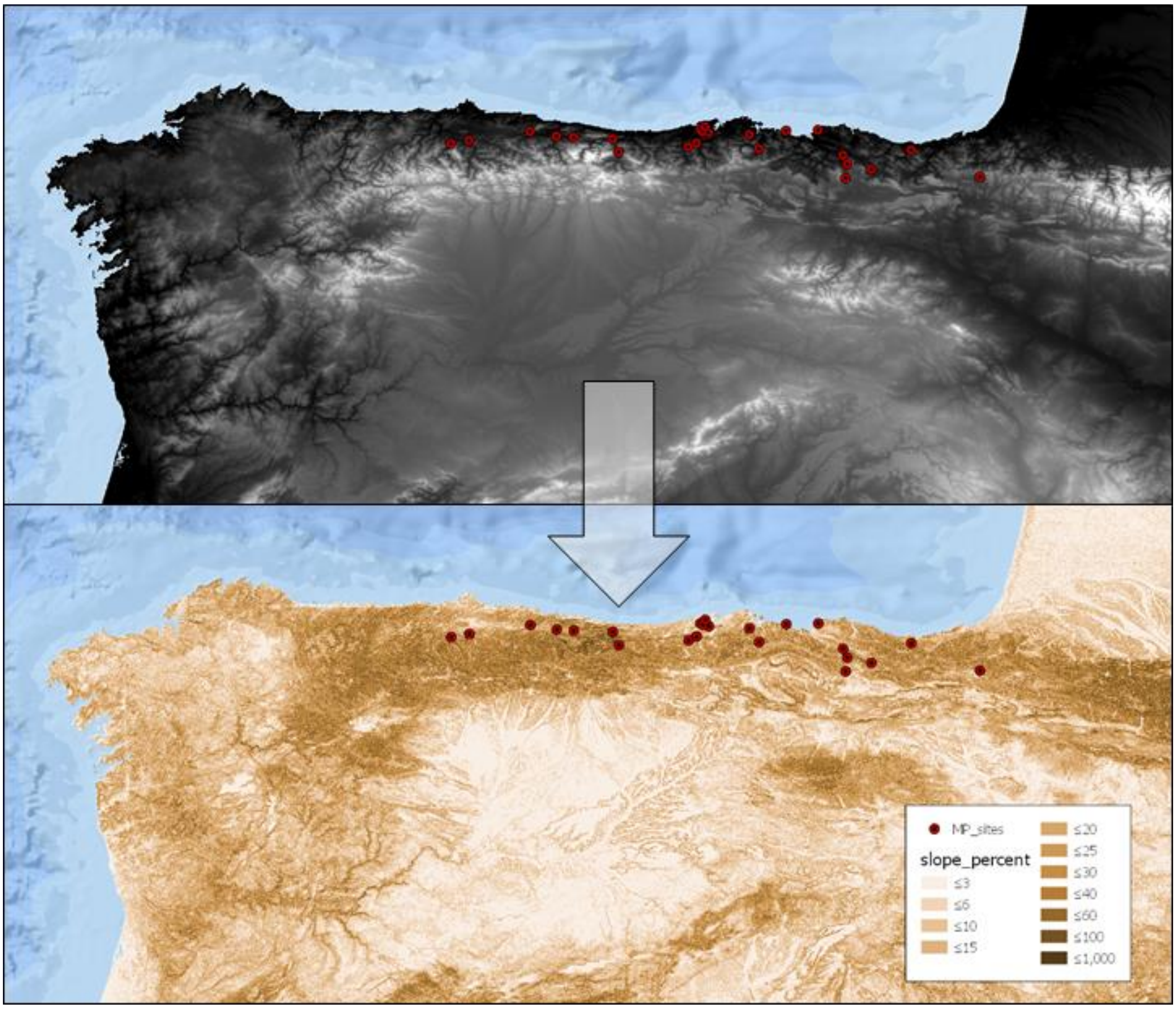


Figure 4.5: A DEM for northern Spain is converted to a raster displaying slope in percent. This was calculated using the 'slope tool' function available in most GIS software. The slope map can then be input into the Pandolf equation to create a cost map.

rate of change in elevation for each DEM cell (Conolly and Lake 2006, 190). The slope tool can be calculated in two types of units, degrees, or as needed in this study, percent rise (ESRI 2017; Figure 4.5). The resulting percentage values range from 0 (a flat surface) to 100 (a vertical surface). The higher the slope value within a cell, the steeper the terrain. This slope map can then be input into the Pandolf equation to create an energy cost map.

The built-in slope tool was chosen for this study due to its popularity in archaeological studies, which should allow for easier comparison between existing models. However, it is acknowledged that other algorithms exist for calculating slope and have the potential to produce quite different values for the same DEM (e.g. Lock and Pouncett 2010). The way these different slope calculation methods impact the results of least cost analysis does need future investigation (Herzog 2014), but is beyond the scope of the current study.

4.6 Accumulating cost

4.6.1 How will costs be accumulated?

In order to calculate the minimal cost of moving through a landscape, the accumulation of costs across a surface need to be tracked. Within GIS software, this 'accumulated cost surface' can be generated by applying a spreading function to the cost map (Conolly and Lake 2006, 221). This process reassigns each cell with the cumulative cost of moving from the origin to the destination. The *Cost Distance* tool available in most GIS software will be used in this study. Whilst there has been some criticism of the spreading functions found in GIS software (see Conolly and Lake 2006, 223-4), it remains the most popular option in archaeological models and therefore allows for comparison to other studies.

4.6.2 What will be the energetic limit?

A precondition for catchment modelling is that humans will eventually reach a point where the energy to procure resources overtakes the energy that would be retrieved. A criticism of early SCA studies was a lack of theoretical basis or empirical data to support the use of a particular limit (see Roper 1979, 124). Whilst the options open to GIS-based modelling are more advanced, this does not override the need to justify this decision.

Previous approaches for studies focused on the Palaeolithic have imposed a time limit for daily foraging, frequently a 2 hour return trip (e.g. Byrd et al. 2016; Gravel-Miguel 2016; Henry et al. 2017; Uthmeier et al. 2008). However, as this study is focused on testing our understanding of Neanderthal energetics, the predetermined limit will be instead based the number of calories used. Chapter 2 reviewed the existing estimates for daily energy expenditure (DEE) for Neanderthals, which have produced a fairly broad, but consistent range of values. It is important to note however, that DEE encompasses all of the energy used by an individual within a typical, active day (Leonard et al. 2005, 458) and therefore is not restricted to the costs of locomotion alone. Mobility costs are arguably the largest contributor to forager activity 'budgets' (Froehle et al. 2013; Churchill 2014), but providing a reliable estimate for past hominins is challenging. In many energetic studies, physical activity levels in Neanderthals are simply assumed as high, often leading to a somewhat circular argument about their mobility. Churchill (2014, 316) attempted to evaluate the reliability of this assumption by creating some speculative estimates for Neanderthal locomotion and domestic activities. The calculations produced average daily mobility costs of about 1200-1800 kcal for females and 2100-2400 kcal for males (Churchill 2014, 319). This study can take this a step further by testing the values produced by Churchill (2014) on a physical landscape. As the Pandolf et al. (1977) equation calculates energy in watts, there will need to be a conversion from kcal/day.

4.7 Study-specific variables: Neanderthals

As this study aims to understand the role of infant carrying in Neanderthal mobility, it will need to use data drawn from the fossil record. The body mass of the adult, weight of the child being carried, and walking speed all impact the cost of walking and the following section will outline the values being used.

4.7.1 Body mass

Body mass is a standard input for calculating energetic cost and often argued to have the largest impact on the cost of walking (Hora and Sladek 2015; Steudel-Numbers and Tilkens 2004). Differences in the estimates for body mass may therefore have an important impact on the values produced for the cost of locomotion. Neanderthals are thought to have been at least 10% heavier than modern day humans (Ruff et al. 1997, 171), but the estimates for average Neanderthal body mass have varied in both energetic studies (see Chapter 2) and cost distance models. Heasley (2015, 140) for example, selected an average of 75 kg for Neanderthal males in their model of mobility in Northeast Italy, based on data from Froehle and Churchill (2009). As the study was primarily

Table 4.2: Body mass estimates for adult Neanderthal females and males. Data derived from Froehle and Churchill (2009). Mass estimated from stature and bi-iliac breadth. Sex as reported in literature.

Neanderthal female		**Neanderthal male**	
Specimen	Body mass (kg)	Specimen	Body mass (kg)
La Quina 5	71.2	Saint-Césaire 1	78.9
Spy 1	67.5	Amud 1	75.3
La Ferrassie 2	67.0	Fond-de-Forêt 1	83.9
Grotte du Prince	**74.8**	Kiik-Koba 1	78.1
Shanidar 6	**59.4**	Neandertal 1	78.9
Krapina 208	68.4	Shanidar 1	80.5
Krapina 209	63.7	Shanidar 3	79.9
Krapina 214	62.2	Shanidar 5	**68.5**
Tabun C1	63.2	Spy 2	83.6
		La Chapelle 1	77.3
		Kebara 2	75.6
		La Ferrassie 1	**85.0**
		Lezetxiki 1	73.9
		Régourdou 1	72.1
		Shanidar 2	75.2
		Shanidar 4	72.0
		Krapina 213	80.6
Average	**66.4**	**Average**	**77.6**
Overall Average		**73.7 kg**	

concerned with creating a comparison of potential routes in their study area, it was not seen necessary to account for sex in this model (Heasley 2015, 140). Similarly, Bryd et al. (2016, 67), in their modelling of AMH in the Southern Levant, used an overall average of 68 kg, though an explanation behind the figure was not given in this case. Given that this study is concerned with differences based on age and sex, the justification for body mass values is more significant.

It is also important to acknowledge the degree of uncertainty in body mass estimations for past hominins. A recent study by Heyes and Macdonald (2015) has argued that the impact of error, spanning the range of commonly used methods, has been previously underestimated. Given this uncertainty, this study will test its impact by varying it as a parameter. Rademaker et al. (2012) have previously varied weight values within Pandolf's equation in modelling least cost paths for prehistoric sites in Southern Highland Peru. They found that regardless of whether the weight input was at the lower or upper ends of the ethnographic ranges for modern foragers, the resulting paths were only slightly different (Rademaker et al. 2012, 38). This however has yet to be tested against cost catchments and has only been used for modern human foragers. Further assessment through this study will therefore add to current understanding, with light, medium, and heavy body mass estimates for Neanderthals from Froehle and Churchill (2009) being compared (see Table 4.2). The relationship between carrier body mass and the carried child body mass may also have important implications (see Kramer 1998), so will be explored as part of the main analysis.

4.7.2 Carrying children

There have been no previous models of child carrying in archaeological studies, so the input values for carrying loads need careful consideration. Modern growth and weight standards for infants and children are freely accessible (e.g. FAO/WHO/UHU 1985; WHO MGRS 2006). However, as discussed above, adult Neanderthals were on average shorter and heavier than modern humans (see Churchill 2014, 72-79 for summary). The question remains whether this difference extended to infants and children. Neanderthal growth and development studies have largely focused on dental and cranial evidence, often leading to conflicting results regarding the rate of maturation. Less attention has been given to postcranial remains, with existing studies similarly offering little consensus (see Cowgill et al. 2007; Rosas et al. 2017; Weaver et al. 2016). Estimated values for infant and child body mass do exist and have been calculated through two main methods. Firstly, extrapolations from direct bone measurements and secondly, models based on comparable recent populations.

Body mass is difficult to estimate for non-adult remains, an issue only compounded by a fragmentary and incomplete fossil record (Cowgill et al. 2007). It is unsurprising therefore that weight estimates are rarely reported for individual child and infant fossils, although there have been a few attempts. Arsuaga et al. (2007) use predictive equations developed by Ruff et al. (2002) to estimate the body mass of the Femur I individual from Cova Negra, Spain. The resulting average of 13 kg is very low for the predicted 5 years of age, which most likely reflects issues with age estimation (Arsuaga et al. 2007). Rosas et al. (2017) similarly use a range of regression equations to estimate the body mass of El Sidron juvenile 1, the partial skeleton of a 7-8-year-old from northern Spain. The predicted weight of ~26 kg is at the higher end for the median values reported for modern children from the USA, which range from 21.8 - 25.3 kg for the same age (FAO/WHO/UHU 1985). The study also notes that maturation of most elements falls within the expected range of modern humans at this age (Rosas et al. 2017). Little can be concluded from two examples, but these values can be compared to modelled estimations based on modern populations.

A number of researchers have suggested that the closest analogue for Neanderthal growth rates is recent populations living in cold environments. Churchill (2014, 92) for example, argues that as modern cold-adapted populations give birth to larger babies, Neanderthals likely did as well. The study estimated Neanderthal birth weight using a predictive equation based on modern birth weight data (~3.45 kg) and adjusting for the underestimation of cold climate populations (~3.76 kg). Growth rates for Evenki herders were then applied, as well as a “more conservative estimate” based on recent data for male British children (Churchill 2014, 94). Application of the Evenki rates suggested Neanderthal children could have attained considerable weight from an early age. For example, a 3-year-old might weigh ~21 kg, in comparison to 13.43 kg when modern British growth rates are applied (Churchill 2014, 96).

Table 4.3: Estimated and average body mass for Neanderthal, Beasain (temperate), Evenki (circumpolar), USA and global populations of infants and children aged between 1 and 6 years old. Values are averages of both sexes and correspond to the end point of each age range.

Age (years)	**Body mass (kg)**				
	Neanderthal (Mateos et al. 2014)[a]	Beasain (Mateos et al. 2014)[b]	Evenki (Mateos et al. 2014)[b]	USA (Kramer 1998)[c]	Global sample (WHO MGRS 2006)[d]
0-1	Not reported	Not reported	Not reported	9.85	9.30
1-2	11.92	13.14	11.52	12.30	11.81
2-3	13.41	15.84	14.40	14.35	14.10
3-4	14.54	18.55	16.63	16.35	16.21
4-5	15.50	21.50	19.33	18.20	18.28
5-6	16.37	24.77	22.17	20.10	Not reported

[a] Sample of six circumpolar populations used to obtain a model to estimate weight from height, with the assumption of comparable body morphology to Neanderthals. Height estimations for Neanderthals were drawn from Martín-Gonzalez et al. (2012).

[b] Direct data from clinical records and population studies.

[c] Average of the median weights calculated by Kramer (1998) from FAO/WHO/UNU (1985), which uses reference growth standards from USA (NCHS 1977).

[d] Average of the mean weights calculated by author. Large scale sample from six participating countries: Brazil, Ghana, India, Norway, Oman and USA (WHO MGRS 2006).

Rather than relying on one population, a study by Mateos et al. (2014) used a mixed sample of six circumpolar populations to model weight from height, again on the premise that these groups shared a similar body morphology to Neanderthals. The estimations were then compared with Beasain and Evenki samples, representing populations from a temperate and cold environment (Table 4.3). In contrast to Churchill (2014), these results indicate that Neanderthal children had a slightly smaller body mass and slower growth rate (Mateos et al. 2014). This difference will in part be due to the choice of dataset, but is also influenced by the attempt to use height estimations for Neanderthal children (see Martín-González et al. 2012).

Bringing all of these estimations together, the average body mass for Neanderthal infants and children remains unclear and in reality, is likely to have varied seasonally, regionally and temporally. It is difficult to conclude which values might represent the most reasonable estimate, but this study can test the significance of these estimated differences.

This study will therefore compare the estimates for Neanderthal infants and children up to the age of 6 (Table 4.3), and how this variable interacts with other factors such as adult body weight and terrain. The limit of 6 years is based on the availability of data and it is assumed that regular carrying is likely to have stopped before this age. A generic light, medium and heavy load will also be tested in order to assess in the initial stability tests.

Finally, beyond the challenge of estimating body mass from the fossil record, there are a few inherent assumptions of this method to be addressed. Firstly, the mode of carrying. There are many different ways to carry with or without tools including front, back, side, and head-supported carrying. Each of these have different associated costs, with some being more energetically economic depending on the context (Watson et al. 2008). The Pandolf equation used in this study only accounts for carrying on the back. In addition, whilst it is argued that Neanderthals were very likely using carrying devices (see Chapter 1), this cannot be factored in within the current method. It is also acknowledged that there are known examples of 'habitual carriers' such as Nepalese porters (Bastien et al. 2005) and east African women (Heglund et al. 1995), who can carry certain loads for much lower costs than seen in other populations. Whilst this is something yet to be considered within evolutionary studies, this study assumes that Neanderthals did not have this advantage for carrying children.

4.7.3 Walking speed

In humans, the relationship between speed and locomotor costs is curvilinear (Wall-Scheffler 2012b, 1). This means that whilst humans can walk at a variety of speeds, there is one speed in which the energetic cost of walking will be at its lowest (Wall-Scheffler 2012b; 2014). Physiological experiments have shown that even across short periods of time, humans naturally prefer to minimise costs and walk at or very close to this optimal walking speed (e.g. Browning et al. 2006; Steudel-Numbers and Tilkens 2004).

Previous studies which have used the Pandolf equation, or some extended form of it, have dealt with walking speeds in different ways. Some have simply assumed a constant, optimal speed, whereas others such as Rademaker et al. (2002) have tested how varying this parameter can impact model results. The study included three levels of speed for a cost path model: 2.4 m/s, the upper speed limit for walking; 1.2 m/s, a medium or optimal velocity; and 0.4 m/s, an extremely low walking speed. They found that whilst the other speeds were fairly consistent, the lowest walking speed appears to fall below a threshold where sloped terrain fails to influence the algorithm (Rademaker et al. 2012, 38). Re-runs at a slightly higher velocity however solved this issue. Several recent studies (Byrd et al. 2016; Heasley 2015; White 2012) have also used Tobler's hiking function to create walking speeds based on slope, although this function has its own associated limitations (see Jobe and White 2009, 1100).

An added complication to the different approaches being used is that the values used above are all based on modern, clinical data and do not take into account physiological differences in our evolutionary past. There have been several attempts to estimate preferred walking speeds in fossil hominins. Wall-Scheffler (2014) for example, applied a regression equation incorporating the strong correlation between tibia length and optimal speed. Whilst "preliminary at best" (Wall-Scheffler 2014, 184), these estimates still appear to provide some meaningful trends. Based on a sample of 12 fossils, average speeds of 1.31 m/s and 1.22 m/s were produced for Neanderthal males and females respectively, in comparison to speeds of 1.43 and 1.34 m/s for AMH (n=16). For both species, preferred walking speeds in males are roughly 7% faster than females, with Neanderthals exhibiting slower walking speeds than AMH (Wall-Scheffler 2014, 187).

Hora and Sladek (2014, 21) similarly reported these differences between sex and species using hip height as a measure, albeit to a slightly lesser degree. They reported velocities of 1.31 m/s (male) and 1.23 m/s (female) for Neanderthals and 1.37 m/s (male) and 1.29 m/s (female) for AMH (Hora and Sladek 2014, 21). Using the GRASS GIS package, Henry et al. (2017) incorporated average estimates by Hora and Sladek (2014) into their model as a constant. However, there has yet to be any other studies which consider a specific optimal speed for Neanderthals. This study will therefore evaluate how different walking speeds impact the modelling results. It will compare a low, medium and high walking speed as part of the initial validity tests. It will also test how walking speed interacts with carrying children, using values produced in Wall-Scheffler and Myers (2013), who specifically tested this relationship. Finally, it is acknowledged that other factors such as level of fitness also affect the speed of walking (Murrieta-Flores 2009, 254). As this is not central to the research question, it will not be currently accounted for.

4.7.4 Terrain factor

A terrain factor refers to any physical characteristics of the surface which may impact the ease of movement. This might include vegetation cover, ice and snow, wetlands and other soil properties. There are many physiological studies available which quantify different surface conditions (see Richmond et al. 2015 for summary). These multipliers range from 1.0 for firm, even surfaces to 1.8 for a swampy bog to 3.8 for unpacked snow (Churchill 2014; Herzog 2014). There were undoubtedly different surface conditions which affected Neanderthal mobility, but these remain difficult to reconstruct in any depth. The terrain factor will therefore be kept constant for this study, but would be a useful extension for future research. For example, whilst the full complexity of land cover features may be beyond reach (Herzog 2014), some generic conditions could provide insights. Snow cover can considerably increase the energetic cost of walking (Pandolf et al. 1977, 579), particularly in conjunction with other factors such as sloped terrain (Churchill 2014, 320). This could therefore have been a major impediment to some Neanderthal groups, which Churchill (2014, 320) linked to archaeological evidence of reduced raw material procurement in cold intervals. Future research on surface conditions and its interaction with other variables may therefore produce useful insights into mobility.

4.8 Chapter 4 summary

This study uses a GIS-based cost distance modelling process in order to test the costs of infant carrying on Neanderthal mobility. Data drawn from the fossil record will be used to input values for body mass, child mass, and walking speed. The next chapter will analyse the results of this modelling, and will discussed within the broader interpretations of Neanderthals in the final chapter.

CHAPTER FIVE

Analysis

5.1 Introduction

This chapter outlines the results of the cost distance modelling within this study. The process and justification for this GIS-based approach is outlined in Chapter 4. The cost catchments produced will bring together energetics data for Neanderthals (Chapter 2), as well as archaeological sites from Middle Palaeolithic northern Spain (Chapter 3). The overall research aim is to assess the influence of infant carrying on Neanderthal mobility, and how this interacts with other variables such as terrain and body mass.

First, the validity tests for the method are reported. These tests are important for all least cost analysis studies, but particularly here, as values for Neanderthals are being used in equations based on modern humans. In addition, this is the first least cost study which has modelled infant carrying costs, so this analysis is also concerned with assessing the feasibility of this method. Following these tests, there will be evaluation of the interactions between the costs of carrying, body mass and terrain. These results will be then be discussed in context to current understanding of Neanderthal mobility, social organisation, and energetics in the next chapter.

5.2 Results of the CDM validity tests

The Pandolf et al. (1977) equation was chosen for this study, given its ability to incorporate carrying loads into the calculation of cost. As discussed in Chapter 4, this equation does not account for downhill walking costs, so many archaeological studies, including studies of the Palaeolithic, have used a modification by van Leusen (2002). Herzog (2014) has reported mistakes within the original alteration, so the first step in this analysis was to test the feasibility of this equation when corrected. Data and catchments produced by this method were also compared to the results from Pandolf et

Table 5.1: Catchment areas for variable based validity tests. Variables tested are body mass (M1-3), load carried (L1-3) and walking speed (S1-3). 2000 kcal/day limit set.

Test	**Model**	**Body mass**[a]	**Speed**[b]	**Load**	**Terrain Factor**	**Catchment area (km^2)**[c]
Body mass	M1	59.4	1.31	0	1	804.87
	M2	73.7	1.31	0	1	507.25
	M3	85.0	1.31	0	1	374.22
Carrying loads	L1	73.7	1.31	5	1	448.32
	L2	73.7	1.31	10	1	398.23
	L3	73.7	1.31	25	1	287.24
Walking speed	S1	73.7	1.00	0	1	992.70
	S2	73.7	1.31	0	1	507.25
	S3	73.7	2.00	0	1	159.35

[a] Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b] Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014)
[c] Average Neanderthal daily mobility energy costs from Churchill (2014).

al. (1977), to assess the accuracy of the van Leusen (2002).

The full results of the equation tests are reported in Appendix 1 and indicate that the modification by van Leusen magnifies the cost of downhill walking and produces significantly smaller catchments than the original Pandolf version. This modification was therefore not used in this study and confirmed issues with van Leusen (2002), as discussed by Herzog (2014).

Further testing of Pandolf were also performed, as validity tests are increasingly seen as good practice in least cost analysis (Kantner 2012; Herzog 2014). This allows the analyst to assess how small changes in variables can impact the resulting catchment. As this study is using an equation based on modern human data, but values estimated for Neanderthals, it was also important to test the feasibility of the equation being used.

As part of validity tests, Rademaker et al. (2012) have previously varied body mass values within Pandolf's equation for cost path analysis. This however has yet to be tested against cost catchments and has only been used for modern human foragers. This study therefore tested light, medium and heavy values for Neanderthals. The resulting catchments are broadly similar in shape and the change in size follows the expected

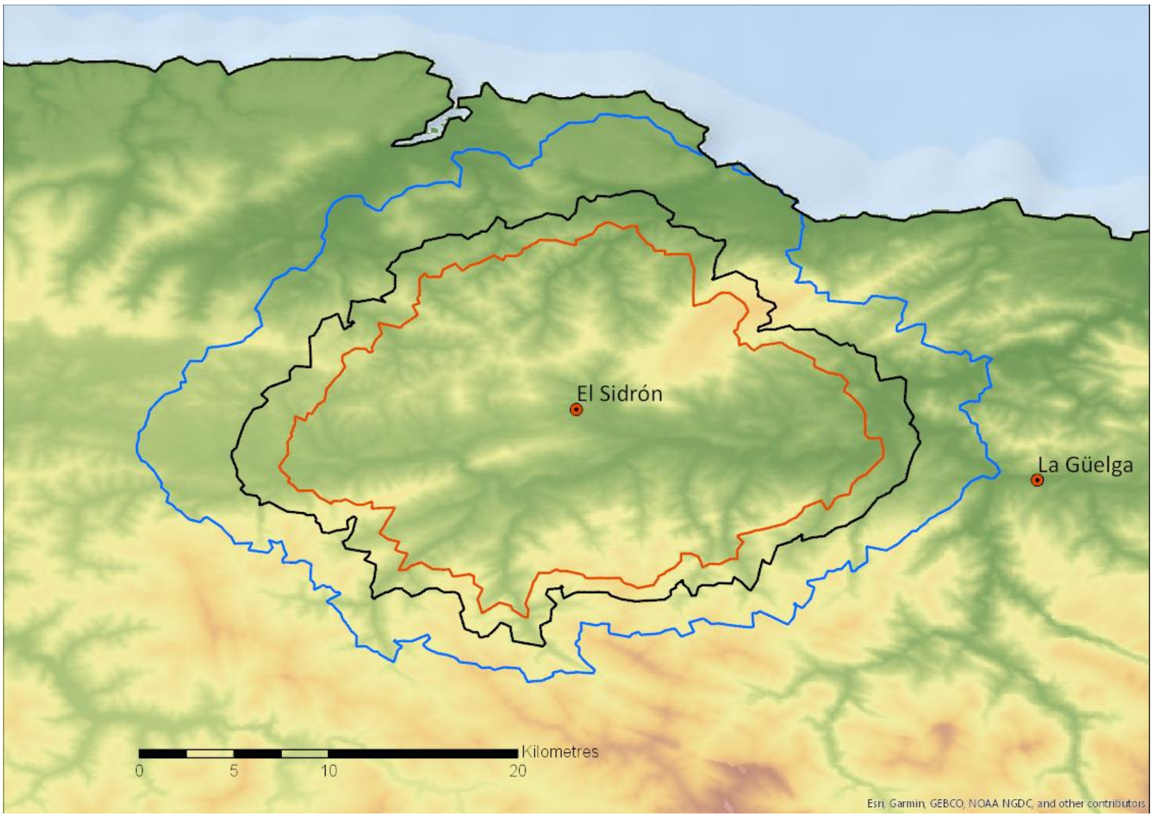


Figure 5.1: Cost catchments comparing body mass values. M1 (low, blue); M2 (average, black); M3 (high, orange). 2000 kcal/day set limit.

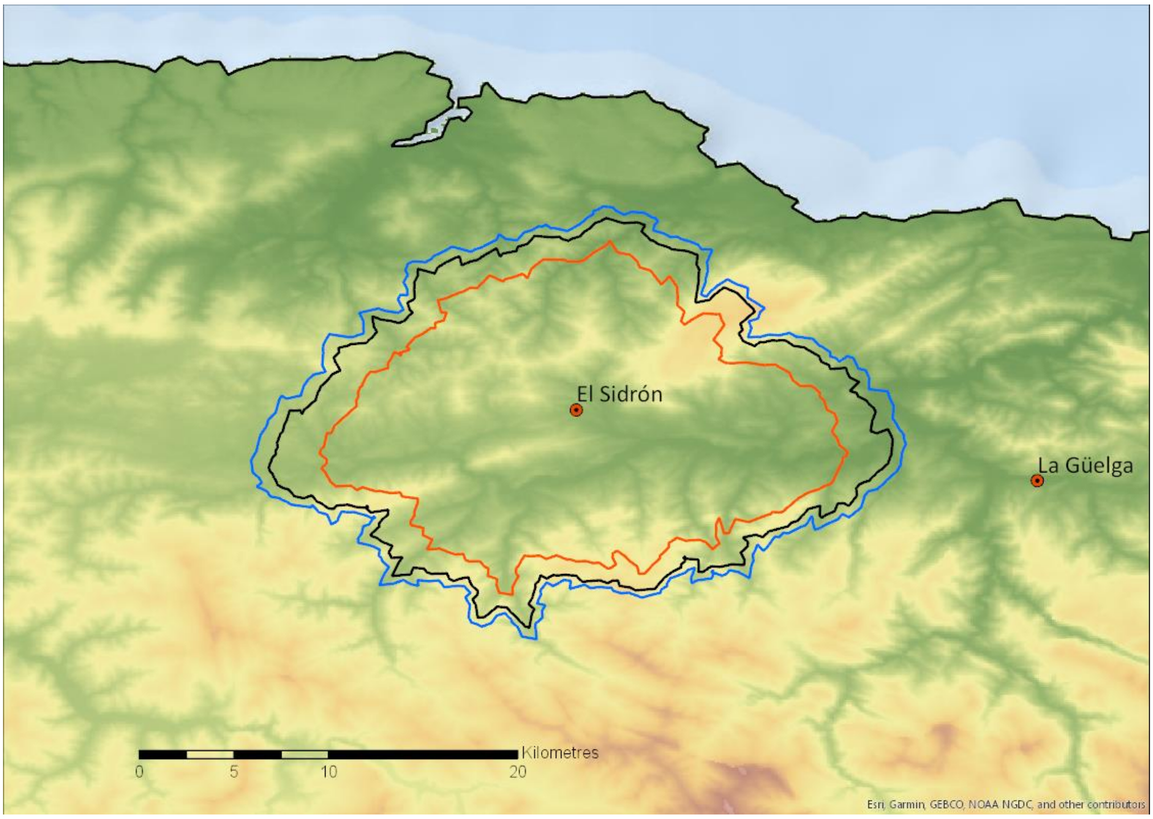


Figure 5.2: Cost catchments comparing values for carrying load. L1 (5kg, blue); M2 (10kg, black); M3 (25kg, orange). 2000 kcal/day set limit.

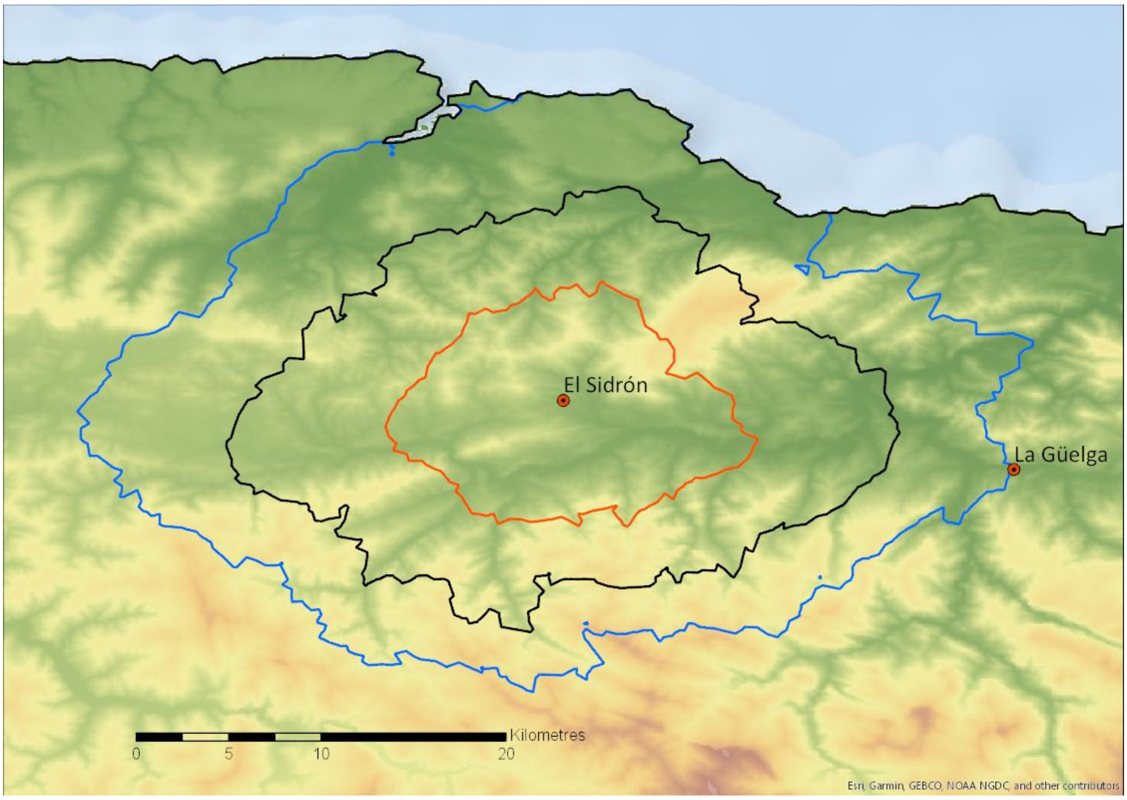


Figure 5.3: Cost catchments comparing walking speed values. M1 (low, blue); M2 (Neanderthal, black); M3 (high, orange). 2000 kcal/day set limit.

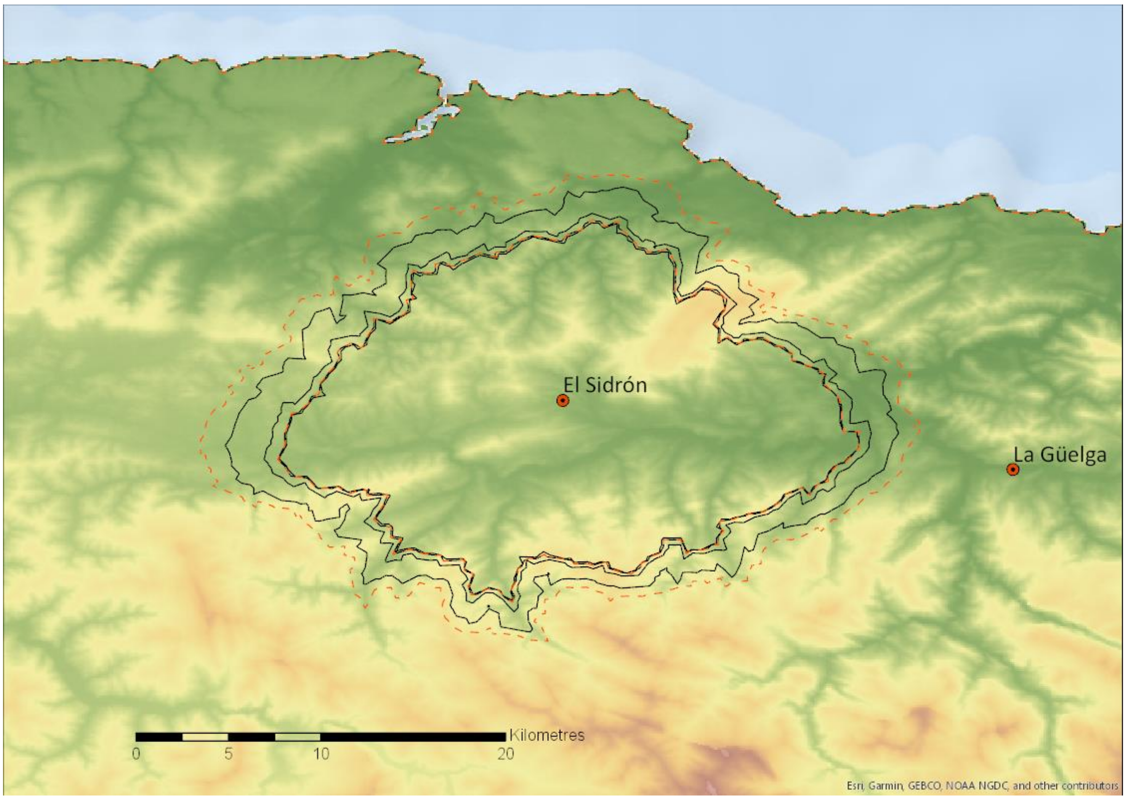


Figure 5.4: Cost catchments comparing the interaction between walking speed and carrying. The orange lines represent unloaded Neanderthal males set Black lines represent Neanderthal females unloaded, versus the mass of a 1, 3 and 6 year child. Limit set to average Neanderthal: 1800 kcal/day.

pattern (Figure 5.1; Table 5.1). This suggests this equation is feasible for the range of Neanderthal body mass values being used in this study (see Table 4.2 in Chapter 4).

Different weights of carried load were also assessed and followed the expected pattern in terms of the size and shape cost catchment (Figure 5.2). The original equation tested loads up to 75 kg (Pandolf et al. 1977), which is far beyond the values being tested here (see Table 4.3 in Chapter 4). This again suggests the values used in this study are feasible.

The final variable tested was walking speed. As discussed in the methodology chapter, Neanderthals are thought to have slower optimum walking speeds based on the specific morphology characteristics. Energetic studies have also shown that carrying loads, including children, results in a slower preferred walking speeds in individuals (Walls-Scheffler and Myers 2013). An estimation for Neanderthal male walking speed was therefore tested against an expected low value speed for carrying load, versus a high speed for comparison. The results again suggest this equation is feasible for the values being used in this study, for unloaded travel (Table 5.1; Figure 5.3). However, as this test is concerned with carrying loads, it also needs to be tested whether this equation accurately predicts how walking speed interacts with carrying loads.

5.3 Testing the relationship between carrying loads and walking speed

In one of the few physiological studies to specifically investigate the costs of carrying children on group mobility, Wall-Scheffler and Myers (2013) found that transporting infants slows the optimal speed of walking for the carrier. This could have important implications for travelling in a group, as non-carriers would either need to slow down and incur additional costs, or the loaded individual would need to speed up and sustain energetic penalties. It was therefore tested whether the Pandolf equation could be used for more complex scenarios of group walking, where loaded and unloaded speeds could be varied.

Table 5.2: Models and catchment areas for testing the interaction between walking speed and carrying load, in order to test the feasibility of the Pandolf equation for modelling more complex scenarios of group walking. First models (GF/GM) tested group walking at male speed and the second models (GFS/GMS) tested female loaded speeds. 1800 kcal/day Neanderthal average limit set.

Test	Model	Body mass[a]	Speed[b]	Load[c]	Terrain Factor	Catchment area 1 (km²)[d]
Female carrying	GF0	66.4	1.31	0	1	505.99
	GF1	66.4	1.31	9.30	1	394.54
	GF3	66.4	1.31	13.41	1	356.99
	GF6	66.4	1.31	16.37	1	345.33
Male	GM0	77.6	1.31	0	1	363.82
Female carrying	GFS0	66.4	1.01	0	1	972.01
	GFS1	66.4	1.01	9.30	1	777.56
	GFS3	66.4	1.01	13.41	1	697.88
	GFS6	66.4	1.01	16.37	1	645.48
Male	GMS0	77.6	1.01	0	1	700.87

[a]Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b]Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014); Wall-Scheffler and Myers (2013)
[c]Neanderthal child mass from Mateos et al. 2014, except 1 year old from a global sample (see Chapter 4).
[d]Average Neanderthal daily mobility energy costs from Churchill (2014).

The results of these tests are presented in Table 5.2 and Figure 5.4. The first models compared the cost between an unloaded male and a female carrying a child at various ages, whilst walking at an average Neanderthal walking speed. The second model compared the same scenario but set the pace of walking to a loaded speed reported by Walls-Scheffler and Myers (2013). Unfortunately, the complex interaction between these two variables is not accounted for by the Pandolf equation. As can be seen in the catchment data reported for model GMS0 (Table 5.2), an unloaded male is calculated to walk a far greater distance, despite walking a much lower, suboptimal speed. Currently, there is not an alternative equation for approaching this in energetics literature, but data by Wall-Scheffler and Myers (2013) can still be discussed as part of the broader implications in the next chapter. This study is not currently looking to produce realistic estimates for Neanderthal mobility, but rather test the feasibility of a new approach and identifying how this can be improved in future work. The Pandolf equation also allows to test the cost of carrying against body mass and terrain, which are often seen as the most significant contributors to the cost of walking.

5.4 Testing the costs of Neanderthal adult body mass

Table 5.3: Models and catchment areas for Neanderthal female and male body mass compared. Unloaded travel, with different energetic limits set, in order to compare average Neanderthal daily limits against sex-specific daily limits from Churchill (2014).

Test	Model	Body mass[a]	Speed[b]	Load	Terrain Factor	Catchment area (km²)[c]	
						1800 kcal/d	1500 kcal/d (f) 2250 kcal/d (m)
Female	FM1	59.4	1.31	0	1	638.64	433.51
	FM2	66.4	1.31	0	1	505.99	345.33
	FM3	74.8	1.31	0	1	391.21	272.58
Male	MM1	68.5	1.31	0	1	472.16	762.16
	MM2	77.6	1.31	0	1	363.83	583.41
	MM3	85.0	1.31	0	1	303.42	480.01

[a] Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b] Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014).
[c] Neanderthal daily mobility energy costs from Churchill (2014).

Body mass is often argued to have the largest impact on the cost of walking (Hora and Sladek 2015; Steudel-Numbers and Tilkens 2004) and given that Neanderthals were at least 10% heavier than modern humans (Ruff et al. 1997, 171), this is likely to have had a significant impact on Neanderthal mobility. This has been well explored in energetic studies, particularly in estimating daily energy requirements for Neanderthals (see summary in Chapter 2). However, this has not been explored in detail in least cost studies. All existing analyses of Neanderthal mobility have selected several different average Neanderthal body mass values (Byrd et al. 2016; Heasley 2015). As this study is concerned with group mobility and the potential impact of different individuals, tests were conducted to explore the impact of sex-specific difference in mass.

If an average daily mobility energy limits are used (1800 kcal/day), the relationship between body mass and costs remain simple. Lighter Neanderthals, specifically females, would be able to move further, as evidenced in Table 5.3 and Figure 5.5. However, if sex-specific daily mobility energy limits are considered (females: 1500 kcal/day; males: 2250 kcal/day), this becomes more complicated. Using averages of the values calculated by Churchill (2014), the picture of group mobility is reversed, with males at all levels of body mass (low, average, high) moving further than females. This is when childcare and pregnancy is an important factor. If females are likely to travel reduced distances, this

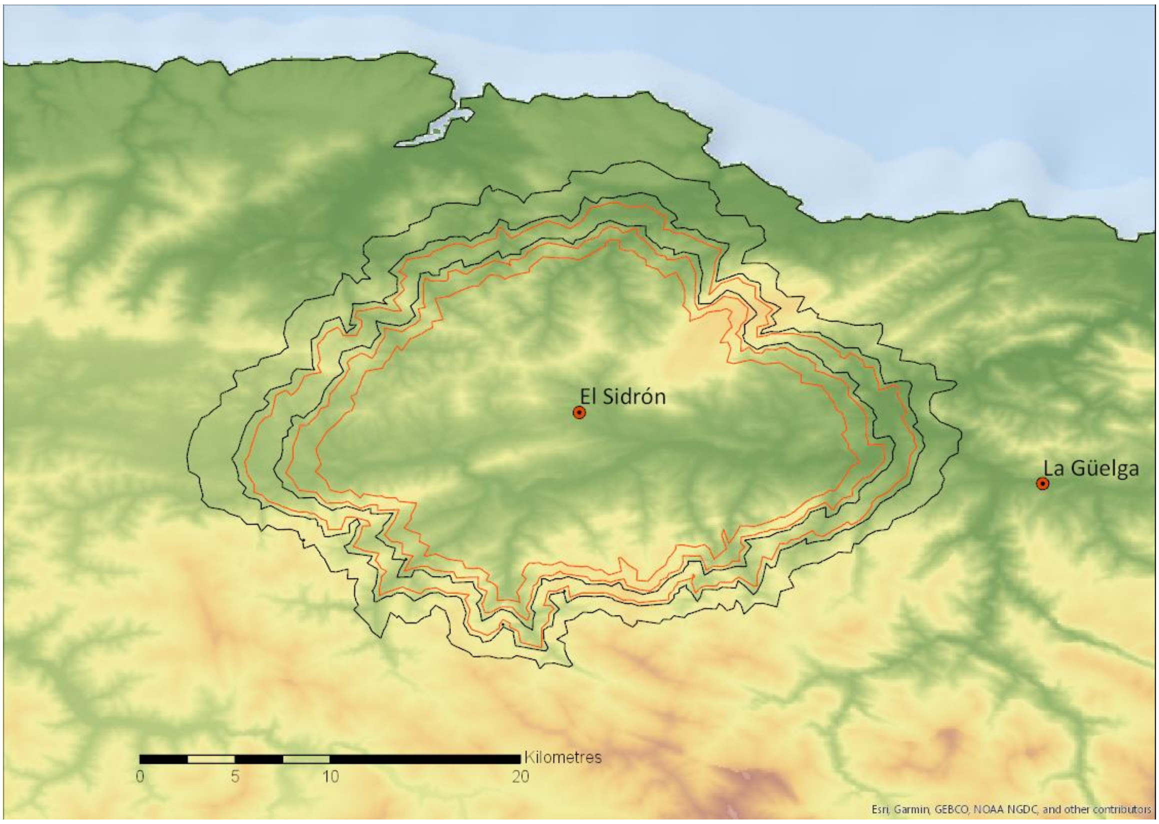


Figure 5.5: Cost catchments comparing the impact of female (black) and male (orange) body mass on the cost of walking. Light, average and heavy values tested. 1800 kcal/day limit set for both sexes.

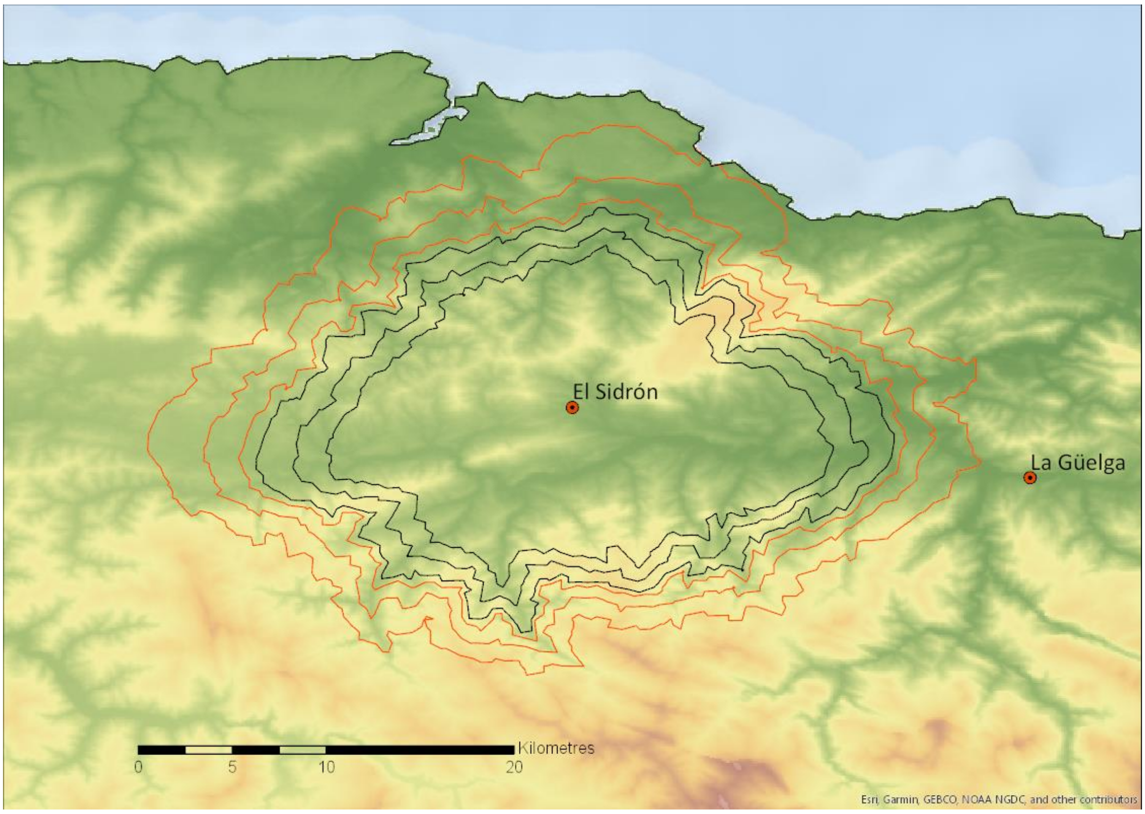


Figure 5.6: Cost catchments comparing the impact of female (black) and male (orange) body mass. Light, average and heavy values tested. Sex-specific energy limits tests (1500kcal vs. 2250kcal/d).

Table 5.4: Models and catchment areas testing average Neanderthal, versus average male and female body mass with unloaded and loaded travel (child aged 1-6 years). 1800 kcal/day average Neanderthal limit set.

Test	**Model**	**Body mass**[a]	**Speed**[b]	**Load**[c]	**Terrain Factor**	**Catchment area (km^2)**[d]	**% decrease vs. unloaded catchment**
Average female body mass	AF0	66.4	1.31	0	1	506.00	/
	AF1	66.4	1.31	9.30	1	395.31	22%
	AF2	66.4	1.31	11.92	1	370.96	27%
	AF3	66.4	1.31	13.41	1	358.11	29%
	AF4	66.4	1.31	14.54	1	348.78	31%
	AF5	66.4	1.31	15.50	1	341.01	33%
	AF6	66.4	1.31	16.37	1	334.22	34%
Average Neanderthal body mass	AN0	73.7	1.31	0	1	403.39	/
	AN1	73.7	1.31	9.30	1	330.49	18%
	AN2	73.7	1.31	11.92	1	309.38	23%
	AN3	73.7	1.31	13.41	1	299.48	26%
	AN4	73.7	1.31	14.54	1	292.20	28%
	AN5	73.7	1.31	15.50	1	286.18	29%
	AN6	73.7	1.31	16.37	1	281.00	30%
Average male body mass	AM0	77.6	1.31	0	1	363.83	0
	AM1	77.6	1.31	9.30	1	298.76	18%
	AM2	77.6	1.31	11.92	1	282.96	22%
	AM3	77.6	1.31	13.41	1	274.48	25%
	AM4	77.6	1.31	14.54	1	268.49	26%
	AM5	77.6	1.31	15.50	1	263.06	27%
	AM6	77.6	1.31	16.37	1	258.17	29%

[a] Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b] Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014).
[c] Neanderthal child mass from Mateos et al. 2014, except 1 year old from a global sample (see Chapter 4).
[d] Average Neanderthal daily mobility energy costs from Churchill (2014).

will only be compounded by the cost of carrying. This also demonstrates the key argument forwarded by this study, that as well as considering individual costs, we need to consider the ramifications for group mobility.

In understanding the energetics of Neanderthals, values for the cost of walking are typically produced in order to provide a comparison to Upper Palaeolithic modern humans. There has been little consideration of how subtle differences in group size and

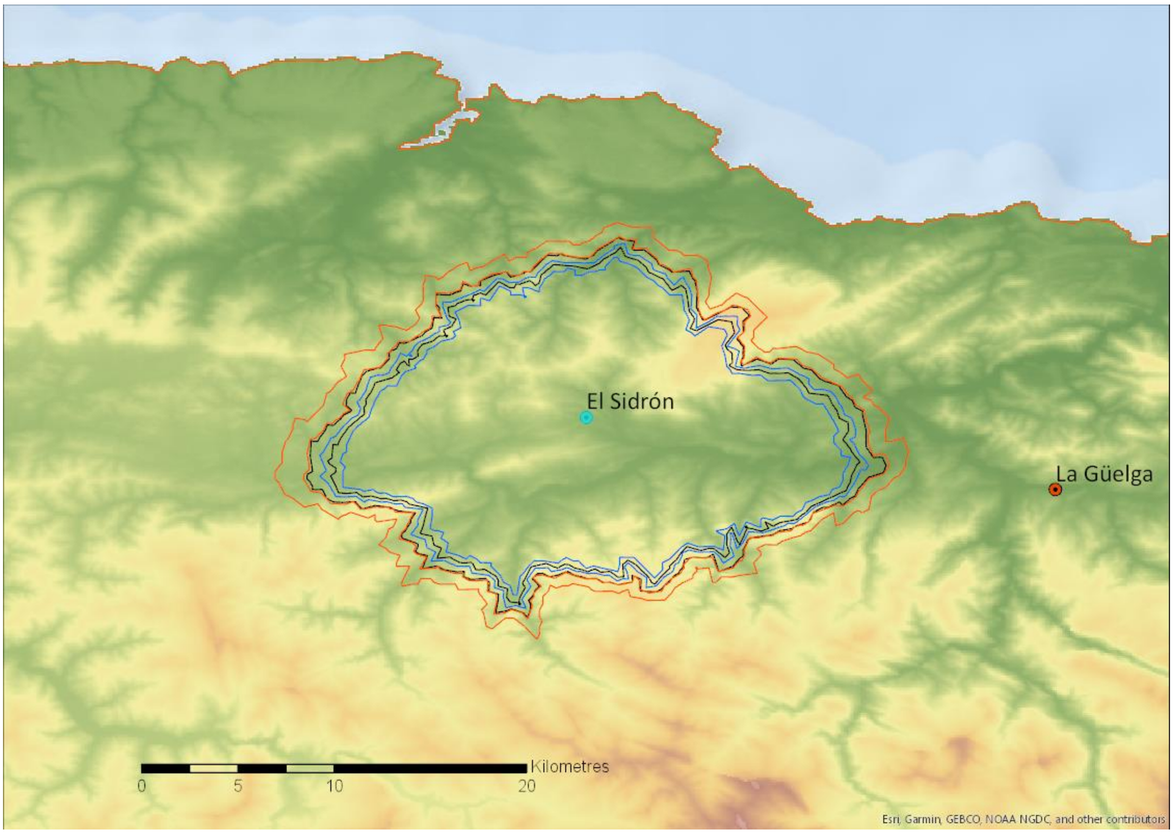


Figure 5.7: Cost catchments comparing the interaction between adult body mass and carried child body mass. Average Neanderthal female body mass (orange), overall average Neanderthal body mass (black), and average Neanderthal male body mass (blue) are compared. Results for unloaded and child mass at 1, 3, 6 years of age included here. 1800 kcal/day limit set.

composition would create intergroup differences within Neanderthals themselves. The significant impact of body mass can also be seen in these cost catchment results. When energetic daily costs are controlled, the catchment area for the lightest Neanderthal female is just over 50% larger than the area calculated for the heaviest Neanderthal male. Adult body mass is also argued to have important implications for child carrying (e.g. Kramer 1998), so this relationship was also explored through further cost distance models.

5.5 Testing the relationship between body mass and carrying children

The data in Table 5.4 and Figure 5.7 explore the interaction between different values of Neanderthal adult body mass and carrying children at different ages (1-6 years). Kramer (1998) has previously argued that the decision to carry a child, over independent walking, can be predicted from the body mass of the mother and child, and the child's age. This is again when the distinct body mass values for Neanderthals could have important ramifications.

Using the estimates for Neanderthal child mass calculated by Mateos et al. (2014), the largest percentage reduction in catchment area is experienced between 0-2 years of age and then decreases more gradually towards the 6 year age limit. This relative effect of carrying load is also slightly less pronounced with heavier body masses. For example, an average weight female Neanderthal experiences a 22% reduction in catchment area, versus a 18% reduction in catchment for an average weight male (Table 5.4). However, as explored earlier, due to the impact of adult body mass more generally, females are still able to travel further when the daily limit for mobility costs are controlled.

As discussed in Chapter 4, reliable estimates of fossil child body mass are far from clear and the values produced by Mateos et al. (2014) are only one example. Testing different values for child body mass will therefore help evaluate how subtle changes impact the cost of mobility.

5.6 Testing the values for child body mass

The model results and catchments produced in Table 5.5 and Figure 5.8 test different values of body mass for children aged 1-6 years for Neanderthal, Evenki and a modern human population (see Chapter 4 for full data). Whilst the weights reported for these groups are fairly consistent up to 3 years of age, the growth model produced by Mateos et al. (2014) suggest a slower rate of body mass attainment in Neanderthal children. This is reflected in the modelling results, with larger catchments for the Neanderthal-based data. By 6 years of age, the percentage decrease in catchment area is 6-8% higher when values for Evenki and modern human children are used. Whilst these changes are not as significant as seen by changes in adult body mass, this needs to be viewed in context of the Neanderthal energy budget. If the overall high daily energy costs reported by numerous authors are correct (see review in Chapter 2), Neandertals could have been particularly sensitive to small changes in energy requirements. The slower rate of body mass attainment reported by Mateos et al. (2014) could therefore hint at subtle

Table 5.5: Models and catchment areas comparing the estimates and values for child mass in Neanderthal, Evenki and modern global populations. 1800 kcal/day average Neanderthal limit set.

Test	Model	Body mass[a]	Speed[b]	Load[c]	Terrain Factor	Catchment area (km^2)[c]	% decrease in catchment area
No load	C0	73.7	1.31	0	1	395.29	/
Neanderthal child mass	NC3	73.7	1.31	13.41	1	299.47	24%
	NC6	73.7	1.31	16.37	1	280.99	29%
Evenki child mass	EC3	73.7	1.31	14.40	1	293.07	26%
	EC6	73.7	1.31	22.17	1	247.42	37%
Global/USA child mass	GC3	73.7	1.31	14.10	1	295.10	25%
	GC6	73.7	1.31	20.10	1	259.20	34%

[a] Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b] Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014).
[c] Average Neanderthal daily mobility energy costs from Churchill (2014).

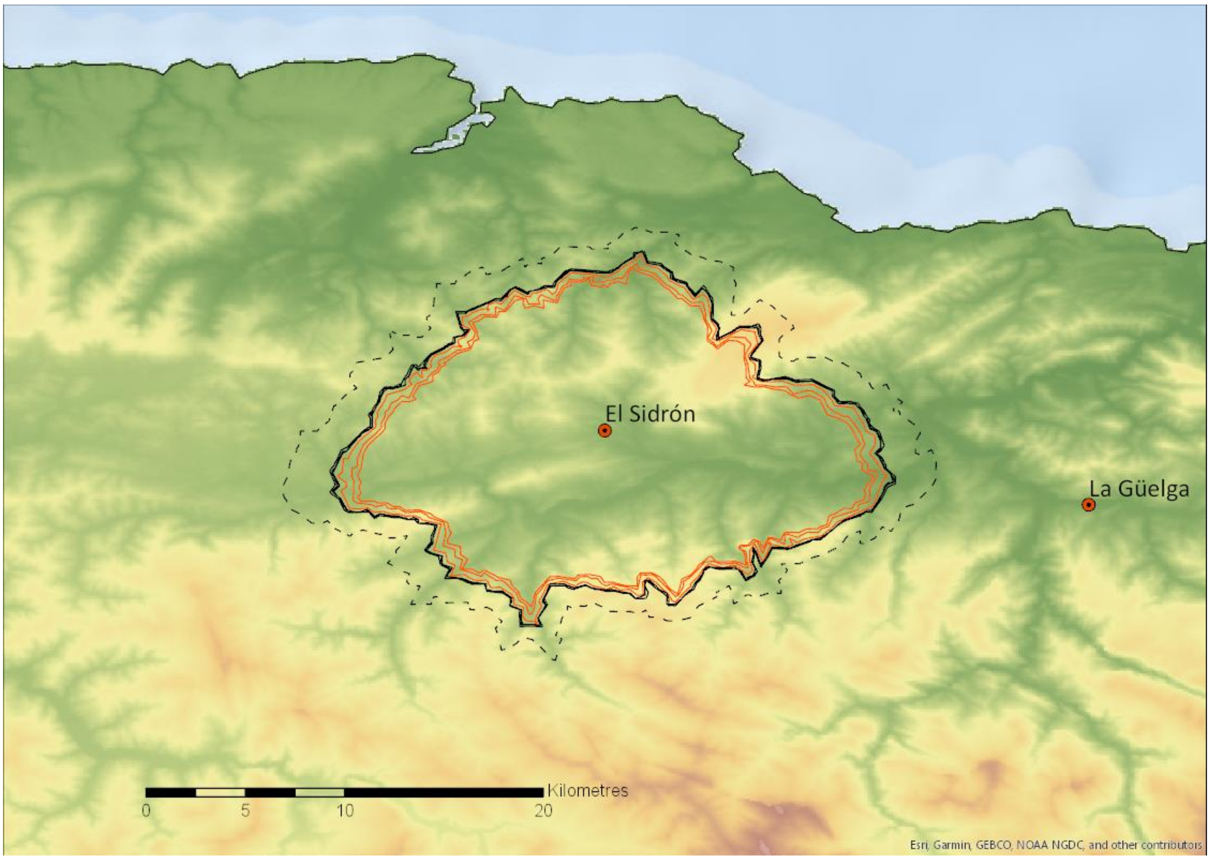


Figure 5.8: Cost catchments comparing the different estimates and recorded values of child mass for Neanderthal, Evenki and a modern global population (results for body mass at 1, 3 and 6 years is depicted here). The dotted line represents unloaded travel, black lines represent modern human values for child mass, and the orange represent modern and Evenki results.

differences in carrying behaviour and will be explored in further detail in the next chapter. In addition to the body mass of the carrier and child, terrain represents a significant variable in the energetic cost of walking and will be explored for all sites in the study region in the next section.

5.7 Testing the relationship between terrain and carrying children

Table 5.6: Models for an average Neanderthal with no load versus carrying 1, 3 and 6 year old child. 1800 kcal/day limit set for all sites in study.

Test	Model	Body mass[a]	Speed[b]	Load[c]	Terrain Factor
Average Neanderthal	T0	73.7	1.31	0	1
	T1	73.7	1.31	9.30	1
	T3	73.7	1.31	13.41	1
	T6	73.7	1.31	16.37	1

[a]Neanderthal adult body mass from Froehle and Churchill (see Chapter 4).
[b]Neanderthal walking speed from Hora and Sladek (2014); Wall-Scheffler (2014).
[c]Neanderthal child mass from Mateos et al. 2014, except 1 year old which is drawn from modern global data.

Table 5.7: Cost catchment areas for an average Neanderthal with no load versus carrying 1, 3 and 6 year old child. 1800 kcal/day limit set.

Site	Catchment area (km^2)			
	T0: No load	**T1: 1 year**	**T3: 3 years**	**T6: 6 years**
1 El Conde	291.11	223.64	199.72	184.76
2 La Viña	461.60	361.42	324.09	299.23
3 El Sidrón	403.39	328.18	299.47	280.99
4 La Güelga	355.00	292.35	269.89	255.03
5 Sopeña	267.01	216.55	197.41	184.73
6 Llonín	197.13	152.90	137.39	127.28
7 El Esquilleu	169.74	132.85	118.60	109.70
8 Hornos de la Peña	390.09	297.93	268.32	249.38
9 El Castillo	540.91	422.76	377.38	347.71
10 La Flecha	606.18	485.61	436.35	404.60
11 Covalejos	501.02	430.08	400.07	380.68
12 El Pendo	498.69	424.71	399.61	381.96
13 El Ruso	452.58	381.74	352.84	332.84
14 Morín	585.68	503.91	473.93	452.10
15 Otero	365.29	289.36	262.28	245.36
16 El Mirón	339.17	270.17	244.66	226.86

17 El Cuco	165.06	134.87	124.57	117.88
18 Aranbaltza III	305.24	254.10	234.00	220.06
19 Arlanpe	426.01	342.05	311.29	290.88
20 Arrillor	527.67	412.82	370.81	343.18
21 Axlor	333.26	260.75	235.74	218.96
22 Lezetxiki	323.16	253.39	230.38	215.91
23 Amalda	259.57	218.05	203.22	192.83
24 Abauntz	446.39	371.44	343.39	324.02

Table 5.8: Cost catchment areas for unloaded travel at Middle Palaeolithic sites in the northern Spain study region. Sites are ordered from smallest to largest catchment size. Site numbers by names correspond to positions on the regional map (see Chapter 3). Sites located close to coast are starred to show that catchment area will have been affected by position.

Site	**Catchment area (km^2)**	**Site**	**Catchment area (km^2)**
17 El Cuco*	165.1	8 Hornos de la Peña	390.1
7 El Esquilleu	169.7	3 El Sidrón	403.4
6 Llonín	197.1	19 Arlanpe	426.0
23 Amalda*	259.6	24 Abauntz	446.4
5 Sopeña	267.0	13 El Ruso*	452.6
1 El Conde	291.1	2 La Viña	461.6
18 Aranbaltza III*	305.2	12 El Pendo*	498.7
22 Lezetxiki	323.2	11 Covalejos*	501.0
21 Axlor	333.3	20 Arrillor	527.7
16 El Mirón	339.2	9 El Castillo	540.9
4 La Güelga	355.0	14 Morín*	585.7
15 Otero*	365.3	10 La Flecha	606.2

Models T0-6 calculate the cost of walking unloaded versus carrying a child aged 1, 3 and 6 years old. These were applied across the 24 sites in the northern Spain study region and the resulting catchment areas are reported in Tables 5.7 and 5.8, with sites sorted by area in the latter. These results demonstrate great variability in terrain experienced by Neanderthals in this region (see Figures 5.9 to 5.28) and emphasises the crucial role of local environment in influencing mobility patterns. For example, in comparison to the largest catchment area calculated at La Flecha, the catchment size at El Esquilleu is around 70% smaller. The particularly restricted movement for this site is confirmed by raw material and faunal evidence explored in Chapter 3. Furthermore, single mobility trips have been modelled here by using total estimates for the daily costs of mobility. Return trips would therefore see distances reduce even further, likely within 5km at El Esquilleu.

This raises the question of how these costs of carrying interact with the effects of terrain. It could be argued that they would simply reduce the distances covered, which in particularly tough terrain could restrict movement even further. However, rough terrain also brings a level of risk, especially for infants, who would likely find it difficult and dangerous on uneven ground. In recent foragers, aspects of risk can often be a key factor in shaping social organisation (e.g. Bird and Bird 2008) and terrain is an important and measurable example of this. The interplay between terrain, risk and mobility will therefore be explored further in the discussion chapter.

5.8 Chapter 5 conclusions

This chapter has modelled the costs of carrying children for Neanderthals and assessed the feasibility of using the Pandolf et al. (1977) equation to understand this behaviour. Adult body mass was unsurprisingly a costly variable, but the effect of individual differences in weight within a group may have previously been underestimated.

Estimates for child Neanderthal body mass from Mateos et al. (2014) were modelled against different levels of adult body mass, and whilst the effect is small in comparison to other variables explored here, it is argued that even subtle differences are likely to have important knock on effects for Neanderthal energy budgets. These carrying costs were also compared against modern and forager estimates for child body mass. If the Neanderthal estimates are correct, with their slower attainment of body mass, this could influence patterns of childcare and carrying behaviour.

Finally, the cost of unloaded and loaded travel was compared across 24 archaeological sites in the northern Spain region, in order to explore the impact of terrain. The resulting costs catchments were very varied, attesting to the need for Neanderthals to adapt their mobility according to the local environment. Overall, it is shown that although least cost models are focused on individual costs, they can and should be used to investigate the dynamics of group mobility. Further development of this energetic approach, which can measure the interaction between walking speed and carrying loads, would be an important next step.

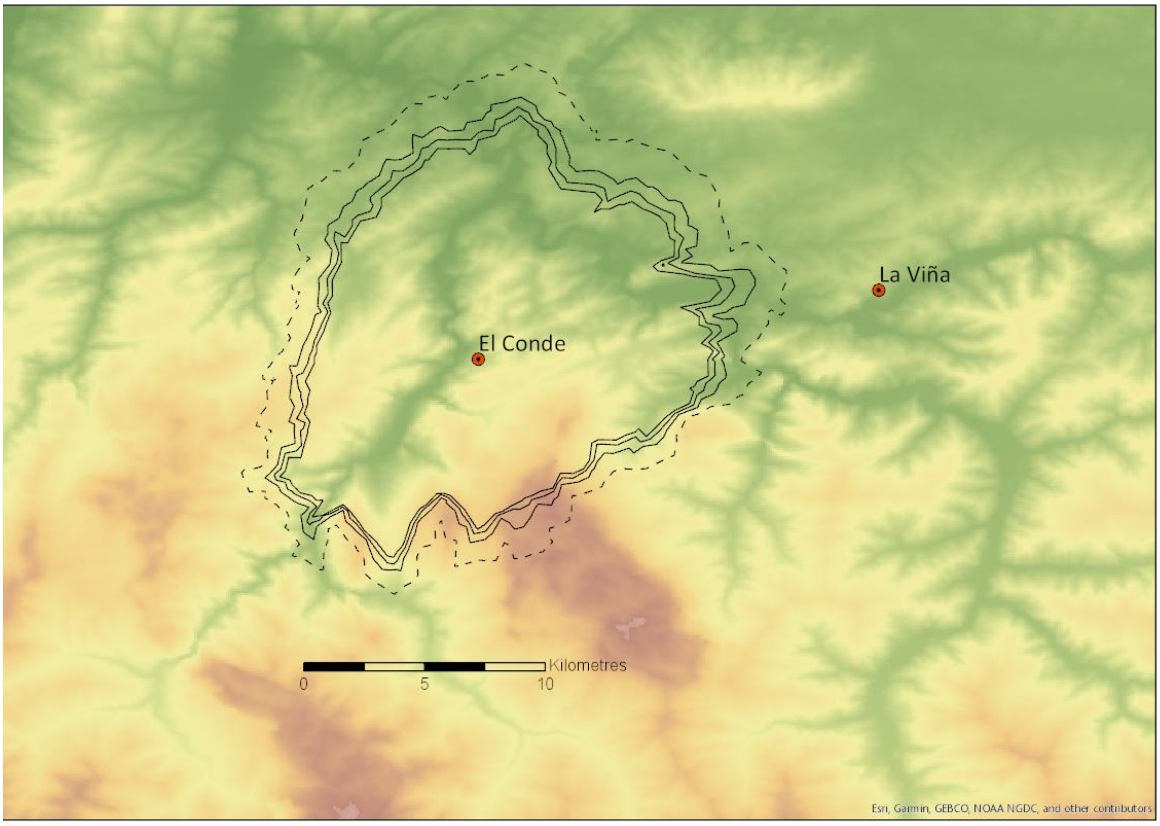


Figure 5.9: Cost catchments at El Conde. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

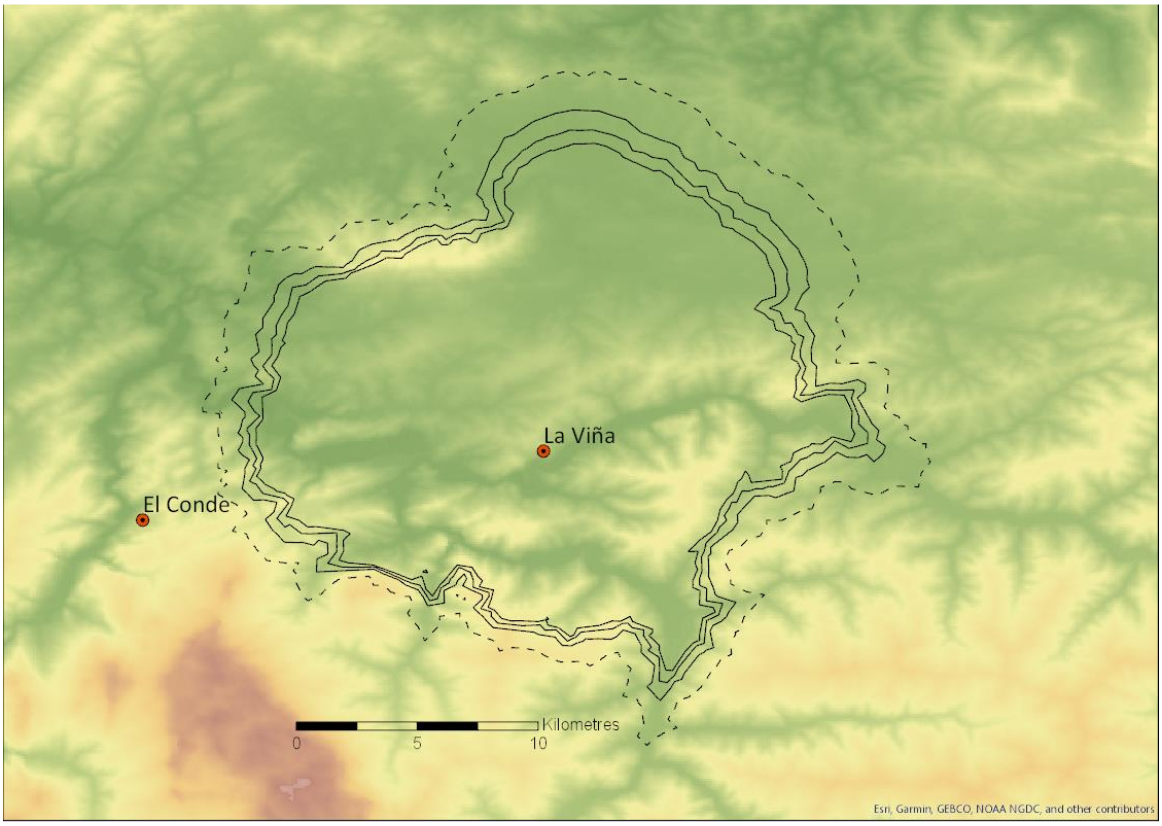


Figure 5.10: Cost catchments at La Viña. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

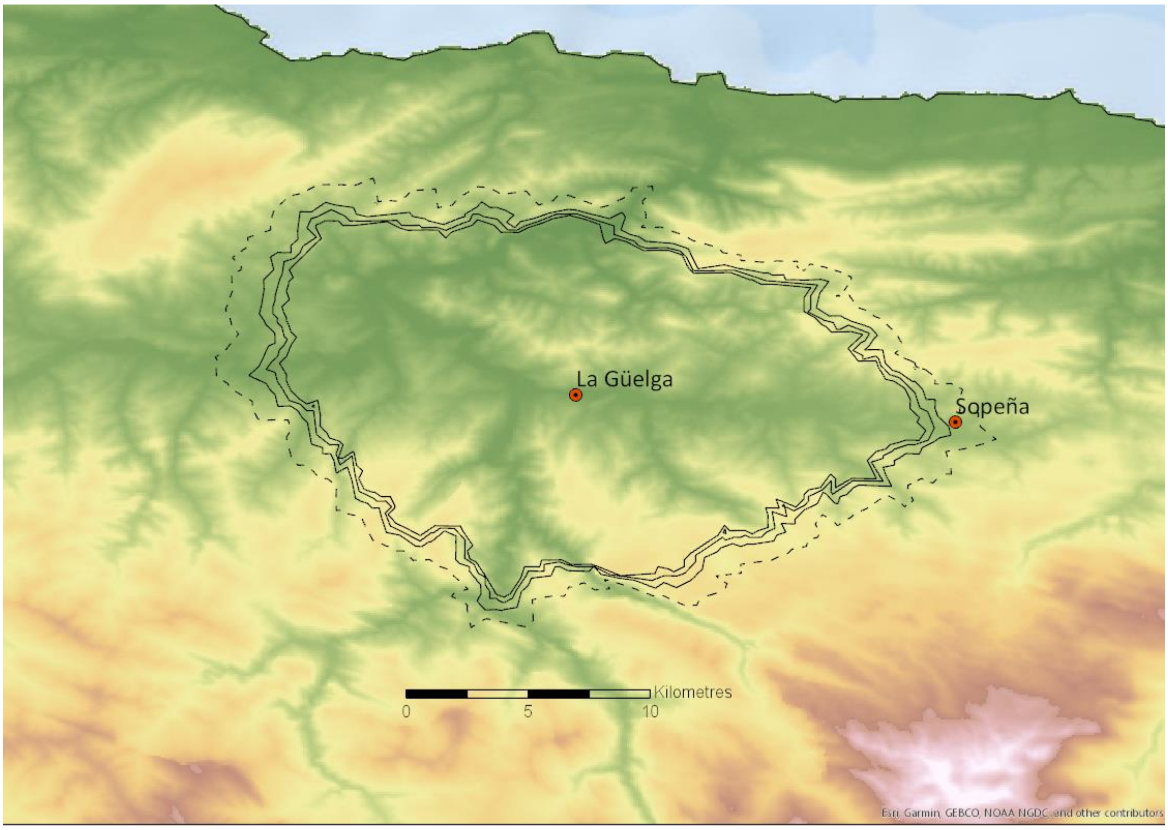


Figure 5.11: Cost catchments at La Güelga. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit.

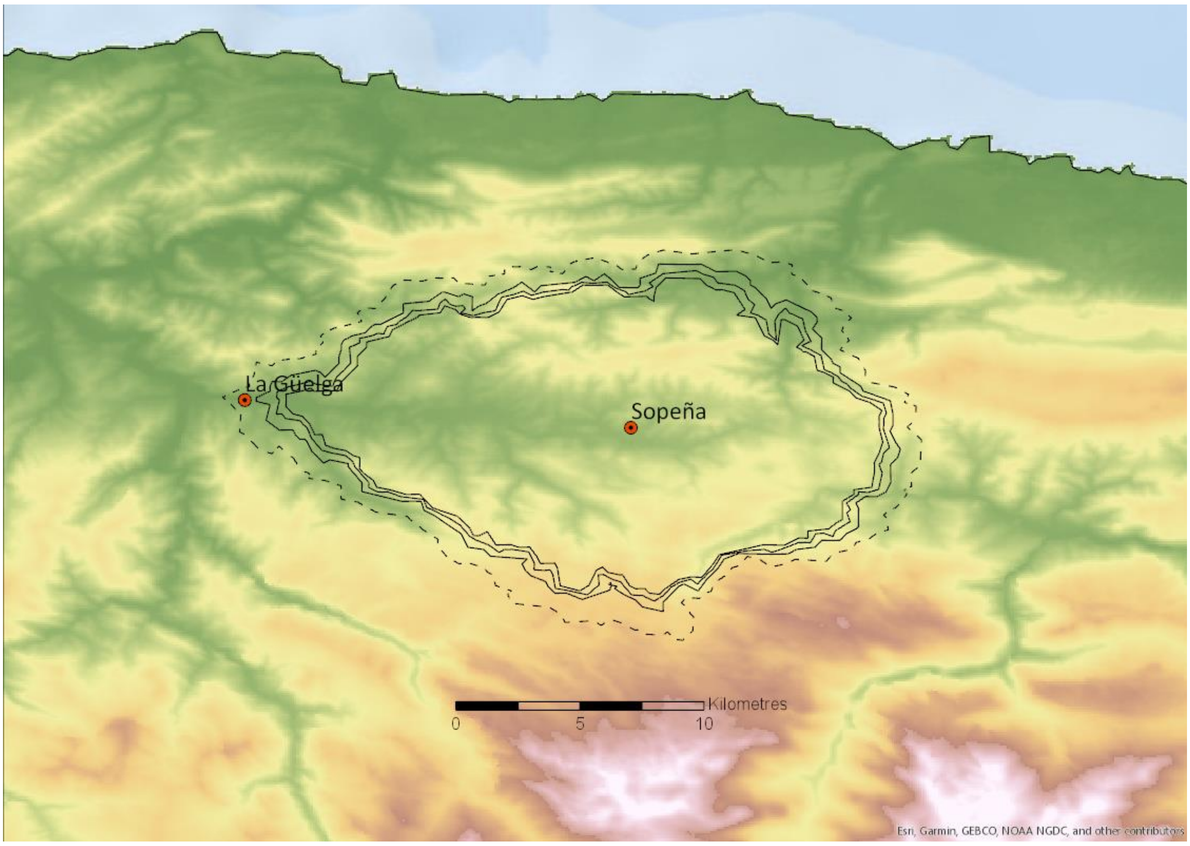


Figure 5.12: Cost catchments at Sopeña. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

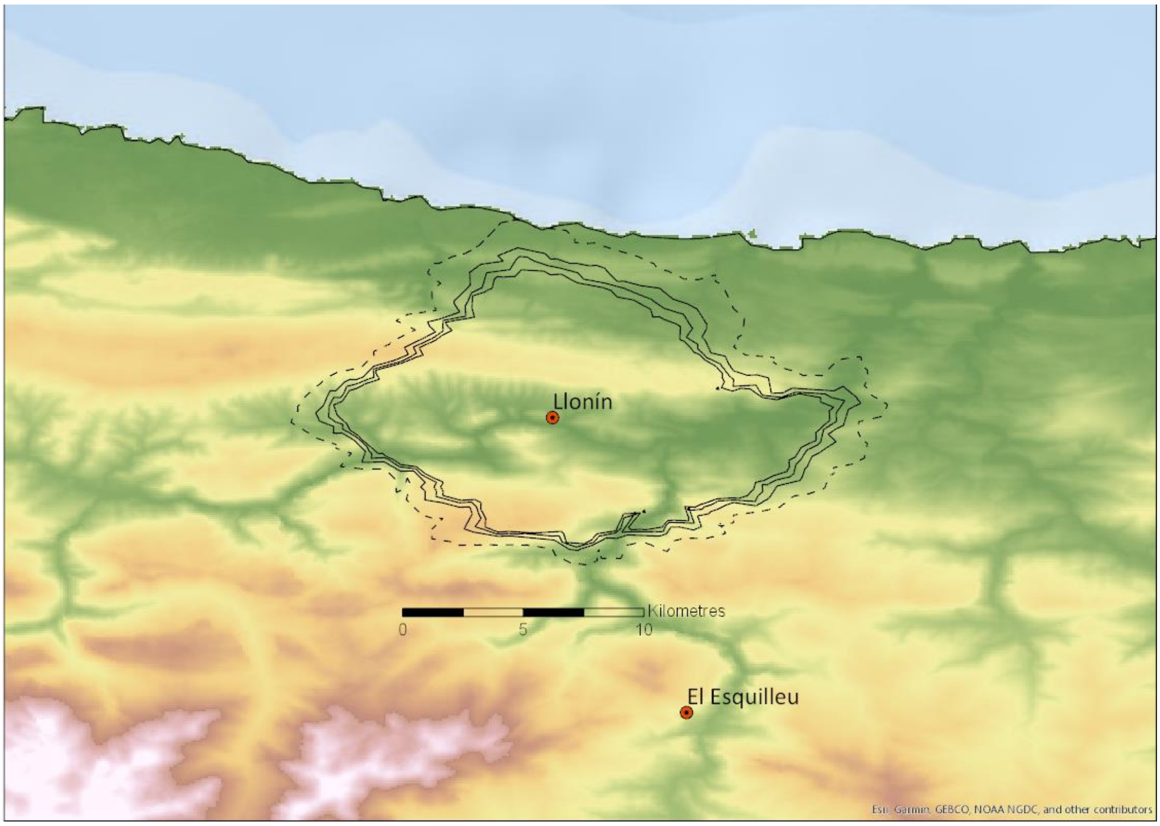


Figure 5.13: Cost catchments at Llonin. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

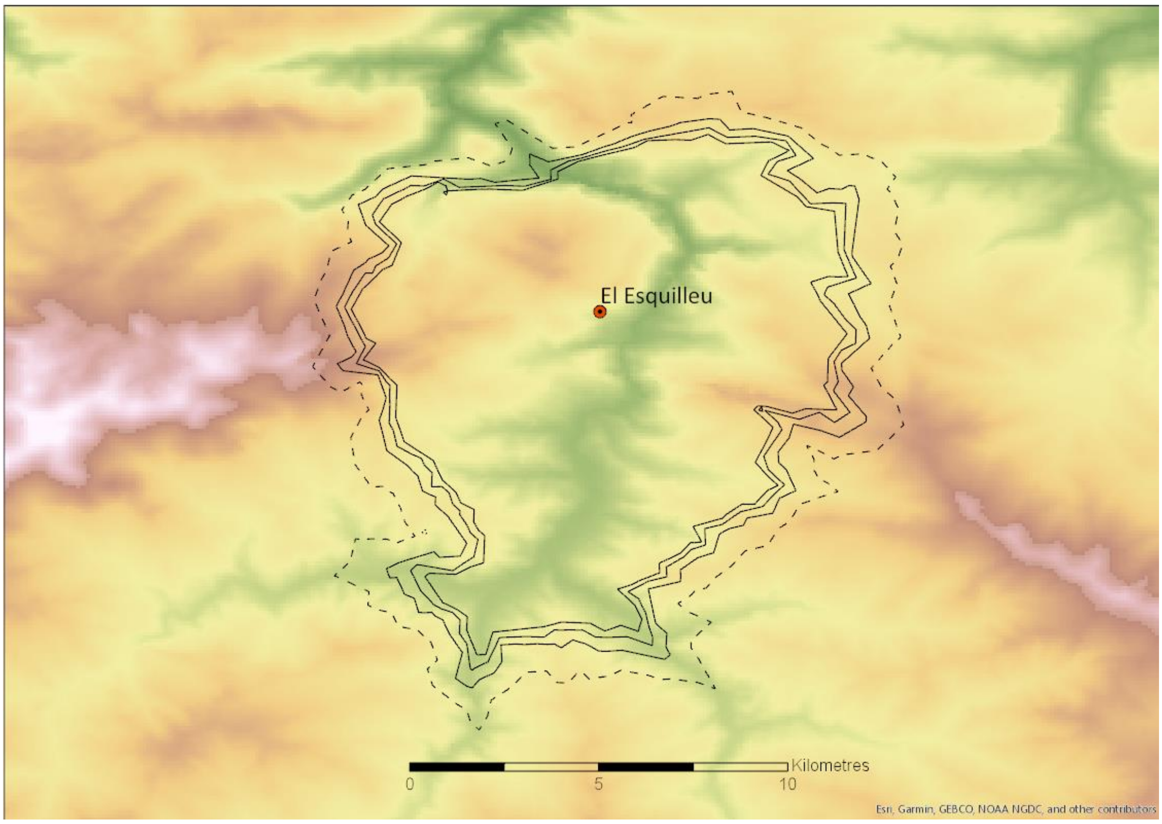


Figure 5.14: Cost catchments at El Esquilleu. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

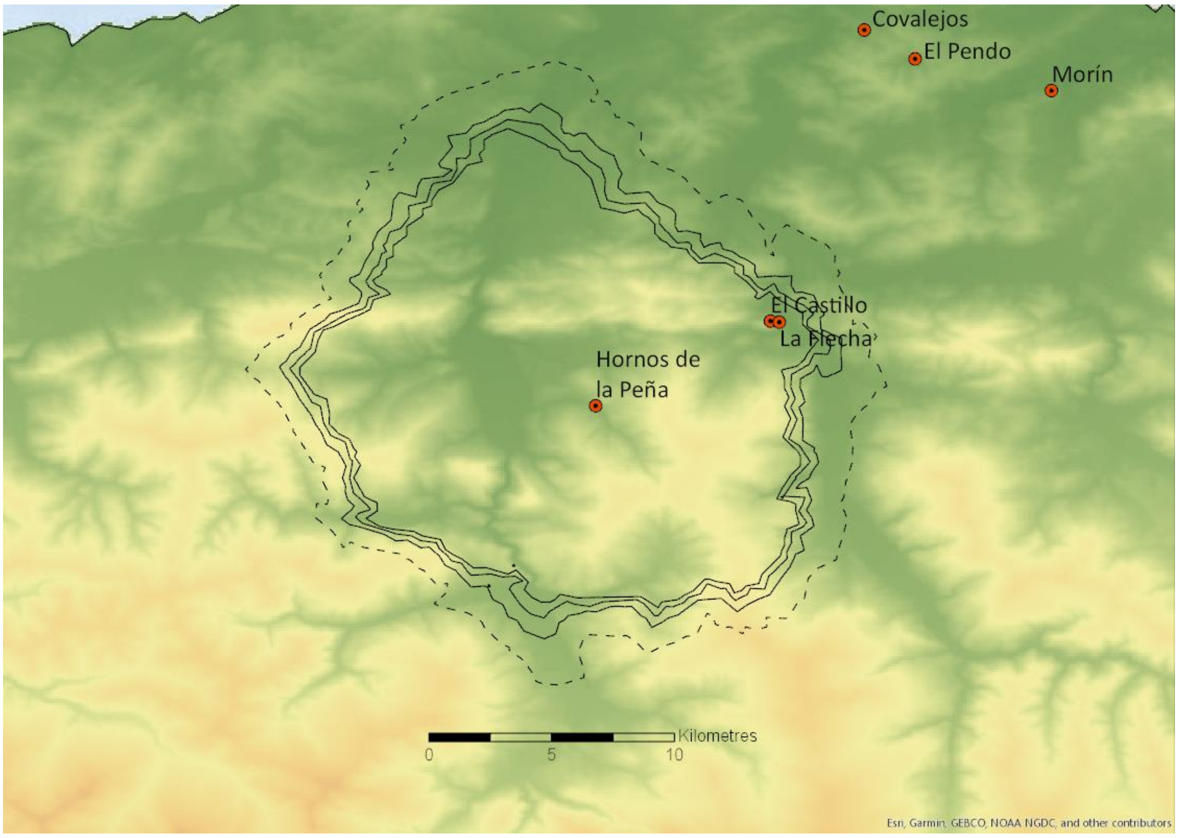


Figure 5.15: Cost catchments at Hornos de la Peña. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

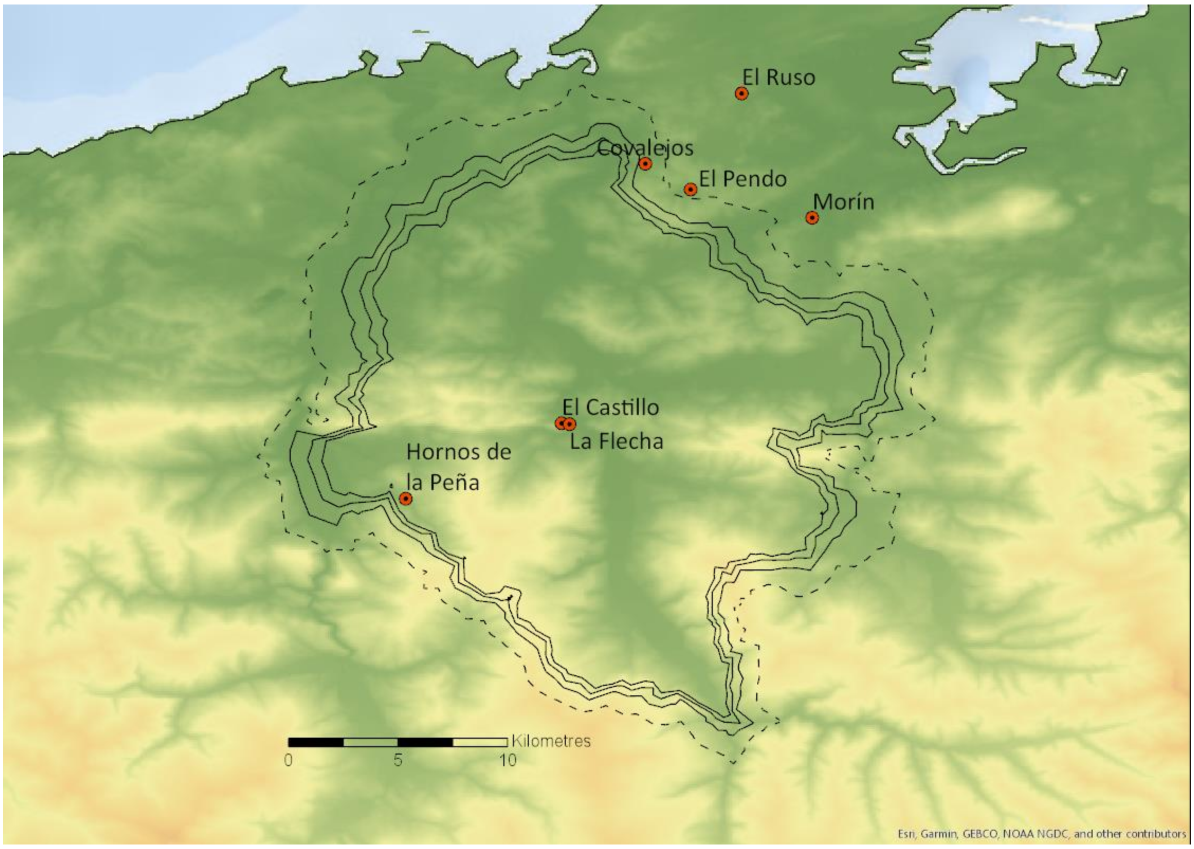


Figure 5.16: Cost catchments at El Castillo. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set

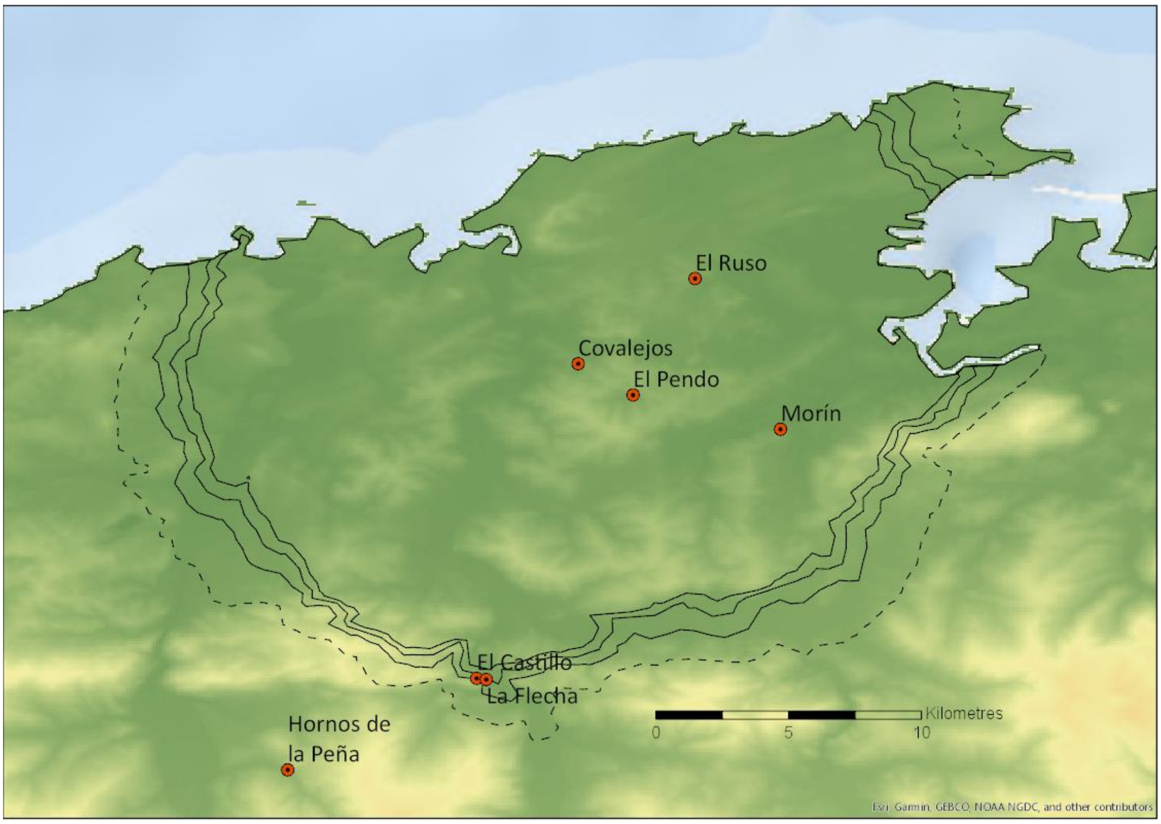


Figure 5.17: Cost catchments at Covalejos. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

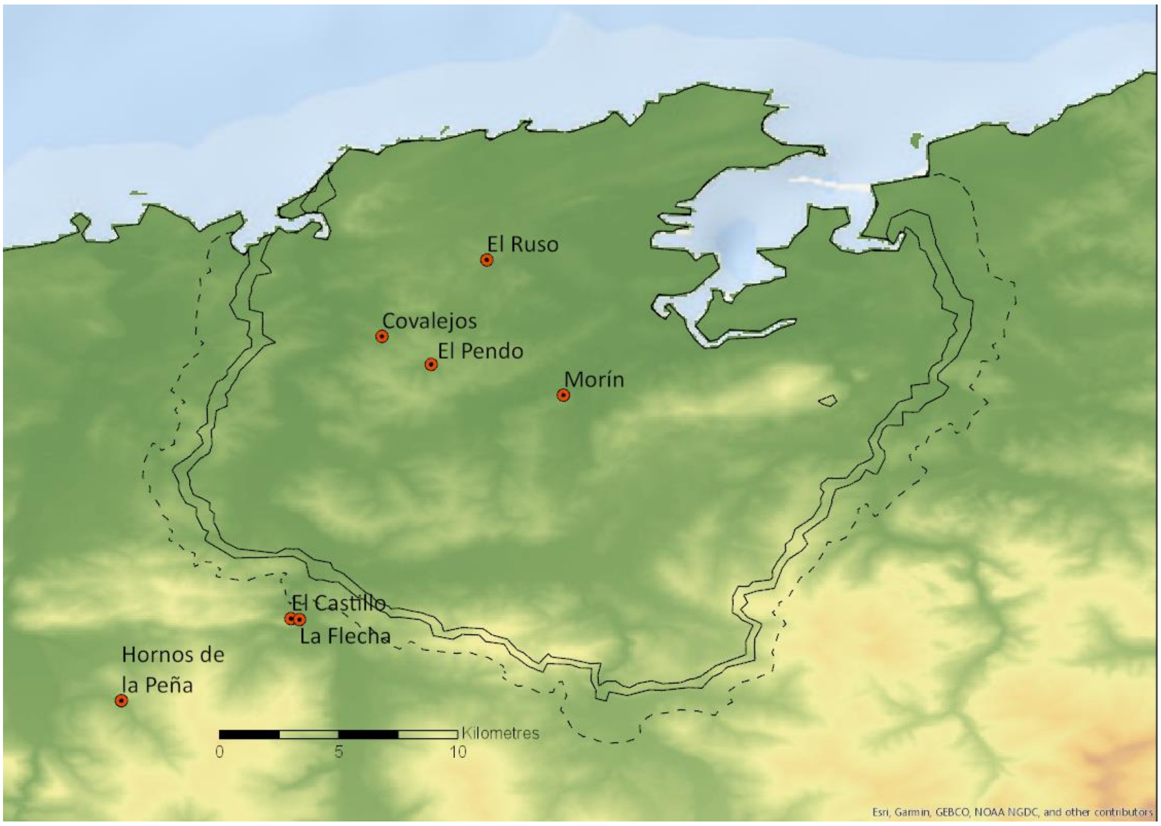


Figure 5.18: Cost catchments at Morín. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

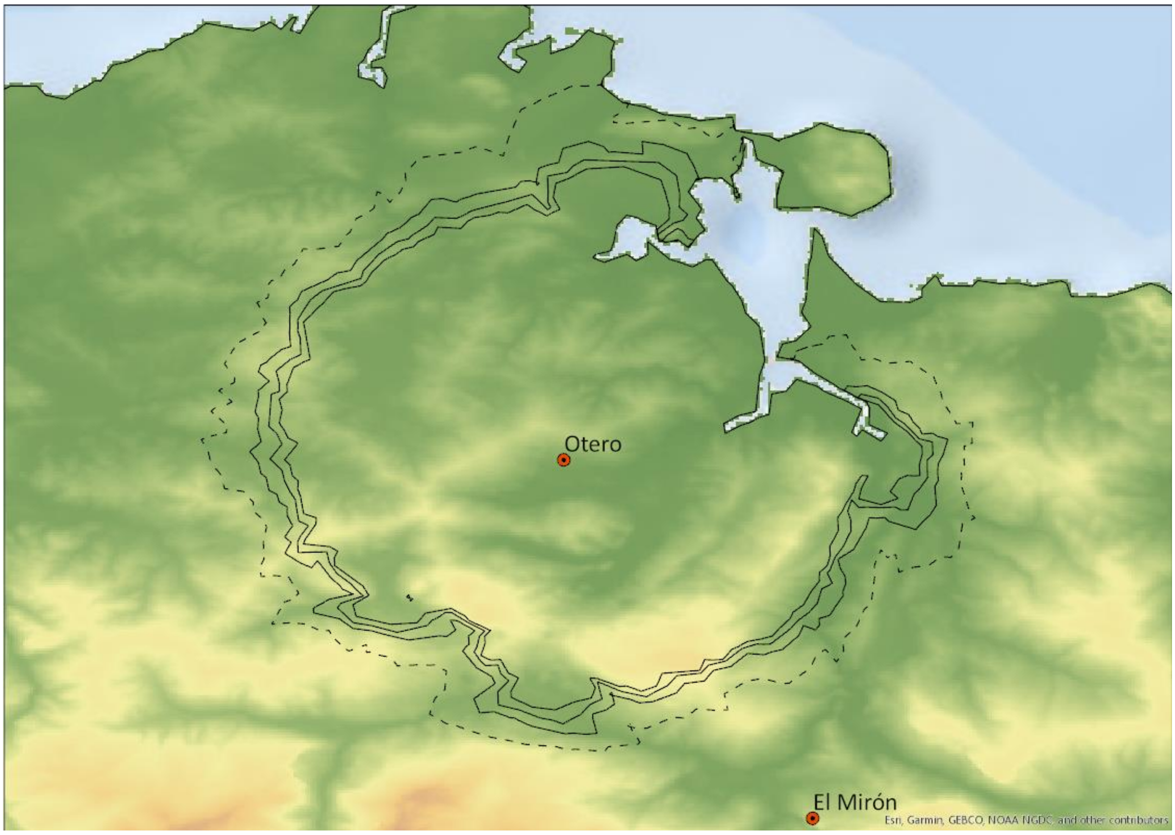


Figure 5.19: Cost catchments at Otero. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

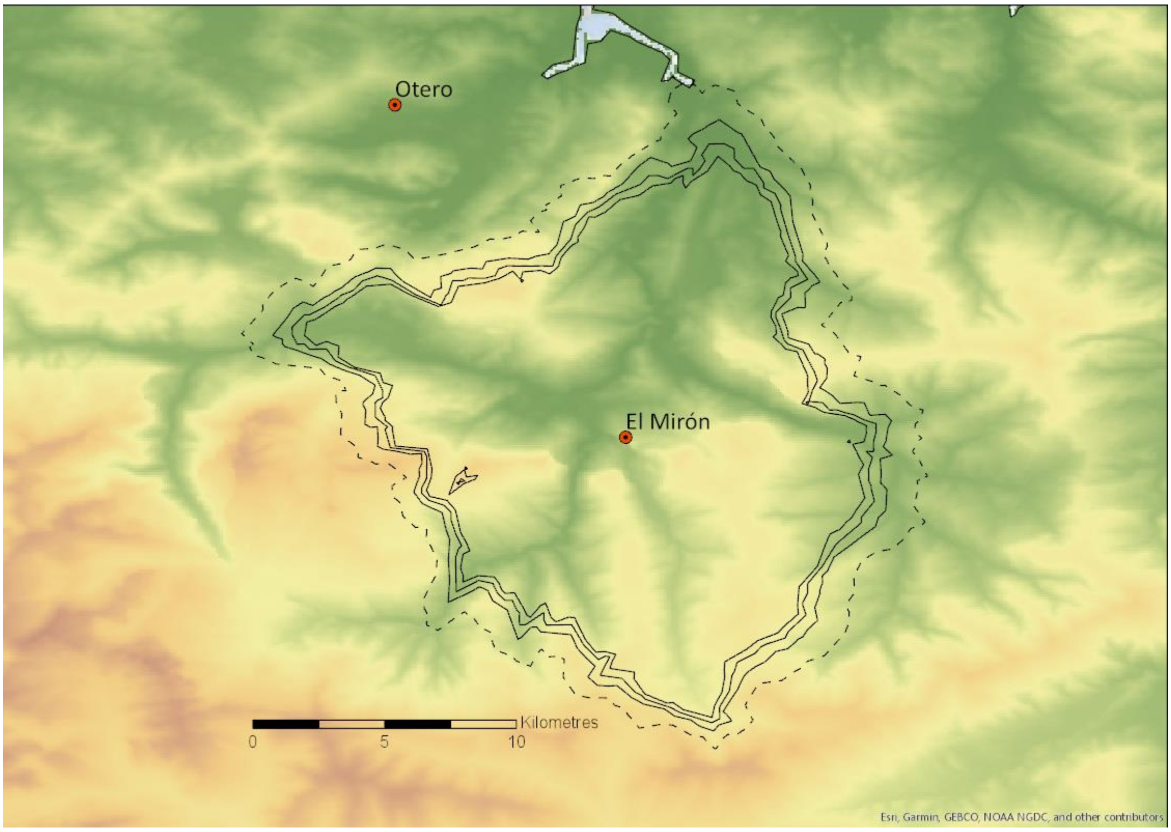


Figure 5.20: Cost catchments at El Mirón. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

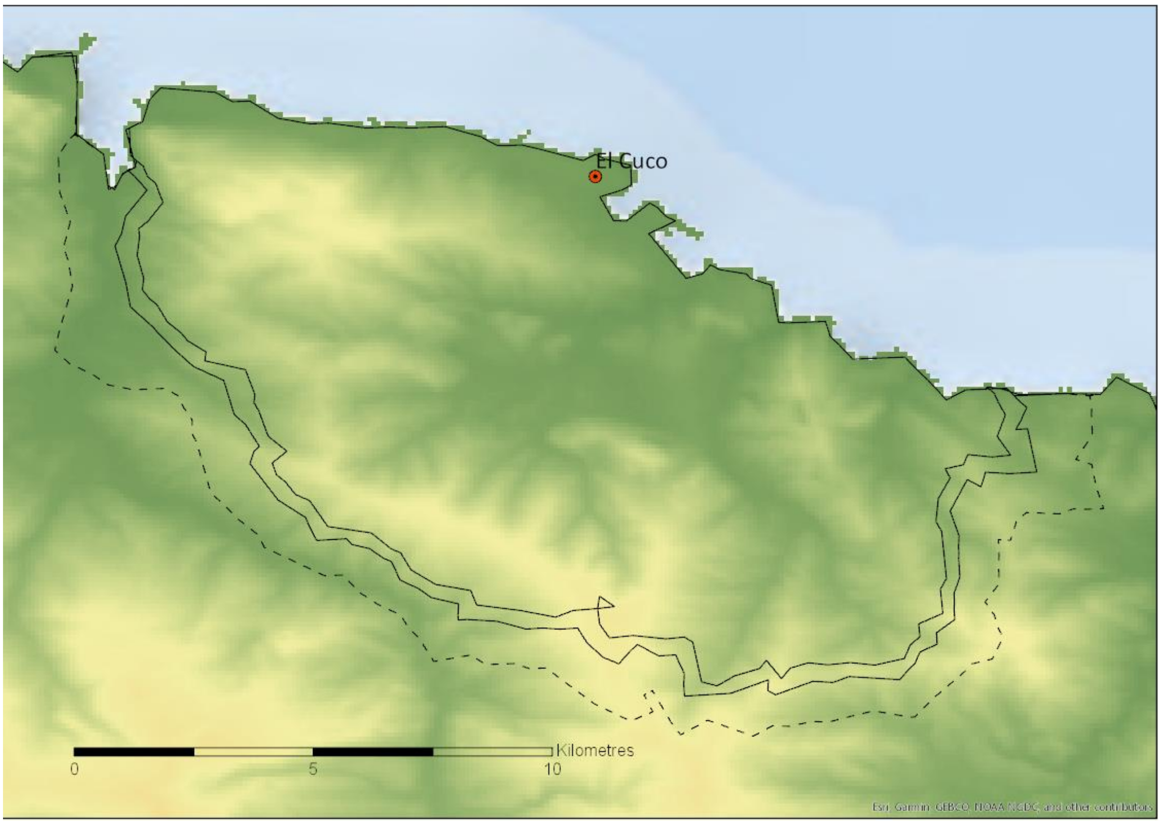


Figure 5.21: Cost catchments at El Cuco. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

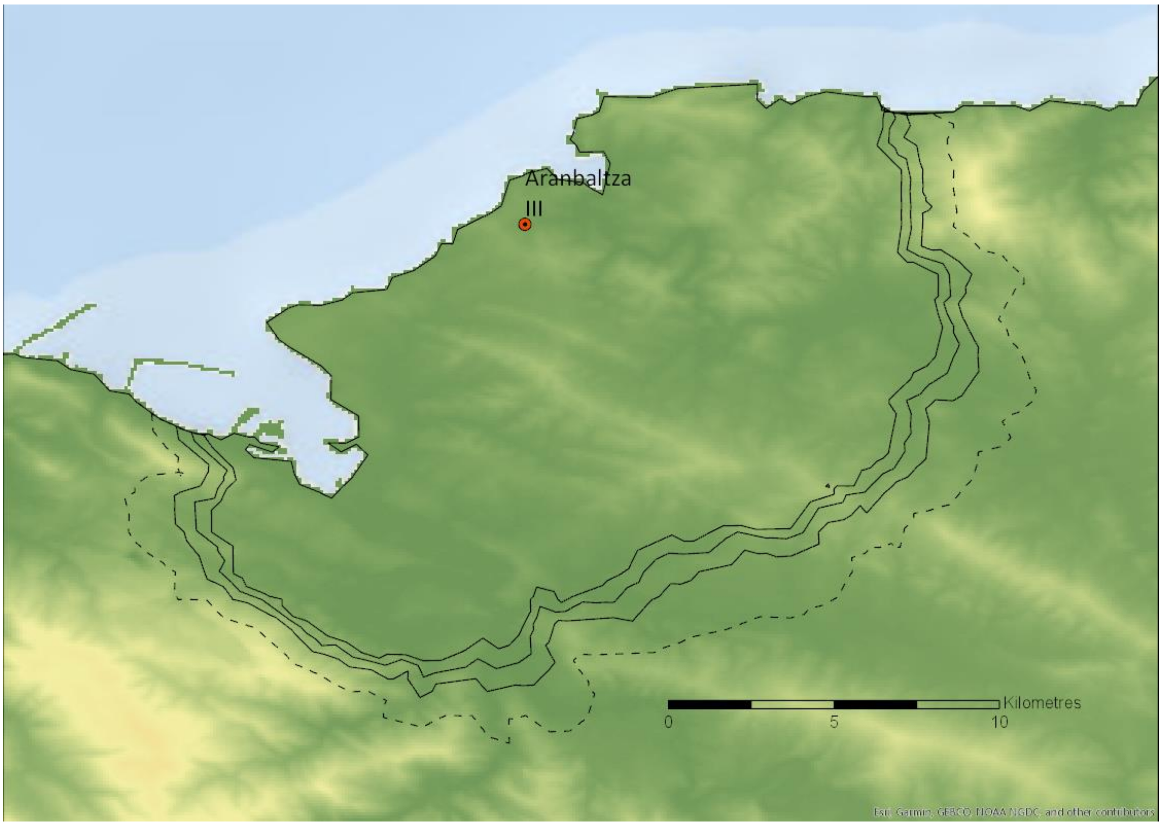


Figure 5.22: Cost catchments at Aranbaltza III. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

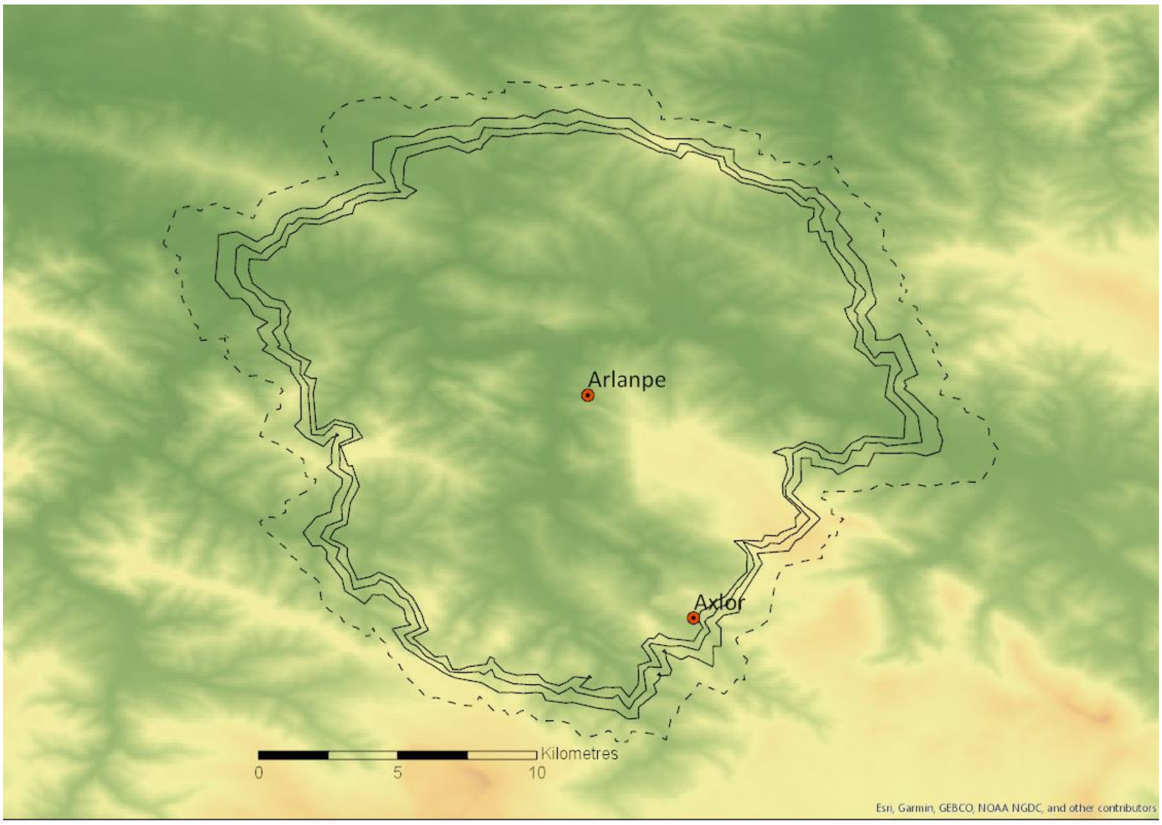


Figure 5.23: Cost catchments at Arlanpe. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average limit.

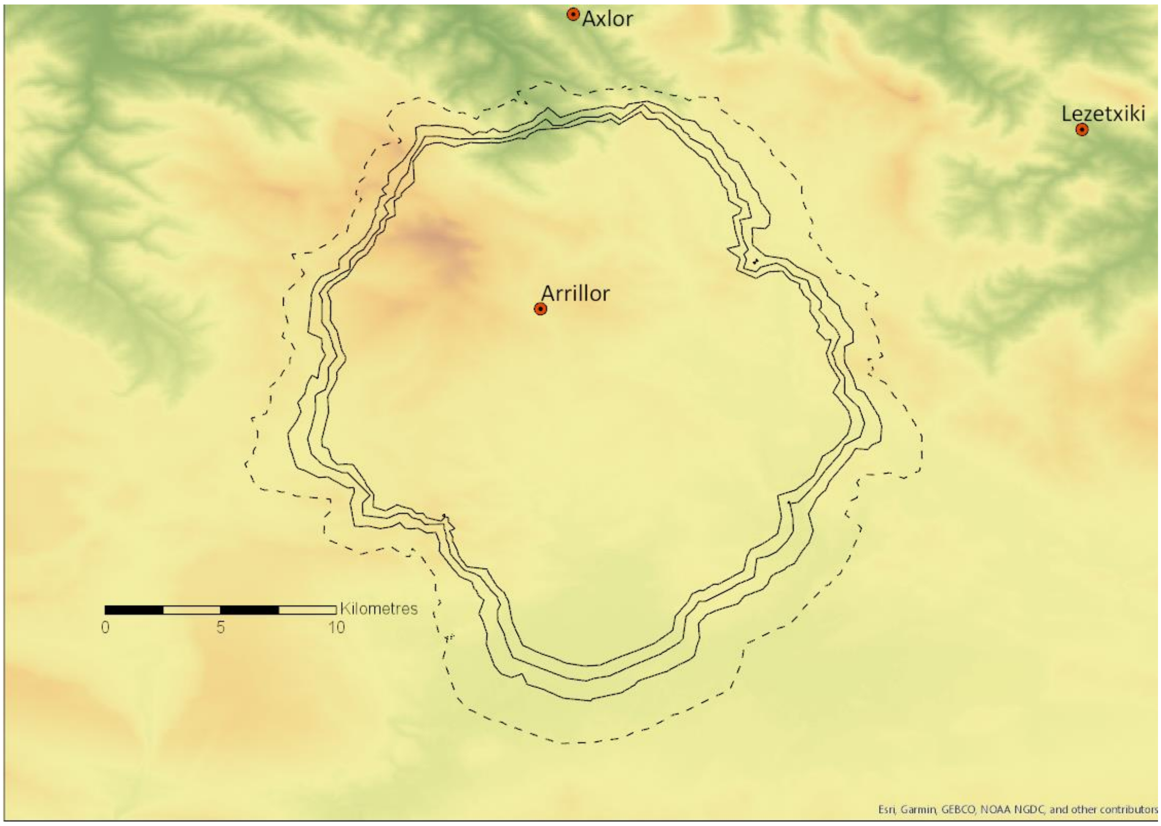


Figure 5.24: Cost catchments at Arrillor. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

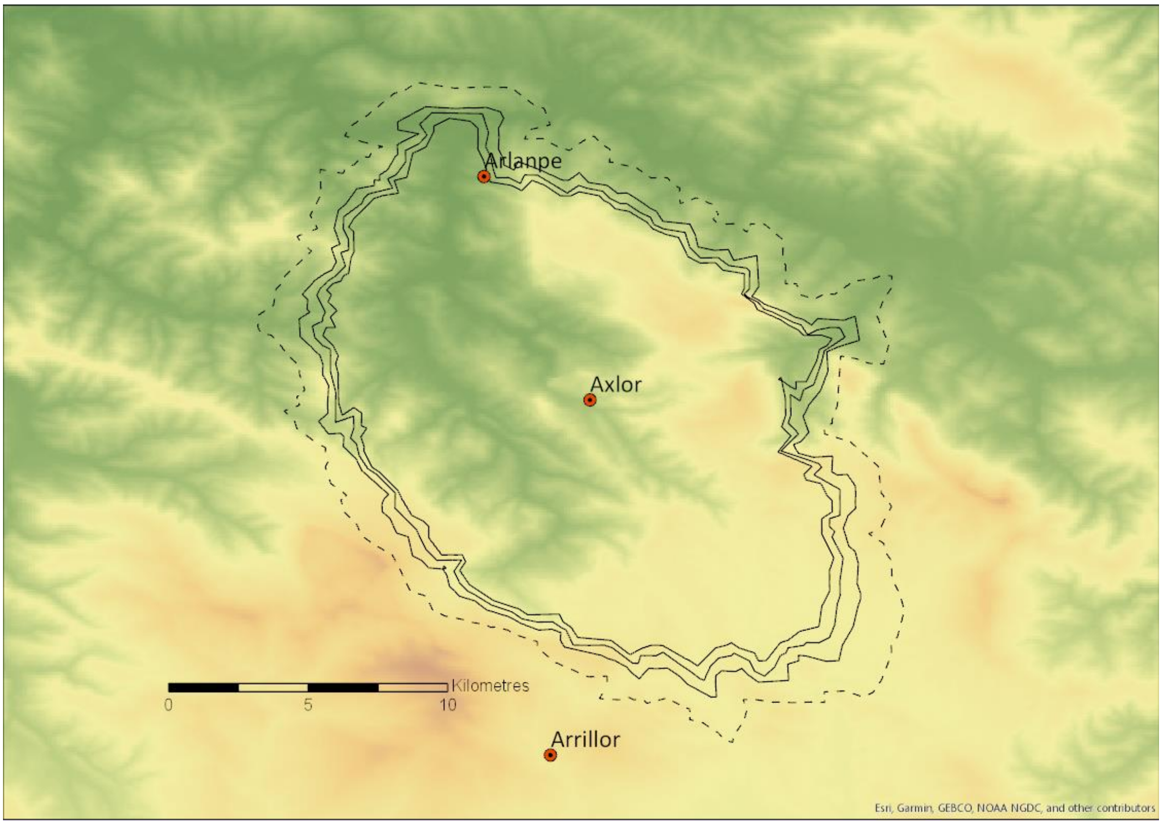


Figure 5.25: Cost catchments at Axlor. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

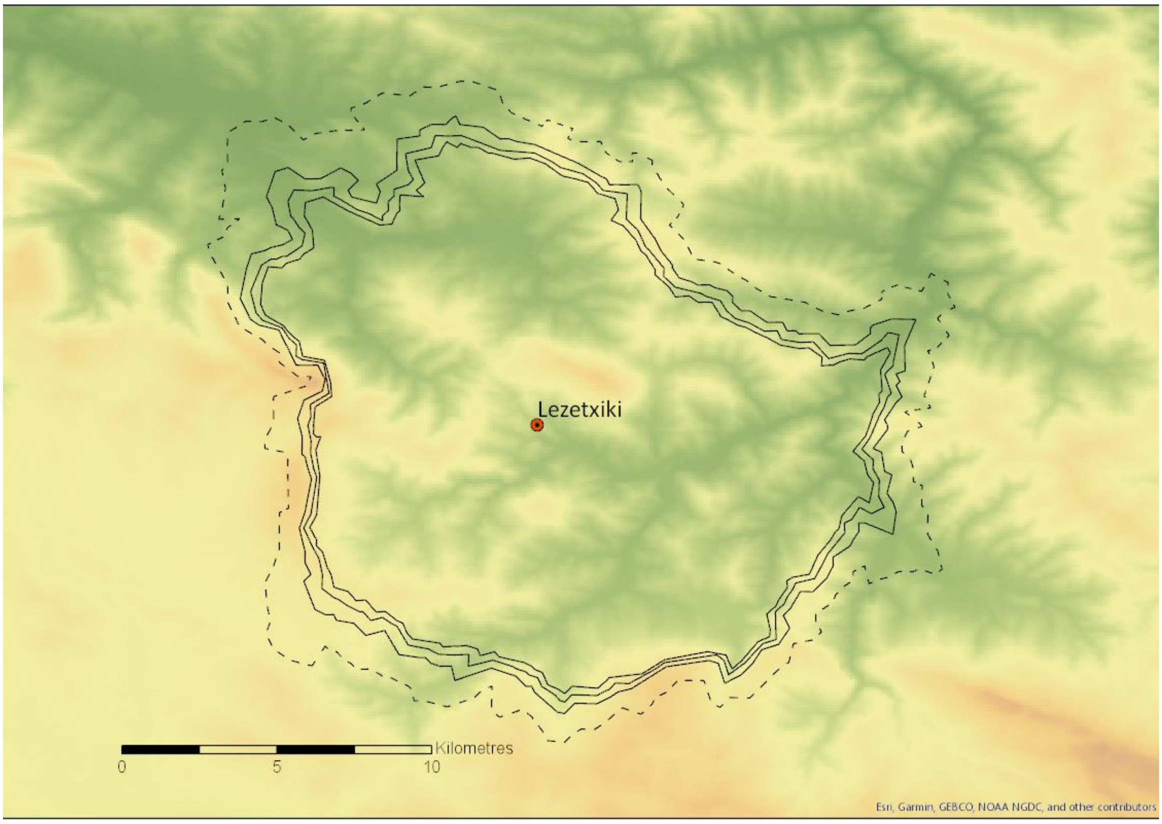


Figure 5.26: Cost catchments at Lezetxiki. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

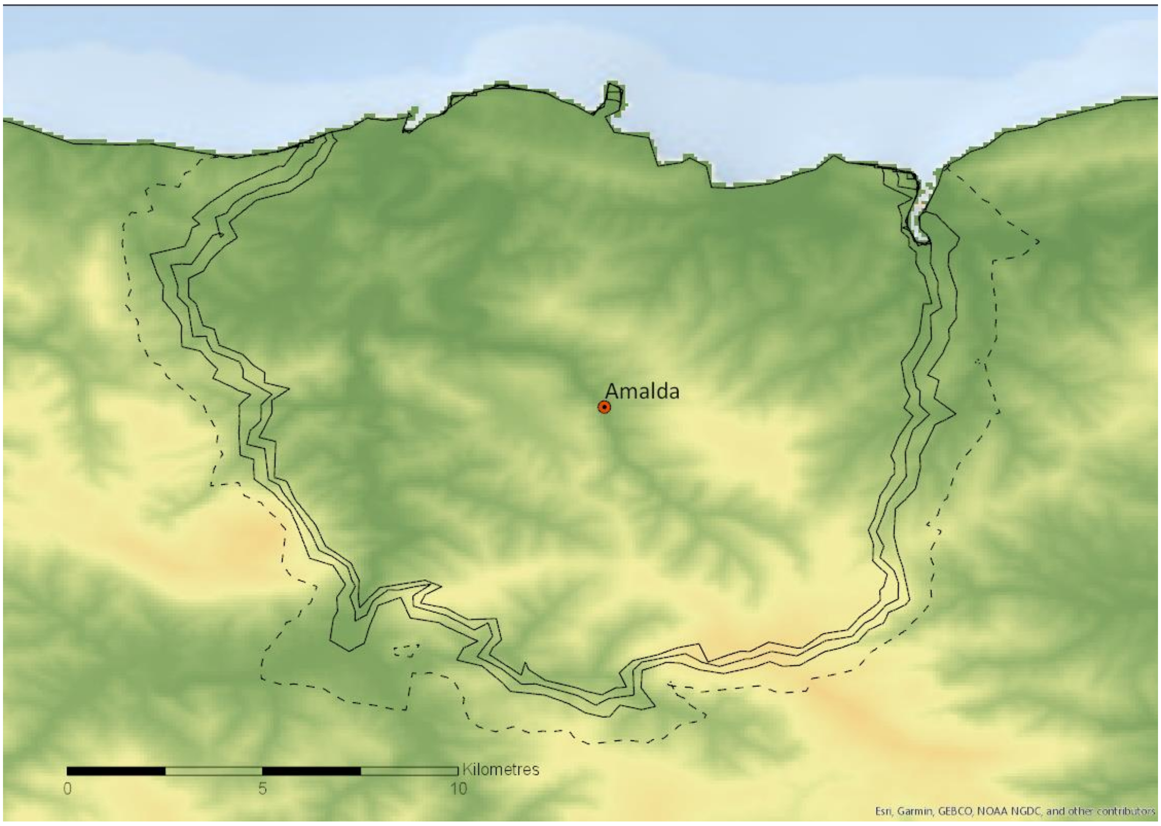


Figure 5.27: Cost catchments at Amalda. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day average Neanderthal limit.

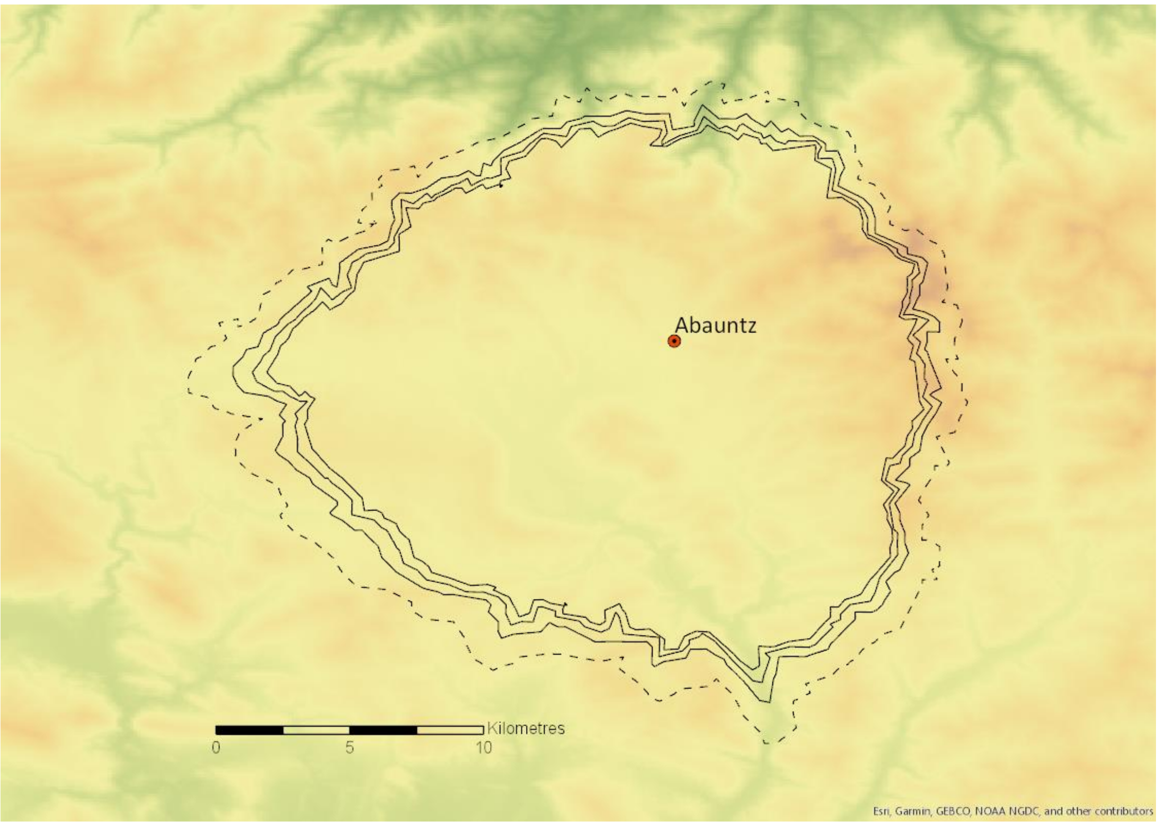


Figure 5.28: Cost catchments at Abauntz. Solid lines represent the results for carrying children aged 1, 3 and 6 years. Dotted line represents unloaded travel. 1800 kcal/day limit set.

CHAPTER SIX

Discussion and conclusions

6.1 Introduction

This chapter will bring together the results of the models produced in this study, with the broader evidence and issues in interpretation discussed throughout this thesis. The example of carrying children will be used to discuss the variability in Neanderthal mobility and the influence of the local landscape and regional context. It is argued that a reassessment of Neanderthal social organisation is warranted and further investigations of the cost of carrying will be discussed.

6.2 Evaluating the energetics approach

Models are, by necessity, imperfect and cannot reflect the full spectrum of factors influencing the cost of walking. However, the use of the Pandolf et al. (1977) equation in this study allowed for some informative exploration between the cost of carrying, body mass, and terrain. This study has also identified some issues with this equation and only through further energetics work, will some of these be resolved.

The issue of downhill walking costs was raised here (Chapter 4) and through comparative tests, it was shown that an existing modification of Pandolf et al. (1977) was unsuitable. An alternative option is physiological experiments which have sought to rectify the predictions for downhill walking. Santee et al. (2001; 2003), for example, have produced a correction factor for the Pandolf equation. This correction factor has since been implemented in several archaeological models with varying degrees of complexity (e.g. White 2012; White and Barber 2012; Wood and Wood 2006). However, there is always a danger of overcomplicating models and cost calculations, which can make it increasingly difficult to pinpoint the effects of different variables. As shown in the validity tests here, least cost analysis is extremely sensitive to small changes in variables and warns against the use of overly convoluted models (see Kanter 2012).

Nevertheless, integrating the relationship being walking speed and carrying load would be an important next step in this research. This was shown to be not possible through the Pandolf calculation but could have particularly important insights for group mobility (see Bouterse and Wall-Scheffler 2018; Wall-Scheffler and Myers 2013). Neanderthals are interpreted to have slower preferred walking speeds in comparison to modern humans, and it could be that this was a function of regularly burdened travel (Wall-Scheffler and 2014, 187).

Given the scale of the Palaeolithic record, the effect of individuals is difficult to assess. However, an energetics approach allows for this by considering the cost of walking by age and sex, in different tasks such as child carrying, and with individual differences such as body mass and walking speed.

6.3 Carrying loads and reassessing the variability of Neanderthal mobility

6.3.1 Carrying children, allocare and the onset of walking in Neanderthals

The tests performed in Chapter 5 use estimates of Neanderthal child mass by Mateos et al. (2004) and suggest a slower body mass attainment in Neanderthals. This could have important implications for child carrying, with Neanderthals potentially being able to transport children to an older age than expected. However, there is little consensus over the interpretation of growth in Neanderthals and the understanding of postcranial development has been explored far less than dental and cranial evidence (see Chapter 4 for review). This study therefore compared the estimates for Neanderthal body mass values with values recorded in Evenki and modern populations. Whilst the differences in cost were slight in comparison to adult body mass, in the context of balancing high energy demands, these could be significant. Further investigation of Neanderthal postcranial development will be vital in assessing the feasibility of the growth model produced by Mateos et al. (2004).

Another source of evidence for investigating the limit of carrying is interbirth intervals in Neanderthals. This was mentioned in reference to El Sidrón cave in Chapter 2, where mtDNA analysis point to potential familial relations and a birth spacing of around 4.5 years. The age of weaning also has a general relationship with interbirth intervals and whilst evidence centres on 3.5-4.5 years of age (Churchill 2014, 94), younger estimates do exist (e.g. Smith et al. 2018).

Changes in long bone strength have also been associated with the onset of bipedal walking in humans, and potentially provide additional insights on the duration of carrying. In a biomechanical study by Cowgill and Johnston (2018), Neanderthals were found to have low ratios of femoral and humeral to tibial torsional strength, in comparison to modern human populations. Given the small sample size of Neanderthals involved, it remains difficult to interpret these results. However, the researchers do suggest that these skeletal traits might represent a difference in timing for the onset of walking (Cowill and Johnston 2018, 143). The relatively elevated tibial strength could be caused by an earlier developmental transition to walking (Cowill and Johnston 2018, 143). Whilst other explanations cannot be dismissed, this offers a promising source of evidence for investigating the timing of carrying and independent walking.

It therefore remains very difficult to interpret the when Neanderthals may typically have stopped carrying children. Furthermore, from an ethnographic perspective, it becomes apparent that we should not be expecting a universal pattern. Lancy (2014, 98) details numerous examples of where local environment has an impact on carrying behaviour in recent foragers. Ache children, for example, grow up amongst difficult and hazardous terrain, so typically remain carried for up to 5 years of age (Lancy 2014, 98). Hadza infants, on the other hand, enjoy a relatively safe environment, so can provision for themselves from an early age and are left behind in camp from 3 years (Lancy 2014, 98). There are also a range of societies which accelerate the transition to walking in infants, in contexts where carrying will be a particular burden (Lancy 2014, 134-135). It is therefore clear that whilst body mass is important (Kramer 1998), it will not always be the primary factor in carrying decisions. This was also demonstrated by the models within this study, where local terrain has wide ranging effects on mobility distances.

The level of allocare could also be a factor in the duration of carrying behaviour in Neanderthals. In their assessment of when it is energetically advantageous to carry children, Kramer (1998, 79) notes that modern humans should begin to encourage more independent walking from about 3 years of age. This age was argued to decrease, however, if the child has nutritional support from sources beyond the mother (Kramer 1998, 80). This suggests that the mode of childcare can have implications for group mobility.

From an energetics perspective, Neanderthals were highly likely to be dependent on non-maternal provisioning (Aiello and Key 2002) and archaeological evidence points to closely bonded, cooperative groups (Spikins 2014; Spikins 2018a). Allocare is therefore likely to have been part of the social dimensions of Neanderthal groups. The role of intergenerational cooperation has been particularly emphasised in evolutionary studies, which stresses the role of post-reproductive females in providing resource support (Hawkes et al. 1997). However, some have suggested that given the limited evidence for older age individuals in Neanderthal skeletal profiles, 'grandmothering' did not play a significant role in their social organisation (Caspari and Lee 2004; Pettitt 2000, 360; Churchill 2014, 341). Accurately ageing older adult individuals remains a contentious issue within biological anthropology and it is clear that broad classifications of age are skewing demographic profiles (Appleby 2018; Buckberry 2015; Falys and Prangle 2015). A lack of older female Neanderthals should also be questioned as a genuine pattern, when skeletal bias and issues in assigning sex to fossil hominins cannot be ruled out.

Nevertheless, if there were less older individuals available to help with childcare, it asks who was supporting the provision of young infants. This again would likely depend on both the size and composition of a group. For example, ethnographic accounts point to the important role of siblings in infant carrying in some societies (Henry et al. 2012). Whilst variable, archaeological and fossil evidence suggests Neanderthal groups were relatively small in general (see Chapter 2 for review) and this could suggest a limited number of child peers for infants to be supported by. Churchill (2014, 342) directly links these small group sizes with a need for young Neanderthals to contribute early to foraging. However, in the few existing examples of group composition reviewed in Chapter 2, it was shown that variation in the numbers of children and adolescents should be expected. As a result, we should also expect flexibility in mobility patterns, subsistence activities and childcare to reflect this.

This study has demonstrated that the composition of a group will have significant effects on the cost of walking. The cost of infant carrying was a fundamental part of Neanderthal life and likely had to be negotiated in different ways by different groups. Travelling together as a whole group would not have been energetically beneficial in all contexts, especially when carrying behaviour is included. Carrying has been neglected in energetics estimates of Neanderthal behaviours but needs to be included in future studies. It is argued that minor changes in load would have important knock-on effects for energy budgets, which in turn might impact aspects of mobility and fertility. This will be explored further in the context of seasonality.

6.3.2 Seasonality and carrying Neanderthal children

Seasonal shifts in energy patterns are known to have profound effects on fertility in modern humans and extant primates, making this likely to extent to past hominins as well (Mussi 2007; Snodgrass and Leonard 2009, 228). Some have suggested that the high energy requirements of Neanderthals would have made them particularly sensitive to this and would result in relatively low overall fertility and pronounced birth seasonality (Snodgrass and Leonard 2009, 228). Churchill (2014, 93) takes this further by specifying that there could have been a strong selective pressure for late spring or early summer births. This is based on the argument that children born later in the year may have a poorer chance of survival, having developed prenatally during a time of nutritional strain (Churchill 2014, 93).

Seasonal nutritional stress is well documented among recent hunter gatherers and dental analysis has indicated that this was also an issue for some Neanderthal groups (e.g.

Guatelli-Steinberg et al. 2004; 2014). For example, teeth from two Neanderthals from Payre, France, reveal pronounced seasonal trends, with stress in one individual corresponding with the coldest part of winter (Smith et al. 2018). This Neanderthal also was found to have been born in spring and weaned in autumn (Smith et al. 2018). Whilst this is only one example and cannot be taken as universal, it does match with a selection for spring births. This suggests that there could have been certain times of the year in which the number of vulnerable young infants within Neanderthal groups were higher. Mobility and social organisation therefore also likely varied on a seasonal basis. If more newborns were born and carried in the spring, it raises the question whether this could be reflected in the use of the site. For example, if a site is interpreted as being used in Spring from faunal analysis, there may be more evidence of social division of labour. Conversely, if there is little evidence of task division, it could be explored whether faunal and lithic evidence indicates reduced foraging ranges, because the group travelled together and the presence of more children restricted mobility.

Seasonality could potentially affect group mobility decisions in other ways. This study has been concerned with testing energy costs, but time can also be an important factor in hunter-gatherer decisions (e.g. O'Connell et al. 1988) and may have been particularly pertinent for Neanderthals during shorter winter days (Wall-Scheffler 2014, 186). If there is less time for activities, whole group travel might not always be feasible from an energetics perspective. Males risk higher costs if walking slower female speeds and vice versa (Wall-Scheffler and Myers 2013). This is an issue only compounded by carrying children or other loads, as demonstrated in this study. Either way, the potential distance that can be covered by travelling together is reduced, so a decision would need to be made regarding group mobility. Other factors would have of course interacted with this, especially safety and risk, as well as subtle differences in group size and composition.

If all group members did need to move together, it could be that Neanderthals respond in other ways, such as increasing loads on a seasonal basis (Wall-Scheffler et al. 2014, 187). In other words, it is accepted that slower walking speeds would be needed, even though time is restricted, so more resources would need to be transported back with each trip. These seasonal differences in load have been documented among recent hunter-gatherers (Hilton and Greaves 2008; Hurato et al. 1992). An important expansion to this study would therefore to model time as a currency and tests how it interacts with the results from energetics, as well as archaeological evidence of mobility distances and seasonality. Expanding to other forms of carrying behaviour, such as food resources, and investigating how this influences time and energy constraints could also provide important insights.

6.3.3 Accommodating group members in Neanderthal mobility: children and healthcare

All studies concerning the cost of transport in past hominins have only considered adult locomotion. Whilst there is a dearth of experimentation data available for child walking in comparison to adults, the few studies that have focused on children provide important insights.

Size, morphology and motor skills all change dramatically during childhood growth and are likely to impact the cost of mobility between age groups (DeJaegar et al. 2001, 538). In an energetic study of young adults and children aged 3-12 years old, DeJaegar et al. (2001) found the age-specific differences to be substantial. For example, at a constant speed, the average gross oxygen consumption of 3-4 year olds was about 70% higher than that of adults, compared to 45% higher in 5-6 year olds, 30% for 7-8 year olds, and 15% for 9-10 year olds (DeJaegar et al. 2011, 540). This difference appears to disappear by the age of 11-12 years (DeJaegar et al. 2011, 540), although other studies have suggested a slightly younger age for reaching adult efficiency (Kramer 1998, 78). Walking for very young children therefore appears to be very inefficient in comparison to adults, with older children being somewhat intermediate (DeJaegar et al. 2011; Kramer 1998; Morgan et al. 2008). DeJaegar et al. (2011, 540) suggests a large part of this pattern is related to the higher energy costs of standing in younger children, which is thought to be associated with greater proportions of fat-free mass and the surface area/mass ratio. Inefficiency in muscle contraction or limb movements may also be important factors (Kramer 1998, 74).

Carrying children therefore involves important energetic costs, but children walking independently can bring further energetic considerations. An expansion of models to include this would be a useful next step in understanding the dynamics of group mobility. For this to be achieved, further energetic studies of child walking are needed to provide reliable predictive equations. Most energetic studies of adults have emerged from military contexts, including the carrying equation by Pandolf et al. (1977), meaning there is significantly less research on the costs of walking in infants and children. It would also be useful to study further examples of group mobility and how different individuals are accommodated, or not, cross-culturally.

Bouterse and Wall-Scheffler (2018) for example, highlight differences in walking between high-contact and low-contact cultures. Ethnic groups in Uganda, such as the Baganda, are known to have a tendency towards closer interpersonal contact and this is forwarded as a factor in them always slowing down in group walking situations, including groups of men (Bouterse and Wall-Scheffler 2018, 12). Such culturally specific aspects of group walking would of course be difficult to investigate in the archaeological record, but the study demonstrates the social complexities in group mobility. A cross-cultural analysis of existing accounts of ethnographic group mobility, and how group composition, walking distance, environment and tasks interact, could provide further insights.

The need to accommodate different walking abilities would have not only been restricted to children. Elderly individuals are known to have a different gait, which affect the cost of walking (Kramer 2010, 498). This could have implications for childcare, as if these individuals are already walking at slower speeds, it might be more feasible for them to carry or travel with children for close distance tasks, whilst other group members travel further. It is debated that there were many older individuals in Neanderthals societies, but there is clear evidence for other group members which may have needed support and provisioning.

Spikins et al. (2018a) discuss several Neanderthal individuals whose mobility was likely affected at some point in their life. For example, for Kiik-Koba 1, stiffening of the vertebral column likely impacted movement, whilst injuries sustained by Shanidar 3 would have required a period of care, followed by constraints in mobility due a foot pathology (Spikins et al. 2018a). In another example, a young female adult, La Ferrassie 2, displays evidence of a healed, but distorted proximal fracture of the right fibula. In a conservative scenario, this injury would cause pain during walking and most likely prevented direct participation in highly active tasks, such as hunting, for around six to eight weeks (Tilley 2015, 257). Rather than seeing these examples as evidence of abandonment by social groups, as previously argued (Trinkaus 1995, 138), signs of healing and wider evidence of healthcare demonstrate these individuals were supported (Spikins et al. 2018a).

This raises the question of whether restricted mobility could be reflected in site use. One way to approach this would be to compare the accessibility of locations to evidence of group size. It could be that locations which are more suitable for individuals who need support, such as children or injured individuals, have evidence of more stable or intense occupation. In addition, evidence of diverse activities intra-site in terms of diet and non-foraging tasks, might also be a signal for diverse social composition and organisation.

Ethnographic evidence of division of labour is often reduced to a simple version of the gendered separation of tasks and mobility, in order to more easily compare this to the past. However, it is perhaps the flexibility in these roles which should be emphasised. It is clear that social organisation adapts across age and sex based on local environment, levels of risk, periods of injury, and variances in group size and composition. Given the scale of the archaeological record, it will not be possible to tease out all these nuances. However, the variability in social organisation needs further exploration, especially for studies of Neanderthals.

6.3.4 Neanderthal anatomy and carrying loads

As discussed in Chapter 1, humans are exceptional in their ability to carry large loads in conjunction with endurance walking (Hilton and Meldrum 2004, 4) and evidence from raw material transport appears to suggest this has a long evolutionary history (e.g. Wynn

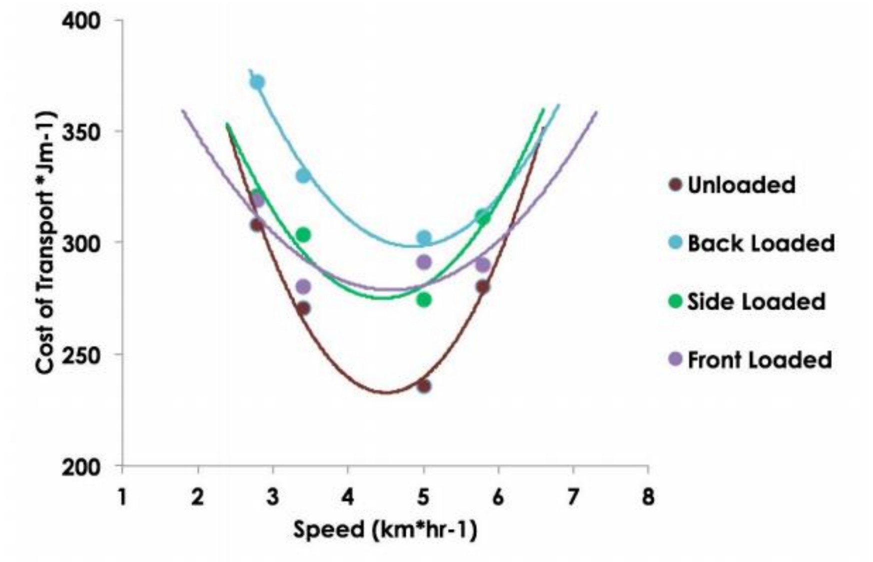


Figure 6.1: A comparison of energy expenditure while walking either unloaded or loaded with a weight in various positions (from Benjamin 2016, 3).

et al. 2011). Neanderthals should therefore be seen as habitual carriers of tools, children and resources, and this could be reflected in their anatomy.

The wide pelvis of Neanderthals has often been linked to cold adaptation (e.g. Weaver 2009). However, with consensus increasingly shifting away from Neanderthal morphology being primarily shaped by climate (e.g. Rae et al. 2011; Stewart et al. 2019), this trait could instead be linked to carrying. It is thought that increasing stride length is particularly key in minimising the energetic costs of increasing load, and this action appears to come from pelvis rotation, rather than any differences in using the lower limbs (Wall-Scheffler et al. 2007; Wall-Scheffler and Myers 2013). Experimental studies of female locomotion have shown that a wider pelvis for one's mass will save energy with both front loads (Wall-Scheffler and Myers 2013; 2017) and back loads (Wall-Scheffler et al. 2007). Neanderthal morphology, with its broad pelvis, therefore appears to be well-suited for walking with heavy burdens (Wall-Scheffler 2012a, 75).

An important future expansion is therefore to explore the impact of carrying beyond children. As discussed in the introduction to this study (see Chapter 1), there has been limited research of carrying behaviour, but in the few existing studies, this has solely focused on lithic tools and raw materials. Carrying other resources such as firewood and food would have been everyday activities for Neanderthals and may have had important ramifications for group mobility and social organisation. In reality, children were also likely carried alongside with resources, as is seen commonly in recent foragers (see Chapter 1). This suggests that the costs of carrying modelled here are a minimum.

Further studies investigating the energetics of carrying and specifically the benefits of particular anatomical traits could also offer important insights. For example, the mode of carrying is known to be an important factor in the cost of walking (Watson et al. 2008), but it has yet to be explored in evolutionary studies. This raises the question whether there were any differences for Neanderthals in the patterns of energy expenditure known for contemporary humans (Figure 6.1). Within modern populations, there is clear evidence of variation. Nepalese porters and women from the East African Luo and Kikuyu tribes, are known to carry very heavy loads in energetically economic ways (Bastien et al. 2005; Maloiy et al. 1986). This is possibly related to training and anatomical change in childhood (Maloiy et al. 1986).

There are some existing options for investigating skeletal indicators of habitual carrying. Evidence of osteoarthritis and osteopythosis in the spine has been linked to heavy load carrying in other prehistoric contexts (see Murrieta-Flores 2009, 256 for discussion). Among Neanderthal evidence, vertebral osteoarthritis has been identified in La Chapelle-aux-Saints 1. The effects of burden carrying were not ruled out in this instance, but it was originally suggested that the degeneration was more likely the result of trauma (Dawson and Trinkaus 1997). Recent reassessment, however, suggests these remains actually reflect normal age-related degenerations (Gómez-Olivencia 2013; Haeusler et al. 2019).

In a study by Weber and Pusch (2008), the spine of two mature Neanderthals aged 30-55 years from Kebara and Shanidar were analysed and were found to have remarkably mild degenerative changes. The research team suggests this indicates there is little correlation between the high activity levels of Neanderthals and degenerative spine disease, and this could be related to the “greater stability” of the entire Neanderthal skeleton (Weber and Pusch 2008, 330). In short, the robusticity and muscularity of Neanderthals helped to keep bone degeneration minimal (Weber and Pusch, 2008) and could therefore be another benefit to regular load carrying. These studies are restricted to only a few sites, so this possibility can only be confirmed by extending the analysis to further examples. Additional studies exploring the specific effect of carrying on the skeleton could also provide important insights.

6.3.5 Lower limbs, carrying loads and terrain

As discussed in Chapter 2, the strength and robusticity of lower limbs are used to infer activity levels in the Palaeolithic and have been argued to indicate comparably high mobility for Neanderthals and modern humans (e.g. Shaw and Stock 2013). Churchill (2014, 311-312), however, discusses the difficulties in interpreting this evidence, with disagreement among osteologists on the underlying cause for lower limb robusticity. For example, there have been several studies of highly mobile recent foragers, which do not display elevated robusticity in comparison to humans from industrial and agricultural societies (e.g. Carlson et al. 2007). This suggests that the mechanism for bone modelling might not be related to distance travelled and the loading experienced during carrying burdens could be an alternative explanation (Churchill 2014, 312). This is complicated by intragroup differences in carrying behaviour, which is commonly seen in ethnographic contexts. For example, among the Venezuelan Pumé foragers, males travel further distances but with little burden, whereas females travel less but regularly transport heavy loads (Hilton and Greaves 2008). Levels of robusticity could therefore be equivalent among different individuals but reflect complex interactions between distances covered and the regularity of load carrying (Churchill 2014, 312).

Carrying loads is not the only alternative explanation for differences in lower limb robusticity. A recent study by Holt and Whittey (2019) investigated the impact of terrain on bone dimensions and found that more rugged terrain impacts the strength of lower limbs, even after accounting for subsistence mode. The researchers still associate these lower limb differences to overall distance travelled, with rugged terrain often forcing travellers to walk more convoluted routes. However, other studies have instead related this to repeated directional changes, which again is often necessitated by obstacles in rough terrain (Carlson et al. 2007; Marchi and Shaw 2011). Either way, terrain was likely an additional factor in Neanderthal lower limb robusticity. The study also reports that more rugged terrain is associated with less circular lower limb diaphyses (Holt and Whittey), but examples of femoral midshaft cross-sections of Neanderthals appear to be more circular than modern human forager examples (see Figure 10.1 in Churchill 2014, 313). This aspect could therefore benefit from further investigation.

There are many interrelated factors in creating robusticity and shaping of lower limbs. In Palaeolithic studies, this is frequently related to the distance and intensity of travel, but other factors such as terrain and carrying loads could also be an important influence. From the modelling of terrain in this study, it is clear that the local environment was an important factor in shaping group mobility, and it could be that Neanderthals are particularly suited to travel in variable terrain. As discussed in Chapter 2, this has also been forwarded by Higgins and Ruff (2011), who argue that although the shorter lower limb lengths in Neanderthals are energetically disadvantageous on flat terrain, this trait could be beneficial in rugged environments. Integration of lower limb length in future mobility models could therefore provide further insights.

6.4 Reassessing the social organisation of Neanderthals

This study has shown that from an energetics perspective, it would not always be feasible for children to be carried and for whole Neanderthal groups to always travel together. It is also argued here that the archaeological record no longer reflects this and the interpretation by Kuhn and Stiner (2006) of a lack of division of labour in Neanderthal groups needs reassessment.

Evidence for the division of labour by gender and age at El Sidrón cave was explored in depth in Chapter 2. This example demonstrated that different individuals at this site were engaged in different processing behaviours. This was both in the repetition of tasks and type of materials processed, as evidenced in striations and chipping in the teeth

(Estalrrich and Rosas 2013). Through taking a regional perspective in this study, it is possible to see that intra-site patterning of social organisation is widespread.

At Amalda cave, for example, a structured productive process has been identified (Rios-Garaizar 2017). The spatial distribution of lithics in level VII suggests there was one central area for flake production and some heavy tasks, as well as two peripheral areas where varied activities were carried out (Rios-Garaizar et al. 2015, 193). Hide processing was the most important activity in one of these areas and woodworking in the other, where heavy tools were used (Rios-Garaizar et al. 2015, 193). In similarity to El Sidrón, this diversity of tasks implies the existence of a social division of labour. Regionally distinct cleavers have also been linked to initial stages of woodworking, hideworking and butchery through use-wear analysis (Claud et al. 2015; Rios-Garaziar 2010; Utrillo and Mazo 1996). This testifies to the variety of tasks undertaken by Neanderthals. At some sites in this region, these tools are also found in great quantities, indicating the repetition of such tasks. At El Castillo, for example, 250 flake cleavers have been recovered in level 20 (Claud et al. 2015).

There has also been a proliferation of evidence for plant resources in the Middle Palaeolithic in recent years (see Hardy 2018 for review), largely due to the introduction of new analytical techniques. At El Sidrón, for example, dental calculus analysis has revealed little evidence of meat consumption by its occupants, and instead points to the consumption of starchy foods, mushrooms, pine nuts and possibly even green vegetables (Hardy et al. 2012; Weyrich et al. 2017). It has been long known that Neanderthals had a sophisticated knowledge of their local environment, as evidenced by their mobility patterns and exploitation of animals. It is unsurprising therfore that this knowledge would extend to the selection and use of certain plants.

This is supported by Henry et al. (2014) who argues that the richness of plant diets now seen at various Neanderthal sites strongly suggests a level of specialisation in gathering. This cannot be proven to be linked to gender but does suggest some form of social division of labour for resource gathering (Henry et al. 2014, 9) and likely varied based on the local availability. At Spy cave in Belgium, for example, dental calculus still suggests

Figure 6.2: The digging stick from Aranbaltza III, measuring 151.7 mm in length and 28.6 mm in width in its original morphology. Detail of the smashed fibres in the point of the Aranbaltza stick (a1) and an experimental example (a2). Evidence of thermal alteration (c) was part of a complex series of manufacturing steps.

that diet was heavily meat based, including animals which are characteristic of the local steppe environment (Weyrich et al. 2017). Different levels of plant and animal exploitation should therefore be expected, with local environment and group composition both having an important influence.

In further support of this view, there is now emerging evidence of technology which points to a diversity in foraging tasks. Two digging sticks have so far been interpreted in Neanderthal contexts, one at Poggetti Vechi in Italy (Arangurena et al. 2018) and the other within this study region at Aranbaltza III. The wooden tool from Aranbaltza III was shaped through a complex series of actions including bark peeling, polishing, thermal alteration, and chopping (Figure 6.2; Rios-Garaizar et al. 2018). The pointed end of the tool also has smashed fibres caused by repetitive mechanical stress, which use-wear analysis indicates is associated with digging soil (Rios-Garaizar et al. 2018).

Digging sticks are common in hunter gatherer societies and often multi-functional. They are most often used for root and tuber extraction, although other uses such as hunting small game, grinding, loosening bark and clam-digging are known (Arangurena et al. 2018; Rios-Garaizar et al. 2018). These tools are particularly linked to women in the ethnographic record (Balme and Bowdler 2006; Crittenden 2016), but this cannot be directly assumed in the past. These tools, however, could be particularly open to use by children. For example, among the Hadza, young girls are given their first digging stick at around 3 years of age, which is usually shorter and blunter, and "As the girl matures, so does her digging stick" (Crittenden 2016, 166). It is a technology easily adaptable for children and often used within safe contexts, such as root extraction. Whilst there are only two examples of digging sticks currently known for Neanderthals and the exact function of these tools remain open to debate, this still adds to the diversity of activities that Neanderthals were undertaking. Neanderthals were involved with a variety of resource acquisition and processing tasks, and it also extended to coastal foraging.

There is growing evidence that some Neanderthals groups exploited marine resources (e.g. Brown et al. 2011; Cortés-Sánchez et al. 2012), including archaeological sites in this study region. At the coastal site El Cuco, for example, shell assemblages are recorded throughout the stratigraphic sequence (Gutiérrez-Zugasti et al. 2018). A variety of marine taxa were identified, with a predominance of limpets from the Patella genus (Gutiérrez-Zugasti et al. 2018, 46). The study team interpreted the limpets and the evidence of sea urchin (*P. lividus*) as purposeful collection and consumption, albeit to a relatively low intensity (Gutierrez-Zugasti et al. 2018). This example once again demonstrates that Neanderthals were flexible and able to take advantage of the local opportunities in the environment. Digging sticks are also known to be used in shellfishing, and whilst there is no direct evidence available at Aranbaltza III, the site is located nearby to El Cuco (Rios-Garaizar et al. 2018).

Marine resources have also been shown to be viable option for child foraging activities, given that they are relatively inexpensive energetically and often do not require particular skills (Brown et al. 2011, 261). For example, a study by Bird and Bird (2000) investigated the role of shellfishing for child foragers and suggested children consistently forage differently to adults, meaning this could be identifiable in the archaeological record. The research team argue that we should expect prey choice to be more diverse and low relative profitability for children's activities. These conditions are also likely to characterise other resources including fruit, berries, nuts and some types of tubers (Bird and Bird 2000, 471). It cannot be assumed that children exploited limpets at El Cuco, but this again shows that there was a range of foraging options open to different group members.

The diversity of tasks, which likely led to social divisions in labour, are also not restricted to food resources. Archaeological material from the northern Spain region reflects the wider increase in evidence of sophisticated use of fire and wood by Neanderthals. The evidence of wooden digging tools have already been mentioned, as well as the regionally distinct cleavers, which have been specifically linked to felling trees (Claud et al. 2015). Wood might have been collected by Neanderthals for use in shelter construction, or other objects such as handle manufacture, as indicated elsewhere in the record (Claud et al. 2015, 20). Abundant evidence for fire use has also been recorded at the sites in this study, whether as actual hearth features or signs of fire alteration on faunal remains (see Table 3.1 in Chapter 3). Despite all this evidence and the necessity for fire for Neanderthal groups, this resource is rarely discussed in interpretations of mobility. Whilst there are some exceptions to this (e.g. Vidal-Matutano et al. 2015; Uzquiano et al. 2008), the energetic cost of carrying firewood has yet to be explored in detail.

Biran et al. (2004) compared the costs of firewood collection between two rural communities in Malawi and Tanzania. Whilst this resource was gathered by women in both groups, there were clear distinctions in the length of journeys and level of loads carried. It was found that the size and structure of families, as well as the differences in local environment, were determining factors (Biron et al. 2004). The longer journey times, heavier loads, and less frequent journeys undertaken by Malawian women appear to reflect the challenges of the local steep terrain (Biron et al. 2014). This also relates to the costs of carrying children, as the shorter trips of the Tanzanian women meant infants could be left behind (Biron et al. 2014). Modelling the cost of carrying firewood could therefore be an important extension of study. This was also forwarded by Henry (2017), in the context of Neanderthal cooking:

"While many of the potential costs cannot be directly compared to the potential gains of cooking, we can at least begin by exploring the caloric costs of fuel collection in different environments and exploring how much time and energy it requires to access different fuels (e.g., dry standing wood, green wood, etc.)."

The methodology used in this study could be adapted to look at the cost of carrying firewood, through the addition of environmental scenarios. The cost of carrying children could also be integrated to further understand the role of social behaviours on Neanderthal mobility.

6.5 Chapter 6 conclusions

The study by Kuhn and Stiner (2006) has remained an influential interpretation of social organisation in Neanderthals. Given the available evidence of faunal remains and overriding influence of isotopic studies, it is unsurprising that past interpretations have focused on large game hunting. As they suggest, Neanderthal women and children could have been engaged in low-risk hunting roles, such as beaters and game drivers. However, it can no longer be maintained that there was a universal lack of social division of labour. The extensive evidence for diverse activities attests to this, including plant gathering, marine resources, hideworking, and the collection and use of wood.

Taking an energetics approach in this study provides further support. The high energetic requirements of Neanderthals are continually emphasised, but the cost of carrying behaviours has been neglected from this research. Carrying children is a fundamental part of life for hunter-gatherers and Neanderthals would need to carefully balance this behaviour against their energy budgets. This study has demonstrated that subtle differences in group size and composition would have influenced the cost of walking and would likely be a contributing factor to the nature of mobility.

Neanderthals are often interpreted as a universal whole, which is understandable given the time scale and patchy nature of the archaeological record. This has often led, however, to 'absence versus presence' approach to understanding the differences between Neanderthals and modern humans. This causes the interpretation of Neanderthals to be ultimately shaped by their extinction.

Kuhn and Stiner's (2006) interpretation was still ingrained in this but taking a regional approach has allowed this study to demonstrate the great flexibility in Neanderthal behaviour. Group mobility undoubtedly varied on local scale, in which the local terrain, availability of resources, and level of environmental risk, all contributed to decisions surrounding movement. This study has demonstrated that social dimensions, such as group size and composition, were intertwined with this in important and influential ways. Further studies which explore the energetic cost of other carrying behaviours, as outlined in this chapter, would contribute additional insights.

Appendix 1

1.1 Coordinates of Northern Spain sites

Table A1.1: Sources of site coordinates used in this study. Coordinates used indicated in bold. NESPOS (2016) was used to collate the list of sites, but GIS precision is not always listed and sometimes indicated as "nearest city". The coordinates were therefore checked against literature where possible, deferring to information from excavators and assemblage researchers where needed. If coordinates are not provided in literature or there was a mismatch between sources, locations where checked versus descriptions given in the literature. Conversions were performed using the Montana State University / Yellowstone Park Foundation converter.

Abauntz Arraitz, Navarre	Latitude (WGS84): 43.0133° N Longitude (WGS84): 1.64167° W Altitude: 700m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Abauntz
	UTM X: 610825, Y: 4763220 Z: 617 [43.01357857241498, -1.6400329491937453]	**Tobalina-Pulido et al. 2015**
Amalda Zestoa, Gipuzkoa, Basque Country	Latitude (WGS84): 43.23° N Longitude (WGS84): 2.2° W Altitude: 205m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Amalda
	UTM X: 564.675 Y: 4.787.360 Z: 205 [43.23626383695526, -2.2034659311361047]	**Altuna 1990**
	43°14′N 2°12′W 210 m.a.s.l. [43.233333333333334, -2.2]	González-Sampériz et al. 2010
Aranbaltza III Barrika, Biscay, Basque Country	Latitude (WGS84): 43.407° N Longitude (WGS84): 2.965° W Altitude: n/a GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Aranbaltza
	UTM x: 502713.6, y: 4805178.6, z: 37	**Rios-Garaizar et al. 2018**

	[43.39948116730206, -2.966489796584991]	
Arlanpe Lemona, Biscay, Basque Country	Latitude (WGS84): 43.19° N Longitude (WGS84): 2.76° W Altitude: 204m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Arlanpe
	UTM X: 519254; Y: 4782262; Z: 204 [43.19288534625506, -2.763036273968078]	**Rios-Garaizar et al. 2011**
Arrillor Murua, Álava, Basque Country	Latitude (WGS84): 42.97° N Longitude (WGS84): 2.74° W Altitude: 710m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Arrilor
	UTM X: 521.057; Y: 4.761.540; Z: 710 m a.s.l [43.00623891131569, -2.741632294621648]	Iriarte-Chiapusso et al. 2019
Axlor Dima, Biscay, Basque Country	Latitude (WGS84): 43.143° N Longitude (WGS84): 2.753° W Altitude: 320m GIS Precision: GPS Site coordinates	https://www.nespos.org/display/PublicNesposSpace/Axlor
	UTM X: 522055.36, Y: 4774266.12, Z: 291.32 [43.12080790863808, -2.7288781096324213]	**Gómez-Olivencia et al. 2018**
El Castillo Puente Viesgo, Cantabria	Latitude (WGS84): 43.292° N Longitude (WGS84): 3.966° W Altitude: GIS Precision: Map Site coordinates	**https://www.nespos.org/display/PublicNesposSpace/El+Castillo**
	43°17′N 3°58′W 170 m.a.s.l. [43.28333333333333, -3.966666666666667]	González-Sampériz et al. 2010
El Conde Tuñón, Santo Adriano,	Latitude (WGS84): 43.298253° N Longitude (WGS84): 5.986963° W	https://www.nespos.org/pages/viewpage.action?pageId=29886679

Asturias	Altitude: 180m GIS Precision: GPS coordinates	
	43°17’15” Lat, 5°58’35” Long, 180 m.a.s.l. [43.2875, -5.976388888888889]	**Adán and Arsuaga 2007**
	43°16′ N 5°58′W 600 m.a.s.l. [43.1, -5.966666666666667]	González-Sampériz et al. 2010
Covalejos Velo, Piélagos, Cantabria	Latitude (WGS84): 43.397° N Longitude (WGS84): 3.933° W Altitude: n/a GIS Precision: Map Site coordinates	https://www.nespos.org/display/PublicNesposSpace/Covalejos
	UTM: X 424560, Y 4805500 [43.398585626850725, -3.931591278801904]	**Yravedra and Gómez-Castanedo 2010b**
	43°24′N 3°56′W 80 m.a.s.l. [43.4, -3.9333333333333336]	González-Sampériz et al. 2010
El Cuco Castro-Urdiales, Cantabria	Latitude (WGS84): 43.39° N Longitude (WGS84): 3.24° W Altitude: n/a GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Abrigo+del+Cuco
	UTM x = 481.507, y = 4.804.428, z = 43 [43.39249936757124, -3.228343512551523]	**del Río et al. 2011; Yravedra 2013**
El Esquilleu Cillorigo de Liébana, Cantabria	Latitude (WGS84): 43.197° N Longitude (WGS84): 4.603° W Altitude: n/a GIS Precision: GPS nearest City Coordinates	https://www.nespos.org/display/PublicNesposSpace/Esquilleu
	UTM X:371520, Y:4790700 [43.25815952110501, -4.5829107623206005]	Yravedra 2013; Yravedra and Gómez-Castanedo 2010b
	43.22° Lat., -4.60° Long.	**Baena Preysler et al. 2019**

	43°12′N 4°36′W 350 m.a.s.l. [43.2, -4.6]	González-Sampériz et al. 2010
La Flecha Puente Viesgo, Cantabria	Latitude (WGS84): 43.3° N Longitude (WGS84): 3.96° W Altitude: 175m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Cueva+de+la+Flecha
	UTM X: 421.900, Y: 4.793.650, Z: 175 m [43.29162460224334, -3.96274687061064]	**Castenedo 2001**
La Güelga Narciandi, Cangas de Onis, Asturias	Latitude (WGS84): 43.35° N Longitude (WGS84): 5.11° W Altitude: 182m GIS Precision: n/a	**https://www.nespos.org/pages/viewpage.action?pageId=29887915**
Hornos de la Peña Tarriba, San Felices de Buelna, Torrelavega, Cantabria	Latitude (WGS84): 43.261° N Longitude (WGS84): 4.03° W Altitude: n/a GIS Precision: Map Site coordinates (Agrees with descriptions and maps in other publication)	**https://www.nespos.org/display/PublicNesposSpace/Hornos+de+la+Pena**
Lezetxiki Arrasate, Gipuzkoa, Basque Country	Latitude (WGS84): 43.076° N Longitude (WGS84): 2.224° W Altitude: n/a GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/Lezetxiki
	43°4′N 2°31′W 350 m.a.s.l. [43.076, -2.524]	González-Sampériz et al. 2010
	X. 538.185, Y. 4.769.360, Z. 345 [43.0759885277492, -2.5309423220164153]	**Baldeón 1993**
Llonín Peñamellera	Latitude (WGS84): 43.33° N Longitude (WGS84): 4.65° W	**https://www.nespos.org/pages/viewpage.action?pageId=29885045**

Alta, Asturias	Altitude: n/a GIS Precision: n/a (Agrees with descriptions and maps in other publications)	
El Mirón Ramales de la Victoria, Cantabria	Latitude (WGS84): 43.14° N Longitude (WGS84): 3.47° W Altitude: 300m GIS Precision: n/a	https://www.nespos.org/pages/viewpage.action?pageId=29886267
	43°14´47.4˝ N y 3°27´4.5˝ O, 250 m.a.s.l. [43.2465, -3.4512500000000004]	**Díez et al. 2012**
Morín Villanueva de Villaescusa, Cantabria	Latitude (WGS84): 43.371° N Longitude (WGS84): 3.855° W Altitude: GIS Precision: GPS nearest City Coordinates (Not nearest city coordinates)	https://www.nespos.org/display/PublicNesposSpace/Cueva+Morin
	43°21′N 3°51′W 57 m.a.s.l. [43.35, -3.85]	González-Sampériz et al. 2010
	Map site coordinates N 0°10’10”, E 43°21’43” I.G.C. 1/50000, hoja 34 Torrelavega.	Yravedra and Gómez-Castanedo 2010b; 2011
	UTM X = 430084 Y = 4802975 [43.37638721170636, -3.863061947429145]	**Alba-Sánchez et al. 2010**
Otero Secadura, Junta de Voto, Cantabria	Latitude (WGS84): 43.36° N Longitude (WGS84): 3.53° W Altitude: 60m GIS Precision: n/a	**https://www.nespos.org/display/PublicNesposSpace/Otero**
El Pendo Escobedo de Camargo,	Latitude (WGS84): 43.388° N Longitude (WGS84): 3.913° W Altitude: n/a	**https://www.nespos.org/display/PublicNesposSpace/El+Pendo**

Cantabria	GIS Precision: Map Site coordinates (Also agrees with tourist site location)	
	43°24′N 3°54′W 54 m.a.s.l. [43.4, -3.9]	González-Sampériz et al. 2010
El Ruso Igollo, Camargo, Cantabria	Latitude (WGS84): 43.43° N Longitude (WGS84): 3.89° W Altitude: 60m GIS Precision: n/a	https://www.nespos.org/display/PublicNesposSpace/El+Ruso
	X: 427800, Y:4808670 UTM 60 m.a.s.l. [43.427445136865074, -3.892004951438865]	**Yravedra and Gómez-Castanedo 2010b; Yravedra et al. 2010**
El Sidrón Borines, Piloña, Asturia	Latitude (WGS84): 43.384° N Longitude (WGS84): 5.329° W Altitude: 139m GIS Precision: Map Site coordinates	https://www.nespos.org/pages/viewpage.action?pageId=29888362
	X = 311,572.815; Y = 4,806,338.042; Z = 167.89 [43.38625898046161, -5.326341483970017)	Santamaría et al. 2010
	43°23’01” N, 5°19’44” W [43.38361111111111, -5.328888888888889]	**Rosas 2006**
Sopeña Avin, Cangas de Onis, Asturias	Latitude (WGS84): 43.34° N Longitude (WGS84): 4.97° W Altitude: 450m GIS Precision: n/a	**https://www.nespos.org/pages/viewpage.action?pageId=29885239**
	43°19′N 4°58′W (43.31666666666667, -4.966666666666667)	González-Sampériz et al. 2010
La Viña La Manzaneda, Oviedo,	Latitude (WGS84): 43.313° N Longitude (WGS84): 5.827° W Altitude: n/a	https://www.nespos.org/pages/viewpage.action?pageId=29886510

Asturias	GIS Precision: Map Site coordinates	
	X = 270725.79 Y = 4799477.68 Z = 292 [43.31319597789898, -5.827225496663563]	**Santamaría et al. 2014**

Appendix 2

2.1 Pandolf versus van Leusen equation

Pandolf et al. (1977) is known as an isotropic function, as it does not account for downhill walking. A popular solution to this in archaeological studies has been to implement a modification by van Leusen (2002), which sets the minimum cost of walking to -6% slope. However, Herzog (2014) identifies mistakes with this modification and suggests it might not be suitable. Resulting models which compare these equations (E1 and E2; Figure A2.1-A2.2) agree with this. The difference in the sizes produced are quite significant, with the Pandolf equation producing a ~40% larger catchment area than the van Leusen version (Table A2.1).

The original version by van Leusen (2002) set the minimum cost of walking to -6% grade rather than the planned -10%, due to confusion over units. This has since been duplicated in other studies, including Palaeolithic least cost analyses (Bryd et al. 2016; Heasley 2015). This study therefore tested a range of estimates for the minimum cost of walking reported in physiological studies (Kramer 2010; Santee et al. 2001; Wanta et al. 1993; Rue and Kramer 2017). These again demonstrate that whilst the shape of catchment remains broadly consistent, the size is affected considerably (Table A2.1). If set to -6%, the total catchment area is ~45% larger than the -16% area. This again suggests unsuitability of the van Leusen (2002) version, and Pandolf et al. (1977) was selected as a result.

Table A2.1: Catchment areas for equation-based validity tests. Load (0), terrain factor (1), body mass (73.7) and walking speed (1.31) were kept constant.

Model	**Catchment area (km2)**
E1 - Pandolf	507.25
E2 - van Leusen	300.87
V1 - van Leusen (-6%)	300.87
V2 - van Leusen (-10%)	230.32
V3 - van Leusen (-16%)	163.97

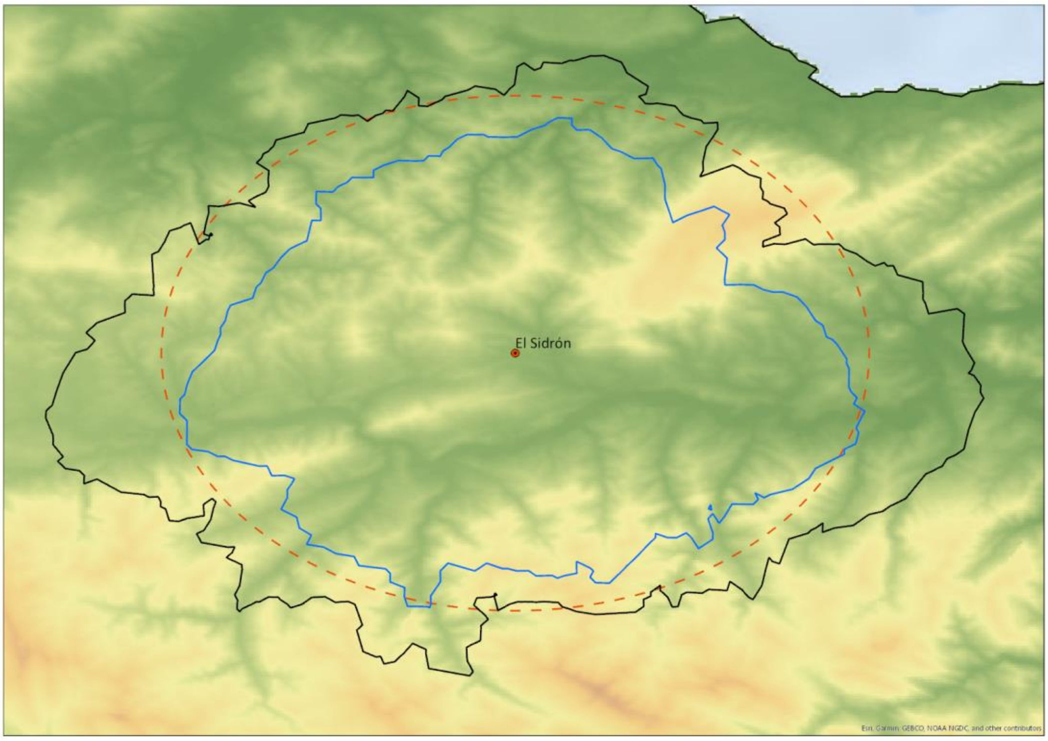


Figure A2.1: Cost catchments for models E1 (black) and E2 (blue), which compares the Pandolf et al. (1977) equation with the modification by van Leusen (2002) to account for downhill walking. Catchment limit has been set at 2000kcal. A 10km buffer has been added for comparison.

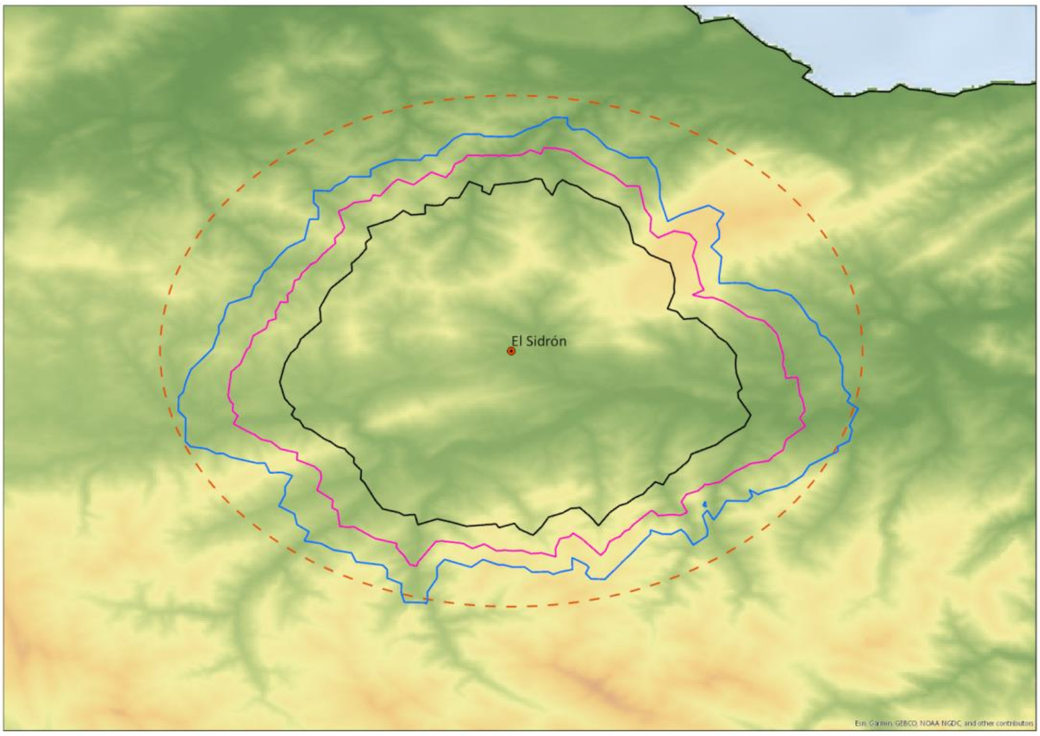


Figure A2.2: Cost catchments for models V1 (blue), V2 (pink) and V3 (black), which set the minimum cost of walking to -6%, -10% and -16%. Catchment limit has been set at 2000kcal. A 10km buffer has been added for comparison.

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