The Dissertation Committee for Christopher Allan Davis Certifies that this is the approved version of the following dissertation:

FORAGING ALONG BLUE HIGHWAYS: SEASONALITY AND SUBSISTENCE STRATEGIES IN THE MIDDLE STONE AGE OF ETHIOPIA

Committee:

John Kappelman, Supervisor

Lawrence Todd

Denne Reed

Liza Shapiro

Curtis Marean

Foraging Along Blue Highways: Seasonality and Subsistence Strategies in the Middle Stone Age of Ethiopia

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Christopher Allan Davis

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Dedication

For Molly Smalls, Char Char, and Ellie Bean. You three are my world, and I love you to the moon and back. And for my parents, who have always believed in and supported me in everything I do. I couldn't have done this without you.

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Foraging Along Blue Highways: Seasonality and Subsistence Strategies in the Middle Stone Age of Ethiopia

Christopher Allan Davis, Ph.D.

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Supervisor: John Kappelman

Modern humans originated in Africa ~200-300,000 years ago (ka) during the Middle Stone Age (MSA; ~320-45 ka), and during this period developed complex foraging behaviors that facilitated their later expansion out of Africa and across the world. Studying early human behavior in the MSA is therefore critical to understanding how modern humans adapted to diverse environments and refining current models of human dispersal out of Africa. Previous work has provided valuable insight into MSA behaviors, but important questions remain, and additional data from sites sampling diverse habitats are necessary to understand the full range of MSA behavioral variability and test hypotheses about late Pleistocene human behavioral evolution and dispersal.

This dissertation uses faunal remains from SM1 (> 40-60 ka), an open-air site located in NW Ethiopia, to investigate human behavior during the late MSA. Ongoing excavations at SM1 have recovered thousands of lithics and faunal remains deposited over multiple seasons of occupation at a time when seasonality and aridity in the region were at least as extreme as today. Zooarchaeological and taphonomic analyses make it possible to reconstruct site formation processes and human foraging behavior, and document diverse terrestrial vertebrates, fish, and mollusks at the site. Taxa present include bovids, suids, primates, hares, rodents, reptiles, amphibians, and birds, as well as multiple families of

catfish, and several cyprinid and cichlid fish genera. Taphonomic analyses document abundant evidence for human accumulation of terrestrial fauna and fish, and moderate damage by non-human agents and processes. Results indicate that foraging behavior was seasonally structured, with an emphasis on hunting small-to-medium-sized terrestrial prey and regular fishing and aquatic foraging during the dry season. Comparative data from MSA sites in Ethiopia, Morocco, and South Africa indicate that taphonomic signatures from SM1 are most similar to other open-air sites, and quite different from cave sites, and suggest caution when interpreting human behavior at open-air sites based on criteria derived largely from caves. Results offer valuable insight into late MSA human behavior in this understudied region of the Horn of Africa, and provide a taphonomic baseline for future studies of open-air MSA sites in Africa.

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Chapter 1: Introduction and Background

INTRODUCTION

Paleontological, archaeological, and genetic data indicate that our species, modern *Homo sapiens*, originated in Africa ~200-300 thousand years ago (ka) (McDougall *et al.,* 2005; Hublin *et al.,* 2017), undertook early expansions out of Africa by ~180-200 ka (Liu et al., 2015; Hershkovitz *et al.,* 2018; Harvati *et al.,* 2019), began the sustained dispersals that gave rise to all living human populations by at least ~60-100 ka (Henn *et al.*, 2011; Mallick *et al.,* 2016), and successfully made their way across much of the Old World by ~30-40 ka (Mellars, 2006; Klein, 2008; Nigst *et al.,* 2014; Bosch *et al.,* 2015). However, questions about the exact nature and timing of dispersals from Africa, and the evolution of complex behaviors that allowed our ancestors to survive in new and changing environments as they moved across the Old World, are still actively debated (Willoughby, 2009; Groucutt *et al.,* 2015). The African Middle Stone Age (MSA: ~320-45 ka) is central to these debates, because this period was the setting for the origins of modern humans in Africa, both their initial and later expansions out of Africa, and the evolution of behaviors they brought with them as they made their way across the Old World (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Marean and Assefa, 2005). Previous work has provided valuable insight into MSA behavior (*e.g.,* Clark, 1988; McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Marean and Assefa, 2005; Willoughby, 2009; Tryon and Faith, 2016), but additional data from MSA sites sampling diverse habitats are necessary to understand the full range of MSA variability and test hypotheses about early human behavioral evolution and population movement in the late Pleistocene (Groucutt *et al.*, 2015).

This dissertation uses zooarchaeological analyses to investigate foraging behavior in the MSA, with an emphasis on documenting evidence for early riverine adaptations and seasonal resource use at the primary study site, Shinfa-Metema 1 (SM1). SM1 is an open-air site located in a largely unexplored region of the Blue Nile Basin in northwestern Ethiopia and was occupied during the late MSA. SM1 is significant, in part, because its temporal and geographic setting are ideal to offer information about modern human behavior in the Horn of Africa, where competing models of modern human dispersal converge, around the time of the expansions out of Africa that ultimately gave rise to all living human populations. Faunal evidence documents use of aquatic food resources and suggests the MSA inhabitants engaged in systematic riverine foraging behavior and structured seasonal resource use. Both of these activities have implications for the evolution of other important aspects of modern human behavior and social organization (Erlandson, 2001; Marean, 2014, 2016), and both behaviors have previously been argued to be rare or absent in the MSA (*e.g.,* Klein, 2000, 2009). This research addresses questions related to these activities, the answers to which are relevant to broader debates about modern human behavioral evolution and dispersal in Africa during the MSA and the subsequent Later Stone Age (LSA; ~45-10 ka).

ORGANIZATION OF THE DISSERTATION

This dissertation is organized into eight chapters. Chapter 1 provides a brief introduction to the issues at hand and lays out the general organization of the dissertation.

Chapter 2 presents an overview of human evolution and behavior in Africa during the MSA and LSA, beginning with a summary of competing models of modern human dispersal and behavioral evolution. This review is followed by a discussion of the

archaeological record for human behavior and habitat use in the late Pleistocene of Africa (*i.e.,* in the middle-to-late MSA and LSA), and the significance of aquatic habitats and food resources in human evolution. Chapter 2 ends with several sections that discuss likely reasons for differences (both real and perceived) in MSA and LSA behavior, and explain why these issues are significant for the work at hand.

Chapter 3 provides the theoretical and analytical framework of the dissertation. This chapter reviews previous zooarchaeological, taphonomic, and MSA research, discusses the many strengths of the current record of MSA behavior, and details the types of data that are still needed in order to build broader comparative frameworks directly applicable to a wider range of sites across Africa. The specific research hypotheses to be tested, as well as the alternatives, and the expected evidence that will support either the hypotheses or the alternatives, are then discussed. Chapter 3 ends by discussing the materials and methods of the study, and providing a basic outline of the analytical procedures to be employed in Chapters 5-7.

Chapter 4 provides background information for SM1. The first section of the chapter reviews the history of investigation at the site, dating work, and the MSA archaeological record from SM1. This review is followed by a discussion in which the spatial distribution of material at SM1 is examined, and four vertical analytical units within the site that are hypothesized to represent distinct occupation layers are proposed, the validity of which are then tested statistically in Chapters 5 and 6. The next section describes the ecogeographical setting of the site, summarizes results of ongoing stable isotope analyses, and discusses the modern terrestrial and aquatic faunal communities. Chapter 4 ends by discussing the potential significance of SM1 and its relevance to current debates about modern human behavioral evolution and dispersal in the late Pleistocene of Africa.

Chapter 5 presents analyses of the terrestrial mammal, bird, reptile, and amphibian (*i.e.,* "non-fish") fauna from SM1. The chapter begins with investigations of taxonomic, skeletal element, and body size abundance and diversity at SM1, and discusses the paleoecological implications of the taxa identified at the site. Taphonomic analyses (*e.g.,* bone surface preservation, post-depositional destruction, thermal alteration, fragmentation, and human and carnivore modification) of the terrestrial faunal assemblage are then undertaken in order to determine processes of site formation and the primary agent(s) of faunal accumulation at SM1. The taphonomic data are also used in this section to test the validity of the four analytical units proposed in Chapter 4. The following section details additional evidence for human and carnivore activity, and discusses the implications of observed patterns of faunal abundance and modification for MSA foraging strategies at SM1, including faunal transport and processing behavior. Chapter 5 ends with a general summary of MSA terrestrial foraging behavior at SM1.

Chapter 6 deals specifically with the fish remains. The chapter begins with analyses of taxonomic and skeletal element abundance at SM1, and comparisons of taxonomic diversity among SM1, a similarly-aged fish assemblage from the Kibish Formation that results primarily from natural accumulation, and data on the natural fish community structure in the modern Shinfa River. These analyses are followed by a section in which total length and body mass are estimated for the SM1 fish using data from a sample of modern fish from the Shinfa River and published regression equations. The next section presents the results of taphonomic analyses for the SM1 fish, including comparisons with data from the Kibish Formation assemblage. As with the terrestrial fauna, the taphonomic data for the SM1 fish are also used to assess the validity of the proposed analytical units within the site. Fish procurement methods and processing behavior are then discussed.

Once again, Chapter 6 ends with a general summary of fish taphonomy and MSA fishing behavior at SM1.

Chapter 7 presents comparative analyses between SM1 and other MSA sites for which similar faunal and taphonomic data are available. The chapter begins by providing background information for comparative sites, and discussing the taphonomic variables chosen for analysis and the reasoning behind their selection. In the following sections, chi-squared tests and other methods are used to examine similarities and differences between SM1 and all of the comparative sites. The question of whether or not systematic differences exist between open-air versus cave sites more generally is also explored. Chapter 7 ends with a discussion of the results, as well as the implications for how SM1 fits within the context of all the other MSA sites as a whole, and for overall patterns of similarity and difference between open-air and cave sites.

Chapter 8 concludes the dissertation with a discussion of MSA foraging strategies at SM1 and the importance of the site for our current understanding of early modern human behavior and dispersal in Africa. The first section revisits each of the five research hypotheses and discusses whether or not they are supported by the data from SM1. This is followed by a section that brings together the results and interpretations from previous chapters, in order to synthesize them into a single, overarching reconstruction of MSA terrestrial and aquatic foraging behavior at SM1. This section also includes a discussion of the significance of new data from SM1 in the context of what is currently known about MSA foraging behavior, and the broader implications for ongoing debates about late Pleistocene behavioral evolution and dispersal in Africa. Chapter 8 concludes with remarks and ideas for future research.

Chapter 2: Human Evolution and Behavior in the Middle and Late Pleistocene of Africa

Models of Modern Human Dispersal and Behavioral Evolution

Competing models of modern human dispersal out of Africa and into Eurasia during the late Pleistocene typically involve: 1) a northern route (NR) from the Horn of Africa along the Nile River and/or Red Sea coast (*e.g.*, Wurz and Van Peer, 2012; Foley *et al.,* 2013; but see Drake *et al.,* 2011); and/or 2) a southern route (SR) from the Horn of Africa across the Red Sea at Bab el Mandab Strait (*e.g.,* Lahr and Foley, 1994; Reyes-Centeno *et al.,* 2014) (Figure 2.1).

NR models posit dispersals from eastern, northern, and/or central Africa into the Mediterranean region, across the Sinai Peninsula into the Levant, and then around and/or across the Arabian Desert (Beyin, 2006, 2011). To reach the Mediterranean region of northeastern Africa, populations moving north from sub-Saharan Africa may have followed the Nile River and its tributaries and/or the Red Sea Coast, while those moving east from central/western Africa may have dispersed along humid corridors through the deserts of northern Africa (Lahr and Foley, 1994; Beyin, 2011; Beyin *et al.,* 2019). It has been argued that the NR was likely only viable during warmer, wetter periods when humid corridors existed through the Sahara, Libyan, and/or Arabian deserts, such as during the interglacial interval of Marine Isotope Stage (MIS) 5 (~130-74 ka), and particularly the interstadial periods MIS 5a (~85-74 ka), 5c (~102-91 ka), and 5e (~130-119 ka), or the relatively moderate glacial conditions during much of MIS 3 (~59-24 ka) (Beyin, 2011; Oppenheimer, 2012; Foley *et al.*, 2013; Lamb *et al.,* 2018). Importantly, these corridors would have followed active river courses, creating a system of "blue highways" for dispersal, and the ability to the hunt, forage, and collect freshwater in and around riverine

ecosystems would have been crucial to the survival of populations expanding north and/or east along inland routes.

Figure 2.1 Map of Africa showing the major hypothesized northern (NR) and southern (SR) routes of modern human dispersal out of Africa (arrows) and the area of the Horn of Africa where the NR and SR converge (box). Map image courtesy of commons.wikimedia.org.

According to SR scenarios, dispersing populations crossed the Red Sea into the Arabian Peninsula via a land bridge across the Bab el Mandab Strait that was exposed during cooler, more arid phases when sea levels were significantly lower than today, for example, during the severe glacial conditions of MIS 6 (~190-130 ka) or the somewhat more moderate glacial interval MIS 4 (~74-59 ka) (Petraglia *et al.,* 2010; Armitage *et al.,* 2011; Oppenheimer, 2012). After exiting Africa, dispersing populations would have proceeded along the coastlines of the Arabian Peninsula, eventually making their way around the Persian Gulf, and then following the Indian Ocean coast into southwest Asia and beyond (Oppenheimer, 2012). Although it is not necessarily clear that sea levels ever dropped far enough to expose a land bridge across Bab el Mandab (Beyin, 2011), recent studies of paleoclimatic data (Rohling *et al.,* 2013) and even Hamadryas baboon biogeography (Kopp *et al.,* 2014) have found support for a land connection across the Red Sea in the late Pleistocene. Once again, proponents of SR models also stress the importance of aquatic food resources and foraging adaptations for dispersals, although in this case, the emphasis is primarily on coastal/littoral habitats and dispersing groups are often referred to as "beachcombers" (Beyin, 2011).

Modern human fossils in the Levant and Europe document early expansions out of Africa by ~180-200 ka (Harvati *et al.,* 2019; Hershkovitz *et al.,* 2019). However, although competing models disagree on specifics, there is now general consensus that the dispersal event(s) which actually gave rise to all living non-African modern humans occurred much later, by at least ~60-100 ka (Armitage *et al.*, 2011; Pagani *et al.*, 2016; Groucutt *et al.,* 2018; Rito *et al.,* 2019), and that dispersing groups passed through the Horn of Africa on their way into Eurasia (Henn *et al.,* 2012). Likewise, there is broad agreement that complex behavior and technological systems flourished during the LSA, but the issue of how, when,

and why these behaviors evolved is debated (Henshilwood and Marean, 2003; Shea, 2011; d'Errico *et al.*, 2012).

Historically, models of modern human behavioral evolution have taken one of two general forms (Henshilwood and Marean, 2003). Punctuated models propose that many of the complex behaviors characteristic of terminal Pleistocene and Holocene humans originated suddenly in the early LSA, or post-45 ka, and compared to their LSA counterparts, MSA humans were less-adept hunters, exploited resources less effectively, did not regularly exploit aquatic food resources, and were less capable of tracking seasonal patterns of resource availability (Klein, 1976, 2000; Klein and Cruz-Uribe, 1996; Ambrose, 1998; Bar-Yosef, 2002). Conversely, gradualist models posit that complex behaviors evolved gradually throughout the MSA (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003). According to these authors, MSA behavior was often quite similar to LSA behavior in terms of complexity and foraging efficiency, and the supposed LSA "behavioral revolution" is largely an artifact of differential preservation, Eurocentric bias projected onto the African record, and/or unwarranted comparisons with Holocene-age LSA sites (Watts, 1997; McBrearty and Brooks, 2000; Henshilwood and Marean, 2003).

Punctuated models have increasingly fallen out of favor, as more recent work in southern and eastern Africa has shown that making clear-cut distinctions between overall behavioral patterns in the MSA and LSA is not nearly as straightforward as it once seemed (see below) (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Marean and Assefa, 2005; Shea, 2011). As such, current discussions are more nuanced in how these questions are framed, but they are nonetheless focused on the same basic issues. Ultimately, these debates continue to center on: 1) whether the complex behaviors, technological systems, and patterns of habitat use that characterize terminal Pleistocene and Holocene hunter-gatherers (*e.g.,* systematic use of aquatic habitats and resources;

seasonal scheduling of foraging activity; regular hunting of prime-age dangerous game; symbolic/ritual behavior; microlithic technology; projectile weaponry) originated in the MSA or later in the LSA; and 2) the extent to which behaviors and technology that did originate in the MSA were fully developed and/or became widespread before the LSA (Henshilwood and Marean, 2003). Obviously, the answers to these questions lie in the MSA and LSA archaeological record of Africa.

MSA AND LSA BEHAVIOR

The onset of the MSA is difficult to pinpoint precisely because it was a complex process, the timing of which was not synchronous across Africa. Early MSA Levallois techniques likely developed out of the preceding Acheulean traditions of the Early Stone Age (ESA), so in many places early MSA and late Acheulean technology actually overlap (Clark, 1988; Marean and Assefa, 2005; Tryon *et al.,* 2006; Morgan and Renne, 2008). Nonetheless, the beginning of the MSA is signaled by technological shifts in which the large cutting tools (LCTs) of the Acheulean were supplanted by smaller flake tools and prepared core techniques (Clark, 1988; Ambrose, 1998, 2001; Marean and Assefa, 2005). Currently, the earliest claimed evidence of the ESA-MSA transition dates to ~500 ka at Kathu Pan 1 in South Africa in the form of small, symmetrical, and unifacially retouched points assigned to the Fauresmith Industry, which appear to have been hafted for use as spear tips (Wilkins *et al.,* 2012).

More definitive evidence comes from ~200 kyr later in Kenya at the Olorgesaille Formation, where sites that are at least ~305-295 ka, and possibly as old as ~320 ka, contain diagnostic MSA forms and lack LCTs (Brooks *et al.,* 2018; Deino *et al.,* 2018; Potts *et al.,* 2018), and the Kapthurin Formation where early MSA and late Acheulean technologies are

interstratified in layers dated to ~285 ka (Tryon and McBrearty, 2002). Similarly, basal units dated to ~280-40 at Florisbad in South Africa have produced a small collection of undiagnostic artifacts described as early MSA (Kuman *et al.,* 1999). Additionally, there are two sites dated to ~276 ka from the Gademotta Formation in Ethiopia that have produced assemblages of artifacts that are clearly, and solely, MSA (Sahle *et al.,* 2014). Other early MSA sites are known from Twin Rivers in Zambia (~230 ka: Clark and Brown, 2001), Bir Tarfawi and Bir Sahara in Egypt (~230 ka: Wendorf and Schild, 1992; Schwarcz and Grun, 1993), Sai Island in Sudan (~200 ka: Van Peer *et al.,* 2003), and the Kibish Formation in Ethiopia (~195 ka: McDougall *et al.,* 2005; Shea, 2008).

Evidence from even the earliest MSA sites attests to an increase in technological and behavioral complexity relative to the Acheulean, reflected in part by the spread and refinement of Levallois/radial core techniques, which first appeared in the late ESA and eventually became a hallmark of MSA technology (Marean and Assefa, 2005; Foley *et al.,* 2013). Common MSA tool types include side- and end-scrapers, denticulates, and pointed forms, and MSA tools often display evidence of retouch (Marean and Assefa, 2005). Levallois, unifacial, and bifacial points are also typical, and the size, shape, and weight of bifacial points are often highly standardized, leading many observers to suggest that they were likely used as components of projectile weapons (McBrearty and Brooks, 2000; Marean and Assefa, 2005). Ample evidence for hafting also indicates that composite tools were a common feature of MSA technology (Ambrose, 2001).

Regional and temporal diversity of artifacts are prevalent during the MSA, and numerous unique styles (*e.g.*, Sangoan, Lupemban, Aterian, Nubian, Pre-Aurignacian, Howiesons Poort, Still Bay) have been identified at sites across Africa (Clark, 1988; McBrearty and Brooks, 2000; Marean and Assefa, 2005; Foley *et al.*, 2013). Additionally, a number of complex artifact forms, such as blades, backed geometrics, and bone tools are

all present during at least the latter part of the MSA (McBrearty and Brooks, 2000; Henshilwood *et al.,* 2001; Ambrose 2002; Yellen *et al.,* 2005; Vogelsang *et al.,* 2010; d'Errico *et al.,* 2012; Henshilwood *et al.,* 2014). Early examples of art and symbolism also occur at multiple MSA sites by at least ~75-110 ka, and include: beads made from ostrich eggshell (OES) and gastropod shells; incised/notched ocher, OES, and bone; and ocher plaques and "pencils" (McBrearty and Brooks, 2000; d'Errico *et al.*, 2003; Zilhao, 2007; Assefa *et al.*, 2008a; Henshilwood *et al.,* 2004, 2009).

Expansion of habitat use is an important facet of MSA behavior, and by at least ~125 ka, populations began venturing into increasingly diverse habitats all across Africa (McBrearty and Brooks, 2000; Marean and Assefa, 2005; Basell, 2008; Vogelsang and Wendt, 2018). In northern Africa, MSA sites are located up and down the Nile Valley of Egypt and Sudan (Wendorf and Schild, 1976; Van Peer *et al.*, 2003; Wurz and Van Peer, 2012). MSA people also occupied the Mediterranean coast, interior mountains, and desert fringes of northern Africa, and even the central Saharan region, albeit episodically in the latter case (Cremaschi *et al.,* 1998; McBrearty and Brooks, 2000; Foley *et al.,* 2013). In western and central Africa, MSA people inhabited the coastal plains and river valleys of Democratic Republic of Congo (DRC: Brooks *et al.,* 1995; Yellen *et al.*, 1995), the woodland plateaus of Zambia (Barham, 2002), and even the tropical forests of Ivory Coast, Ghana, Cameroon, Guinea, Gabon, and Central African Republic (Mercader, 2002).

In eastern Africa, MSA sites are known from the northwestern lowlands, eastern Rift Valley, central highlands, and southern high-altitude mountains and river valleys of Ethiopia (Clark *et al.*, 1984; Yellen *et al.,* 2005; Shea *et al.,* 2007; Basell, 2008; Kappelman *et al.,* 2014; Vogelsang and Wendt, 2018); along the Red Sea Coast of Eritrea (Beyin, 2011, 2013); in the Turkana Basin, central highlands, and southern Athi-Kapiti Plains of Kenya (Marean, 1992; Basell, 2008; Shea and Hildebrand, 2010; Tryon *et al.,* 2010); and in

Olduvai Gorge, the Serengeti Plains, and the Lake Eyasi basin of Tanzania (Bower, 1979; Dominguez-Rodrigo *et al.,* 2007; Prendergast *et al.,* 2007; Eren *et al.,* 2014; Tryon and Faith, 2016). In southern Africa, there are numerous MSA sites along the southern and western Cape coastlines (Klein, 1976, 1977; Henshilwood *et al.,* 2001; Soriano *et al.,* 2007; Avery *et al.*, 2008; Rector and Reed, 2010; Faith, 2013), as well as in various ecosystems in the interior provinces of South Africa, Botswana, and Namibia (de Ruiter *et al.*, 2008; Clark, 2009; Vogelsang *et al.,* 2010; Hutson, 2012a; Staurset and Coulson, 2014; Marean *et al.,* 2014; Wadley, 2015).

Much like the geographical regions they inhabited, the foraging behavior of MSA people was also quite diverse (McBrearty and Brooks, 2000; Marean and Assefa, 2005; Faith, 2008). Faunal remains from numerous MSA sites across Africa attest to the presence of diverse terrestrial and aquatic taxa in MSA assemblages, and taphonomic analyses at several sites demonstrate that MSA humans regularly hunted, collected, and processed prey species of all shapes and sizes (Marean *et al.,* 2000; McBrearty and Brooks, 2000; Assefa, 2006; Henshilwood and Marean, 2003; Faith, 2008; Thompson, 2010; Thompson and Henshilwood, 2011; Clark, 2011; Faith 2013; Hutson, 2018). This work has demonstrated that MSA people hunted numerous ungulate species (d'Errico and Stringer, 2011), including both highly aggressive (*e.g.,* Cape buffalo and bushpig) and relatively more even-tempered (*e.g.,* eland) large artiodactyls, as well as numerous other ungulates and terrestrial mammals of various sizes and temperaments (McBrearty and Brooks, 2000; Faith, 2008). Additional faunal remains at a number of sites further attest to the fact that MSA people also often targeted various small mammals, reptiles, and birds, many of which were likely caught with snares and/or traps (McBrearty and Brooks, 2000; Wadley, 2010; d'Errico and Stringer, 2011; Armstrong, 2016). Additionally, analyses of ground stone tools, fossil pollen, and geophyte residues from MSA sites in Egypt, DRC, Zambia, Botswana, South

Africa, and elsewhere demonstrate that MSA people utilized a variety of terrestrial plant foods, many of which were processed with implements specialized for the task (Opperman and Heydenrych, 1990; McBrearty and Brooks, 2000).

Although the intensity and/or efficiency with which MSA people utilized aquatic food resources is debated, there is no doubt that aquatic/marine animals were regularly exploited at many MSA sites (McBrearty and Brooks, 2000; Marean, 2014, 2016). Faunal remains from sites located in coastal regions and around inland rivers and lakes attest to incorporation of aquatic/marine fish, mollusks, reptiles, birds, and mammals in MSA diets (McBrearty and Brooks, 2000; Henshilwood *et al.,* 2001; Marean and Assefa, 2005; Yellen *et al.*, 2005; Avery *et al.*, 2008; Marean, 2010; Dibble *et al.*, 2012)). Moreover, despite arguments to the contrary (*e.g.*, Klein, 2000, 2009), there is evidence for deliberate fish exploitation by MSA people living on the Semliki River at Katanda ~90 ka (sites Kt2, Kt9, and Kt16: Brooks *et al.*, 1995; Yellen *et al.,* 1995; see below for more detail), and, as will be demonstrated in subsequent chapters, the Shinfa River at SM1 (> 40-60 ka) (Kappelman *et al.*, 2014).

The MSA ends with the onset of the LSA ~45-50 ka (Clark, 1988), although the transition is once again difficult to pinpoint and assign a single date, because it was not synchronous across Africa and scholars often disagree over the technological criteria that distinguish the early LSA from the late MSA (Wadley, 1993; McBrearty and Brooks, 2000). Nonetheless, the beginning of the LSA is also associated with technological and behavioral changes, early evidence of which is found at Border Cave in South Africa (Villa *et al.,* 2012), Mumba Rockshelter and Kisese II in Tanzania (Gliganic *et al.,* 2012; Tryon *et al.,* 2018), and Enkapune Ya Muto in Kenya (Ambrose, 1998).

Transitional industries at Border Cave document a shift toward simpler bipolar knapping techniques and an increase in microliths, bone and wood tools, and ornaments,

and suggest that the LSA began to emerge gradually ~55 ka, and was fully in place by ~45-40 ka (Villa *et al.,* 2012). Likewise, the earliest LSA levels at Mumba date to ~49 ka and contain diagnostic lithics and numerous OES beads (Gliganic *et al.,* 2012; but see Mehlman, 1989), while backed microliths and OES beads are known from as early as ~42-46 ka at Kisese II, where patterns of technological change suggest the MSA/LSA transition occurred by at least ~39-34 ka (Tryon *et al.,* 2018). At Enkapune Ya Muto, early LSA artifacts occur in levels dated to ~46 ka, but may be several thousand years older (Ambrose, 1998). However, despite early dates for the LSA at these sites, MSA technology also persists at later sites in Ethiopia (Goda Buticha: ~34 ka), Kenya (Lake Victoria Basin: < 36 ka), Malawi (Mwanganda's Village: 42-22 ka), South Africa (Rose Cottage Cave and Strathalan Cave: ~30-25 ka), and Namibia (Apollo 11 Rockshelter: ~30-25 ka) (Opperman, 1996; Soriano *et al.,* 2007; Vogelsang *et al.*, 2010; Wright *et al.,* 2014; Blegen *et al.,* 2017).

Regional differences in the timing of the transition and disagreement over technological criteria aside, there are a number of technological and behavioral features that characterize the LSA and help distinguish it from the MSA. One of the most prominent technological distinctions between the MSA and LSA involves the replacement of industries dominated by flake tools produced on Levallois and radial cores with faceted platforms, by new traditions that emphasized tools made on cores with plain platforms and often relied heavily on bipolar knapping and indirect and/or soft-hammer percussion (Ambrose, 1998, 2001). Additionally, whereas MSA assemblages often contain high frequencies of relatively large flake tools, pointed forms, and scrapers, LSA industries tend to emphasize backed forms (*e.g.,* geometric segments), blades, and microlithics (*e.g.,* points, blades, and burins, which became increasingly miniaturized over time), with blades and microblades often produced on standardized, cylindrical cores (McBrearty and Brooks, 2000; Ambrose, 1998, 2002; Powell *et al.,* 2009; Tryon and Faith, 2016). Although most,

if not all, of these tool forms were also present during the MSA, they become more common during the LSA.

Moreover, the trend of lithic miniaturization, at least with respect to points, is likely related to the fact that the LSA is the first time that projectile technology is unquestionably present in Africa (Shea, 2006). In addition, LSA artifacts were regularly made out of bone, ivory, and other non-lithic raw materials, and were often ground, drilled, polished, perforated, or otherwise enhanced (Ambrose, 1998, 2001; McBrearty and Brooks, 2000). Regional and temporal variation in lithic technology and artifact styles also became more pronounced during the LSA, and this period saw a significant upsurge in the variety and complexity of tool types, with previously unseen or rare forms such as harpoons, fish hooks, needles, awls, and buttons, becoming increasingly common through time (Ambrose, 2001; Powell *et al.,* 2009). Once again, many of these features were also present during the MSA, but appear to occur with much greater frequency during the LSA (McBrearty and Brooks, 2000).

The LSA also bore witness to an unprecedented proliferation of symbolic behavior, and there is little doubt that well-developed symbolic systems, notions of group identity, and complex ritual behaviors similar to those that characterize early Holocene and historic hunter-gatherers were in place during the LSA (McBrearty and Brooks, 2000; Ambrose, 2001). Beads (*e.g.,* made of OES or gastropod shells), ornaments (*e.g.,* tooth and bone pendants), and notched, incised, and engraved pieces (*e.g.,* OES, ocher slabs, and bone) are common and often rather abundant at many sites, indicating widespread production and use of symbolic/artistic objects during the LSA (McBrearty and Brooks, 2000; Ambrose, 2001; Orton, 2008; Parsons, 2008; Dayet *et al.,* 2017; Tryon *et al.,* 2018). There is also extensive evidence for other symbolic/artistic behavior, including paintings and engravings on cave walls, rock outcrops, and even portable slabs (*i.e.,* mobiliary art) throughout the

LSA (Thackeray, 1983; McBrearty and Brooks, 2000; Tryon *et al.,* 2018; Assefa *et al.,* 2014; Bwasiri and Smith, 2015). Much of this art was produced using pigments (*e.g.,* ocher, limonite, hematite), and the presence of pigment fragments and ground stone tools with pigment traces at numerous LSA sites further documents extensive use of these minerals for coloration and other non-utilitarian purposes (McBrearty and Brooks, 2000). Similarly, the practice of ritual burial, including deliberate placement/positioning of bodies within a burial pit, as well as decorating (*e.g.,* with pigments, flowers) and/or interring them with abundant and often finely-made grave goods (*e.g.,* beads, ornaments, painted slabs, stone tools), became commonplace during the LSA (Rudner, 1971; Hall and Binneman, 1987; Hall, 2000).

The expansion of habitat use that began in the MSA also intensified during the LSA, and LSA people occupied a wide range of habitats and were even more successful at figuring out novel ways to survive in increasingly inhospitable environments (Klein, 2000; Wedage *et al.,* 2019). As such, it should be no surprise that LSA foraging strategies were often multifaceted and remarkably sophisticated, or that LSA people often utilized both animal and plant resources more intensively than did MSA people (Ambrose, 2001; Klein and Cruz-Uribe, 1996, 2000). Once again, faunal remains from numerous archaeological sites demonstrate that LSA humans were highly skilled hunters and regularly took terrestrial and aquatic prey of all shapes and sizes. LSA hunters often targeted prime-age individuals of large and/or dangerous prey species (*e.g.,* Cape Buffalo and bushpig), as well as a varied assortment of other bovid, suid, and equid species (Klein, 1976, 1977, 2000). Furthermore, small and agile prey, such as hares, rabbits, and various birds, which are often difficult to catch without specialized technology (*e.g.,* snares, traps, fowling gear), are common at LSA sites (Klein, 2000). Additionally, the presence of abundant ground stone tools and other food processing implements at LSA sites further demonstrates that

LSA people regularly used and processed a variety of both terrestrial and aquatic plant foods (McBrearty and Brooks, 2000; Willoughby, 2012).

Intensive use of aquatic habitats and resources was also an important feature of LSA foraging behavior (Klein, 2009). Abundant remains of fish, mollusks, and aquatic mammals, birds, and reptiles, as well as the earliest evidence for maritime activities, document that adaptations to coastal and marine habitats flourished during the LSA (Erlandson, 2001; Fujita *et al.,* 2016; Marean, 2016). Likewise, there are numerous LSA sites with evidence for well-developed adaptations to riverine and lacustrine habitats located across the interior regions of Africa, many of which document groups whose livelihoods focused largely on fish and, to a lesser extent, other aquatic food items, for part or most of the year (Stewart, 1989; Yellen, 1998; Van Neer, 2004). Moreover, many LSA fishing sites contain evidence for extensive development of complex fishing technology, including barbed bone harpoons, bone fishhooks, sinkers, nets, and even rafts and boats (Yellen, 1998; Van Neer, 2004; Barham and Mitchell, 2008). Additionally, the development of ceramic storage technology at many of these sites is likely related, at least in part, to the need to preserve, dry, and/or even cook fish and perhaps other aquatic food items (Dale and Ashley, 2010; Prendergast and Lane, 2010; Marean, 2016).

The latter part of the LSA is associated with the development of pastoral and, in some cases, even small-scale agricultural societies in many places across Africa beginning ~10 ka (McCall and Taylor, 2014). The LSA ends with the introduction of metal tools, hunting implements, and weaponry at the onset of the Iron Age, which were relatively widespread across many parts of Africa by at least ~1-2 ka. However, it should be noted that 1) once again, the transition was not a synchronous single continent-wide event, 2) the use of iron and stone technology were not necessarily mutually exclusive, and 3) many

groups continued to make and use stone tools in Africa (and elsewhere across the world) well into historical times (McCall and Taylor, 2014).

AQUATIC FOOD RESOURCE USE AND HUMAN EVOLUTION DURING THE MSA AND LSA

Given that identifying foraging behaviors for aquatic food resources at SM1 is a primary goal of this dissertation, it is useful to discuss in more detail the role of aquatic foraging adaptations in human evolution, a topic which has long been the subject of lively debate, particularly with regard to the MSA and LSA (*e.g.,* see: Erlandson, 2001; Erlandson and Fitzpatrick, 2006 for a review). As noted above, it is clear that well-developed aquatic foraging adaptations were present in the LSA at both inland and coastal sites across Africa (Stewart, 1989; Yellen, 1998; Van Neer, 2004). Some of the oldest of these sites date to between ~17-25 ka, and are found in riverine settings at Ishango in DRC, White Paintings Shelter in Botswana, and Wadi Kubanniya in Egypt (Gautier and Van Neer, 1989; Stewart, 1989; Peters, 1990; Robbins *et al.,* 1994). There are also younger sites in eastern and central Africa, including several around Lake Turkana (≤ ~9.5 ka), and Kansyore sites (~8-2 ka) largely concentrated around Lake Victoria (Philipson, 1977; Robertshaw *et al.,* 1983; Robbins, 1984; Clark, 1989; Stewart, 1989; Dale, 2007; Prendergast and Lane, 2010). Additionally, abundant fishing sites are known from the latest Pleistocene (~14 ka) and younger along the Nile River, and its tributaries including the White Nile, Blue Nile, and Atbara rivers in Egypt and Sudan (Marks, 1987; Clark, 1989; Van Neer, 2004; Chaix, 2003; Vermeersch *et al.*, 2000).

All of these archaeological sites have large quantities of fish remains, indicating that aquatic food resources were an important part of the subsistence economies of their inhabitants. Additionally, as noted above, barbed bone points occur at many sites, including

Ishango and White Paintings, and many of the sites around the Rift Valley lakes and in the Nilo-Sudanic region (Stewart, 1989; Yellen, 1998). Early sites (*i.e.,* > ~10 ka) were typically occupied by groups that: 1) were highly mobile; 2) had markedly seasonal foraging strategies; 3) relied on terrestrial game as a major food source for much of the year; 4) fished opportunistically on a seasonal basis; and 5) exploited a limited range of fish taxa (*e.g., Clarias*, *Barbus, Oreochromis*), many of which have spawning/nesting habits that make them predictably abundant and easy to catch with simple methods in early rainy season floodplains, late rainy season mudflats, dry season waterholes, and/or shallow, inshore lake waters (Van Neer, 1989, 2004; Stewart, 1989; Yellen *et al.,* 1995).

Conversely, at younger sites (*i.e.,* < ~10 ka), groups often: 1) were seasonally mobile, but also semi-sedentary for part of the year; 2) had storage technology (*i.e.,* ceramics); 3) employed more sophisticated fishing methods, including rafts and boats that allowed them to fish for more of the year and exploit deeper lake waters and main river channels; 4) exploited a wider range of fish taxa, including many "open-water" species (*e.g.*, *Lates, Bagrus*); and 5) had subsistence economies focused heavily on fish and other aquatic food resources (Stewart, 1989; Van Neer, 2004; Dale, 2007; Dale and Ashley, 2010; Prendergast, 2010; Prendergast and Lane, 2010; Prendergast and Beyin, 2018). Importantly, despite differences in fishing and foraging behavior at early and later sites, in both cases fish formed a significant part of the subsistence base, and the availability of fish (and other aquatic food resources) had important effects on other facets of behavior and social organization, including the degree of mobility, scheduling of foraging activity, and development of complex technology (*e.g.,* storage vessels, fishing gear, boats/rafts) (Marean, 2016).

An apparent lack of similar evidence from sites predating ~25 ka led previous workers to suggest that regular use of aquatic habitats and food resources was a relatively

recent innovation (Erlandson, 2001). It has even been argued that MSA people, specifically, could and/or did not regularly fish (Klein, 2000). Part of this argument rests on the idea that MSA people were not capable of, or perhaps simply not interested in, producing the requisite complex technology needed to catch fish on a regular basis (*e.g.,* barbed harpoons, bone fishhooks, sinkers, nets, boats/rafts). This notion is arguable in itself given the evidence of aquatic resource use from Katanda (see below) and other MSA sites, but it also assumes that complex technology is required to regularly catch fish in all habitats.

While the idea that fishing requires complex technology may be true in some environments (*e.g.,* in deep/open water on lakes and seas or fast-moving rivers), it is demonstrably false for others. As will be discussed in more detail in Chapter 4, in the temporary rivers that surround SM1, local people of all ages catch fish throughout the dry season using methods that are relatively simple, quite effective, and incorporate perishable materials not likely to be preserved in the archaeological record (Abbute, 2004; Tewabe, 2008; Tewabe *et al.,* 2008; Kappelman *et al.,* 2014). Moreover, in some cases the only technology required to catch fish in this area is the ability to corral them into the shallow waters at the edge of isolated waterholes and grab them by hand (Kappelman *et al.,* 2014). Further, there is no obvious reason to assume that the same should not be true of similar riverine ecosystems elsewhere in Africa and around the world, both now and in the past.

As noted in the previous section, additional work documents aquatic/marine resource use at many MSA sites, including riverine fishing at the Katanda sites ~90 ka (Yellen *et al.*, 1995; Marean, 2014). Moreover, the evidence from Katanda fits well with the pattern described above for late Pleistocene (*i.e.,* "early") LSA fishing sites because: 1) barbed bone points are present, which are typologically similar to those at many of the LSA sites; 2) faunal remains include abundant fish and numerous terrestrial mammals; 3)

although 13+ fish taxa are present, *Synodontis, Clarias,* and, to a lesser extent, cichlids, seem to have been preferentially targeted; and 4) fish capture appears to have taken place primarily during seasonal spawning runs (Brooks *et al.*, 1995; Yellen *et al.*, 1995; Yellen, 1998).

Despite the fact that the Katanda sites are apparently ~70 ka older than the oldest LSA sites, these similarities indicate a degree of continuity between them, and the fact that Ishango is only ~6 km south of Katanda further suggests the possibility of a regional aquatic foraging adaptation that extends from the MSA through the terminal Pleistocene (Yellen *et al.,* 1995). Regardless, it is clear that MSA people in both coastal and inland habitats exploited aquatic food resources, albeit with varying degrees of regularity and efficiency, and evidence from Katanda documents that systematic riverine fishing was part of the MSA behavioral repertoire in at least some places (Brooks *et al.,* 1995; Yellen *et al.,* 1995). However, given that Katanda is currently the only MSA locality where such behavior is known, the extent to which riverine foraging strategies were fully developed in the MSA, and the range of variation that exists among such strategies, remains uncertain.

EXPLAINING THE DIFFERENCES BETWEEN MSA AND LSA BEHAVIOR

From the above discussion, it is clear that many of the features that characterize LSA technology and behavior were also present during the MSA. For example, complex artifact forms, such as blades, backed geometrics, microliths, and bone tools, are certainly ubiquitous in the LSA, but nonetheless all first appear during the MSA. The same can be said of many of the symbolic/artistic elements of the LSA, such as beads, notched/incised pieces, and non-utilitarian pigment use, which also occur in MSA contexts. Similarly, patterns of habitat use (*e.g.,* expansion into increasingly harsh environments, such as those

with seasonal extremes and/or sub-/semi-/deserts with low net above-ground productivity) and foraging behaviors (*e.g.,* hunting terrestrial prey of all sizes and temperaments, utilization of aquatic food resources, and exploitation of a variety of plant foods) appear to have been at least broadly similar between the MSA and LSA (McBrearty and Brooks, 2000; Klein, 2000, 2009; Henshilwood and Marean, 2003; Faith, 2008).

As such, it seems that many of the distinctions between the MSA and LSA relate to the frequency and intensity of expression and/or refinement of particular behaviors and do not necessarily reflect innate differences in the ability of humans to perform the behaviors themselves, and there are several reasons to believe this may be the case. To begin with, if many of the behaviors supposedly distinctive of the LSA actually originated during the MSA, it is reasonable to hypothesize that they would be more patchily expressed and less refined immediately following their initial appearance (*i.e.,* in the early/middle MSA), but become more refined through time (*i.e.,* in the later MSA and LSA). Moreover, to suggest inherent differences between MSA and LSA human behavior implies a disconnect of at least ~100-200 ka between the appearance of essentially modern human skeletal anatomy and the origin of modern cognitive capacity, and there is no obvious reason to *a priori* assume this should be the case (Day, 1969; McBrearty and Brooks, 2000; Pearson *et al.*, 2008; Hublin *et al.*, 2017).

Nonetheless, the fact remains that particular aspects of lithic technology, foraging behavior, and symbolic expression seem to have been more common and well-developed during the LSA, and to have reached levels of complexity that are simply not observed in the MSA (Mellars, 2006; Klein, 2009). In particular, there appear to be clear changes and/or differences in: 1) lithic production techniques and raw-material utilization; 2) the frequency of complex artifact forms, and the variety and complexity of tool types in general; 3) the development and expression of symbolic/ritual systems and behavior; 4) the

diversity of habitats and the regularity with which people managed to survive in even the most marginal ecosystems (*e.g.,* sub-/semi-/deserts, tropical rainforests); and 5) the intensity of resource extraction and utilization, particularly with regard to small prey and aquatic food resources.

It has been suggested that a neural mutation that arose ~50 ka and resulted in significant cognitive differences between MSA and LSA people may account for these behavioral differences (*e.g.,* Klein, 2000, 2009). However, this explanation requires that such a mutation first occurred in Africa near the MSA-LSA boundary and subsequently spread across the Old World with populations expanding out of Africa *after ~50 ka*. This is seemingly impossible, given that fully modern – both biologically and behaviorally – humans had already dispersed into Australia by *at least 50 ka,* and possibly as early as 65 ka (Bowler *et al.,* 2003; Clarkson *et al.,* 2017). As such, alternative scenarios involving demographic expansion and its effects on human technology and behavior offer a more parsimonious, and much more likely, explanation for observed differences between the MSA and LSA (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Powell *et al.*, 2009; Tryon and Faith, 2016; Bons *et al.,* 2019).

Late Pleistocene demographic expansion and population pressure

Over the last three decades, a large body of work has focused on using genetic data from mtDNA, Y-chromosomes, and whole genome sequences to investigate the demographic structure of ancient human populations, and the nature and timing of past population contraction/expansion events (*i.e.,* genetic bottlenecks) (Rogers, 1995; Harpending *et al.,* 1998; Zhivotovsky *et al.,* 2003; Fagundes *et al.,* 2007; Amos and Hoffman, 2010; Pereira *et al.,* 2010; Soares *et al.*, 2012; Henn *et al.,* 2012; Mallick *et al.,*

2016; Pagani *et al.,* 2016). Although exact estimates differ, a general consensus has emerged on several points, including that: 1) effective hominin population sizes (*i.e.,* the number of breeding individuals) were likely no larger than ~10,000 throughout the early and middle Pleistocene; 2) the ancestral modern human population originated in Africa by at least ~150-200 ka and likely had an effective size of ~12,000-15,000 individuals; 3) the ancestral population experienced a significant reduction in size ~60-80 ka within Africa; 4) small populations, with effective sizes of ~1,000-2,500 individuals, began dispersing out of Africa by at least ~60-90 ka; 5) a period of rapid population growth began in Africa ~45-60 ka and continued outside of Africa as groups moved into the Near East and across Eurasia; and 6) the global spread of modern humans is associated with a continued loss of genetic diversity resulting from a series of genetic bottlenecks (Cann *et al.,* 1987; Hammer, 1995; Harpending *et al.,* 1998; Harpending and Rogers, 2000; Underhill *et al.,* 2000, 2001; Underhill and Kivisild, 2007; Fagundes *et al.,* 2007; Amos and Hoffman, 2010; McEvoy *et al.,* 2011; Henn *et al.,* 2012).

The general agreement that ancestral modern human populations were relatively small before ~60-80 ka, but experienced episodes of expansion beginning ~45-60 ka is of particular importance for the present discussion. In this case, demographic expansion during the late Pleistocene ~45-60 ka (*i.e.,* during the latest MSA and early LSA) likely involved a significant and relatively rapid increase in the number of people on the landscape, and this process would have had numerous consequences for modern human behavior and the material traces of it left behind in the archaeological record. To begin with, a substantial surge in human population sizes during the LSA would almost certainly be accompanied by a parallel rise in the number of archaeological occurrences, thereby increasing the archaeological visibility of behavioral signatures from the LSA. As the landscape became increasingly crowded during the LSA, group mobility would also likely

be reduced, often leading to longer and more intensive periods of occupation at LSA sites, and further increasing the visibility of LSA archaeological material (McBrearty and Brooks, 2000; Tryon and Faith, 2016).

Likewise, as populations expanded and grew increasingly crowded, contact between neighboring groups would become more frequent and there would be more opportunities for intergroup exchange of goods (*e.g.,* raw materials, tools, ornaments, foodstuffs), information (*e.g.,* about technology, foraging behavior, cultural practices), and even people (*e.g.,* marriage partners). Larger exchange networks, in turn, would make it easier for aspects of technology and behavior to spread farther and more rapidly, and therefore become more common and refined, during the LSA than they did during much of the MSA, when populations and exchange networks were smaller and more thinly dispersed across the landscape (McBrearty and Brooks, 2000; Tryon and Faith, 2016). The same is true of symbolic objects and behaviors (*e.g.,* artifact traditions, beads, ornaments, art objects), all of which occur regularly in the LSA and are also present, but less common, during the MSA. Moreover, the symbolic systems associated with these objects would likely be less important when populations were small and sparsely distributed, but the need to clearly and regularly distinguish oneself would intensify as populations continued to grow and neighboring groups came into contact (and conflict) more frequently (McBrearty and Brooks, 2000; Marean, 2016). Moreover, large social networks would have facilitated the rapid spread and elaboration of these symbolic systems (Tryon and Faith, 2016).

Demographic increase would also inevitably lead to increased resource stress, as more people were forced to compete for a finite set of resources (*i.e.,* food, water, raw materials, mates) within a given area. Resource stress, in turn, would often result in resource intensification, a process whereby foragers broaden their diets to include new foods and/or a larger number of low-ranked and less-preferred food items when high-

ranked and preferred resources become depleted (MacArthur and Pianka, 1966; Krebs, 1977; Winterhalder and Smith, 2000; Stiner and Munro, 2002). According to foraging theory, foragers should typically make foraging decisions that maximize their net return rates of energy and nutrients per unit of foraging time (Charnov, 1976a, b; MacArthur and Pianka, 1966). Thus, low-ranked foods are those that have relatively high search and/or handling costs (*i.e.,* the time and effort required to locate, pursue, acquire, process, and eat a food item) and relatively low nutritional and energetic return rates (Charnov, 1976a, b; MacArthur and Pianka, 1966; Krebs, 1977; Smith, 1983).

With respect to prey species, generally speaking, there is a fairly strong relationship between body size and prey rank - in other words, the larger the animal, the higher its rank (Broughton *et al.,* 2011). However, species that are both large-bodied and aggressive (*e.g.,* Cape buffalo) are generally low-ranked because the effort and risk involved in acquiring them reduces otherwise large net return rates; the same is true of many small and agile taxa (*e.g.,* hares, rabbits, rodents, flying seabirds), which provide relatively low returns and often require specialized technology to acquire (Stiner *et al.*, 2000; Henshilwood and Marean, 2003). Similarly, fish are often considered low-ranked prey because specialized tackle (*e.g.,* hooks, barbed points, lines, nets) may be needed to catch them (Henshilwood and Marean, 2003), although this is not necessarily true in all ecological settings (Tewabe *et al.,* 2010; Kappelman *et al.*, 2014). In any case, generally speaking, large and dangerous prey, small and nimble animals, and, at least in some circumstances, fish, are low-ranked prey and therefore would likely not form a substantial portion of the diet under conditions of relatively low resource stress. However, the frequency of these and other low-ranked food items in the diet would be expected to increase as resource stress became more severe and resource intensification amplified. Likewise, the complex technology and behaviors

often needed to obtain low-ranked prey should also become more common and refined as levels of resource stress continue to rise and forager diets grow increasingly broad.

Resource intensification associated with increased population crowding and competition over resources would also likely lead to more frequent expansion into new habitats (Henshilwood and Marean, 2003). Much like individual resources, different foraging patches (*i.e.,* habitats) can be ranked according to their return rates relative to other patches. Given that they should generally make decisions that optimize foraging efficiency, there is thus little reason to expect a group of foragers to spend significant amounts of time in patches with low returns if patches with higher returns are available (Charnov, 1976a; Krebs, 1977; Henshilwood and Marean, 2003). However, a group of foragers would be expected to enter and stay longer in a low-return patch if: 1) high-return patches are depleted, 2) there are substantial risks associated with foraging in available high-return patches, and/or 3) access to high-return patches is restricted by groups that already inhabit and defend them (Henshilwood and Marean, 2003). Therefore, as dense occupation and aggressive defense of highly productive habitats, both of which would be expected to accompany substantial increases in population size, made foraging progressively more difficult and less profitable, people would be expected to start entering less productive habitats in search of food and other resources more frequently. Once again, this process of population displacement and expansion into new habitats would also be expected to act as a catalyst for technological and behavioral innovation, as it became increasingly important for groups to find novel ways to adapt to and survive in less hospitable environments.

In sum, there is a good case to be made that rapid and substantial demographic expansion would have significantly impacted patterns of human behavior in ways that can plausibly account for many of the differences between MSA and LSA behavior and

technology (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003). Increasingly crowded landscapes would have made it easier and more important to form large exchange networks through which goods and ideas could circulate more widely and rapidly. More frequent intergroup contact and/or conflict would have amplified the need for fully developed symbolic systems used to express and reinforce individual and group identity. Resource intensification brought on by resource stress would have forced people to become increasingly reliant on lower-ranked prey that were dangerous and/or difficult to procure, and to expand into lower quality habitats more frequently as competition for and defense of high-quality patches intensified.

Moreover, all of these developments would likely have been associated with corresponding increases in technological complexity. As such, the fact that earlier MSA populations did not engage in the same behaviors as their LSA counterparts, or at least not in exactly the same way or with the same regularity, need not imply that MSA people inherently lacked the requisite (*i.e.,* "modern") cognitive capacities. Rather, it is likely that many of these behavioral patterns were not developed more fully during the MSA simply because they were not as important until late Pleistocene population expansion created a selective regime in which large exchange networks, symbolic systems, increased diet breadth, and more habitat flexibility were necessary for survival and provided more distinctive selective advantages (McBrearty and Brooks, 2000; Powell *et al.,* 2009; Tryon and Faith, 2016).

THE IMPORTANCE OF THE MSA FOR UNDERSTANDING HUMAN EVOLUTION

The preceding sections clearly demonstrate that the origins of many of the behaviors that characterize later Pleistocene and Holocene humans are firmly rooted in the

MSA. Furthermore, many of the complex behaviors that originated in the MSA and subsequently became both more frequent and more sophisticated during the LSA formed the foundation of the flexible adaptive strategies that modern human populations brought with them as they dispersed out of Africa and across the rest of the world. Thus, determining how, when, where, and why these behaviors evolved, and documenting the range of variation in the adaptive strategies of early humans among whom these behaviors were developed and/or refined, is essential to understanding how and why our ancestors were able to leave Africa and make their way across most of the Old World in a relatively short span of time, and to successfully occupy an impressive array of ecosystems across the globe.

Likewise, understanding the origins and evolution of particular behaviors and adaptive strategies offers important insight into the range of environmental settings that early modern humans were adapted to and capable of surviving in when they expanded out of Africa and, in turn, the types of ecological conditions that may have supported dispersing populations and facilitated dispersal behavior. Thus, data on human behavior in the MSA continue to play a central role in the formulation and refinement of current models of modern human behavioral evolution and dispersal, and these data form the basis of ongoing debates about these and related issues. As will be discussed in the next chapter, analyses of zooarchaeological and taphonomic data from archaeological sites can offer an important window into the lives of early humans and, in so doing, help provide answers to many of the questions that still persist regarding modern human evolution, behavior, and dispersal.

Chapter 3: Theoretical and Analytical Framework of the Dissertation

INTRODUCTION

The current chapter begins with an overview of the history of zooarchaeological, taphonomic, and MSA research over the last several decades. This overview is followed by a more detailed discussion of some of the specific concepts and methods used in Chapters 5-7 to analyze the faunal remains from SM1 and several comparative MSA sites. The next section lays out the specific hypotheses to be tested in Chapters 5-7, as well as the alternatives and expectations for each of them. The chapter ends with a description of the materials and methods for the study and a basic outline of the analytical procedures.

ZOOARCHAEOLOGY, TAPHONOMY, AND MSA RESEARCH

A large body of ethnographic, experimental, and taphonomic research has been aimed at using the characteristics of faunal assemblages to reconstruct past human behavior. Ethnographic work has focused on better understanding the factors that influence foraging decisions and behavior among modern hunter-gatherer groups in diverse settings, and documenting the physical remnants of faunal acquisition, transport, processing, and discard behavior that might be identified in the archaeological record (*e.g.,* Gifford and Behrensmeyer, 1977; Yellen, 1977, 1986, 1991a, 1991b; Binford, 1978; Hawkes *et al.,* 1982, 1991; Hill *et al.,* 1987; Bunn *et al.,* 1988; Gould, 1991; Gifford-Gonzalez *et al.,* 1999; Lupo, 2006). Similarly, experimental and taphonomic investigations have been aimed at identifying patterns of faunal accumulation and modification that can be used to investigate the paleoecology of a site and various processes of site formation, including distinguishing between human and non-human taphonomic agents and producing reliable interpretations of human behavior (*e.g.,* Lyon, 1970; Behrensmeyer, 1978; Hill, 1979; Haynes, 1983; Blumenschine, 1986, 1988, 1995; Blumenschine and Selvaggio, 1988;

Marean, 1991; Villa and Mahieu, 1991; Blumenschine *et al.*, 1996; Capaldo, 1998; Marean and Kim, 1998; Cutler *et al.*, 1999; Marean and Cleghorn, 2003; Dominguez-Rodrigo and Barba, 2005; Soligo and Andrews, 2005; Njau and Blumenschine, 2006; Pickering *et al.*, 2006; Dominguez-Rodrigo *et al.*, 2009, 2010; Pante *et al.*, 2012, 2015; Willis, 2014).

Previous work has made it clear that documenting the taphonomic history of a site and accounting for damage related to non-human agents and processes, as well as potential bias due to excavation protocols and/or analytical procedures, is necessary to ensure robust behavioral interpretations and meaningful comparative analyses (Lyman, 1994; Gifford-Gonzalez, 2018). Assuming careful consideration of taphonomic factors, this research has also clearly demonstrated the value of faunal remains for understanding numerous aspects of human behavior, including: the timing of hominin access to carcasses (*i.e.,* hunting versus active and/or passive scavenging) (*e.g.,* Binford, 1984; Blumenschine, 1986, 1988, 1995; Capaldo, 1997, 1998; Selvaggio, 1998); faunal transport and processing strategies (*e.g.,* Blumenschine, 1991; Stiner and Kuhn, 1992; Bunn and Ezzo, 1993; Marean and Cleghorn, 2003; Munro and Bar-Oz, 2005; Faith and Gordon, 2007; Niven, 2007; Manne *et al.,* 2012; Schoville and Castillo, 2014); prey choice (*e.g.,* Klein and Cruz-Uribe, 1996; Frison, 1998; Cannon and Meltzer, 2004; Faith, 2008); season of occupation (*e.g.,* Brewer, 1987; Todd *et al.,* 1990); aquatic resource use (*e.g.,* Colley, 1990; Stewart, 1994; Dusseldorp and Langejans, 2013; Marean, 2014); dietary breadth and resource intensification (*e.g.,* Speth, 1987; Stiner *et al.,* 1999, 2000; Stiner and Munro, 2002); and mobility and land use (*e.g.,* Kelly and Todd, 1988; Knell and Hill, 2012).

In the late 1970's and early 1980's, a number of researchers began using zooarchaeological methods and theory to reconstruct early human behavior at several well-known MSA sites, often with the intent of comparing behavioral signatures from the MSA to those of the subsequent LSA (*e.g.,* Klein, 1976, 1977; Klein and Cruz-Uribe, 1997).

Many of these earlier studies of MSA foraging behavior often focused on determining whether or not MSA people primarily hunted and/or scavenged large game (*e.g.,* Klein, 1976; Binford, 1984; Milo, 1998). There is now little doubt that hunting was an integral part of the modern human adaptive suite by at least the middle and later MSA (McBrearty and Brooks, 2000; Marean and Assefa, 2005). However, as discussed in Chapter 2, questions persist about the ability of MSA humans to regularly hunt prime-age individuals of large and dangerous taxa, effectively track seasonal patterns of resource availability, and efficiently exploit aquatic resources (Klein, 2000). The fact that MSA populations occupied various ecosystems across Africa means that resolving these issues requires detailed data on MSA behavior from diverse habitats. Yet, particular aspects of previous work on MSA behavior currently limit our ability to create a temporally, geographically, and ecologically broad comparative framework within which to address these questions (Thompson, 2008; Thompson and Henshilwood, 2011).

To begin with, although there are numerous MSA sites with large excavated assemblages of chipped stone artifacts, there are far fewer sites with comparable collections of well-preserved faunal material, and fewer still for which the fauna has been analyzed in detail (Thompson and Henshilwood, 2011). Further, in many cases where data on large faunal assemblages are available, biased collection and/or analytical techniques often limit their interpretive value (Bartram, 1993; Bartram and Marean, 1999; Marean *et al.*, 2000). In the past, it was common for excavators to collect only readily identifiable bones in the field and to discard less identifiable fragments, particularly of long bone shafts. Even when shaft fragments were collected, behavioral analyses often relied primarily on bones with easily identified articular ends, and ignored less identifiable fragments of long bone shaft (Marean and Kim, 1998; Marean *et al.,* 2000). However, more recent work has shown that including shaft fragments can fundamentally alter interpretations of skeletal element

abundance (and, by extension, foraging behavior), and has demonstrated the importance of these specimens for understanding patterns of bone fragmentation and other taphonomic processes (Bartram, 1993; Marean and Kim, 1998; Bartram and Marean, 1999; Marean and Assefa, 1999; Outram, 2001; Pickering *et al.,* 2003).

Of similar concern, earlier studies of MSA foraging behavior often did not include comprehensive taphonomic evaluations (*e.g.,* Klein, 1976, 1977). As such, although much more attention has been given to taphonomy in recent work, the sample of MSA sites where detailed taphonomic studies have been undertaken in combination with behavioral analyses is still rather limited in its geographical and ecological scope (Table 3.1). Of the nine sites listed in Table 3.1, Porc Epic and Contrebandiers Cave are the only two located outside of South Africa, and Porc Epic is the only cave site that is not in a coastal setting (Assefa, 2002; Hallett, 2018). Further, Bundu Farm and Pniel 6 are the only two open-air sites in this group, and while both are located inland, they are nonetheless also in South Africa (Hutson, 2012a, 2018). Bundu Farm and Pniel 6 also both date to the early MSA, contain sparser and more ambiguous evidence of human involvement, and may represent short-term kill/butchery sites or places where early humans intermittently scavenged carnivore kills (Hutson, 2012a, 2018). This is in contrast to most of the other sites (including SM1 – see Chapters 4-8), which date to the middle or late MSA, were occupied more intensively, and contain clear evidence for MSA people engaging in systematic hunting and/or aquatic foraging behavior (Marean *et al.,* 2000; Assefa 2006; Thompson, 2010; Thompson and Henshilwood, 2011; Clark, 2011; Hutson, 2018; Faith, 2013; Hallett, 2018).

The relative lack of ecogeographical and site type diversity in the current MSA record is important, because the current framework for using fauna and taphonomy to interpret MSA behavior is built largely on the sites listed in Table 3.1. However, these sites clearly do not represent the full range of geographical locations, occupational settings (*i.e.,*

Table 3.1 MSA sites where behavioral analyses include specific consideration of both human and non-human taphonomic processes.

Site	Type	Period	Country
Porc Epic	Cave	Late MSA	Ethiopia
Contrebandiers Cave	Cave	Middle/Late MSA	Morocco
Bundu Farm	Open-air	Early MSA	South Africa
Pniel 6	Open-air	Early MSA	South Africa
Blombos Cave	Cave	Late MSA	South Africa
Pinnacle Point 13B	Cave	Late/Middle MSA	South Africa
Die Kelders Cave 1	Cave	Late MSA	South Africa
Sibudu Cave	Cave	Late MSA	South Africa
Boomplaas Cave	Cave	Late MSA	South Africa
Sources: Marean *et al.* (2000); Assefa (2002, 2006); Thompson (2008, 2010); Thompson and Henshilwood (2011); Clark (2009, 2011); Faith (2013); Hallett (2018)			

open-air versus cave versus rockshelter; inland versus coastal), and/or complex behavioral strategies that were present during the late MSA (McBrearty and Brooks, 2000; Basell, 2008). The paucity of open-air sites is particularly worrisome, given that: 1) open-air occupations were likely at least as common as those located in caves and rockshelters (McBrearty and Brooks, 2000; Basell, 2008), 2) open-air and cave/rockshelter sites potentially represent very different environments for bone deposition, burial, and preservation (Brain, 1981; Hutson, 2012b), and 3) previous work documents that many aspects of taphonomy and human behavioral signatures may not be directly comparable between open-air and cave sites (Hutson, 2018). Similarly, while there is little doubt that coastal occupations were common in the MSA, there are far more interior sites in the African record as it is currently known (McBrearty and Brooks, 2000; Basell, 2008). As such, the emphasis on coastal settings is probably also less than ideal, since there are likely

to be differences in the contexts of deposition, burial, and preservation between interior and coastal sites, as well (Hutson, 2018).

Thus, while previous work at the sites listed in Table 3.1 has clearly demonstrated the potential for using zooarchaeological analyses to reconstruct MSA behavior (*e.g.,* Marean *et al.,* 2000; Assefa, 2002; Thompson, 2010; Clark, 2011), additional data from MSA sites sampling a more diverse range of ecogeographical contexts and site types are necessary to understand the full range of MSA adaptive strategies across Africa. Specifically, there is a need for new data, particularly from open-air sites, that have been collected and interpreted using methods that stress unbiased recovery and analysis of all faunal material, adequately account for taphonomy, and facilitate inter-site comparisons.

THE ANALYTICAL FRAMEWORK

The previous section serves primarily to highlight the nature and diversity of zooarchaeological and MSA research over the last 40+ years. It is not meant to be an exhaustive review of these topics, numerous examples of which are already available in the paleoanthropological literature from the past two decades (*e.g.,* Klein, 2000, 2009; McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Marean and Assefa, 2005; Marlow, 2005; Klein, 2009; Shea, 2011; Tryon and Faith, 2013). However, many of the concepts and methods that developed out of the work summarized above provide the foundation for the faunal and taphonomic analyses, and subsequent behavioral interpretations, offered in Chapters 5-8. Thus, before moving forward it is important to discuss more fully those aspects of the vast body of previous research that are directly relevant to this study.

In order to provide a more comprehensive picture of the analytical framework of this dissertation, the following sections discuss many of the primary zooarchaeological and taphonomic methods used for the analyses presented in Chapters 5-7. These discussions also serve as the foundation for specific criteria that will be used to test several hypotheses about site formation and early human foraging behavior at SM1, and how SM1 fits within the context of other MSA sites where faunal remains and taphonomy have been studied using methods that give full consideration to both human and non-human agents and processes of site formation and faunal modification.

Documenting assemblage composition and taxonomic diversity

The overarching goals of zooarchaeological analysis typically involve reconstructing past human behavior, paleoenvironmental conditions, and/or the structure of ancient faunal communities at or around an archaeological site (Grayson, 1984; Lyman, 2008; Reitz and Wing, 2008; Gifford-Gonzalez, 2018). Researchers are also often interested in comparing various aspects of behavior, paleoecology, and faunal community structure among sites in different geographical, environmental, and/or temporal settings in order to document, and ultimately offer explanations for, similarities and differences that exist among them (Lyman, 2008; Reitz and Wing, 2008). As may seem obvious, accomplishing any of these goals first requires that the analyst understand the overall makeup of a faunal assemblage. Thus, documenting what taxonomic groups and skeletal parts are present at a site, and quantifying the frequencies at which different taxa and bones occur, is one of the first and most basic steps in any zooarchaeological analysis (Binford, 1978, 1981; Lyman, 1994; Gifford-Gonzalez, 2018).

Documenting assemblage composition

Documenting the overall composition of an archaeofaunal assemblage entails identifying the taxonomic groups and skeletal elements that are represented at a site, and often involves the use of modern and/or fossil comparative collections of similar faunal species to aid in the process of identification (Reitz and Wing, 2008; Gifford-Gonzalez, 2018). Although not necessarily an easy task, even for a trained analyst in many cases, this is perhaps the most straightforward step in archaeofaunal analysis, and one that is fundamental to the ability of the researcher to proceed with any additional analytical steps.

Quantifying taxonomic and skeletal part abundance

Once identifications have been made, there are several measures that are commonly used to quantify the taxonomic groups and skeletal parts present at a site for further analysis (Binford, 1978, 1981; Lyman, 1994). The simplest and most straightforward of these quantitative measures is the number of identified specimens (NISP) (Grayson, 1984, Lyman, 1994, 2008; Gifford-Gonzalez, 2018). NISP is an observational unit that by definition refers to the number of specimens identified for a particular taxon, although it is also sometimes used in reference to specimens identified to skeletal element or some other subset of the data (Grayson, 1984; Lyman, 1994; Reitz and Wing, 2008). In practice, NISP counts can be tabulated for essentially any taxonomic or anatomical aggregate, as long as the sample being described is clearly defined in each case (Lyman, 1994). Normalized NISP (nNISP) is a closely related, but slightly more derived, unit which simply divides the NISP of an element by the number of times it occurs in the body. As such, nNISP provides a means of standardizing raw NISP values in a way that better accounts for the differential representation of elements in a complete skeleton (Grayson and Frey, 2004).

Many zooarchaeological studies also employ counts of the minimum number of elements (MNE), individuals (MNI), and/or animal units (MAU) (Klein and Cruz-Uribe, 1984; Lyman, 1994; Gifford-Gonzalez, 2018). MNE is the minimum number of each skeletal element that is present for a given taxonomic aggregate and, depending on the investigator and method of quantification, its calculation may include consideration of additional factors such as the size, age, sex, side, and/or anatomical overlap of specimens (Klein and Cruz-Uribe, 1984; Lyman, 1994; Marean *et al.*, 2001). MNI is the smallest number of individuals required to account for the bones in an assemblage, and may be calculated using either NISP or MNE values (Lyman, 1994). As with MNE, the criteria (*e.g.,* age, size, sex, side, and/or overlap) factored into the calculation of MNI may vary depending on the researcher and method of analysis (Lyman, 1994). MAU measures the abundance of different skeletal portions (*i.e., "*animal units") at a site, and is calculated by dividing the MNE of a particular element (without reference to side) by the number of times it occurs in the body (Binford, 1978). An animal unit (*i.e.,* portion) may refer to part of an element (*e.g.,* proximal femur), a single element (*e.g.,* femur), or even a skeletal segment (*e.g.,* hindlimb), and it is again important for the analyst to always specify what exactly is being measured (Lyman, 1994).

Because it is an observational unit, NISP is the simplest way to describe faunal abundance at a site (Grayson, 1984). Beyond simply identifying, recording, and counting the specimens of interest, generating NISP counts requires little additional manipulation of the raw data that can increase the chance for errors in tabulation and/or discrepancies between the results produced by different researchers. Although there are still some decisions to be made about how to record the data that may lead to slight differences between studies, once the data are gathered, there is really only one way to calculate NISP (*i.e.,* simply count the number of specimens). The very straightforward nature of NISP is

one of the major strengths of this unit because it means that NISP data are inherently comparable across similar samples from basically any site. NISP also provides larger sample sizes than nNISP, MNE, MNI, and MAU, which is an added advantage, particularly at sites where minimum number counts are drastically reduced compared to NISP.

Despite its simple and straightforward nature, or perhaps because of it, previous authors have also pointed out several potential problems with NISP, including its failure to account for the fact that all taxa and elements are not equally likely to be represented at a site (Grayson, 1984; Lyman, 1994). For example, smaller animals are often transported back to camp sites as complete or mostly complete carcasses, while larger animals are more extensively butchered in the field with only select parts brought back to camp (Binford, 1978; Bunn *et al.,* 1988; Yellen, 1991). As such, NISP counts for small animals may be higher than those for larger animals simply because more elements from each of the smaller animals made their way into the site, but that does not necessarily mean that small animals are actually more abundant overall. Likewise, simply comparing NISP counts of, say, size three bovid humeri and phalanges, does not take into account that each skeleton has only two humeri but 24 phalanges (12 each for fore- and hindlimbs). Thus, a site where NISP = 25 for humeri and NISP = 55 for hindlimb phalanges does not necessarily contain more hindlimbs than forelimbs, even though NISP counts indicate that the hindlimb elements are more than twice as abundant as the forelimb element. In fact, given these numbers, and assuming that all the phalanges are unique elements, there could be as few as five hindlimbs and as many as 25 forelimbs at the site.

NISP is also particularly susceptible to interdependence, wherein multiple elements from the same animal are counted individually, leading to an artificial inflation of the specimen count for that taxon relative to the actual number of individuals present at the site (Grayson, 1984). Likewise, NISP counts are potentially more sensitive to issues of

fragmentation than other measures, particularly at sites where large numbers of bones are broken into multiple pieces, but many of the fragments are still identifiable to skeletal element and/or taxon (Grayson, 1984; Lyman, 1994). For example, at a site where such fragmentation is largely human-induced, NISP counts of humeri and femora, both of which are regularly broken by humans for marrow removal, may be inflated due to multiple identifiable fragments of the same bone being counted separately (Clark, 2009). A similar increase would not be expected for elements that are not regularly fragmented by humans, such as vertebrae and pelves, potentially leading to NISP counts that are biased in favor of humeri and femora, even though these elements may not actually be more common than vertebrae and pelves (Grayson, 1984; Clark, 2009). The same type of bias may also occur at the taxonomic level because some animals may be more likely to be extensively processed than others.

All of the other quantitative units are derived either directly or indirectly from NISP counts, use data that are standardized in some way, and measure the relative abundance of taxa and/or skeletal parts, in order to avoid many of the problems just discussed for NISP (Lyman, 1994; Marean *et al.,* 2001; Grayson and Frey, 2004; Reitz and Wing, 2008). Although nNISP is perhaps not as common as minimum number counts, this unit is less complicated to calculate than MNE and MNI, and provides a simple way to normalize raw NISP counts that requires only a single additional analytical step (Grayson and Frey, 2004; Clark, 2009). Normalizing NISP data in this way produces nNISP values that are more directly comparable to MNE and MNI counts (Grayson and Frey, 2004). Yet, the fact that nNISP is only one analytical one step removed from NISP potentially leaves it open to some of the same criticisms leveled at NISP.

Conversely, MNE and MNI were developed specifically to avoid several problems associated with NISP counts (Grayson, 1984). Because they employ aggregates of data that

are assumed to be independent of one another (*e.g.,* right humeri or left tibiae; the number of wildebeest versus warthog; the number of zebra in different levels), at least in theory, both MNE and MNI circumvent the problem of interdependence which, depending on the question of interest, may be one of the biggest limitations of NISP (Grayson, 1984). Likewise, because MNE and MNI are estimates of the number of whole bones and animals that are, or once were, present at a site, these units should be less sensitive to issues of differential preservation and recovery that can cause particular taxa and elements to be artificially overemphasized in NISP counts (Grayson, 1984). For instance, at a site where NISP = 500 for size 1 bovid humeri, and NISP = 100 for size 3 bovid humeri, if all of the fragments in both groups are actually only from 20 right humeri, then MNE = 20 for both groups. Moreover, if the right humerus is the most common element, MNI = 20 for both groups, as well, despite the fact that there are five times as many specimens from size 1 bovids at the site.

However, both MNE and MNI also have drawbacks, some of which may actually be more serious than those discussed above for NISP (Grayson, 1984). To begin with, deriving MNE and MNI counts entails a reduction in sample sizes relative to NISP, in some cases to the point that samples are no longer suitable for statistical analysis (Grayson, 1984; Lyman, 1994). MNI is also prone to overestimating the abundance of rare taxa and, although both measures may be less sensitive at sites with low-to-moderate levels of fragmentation, MNE and MNI counts are often more likely than NISP to be depressed at sites where extensive fragmentation has taken place and there are relatively few bones identified to element and/or taxon (Marshall and Pilgrim, 1993). In this case, the artificial depression of count data (*i.e.,* in terms of what can be identified relative to what is actually present) would affect all three measures, but the bias would be increasingly pronounced as one moved from NISP to MNE to MNI (Marshall and Pilgrim, 1993).

There are also drawbacks involving the ways in which MNE and MNI are calculated (Clark, 2009; Thompson, 2008). By their very nature as derived units of measure, both MNE and MNI are more complicated to calculate than NISP or nNISP, and require that the analyst make additional decisions about what criteria to consider (*e.g.,* age, size, sex, side, and/or overlap), all of which can influence the final results (Klein and Cruz-Uribe, 1984; Lyman, 1994; Marean *et al.,* 2004). There are also multiple methods for calculating both MNE and MNI, each of which employ different sets of criteria in different ways to produce the counts (Grayson, 1984; Lyman, 1994; Thompson, 2008; Clark, 2009). If the specific method of quantification and/or set of criteria are not explicitly defined, which is often the case, there is no way to know if data from one study are directly comparable to those from another study (Klein and Cruz-Uribe, 1984; Lyman, 1994; Marean *et al.,* 2001; Clark, 2009).

What may be an even more serious drawback of MNE and MNI is actually related to one of the perceived strengths of these measures (Grayson, 1984; Clark, 2009). As already noted, MNE and MNI attempt to circumvent the problem of interdependence by employing aggregates of data that are assumed to be independent of one another. Yet, as Grayson (1984) points out, it is often difficult or impossible to be certain that the units of aggregation (*e.g.,* vertical levels within a site) are truly independent of one another. Perhaps more importantly though, MNE and MNI counts will vary, sometimes substantially, depending on the aggregate employed, and the differences may be much greater for some taxa than they are for others (Grayson, 1984; Clark, 2009).

Generally speaking, MNE and MNI counts will increase as an assemblage is divided into smaller aggregates (Grayson, 1984). For instance, to take a modified version of an example from Grayson (1984: p. 32), one can imagine a site with three vertical levels and NISP counts for warthogs that are as follows: 40 left femora and 10 left tibiae in Level

A, 30 right humeri Level B, and 10 left tibiae in Level C. If the assemblage is analyzed as a single aggregate, the most abundant element is defined once as the left femur, and MNI = 40 warthogs for the site. Alternatively, if the site is aggregated by levels, the most abundant element is defined three different times, and warthog MNI counts are 40 in Level A, 30 in Level B, and 10 in Level C. Thus, an analysis of the exact same sample using different aggregates results in doubling the MNI to 80 warthogs for the entire site. Moreover, other researchers could not recreate these MNI counts or recalculate MNI using different aggregates without access to the original raw data, including both specimen counts and any other information related to the criteria employed to calculate the original counts, which are typically not published in full or at all (Grayson, 1984; Clark, 2009). Thus, the problem of aggregation may be the most significant weakness of MNE and MNI counts and, at the very least, provides a strong argument against relying too heavily on these measures to the exclusion of other quantitative units (Grayson, 1984; Grayson and Frey, 2004; Clark, 2009).

Methods that use fractional values to calculate MNE, such as the "fraction summation approach" of Klein and Cruz-Uribe (1984) and the "GIS image-analysis approach" recommended by Marean *et al.* (2001), produce estimates that, much like NISP, are additive, and therefore at least partly avoid the problems of aggregation just discussed. However, the use of "fractional value" approaches is by no means universal, and both of those listed above also have limitations of their own. For example, MNE estimates produced using the fraction summation approach can vary significantly based on which anatomical zones the analyst chooses to quantify for each element, and may be biased downward if preservation is not similar across all parts of a particular zone (Marean *et al.,* 2001). Likewise, although the GIS image-analysis approach provides one of the more robust techniques currently available for estimating MNE, it requires access to specific

computer software during data collection and the process of drawing every identified element onto a GIS template is potentially quite time-consuming, particularly in cases where specimens number in the thousands (Marean *et al.,* 2001).

It is clear that both specimen and minimum number counts have particular strengths and weaknesses, and decisions about which unit(s) and method(s) of calculation are the most appropriate for a given analysis should take these factors into account. Ultimately, however, the choice of whether an analysis would be better-served by the use of specimen versus minimum number counts may not be as consequential as it seems at first glance (Grayson and Frey, 2004). Grayson and Frey (2004) have shown that the relationship between NISP, MNE, MNI, and MAU is actually highly predictable. Moreover, and importantly for this study (see below), using data from Middle Stone Age and Middle Paleolithic sites in South Africa, Israel, and France, these authors have persuasively demonstrated that analyses using NISP and nNISP values produce results that are quite similar to those employing MNE, MNI, and MAU (Grayson and Frey, 2004; Clark, 2009). The discussion above also highlights the fact that clearly defining the sample being quantified and, in the case of minimum number counts, the criteria and methods that were used to derive the values, is perhaps just as important as the choice of which quantitative unit(s) to use (Grayson, 1984; Lyman, 1994; Reitz and Wing, 2008).

Taxonomic diversity

Another way of quantifying faunal abundance that is often useful for zooarchaeological studies is through measures of taxonomic diversity (Grayson, 1984). Diversity refers to both the structure and composition of a faunal collection, and measures of taxonomic diversity provide additional information about faunal representation that is not conveyed by basic specimen counts or minimum counts of elements and individuals

(Lyman, 2008). Along with taxonomic composition, which refers to which taxa are present at the site and was discussed earlier in this chapter, zooarchaeologists are often also interested in understanding taxonomic richness, evenness, and heterogeneity (Lyman, 2008; Reitz and Wing, 2008).

The number of taxa (NTAXA) is a very straightforward measure of taxonomic richness, which simply refers to how many taxa are present at a site (Lyman, 2008; Reitz and Wing, 2008). NTAXA is similar to NISP, in that it is a basic count of the total number of groups present in the assemblage at the taxonomic level of interest (Grayson, 1984; Lyman, 2008). NTAXA can be calculated for species, genera, families, or higher-level groupings, but it is important that only one group is considered at a time; for example, NTAXA should not be used to refer to the number of both species and genera at the same time (Lyman, 2008). Measuring evenness and heterogeneity requires more complex calculations than NTAXA, but also provides more detail about the actual makeup of the assemblage (Lyman, 2008).

As the name implies, evenness refers to how evenly individuals (or specimens) are distributed among the taxa in an assemblage. A highly even assemblage is one in which taxa are represented by roughly similar numbers of individuals, while a highly uneven assemblage is one in which most of the individuals belong to one or a few taxonomic groups (Lyman, 2008). Conversely, heterogeneity is a function of both taxonomic richness and evenness, and therefore reflects both the abundance of taxa and how individuals (or specimens) are represented among them (Lyman, 2008). A very heterogeneous assemblage will contain a high number of taxa with roughly equal numbers of individuals, whereas a collection with low heterogeneity is one in which there are only a few taxa present and/or the distribution of individuals across the groups is highly uneven (Lyman, 2008).

Along with NTAXA, paleontologists and archaeologists also use a number of other measures, or indices, of diversity that describe taxonomic richness, evenness, and heterogeneity and are important for archaeofaunal analyses for a number of reasons (Grayson, 1984; Reitz and Wing, 2008). First, and most fundamentally, these indices provide a way to quantitatively characterize assemblage composition and diversity at an archaeological site (Lyman, 2008; Reitz and Wing, 2008). Additionally, diversity indices are useful for understanding various aspects of human foraging behavior at a site, including dietary breadth, prey selectivity, and resource intensification (*e.g.,* Broughton, 1994; Grayson and Delpech, 1998; Jones, 2004). Likewise, these measures also allow for quantitative comparisons of various aspects of taxonomic diversity between sites in disparate settings and, more importantly, make it possible to document and offer potential explanations for similarities and/or differences between them (*e.g.,* human behavior, technological constraints, environmental factors) (Grayson, 1984; Lyman, 1994; Reitz and Wing, 2008). Thus, examination of taxonomic diversity can provide additional information related to human behavior and/or natural processes, which is important for gaining a full understanding of faunal representation and abundance in an archaeofaunal collection.

Taphonomy of terrestrial fauna

As discussed in the first section of this chapter, a large body of previous work has made it clear that detailed investigation of the various non-human agents and processes that can impact an assemblage is a necessary step in using faunal remains to interpret past human behavior (Lyman, 1994; Gifford-Gonzalez, 2019). The higher-order analyses upon which such interpretations are based require that the analyst: 1) understand the extent to which the assemblage is a function of human activity and 2) account for potential sources

of taphonomic bias (Lyman, 1994). Likewise, it is also important to understand the taphonomic character of an assemblage and the extent of post-depositional bone destruction before undertaking interassemblage comparisons, because certain classes of data from sites with very different taphonomic histories may not be directly comparable (Marean, 1991). The taphonomic processes of interest here concern nutritive (*i.e.,* related to human and/or carnivore nutrient extraction) and non-nutritive (*i.e.,* not related to nutrient extraction) bone modification, and include mechanical, chemical, animal, and cultural agents which can significantly impact the composition and preservational state of a faunal assemblage. Only once these processes are fully understood is it possible to develop robust and reliable interpretations of human behavior in the past.

Bone surface preservation

Once deposited on the surface of the ground, and particularly after all of the muscle and tissue are gone, a bone is potentially subject to numerous natural processes that can adversely affect the integrity of both its outer surface and internal structure (Behrensmeyer, 1978; Behrensmeyer *et al.,* 1986; Lyman, 1994). For example, exposure to extreme temperatures, adverse weather (*e.g.,* rain, snow, sleet, hail), wind-blown particles, and other processes, can cause cracking, exfoliation, erosion, and other damage to the bone surface, beginning within a few years, or perhaps even a matter of months, after death, depending on the depositional environment (Behrensmeyer, 1978; Fernandez-Jalvo and Andrews, 2016). As long as the bone remains unburied and exposed on the surface, the damage will become increasingly severe and complete decomposition of the bone may occur in ~10-15 years in some ecosystems (Behrensmeyer, 1978). Animal trampling, and fluvial/alluvial (*i.e.,* waterborne), aeolian (*i.e.,* windborne), and colluvial (*i.e.,* gravity-borne) transport may also cause smoothing, polish, sheen, and/or abrasion on the outer

surface of the bone, as well as other changes to its original shape and/or structure (Behrensmeyer *et al.,* 1986; Lyman, 1994; Fernandez-Jalvo and Andrews, 2016). Furthermore, even after a bone is buried, extreme temperatures, soil pH conditions, root and insect activity, calcium-carbonate formation, and other processes may result in etching, pocking, staining, or other damage that can further obscure or destroy the surface and weaken the bone (Thompson, 2005; Fernandez-Jalvo and Andrews, 2014).

The issue of bone surface preservation is important from an archaeological standpoint, because it has the potential to bias interpretations of human behavior. For example, bones that are heavily decomposed due to extended surface exposure may be more susceptible to natural post-depositional fragmentation than others from the same site that were buried rapidly and are much better-preserved overall (Marean *et al.,* 2000). Similarly, human and carnivore modifications are less likely to be distinguishable, and may even be completely destroyed, on bones with surfaces that are severely degraded (*e.g.,* cracked, exfoliated, eroded) and/or otherwise obscured (*e.g.,* covered in carbonate).

Thus, analyses of bone fragmentation and surface modification at an archaeological site must account for preservational factors in order to obtain an accurate picture of human behavior and distinguish between damage resulting from human activity and that attributable to non-human agents and processes. Additionally, frequencies of surface modification at a site where surface visibility and preservation are particularly poor across much of the assemblage are more likely to be artificially depressed than for a site where the majority of specimens are largely unaltered from their original state at the time of deposition. Therefore, meaningful comparisons between the two sites would likely require the analyst to account in some way for differential preservation between them, perhaps by examining relative, rather than absolute, proportions of surface modification at each site (Thompson *et al.,* 2017).

Given the above discussion, it is clear that investigation of attributes related to bone preservation is necessary to provide important contextual information about a fossil assemblage, including the depositional history of the bones and the timing of their burial. Such analyses can be used to document and even quantify the damage caused by the myriad of processes that may act on bones between their original deposition, subsequent burial, and eventual recovery (Gifford and Behrensmeyer, 1976; Behrensmeyer, 1978; Behrensmeyer *et al.,* 1986). Finally, and perhaps most importantly for this study, a detailed understanding of the nature and extent of bone preservation and degradation at archaeological sites is crucial to building robust interpretations of human behavior and ensuring that comparative analyses between sites are reliable and provide meaningful results (Lyman, 1994).

Thermal alteration of bone

Analysis of burned bone is another potentially useful tool for understanding both natural processes and human behavior at archaeological sites (Lyman, 1994). Burning weakens bones, making them more susceptible to natural destruction, and can obscure or completely delete surface modification marks (Marean *et al.,* 2000; Clark, 2009). Thus, if extensive burning is documented across large portions of an assemblage, it is important to consider this fact when analyzing and interpreting patterns of bone fragmentation, fracture morphology, post-depositional destruction, density-mediated attrition, and surface modification (Marean *et al.,* 2000; Thompson, 2008).

Information on the extent and severity of burning can also offer clues to whether or not it is produced by natural fires, human action, or both (Lyman, 1994). Natural brush fires are a common occurrence in the woodlands and grasslands of eastern Africa, and it is

safe to assume that this was also the case in the ancient past (Morley and Richards, 1993; Jacobs, 2004; Pausas and Keeley, 2009; Attwell *et al.,* 2015). The mere presence of burned bone at an archaeological site is therefore not necessarily direct proof of human activity, and could potentially also be due to natural causes (David, 1990; Lyman, 1994). Moreover, naturally-occurring fires may cause both carbonization and calcination of bone in many cases, particularly if bones are in an advanced state of decomposition, largely devoid of muscle and tissue, and/or in proximity to tree stumps, down wood, animal dung, or other material that may continue to burn or smolder long after the fire has moved through an area (Keough *et al.,* 2015; Alvarez *et al.,* 2017; L.C. Todd, personal communication). However, previous experimental work suggests that natural brush fires in grassland/woodland settings often move through a given area rather quickly and only burn hot and long enough to carbonize bone, but not to cause calcination (David, 1990; Buenger, 2003).

Conversely, at human residential sites, bone (and other refuse) may be disposed of in fire-pits and hearths and/or used as fuel for fires, resulting in exposure to very high temperatures for extended periods of time, which will eventually cause many fragments to become partially or fully calcined (Gifford-Gonzalez, 1989; Spenneman and Colley, 1989; David, 1990; Lyman, 1994; Thery-Parisot, 2002), Thus, although it is not necessarily unequivocal proof, the presence of calcined bone is nonetheless often a reliable indication of human activity at a site, particularly when combined with other lines of evidence for human involvement (David, 1990; Lyman, 1994). Additionally, if thermal alteration is the result of human activity, the spatial distribution of burned bone (and chipped stone) may also be useful for identifying the presence of hearths, cooking features, and/or other specific activity areas within the site (Stewart and Gifford-Gonzalez, 1994; Cain, 2005; Blasco *et al.,* 2015).

Bone fragmentation and fracture morphology

Humans often fragment the bones of terrestrial fauna in order to extract nutrient-rich marrow from the medullary cavities of long bones, as well as bone grease and fat from long bone epiphyses and other spongy elements (Binford, 1978, 1981; Gifford-Gonzalez, 1989). Human-produced sites, and particularly residential camps, are therefore often characterized by a high degree of fragmentation and correspondingly high frequencies of non-identifiable bone fragments (Gifford-Gonzalez, 1989). Human-induced fragmentation is often focused on breaking open long bone shafts to access marrow contained within the medullary cavity, so human sites typically have an abundance of small long bone midshaft fragments and relatively few tubular long bone fragments that retain half or more of the original shaft circumference (Bunn, 1983; Gifford-Gonzalez, 1989).

Data from sites produced by a variety of carnivores, including brown and spotted hyaenas, leopards, wolves, and domestic dogs, indicate that carnivore assemblages may also be quite fragmentary, although in many cases the patterns of fragmentation differ from those at human sites (Binford, 1981; Brain, 1981; Gifford-Gonzalez, 1989; Marean and Spencer, 1991). These differences occur because bone-crushing carnivores, such as hyaenas and canids, often preferentially target grease, fat, and soft tissue in long bone epiphyses and do not destroy long bone midshafts to the same extent as humans (Bunn, 1983; Gifford-Gonzalez, 1989). The level of overall bone destruction is also typically not as high at carnivore kill sites, particularly in the case of species whose masticatory apparatus is designed primarily for defleshing bone (*e.g.,* lions, leopards, cheetahs), since they do not have the same capacity to access within-bone nutrients as "bone-crushing" hyaenas and canids (Gifford-Gonzalez, 1989). As such, carnivore sites are often characterized by a higher frequency of identifiable fragments overall, lower frequencies of long bone epiphyses and articular ends, and relatively high frequencies of tubular long bone

shaft fragments that retain more than half of the original shaft circumference (Binford, 1978; Bunn, 1983; Gifford-Gonzalez, 1989).

Non-human processes (*e.g.,* trampling, soil compaction, fluvial transport) can also result in destruction of bone, and therefore must also be accounted for in analyses of bone fragmentation (Behrensmeyer *et al.,* 1986; Olsen and Shipman, 1988; Dominguez-Rodrigo *et al.,* 2009, 2010). Patterns of long bone fracture end morphology are particularly useful in this respect, because the morphology of breaks typically differs between bones that were broken fresh as a result of nutritive destruction and those broken while dry as a result of non-nutritive destruction (Villa and Mahieu, 1991; Outram, 2002). More specifically, the fracture ends of bones broken while fresh tend to have oblique (*i.e.,* acute or obtuse) angles and curved or v-shaped outlines, while dry bone breaks commonly display right angles and transverse outlines (Villa and Mahieu, 1991). There are several other "intermediate" fracture angle and outline types that may occur, but generally speaking, examining the frequencies of oblique and curved/v-shaped versus right and transverse breaks can provide a reliable measure of the relative amounts of nutritive versus non-nutritive bone destruction at a site (Villa and Mahieu, 1991; Outram, 2002).

Density-mediated attrition and post-depositional destruction

Previous work has demonstrated that the potential for bones to survive the myriad of taphonomic processes to which they are subject between the time of their original deposition and later discovery is influenced in part by the structural density of the element in question (Lyman, 1984, 1994). More specifically, this work has shown that bones or bone portions with lower mineral densities are more susceptible to attrition by both nutritive and non-nutritive destructive forces, while those with higher densities are more resistant to such destruction (Lyman, 1994). Thus, with respect to taphonomy, elements

and portions composed largely of more porous cancellous bone (*e.g.,* long bone epiphyses, vertebral centra, pelves) are more likely to be destroyed by non-nutritive processes such as trampling, sediment compaction, and chemical erosion than elements composed of denser cortical bone (*e.g.,* long bone shafts). Similarly, long bone midshafts, which contain the densest cortical bone, are more likely to survive intact than near epiphysis shafts, which are typically thinner and less dense (Lyman, 1984; Lam *et al.,* 1998, 1999). Examining the relationship between bone mineral density (BMD) and skeletal element/portion representation can therefore provide a means of assessing the nature and extent of density-mediated bone attrition at archaeological sites, particularly among terrestrial mammals, for which there are now published bone density values for multiple taxa (*e.g.,* Lyman, 1984: deer, pronghorn antelope, domestic sheep; Kreutzer, 1992: bison, deer; Lam *et al.,* 1998, 1999: domestic goat, blue wildebeest; Pickering and Carlson, 2002: baboon, domestic sheep).

Analyses of bone fragmentation patterns among the compact bones (*i.e.,* carpals, tarsals, sesamoids, phalanx 3, patella) of terrestrial mammals offers an additional avenue by which to investigate the severity of post-depositional bone destruction (Marean, 1991; Villa *et al.,* 2012). Compact bones are small and quite dense, and they generally contain very little nutritive content in the way of marrow or bone grease that would be of interest to humans and carnivores (Binford, 1978; Marean, 1991; Lyman, 1994). These elements are also usually situated far enough away from other muscle- and marrow-bearing portions that they are unlikely to be damaged in the process of, for example, hammerstone percussion of metapodials for marrow removal (Marean, 1991). Thus, carpals, tarsals, and other compact bones are rarely fragmented by humans, either purposefully or incidentally (except, perhaps, in cases of severe resource stress), and are also often largely ignored by carnivores (although they are sometimes swallowed whole by larger carnivores), so

fragmentation of these elements should primarily track the degree of natural post-depositional destruction that has occurred at a site (Marean, 1991).

Human and carnivore activity

Bone surface modification

Data about the frequency and placement of cut, percussion, and tooth marks offer one of the most reliable means to distinguish between humans and non-human carnivores as the primary agents of faunal modification, and to identify sequences of carcass access at a site (Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Dominguez-Rodrigo, 1997; Marean *et al.*, 2000). In order to determine the primary agent(s) of faunal accumulation and modification for a given site, it is common for researchers to compare the proportions of human and carnivore-modified bone from archaeological sites to those from actualistic and/or experimental assemblages with known (or confidently inferred) taphonomic histories (*e.g.,* Marean *et al.,* 2000; Thompson, 2010; Thompson and Henshilwood, 2011). In the case of experimental data, several types of scenarios have been modeled to replicate different sequences of access to carcasses by humans and carnivores: 1) humans only (HO), 2) humans-then-carnivores (H-C), 3) carnivores only (CO), 4) carnivores-then-humans (C-H), and 5) carnivores-then-humans-then-carnivores (C-H-C) (Blumenschine, 1995; Dominguez-Rodrigo, 1997; Capaldo, 1998; Selvaggio, 1998).

H-C experimental scenarios involve humans fileting fully-fleshed bones for meat and/or using hammerstones to process defleshed long bones, after which the bones were given to carnivores to extract the remaining nutrients. Conversely, C-H situations consisted of humans using cutting tools and/or hammerstones to extract whatever nutrients were left behind after bones were first defleshed and otherwise processed by carnivores. HO and CO

experiments consisted of all the same actions, but with only one modifying agent in each case, instead of two. Scenarios in which carnivores had initial or secondary access to bones were modeled using several different mammalian carnivores with different feeding ecologies that would be expected to result in distinct patterns of surface modification on the remaining carcass parts (*e.g.,* bone-crushing hyaenas can extract both within- and outside-bone nutrients, whereas lions generally only consume muscle and tissue from the outside of bones) (Blumenschine, 1988; Capaldo, 1995, 1998; Dominguez-Rodrigo, 1997; Marean *et al.,* 2000). For all experiments, detailed observations were made of the frequency and location of cut, percussion, and/or tooth marks on bones. These observations were then used to build models for each type of scenario and develop criteria concerning the frequency and placement of marks that one might expect to find in the archaeological record based on the primary accumulator of a site and the order in which hominins and carnivores accessed the faunal remains (Blumenschine, 1988; Capaldo, 1995, 1998; Dominguez-Rodrigo, 1997; Selvaggio, 1998; Marean *et al.,* 2000).

However, subsequent authors have noted some limitations regarding direct comparisons of experimental and archaeological datasets (Thompson *et al.,* 2017). First, because most of the experimental datasets only included bone fragments > 2 cm in maximum length, using this cutoff point greatly reduces the number of specimens available for comparison with many archaeological assemblages, sometimes to the point of significantly diminishing the reliability of statistical analyses (Thompson *et al.,* 2017). Previous work has also demonstrated that extensive bone fragmentation, which is not uncommon at MSA sites (*e.g.,* Assefa, 2002; Thompson, 2008; Clark, 2009), can artificially deflate the frequency of surface modification in an archaeological assemblage by increasing the number of bone fragments while the number of marks (which was fixed at the time the bones were discarded) stays constant (Bartram, 1993; Abe *et al.,* 2002).

Additionally, marks on archaeological specimens may be obscured or destroyed as bone is degraded and/or lost, further reducing the number of identifiable marks relative to bone fragments (Abe *et al.,* 2002). This "fragmentation problem" can bias estimates of surface modification frequency derived from both the number of modified specimens and individual marks, and has been shown to depress relative frequencies of surface modification in analytical methods that rely on NISP, MNE, MNI, and MAU to quantify surface modification frequencies (Abe *et al.,* 2002).

Given the above discussion, it follows that direct comparisons between archaeological and experimental assemblages may not be appropriate in many cases without first accounting for differential fragmentation and other taphonomic processes to which archaeological sites are subject. Previous authors have developed several methods to compare surface modification across differentially fragmented specimens and assemblages, including comparing the total number of cut marks per 1000 mm^2 of bone surface area (*e.g.,* Rapson, 1990) and the use of a GIS program that corrects cut mark frequencies by the total amount of bone surface area analyzed (Abe *et al.*, 2002). Yet, Thompson *et al.* (2017) have also demonstrated that simply examining the relative proportions of human and carnivore modification offers an effective, and much more straightforward, way to compare experimental assemblages to archaeological sites where modification frequencies may be depressed for various reasons (Thompson *et al.,* 2017).

Long bone midshaft fragments are particularly informative in this respect because long bones contain large and relatively easy-to-access packages of muscle tissue, marrow, and/or bone grease that are of interest to both humans and carnivores. When humans have first access to a carcass, long bone shafts are a primary location for cut and percussion marks created during defleshing and marrow extraction (Blumenschine, 1988; Capaldo, 1995, 1998; Dominguez-Rodrigo, 2002). Carnivores also target the muscle tissue and

marrow from long bone shafts at fresh kills (*i.e.,* when they have first access) and typically leave behind high frequencies of tooth marks on midshafts and shaft fragments in the process. Conversely, when scavenging human kill sites where most of the nutritive content has already been removed from long bone shafts, there is usually little incentive for carnivores to substantially modify these elements further (Blumenschine, 1988; Capaldo, 1995, 1998; Selvaggio, 1998). Moreover, it is well-documented that in both first-access and scavenging situations, bone-crushing carnivores often preferentially target the grease-rich epiphyseal ends of long bones (which are often not processed by humans), differentially deleting these portions from a site. Thus, long bone shafts and shaft fragments are often the bulk of what is left behind by both humans and carnivores, and can provide reliable information about the primary faunal accumulator and sequences of carcass access at a site (Blumenschine and Marean, 1993; Thompson *et al.,* 2017).

Finally, previous work has also shown that patterns of stone-tool cut mark placement can be used to distinguish between different butchery processes in the archaeological record (*e.g.,* Binford, 1981; Nilssen, 2000; Dominguez-Rodrigo, 2002). Evisceration is often the first activity undertaken when an animal is butchered, and involves removing the organs from the abdominal cavity (Nilssen, 2000). Rib shafts are the most common location for marks produced during evisceration, but these may also be found on the bodies and processes of cervical and thoracic vertebrae. Removal of the animal hide during skinning may further result in cut marks on mandibles, metapodials, tarsals, and other elements that are in close proximity to the hide without a substantial barrier of muscle or other tissue in between (Binford, 1981; Nilssen, 2000).

Disarticulation involves separation of two adjoining skeletal parts and generally produces cut marks on the epiphyseal and near epiphyseal portions of long bones, as well as vertebrae, ribs, crania, and mandibles (Binford, 1981; Nilssen, 2000; Dominguez-

Rodrigo, 2002). Additionally, cut or chop marks may also be left on carpals and tarsals during the process of disarticulating distal limb segments (Nilssen, 2000). Defleshing (or fileting), which refers to the removal of muscle and tissue from long bones, often results in marks that are concentrated along the midshafts of long bones. These may include both cut marks from initial meat removal, as well as scrape marks from removing periosteum and leftover scraps of tissue from bones that are already largely defleshed (Binford, 1981; Dominguez-Rodrigo, 1997, 2002; Nilssen, 2000).

Faunal transport strategies

Analysis of skeletal part abundances and the relationships between element representation and economic utility can offer additional information to help elucidate patterns of prey selectivity, butchery practices, and faunal transport behavior by humans and carnivores in the past (Binford, 1978, 1981; Bunn, 1986; Bunn and Kroll, 1986; Metcalfe and Jones, 1988; Marean and Cleghorn, 2003; Cleghorn and Marean, 2004; Faith and Gordon, 2007). Ethnographic work by Binford (1978, 1981), as well as later reanalysis of Binford's data by Metcalf and Jones (1988; Jones and Metcalf, 1988), documented close relationships between faunal transport-discard decisions and the economic value of skeletal parts among modern foragers. This realization, in turn, led to the development of a series of economic utility indices, whereby skeletal parts are assigned a scaled rank based on their nutritive content and/or anatomical position, for use in interpreting faunal transport behavior in the past. More specifically, Binford (1978) and Metcalf and Jones (1988) posited that different patterns of correlation between utility indices and element abundance could be used to identify distinct modes of faunal butchery and transport-discard behavior in the archaeological record.

However, more recent work by Faith and Gordon (2007) suggests caution in using correlation alone to interpret transport strategies. These authors posit using Shannon's evenness index (*e* – see below for a more detailed discussion of *e* and how it is calculated for the taxonomic groups in an assemblage) as an additional and more reliable way to distinguish between four different types of faunal transport strategy: "gourmet," "bulk," "unbiased," and "unconstrained" (Faith and Gordon, 2007). Each strategy models a situation where hypothetical foragers make different decisions about the quality and quantity of parts to transport away from a kill site, which lead to assemblages at both kill-butchery sites (where parts are discarded) and residential sites (to which transported parts are taken) characterized by different distributions of high-, medium-, and low-utility skeletal elements in each case. Importantly, this also results in each strategy being associated with a (mostly) unique range of evenness values that can be used to distinguish it from all of the others (Faith and Gordon, 2007). As such, analyses that incorporate evenness values, as well as correlations between element abundance and utility indices, can provide reliable information regarding faunal transport behavior in the past.

Fish taphonomy

As with terrestrial fauna, investigating the taphonomy of fossil fish bones is a crucial first step in understanding how fish bones arrived at a site and the various processes they were subject to before and after being deposited there (Colley, 1990; Butler, 1993). However, much of the work discussed above focused specifically on terrestrial fauna (and mostly mammals), and taphonomic analysis of fish bones is not always directly analogous to that of terrestrial vertebrates. This is because there are a number of factors specific to the circumstances of fish bone deposition and preservation at both human and natural (*i.e.,* non-human) sites which are not a concern, or at least not as much of one, for terrestrial

fauna (Elder and Smith, 1988; Stewart, 1989; Colley, 1990; Butler, 1993; Cutler *et al.,* 1999; Zohar, 2003). Depending on the depositional and burial environment (*e.g.,* riverine versus lacustrine versus coastal/marine; littoral versus open-water; main channel versus floodplain), these issues can include the depth and temperature of the water, levels of salinity and oxygenation, and/or movement by tides or flowing currents (Zohar, 2003). Likewise, there are differences in bone composition and structure between fish and terrestrial vertebrates, which warrant caution in assuming that the same criteria used to assess surface preservation in terrestrial fauna are also directly applicable to fish (Gifford, 1981; Elder and Smith, 1988; Stewart, 1989, 1991; Colley, 1990; Butler, 1993; Belcher, 1998; Zohar *et al.,* 2001; Zohar, 2003; Willis *et al.,* 2008; Willis, 2014).

In some lacustrine environments, fish bone can become completely fossilized in only a few hundred years, which is much faster than would typically be expected for mammal bones deposited on the ground and eventually buried in a terrestrial setting (Stewart, 1989). Additionally, Gifford (1981) and Gifford-Gonzalez *et al.* (1999) have shown that, when left exposed on the surface in terrestrial environments, fish bones often weather more heavily and degrade faster than mammal bones in similar conditions. It is also fairly common for fish bones from archaeological sites to take on a dark coloration and even bone that has not been exposed to fire is often stained brown, dark brown, or black, making it difficult to discern the early stages of burning in particular (*i.e.,* carbonization) on the basis of color alone (Stewart 1989; Zohar, 2003). Given these considerations, it is apparent that taphonomic data collection systems designed specifically for terrestrial fauna, and primarily terrestrial mammals, may not be entirely appropriate for assessing taphonomy in an assemblage of fossil fish bones (Stewart, 1989; Zohar, 2003; Willis, 2014).

Several authors have modified existing recording systems for terrestrial fauna to make them more applicable to fish and developed new criteria to examine similar taphonomic attributes specifically in fossil fish assemblages (*e.g.,* Stewart, 1989; Zohar, 2003). In her study of Holocene fishing sites around Lake Turkana, Stewart (1989) found that the weathering stages developed by Behrensmeyer (1978) for mammal bone were not appropriate for the Turkana fish bones. As such, Stewart (1989) developed a new set of weathering categories based on criteria more specific to the conditions of fish bone deposition and preservation. The new categories focused on whether or not fish bones: 1) displayed evidence of "clay-shattering", such as friability, crumbling, or cracking, caused by preservation in constantly expanding and contracting soils, 2) exhibited smoothing, polish, and/or rounded edges indicative of significant post-depositional transport, or 3) appeared fresh and to have been largely undisturbed following their initial deposition (Stewart, 1989). Stewart (1989) also developed a "Stain Index" based on the outward color of the bone, which can be used to further examine the depositional history and context of fish bones. Bones deposited around the same time and under similar conditions will typically be of a similar color, while more heterogeneous patterns of coloration (*i.e.,* staining) suggest different depositional episodes and/or contexts for the bones in question. Additionally, bones deposited and buried rapidly tend to be darker in color, while those exposed to more subaerial weathering are often lighter colors (Stewart, 1989).

Stewart (1989) also discusses the potential difficulty in distinguishing between carbonization and manganese-oxide staining, both of which are expected to produce a range of colors between dark-brown and black similar to that from lower-level burning, on fossil fish bone. Interestingly, the single fish fossil that she had chemically tested, which was black and very similar in color to charred terrestrial mammal bone, was found to have levels of manganese thousands of times higher than a light-colored recent fish bone that

was clearly unburnt (Stewart, 1989). These data suggest that the black coloration on the fossil resulted from manganese-staining rather than burning, despite the fact that the specimen would almost certainly be classified as carbonized based on the visual criteria often used to identify burning on terrestrial animal bones (Stewart, 1989). Zohar (2003) notes a similar problem at the site of Ohalo-II (~23 ka), located just off the southern shore of Lake Kinneret (*i.e.,* the Sea of Galilee) in Israel, where the black coloration of many fish bones is likely due to their preservation in an oxygen-rich lacustrine environment, making it virtually impossible to definitively determine if bone is carbonized, stained, or both, on the basis of color alone (Zohar, 2003). Moreover, there is no reason to assume that this problem is isolated to the lacustrine sites studied by Stewart (1989) and Zohar (2003), and it almost certainly extends to sites in both riverine and coastal environments, as well.

Alternatively, calcined bone is relatively easy to identify in both fish and terrestrial vertebrates because calcination produces characteristic gray, blue, and/or whitish coloration, and in later stages the bone often becomes pure white with a chalky texture (Shipman *et al.,* 1984; David, 1990; Zohar, 2003). As discussed above, although natural fires can also result in high frequencies of intensively burned bone (Keough *et al.,* 2015; Alvarez *et al.,* 2017), calcination is often an indication of human activity because many natural fires do not burn hot or long enough to calcine bones (David, 1990; Buenger, 2003). Thus, assuming the time and funding are not available for extensive laboratory testing of dark-colored fish bones for evidence of heating, focusing specifically on identification of calcined bone is a simple and effective way to assess burning and potential human involvement in an assemblage of fossil fish bones (Zohar, 2003).

As with terrestrial fauna, data on the nature and extent of bone fragmentation among fish can also offer insight into the processes of site formation, including the degree of post-depositional destruction and human foraging behavior at archaeological sites

(Zohar, 2003). Once again, many of the criteria used to investigate patterns of fragmentation in terrestrial fauna, such as fracture angle and outline morphology and long bone shaft circumference, are obviously not appropriate for fish bones. However, analyses of maximum specimen lengths and fragment size categories can be used in a similar capacity for fossil fish. Additionally, indices of fragmentation and survivorship developed specifically to measure specimen completeness and compare overall levels of preservation for fossil fish bones, can be used to gain a more detailed understanding of fragmentation and the extent of natural post-depositional destruction in a fossil fish assemblage (Zohar *et al.,* 2001, 2008; Zohar, 2003).

Distinguishing natural versus cultural fish assemblages

Analyses of taxonomic representation, skeletal part abundance, bone fragmentation, burning, and surface modification can offer important insight into whether an assemblage of fossil fish results from human behavior or natural (*i.e.,* non-human) processes (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994; Zohar, *et al.,* 2001; Zohar, 2003). In their study of natural fish bone accumulations and modern fish camps around Lake Turkana, Stewart (1989, 1991), Stewart and Gifford-Gonzalez (1994), and Gifford-Gonzalez *et al.* (1999) found that lakeshore assemblages of naturally-accumulated fish tended to have high taxonomic diversity, with species represented in proportions roughly similar to their natural abundances in modern Lake Turkana. Zohar (2003; Zohar *et al.,* 2008) also observed high species diversity in natural fish bone assemblages that were excavated from multiple 0.5 m^2 units along the shoreline of Lake Kinneret in Israel, although values did tend to decrease with excavation depth and were lowest in the deepest layer of the excavated area.

Conversely, Dassanetch fish camps and fish processing sites around Lake Turkana typically had much lower levels of taxonomic diversity than the natural shoreline assemblages, reflecting the fact that human fishing practices were often selective and focused on a limited range of species (Stewart, 1991; Stewart and Gifford-Gonzalez, 1994). Similarly, Prendergast and Beyin (2018) note that, although there are 33 fish genera in modern Lake Turkana, archaeological assemblages from late Pleistocene and Holocene sites around the lake tend to be dominated by various combinations of only six of these genera: *Clarias, Bagrus, Synodontis, Oreochromis, Lates,* and *Labeo*. Once again, this likely results from humans targeting particular species with ecological and biological preferences (*e.g.,* living in shallow water, spawning on the floodplain) that made them an attractive and reliable food source (Stewart, 1989, 1991; Prendergast and Beyin, 2018).

Other authors have noted that taxonomic diversity at human fishing sites can actually be rather variable and, depending on the ecological setting and method of fish capture, may be quite high in some cases (Van Neer, 1995; Zohar *et al.,* 2001; Zohar, 2003). For example, groups that regularly exploit both open-water zones and near-shore habitats will likely have access to a wider range of species, and therefore produce assemblages that are more diverse, than groups that primarily capture fish nearshore or on the flood plain (Van Neer, 1995). It is also possible for a natural assemblage to have very low taxonomic diversity (Zohar *et al.,* 2001), as might be expected in the case of an environmental change (*e.g.,* sudden increase in salinity) that causes a natural die-off, but only affects a limited range of species (*e.g.,* those with a low tolerance for highly saline water conditions). Nonetheless, the general expectation is that human sites should have relatively low taxonomic diversity compared to natural accumulations (Stewart, 1989; 1991; Stewart and Gifford-Gonzalez, 1994).

The fact that humans often preferentially target particular species also tends to create assemblages in which the proportions of species are quite different from their actual abundance in the natural fish community (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994; Gifford-Gonzalez *et al.,* 1999). For example, at several modern fish camps and archaeological sites around Lake Turkana, ~60-90% of the fish are *Clarias* and/or *Lates,* but these genera combined account for < 20% of the fish in the modern lake (Stewart, 1989, 1991; Prendergast and Beyin, 2018). Alternatively, cichlids, which represent ~40-50% of the fish in the modern lake, make up no more than 25% of the fish at many of the human fishing sites, and are quite rare or completely absent at some of them (Stewart, 1989, 1991; Prendergast and Beyin, 2018). This contrasts with natural scatters of recent and fossil fish bones collected from both sides of the lake, in which *Clarias* and *Lates* are less dominant and cichlids are present in all cases, although it should be noted that *Clarias* and *Lates* are still over-represented (~20-50% of MNI combined) and cichlids under-represented (~20-30% of MNI) in the natural accumulations (Stewart, 1991; Prendergast and Beyin, 2018).

At the Lake Turkana sites, Stewart (1989, 1991) also observed that bone scatter frequency (BSF: total number of fish bones/m^2) was typically much higher at human-produced sites than it was in natural accumulations. For example, BSF at AS1, a dedicated modern fish processing site, was 6.01 bones/m^2, while BSF for the natural lakeshore bone scatters of PS1 and PS2 were 0.11 and 0.03 bones/m^2, respectively. Similarly, BSF for the archaeological site of FxJj12 (~9.5-8.3 ka) averaged ~4 bones/m^2 for all the excavated and surface-collected units, while the mean BSF for all levels from the site of Ishango 11 (~20-25 ka) was 107.6 bones/m^2. Moreover, even if two layers with unusually high densities of 407.1 and 134 bones/m^2 are excluded, the remaining levels at Ishango 11 still have an average BSF of 42.5 bones/m^2 (Stewart, 1989). However, investigation of additional sites

around Lake Turkana did document that BSF at modern fish camps was low and basically indistinguishable from that of a natural bone scatter in ~30% of cases (Stewart and Gifford-Gonzalez, 1994).

Zohar (2003) also found that low BSF could not be used to differentiate between natural and cultural fish remains at Lake Kinneret, although in this case it was because the natural shoreline assemblage had a very high mean BSF of 423 bones/m^2 for all the excavated units. Thus, in many cases, BSF alone is not sufficient to distinguish between human versus naturally-derived fish remains (Stewart and Gifford-Gonzalez, 1994; Zohar, 2003). Yet, when combined with other evidence of human activity (see below), a high BSF (*i.e.,* 1+) is nonetheless a potential indicator of human agency in accumulating fossil fish (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994; Gifford-Gonzalez *et al.,* 1994).

Patterns of skeletal part representation can also be helpful in determining whether or not an assemblage of fossil fish bones is more likely to be cultural or natural (Stewart, 1989, 1991; Belcher, 1998; Gifford-Gonzalez *et al.,* 1999). Patterns of skeletal element abundance at human sites often differ substantially from element proportions in a complete skeleton, although how these differences are manifest may vary depending on the function of the site (Stewart, 1989, 1991; Gifford-Gonzalez *et al.,* 1999). At temporary fish processing sites around Lake Turkana, fishermen often decapitated and consumed the heads of larger fish before transporting the rest of the body back to base camps (Stewart, 1989, 1991). Accordingly, decapitated bodies of large fish were more likely to be introduced to temporary and semi-/permanent base camps, while small-to-medium-sized fish were often transported back to these sites whole (Stewart, 1989; 1991; Stewart and Gifford-Gonzalez, 1994).

Thus, processing sites in the archaeological record might be expected to have high frequencies of cranial elements (*e.g.,* neurocrania, opercula, hyoids) and vertebrae (at least

some of which are typically removed during decapitation), particularly of larger and heavier fish, and relatively low frequencies of postcranial elements (*e.g.,* spines, fins). Archaeological base camps, in turn, may have high frequencies of both cranial and postcranial elements, or high frequencies of postcranial elements and a relative paucity of cranial bones (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994). In all cases, the pattern of skeletal representation contrasts with natural accumulations, which are expected to contain elements in proportions that are more similar to a complete skeleton, particularly for larger fish and species with robust skeletons (Stewart and Gifford-Gonzalez, 1994).

Data on bone fragmentation can provide further important information regarding both human behavior and the degree of natural post-depositional destruction in an assemblage of fossil fish (Zohar, 2003). Levels of bone fragmentation are often more extensive at human sites than at sites resulting from natural fish die-offs. In their excavations of naturally-occurring fish bone along the beaches of Lake Kinneret, Zohar *et al.* (2008) found that, on average, just over half of the bones were between 91-100% complete in all three of the lithofacies (*i.e.,* stratigraphic units) they defined. Moreover, in all three lithofacies, more than 80% of bones were at least 70% complete (Zohar *et al.,* 2008). Conversely, Stewart (1991) and Gifford-Gonzalez *et al.* (1999) note that heavy fragmentation is often distinctive of human-produced sites around Lake Turkana. This is particularly true with respect to catfish brain cases, for example, which were fragmented 50% of the time on average at fish camps, compared to fragmentation of only 2% of braincases in natural shoreline scatters (Stewart, 1991).

With respect to measuring post-depositional destruction, it is often informative to examine the relationships between fish bone fragmentation, survivorship, and measures of taxonomic abundance (Zohar *et al.,* 2001; Zohar, 2003). More specifically, correlation (positive or negative, depending on the measures of each variable that are employed – see

Chapter 6) between the extent of fragmentation, bone survivorship, and taxonomic abundance, is the expectation for sites where natural destruction of fish bone is extensive (Zohar *et al.,* 2001). High levels of post-depositional (*i.e.,* non-nutritive *and* non-selective) destruction, in turn, better fit the pattern for naturally-accumulated fish bones (Zohar *et al.,* 2001; Zohar, 2003). Alternatively, human fragmentation of fish is generally expected to be more intentionally directed and to differentially affect some elements (*e.g.,* neurocrania) over others (*e.g.,* fins). (See Chapter 6 for additional discussion of these relationships, with reference to the specific indices that are used to assess them in this study.)

As with terrestrial fauna, signs that indicate human activity either on or in association with fossil fish remains are obviously also useful for distinguishing between natural and human-created sites (Stewart, 1989, 1991; Butler, 1993, 1996; Belcher, 1998; Gifford-Gonzalez *et al.,* 1999; Zohar *et al.,* 2001, 2008; Zohar, 2003; Willis *et al.,* 2008; Willis, 2014; Willis and Boehm, 2014). This includes close spatial association of fish bones with abundant chipped stone and other artifacts, which is a fairly strong signal of human involvement, particularly if the material is extensively intermingled throughout a site. The presence of human cut and/or percussion marks is an unequivocal indication that humans caught and/or processed fish, as well (Stewart, 1989, 1991; Gifford-Gonzalez *et al.,* 1999; Willis *et al.,* 2008; Willis and Boehm, 2014). Much like terrestrial fauna, previous work has also shown that the placement of human-induced modification can be used to differentiate between butchery practices (Stewart, 1989, 1991; Belcher, 1998). Finally, the presence of burned bone can also be used to identify human involvement in accumulating fish bones. Once again, this is particularly true for calcined bone, given both the potential difficulty in distinguishing between staining and carbonization on fish bones (see above), and the fact that calcination is potentially a less ambiguous signal of human activity than carbonization (Stewart, 1989; David, 1990; Lyman, 1994; Zohar, 2003).

Summary of analytical techniques

The concepts and methods outlined above have been developed and refined over the last several decades by researchers interested in using the remains of both terrestrial and aquatic fauna to disentangle the complexly intertwined signatures of human and non-human agents at archaeological sites and reconstruct the lifeways of ancient humans. Taken together, these methods provide a strong foundation from which to evaluate site formation processes and the taphonomic history of SM1, and to build robust interpretations of MSA human behavior at the site.

RESEARCH QUESTIONS AND HYPOTHESES

This project uses terrestrial and aquatic faunal remains to understand site formation processes and reconstruct early human behavior at the primary study site, SM1. The faunal remains at SM1 are distributed across a limited aerial extent and through a well-defined archaeological sequence (see Chapter 4), which strongly suggests that many of the animals were human prey items. Yet, previous work at other sites has made clear that close association with archaeological material is not, in and of itself, sufficient to infer human agency in accumulating faunal remains (Lyman, 1994). Thus, the first and most basic goal of this dissertation is simply to determine if humans are responsible for introducing terrestrial and aquatic animals to the site. Assuming the fauna are largely human-collected, this project also aims to: 1) document overall terrestrial and aquatic foraging behavior at SM1; 2) determine if the site preserves evidence for early riverine adaptations and seasonally-structured foraging in the MSA; 3) determine if the site represents material from multiple episodes of occupation; and 4) understand how SM1 compares to other MSA sites that have been studied in similar detail. In order to achieve these goals, five hypotheses related to site formation and MSA foraging behavior at SM1 will be tested.

Hypothesis 1: Terrestrial and aquatic fauna at SM1 were primarily collected by MSA humans. Hypothesis 1 will test one of the most basic questions of any zooarchaeological analysis: Do the animal bones at the site represent the remains of human prey items? This is a fundamental question that must be answered before more detailed analyses of human behavior can proceed, and to determine if such analyses are even warranted.

Alternative to Hypothesis 1: The alternative to Hypothesis 1 is that non-human agents and processes (*e.g.,* natural death, carnivore activity, brush fires, trampling, soil compaction, alluvial/fluvial action) are responsible for accumulating the SM1 fauna, and for observed patterns of bone modification. If taxonomic and taphonomic data are found to better support the alternative, then investigation of subsequent questions about the foraging behavior of MSA humans at SM1 will not be warranted.

Expectations: If terrestrial and/or aquatic fauna are primarily human-accumulated, general expectations include: close association of faunal remains with archaeological material (*e.g.,* chipped stone artifacts, occupation features); the presence of cut and percussion marks (at varying frequencies, depending on the context); the presence of burned bone, and calcined specimens in particular; extensive fragmentation that is not due to natural post-depositional destruction; and low frequencies of carnivore tooth marks and other evidence for carnivore activity (*e.g.,* coprolites, carnivore remains) (Table 3.2). Other indicators that terrestrial fauna, specifically, are human-collected may also include high frequencies of epiphyseal and/or near epiphyseal fragments (depending on post-discard carnivore involvement), and midshaft fragments relative to near-epiphyseal fragments. Additionally, human-accumulated fish assemblages are expected to have: high BSF; taxonomic distributions that differ significantly from the natural fish community; skeletal element abundances that are substantially different from the proportions in a complete

Table 3.2 Expectations for terrestrial fauna and fish at sites created primarily by humans.

Evidence	Human sites	Expected for
Archaeological association	Yes	Terr. fauna and fish
Cut/percussion marks	Yes (varying frequencies)	Terr. fauna and fish
Tooth marks	No (or low frequency)	Terr. fauna and fish
Burned bone	High frequency	Terr. fauna and fish
Calcined bone	Yes	Terr. fauna and fish
Gastric etching	No	Terr. fauna and fish
Fragmentation	High overall	Terr. fauna and fish
Bone density and fragmentation	Not correlated	Terr. fauna and fish
Articular ends	High frequency	Terr. fauna
Midshaft fragments	High frequency	Terr. fauna
Fresh bone breaks	High frequency	Terr. fauna
Axial and compact bones	Variable	Terr. fauna
Carnivore remains	Low frequency	Terr. fauna (den sites)
Coprolites	No	Terr. fauna (den sites)
Bone scatter frequency	High	Fish
Taxonomic abundance	Differs from natural community	Fish
Taxonomic diversity	Lower than natural community	Fish
Skeletal representation	Differs from complete skeleton	Fish
Body size	Limited range	Fish

Sources: Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Stewart, 1989, 1991; Marean, 1991; Villa and Mahieu, 1991; Butler, 1993, 1996; Stewart and Gifford-Gonzalez, 1994; Capaldo, 1998; Gifford-Gonzalez *et al.*, 1999; Marean *et al.*, 2000; Zohar *et al.*, 2001, 2008; Pickering, 2002; Marean and Cleghorn, 2003; Villa *et al.*, 2004; Munro and Bar Oz, 2005; Clark, 2009

skeleton; limited taxonomic and body size diversity; high frequencies of cranial elements; and heavy fragmentation, particularly of cranial bones (Table 3.2) (Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Stewart, 1989, 1991; Villa and Mahieu, 1991; Butler, 1993, 1996; Stewart and Gifford- Gonzalez, 1994; Capaldo, 1998; Gifford-Gonzalez *et al.,* 1999; Marean *et al.*, 2000; Pickering, 2002; Villa *et al.*, 2004; Munro and Bar Oz, 2005; Willis, 2014).

Conversely, both terrestrial fauna and fish accumulated by carnivores and/or other non-human agents and processes are expected to lack archaeological associations, cut and percussion marks, intensive burning, and other evidence of human involvement (Table 3.3). In the case of carnivore kill or den sites, high frequencies of tooth marks are also expected and den sites, in particular, may have relatively high frequencies of carnivore remains (*i.e.,* ~20+% of MNI) and contain other evidence of carnivore activity, such as coprolites. Additionally, carnivore sites often have high frequencies of tooth-marked midshaft fragments, in particular, and low frequencies of epiphyseal fragments, articular ends, and axial elements (Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Capaldo 1998; Munro and Bar Oz, 2005).

Expectations for sites heavily impacted by natural post-depositional and density-mediated attrition of bone include: high frequencies of right angle and transverse outline breaks; negative correlations between BMD and fragmentation; positive correlation between BMD and element survival; low frequencies of "low-survival" elements (*e.g.*, vertebrae, pelves, ribs, scapulae); and heavy fragmentation of compact bones (*e.g.*, carpals, tarsals, phalanges). Naturally-accumulated fish bones are also expected to have: low BSF values; patterns of taxonomic representation and diversity similar to the natural fish community; higher taxonomic and body size diversity than human sites; skeletal part abundances similar to a complete skeleton; and correlations between fragmentation, bone

Table 3.3 General expectations for terrestrial fauna and fish at sites created primarily by carnivores and/or natural accumulations.

Evidence	Carnivore/Natural sites	Expected for
Archaeological association	No	Terr. fauna and fish
Cut/percussion marks	No (or low frequency)	Terr. fauna and fish
Tooth marks	Yes (varying frequencies)	Terr. fauna and fish
Burned bone	No (or low frequency)	Terr. fauna and fish
Calcined bone	No	Terr. fauna and fish
Bone density and fragmentation	Correlated for natural destruction	Terr. fauna and fish
Axial and compact bones	Low frequency	Terr. fauna
Articular ends	Low frequency	Terr. fauna
Midshaft fragments	Low frequency	Terr. fauna
Fresh bone breaks	High frequency	Terr. fauna
Carnivore remains	Yes	Terr. fauna (den sites)
Coprolites	Yes	Terr. fauna (den sites)
Bone scatter frequency	Low	Fish
Taxonomic abundance	Similar to natural community	Fish
Taxonomic diversity	Similar to natural community	Fish
Skeletal representation	Similar to complete skeleton	Fish
Body size	Wide range	Fish

Sources: Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Stewart, 1989, 1991; Marean, 1991; Villa and Mahieu, 1991; Butler, 1993, 1996; Stewart and Gifford-Gonzalez, 1994; Capaldo, 1998; Gifford-Gonzalez *et al.*, 1999; Marean *et al.*, 2000; Zohar *et al.*, 2001, 2008; Pickering, 2002; Marean and Cleghorn, 2003; Zohar, 2003; Villa *et al.*, 2004; Munro and Bar Oz, 2005; Clark, 2009; Willis, 2014

survivorship, and taxonomic representation (Table 3.3) (Stewart, 1989, 1991; Marean, 1991; Villa and Mahieu, 1991; Butler, 1993, 1996; Stewart and Gifford-Gonzalez, 1994; Gifford-Gonzalez *et al.,* 1999; Marean *et al.,* 2000; Zohar *et al.,* 2001, 2008; Pickering 2002; Marean and Cleghorn, 2003; Zohar, 2003; Villa *et al.*, 2004; Clark, 2009).

Hypothesis 2: MSA people at SM1 engaged in systematic riverine fishing and foraging behavior. Hypothesis 2 will test whether or not MSA foraging behavior at SM1 involved regular exploitation of riverine food resources. Although the focus will primarily be on analysis of the fish remains, the assumption is that, if support is found for regular riverine fishing, this activity was very likely part of a behavioral strategy that involved exploiting the mollusks that are also found at the site and perhaps other riverine food resources, such as reptiles and amphibians, as well.

Alternative to Hypothesis 2: The alternative to Hypothesis 2 is that regular riverine fishing and foraging were not part of the subsistence strategy of MSA humans at SM1. If the evidence is found to support the alternative hypothesis, the possible conclusions are that MSA people at SM1 either did not exploit riverine food resources at all, or that riverine foods were obtained opportunistically and largely at random, and did not form a substantial part of the resource base.

Expectations: For Hypothesis 2 to be supported, the expectation is that most or all of the criteria outlined above for Hypothesis 1 will strongly favor or unambiguously indicate humans as the primary accumulator of the fossil fish bones. Assuming a robust case can be made for humans accumulating the fish, the fact that fish and mollusks make up almost half of the presumed food items at SM1 can be taken as a strong indication that aquatic resources were an important part of the subsistence base for MSA humans, and one that was exploited on a systematic basis. Additionally, although the possibility seems rather

unlikely, if fish are found to be human-collected, but not terrestrial fauna, this will suggest that aquatic resources were *the* main food source for MSA people during the time(s) they occupied SM1 and that fishing was *the* primary foraging activity at the site. Conversely, results indicating that terrestrial animals, but not fish, are human-collected will support the alternative scenario that riverine fishing and foraging was not a regular part of the subsistence strategy of the SM1 people. Likewise, if analyses of the fossil fish are indeterminate, or document only very minimal human involvement in procuring fish, this may generally be viewed as providing better support for the alternative to Hypothesis 2.

Hypothesis 3: MSA foraging strategies at SM1 involved structured seasonal exploitation of dense and predictable riverine food resources during the dry season. Hypothesis 3 will test whether or not there is evidence that MSA people scheduled foraging activity and occupation of SM1 around the seasonal availability of fish, mollusks, and other riverine resources. For reasons that will be made clear in Chapters 4 and 6, this would strongly suggest that SM1 was often occupied specifically during the dry season in the late MSA.

Alternative to Hypothesis 3: The alternative to Hypothesis 3 is that riverine fishing and foraging behavior at SM1 was not tied to a specific season or time of year. If this is the case, one possible conclusion will be that site use at SM1 and the overall seasonal foraging round of the people who lived there were not structured around the availability of aquatic foods in the dry season. Finding support for the alternative would also suggest that fish, mollusks, and other aquatic fauna may have been captured at any time of year, perhaps opportunistically and largely at random.

Expectations: Hypothesis 3 will be supported if it can be established that people returned to SM1 regularly, but perhaps not exclusively, during the dry season. Answering

this question will require data on fish remains, bone fragmentation, and taxonomic and element abundances. Although documenting seasonal resource use in the past is difficult, each line of evidence can provide support for dry season habitation, which in turn may indicate structured seasonal resource use at SM1. Once again (and for reasons that will be explained further in Chapters 4 and 6), confirming that fish are human-collected will strongly imply dry season site use, because the geomorphology of the Shinfa River and extreme seasonality of rainfall in the region combine to make fishing highly impractical, if not impossible, during the wet season (Nachman *et al.*, 2011, 2015; Kappelman *et al.,* 2014; Tabor and Kappelman, 2014). Since the dry season is often a time of elevated resource stress in this part of eastern Africa (Speth, 1987), evidence for resource intensification in the form of increased dietary breadth, intensive marrow processing, and/or non-selective transport strategies may also support dry season site use (Table 3.4).

High frequencies of small and low-ranked prey are expected signs of increased diet breadth, while expected indicators of intensified marrow processing include extensive processing of small prey and elements with low marrow utility, and heavy processing of distal limb bones since the marrow reserves in these elements are the last to mobilize in resource-stressed ungulates (Speth, 1987; Outram, 2000; Munro and Bar-Oz, 2005). In terms of transport strategies, expected signs of intensification include high frequencies of low-ranked prey and low-utility elements that would typically be consumed or discarded at kill sites (Clark, 2009). Additionally, a non-selective transport strategy should result in all skeletal portions (*i.e.,* cranial, axial, and appendicular) being introduced into the site, and at roughly equal proportions to their abundance in a complete skeleton (Faith and Gordon, 2007).

Table 3.4 Potential lines of evidence and expectations that indicate resource intensification.

Evidence	Expectation	Reference(s)
Increased diet breadth	High frequencies of small and low-ranked prey	Munro and Bar-Oz, 2005
Intensive processing	Extensive fragmentation of all marrow- and/or grease-bearing bones, including low-utility elements and bones of small prey	Speth, 1987; Outram, 2000
Non-selective transport	High frequencies of low-ranked prey and low-utility elements; all skeletal portions represented	Faith and Gordon, 2007; Clark, 2009

Hypothesis 4: SM1 was a base camp and preserves evidence of multiple discrete episodes of occupation during the late MSA. Hypothesis 4 will test whether or not SM1 was a residential camp to which people returned repeatedly, and perhaps on a largely seasonal basis, in the late MSA. The rationale for this hypothesis is based in part on preliminary evidence, which will be discussed in Chapter 4 and suggests that there are multiple depositional layers present within the excavated levels of the site.

Alternative to Hypothesis 4: The presence of abundant chipped stone artifacts and other archaeological material and features preserved largely *in-situ* (see Chapter 4) rules out the possibility that humans were not involved in the process of site formation at SM1. As such, the only really viable alternative to Hypothesis 4 is that SM1 was a single-use site and therefore, by definition, does not contain material from more than one occupational event. If this idea is best-supported by the data, then it may follow that SM1 was a temporary camp or some sort of logistical site (*e.g.,* a large-scale kill and butchery site), where MSA people stopped for a few days at most before moving on and not returning. However, another possible conclusion may be that multiple occupations are present at

SM1, but that the material from them is extensively intermixed, making it difficult or impossible to reliably distinguish between the levels.

Expectations: For reasons detailed in Chapter 4, discrete stratigraphic or depositional layers were not defined for SM1 at the time of excavation, so it was necessary instead to define potential levels of interest *post-hoc,* based largely on the spatial distribution of material throughout the sediment column. In order to test the hypothesis of multiple episodes of occupation, four vertical analytical units that are proposed to represent discrete occupational layers were delineated for this study, and tested for independence using taphonomic variables (*i.e.,* frequencies of weathering, post-depositional damage, burning, fragmentation, and surface modification). The expectation here is that chi-squared tests will indicate significant differences between analytical units for many of the taphonomic attributes tested if they do, in fact, represent distinct depositional and occupational layers within SM1. Conversely, if all of the material at the site was deposited during a single occupation event, the expectation is that the taphonomic character of all four units (*e.g.,* frequencies of weathered versus unweathered bone, specimens with exfoliation, levels of fragmentation) should be largely similar overall, because this would suggest similar depositional and preservational conditions among the units. Chapter 4 provides additional detailed discussion on how the analytical units were defined and tested for independence.

Hypothesis 5: SM1 is unique among MSA sites, and particularly distinct from cave sites, with respect to taphonomic attributes that are important for interpreting early human behavior and foraging strategies. Hypothesis 5 will test whether or not aspects of bone preservation and modification at SM1 differ in meaningful ways from several other MSA open-air and cave sites in Ethiopia, Morocco, and South Africa. If SM1 is found to

be unique among the sites investigated, it will be of interest to examine if the differences relate to human behavior, depositional/preservational context, ecological setting, and/or other factors. Additionally, if SM1 is significantly different from the cave sites, in particular, this finding may suggest that the current comparative framework for using fauna and taphonomy to interpret MSA behavior, which is based largely on studies of South African cave sites (see above and below), is not entirely appropriate for SM1 and perhaps not for other open-air sites, as well.

Alternative to Hypothesis 5: The alternative to Hypothesis 5 is that SM1 does not differ substantially from other MSA sites with respect to taphonomy or human behavior. If the evidence is found to support this alternative conclusion, it obviously follows that subsequent investigation of potential reasons for dissimilarities between SM1 and comparative sites will not be necessary. Generally speaking, such a result may also imply that interpretive criteria developed from studies of cave sites are largely appropriate for open-air sites as well. At the very least, this finding would suggest that these criteria are directly applicable to SM1.

Expectations: The expectations here are straightforward. Support for Hypothesis 5 is expected in the form of chi-squared tests and/or other analyses that indicate statistically significant differences between SM1 and comparative sites for the taphonomic attributes of interest. With respect to the question of whether or not SM1 is unique among MSA sites overall, the more results that indicate significant differences between SM1 and comparative sites, the better the support for the position that this is indeed the case. Moreover, the idea that interpretive criteria based largely on cave sites are not directly applicable to SM1 will be supported if the SM1 fauna are found to have a clear human signature, but the site nonetheless differs significantly from the cave sites for attributes related to bone preservation and modification. A similar conclusion may also be indicated for open-air

sites in general if SM1 is found to be more similar to other open-air sites overall, and quite different from most of the cave sites for many of the taphonomic attributes being tested. Conversely, if the results of comparative analyses do not suggest significant differences between SM1 and comparative sites for any or most of the variables of interest, this will provide support for the alternative hypothesis.

MATERIALS AND METHODS

Testing the hypotheses outlined above will require a description of the faunal assemblage from SM1 and determination of whether or not the faunal remains were introduced by humans. Assuming human accumulation of both terrestrial and aquatic fauna, documentation of riverine foraging adaptations will rely largely on data from fish remains. Determination of structured seasonal (*i.e.*, dry season) occupation will require identifying seasonal signals, in the form of riverine fishing and foraging, and/or evidence for the types of resource intensification that might be expected during the dry season in this part of Africa. The materials and methods used to accomplish these tasks, as well as a basic outline of the analytical steps to be followed, are described below.

SM1 faunal assemblage

All specimens from SM1 were studied at the National Museum of Ethiopia, under the Authority for Research and Conservation of Cultural Heritage (ARCCH), in Addis Ababa. Zooarchaeological data from SM1 are derived from specimens collected during fieldwork at the site between 2002-2018. Material analyzed for this study includes most piece-plotted vertebrate specimens from controlled excavations in 2010, 2011, 2012, 2013, 2016, and 2018, water-screen material from the 2010-2018 excavations, and the majority

of excavated and surface-collected faunal specimens from preliminary investigations in 2002-2003 (Table 3.5). Water-screened items number in the tens of thousands, and much of the material remains largely unsorted, so the primary focus here was on material that was already pre-sorted into broad categories (*i.e.,* terrestrial vertebrate, fish, mollusk, chipped stone). An effort was made to obtain a representative sample of water-screened material, including specimens from all fieldwork seasons and throughout the entire horizontal and vertical extent of the site. Chapter 4 provides additional information on the history of investigation and excavation protocols at SM1.

Table 3.5 Provenience information for recorded faunal specimens from SM1.

Provenience	**2002**	**2003**	**2010**	**2011**	**2012**	**2013**	**2016**	**2018**	**Total**
Mapped *in-situ*	-	-	821	737	880	555	1223	1169	5385
Water-screen	-	-	62	1067	76	84	405	95	1789
Surface collection	82	8	-	34	3	-	-	-	127
Test excavation[1]	-	250	-	-	-	-	-	-	250
Unknown	-	17	3	7	4	10	1	11	53
Total	82	275	886	1845	963	649	1629	1275	7604

[1]Items from the 2003 test excavation were also mapped *in-situ*, but using a different grid system than the large-scale excavations beginning in 2010. See Chapter 4 for details.

Comparative MSA faunal assemblages

All comparative collections examined specifically for this project were studied at the National Museum of Ethiopia. Data on other archaeological fauna collected for comparison with SM1 derive from two open-air archaeological sites at Aduma (~100-80 ka) in the Middle Awash Valley of north-central Ethiopia (Yellen *et al.,* 2005) and multiple paleontological localities from the Kibish Formation (~200-3 ka) in southern Ethiopia (Yellen *et al.,* 2005; McDougall *et al.,* 2005, 2008) (Table 3.6). Faunal material from Aduma comes from sites A2 and A8A, and includes terrestrial vertebrates and fish

Table 3.6 Dates and NISP counts for comparative sites at Aduma and geological members from the Kibish Formation in which fossil localities occur.

Site/Member	n[1]	Age (ka)
Aduma A2	944	100-80
Aduma A8A	1213	100-80
Total	**2157**	
Kibish Fm. Member I	167	~196
Kibish Fm. Member III	112	~104
Kibish Fm. Member III/IV	51	~104-8.6 ka[2]
Kibish Fm. Member IV	47	9.5-3.3
Total	**377**	

[1] Basic specimen counts from the database

[2] These specimens are from Kibish locality CHS, for which the Member and exact age are uncertain

References: McDougall et al. 2005, 2008; Yellen et al. 2005; Brown and Fuller 2008

collected during fieldwork conducted between 1994-1998. Fauna at both sites are from excavated, screened, and surface-collected contexts and, generally speaking, the collection strategy was unbiased in both cases (Yellen *et al.,* 2005). Comparative data on fauna from the Kibish Formation consists entirely of fossil fish from 41 localities in Members 1, 3, & 4 collected during fieldwork in 2002 and 2003. Most of the fish were surface-collected, although some derive from screening of excavated archaeological sediments, as well. In both cases, the collection strategy was focused on elements that were relatively intact and readily identifiable (Trapani, 2008). A more detailed discussion of the reasoning behind the choice of comparative sites, the excavation/collection history of each site, and the size

and composition of comparative datasets collected specifically for this study can be found in Appendices B and C.

All of the faunal material from Aduma and the Kibish Formation has been studied previously (*e.g.,* Yellen *et al.,* 2005; Trapani 2008; K. Stewart personal communication), so the primary focus here was on gathering taphonomic data that were not previously recorded and/or published. There is no obvious reason to doubt the taxonomic designations found in previous publications and site catalogs, which were generously provided by the research teams from both projects, so in all but a handful of cases (mostly involving small fish bones), the original identifications were retained.

Taxonomic and taphonomic data for the Kibish Formation fish are used in Chapter 6 as an example of a natural accumulation of fish bones in order to help determine whether or not the SM1 fish more likely result from human or non-human accumulation. Data from the Aduma sites are employed primarily for the comparative analyses presented in Chapter 7. The Aduma sites are particularly important for this purpose because they double the sample of open-air sites available for comparison with SM1 and, unlike the other two open-air sites in the sample (see below), they date to the late MSA and are located specifically in riverine habitats in the Horn of Africa.

Additional comparative data for the analyses in Chapter 7 derive from several other cave and open-air sites in Ethiopia, Morocco, and South Africa, and were either compiled from the literature or produced using original datasets that were generously shared by the researchers who initially studied the site. This part of the comparative sample includes the open-air sites of Bundu Farm and Pniel 6 in South Africa (Hutson, 2012a, 2018), as well as the cave sites of Porc Epic in Ethiopia (Assefa, 2002, 2006), Contrebandiers Cave in Morocco (Hallett, 2018; E. Hallett personal communication), and Pinnacle Point 13B (Thompson, 2008, 2010; J. Thompson personal communication), Blombos Cave

(Thompson, 2008; Thompson and Henshilwood, 2011; J. Thompson personal communication), Die Kelders Cave 1 (Marean *et al.,* 2000), and Sibudu Cave (Clark, 2009; Clark and Ligouis, 2010) in South Africa. Additional details on dating, sample sizes and composition, and other information for the comparative sites can be found in Chapter 7 and the original publications cited above for each.

Modern fish comparative data

Data from a sample of modern fish collected in the Shinfa River near SM1 between 2011-2016 were used to help reconstruct the total length and body mass of fossil fish from SM1 (Table 3.7) and assist with identifications of the fossil fish bones. The sample includes siluriform catfish, cyprinids, and one cichlid. Upon collection, all fish were assigned a unique number, identified to species, measured, and, in some cases, weighed. Once recorded, several fish were skeletonized in boiling water, bagged, and transported to comparative collections in the National Museum of Ethiopia, where they were recorded for this study. Additionally, select elements (*e.g.,* spines, otoliths) of some of the modern fish were exported to the University of Texas at Austin, for further recording and analysis.

The majority of the fish were buried in the field at SM1 and allowed to skeletonize naturally over a period of 1-3 years, often enclosed in mesh screen pouches to ensure maximum element recovery when the skeleton was eventually dug up and collected. Once collected, the entire contents of the pouch were bagged, numbered, and transported to the comparative collections at the National Museum of Ethiopia. Both cranial and postcranial bones were measured for this study, with an emphasis placed on elements that are common at SM1 and other late Pleistocene archaeological sites in Africa, and those considered most likely to have a strong correlation to body size (Gautier and Van Neer, 1989; Stewart, 1989;

Table 3.7 Sample of modern fish from the Shinfa River used to estimate body size for the fossil fish from SM1.

Genus	n	TL	WT
Auchenoglanis	10	9	2
Bagrus	20	17	12
Clarias/Heterobranchus	4	4	4
Schilbe	4	4	2
Synodontis	23	8	3
Labeo/Labeobarbus	14	14	14
Oreochromis	1	1	1
Total	**76**	**57**	**38**

n = total specimens recorded
TL = specimens with total length measurements
WT = specimens with weight measurements

Van Neer, 1989, 2004; Van Neer and Lesur, 2004; Dale, 2007; Prendergast, 2010; Prendergast and Beyin, 2018).

Additionally, comparative data on the modern fish communities in the Shinfa River and several other Blue Nile tributaries in the region were gathered from Tewabe (2008; Tewabe *et al.,* 2010), and Mr. Tewabe oversaw the collection of most of the modern fish recovered by the Project. These data are used for comparisons of taxonomic representation and diversity with SM1 in order to help evaluate if the SM1 fish are more likely to represent a naturally- or human-accumulated assemblage.

Faunal and taphonomic data collection

The data collection and analytical protocols described in the following sections were used to record all terrestrial and aquatic vertebrates from SM1, the Aduma sites, and the Kibish Formation. These methods were chosen specifically to facilitate comparisons with other MSA sites for which faunal and taphonomic analyses have previously been

undertaken (*e.g.,* Assefa, 2006; Marean *et al.,* 2000; Thompson, 2010; Clark, 2011; Thompson and Henshilwood, 2011; Hutson, 2018; Hallett, 2018).

Specimens were cleaned of excess sediment with fresh water, assigned an individual catalog number, and entered into a database that was designed specifically for this project, and modeled on a data collection system used for previous analyses of faunal assemblages from Porc Epic, Die Kelders Cave 1, Pinnacle Point 13B, Blombos Cave, and Contrebandiers Cave (C. Marean, Z. Assefa, J. Thompson, and E. Hallett, personal communication). Maximum length and width (to the nearest .01 mm), basic color of the bone, degree of fossilization, and conjoining unit (when relevant) were recorded for all specimens for which a determination could be made. Additionally, for all bones that could be confidently identified as long bone shaft fragments, cortical thickness was measured to the nearest 0.01 mm and maximum circumference was recorded as less than half, more than half, or complete (Bunn 1983).

A modified version of the tripartite system described by Gifford and Crader (1977) was used to record the element (*e.g.,* humerus), portion (*e.g.,* proximal shaft), and segment (*e.g.,* fragment) as specifically as possible for each specimen. Specimens identifiable to skeletal element were further classified to the lowest taxonomic level possible and sided. Terrestrial fauna were assigned a body size class following Brain (1981), with the addition, size class 1a, which was created to distinguish between small "collectible" terrestrial fauna (≤ 5 kg) and small "hunted" animals (*i.e.,* 6-23 kg) that are grouped together in the original size class 1 (Table 3.8). From an analytical standpoint, this distinction is potentially important, because the presence of lagomorphs, rodents, birds, and other small, "collectible" vertebrates may have specific implications for foraging behavior (*e.g.,* use of snares and/or traps) that warrant their consideration as a separate unit from other size 1 animals. Additional information on body size in terrestrial fauna was derived from long

Table 3.8 Body size classes (Brain 1981).

Size class	Weight range (kg)
1a	0 - 5
1	0 - 23
2	23 - 84
3	84 - 296
4	296 - 900
5	900+

Table 3.9 Long bone cortical thickness (CT) codes and corresponding approximate size classes (Reynard *et al.* 2014).

CT code	CT (mm)	Brain (1981)	Weight range (kg)
1	<2	Size 1	4.5-19
2	2-3.9	Size 2	18-84
3	4-5.9	Size 3	77-299
4	6-7.9	Size 4	367-900
5+	>8	Size 5	>900
CT = maximum cortical bone thickness			

bone fragments, which were assigned to categories based on cortical bone thickness (CT) following Reynard *et al.* (2014) (Table 3.9). Each CT code corresponds approximately to a size class of Brain (1981), making it possible to include non-identifiable long bone fragments and thereby increase the sample sizes for analyses of body size representation.

The stage of epiphyseal fusion (*i.e.,* unfused, partially fused, fusion line visible, complete fusion) was recorded on all specimens for which a determination could be made, and subadult features were noted as present, absent, or not observed, when relevant. The preserved portion of the bone (*i.e.,* proximal/distal epiphysis, near epiphysis shaft, middle shaft) was documented for all long bones and long bone fragments, and the presence of diagnostic landmarks was recorded in increments of 10% for all identified elements

(Thompson, 2008; C. Marean personal communication). Additionally, for all identifiable specimens, the estimated percentage of the complete bone remaining was recorded in 5% increments. Standard osteological measurements were taken to the nearest 0.01 mm on all identifiable specimens, following von den Driesch (1976: mammals and birds), Cohen and Serjeantson (1996: birds), and Morales and Rosenlund (1979: fish).

Taphonomic data were collected on all specimens for which determinations could be made. Specimens were examined under bright light at 10-30x magnification using a hand-lens, and a binocular microscope was also used in a few cases where higher magnification was necessary to verify marks initially identified with a hand-lens. Surface visibility was recorded in 10% increments, and the extent of carbonate coverage was coded as 0%, 1-50%, 51-99%, or 100%. For terrestrial fauna, surface preservation was assessed using the weathering categories of Behrensmeyer (1978), which encode information primarily (but not solely) related to processes that occur during subaerial surface exposure of the bone. The extent and severity of five types of post-depositional damage that can further obscure surface visibility and provide information on depositional history – dendritic etching, pocking, exfoliation, sheen, smoothing, and erosion – were also recorded following Thompson (2005). The degree of thermal alteration was categorized into six stages ranging from unburned to fully calcined based on bone surface coloration (Table 3.10) (Shipman *et al.,* 1984).

Fracture angle and outline categories were recorded for each longitudinal end of all relevant long bone shafts and shaft fragments (*i.e.,* excluding birds, microfauna, non-identifiable shaft fragments with cortical thickness < 1.25 mm, and tiny splinters of long bone shaft) following Villa and Mahieu (1991). Criteria from the literature were used to classify human and carnivore damage and natural/post-depositional modification (*e.g.,* Binford, 1981; Haynes, 1983; Shipman and Rose, 1983; Behrensmeyer *et al.,* 1986;

Table 3.10 Thermal alteration stages for terrestrial fauna and fish.

Burn code	Description (Shipman *et al.*, 1984)
0	Unburned
1	Localized carbonization (< 50% dark brown or black)
2	Moderate carbonization (> 50% dark brown or black)
3	Full carbonization (100% dark brown or black)
4	Localized calcination (< 50% gray, blue/gray, or white)
5	Moderate calcination (> 50% gray, blue/gray, or white)
6	Full calcination (100% gray, blue/gray, or white)

Blumenschine and Selvaggio, 1988; Lyman, 1994; Fisher, 1995; Blumenschine *et al.,* 1996; Thompson, 2005; Njau and Blumenschine, 2006; Pickering and Egeland, 2006; Dominguez-Rodrigo *et al.,* 2009; Fernandez-Jalvo and Andrews, 2016). Rodent gnawing, trampling damage, recent damage, and non-identifiable marks were recorded as absent, present, or probable/possible. Human and carnivore modification categories include cut marks, percussion marks, percussion notches, tooth marks, and tooth notches. The number of cut marks, percussion marks/notches, and tooth marks/notches was recorded for all specimens. For cut marks, the anatomical location (*i.e.,* proximal end, proximal shaft, middle shaft, distal shaft, distal end, location non-ID) of each mark or set of marks was also documented.

Taphonomic attributes of the fossil fish

Taphonomic data for fish were collected using the same basic system as for terrestrial fauna, but with modifications to the definition and/or coding scheme of some attributes in order to make them specifically applicable to fish bones. Variables analogous to the weathering categories and Stain Index of Stewart (1989) were used to assess the

depositional context and surface preservation of fossil fish. The weathering categories of Stewart (1989) are concerned with documenting whether or not bones display evidence of damage (*e.g.,* friability, crumbling, cracking) related to poor preservational conditions (category 2), have damage (*e.g.,* sheen, polish, rounded edges) indicative of significant fluvial transport (category 3), or appear to be fresh and largely undamaged (category 4). All of the same information is encoded here, albeit in a slightly different way that employs several different variables already in place for recording surface preservation in terrestrial fauna (Table 3.11).

Four weathering stages (WS 0-3) were used for the fish bones in this study that represent increasingly severe surface degradation based on criteria similar to those for category 2 from Stewart (1989). The processes encoded in weathering category 3 of Stewart (1989) are recorded here as separate variables called smoothing and sheen, which were already in place under the "Post-depositional Processes" class of data for terrestrial fauna(Table 3.11). Additionally, the basic bone color field mentioned above was employed here in much the same way as the Stain Index of Stewart (1989), in order to give a basic assessment of the timing and context of deposition for fossil fish bones (Table 3.12).

Thermal alteration of fish bones was recorded using the same coding scheme and criteria (*i.e.,* burn codes 0-6, based on color and/or texture changes) as terrestrial fauna (Table 3.10). However, given the potential difficulty in distinguishing between carbonization and dark staining on fish bone based on color alone, a decision was made to only consider burning for fish bones that were either clearly unburnt (i.e., beige or light-to-medium brown with no darker coloration) or calcined (i.e., blue-gray, gray, or white, often with a chalky texture) (e.g., Zohar, 2003). Bones that appeared to be carbonized based on very dark brown or black coloration were recorded as such in the database, but for analytical purposes were treated as "indeterminate" and excluded from the final analyses.

Table 3.11 Surface preservation variables from this study, corresponding weathering categories from Stewart (1989), and the taphonomic processes of interest for each variable.

Variable[1]	Description[1]	Stewart (1989)	Process(es) of interest
WS 0	little or no degradation; bone looks fresh	WC 4	surface integrity; “clay-shattering”
WS 1	localized degradation (< 50% of surface)	WC 2 (light damage)	surface integrity; "clay-shattering"
WS 2	moderate degradation (50-80% of surface)	WC 2 (moderate damage)	surface integrity; "clay-shattering"
WS 3	heavy degradation (80-100% of surface)	WC 2 (severe damage)	surface integrity; "clay-shattering"
Smoothing	bone shows signs of rounding and/or polish	WC 3	post-depositional transport
Sheen	bone looks polished and "shiny"	WC 3	post-depositional transport
Color Index	basic color of bone	Stain Index	preservational and depositional context

[1]Variables and descriptions from this study

WS = weathering stage; WC = weathering category

Table 3.12 Color index codes and descriptions for fossil fish.

Color code	Description
Bl	black
dBr	dark brown
mBr	medium brown
lBr	light/yellowish-brown
orBr	brown with orange and/or red mottling
gBr	gray-brown
Gr	gray
Be	beige
Wh	white

Quantitative units

NISP and nNISP were chosen as the primary quantitative units because they are the most straightforward measures of faunal abundance, are simple to calculate, and more readily facilitate comparisons among sites. The fact that the SM1 fauna is extensively fragmented and the number of specimens identified to skeletal element and/or taxon is rather low (see Chapters 5-7) also suggests that NISP counts may actually provide a more accurate picture of faunal representation than MNE or MNI in this case (Pilgrim and Marshall, 1993). In fact, for many of the taphonomic and other variables of interest, MNI values, in particular, are too low to allow for meaningful statistical analysis. Additionally, as already discussed, Grayson and Frey (2004) have demonstrated that analyses conducted with NISP/nNISP versus MNE/MNI/MAU should produce very similar results, which means that overall interpretations are likely to be quite similar, regardless of which measures are used. Nonetheless, MNE and MNI counts are also provided for both terrestrial fauna and fish as this is standard practice in zooarchaeological studies. MAU and standardized MAU (%MAU: calculated as the MAU for a single element divided by the largest MAU in the sample) values are also used at times to ensure that data from SM1 are analogous to comparative datasets.

The term specimen refers here to a single bone, tooth, or fragment thereof. On the rare occasion that articulated terrestrial faunal bones were found, the entire segment was counted as a single specimen (recorded as the larger or most prominent piece), but the fact that more than one element was present was coded into the database. Conversely, as is common in studies of archaeological ichthyofauna (*e.g.,* Stewart, 1989; Belcher, 1998; Zohar, 2003), the constituent bones of the fish neurocranium (numerous elements), mandible (articular and dentary), hyoid bar (ceratohyal and hypohyal), suspensorium (quadrate, hyomandibular, preoperculum, and pterygoids), and cleithrum (cleithrum and

coracoid) were counted as individual specimens even if they were found in articulation. However, the entire neurocranium (*i.e.,* all bones combined), mandible (*i.e.,* angular + dentary), hyoid (*i.e.,* ceratohyal + hypohyal), and cleithrum (*i.e.,* cleithrum + coracoid) were considered as the unit of interest for the purposes of MNE counts, rather than the individual parts of each. In other words, for a complete/intact right mandible, the NISP would be two (angular + dentary), but the MNE would be one (mandible); if both sides were present, NISP and MNE would be four (R and L angular + dentary) and two (R and L mandible), respectively. Additionally, for both terrestrial fauna and fish, fragments that refit were entered into the database separately, but were treated as a single specimen for the purposes of count data.

Unless specifically stated in the text, count data were calculated for the entire assemblage treated as a single aggregate. The only other commonly-used spatial aggregates are the four proposed vertical analytical units within the site, although at times the data are also subdivided horizontally by excavation blocks (see Chapter 4). The spatial aggregate being employed is always clearly stated throughout, in order to avoid any potential confusion. It should also be noted here that the majority of specimens from SM1 were not identifiable to lower taxonomic levels (*i.e.,* genus or species), especially for terrestrial fauna. Thus, the term "taxa" may refer to genera, species, or families, but in many cases is also used to reference more broadly-defined groups, such as "Carnivores" or "Size 2 vertebrates".

Following the standard definition, NISP is primarily used here to describe the number of specimens identified to a specific skeletal element and taxonomic group. NISP values may at times also include bones that were not identified to a specific skeletal element but were identified to at least a broad taxonomic group (*e.g.,* bird long bone fragments; Clariid headplate fragments) or may refer to samples that include some bones for which

both taxonomy and element are only very broadly identified (*e.g.,* specimen counts for analyses of long bone fracture morphology, which include 1000+ largely non-identified mammal long bone fragments, are also referred to as NISP). Importantly, in all cases, the composition of the sample being described by a given NISP count is always clearly defined in the table, figure, and/or accompanying text.

MNE refers to the minimum number of elements (for both sides) that can be attributed to a single taxonomic group. Criteria factored into the calculation of MNE values include body size, side, and anatomical overlap. Specimens were not assigned a sex and there were very few for which an age other than "adult" could be inferred, so age and sex were not considered. It was assumed that specimens classified to broader taxonomic groupings were not from the same specimens as those identified to more narrowly-defined taxa. For example, specimens classified as "size 2 bovid" were assumed to be from different individuals and elements as those identified as *Gazella* or *Aepyceros,* which are also size 2 bovids. Likewise, "size 3 vertebrate" bones were not referenced against the "size 3 bovid" material, because the two groups were presumed not to overlap.

To calculate MNE, bones were first grouped by side and then all specimens within each group were compared for similarities in size and overlap of anatomical regions. For terrestrial vertebrates, most specimens were drawn onto digital templates, so comparisons were made visually using these images. Templates were not used for fish bones, so overlap was determined based on the presence of specific anatomical landmarks that were coded into the database for identified specimens (see above). Specimens from the same side that overlapped, or were substantially different in size, were counted as separate elements. In the case of fish bones, when possible, data on size variation in the modern fish sample were also used to help guide decisions about whether size differences between two non-overlapping specimens warranted counting them separately. Specimens of similar size that

did not overlap were considered to have potentially come from the same element and were not included in MNE counts. Un-sided specimens were only added to MNE counts if they could be shown to overlap with all sided specimens for that element, and therefore to represent another unique element, regardless of side. If multiple portions of an element were represented and none of the specimens overlapped, the MNE was simply the sum of left and right sides for the most common portion.

In the case of elements for which no landmarks were coded and it was not otherwise possible to check overlap (*e.g.,* rodent incisors, fish spine shaft fragments and vertebral centra), MNE was based on the sum of the "percentage complete" values recorded in the database (see above). For catfish spine shaft fragments, this total was added to the count of identified spines (all of which included the base and usually some portion of the shaft) for the taxon, with the assumption that all of the shaft-only fragments were distinct from specimens that also retained the base. Although it is possible that this decision may have introduced some level of interdependence in the MNE data for fish spines, overall element counts are already probably quite depressed by extensive fragmentation (see Chapter 6), the relatively conservative method of calculating MNE, and the fact that the entire site was considered as a single aggregate (Grayson, 1984; Pilgrim and Marshall, 1993). Thus, even if some spines were counted twice, the MNE counts presented in Chapter 6 are still likely to underestimate the actual abundance of unique catfish spines at the site. It should also be pointed out here that MNE counts are likely to be similarly depressed for the majority of elements from both terrestrial fauna and fish at SM1.

MNI counts were generated directly from NISP data. MNI values were first calculated for all elements present for a particular taxon. The starting point for tabulating each MNI value was the NISP for the most abundant portion and/or side for each element, and all the same criteria used for MNE (*e.g.,* side, size, and anatomical overlap) were also

considered for calculating MNI. The highest per-element MNI was then chosen as the total MNI for the taxon. MNI counts were not generated for mostly (*i.e.,* non-descript long bone and tooth fragments) or completely non-identifiable specimens and, as with MNE, individuals in broadly-defined taxonomic groups were assumed not to overlap with those assigned to lower taxa. Once again, the MNI counts presented in Chapters 5 and 6 may well be substantial underestimates of the actual number of individuals at the site, given that MNI is, by definition, already meant to provide a conservative estimate and the MNI counts at SM1 are likely to be further depressed for all the same reasons noted above for MNE.

Diversity Indices

Four measures commonly used to assess taxonomic diversity in archaeofaunal assemblages (*e.g.,* Faith 2008; Clark, 2011; Hutson, 2018) were calculated for the fauna from SM1. Taxonomic richness is examined using NTAXA, which in this case, refers to genera and families (*i.e.,* rather than species). The distribution of individuals among taxa is analyzed using the Evenness Index (*e*), which is calculated as:

$$e = H / lnS$$

where S = the number of taxa present (*i.e.,* NTAXA) and H = the value of the Shannon Diversity Index (see below) (Lyman, 2008). Values for *e* range from 0-1, with 1 representing a completely even assemblage and 0 representing a completely uneven one (Faith and Gordon, 2007; Lyman, 2008).

Another measure of evenness is the reciprocal of Simpson Index (1/D), which also takes species richness into account and is more sensitive than *e* to one or a few taxa dominating an assemblage (Lyman, 2008). This index is calculated as:

$$1/D = 1 / \sum [n_i(n_i - 1)/N(N-1)$$

where n_i = the number of specimens for each taxon and N = the total number of specimens identified to the taxonomic level of interest for the entire site (Lyman, 2008). Values for 1/D vary between a minimum of one and a maximum equal to NTAXA for the group in question. Lower values indicate less evenness (*i.e.,* more dominance by one taxon) and biodiversity, while higher values indicate more evenness in the distribution of individuals among taxa and more diversity in the taxa represented (Lyman, 1994, 2008).

The Shannon Diversity Index (H) is used as a measure of heterogeneity, and is calculated as:

$$H = -\sum P_i(lnP_i)$$

where P_i = the proportion of each taxon (*i.e.,* genus or family) in the assemblage (Grayson, 1984; Lyman, 2008). Values of H typically range between 1.5-3.5, with lower values indicating less heterogeneity, or an assemblage for which there is a relatively high probability of correctly predicting the taxonomic identity of a randomly-drawn individual, because there are not many taxa (*i.e.,* diversity is low), most of the individuals belong to only one or a few taxa (*i.e.,* evenness is low), or both (Lyman, 2008). Conversely, higher values of H indicate a more heterogeneous (*i.e.,* diverse and/or even) assemblage (Grayson, 1984; Lyman, 2008; Reitz and Wing, 2008).

Statistical analyses

Several statistical analyses are employed throughout the study. Spearman's Rho (r_s) is used to assess correlation among either two ranked-choice variables, or a ranked variable and a measurement variable. Chi-squared (χ^2) tests of independence are used for comparisons of various faunal and taphonomic attributes between different analytical units within SM1, as well as for comparing data from SM1 to that from a number of different

comparative sites and assemblages. In one case where small sample sizes raised questions about the use of chi-squared tests, Fisher's Exact Test (FET) is used in the same capacity, but the results of chi-squared tests are also presented. Additionally, in cases where chi-squared tests indicate significant differences between analytical units and/or sites, the adjusted residuals from partial chi-squared tests are used to examine in more detail the patterns of association and dissociation (*i.e.,* the nature and direction of differences) between analytical units at SM1 and among SM1 and comparative sites.

Least-squares regression is also used to create regression models describing the relationship between osteometric measurements and body size in the sample of modern fish from the Shinfa River. In cases where Shapiro-Wilk tests indicated that the residuals of the linear model are distributed normally, the linear regression models are then applied to the fossil assemblage in order to predict body size in the fossil fish. Finally, t-tests are also employed in several analyses to test for significant differences in mean fragment sizes of specimens with and without particular types of taphonomic damage.

Documenting faunal assemblage composition

Documenting faunal assemblage composition at SM1 required information on what taxonomic groups, body size classes, and skeletal elements are present at the site, and the frequencies at which each of them occur. Identification of the taxonomic groups that are present and calculation of diversity of indices allows for reconstruction of overall foraging strategies, and investigations of diet and dietary breath (Faith 2008). Assuming human collection of the fauna, identification of the taxa and body size classes present at the site may also provide further insight into MSA hunting, fishing, and other foraging behavior, including patterns of prey selectivity by MSA humans. Documenting skeletal element abundances will also be informative with respect to overall assemblage

composition, as well as for understanding various other aspects of faunal abundance and diversity, and human foraging and faunal processing behavior at SM1 (Grayson, 1984; Lyman, 1994, 2008; Reitz and Wing, 2008).

Taphonomic and behavioral analyses: terrestrial fauna

In order to identify agents of accumulation, the frequencies of human versus non-human carnivore damage were evaluated along with other evidence of human (e.g., archaeological association, spatial distribution, burning) and carnivore activity. Frequency and/or placement of cut/percussion and tooth marks, and patterns of skeletal element/portion representation were examined and compared to known carnivore- and human-produced assemblages (archaeological and experimental) (Blumenschine 1988; Capaldo 1998; Marean *et al.,* 2000; Dominguez-Rodrigo and Barba, 2006; Galan *et al.,* 2009). Relative frequencies of fresh versus dry fractures were used to evaluate the proportions of fragmentation attributable to nutritive versus non-nutritive bone modification. To further test the effects of post-depositional bone destruction and density-mediated attrition, relationships between BMD and MAU were evaluated (Lam *et al.,* 1998, 1999), and completeness indices (CI) for compact bones examined (Marean, 1993; Villa *et al.,* 2004). More information on the BMD data used and the procedure for calculating CI is provided in Chapter 5. Dietary breadth and prey choice were examined using measures of taxonomic richness (NTAXA), evenness (e and Simpson's 1/D), and heterogeneity (Shannon's H) (Faith, 2008; Clark, 2009; Hutson, 2012a). Focusing on high survival elements, faunal transport strategies were identified using evenness values and correlations between element abundance (nNISP; MAU) and the standardized food utility index (SFUI) (Marean and Cleghorn 2003; Faith and Gordon 2007; Clark 2009).

Taphonomic and behavioral analyses: fish

Fish bones were grouped according to three broad anatomical regions and eight skeletal element structures, which make up the different regions, following a modified version of the classification systems used in Wheeler and Jones (1989) and Zohar (2003) (Figure 3.1 and Appendix D). Differences between recording systems relate primarily to the inclusion of pharyngeal teeth and branchiostegals as cranial elements for the purposes of overall NISP counts in this study and the treatment of postcrania and the vertebral column as separate anatomical regions. Throughout the text, analyses of fish bones may proceed at the level of taxon, anatomical region, skeletal structure, and/or individual element, depending on the question at hand and the available sample sizes for relevant material.

Depositional context and bone surface preservation were assessed through analyses of bone color, weathering categories, and post-depositional processes. Levels of pre- and and/or post-depositional destruction were further examined using fragmentation and survivorship indices developed specifically for the study of fish bones (Zohar *et al.,* 2001; 2008; Zohar, 2003). The fragmentation index (FI) expresses the proportion of the original complete element represented by the recovered fossil specimen (Zohar *et al.,* 2008). A weighted mean index (WMI) of fragmentation was also employed, in order to standardize levels of fragmentation across different skeletal parts and taxa (Zohar *et al.,* 2001; Zohar, 2003). The survivorship index (SI) represents the number of observed versus expected bones for a particular element and taxon, and provides a means of comparing overall representation and preservation among different skeletal parts and/or taxa (Zohar *et al.,* 2001, 2008). More detail on how each index was calculated and employed is provided in Chapter 6.

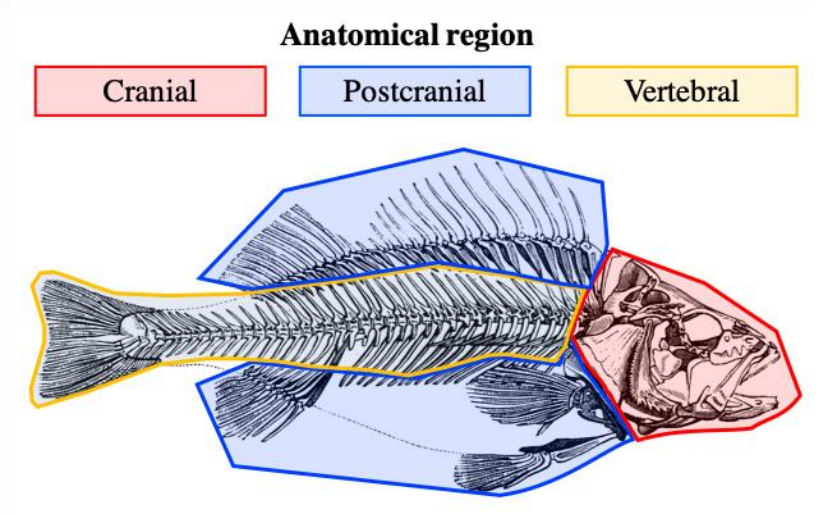

Figure 3.1 Generalized fish skeleton showing the three anatomical regions in the classification system used to examine skeletal part representation at SM1. Image courtesy of etc.usf.edu.

In order to assess whether or not the fish bones represent a culturally- or naturally-derived assemblage, fish were inspected for evidence of human processing, including cut and percussion marks and burning. Data on taxonomic abundance, body size distribution, and element representation were used to investigate whether or not observed patterns better match those expected for natural or human-produced sites (Butler, 1993; Stewart and Gifford-Gonzalez, 1994). Taxonomic abundance at SM1 was examined and compared to the natural structure of modern fish communities in several rivers in the Blue Nile Basin. Once again, assemblage diversity was examined using measures of taxonomic richness (NTAXA), evenness (Shannon's e and Simpson's 1/D), and heterogeneity (Shannon's H) (Faith, 2008; Clark, 2009; Hutson, 2012a). Likewise, patterns of skeletal element representation for SM1 were evaluated and compared to the expected proportions in a complete fish skeleton (Appendix D). Additional lines of evidence for human involvement,

including archaeological association, spatial distribution, and bone scatter frequency, were also analyzed to determine if fish bones were accumulated by humans (Stewart, 1989).

Comparative analyses

Comparative analyses were used to place SM1 within a broader context of MSA sites in eastern, northern, and southern Africa with respect to the taphonomic history and character of the site, and the behavior of the MSA people who lived there. Comparative analyses were also used to determine if aspects of site formation and/or human behavior at SM1 are unique relative to the other sites for which similar faunal and taphonomic data were available for comparison, and examine whether or not broader patterns of taphonomic difference exist between open-air and cave sites more generally.

Conclusion

Modern techniques for zooarchaeological analysis have been developed through decades of experimental and actualistic work aimed at using faunal remains to identify the distinct signatures of human and non-human agents and processes in the archaeological record, in order to understand site formation processes and past human behavior. The materials and methods described in this chapter are based on these time-tested and well-proven techniques, and have been specifically tailored to address the research questions and issues outlined above for SM1. Employing these methods in the following chapters will therefore allow for the development of a robust and reliable reconstruction of MSA foraging behavior at SM1, which can then be placed into the broader context of late Pleistocene human behavior and evolution in Africa.

Chapter 4: The Project Study Site: SM1

History of Archaeological Research

SM1 (12°35'34.62"N, 36°2'9.55"E; Figure 4.1) was discovered in 2002 during survey of Blue Nile tributaries in the lowlands of northwestern Ethiopia. Several hundred lithic artifacts and faunal remains were surface-collected at the site during the initial field season. In 2003, additional surface collection was conducted, a geological profile trench was opened, and four 100 x 50 cm test trenches were excavated to depths of ≥ 30 cm. A Sokkia surveying system, employing three static Ashtech Locus receivers and rover units with ~1 cm accuracy, was used to establish a grid and map most, but not all, of the surface-collected and excavated items. Sediment from test excavations was removed in 10-cm levels and screened. In total, these early investigations produced 704 individually recorded MSA artifacts and faunal remains, as well as hundreds more pieces of chipped stone and bone collected in aggregate from water-screened samples.

The first large-scale excavations at SM1 were carried out in 2010, with subsequent excavation seasons in 2011, 2012, 2013, 2016, and 2018. Unfortunately, the control point markers from the original grid were removed between 2003 and 2010, so it was necessary to set up a new grid system, based on the best approximation of relocated marker points from 2003. It was possible to relocate the original datum point for static GPS receivers within 20-30 cm, but the positions of the original back-sight locations for the 2003 grid could only be estimated with an accuracy of ~1-2 m. Thus, while the 2010 grid system closely approximates the original one from 2003, it was not possible to perfectly realign the two grids.

To date, 58 m^2 have been excavated at SM1 using the new grid system established in 2010, with units taken down to various depths of up to ~70 cm and none having yet reached sterile sediment (Figure 4.2). The excavation grid system employs metric and

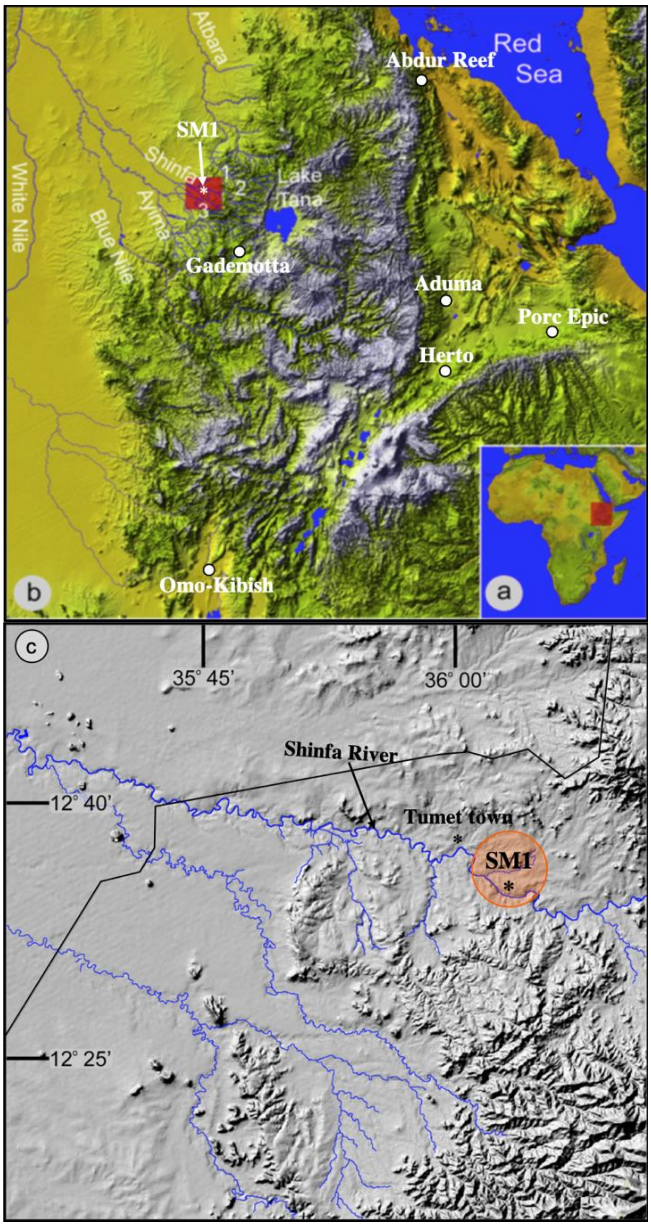

Figure 4.1 Topographic map of (a) Africa with the area of the Horn of Africa (red inset) and enlargements showing (b) trunk tributaries of the Blue Nile River, with the Guang (1) and Gendwuha (2) Rivers tributaries of the Atbara River, and the Shinfa and Gelegu (3) Rivers tributaries of the Blue Nile River, and the study area (red inset) with SM1, and other MSA sites in the Horn of Africa and (c) study site showing location of SM1 on the Shinfa River in the NW lowlands of Ethiopia.. Modified from Kappelman *et al.* (2014).

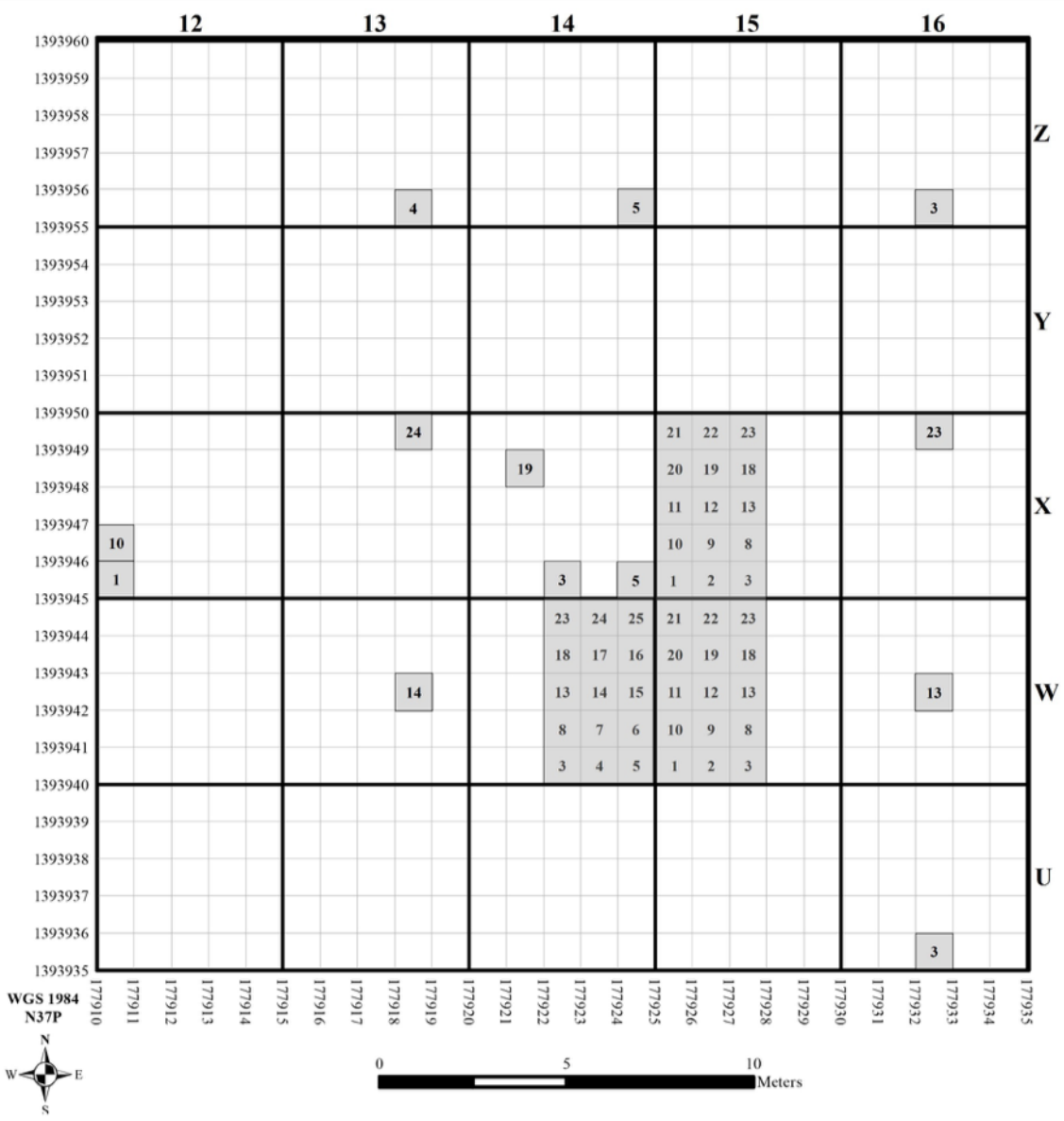

Figure 4.2 Plan map of SM1 excavation grid. Square-meter units excavated from 2010-2018 are highlighted in gray. Two grid systems, metric and alpha-numeric, are used simultaneously. The letter V is intentionally excluded from the alpha-numeric grid system to avoid possible confusion with the letter U in handwritten documentation and field notes.

alpha-numeric grids simultaneously, allowing for every provenience unit to have its location documented in two independent ways, and making it easier to identify and correct potential field-recording and/or note-taking errors. Point provenience, orientation, inclination, and side upward were recorded for all specimens > 10 mm in maximum dimension. Sediment from each excavation block was wet-sieved in 10-cm levels using 1.6 mm metal screen and water pumped directly from the Shinfa River, and the remaining matrix hand-picked for fossils and lithics. These excavations have produced over 11,000 individually mapped items, as well as a collection of ~2,000 water-screened matrix containing thousands of additional artifacts and faunal specimens. All of the *in-situ* material within the site was sealed by ancient over-bank deposits of fine-grained sediment and has a spatial distribution that suggests multiple seasons of occupation (see below).

DATING

Currently, the most reliable preliminary age estimate for SM1 comes from radiocarbon (AMS ^{14}C) dates based on several fragments of ostrich eggshell (OES), which are stratigraphically controlled and carbon-infinite in age (*i.e.,* > 40-60 ka: Taylor and Bar-Yosef, 2016). However, work is ongoing to obtain more precise age control for SM1 using a combination of several different radiometric techniques. The current approach involves obtaining uranium-series (U-series) dating on splits of large OES fragments that already have secure AMS ^{14}C dates (*i.e.,* > ~40 ka), in order to assess correspondence between the ages and systematic errors, if any exist. This combined approach will potentially make it possible to more confidently assess the age of the site beyond the radiocarbon limit using the U-series technique.

MSA ARCHAEOLOGY AT SM1

The archaeological record at SM1 is in broad agreement with dating studies and indicates that the site dates to the late MSA. The flake-based technology from SM1 includes tabular and flake tools, prismatic blades, scrapers, and various classes of debitage, all of which are typical MSA (Figure 4.3) (Marean and Assefa, 2005). Bifacial, unifacial, and Levallois points (n = 24) are the most common formal tools at SM1 and are similar to those from numerous other MSA sites across Africa (McBrearty and Brooks, 2000; Marean and Assefa, 2005). Although their function is not known for certain, many are standardized for size, shape, and weight in ways that would have made them quite aerodynamic if used as projectile points (J. Kappelman, personal communication). Neither the LCTs that characterize the ESA, or the specialized microblade cores, bladelets, and other forms distinctive of the LSA (McBrearty and Brooks, 2000), have been recovered at SM1.

Both formal tools and more expedient implements were created primarily on relatively small, often tabular, stream-rolled cobbles collected from the medial gravels of the paleo-Shinfa River, which was probably never more than a few hundred meters from SM1 (Kappelman *et al.,* 2014). Tool production often involved initial bipolar splitting, followed by various methods of in/direct percussion and pressure flaking to further reduce and shape the tools (Kay *et al.,* 2012) (Figure 4.3). The presence of abundant debitage, including thousands of tiny flakes averaging < 5-10 mm in maximum length, and numerous refit specimens among the chipped stone documents that intensive knapping and stone tool production regularly took place on-site at SM1. The presence of very tiny flakes and refit specimens further attests to the spatial integrity of the *in-situ* material at SM1, and documents that artifacts and fauna were not transported into the site from elsewhere.

MSA people utilized a number of different raw materials for tool production at SM1 including basalt, chert, cryptocrystalline (*e.g.,* chalcedony) and crystalline quartz, and

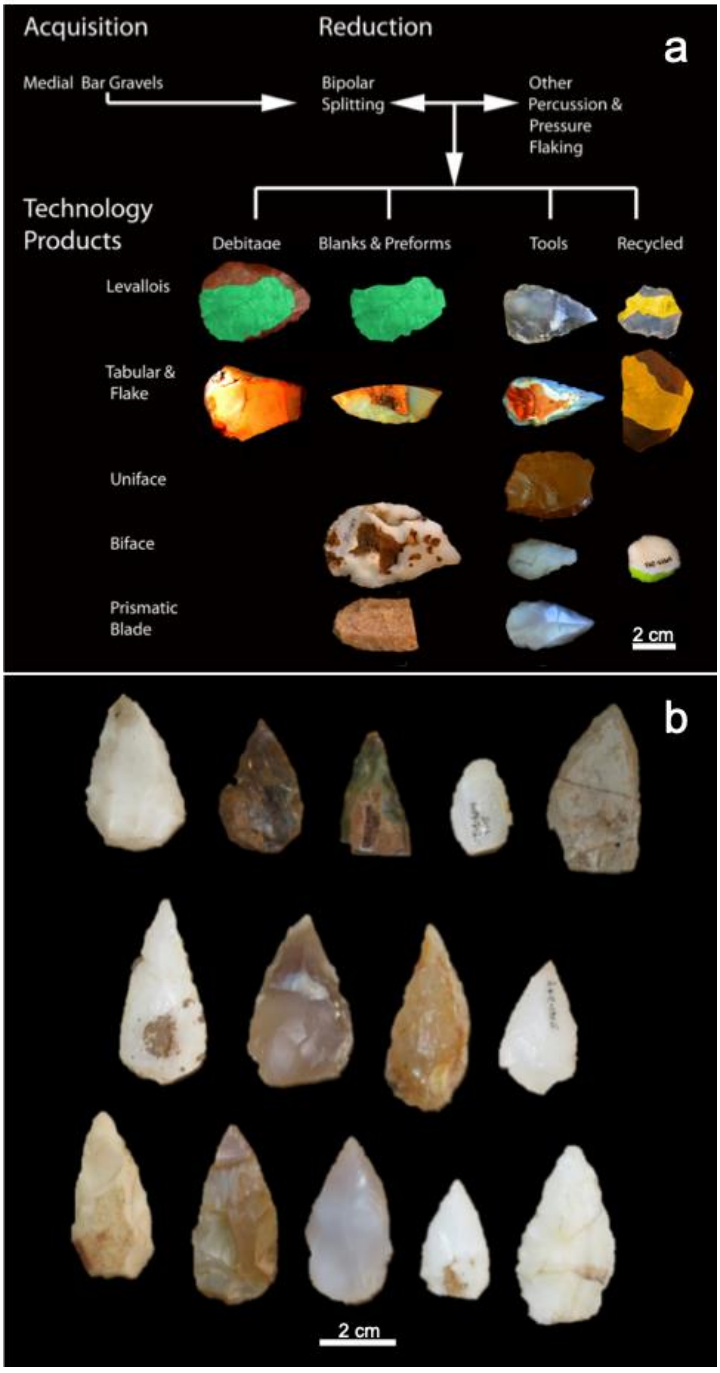

Figure 4.3 a) Diagram showing various artifacts from SM1 and outlining steps in the tool-making process. Modified from Kay *et al.* (2012). b) Unifacial, bifacial, and Levallois points from SM1.

quartzite. Most of the formal tools (*e.g.,* unifaces, bifaces, scrapers) are made of chert (45.8%) or chalcedony (41.7%), while quartzite (8.3%) and basalt (4.2%) were used much less often (Figure 4.4). Similarly, chalcedony (51.4%) is the most common raw material for utilized/worked flakes, followed by chert (37.1%), and basalt (11.4%), although in this case none of the implements are made of quartzite. In contrast, the largest number of cores are crystalline quartz (32.6%), with chalcedony (27.9%), basalt (24.4%), and chert (12.8%) also rather abundant among this artifact class. Finally, angular and other types of debitage are relatively evenly split between chalcedony (35%) and basalt (33.9%), with chert much less common (22.8%) (Figure 4.4). As already noted, most or all of these raw materials are available locally and were likely acquired in the form of small-to-medium-sized cobbles from the ancient river channel (Kay *et al.,* 2012).

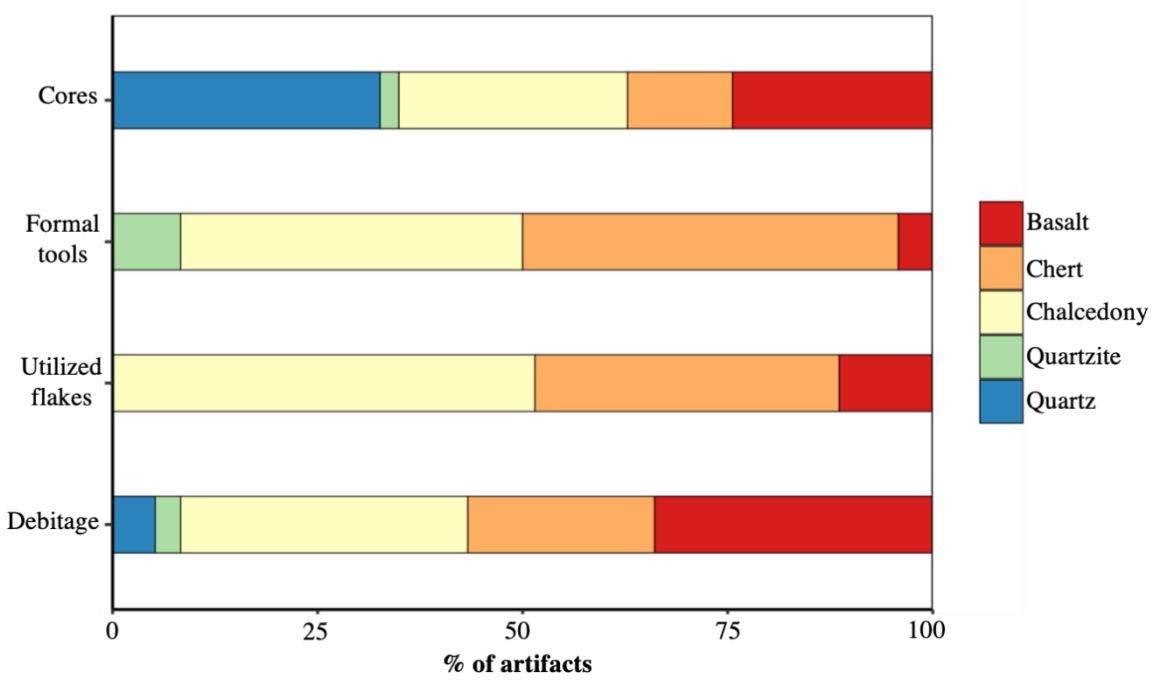

Figure 4.4 Summary of basic artifact classes and raw material frequencies.

SPATIAL DISTRIBUTION OF ARTIFACTS AND FAUNA

Of the 58 m^2 units excavated at SM1, all have produced at least one type of archaeological material, and 57 contain chipped stone, 53 contain terrestrial vertebrates, 52 contain fish, 39 contain mollusks, and 25 contain ostrich eggshell. However, the majority of the current excavated sample (~95%) derives from 45 m^2 in three excavation blocks near the center of the excavated area: W14, W15, and X15 (Figure 4.2). As such, the following overview of the spatial distribution of material at SM1 will focus primarily on the main excavation area represented by these three blocks. The horizontal distribution of fauna and artifacts across the main excavation area at SM1 is pictured in Figure 4.5; specimen counts for chipped stone artifacts and basic faunal groups in each block are presented in Table 4.1.

For the material mapped here, the three main excavation blocks contain 3,679 (W14), 3,737 (W15), and 4,755 (X15) items each, with chipped stone, terrestrial fauna, fish, mollusks, and ostrich eggshell found in all three blocks. The one small section in W15 where there appears to be very little material of any kind is actually the location of a test trench from 2003, which produced both artifacts and faunal remains. However, the items are not plotted here because provenience data for them was recorded using the 2003 grid system which, as discussed above, is not well-aligned with the new grid established in 2010.

Artifacts and faunal remains are closely associated and relatively evenly dispersed over most of the horizontal extent of the site and, generally speaking, there is no indication that distinct clusters of certain types of material to the exclusion of others exist (Figure 4.5). This is particularly true with regard to chipped stone artifacts, terrestrial fauna, and fish bones, all of which are widespread, abundant, and substantially intermixed throughout all three excavation blocks. Mollusks are much less abundant and spread somewhat less evenly across the site, but are nonetheless present in over 80% of the m^2 units in the main

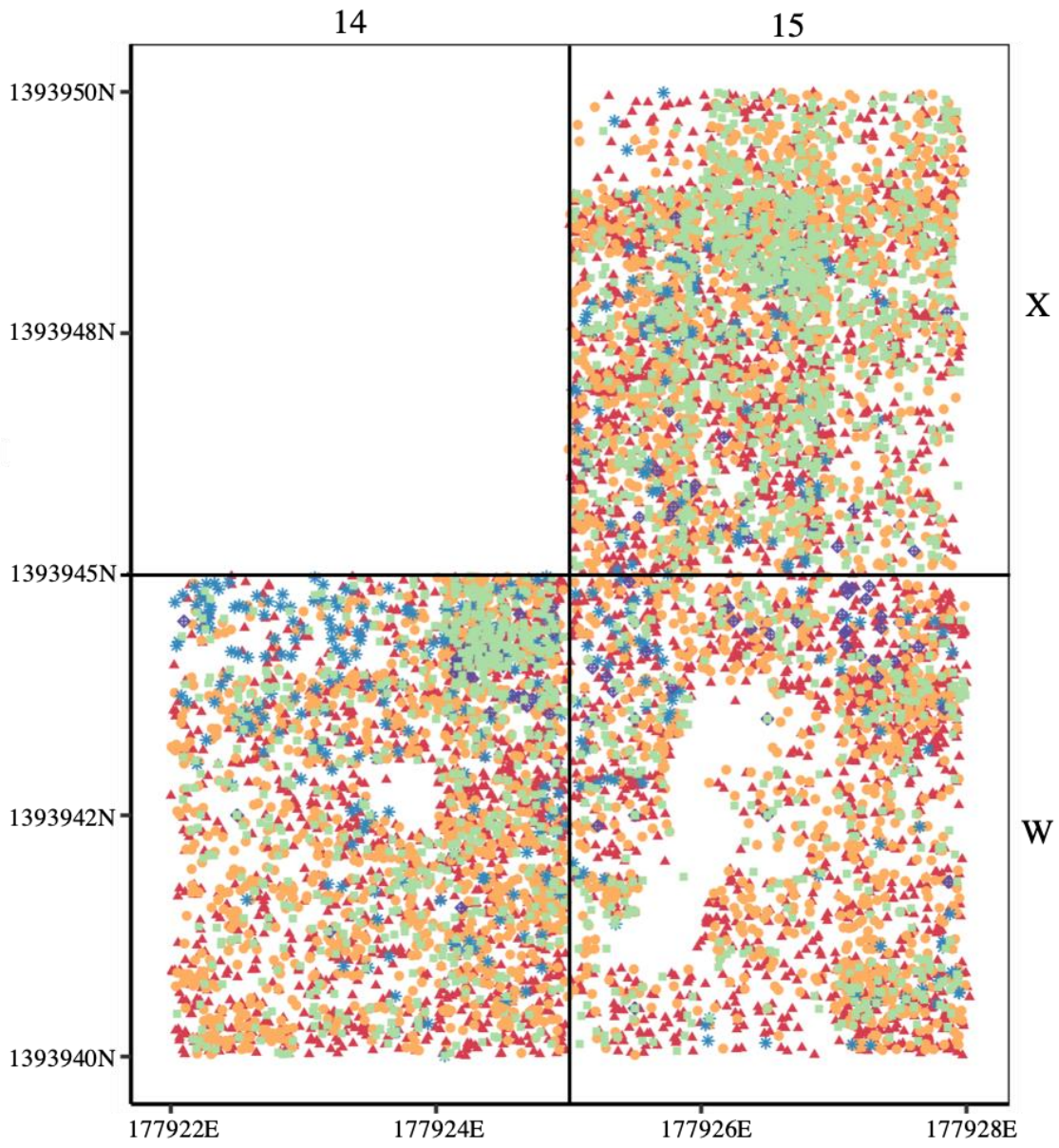

Figure 4.5 Plan map of the main excavation area at SM1. Red triangle = chipped stone; orange circle = terrestrial vertebrate; green square = fish; blue star = mollusk shell; purple diamond = ostrich eggshell.

Table 4.1 Specimen counts and frequencies for artifacts and faunal remains in the main excavation block at SM1.

Excavation	CS		FV		PI		ML		OS		
block	**n**	**%***	**n**	**%***	**n**	**%***	**n**	**%***	**n**	**%***	**Total**
W14	1441	39.2	1237	33.6	738	20.1	215	5.8	48	1.3	3679
W15	1259	33.7	1313	35.1	991	26.5	79	2.1	95	2.5	3737
X15	1739	36.6	1607	33.8	1263	26.6	113	2.4	33	0.7	4755
Total	**4439**	**36.5**	**4157**	**34.2**	**2992**	**24.6**	**407**	**3.3**	**176**	**1.4**	**12171**

*Percentage of material within each excavation block and for the entire site
CS = chipped stone: FV = terrestrial fauna; PI = fish; ML = mollusk; OS = ostrich eggshell

excavation area. Ostrich eggshell fragments are the only exception, as they are found in less than 45% of units, most of which are located along or near the border between W15 and X15.

The vertical distribution of fauna and artifacts in arbitrary five-centimeter layers is shown in Figure 4.6. Chipped stone, terrestrial fauna, and fish are abundant throughout much of the vertical extent of the site, but there are a handful of levels near the surface in which fish and/or terrestrial fauna are not found. Mollusks are also distributed through much of the stratigraphy, although they are basically confined to levels between 581-582 m, and are absent in both the uppermost and lowermost levels. Large basalt cobbles (≥ 30 mm in maximum length; n = 225), most of which are likely manuports introduced to the site by humans, are also pictured here. Similar to mollusks, the cobbles are found throughout most of the vertical extent of the site, but are absent from the upper- and lowermost levels. Likewise, the ostrich eggshell fragments are distributed across approximately one vertical meter of the sediment column, but do not occur in the highest or lowest stratigraphic levels of the site (Figure 4.6).

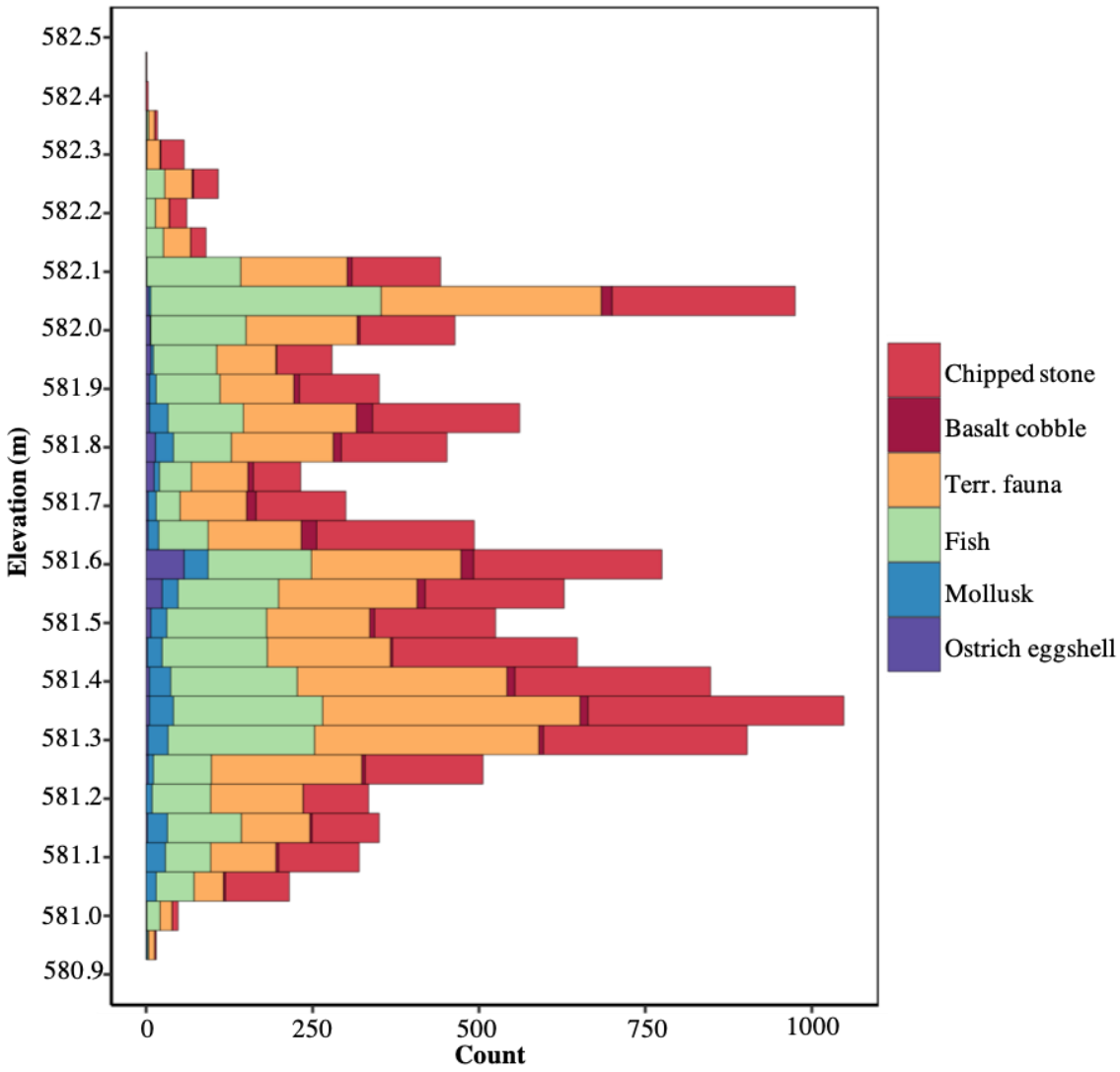

Figure 4.6 Elevation plot showing the frequency of artifacts and faunal remains through the vertical extent of the main excavation area at SM1.

As already noted in Chapter 3, there are several apparently natural breaks in Figure 4.6 that suggest discrete concentrations of material that may represent more than one episode of occupation at SM1. Although distinct depositional layers were not obvious during excavation, closer examination of the north wall of W14 and W15 in 2013 identified several apparent unconformities that strongly suggest at least two different depositional

episodes, further supporting the idea that fauna and artifacts from multiple seasons of occupation are preserved at SM1 (Figure 4.7). Determining if multiple episodes of occupation are present at SM1 is important, because understanding whether or not this is the case is obviously necessary for a full understanding of site formation and patterns of site use. Additionally, it may be of interest for future analyses to examine potential similarities and differences between occupations in terms of taxonomy, ecology, and various aspects of site formation and human behavior.

Because clear separation between layers was not apparent during initial excavations, distinct stratigraphic or depositional layers were not defined at the time of data collection in the field. Therefore, in order to define vertical units representing possible or probable discrete occupational layers that may be of interest for current and future analyses, it is necessary to rely largely on the spatial distribution of material through the stratigraphy by using the occurrence of large items and particularly dense artifact clusters as primary indicators for the presence of different depositional surfaces. This process was achieved as follows:

1. Large basalt cobbles (*i.e.,* with maximum length ≥ 30 mm) were first plotted for each of the six one-meter-wide transects that run north-to-south through the main excavation area (see Figure 4.2). The basalt cobbles provide a good starting point for defining analytical units because they were almost certainly introduced to the site by humans and their large size makes them less likely to have experienced significant vertical (or horizontal) movement within the sediment column (*e.g.,* due to soil cracking during shrink-swell episodes) than smaller artifacts and faunal remains. Generally speaking, these cobbles can be assumed to have remained closer to the surface on which they were originally deposited than many of the other smaller items from the site.

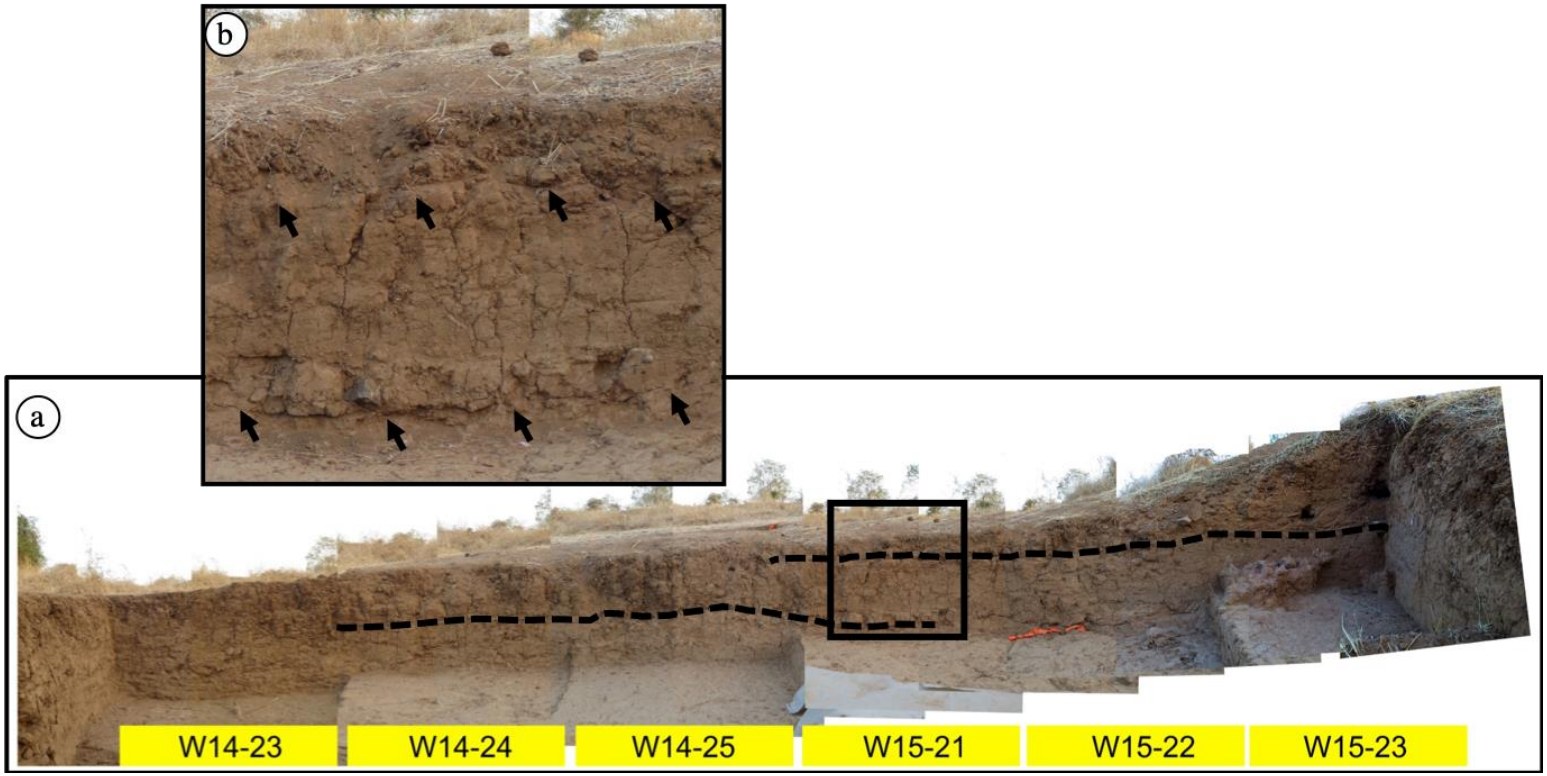

Figure 4.7 a) Overview of the north wall of W14 and W15 showing apparent unconformities (dotted lines) that strongly suggest multiple occupational surfaces and depositional episodes at SM1 and b) close-up of unconformities (arrows) on the wall of W15-21.

2. A series of floors for several analytical units were next delineated based on the position of basalt cobbles in the most eastern transect of the main excavation block (W15- and X15-3/8/13/18/23). These floors were then overlaid onto each successive north-south transect moving west through the site and adjusted when necessary in order to accommodate different groups of cobbles in a given transect. The end result was an initial set of four surface floors, defined solely on the vertical distribution of large basalt cobbles, which could be traced laterally throughout all of the north-south transects in the site (Figure 4.8).

3. This process was then repeated, with the initial floors overlaid onto each north-south transect once more, but this time with chipped stone artifacts and faunal remains plotted along with the basalt cobbles. Once again, floor surfaces were extended and otherwise adjusted as needed to accommodate the material in different transects. Although probable mixing in some areas of the site made it more difficult to confidently sort items into one unit over another, it was nonetheless assumed that all artifacts could be assigned to a specific analytical unit. Modifications to the surface floor lines were largely guided by the position of particularly dense clusters of artifacts, and items floating in between the densest concentrations were simply assigned to the analytical unit in which they occurred based on the final positioning of the surface floors.

4. Once completed, this process produced a final set of surface floors that delineate four separate analytical units (*i.e.,* proposed occupation levels) and can be traced laterally throughout the site. The validity of the final surface floors was then further verified by examining their placement with respect to the vertical distribution of material viewed along east-west transects through the site, and comparing them to the position of the unconformities identified along the north wall of W14 and W15.

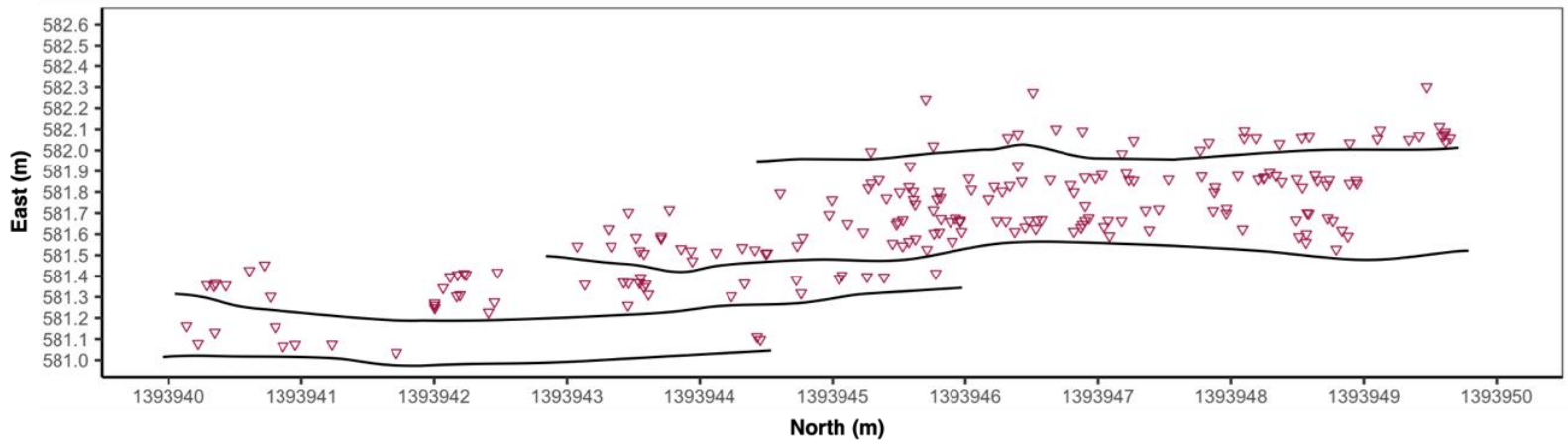

Figure 4.8 Backplot showing the vertical distribution of basalt cobbles in all six of the north-south transects in the main excavation area, and initial floors (black lines) based on the position of cobbles.

The four analytical units defined for SM1 through the process described above along three N-S transects at the eastern and western borders and in the center of the main excavation area are depicted in Figure 4.9. Given that the entire extent of the site uncovered to date appears to have been occupied during the late MSA, the units were simply designated MSA-1, MSA-2, MSA-3, and MSA-4, with MSA-1 being the youngest and MSA-4 being the oldest. As the data in Table 4.2 demonstrate, the analytical units range in total depth from ~34-55 cm, and the two lower units appear to be more compressed than the two upper units. A majority of items are from MSA-2 and MSA-3, which together contain just over 70% of the currently excavated material. MSA-1 accounts for another ~20% of items, and MSA-4 contains the remaining ~10% of fauna and artifacts. Overall, the proportions of each type of material are relatively similar between the analytical units. However, the large basalt cobbles are heavily concentrated in MSA-2, and the proportion of fish in MSA-1 appears to be particularly high relative to the other units. Additionally, only a handful of mollusks occur in MSA-1, and ostrich eggshell is rare in MSA-3 and absent from MSA-4 (Table 4.2).

As already discussed above and in Chapter 3, these analytical units are hypothesized to represent multiple discrete episodes of occupation at SM1. However, because the units were designated *post-hoc* largely on the basis of the spatial distribution of material, without reference to taphonomic, preservational, or other attributes that might further indicate multiple occupation events, they can also be viewed as models of site formation that require further evaluation and confirmation. As such, analyses in the following chapters will employ chi-squared tests of independence between analytical units in terms of faunal representation, bone preservation, and other taphonomic attributes. As described in Chapter 3, if the analytical units are found to differ significantly for one or more of the variables tested, this will indicate that they vary independently of one another

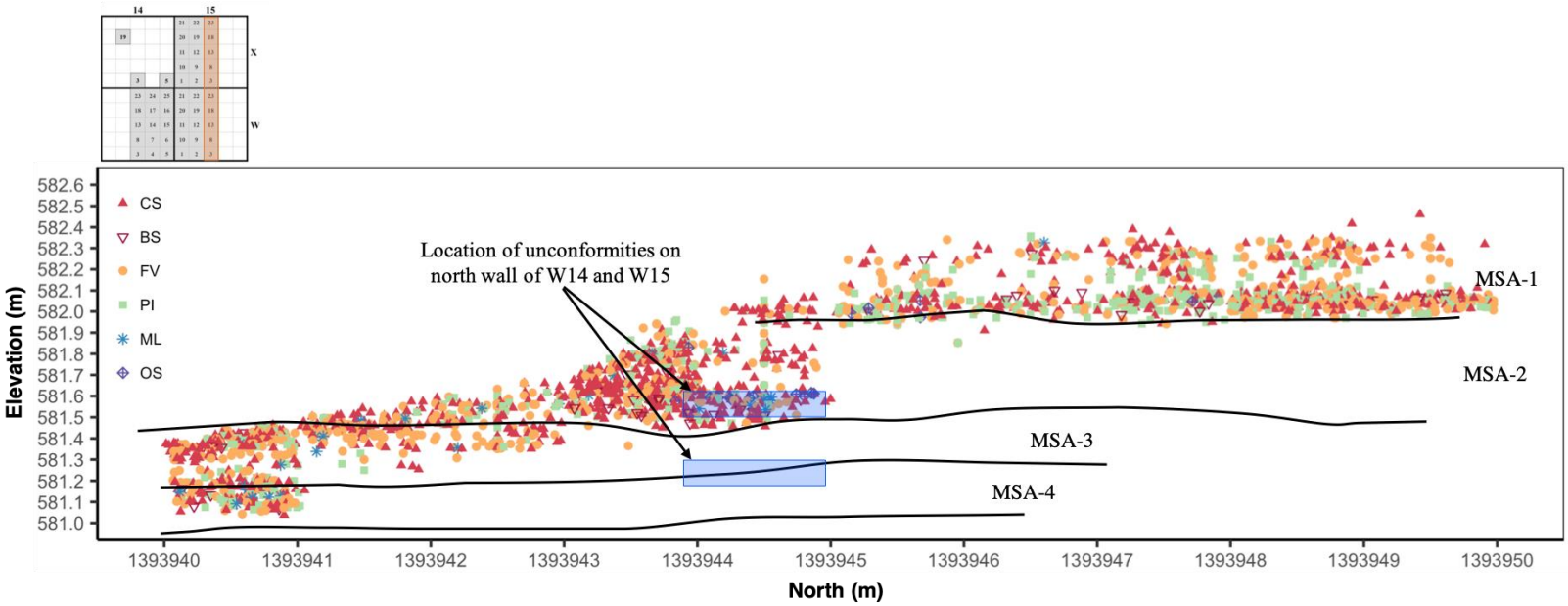

Figure 4.9 a) Backplot of W15- and X15-3/8/13/18/23 showing the proposed occupation floors (black lines). CS = chipped stone; BS = basalt cobble; FV = terrestrial vertebrate; PI = fish; ML = mollusk; OS = ostrich eggshell.

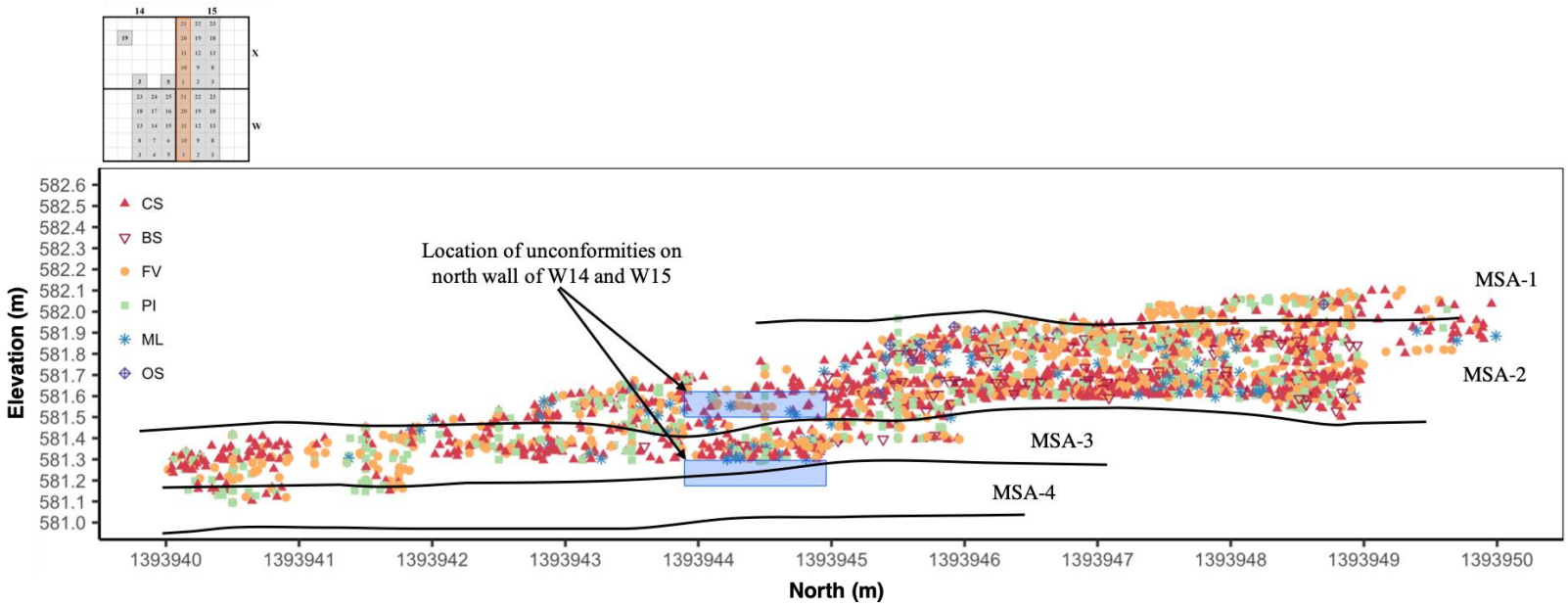

Figure 4.9, cont. b) Backplot of W15- and X15-1/10/11/20/21 showing the proposed occupation floors (black lines). CS = chipped stone; BS = basalt cobble; FV = terrestrial vertebrate; PI = fish; ML = mollusk; OS = ostrich eggshell.

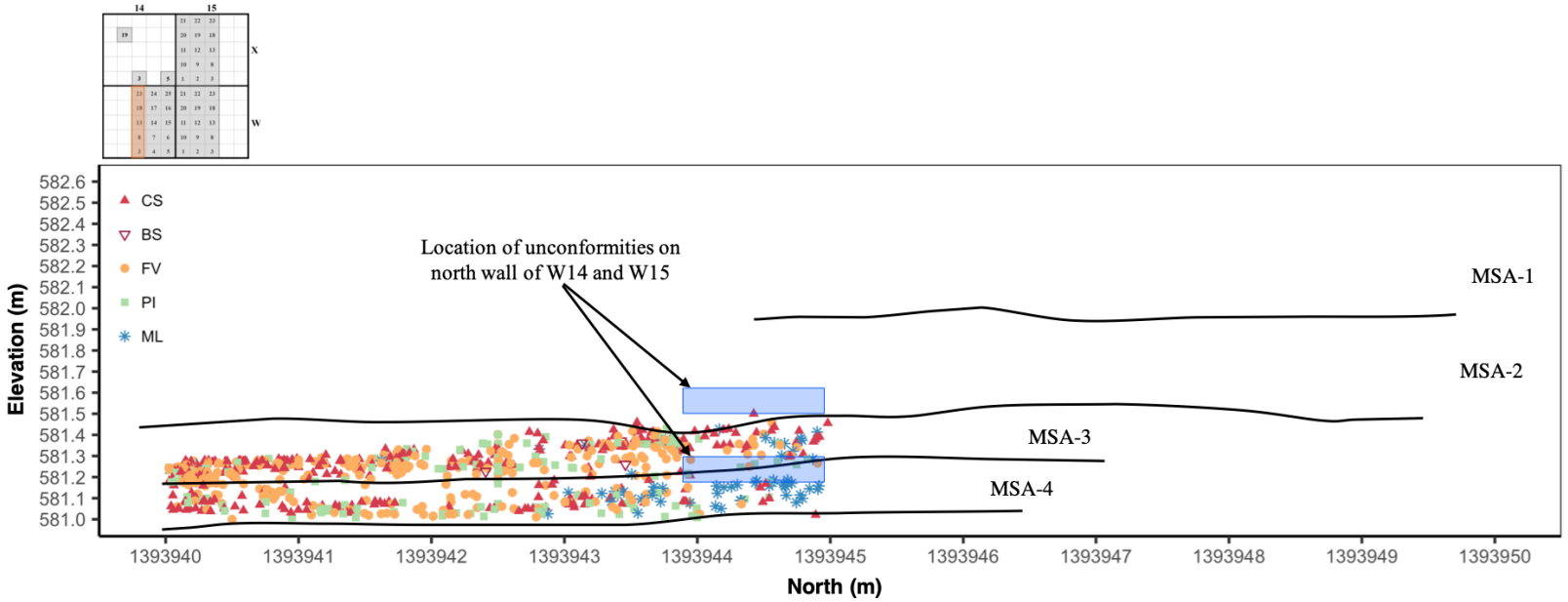

Figure 4.9, cont. c) Backplot of W14-3/8/13/18/23 showing the proposed occupation floors (black lines). CS = chipped stone; BS = basalt cobble; FV = terrestrial vertebrate; PI = fish; ML = mollusk; OS = ostrich eggshell.

Table 4.2 Frequencies of artifacts and faunal remains, and total depth of proposed analytical units at SM1.

	CS	COB	FV	PI	ML	OS	% Total	Depth (m)
MSA-1	677	30	774	705	5	13	18.4	0.49
MSA-2	1668	129	1421	985	187	133	37.6	0.55
MSA-3	1490	38	1513	919	125	16	34.1	0.34
MSA-4	395	10	372	318	90	3	9.9	0.34

AU = analytical unit; CS = chipped stone; COB = basalt cobble; FV = terrestrial mammals, reptiles, amphibians, and birds; PI = fish; ML = mollusk; OS = ostrich eggshell

and provide further support for the idea that they represent multiple occupational levels and have been identified accurately. Assuming this is the case, comparisons will be explored in more detail to determine the nature and direction of differences between units.

If the analytical units are found to be statistically indistinguishable for most or all of the variables tested, this could suggest that multiple occupation levels are not actually present at SM1. However, this possibility seems unlikely, given the identification of the unconformities indicating at least two occupational surfaces on the north wall of W14 and W15 (Figure 4.7), and the fact that backplots of the assemblage along both north-south and east-west transects clearly show several discrete, and often very dense concentrations of artifacts that also suggest multiple occupation events. Alternatively, it may be the case that multiple occupation levels exist at SM1, but: 1) the partitioning of the levels here is not entirely accurate and needs revision; 2) site formation processes are similar across levels, so taphonomic data and human behavioral signatures are simply not that useful for helping validate the presence of separate occupational units; and/or 3) the site is a highly mixed palimpsest of material from multiple occupations and it is not possible to reliably delineate

different levels in the manner described above. These issues will be discussed further in subsequent chapters.

THE GEOGRAPHICAL AND ECOLOGICAL SETTING OF SM1

Modern environments and geomorphology of the Shinfa River

SM1 is situated adjacent to an ancient point bar ~80 m from the banks of the modern Shinfa River, a major trunk tributary of the Blue Nile River, in the lowlands of northwestern Ethiopia at an elevation of ~580 m asl (Figure 4.1). Daily temperatures in the lowlands range from ~20 °C in the rainy season to 40+ °C in the height of the dry season, with annual averages between 22-28 °C (ILRI 2005; Desalew, 2008). Terrestrial habitats in the region consist primarily of broad-leafed woodlands predominated by bushwillow (*Combretum*) and myrobalan (*Terminalia*) trees, and shrubland composed of various herbaceous taxa, including acacia (*Acacia*) and frankincense (*Commiphora*) bushes, bushweeds *(Flueggea*), day flowers (*Commelina*), myrrh *(Boswelia),* burr marigolds (*Bidens*), tick clover (*Desmodium*), spurge (*Euphorbia*), and various legumes (*e.g., Dichrostachys, Indigofera, Piliostigma, Vigna*), with an understory of perennial savanna grasses (*e.g., Brachiaria, Cenchrus, Cynodon*, *Eleusine, Eriochloa, Hyparrhenia, Rhamphicarpa, Setaria, Urochloa)* and sedges (*e.g., Cyprus*) (ILRI 2005; Desalew, 2008; Tewabe, 2008). The primary vegetation found in riparian areas along the Shinfa River and other Blue Nile tributaries in the region includes baobab (*Adansonia digitata*), tamarind (*Tamarindus indica*), and fig (*Ficus vasta; Ficus spp.*) trees, as well as soap berry (*Balanites aegyptiaca*) and buckthorn (*Ziziphus spinachristi*) bushes (Tewabe, 2008). Soils are primarily clay-rich black vertisols, which are subject to significant shrink/swell

episodes produced by extreme ranges in temperature and precipitation (see below) between the wet and dry seasons (ILRI, 2005; Tadesse, 2008).

The Shinfa River, also known as the Rahad River in Sudan, originates in the central highlands of Ethiopia and, along with two other major tributaries of the Blue Nile River, the Gelegu River and Dinder River, drains the central Ethiopian plateau as it runs west/northwest into the lowlands (Kappelman *et al.,* 2014), where it eventually crosses into Sudan and meets the Blue Nile River ~150 km southeast of Khartoum. The river follows a steeply inclined gradient as it leaves the plateau and drops ~1600 m in elevation down into the lowlands; once in the lowlands, the incline of the gradient decreases dramatically and the river begins a significantly more meandering course. For much of its length, the river channel is carved into basalt flows, which constrain channel form in many places (Kappelman *et al.,* 2014). The channel is steep-sided, narrow, and primarily vertically eroded along the upper course of the river in the highlands (Kappelman *et al.,* 2014). The gradient along the middle course of the river becomes less steep, and lateral erosion is more prevalent as the river channel begins to widen. Along the lower course of the river, as the incline continues to decrease, lateral erosion is even more marked and the river channel becomes increasingly wide and its course progressively more sinuous (Kappelman *et al.,* 2014).

The bed load of the Shinfa River consists primarily of highly rounded basalt clasts (sand to boulder size), although pebbles and cobbles of cryptocrystalline quartz (*e.g.,* banded chalcedony) and crystalline quartz are also present (Kappelman *et al.,* 2014). A suspended load of sand, silt, and clay is present throughout the year, but increases dramatically during the wet season when high flows cause heavy erosion of the channel along the upper and middle courses of the river (Kappelman *et al.,* 2014). These high flows, in turn, are produced by heavy rainfall during the brief wet season in the region.

Yearly rainfall totals across the highlands average ~1000-1500 mm; in the lowlands, yearly totals range from 500-1000 mm, and average ~700 mm (Himeidan *et al.,* 2011; Kappelman *et al.,* 2014; Fazzinni *et al.,* 2015). Importantly for this study, the rainfall regime is highly seasonal throughout the region. In the highlands, ~80% of yearly rainfall occurs between June and September, while 50% occurs in July and August. Similarly, ~90% of rain falls between June and September in the lowlands, and a full 60% of yearly rainfall occurs in July and August alone (Figure 4.10) (ILRI 2005; Kappelman *et al.,* 2014). Accordingly, stream flows of the Shinfa River and the other Blue Nile tributaries that originate on the plateau (*e.g.,* Gelegu and Dinder Rivers) are highly variable between wet and dry seasons (Figure 4.10).

During the wet season, narrow channels along the upper course of the river are quickly inundated, producing powerful flows that rush down the steep gradient into the middle and lower courses, causing heavy erosion of channel sides and often carving out deep waterholes in the channel base; lowland rainfall further contributes to heavy wet season flows, albeit to a lesser degree (Kappelman *et al.,* 2014). As rainfall begins to wane at the start of the dry season, stream flows subside and within a short period of time, flows cease altogether and evaporation begins to outpace surface and groundwater recharge (Kappelman *et al.,* 2014). This process continues until the beginning of the next wet season, when the rivers are once again replenished and the cycle begins anew.

The unique geography and geomorphology of the Shinfa River combine with the markedly seasonal rainfall regime in the region to produce a typical 'temporary river' (Larned *et al.*, 2011; Steward *et al.,* 2012), with powerful, bank-full flows during the wet season that decrease during the dry season as the river is reduced to a series of disconnected waterholes (Figure 4.11). High and rapid flows make foraging for aquatic resources in the main river channel essentially impossible during the rainy season. Moreover, despite the

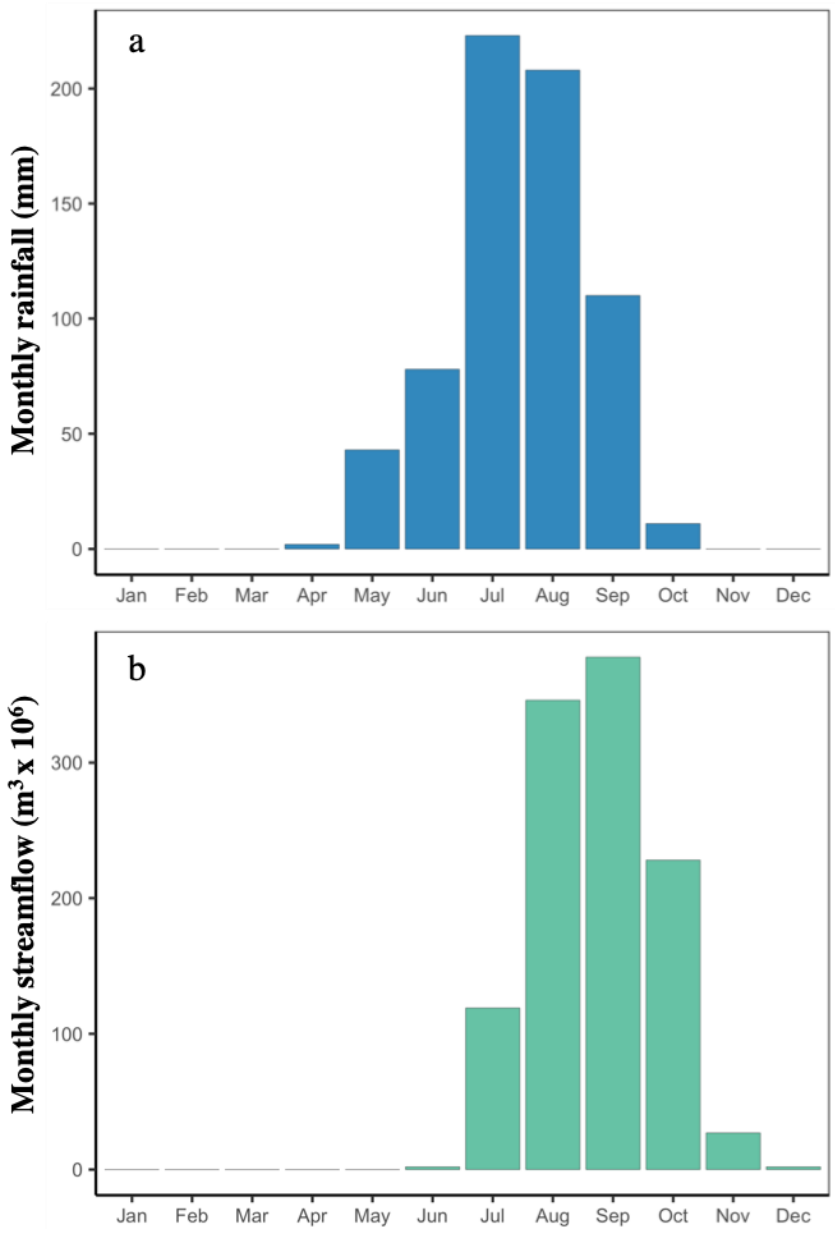

Figure 4.10 a) Monthly rainfall at Gadaref along the Shinfa (Rahad) River in Sudan between 2005-2006 (Himeidan *et al.,* 2011). b) Mean monthly streamflow at the mouth of the Shinfa (Rahad) River between 1908-1997 (Sutcliffe and Parks, 1999).

bank-full flows during much of the wet season, the Shinfa River rarely overflows it banks and inundates the adjacent floodplain (Kappelman *et al.,* 2014). Thus, the floodplain spawning behavior of *Clarias* and other taxa (see Chapter 6), which allow fishers along the Nile River and other river systems in Africa to catch large numbers of these fish during the wet season with relative ease (Stewart, 1989; Van Neer, 2004), rarely occurs at Shinfa (Kappelman *et al.,* 2014). In contrast, the isolated waterholes represent the only surface water during the dry season, and fish, mollusks, and aquatic reptiles are concentrated in these waterholes, while terrestrial mammals must visit them daily for drinking water. As such, the dry season waterholes potentially represent localized resource patches with highly dependable foraging returns in terms of both food and freshwater (Kappelman *et al.*, 2014).

Local Gumuz people restrict fishing largely to the dry season and concentrate their activity in and around the isolated waterholes. During this time of year, fish capture is accomplished by men, women, and children using a variety of traditional methods, many of which employ relatively simple technology, including bow and arrow, wooden weirs, cloth nets, basket traps, and plant poisons, or potentially no technology at all, as in the case of corralling fish into the shallow waters at the edge of a waterhole (Tewabe *et al.*, 2010; Kappelman *et al.,* 2014). As the dry season wears on and pools continue to evaporate and aquatic food resources become depleted, foragers may move along the river in search of other waterholes. Thus, the dynamic nature of the pool reduction and depletion cycle potentially serves to keep groups moving along the river channel throughout the dry season. An analogous focus of foraging and hunting activities around waterholes during the dry season has also been observed among the !Kung San in Botswana (Yellen, 1977) and Hadza in Tanzania (Marlowe, 2003), suggesting that this sort of behavior is not unique to the Blue Nile Basin.

Figure 4.11 The Shinfa River near the height of the dry season in 2016.

The pronounced fluctuations in rainfall, river flow, and aridity that occur in the region around SM1 today result in sizeable shifts in $\delta^{18}O$ values between the wet and dry season that are recorded in weekly water samples from the Shinfa River, as well as in the tooth enamel of bovids that regularly drink from the river, and the shells of mollusks that live therein **(**Nachman *et al.,* 2011; Plummer *et al.,* 2019**)**. Stable isotope analyses of fossil bovid tooth enamel and mollusk shell from SM1 are currently ongoing, and initial results strongly indicate that past climatic conditions at SM1 were also very arid and highly seasonal. These data also suggest that modern environments are likely to be a suitable analog for the MSA, and that MSA people were adapted to many of the same ecological

rhythms and climatic patterns that are present in the region today (*e.g.,* Nachman *et al.* 2011, 2015; Tabor and Kappelman 2014; Kappelman *et al.,* 2014; Wyman *et al.*, 2018; Plummer *et al.,* 2019).

Modern terrestrial and aquatic fauna in the Blue Nile Basin

The rivers, lakes, and terrestrial habitats in the lowlands of northwestern Ethiopia and southeastern Sudan are home to a diverse array of mammals, reptiles, birds, amphibians, fish, and mollusks (Yalden *et al.,* 1996; Habtamu and Bekele, 2008; Mengeshe and Bekele, 2008; Hashim and Mahgoub, 2008; Tewabe *et al.,* 2010; Awoke *et al.,* 2015; Bauer and Rskay, 2015; Bauer *et al.,* 2017). Larger mammal species include carnivores, such as lions (*Panthera leo*), leopards (*Panthera pardus*), and hyaena (*Hyaena hyaena*, *Crocuta crocuta*), as well as numerous ungulates, including Cape buffalo (*Syncerus caffer*), bushbuck and kudu (*Tragelaphus* sp.), reedbuck (*Redunca redunca*), waterbuck (*Kobus* sp.), oribi (*Ourebia ourebia)*, gazelle (*Gazella* sp.), and warthog (*Phacochoerus africanus*) (Tomor, 2006; Hashim and Mahgoub, 2008; Mengeshe and Bekele, 2008; Bauer and Rskay, 2015; Bauer *et al.,* 2017). Additionally, giraffes (*Giraffa camelopardis*) inhabited the region historically, but have not been observed in several decades within either Alatish National Park (ANP) or Dinder National Park (DNP), which are ~50-75 km south and west of SM1, respectively, and converge at the Ethiopia-Sudan border just southwest of the site (Tomor, 2006; Bauer and Rskay, 2015). Likewise, elephants (*Loxodonta africana*) are known to visit ANP seasonally, but may have been more common in the area in the past (Bauer and Rskay, 2015).

Smaller mammals that inhabit this region include baboons (*Papio* sp.), vervet, patas, and grivet monkeys (*Cercopithecus/Chlorocebus* sp.), and bushbaby (*Galago senegalensis*) (Tomor, 2006; Bauer *et al.,* 2017). There are also numerous small carnivores,

such as serval (*Leptailurus serval*), genet (*Genetta* sp.*),* wildcat (*Felis libyca*), jackal (*Canis anthus*), fox (*Vulpes* sp.), mongoose (*Herpestes* sp., *Ichneumia* sp.), and ratel (*Mellivora capensis*) (Hashim and Mahgoub, 2008; Bauer *et al.,* 2017). Other small mammal taxa include porcupine (*Hystrix cristata*), hyrax (*Procavia* sp.), and aardvark (*Orycteropus afer*). Micromammals are abundant and include murid, cricetid, sciurid, soricid, and erinacid rodents, as well as several species of bats (Yalden *et al.,* 1976, 1996; Habtamu and Bekele, 2008; Kruskop *et al.,* 2016).

There are numerous reptiles found in the region around SM1 today, including crocodiles (*Crocodylus niloticus*), tortoises (*Testudo* sp.), and monitor lizards (*Varanus varias*), all of which are quite common in the area (Tewabe *et al.,* 2010). Snakes, such as the rock python (*Python sebae*), black mamba (*Dendroaspis polylepis*), and Egyptian cobra (*Naja haje*), are present in the ANP-DNP area (Berhanu and Teshome, 2018). Amphibian diversity is also quite high in the lowlands of Ethiopia and Sudan, with numerous species of frog from the families Bufonidae, Hemisidae, Hyperoliidae, and Ranidae all living in the region (Largen, 2001).

There are over 120 species of bird known from ANP alone (Mengesha and Bekele, 2008). The black-headed weaver (*Ploceus cucullatus*) and helmeted guineafowl (*Numida meleagris*) are two of the most common birds (in that order), while red-eyed dove (*Streptopelia semtorquata*), giant kingfisher (*Megaceryle maxima*), Ruepell's starling (*Lamprotornis purpuropterus*), and gray heron (*Ardea cinereal*) are also relatively abundant (Mengesha and Bekele, 2008). Raptors, including the fish eagle (*Haliaeetus vocifer*) and hawk eagle (*Hieraaetus spilogaster*), osprey (*Pandion haliaetus*), barn owl (*Tyto alba*) and eagle owls (*Bubo africanus, B. lacteus*), and other large birds, such as storks (*Anastomus lamelligerus, Ciconia Ciconia*) and vultures (*Aegypius tracheliotus*) are present as well, but typically much less common than the other species noted above.

There are at least 36 species of freshwater fish in the Blue Nile River, 27 of which are found in the four major tributaries (Shinfa, Dinder, Guang, and Gendwuha Rivers) located in the area immediately surrounding SM1 (Tewabe *et al.,* 2010; Awoke, 2015). Carp (*Labeo* sp.) and yellowfish/barbs (*Labeobarbus* sp.) are the most abundant fish in the Blue Nile and its tributaries, and the Nile tilapia (*Oreochromis niloticus*) is also relatively common in this region (Tewabe *et al.,* 2010; Awoke, 2015). Additionally, there are numerous genera and species of siluriform catfish, including the African sharp-toothed catfish (*Clarias gariepinus*), wahrindi and shield-head squeaker (*Synodontis schall* and *S. serratus*), silver catfish (*Bagrus* sp.), butter catfish (*Schilbe* sp.), and yellow spiny catfish (*Auchenoglanis biscutatus*). Other fish that inhabit the rivers and lakes in the region around SM1 include tigerfish (*Hydrocynus forskalii*), silversides (*Alestes baremoze*), tetra (*Brycinus* sp.), and electric and elephant-snout fish (*Mormyrus* sp.) (Tewabe, 2008; Tewabe *et al.,* 2010). In addition to fish and aquatic reptiles, the rivers and lakes in the region also contain abundant mollusks, with the Nile bivalve mollusk (*Etheria elliptica*) and several bivalve species of the genus *Chambardia* being some of the most common.

The fauna that live in the area around SM1 today, and/or that are known historically from the region, represent a diverse group of terrestrial and aquatic taxa. Assuming similar faunal communities in the past, it is likely that the SM1 people would have had access to a broad spectrum of potential prey species that could have been exploited at different times of the year for food. Preliminary evidence suggests that the SM1 people hunted, trapped, and caught a wide range of both terrestrial and aquatic animals, and the analyses presented in the following chapters will be used in part to help determine whether or not this is, in fact, the case.

CONCLUSION

The available archaeological and geochronological evidence indicates that SM1 can be confidently assigned to the late MSA (*i.e.,* > 40-60 ka). The site is also located in a region of the Horn from which access to either of the major hypothesized dispersal routes for modern human expansion out of Africa would have been possible. Data from SM1 therefore potentially provide evidence about the adaptive strategies of populations living in similar environments along one or both of the proposed dispersal corridors around the time when humans were dispersing out of Africa. Additionally, the extremes of seasonality in this region of Ethiopia may well be suitable analogs for the fluctuating climatic regimes associated with models of early modern human dispersal behavior in the late Pleistocene.

The diverse faunal remains from SM1 appear to be extensively fragmented, and initial indications are that humans were the primary cause of this fragmentation (see Chapters 5-7). Intensive fragmentation often results from resource intensification during periods of resource stress, which typically occur during the dry season in this part of Africa (Binford, 1984; Speth, 1987). Taken together with the presence of abundant fish and mollusks, which are unlikely to have been collected during the wet season when the river was bank-full and fast-flowing, this evidence suggests that SM1 may have primarily been occupied during the dry season, and these data can be used to test the hypotheses discussed in Chapter 3 regarding riverine foraging and seasonally-focused exploitation of food resources. Thus, SM1 provides an opportunity to assess the counterintuitive idea that, although overall food availability may decrease, the dry season in this region is a period when aquatic food resources are densely aggregated and provide predictable foraging returns (Kappelman *et al.,* 2014).

SM1 also presents a chance to evaluate MSA behavior specifically within the context of temporary river ecology. Ecologists have recently begun to appreciate the socio-

ecological value of temporary rivers for humans, and their roles as faunal refugia and terrestrial corridors during periods of flow cessation (Larned *et al.,* 2010; Datry *et al.,* 2011; Steward *et al.,* 2012), and this study offers a chance to address the role of seasonal extremes and temporary river ecosystems in shaping late Pleistocene adaptive strategies and dispersal. The stable isotope data from SM1 indicate that MSA humans were likely adapted to extremely arid and highly seasonal environments analogous to those present in the region today. Thus, as with modern foragers, the yearly cycle of water hole evaporation, food resource depletion, and relocation to new waterholes may have acted as a sort of "siphon" to keep MSA populations moving along the river channel in the dry season and during drier climatic intervals in general (Kappelman *et al.,* 2011). If this is the case, the implication may be that it is time to reconsider some long-held notions about how and when early humans left Africa, namely the idea that large-scale dispersals were only possible during warmer, wetter periods when "green corridors" existed along river courses in the most arid parts of northern Africa and Arabia (e.g., Drake *et al.,* 2011; Foley *et al.* 2013).

Chapter 5: The terrestrial fauna

INTRODUCTION

The SM1 faunal assemblage includes terrestrial vertebrates, fish, and mollusks, and the primary focus of this dissertation is the analysis of all the vertebrate fauna. The present chapter deals with terrestrial mammals, birds, reptiles, and amphibians, which account for ~55% of the total specimens. Fish make up another ~40% of the SM1 faunal remains, and are discussed separately in chapter 6. Mollusks comprise the remaining ~5% of the fauna, and are also briefly discussed in Chapter 6, but are not analyzed in detail (Table 5.1).

The data presented in this chapter are specifically relevant to testing Hypothesis 1 (*i.e.,* the identity of the primary accumulator of the SM1 fauna), Hypothesis 3 (*i.e.,* seasonal site use), and Hypothesis 4 (*i.e.,* the presence of discrete occupational levels within the site). The results of the following analyses will be discussed in more general terms throughout the chapter and summarized in the last section. All of the results from Chapters 5-7 will then be synthesized and discussed specifically in the context of testing hypotheses about site formation and MSA human behavior in Chapter 8.

TAXONOMY AND PALEOECOLOGY

Taxonomic representation

The following discussion of taxonomic representation among terrestrial mammals, birds, reptiles, and amphibians derives from 4467 specimens recorded for this study, of which 401 were identifiable to at least a broad taxonomic category (e.g., bovid, carnivore, bird). Throughout the chapter these animals are often referred to as "terrestrial fauna" or "terrestrial vertebrates" in order to differentiate them from the fish and mollusks, although the sample does include crocodiles, which are actually aquatic reptiles, and frogs, which

Table 5.1 Basic faunal sample sizes at SM1.

Faunal group	n
Terrestrial mammal[1]	4288
Reptiles	8
Birds[2]	339
Amphibians	10
Fish	3163
Mollusks[3]	410
Total	**8218**

[1] Includes non-identified fragments

[2] Includes ostrich eggshell, which were not analyzed for this study

[3] Not analyzed for this study

may also be more aquatic than terrestrial. NISP, MNE, and MNI counts for the faunal taxa identified at SM1, as well as for specimens classified only as non-fish vertebrates, most of which are likely from terrestrial mammals, are provided in Table 5.2. The relative percentages of NISP, MNE, and MNI accounted for by each of the major faunal groups represented at SM1 are presented in Table 5.3. A full catalog of taxonomic and skeletal element count data for SM1 is provided in Appendix E. Based on comparisons with modern material from the comparative skeletal collections at Ethiopian National Museum, the majority of identifiable material from SM1 falls within the range of variation seen in extant members of the faunal taxa represented at the site.

Table 5.2 Taxonomic representation for terrestrial fauna at SM1.

	NISP	MNE	MNI
Artiodactyla			
Aepyceros sp.	1	1	1
Gazella sp.	5	4	1
Antilopini size 1/2	2	2	1
Reduncini/Tragelaphini size 2	2	2	2
Bovid size 1	32	28	4
Bovid size 2	82	61	5
Bovid size 3	11	8	1
Bovid size 4	1	1	1
Bovid size indet.	37	17	1
Phacochoerus sp.	1	1	1
Carnivora			
Felis lybica	3	3	1
Carnivora indet. (size 1a and 1)	4	4	3
Primates			
Chlorocebus sp.	5	5	1
Lagomorpha			
Lepus sp.	1	1	1
Rodentia			
Hystrix	1	1	1
Gerbilinae	7	7	2
Murinae	5	5	2
Rodentia indet.	22	17	2
Reptilia			
Crocodylus niloticus	3	3	1
Varanidae indet.	1	1	1
Serpentes indet.	3	3	1
Reptilia indet.	1	1	1
Aves			
Numida meleagris	18	15	3
Struthio camelus	178		
Aves indet.	143	14	2
Amphibia			
Anura	10	9	4
Terrestrial vertebrate indet.			
Size 1a	68	49	2
Size 1	20	11	1
Size 2	31	20	3
Size 3	1	1	1

Table 5.3 Percentage of total[1] NISP, MNE, and MNI for major terrestrial taxa at SM1.

	% NISP	% MNE	% MNI
Artiodactyls	63.7	59	43.9
Bovids	*63.4*	*58.5*	*41.5*
Suids	*0.4*	*0.5*	*2.4*
Carnivores	2.6	3.3	9.8
Primates	1.8	2.4	2.4
Lagomorphs	0.4	0.5	2.4
Rodents	12.8	14.2	12.2
Reptiles	2.9	3.8	7.3
Birds[2]	12	13.7	12.2
Frogs	3.7	4.2	9.8

[1]Based on specimens identified to Order or lower

[2]Does not include ostrich eggshell fragments or 128 largely non-identifiable long bone fragments

The ungulate assemblage consists of several bovid taxa and a single genus of suid. Bovids are the most abundant faunal group, and make up 63.4% of NISP for specimens identified to a taxonomic order or lower taxonomic level. Bovids are represented by the tribes Antilopini, Reduncini, Aepycerotini, and possibly Tragelaphini. The only bovids identified below the level of tribe are the genera *Gazella* (slender gazelle), on the basis of a single horn core that preserves a fragment of the shaft, most of the base, and part of the orbit, and *Aepyceros* (impala) based on an isolated mandibular molar. Several other specimens, including an additional horn core fragment, a proximal femur, and two mandible fragments, were also referred to cf. *Gazella*. A small number of specimens classified simply as Antilopini are from relatively small animals, as well, so it is likely that they too derive from one or more gazelles of genus *Gazella* and/or *Eudorcas*. A single complete molar was identified as belonging to the tribe Reduncini (rhebok, reedbuck, kob),

and an additional partial molar was classified as Reduncini or Tragelaphini (bushbuck, kudu, eland) based on the presence of the "goat fold" on the buccal side of the tooth. Additionally, the suid genus *Phacochoerus* (warthog) was identified at the site on the basis of a single complete third molar (0.4% of NISP).

Carnivore specimens, which make up 2.6% of NISP, include several phalanges and a metatarsal that were referred to *Felis lybica* (African wildcat) largely on the basis of their very small size and the fact that this species is common at late Pleistocene sites in eastern and central Sudan and is still present in the area around SM1 today (Marks, 1987; Peters, 1989). It is also possible that these bones are from a juvenile *Leptailurus serval* (serval), which is another relatively small cat roughly twice the size of *F. libyca,* but the fact that the proximal epiphyses appear to be fully fused further supports the classification as an adult *F. lybica.* Additional specimens, including a premolar fragment, a metapodial fragment, and two proximal radii, were also identified as belonging to carnivores but could not be assigned to a more specific taxon.

The primate material represents 1.8% of total NISP, and consists of two partial molars, an isolated femoral head, a proximal humerus fragment, and a complete radius shaft. All of the specimens are from monkeys of the subfamily Cercopithecinae, and most likely belong to one or more species of *Chlorocebus* (*e.g.,* grivets, vervets), given the size and morphology of the material, and the geographic distribution of these taxa both now and in the past (Haus *et al.,* 2013; Bauer and Rskay, 2015; Bauer *et al.,* 2017). The two most likely candidate species are *C. aethiops* and *C. pygerythrus,* of which *C. aethiops* is still extant in the region around SM1 today (Bauer and Rskay, 2015; Bauer *et al.,* 2017).

Lagomorphs (0.4% of NISP) were identified on the basis of a single complete calcaneus that was identified as *Lepus* sp., and may belong to *L. capensis* (cape hare), a species that still inhabits the Blue Nile Basin and is known from late Pleistocene sites along

the Nile and its tributaries in eastern Sudan and Egypt (Gautier and Van Neer, 1989; Van Neer *et al.,* 2000; Osypinski *et al.,* 2011). It is also possible that this specimen is from *L. saxatillis* (scrub hare), which is also present in the region today, but may not have been as common in the past (Kingdon, 2015). Rodents are both more common, representing the second-most abundant faunal group with 12.8% of NISP, and more diverse in terms of identified taxa. *Hystrix cristata* (crested porcupine) is the only larger-bodied (*i.e.,* size 1) rodent identified at SM1, on the basis of a single molar. Smaller rodent taxa at the site are all from the family Muridae (rats, mice, and gerbils). Three complete mandibles, three isolated third molars, and a hemimandible with teeth that were similar but heavily worn and therefore more difficult to identify, were classified as the subfamily Gerbilinae (gerbils), and probably belong to the genera *Gerbillus, Gerbilliscus,* and/or *Taterillus* based on the current distribution of these taxa (Happold, 1967; Yalden *et al.,* 1976, 1996). An additional three mandibles and two isolated first molars were also identified as belonging to the subfamily Murinae (rats and mice). The rest of the specimens, including several complete compact bones and vertebrae, partial long bones, and fragmentary teeth and mandibles, could not be identified to a particular taxon within Rodentia, but all come from very small animals and are likely also from one or more taxon of murid rodent.

There are three groups of reptiles represented at SM1, which together make up just under 3% of NISP. Two similarly-sized partial phalanges found centimeters apart, and which are almost certainly from the same individual, were identified as belonging to *Crocodylus niloticus* (Fergusson, 2010). An additional partial vertebra was classified as cf. *Crocodylus*, but was too degraded and fragmented for a definitive classification. The other reptile taxa identified are the family Varanidae (lizards), which is represented by a largely complete cervical vertebrae, and suborder Serpentes (snakes), which was also identified based on the presence of three indeterminate vertebrae fragments. A final specimen, which

consists of a long bone epiphysis and partial shaft that appears to be from a small-to-medium sized reptile, but did not match any of the comparative material available for examination, was classified simply as an indeterminate reptile.

When only specimens classified to a specific skeletal element are considered, birds are the third-most abundant faunal group, making up 12% of total NISP. If non-identifiable specimens are included, birds represent 40.1% of NISP, largely because the distinctive morphology of bird bones (*i.e.,* hollow and light, with very thin cortical surfaces) makes them easy to recognize even as small and otherwise non-identifiable fragments. Thus, when non-identified bones are considered, the NISP count for birds is more than doubled by the presence of 128 generic (*i.e.,* largely non-descript) long bone fragments that were nonetheless identifiable as birds.

Numida meleagris (helmeted guineafowl) is the only bird taxon identified definitively based on skeletal elements, and is represented by multiple coracoids, humeri, ulnae, and tarsometatarsi, and a single tibiotarsus. Several phalanges, a femoral shaft fragment, and a tibiotarsus shaft also likely belong to *N. meleagris*, but were too broken and/or degraded to identify conclusively. The remainder of the bird bones, many of which are non-identifiable long bone shafts and/or fragments, could not be classified to a specific taxon, but almost all of them appear to come from birds of a similar size as *N. meleagris* or smaller. The only exception is a heavily eroded proximal tibiotarsus fragment from a bird that is quite a bit larger, possibly a medium-sized water-bird (*e.g.,* pelican, stork) or Rüppell's vulture. Additionally, 178 eggshell fragments from *Struthio camelus* (ostrich) eggs were also recovered at SM1, but were not analyzed for this study.

Several specimens of the class Amphibia were also recovered and represent 3.7% of NISP. These bones include a complete pelvis, a mostly complete innominate, and multiple radio-ulnae, and all are from the order Anura (frogs). Although none of the

specimens were identified to a lower taxonomic level, it is quite possible that they represent one or more of the multiple species of family Bufonidae, Hemisidae, Hyperoliidae, and/or Ranidae that are currently found in the arid, lowland regions of western Ethiopia (Largen, 2001).

Taxonomic diversity

Examining taxonomic abundance in the SM1 assemblage through measures of diversity, heterogeneity, and evenness may offer insight into aspects of early human behavior, including diet breadth and prey choice. There are at least four animal classes, 10 orders, and 13 families represented among the terrestrial fauna (including snakes and frogs, which are represented by at least one family each, although identifications were only possible to the level of order); when fish and mollusks are included, these numbers increase to six classes, 14 orders, and 21 families. However, due to the highly fragmented nature of the assemblage and a lack of intact craniodental specimens (see below), the sample of terrestrial specimens identified to lower taxonomic levels (*i.e.,* genus/species), which are typically used for calculating measures of taxonomic diversity, is quite small.

Nonetheless, considering the limited sample of terrestrial fauna identified to at least the genus level (n = 38), NTAXA = 9, which in turn produces values of 0.76 for taxonomic evenness (*e*), 3.92 for the reciprocal of the Simpson Index (1/D), and 1.67 for the Shannon Index (H). Taken together, these values indicate an assemblage that is moderately diverse and even, and not very heterogeneous. The value of 1/D, in particular, suggests a fairly pronounced predominance of one or a few taxa, a pattern which in this case is largely due to the fact that *Numida* accounts for over 40% of the small number of specimens identified to genus.

When taxonomic diversity is considered at the level of family, which allows for the inclusion of a larger portion of the total sample (n = 218), NTAXA = 10 families, and the indices are as follows: e = 0.35, 1/D = 1.56, and H = 0.85. Although taxonomic richness is slightly higher in this case, with ten families identified as opposed to only nine genera, these values also suggest less evenness (e = 0.35) among the taxa in the assemblage, more dominance by a single taxon (1/D = 1.56), and lower levels of heterogeneity (H = 0.85). In this case, the low values are clearly driven by the relative abundance of bovids, which account for ~80% of terrestrial fauna identified to family, and between ~40-65% of specimens identified to any taxonomic group, depending on which measure of taxonomic abundance is used (Table 5.3).

Paleoecological implications of the faunal assemblage

Modern and fossil Antilopine bovids are well-adapted to arid landscapes, and extant *Gazella* and *Eudorcas* species are primarily grazers or mixed feeders that live in a range of sparsely-to-moderately vegetated habitats, including deserts, sub-/semi-deserts, grassland savannas, and mosaic shrublands, parklands, and montane woodlands (Mendelssohn *et al.,* 1995; Yom-Tov *et al.,* 1995). Reduncine bovids include grazers, browsers, and mixed feeders, many of which are also found in more open habitats, such as valley grasslands, riverine floodplains, and volcanic outcrops (Kingdon, 2015). Unlike many species of *Gazella*, which can obtain sufficient moisture from vegetation alone, Reduncines are typically found in more well-watered areas with a permanent source of water nearby (Table 5.4) (Kingdon, 2015).

Aepyceros melampus is a mixed feeder that occupies the ecotones between open grasslands and dense woodlands, often spending more time in the grasslands during the

Table 5.4 Habit attributions for extant members of the terrestrial faunal taxa present at SM1.

Taxon	Cover	Habitat(s)
Aepyceros melampus	light-to-heavy	open grassland/woodland
Gazella sp.	open; light	grassland; shrubland; sub/semi-desert
Tragelaphine bovid	medium-to-heavy	bushland, woodland, forest
Reduncine bovid	light-to-heavy	well-watered grassland or woodland
Phacochoerus sp.	open; light	open woodland; bushland
Felis libyca	variable	variable
Lepus sp.	open; light	grassland; scrubland; woodland
Chlorocebus sp.	open-to-medium	riverine woodland; riparian savanna
Hystrix cristata	open; light	grassland; woodland
Gerbilinae	variable	grassland; arid or moist woodland
Crocodylus niloticus	-	riverine (aquatic)
Numida meleagris	open; light	well-watered grassland; woodland
Struthio camelus	open; light	grassland; open woodland

Sources: Rector and Reed, 2008; Kingdon, 2015

rainy season and more time in the woodlands during the dry season (Kingdon, 2015). This species also prefers woodlands and shrublands populated with *Acacia* and *Combretum* shrubs and trees, both of which are common in woodland habitats around SM1, and in the Blue Nile Basin more generally, today. Tragelaphine bovids are largely browsers and many species inhabit more closed environments that range from moderately vegetated woodlands to deciduous thickets and dense evergreen forests (Kingdon, 2015). The extant warthogs, *Phacochoerus aethiopicus* and *P. africanus,* are well-adapted to highly seasonal environments and can tolerate a range of habitats, from sub-/semi-deserts to grasslands to

thin woodlands, but all of which are relatively open and arid (Table 5.4) (Yalden *et al.,* 1984; d'Huart and Grubb, 2001).

The two candidate species for the fossil monkeys at SM1, *Chlorocebus aethiops* and *C. pygerythrus,* are both largely restricted to grassland savannas and lightly wooded areas, including riverine woodlands (Struhsaker, 1967; Zinner *et al.,* 2002). The two species of hare that currently inhabit this region of eastern Africa are somewhat distinct in terms of habitats. *Lepus capensis* is found primarily in completely open savanna, while *L. saxatillis,* lives in a variety of grassland, scrubland, and woodland ecosystems (Kingdon, 2015). The crested porcupine, *Hystrix cristata,* often lives in wooded grasslands, riverine woodlands, and bamboo woodlands in the region around SM1 (Habtamu and Bekele, 2008). Habitat preferences for the other rodents from SM1 are difficult to identify, given that the material was classified only as belonging to Gerbilinae and Murinae, both of which are very large subfamilies, although many extant species of the Gerbilinae also live in relatively open grassland and woodland habitats (de Ruiter *et al.,* 2008) (Table 5.4).

Freshwater crocodiles are found in rivers and lakes across Africa, and spend the majority of their time near the shoreline, either submerged in the water or sunning themselves on the shore (Hutton, 1989). Once again, it is difficult to infer habitat preferences for the other reptiles from SM1, given that specimens were only identified as belonging to broad taxonomic groups. The same is true of the amphibian material, none of which could be assigned to a specific taxon within the order Anura.

Similar to many of the terrestrial mammal taxa, the bird species identified at SM1 are also generally associated with open woodland and grassland habitats. *Numida meleagris* can be found in a variety of habitats, from parched plains to dense forest margins, but is most common in well-watered savanna grasslands and open woodlands (Ratcliffe and Crowe, 2001). *Struthio camelus* historically occupied a wide range of ecosystems

across Africa, from semi-desert lowlands, to arid grasslands, to woodland forests, but all of which are relatively open and typically lack dense vegetation or tree cover (Cooper *et al.,* 2009, 2010).

Taken together, the makeup of the faunal assemblage suggests a mix of open and light-to-moderate cover habitats around SM1 during the late MSA (Table 5.4). Taxa such as *Gazella, Phacochoerus, Lepus*, and *S. camelus*, are generally indicative of more open environments (*e.g.,* grassland, shrubland), although many of these animals may also be found in more closed woodland habitats in some places. *Gazella* species are well-adapted to extreme aridity, but many of the other taxa are water-dependent, and the presence of reduncine bovids and *N. meleagris* in particular, indicates that even open grasslands were likely to have been relatively well-watered. This is unsurprising, given that SM1 is located directly adjacent to an ancient point bar and may have never been more than a few hundred meters from the main course of the paleo-Shinfa River over the last 100 ka. The presence of *Crocodylus*, as well as fish and mollusks (see Chapter 6), is also an indication that SM1 was located in a riverine habitat very close to permanent water during its occupation, although the possibility that these animals could have been caught at some distance away and simply transported back to SM1 cannot be completely ruled out.

The identification of *Aepyceros* and possibly tragelaphine bovids at SM1 also implies the likely presence of more light and/or moderate cover habitats, such as woodlands, thickets, and gallery forests, around SM1 during the late MSA. This inference is further supported by the identification of *Chlorocebus* monkeys, given that the likely candidate species are known to inhabit woodlands and savannah grasslands. Once again, the presence of woodlands, thickets, and/or gallery forests is unsurprising, given the probable proximity of the site to the paleo-river channel. Overall, the mosaic of habitats suggested by the terrestrial faunal assemblage from SM1 is similar to the those found in

the region today, although it is possible that wide-open grassland and shrubland was more prevalent in the immediate vicinity of SM1 during the late MSA than is currently the case.

SKELETAL ELEMENT REPRESENTATION

It is useful to consider the representation of skeletal elements as part of the broader overview of the general taxonomic makeup of the terrestrial faunal assemblage at SM1, although this subject will also be returned to later in the chapter when considering the behavioral implications of human and carnivore activity at the site (see below). A complete list of skeletal elements by taxonomic group and size class is available in Appendix E.

The majority (90.2% of NISP) of terrestrial faunal specimens are mostly or completely non-identifiable fragments of bone and tooth (Table 5.5). Of these specimens, 37.1% were identifiable as otherwise non-descript fragments of terrestrial mammal or bird long bone shafts, and another 5.2% were small fragments of tooth enamel. The remaining ~48% of these specimens could not be identified more specifically than simply belonging to terrestrial vertebrates, most of which are likely mammals (Table 5.5). The identifiable portion of the assemblage includes 436 specimens (9.7% of NISP). Long bones (38.4%) are the most abundant and along with axial elements (23.8%) represent just over 60% of the identified specimens. Identifiable teeth (14.6%) and compact bones (13.5%) are also relatively well-represented, making up another ~30% of the collection combined. Cranial bones, which consist mostly of horn core (n=15) and mandibular fragments (n=26), as well as a single non-identifiable skull fragment from a small mammal, are the rarest and make up less than 10% of the total specimens identified to a specific skeletal element.

Table 5.5 NISP counts and frequencies (%) of skeletal element groups by taxon at SM1.

Element type	ART	CV	LG	PR	RO	RP	AV	AM	UN	% ID	% Total
Cranial bones[1]	30	-	-	-	8	-	-	-	4	**9.6**	**0.9**
Teeth	31	1	-	2	14	-	-	-	16	**14.6**	**1.4**
Axial elements[2]	3	-	-	-	3	4	10	2	82	**23.8**	**2.3**
Long bones[3]	77	6	-	3	7	3	18	8	46	**38.4**	**3.8**
Compact bones[4]	33	-	1	-	3	-	4	-	18	**13.5**	**1.3**
Non-ID long bone fragment	-	-	-	-	-	-	128	-	1531	-	**37.1**
Non-ID tooth	-	-	-	-	-	-	-	-	232	-	**5.2**
Non-ID bone	-	-	-	-	-	-	-	-	2139	-	**47.9**

[1] Cranium, mandible, horn core

[2] Vertebrae, scapula, ribs, pelvis

[3] Includes phalanx 1 and 2

[4] Phalanx 3, carpals/tarsals, sesamoids, patella

%ID = percentage of specimens identified at least a taxonomic Order

ART=artiodactyl; CV=carnivore; LG=hare; PR=primate; RO=rodent; RP=reptile; AV=bird; AM=frog; UN=non-ID

Given that bovids make up a large portion of the specimens identified to taxon, it is not surprising that this group also dominates the collection of specimens identified to skeletal element. Bovids account for ~45-70% of cranial bones, teeth, long bones, and compact bones. The only exception is axial elements, for which bovids represent only 2.9% of the identified specimens. This very small value is almost certainly due in part to the fact that most of the axial elements (78.8%) are not identifiable to a specific taxon, with just under half (46.2%) of them being small rib fragments that average ~2.5 cm in maximum length, and the longest of which is only ~5 cm. Another 27.4% of the bones not identified to taxon are long bones, many of which are small phalanges and fragments thereof that all likely belong to birds or micromammals, although a definitive determination was not made

between the two. Phalanx 1 and 2 are included with long bones because in larger mammals they represent elements with two epiphyses and a tubular shaft which contains a small amount of marrow (Thompson, 2008). Similarly, most of the 30.5% of compact bones not identified to a taxonomic group belong to rodents or other micromammals that were simply classified as microfauna because a more specific distinction was not made at the time of data collection (Table 5.5)

BODY SIZE REPRESENTATION

It is also informative to consider animal body size representation at SM1 as part of the general taxonomic character of the terrestrial faunal assemblage. Once again, the topic of animal body size will be revisited in subsequent sections on human and carnivore behavior, following discussion of taphonomic analyses of the terrestrial fauna. The following discussion of body size class (Brain, 1981) representation is based on 341 specimens that were identified as a specific skeletal element and assigned a body size class, of which 230 were also classified to at least to a taxonomic order. Analyses of body size based on long bone cortical thickness (CT) categories (Reynard *et al.*, 2014; and see Chapter 3) are based on 1607 long bones and long bone fragments for which maximum cortical bone thickness was measured, most of which were not identifiable to a specific taxon (88%) or element (94%).

Of the identified specimens that were assigned a body size class, 41.9% are size 1a, 18.2% are size class 1, and 36.1% are size class 2 (Figure 5.1). Animals larger than size 2 make up less than 4% of the total fauna, and there are no identified elements from animals larger than size class 4. The numbers are quite similar when MNE (n=276) is considered, albeit with small increases in the percentages of size 1a (44.9%) and size 4 (0.4%) elements

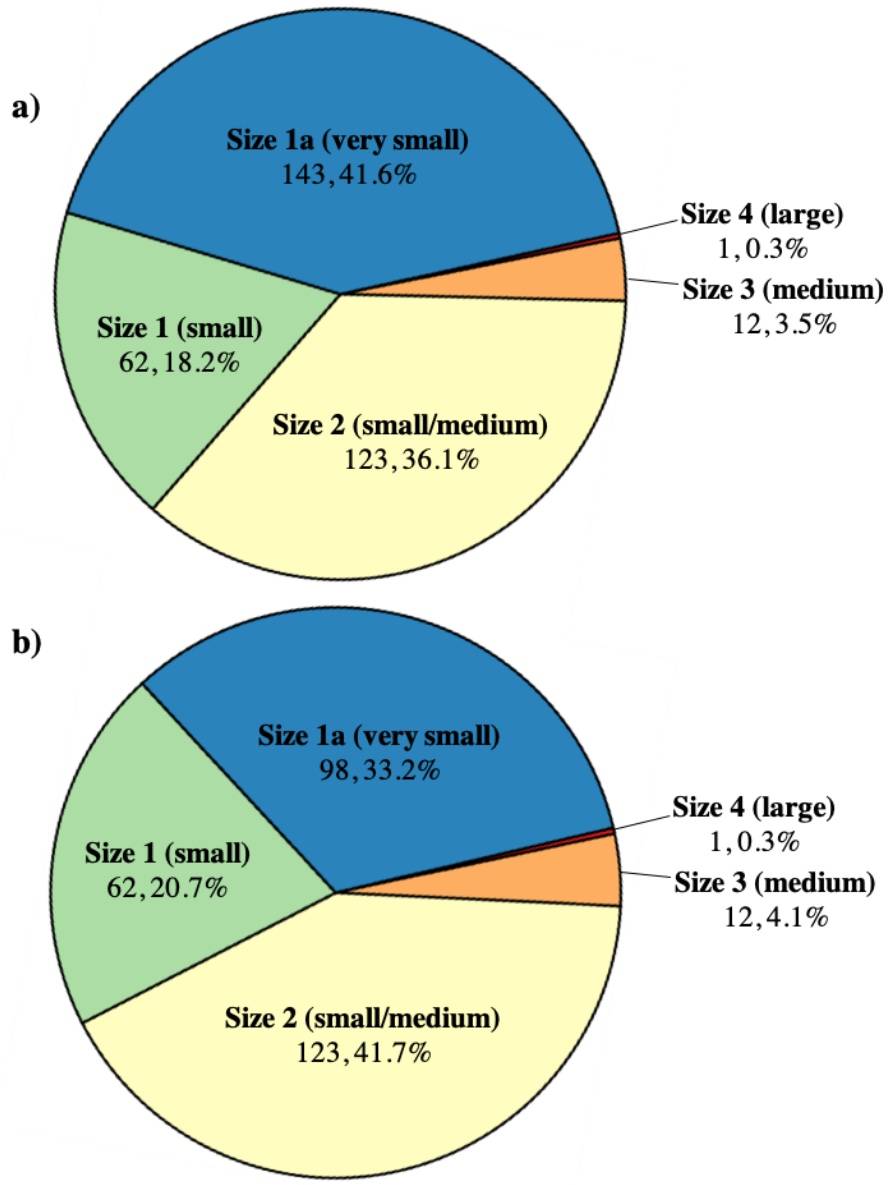

Figure 5.1 NISP counts and frequencies of each body size class a) with and b) without microfauna (*i.e.,* ≤1 kg) included. Weight ranges: size 1a = < 5kg; size 1 = 5-23 kg; size 2 = 23-84 kg; size 3 = 84-296 kg; size 4 = 296-900 kg; size 5 = 900+ kg.

and slight decreases in the percentages of size 2 (32.6%) and 3 (2.9%) elements, while the percentage of size 1 elements (19.2%) remains exactly the same.

When the smallest microfauna (*i.e.,* those weighing < ~1 kg: murid rodents, lizards, snakes, and frogs), are excluded the size class data indicate that size 2 (41.7%) animals are actually the most abundant, followed by size 1a (33.2%) and size 1 (20.7%) (Figure 5.1). These data are more in line with analyses of body size representation based on CT categories which also indicate that small/medium taxa are the most common at SM1 (Figure 5.2). In this case, 29.3% of the bones are from very/small (*i.e.,* size 1a and 1) animals, 59.3% are from small/medium (*i.e.,* size 2) animals, 10.3% are from medium-sized (*i.e.,* size 3) animals, and 1% are from medium/large (*i.e.,* upper end of size 3 or size 4) animals. There are also six specimens (0.4%) from very large (*i.e.,* size 5) taxa.

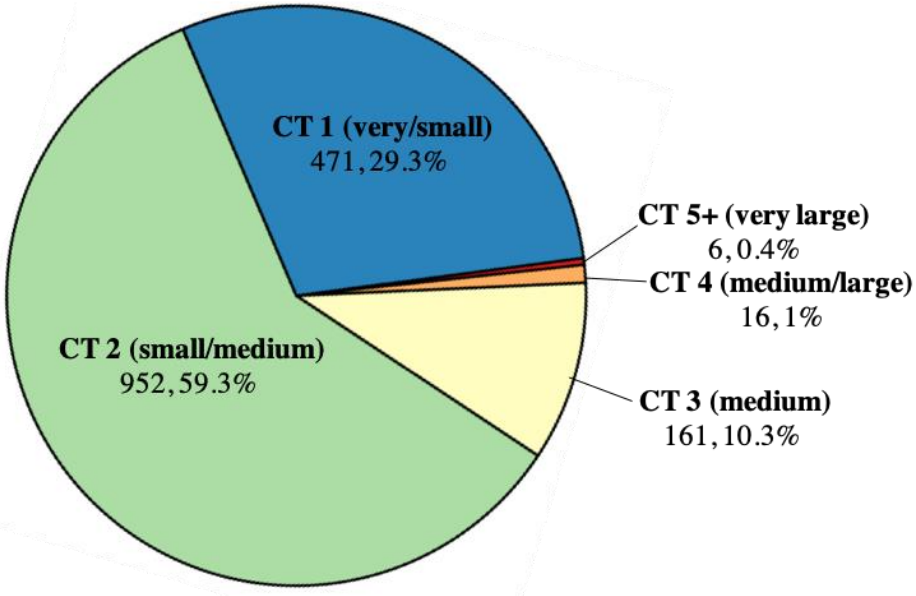

Figure 5.2 NISP counts and frequencies (%) of each long bone cortical thickness (CT) category.

Body size and taxonomy

Rodents (23.1%) and birds (21.7%) make up just under half of the size 1a specimens, with another 41.2% belonging to small terrestrial vertebrates that were not identifiable to a specific taxonomic group (Table 5.6). The remainder of the size 1a animals are frogs (6.3%), small carnivores (4.2%), lizards and snakes (2.8%), and a hare (0.7%). The size 1 assemblage is mostly bovids (58.1%) and generic terrestrial vertebrates (29%), with several primates (8.1%), and a single specimen each of *Hystrix,* a small carnivore, and a larger-sized bird (1.6% each) also included. Once again, most of the identified size 2 animals are bovids (71.5%), and the rest are non-descript mammals (25.2%), crocodiles and a non-identified reptile (2.4%), and a warthog (0.8%). Finally, all but one of the size 3 specimens (91.7%) and the one size 4 specimen (100%) are bovids. The only other medium/large specimen is from a size 3 animal for which a taxon could not be determined.

The bovid material spans a range of body sizes, but the overwhelming majority of bovids are size 1 (26.5%) and 2 (64.7%) (Table 5.7). As noted above, there are also several specimens from size class 3 (8.1%), and a single specimen attributed to size class 4 (0.7%). The single suid specimen is also from a size class 2 animal. All of the primate material derives from a relatively small *Chlorocebus* monkey, species of which typically weigh between ~3-8 kg, placing them at the high end of size 1a or the low end of size 1 in terms of body mass. All specimens were classified as size 1 here, but even individuals at the high end of that weight range represent prey items that could have been caught using snares and/or traps (Wadley 2010), so could also be considered size 1a in that respect. Although the sample is small, all of the carnivore specimens are also from animals of size class 1a or 1, and no medium- or large-sized carnivores were identified at the site. Likewise, the single *H. cristata* tooth represents the only larger-bodied (*i.e.,* size 1) rodent in the

assemblage, and all of the rest of the rodent specimens (97.1%) are from mice, gerbils, and perhaps other very small taxa (Table 5.7).

Table 5.6 Frequency (%) of each body size class represented by different taxa at SM1.

Taxon	1a	1	2	3	4
Bovid		58.1	71.5	91.7	100.0
Suid			0.8		
Carnivore	4.2	1.6			
Primate		8.1			
Lagomorph	0.7				
Rodent	23.1	1.6			
Reptile	2.8		2.4		
Bird[1]	21.7	1.6			
Frog	6.3				
Indet. terrestrial vert.	41.2	29.0	25.2	8.3	
Percentages based on NISP Weight ranges: size 1a = < 5kg; size 1 = 5-23 kg; size 2 = 23-84 kg; size 3 = 84-296 kg; size 4 = 296-900 kg; size 5 = 900+ kg.					

Table 5.7 Frequency (%) of each taxon represented by different body size classes at SM1.

Taxon	1a	1	2	3	4
Bovid		26.5	64.7	8.1	0.7
Suid			100.0		
Carnivore	85.7	14.3			
Primate		100.0			
Lagomorph	100.0				
Rodent	97.1	2.9			
Reptile	57.1		42.9		
Bird	96.9	3.1			
Frog	100.0				
Indet. terrestrial vert.	54.1	16.5	28.4	0.9	
Percentages based on NISP Weight ranges: size 1a = < 5kg; size 1 = 5-23 kg; size 2 = 23-84 kg; size 3 = 84-296 kg; size 4 = 296-900 kg; size 5 = 900+ kg.					

The reptiles are split between size 1a (57.1%) and size 2 (42.9% each), with all of the smaller specimens belonging to lizards and snakes and the larger elements from at least one crocodile and a generic reptile of an unknown taxonomic status. All but one of the identified bird bones (96.9%) are size 1a, and over half of them are from helmeted guineafowl. As noted above, the remaining bird specimen comes from a bird roughly the size of a Rüppel's vulture, which typically weigh ~6-9 kg, and was accordingly assigned to size 1. Although this specimen is not classified as "small, collectible prey" (*i.e.,* < 5 kg) based on body mass (see Chapter 3), it is still entirely plausible, and perhaps quite likely, that a bird of this size would have been caught using snares, traps, or even small projectile weaponry. Additionally, like many of the reptiles and most of the birds, all of the frogs (100%) are obviously also size 1a.

The relative frequencies of body size classes within each of the analytical units (*i.e.,* hypothesized occupation levels) defined in the previous chapter are depicted in Figure 5.3. The results of chi-squared tests of independence between the analytical units for body size class representation are provided in Table 5.8. The p-values from Fisher's Exact Test (FET) using the same data are also included because in every pairwise comparison among the analytical units, at least one cell had expected counts less than 5, meaning that chi-squared tests may not be appropriate for these data. The final totals were unknown at the time of data collection, so marginal sums were not fixed beforehand in this analysis, which may also affect the accuracy of FET results. Nonetheless, both tests are largely in agreement, with three or four of the six pairwise comparisons denoting statistically significant differences in body size representation between units. The only comparison for which the two analyses do not agree is between MSA-2 and MSA-3, with chi-squared tests suggesting differences between the two units are not significant and FET indicating that they are significantly different at $\alpha = 0.05$. Nonetheless, the general agreement between chi-squared

and FET results suggest that any effects from small samples or non-fixed margins are unlikely to substantially alter the overall conclusions from these analyses.

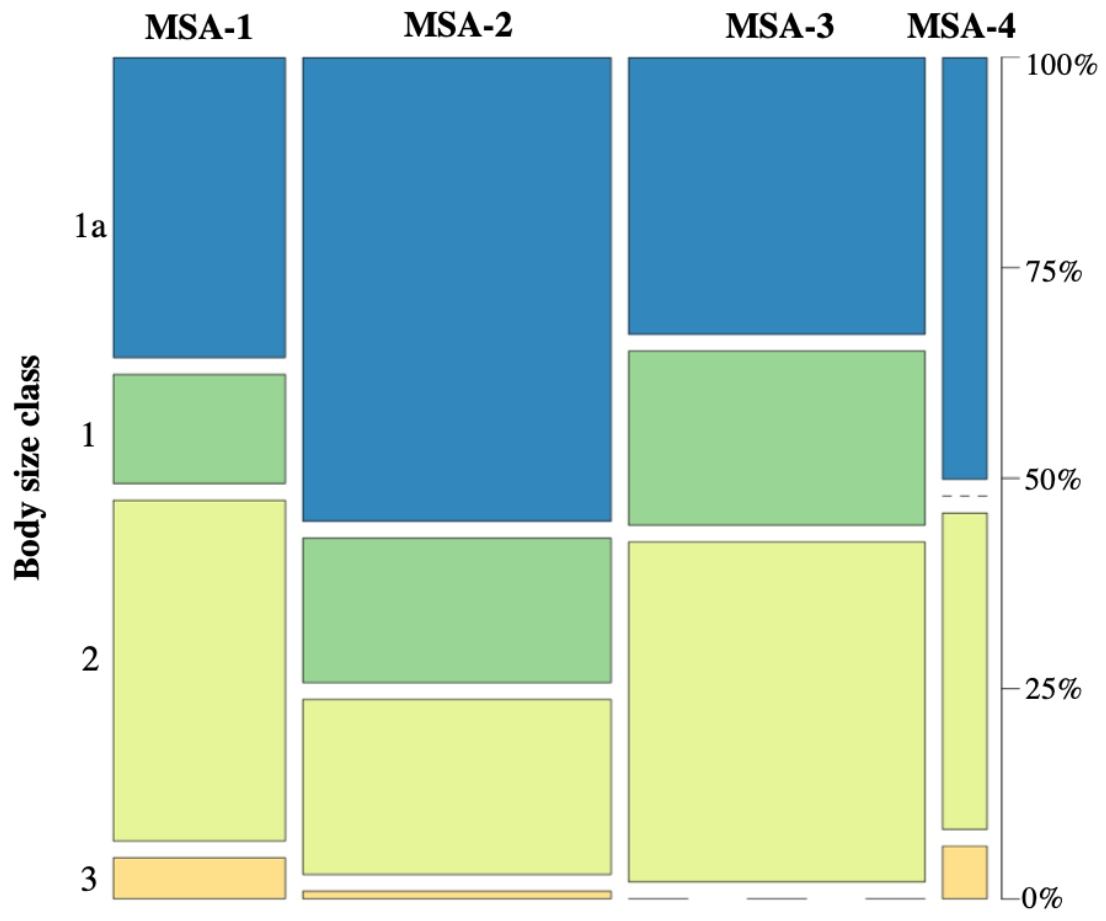

Figure 5.3 Relative frequencies (based on NISP) of each body size body size class for the four analytical units. Bin height scales to the relative percentage of each group within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

Table 5.8 Chi-squared and Fisher's Exact Test of independence between analytical units for body size classes.

AU 1	AU 2	χ^2	χ^2 p-value	FET p-value
MSA-1	MSA-2	11.36 [1]	0.01*	0.01*
MSA-1	MSA-3	6.55 [1]	0.08	0.1
MSA-1	MSA-4	2.9 [1]	0.4	0.39
MSA-2	MSA-3	12.86 [1]	0.01*	< 0.01*
MSA-2	MSA-4	7.95 [1]	0.08	0.05*
MSA-3	MSA-4	11.17 [1]	0.01*	0.02*

[1]Some cells contain expected counts lower than 5

*p-value significant at $\alpha = 0.05$

MSA-2, in particular, appears to be quite distinct from the other units in terms of size class representation. The results of partial chi-squared tests for body size class representation across all four analytical units, and indications of the direction of deviation between observed versus expected values and which deviations are statistically significant, are presented in Table 5.9. These data suggest that the differences between MSA-2 and other levels are driven in large part by a relatively high frequency of size 1a animals and a low frequency of size 2 animals in MSA-2 (Table 5.9). That these deviations are statistically significant indicates that size 1a animals are substantially more common than expected in MSA-2 based on the frequency of this size class in all of the units combined, while size 2 animals are substantially less common than expected in MSA-2. In other words, deviations of this magnitude (positive for size 1a and negative for size 2) would be expected to occur less than 5% of the time by chance alone.

Although birds are relatively common across all units, the over-representation of size 1a animals is likely due in large part to an abundance of bird bone in MSA-2 (Table 5.10). Moreover, rodents appear to be somewhat overrepresented in MSA-2, as do

Table 5.9 Partial chi-squared tests among analytical units for size class representation.

Size class	MSA-1	MSA-2	MSA-3	MSA-4
1a	(-)	(+)*	(-)*	(+)
1	(-)	(+)	(+)	(-)[1]
2	(+)	(-)*	(+)	(+)
3	(+)*	(-)[1]	(-)[1]	(+)[1]

(+) observed values > expected; (-) observed values < expected
[1]Expected counts < 5
*p-value significant at $\alpha = 0.05$

Table 5.10 NISP counts of size class 1a animals across analytical units.

Taxon	MSA-1	MSA-2	MSA-3	MSA-4
Amphibian	1	3	5	1
Bird	18	73	41	18
Carnivore	-	5	1	-
Rodent	10	19	1	-
Reptile	-	1	2	1
Indet. terrestrial vert.	10	29	14	2

specimens assigned to size class 1a that could not be identified to a specific taxon, many of which are also likely rodents. Additionally, the observed counts of size 3 animals in MSA-1 are significantly larger than expected, while counts of size 1a animals in MSA-3 are significantly smaller than expected (Table 5.9). Once again, the CT category data tell a somewhat different story concerning body size representation at SM1 (Figure 5.4 and Table 5.11). In this case, chi-squared tests of independence between each pair of analytical units indicate that none of the differences between them are significant at $\alpha = 0.05$ (or even $\alpha = 0.1$). Additionally, p-values indicate that several of the comparisons are actually highly non-significant (Table 5.11).

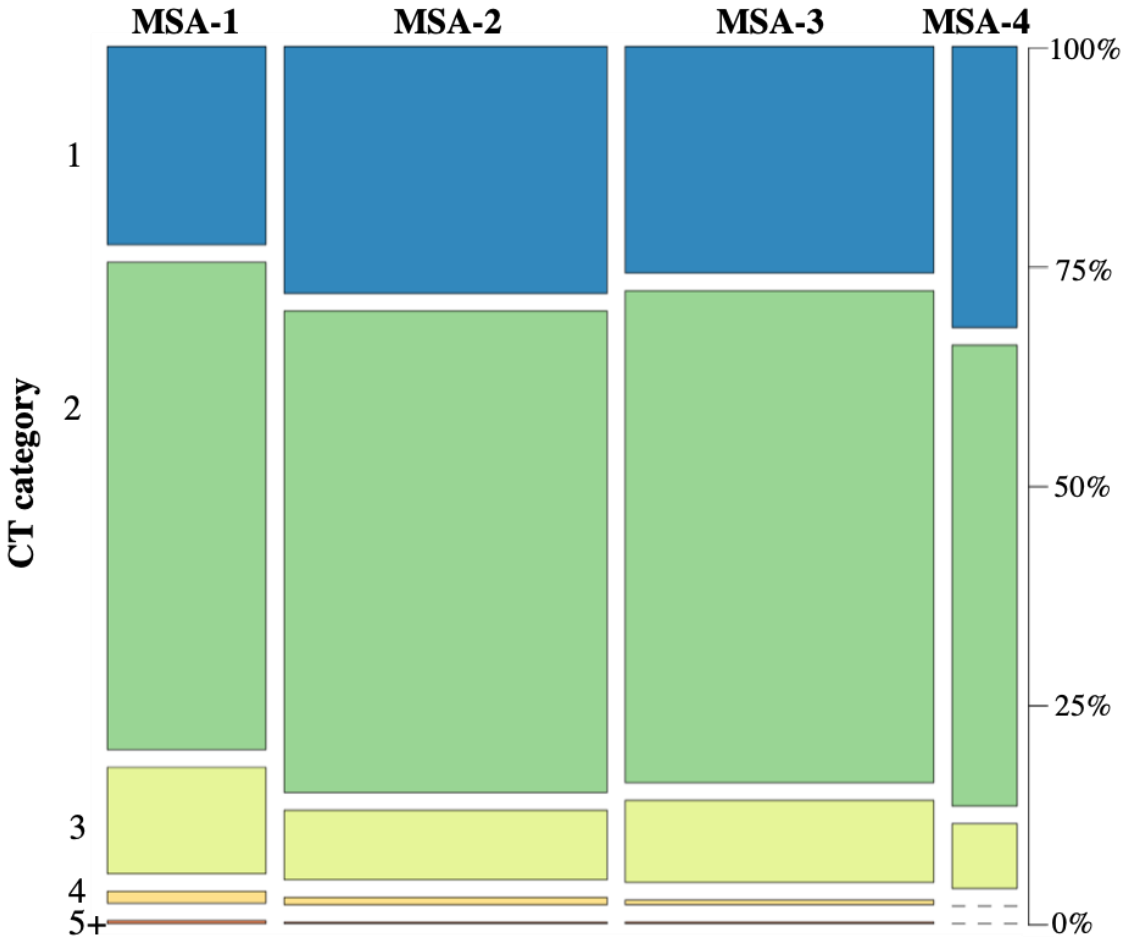

Figure 5.4 Relative frequencies (based on NISP) of each CT category for the four analytical units. Bin height scales to the relative percentage of each group within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

Table 5.11 Chi-squared tests of independence between analytical units for CT categories.

AU 1	AU 2	χ^2	p-value
MSA-1	MSA-2	6.9	0.14
MSA-1	MSA-3	4.2	0.38
MSA-1	MSA-4	7.05	0.13
MSA-2	MSA-3	1.76	0.78
MSA-2	MSA-4	1.89	0.76
MSA-3	MSA-4	2.95	0.57

Summary of body size data

The data on body size class and CT categories present somewhat different pictures of size representation at SM1. The body size class data suggest that very small animals (size 1a) are the most abundant and are ~8% more common than the next most frequent group, small/medium-sized animals (size 2). Additionally, very small and small animals (size 1a and 1) combined account for just over 60% of the total NISP and just under 65% of total MNE. When very small microfauna are excluded, the size class data indicate that size 2 animals are actually the most common, representing just over 40% of NISP, with size 1a and 1 accounting for another ~50% combined. As noted above, these data align better with those on CT categories, which indicate that small/medium animals are by far the most abundant at SM1, and represent ~60% of the specimens analyzed, while very small and small taxa combined represent another ~30% of the total fauna.

The size class and CT category analyses also provide somewhat contradictory results when comparing body size distributions across the four analytical units. The size class data clearly indicate substantial differences in body size representation between several analytical units, with MSA-2 in particular appearing to be quite distinct from all of

the other units. However, as already discussed, these results should be viewed with caution due to the relatively small sample sizes and low expected frequencies in many cases, which can affect the accuracy of the partial chi-squared approximations used to determine whether or not over-/under-representation of a particular size class was statistically significantly for each unit. By contrast, the CT category data suggest that body size representation is quite similar across all four analytical units, with none of the chi-squared tests returning significant results and several producing p-values that were actually highly insignificant.

There are several potential explanations for the differences in the two datasets, beginning with the fact that the size class data are derived entirely from the relatively small sample of identified specimens, while the CT data include all identified long bones and non-identifiable fragments for which cortical thickness could be measured. This leads to a sample for the CT data that is around five times larger than that for body size classes. It is also the case that bones of microfaunal taxa are often more readily identifiable among highly fragmented assemblages (see below), because even small fragments of microfaunal bones are more likely to retain distinctive landmarks than are similarly-sized fragments of the same bone from larger animals (*e.g.,* a random 1 cm fragment of a rodent femur is more likely to retain an identifiable feature than is a random 1 cm fragment from the femur of a size 2 bovid). Given that the size class data are based solely on identified specimens, this fact may at least partly explain the seeming dominance of size 1a taxa in this dataset.

Assuming that the assemblage consists largely of prey items collected and processed by humans for food (see below), it is also quite possible that human behavior is responsible for at least some of the discrepancies between the two datasets. For example, it is likely that many bones of animals larger than size 1a would regularly have been fractured by human foragers for marrow removal, resulting in an increase in the number of

non-identifiable fragments, and a decrease in overall fragment size and the number of identifiable elements among these taxa. Conversely, if many of the smallest microfauna (*e.g.,* murid rodents, lizard, snakes, frogs) do in fact represent human food waste, which seems probable, it is unlikely that their bones would have been processed in the same way as those of macrofaunal taxa. Thus, a lack of intensive processing may also help explain the higher frequencies of identifiable elements among the smallest animals at the site, and therefore their over-representation in the body size class dataset.

Given the above, it seems likely that the CT category data provide an overall more accurate picture of body size representation at SM1, at least with respect to the animals most likely to have been collected for food by MSA humans. In other words, MSA hunting and foraging activity probably did not focus more on the smallest microfaunal taxa (*e.g.,* small rodents, lizards, snakes, frogs) than on larger faunal taxa, as suggested by the seeming overabundance of size 1a animals in the body size class data. Nonetheless, it is important to note that both datasets indicate that the SM1 faunal assemblage is heavily weighted towards smaller-bodied faunal taxa. Moreover, size 1a animals still represent over 30% of the collection even after microfauna (*i.e.,* < 1 kg) are removed from the calculations, which also indicates that other small, "collectible" prey items (*e.g.,* primates, birds, lagomorphs) were likely a significant component of MSA diets at SM1. In all cases, small-to-medium-sized animals (*i.e.,* sizes 1a-2) account for ~90-95% of the fauna in terms of NISP, and the size class data indicate a similar situation for the percentage of MNE. Likewise, it seems clear from both datasets that large and very large animals (size 4 and 5) are, in fact, quite rare at SM1.

Based on the taxonomic breakdown of the size class data, it appears likely that many of the non-identified long bone fragments at the site belong to bovids, and particularly those specimens that were classified to CT categories corresponding to body

size classes 1, 2, and 3. It is also quite possible that the fragments from large and very large animals are also bovids, since the only identified element larger than size 3 at the site is a bovid metapodial. With respect to very small animals, there are 130 non-identified long bone fragments with cortical thickness values of 1.5 mm or less that can be assumed with some confidence to derive from size 1a animals, and many of which may belong to birds and/or rodents, the two most abundant size 1a taxa at SM1. Yet, given that each of these groups only account for ~20% of the assemblage, and that 40% of the identified elements from size 1a animals could not be assigned to a specific taxon, it is a bit more difficult to make an informed prediction about the identity of candidate species in the case of these fragments.

TAPHONOMY: IDENTIFYING PROCESSES OF SITE FORMATION

As discussed in Chapter 3, detailed investigation of the various agents and processes that can impact an archaeofaunal assemblage is a necessary first step in using faunal remains to interpret past human behavior, because the higher-order analyses upon which such interpretations are based require that the analyst understand: 1) the extent to which the composition of an assemblage is a function of human activity, and 2) the influence of other non-human agents and processes that can also alter a faunal collection (Lyman, 1994). It is also important to determine the taphonomic character of an assemblage and the extent of post-depositional bone destruction before undertaking interassemblage comparisons (Marean, 1991). The processes of interest here involve both nutritive and non-nutritive destruction of bone, and include mechanical, chemical, animal, and cultural agents that can impact the composition and preservational state of a faunal assemblage. Only once these processes are fully understood is it possible to develop robust and reliable interpretations of human behavior in the past. Unless otherwise noted, the following

taphonomic analyses are based on *in-situ* specimens only, and do not include surface-collected specimens or specimens of uncertain provenience. Given the difficulty of reliably assessing the state of bone surface preservation on very tiny bones and fragments, microfaunal taxa and specimens with maximum length less than 10 mm were also excluded from analyses of weathering and post-depositional processes.

Bone surface preservation

Overall bone surface visibility and preservation are good at SM1. Approximately 20% of bones have their surfaces obscured to some degree, almost always due to the presence of carbonate nodules, although in most cases only a small portion of the surface is actually obstructed from view. For the large majority of specimens, the preserved bone surface is either completely or mostly visible, and at least half the surface is visible for ~95% of specimens (Table 5.12).

Table 5.12 Bone surface visibility at SM1.

Surface visible	n	% specimens
None	3	0.1
10-20%	85	2.3
30-40%	117	3.1
50-60%	215	5.8
70-80%	226	6
90-100%	3097	82.8

Most specimens also display minimal damage from subaerial weathering (Table 5.13 and Figure 5.5). Weathering stages 0 (47.8%) and 1 (37.1%) are the most common, and together make up a large majority of the assemblage. Bones weathered to stage 2 (10.1%) are much less common, while bones weathered to stages 3 (4.1%) and 4 (0.9%) are even rarer. No specimens were observed to be weathered past stage 4. Likewise, specimens exhibiting dendritic etching, pocking, exfoliation, erosion, sheen, and smoothing, all of which can hinder visibility and interfere with assessments of surface modification (Thompson, 2005), are relatively rare at SM1. The most common type of damage, exfoliation, occurs on 13.5% of specimens, while all of the others were observed on 10% or less of bones overall (Table 5.13 and Figure 5.6).

Table 5.13 Frequencies of weathering and other post-depositional surface damage at SM1.

Weathering stage	**n**	**% specimens**
0	1049	47.8
1	814	37.1
2	222	10.1
3	89	4.1
4	19	0.9
Post-depositional damage		
Dendritic etching	25	1.1
Pocking	171	7.7
Exfoliation	299	13.5
Erosion	193	8.7
Sheen	229	10.3
Smoothing	78	3.5
Includes only in-situ specimens & specimens with ML > 10 mm		

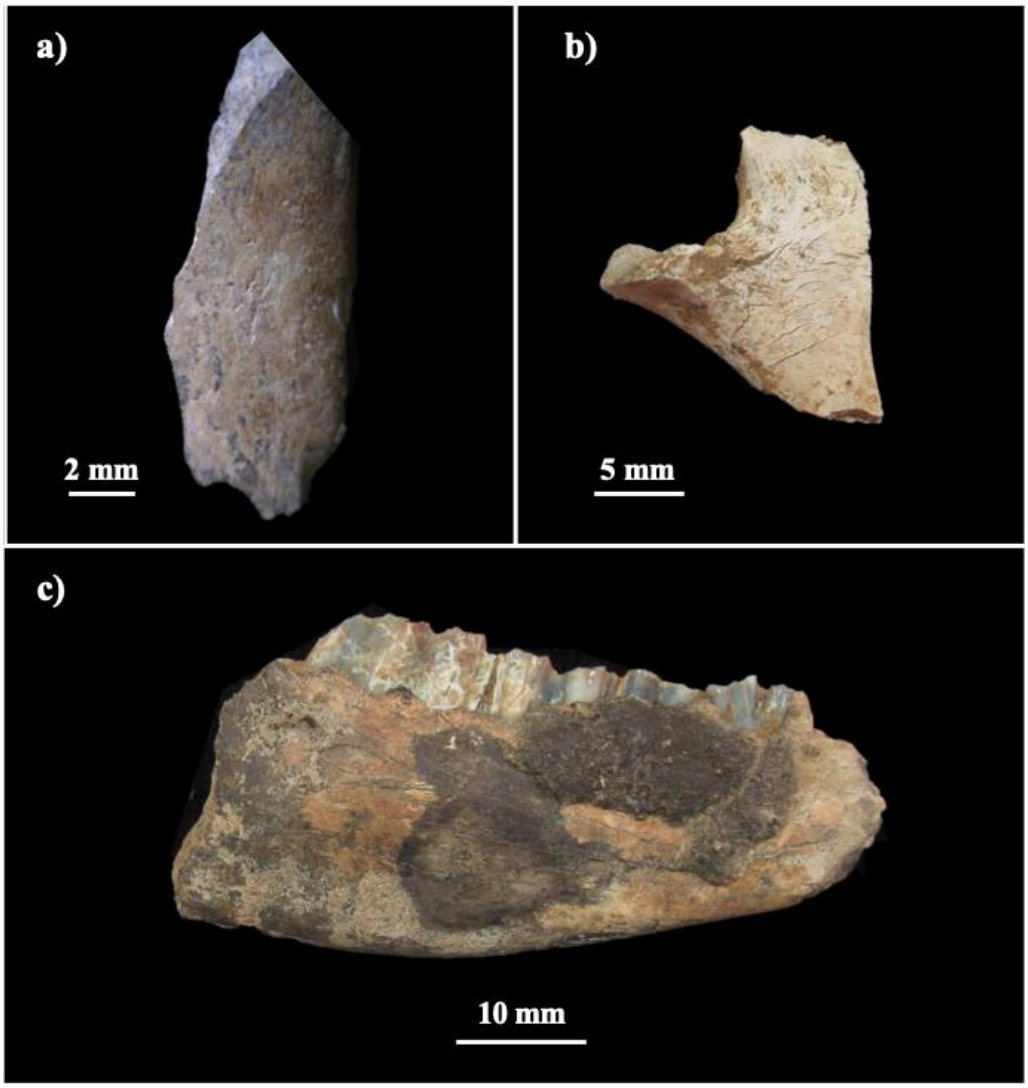

Figure 5.5 Terrestrial faunal specimens displaying the most common weathering stages observed at SM1. a) Stage 0 (long bone fragment; X15-18-248). b) Stage 1 (bovid mandibular condyle; SM1-666/2/4-9). c) Stage 2 (bovid mandible; X15-11-121).

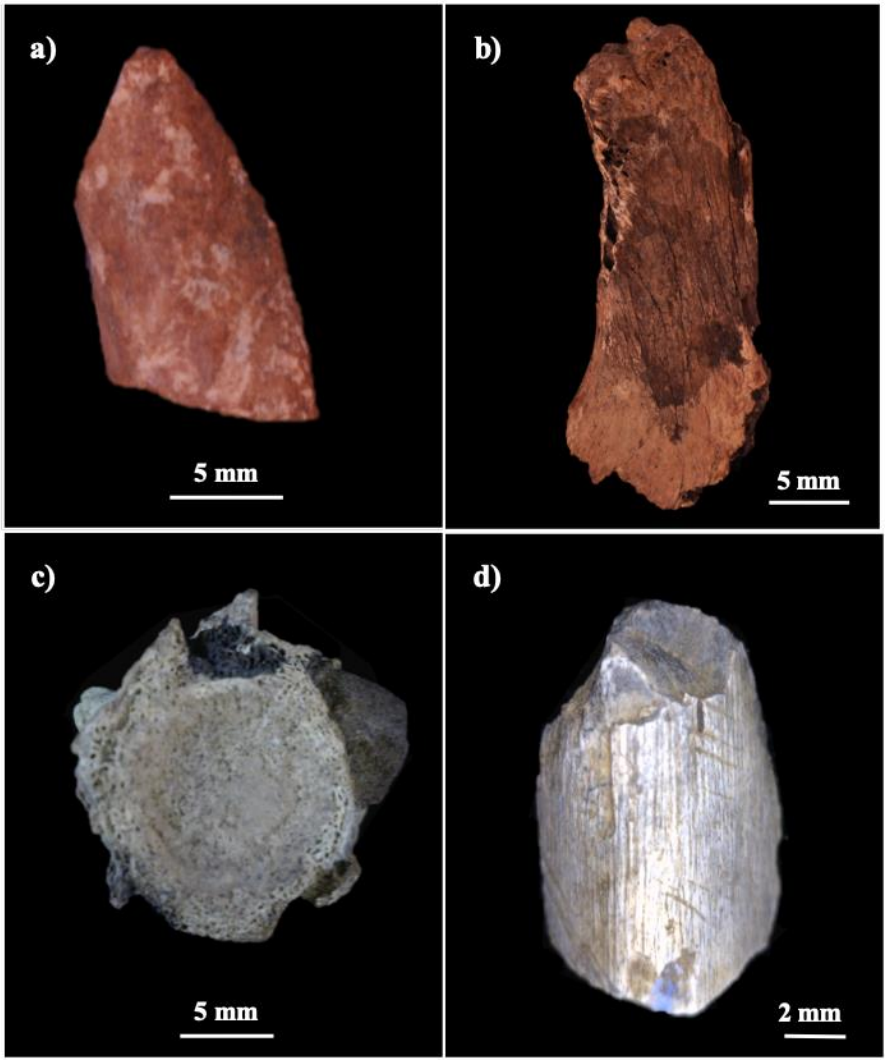

Figure 5.6 Terrestrial faunal specimens from SM1 with post-depositional damage. a) Long bone fragment with pocking (W14-6-117). b) Non-identified fragment with exfoliation (W15-21-32). c) cf. *Crocodylus* vertebra with erosion around the edges (W15-22-134). d) Non-identified fragment with sheen (and cut marks) (SM1-671; this specimen is also shown in Figure 5.18a).

It is also informative to examine whether or not specimens of different sizes show differential effects from subaerial weathering. For example, if larger specimens are consistently more heavily weathered than smaller ones, this difference might indicate distinct burial processes and taphonomic histories for specimens of different sizes. Maximum length is used as a proxy for specimen size here instead of total area because the analyzed sample includes both partial and complete specimens, many of which are not necessarily uniform in shape across the entirety of the element. Therefore, simply multiplying maximum length and width may not produce a reliable calculation of surface area for some specimens. For instance, the maximum medio-lateral width of the proximal end of a bovid femur would be taken from the fovea capitis to the greater trochanter, and is not the same as the maximum width of most of the shaft, which is much narrower along most of its length. As such, using a maximum width measured at the proximal end would greatly overestimate the actual surface area of the total bone; similarly, taking the maximum width along the shaft would likely underestimate the total area. Maximum length, on the other hand, is much more straightforward to diagnose and measure, regardless of the size and shape of the specimen.

Several points stand out regarding the relationship between maximum bone length and the presence and severity of weathering damage (Figure 5.7). First, there is clearly a great deal of overlap in size between unweathered specimens and those weathered to Stages 1-3. When four very large outliers are excluded, the overall size range for most of the weathering stages are also quite similar, although the interquartile range for unweathered specimens is actually somewhat smaller than those of the other weathering stages. Additionally, it is clear that unweathered specimens tend to be smaller than weathered specimens and, generally speaking, specimen size does tend to increase along with the severity of weathering. Pairwise t-tests further support this conclusion, and indicate that

there are significant differences between the mean lengths of unweathered versus weathered specimens (t = -6.52; p-value = < .01).

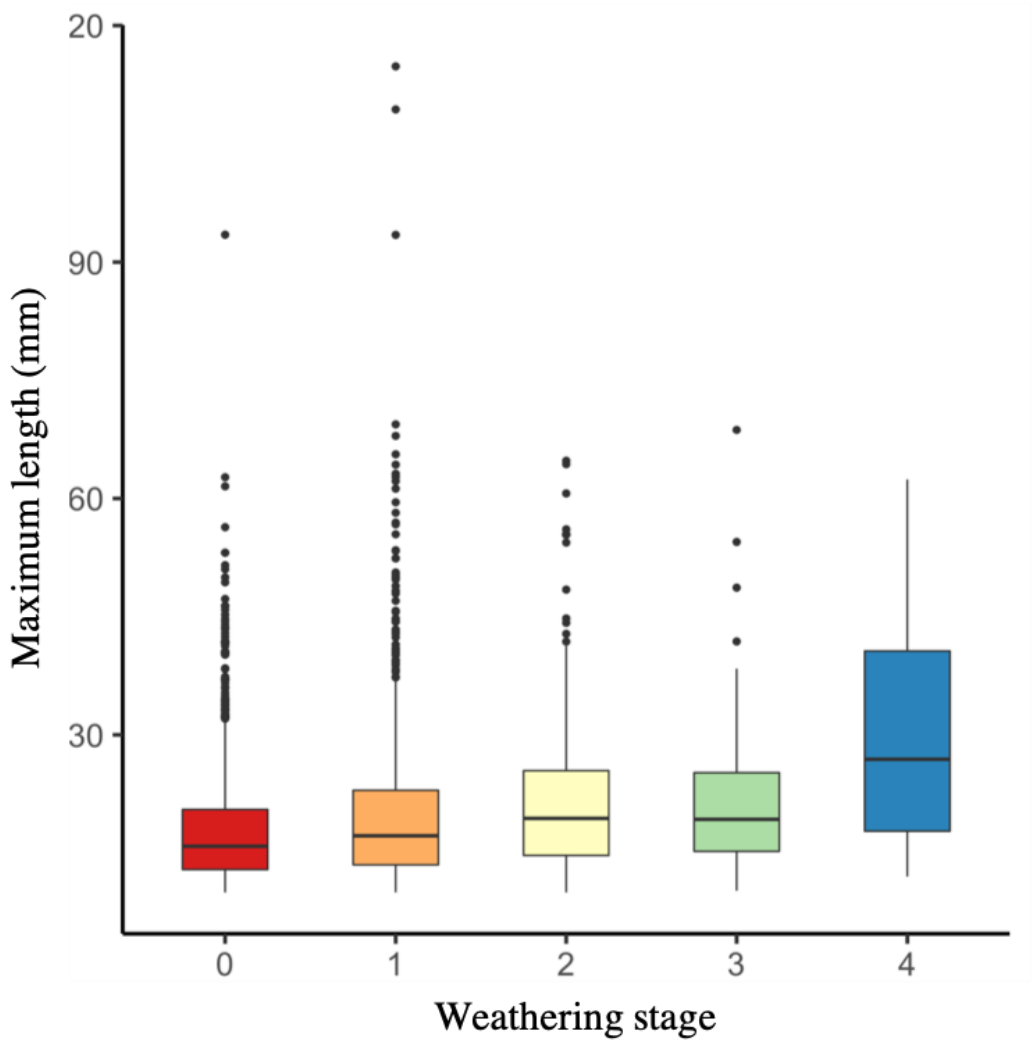

Figure 5.7 Weathering stage by maximum specimen length.

The relative frequencies of unweathered (stage 0), lightly/moderately weathered (stages 1 and 2), and heavily weathered (stages 3 and 4) bone for each analytical unit are shown in Figure 5.8, and chi-squared tests reveal significant differences for three out of the six pairs of units for these attributes (Table 5.14). Examining these data in more detail indicates that the differences arise from the fact that MSA-1 has significantly more unweathered specimens than expected and fewer weathered specimens overall, with the association being statistically significant in the case of specimens with light-to-moderate weathering (Table 5.15). Conversely, MSA-3 displays the opposite pattern, with unweathered bones significantly under-represented, and both heavily and lightly-to-moderately weathered specimens over-represented, although the difference is only statistically significant in the latter case. Additionally, MSA-2 also has more heavily weathered bones than expected, although the association is non-significant. With respect to the presence of one or more types of postdepositional damage, MSA-4 is significantly different from all of the other units, but differences among all other units are non-significant (Table 5.14). Undamaged specimens tend to be overrepresented in MSA-1 and MSA-2, while damaged specimens are more common than expected in MSA-3 and MSA-4. However, MSA-4 is the only analytical unit in which the deviations between the observed and expected values are statistically significant (Table 5.15).

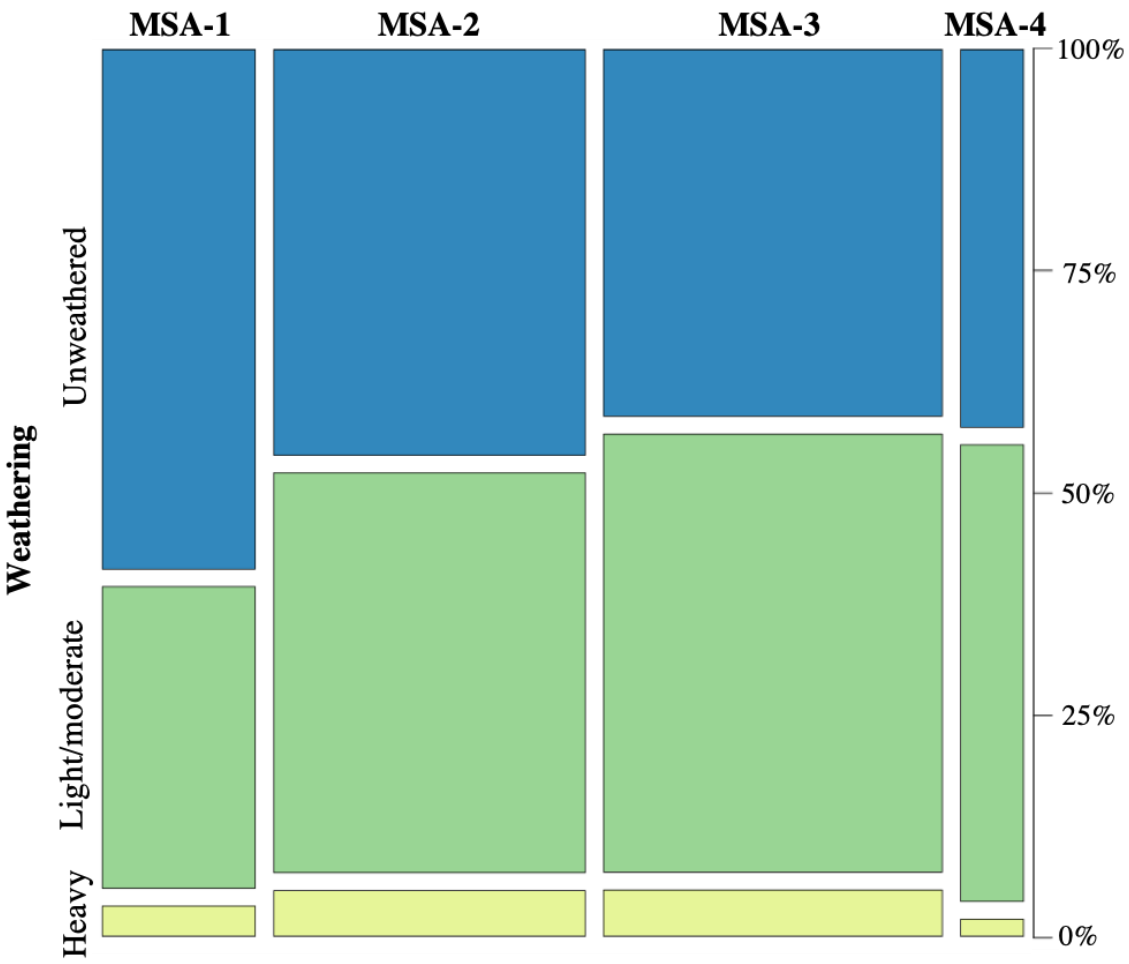

Figure 5.8 Relative frequencies (based on NISP) of unweathered, lightly/moderately weathered, and heavily weathered bone for the four analytical units. Bin height scales to the relative percentage of each group within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

Table 5.14 Chi-squared tests of independence between analytical units for weathering and post-depositional processes.

		Weathering		Post-depositional processes	
AU 1	**AU 2**	χ^2	**p-value**	χ^2	**p-value**
MSA-1	MSA-2	17.78	< 0.01*	0.35	0.55
MSA-1	MSA-3	32.55	< 0.01*	2.68	0.1
MSA-1	MSA-4	14.85	< .01*	9.23	< 0.01*
MSA-2	MSA-3	3.37	0.18	1.53	0.22
MSA-2	MSA-4	4.42	0.11	8.1	< 0.01*
MSA-3	MSA-4	3.24	0.2	4.4	0.04*
*p-value significant at $\alpha = 0.05$					

Table 5.15 Partial chi-squared tests among analytical units for weathering and post-depositional processes.

Weathering	**MSA-1**	**MSA-2**	**MSA-3**	**MSA-4**
Unweathered (stage 0)	(+)*	(-)	(-)*	(-)
Light/moderate (stage 1-2)	(-)*	(-)	(+)*	(+)
Heavy (stage 3-4)	(-)	(+)	(+)	(-)
Post-depositional processes				
No damage	(+)	(+)	(-)	(-)*
Damage	(-)	(-)	(+)	(+)*
(+) observed values > expected; (-) observed values < expected *p-value significant at $\alpha = 0.05$				

Thermal alteration

Approximately 60% of terrestrial faunal bones at SM1 show no evidence of exposure to fire, while an additional ~30% of bones are lightly-to-fully carbonized, and the remaining ~10% are in one of the three stages of calcination (Table 5.16 and Figure 5.9). Among the burned assemblage, moderately carbonized bones are the most common, while fully calcined specimens are the rarest. Interestingly, although carbonized bone is approximately three times more abundant than calcined bone, lightly calcined specimens are actually slightly more common than fully carbonized ones.

The relative frequencies of unburned (stage 0), carbonized (stage 1-3), and calcined (stage 4-6) bone for each analytical unit are depicted in Figure 5.10. Chi-squared tests of independence between units for these attributes indicate significant differences in the amount and/or degree of burning damage between all units except MSA-2 and MSA-3 (Table 5.17). A closer look at the associations among units illuminates some patterns that help explain the differences among them (Table 5.18). The specific patterning of positive and negative associations differs between them, but generally speaking, intensively burned bone tends be overrepresented in both MSA-1 and MSA-2. More specifically, there are significantly more calcined specimens in MSA-1 than expected, although carbonized specimens are also significantly under-represented in this unit. For MSA-2, both calcined and carbonized bone are over-represented, but the association is not statistically significant in either case. MSA-4 displays the opposite pattern to MSA-1, with carbonized bone significantly more abundant, and calcined bone less abundant, than expected. Conversely, burned bone overall is under-represented in MSA-3, although not significantly so for either burning category (Table 5.18).

Table 5.16 Frequencies of burned bone at SM1.

Burn category	n	% specimens
Unburned	2073	60.4
Localized carbonization	294	8.6
Moderate carbonization	577	16.8
Full carbonization	145	4.2
Localized calcination	177	5.2
Moderate calcination	102	3
Full calcination	62	1.8

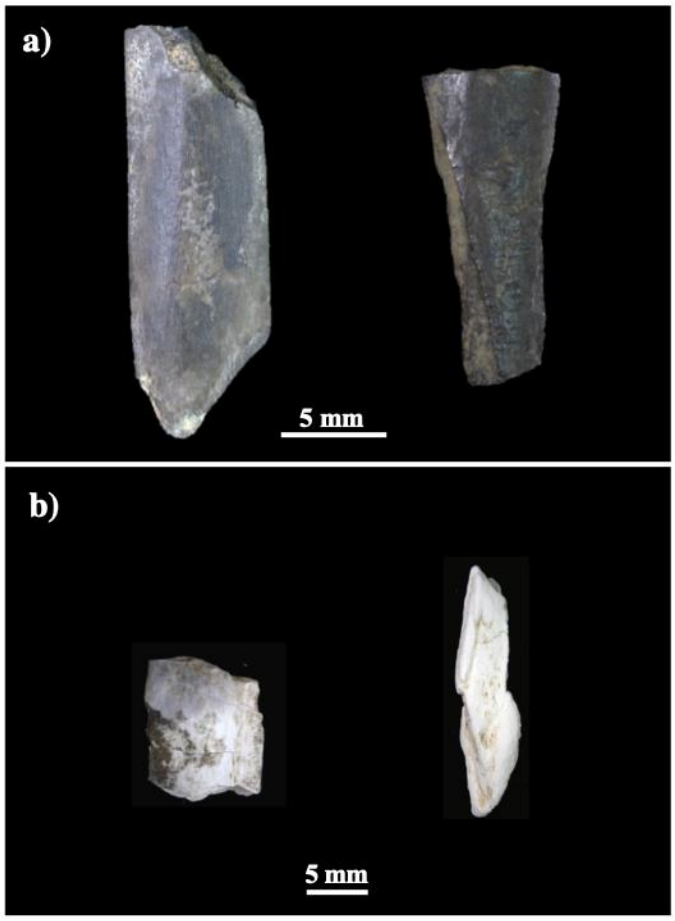

Figure 5.9 Long bone fragments displaying moderate and full a) carbonization (W15-18-337 and W14-13-39) (and b) calcination (W15-21-52 and W14-25-509).

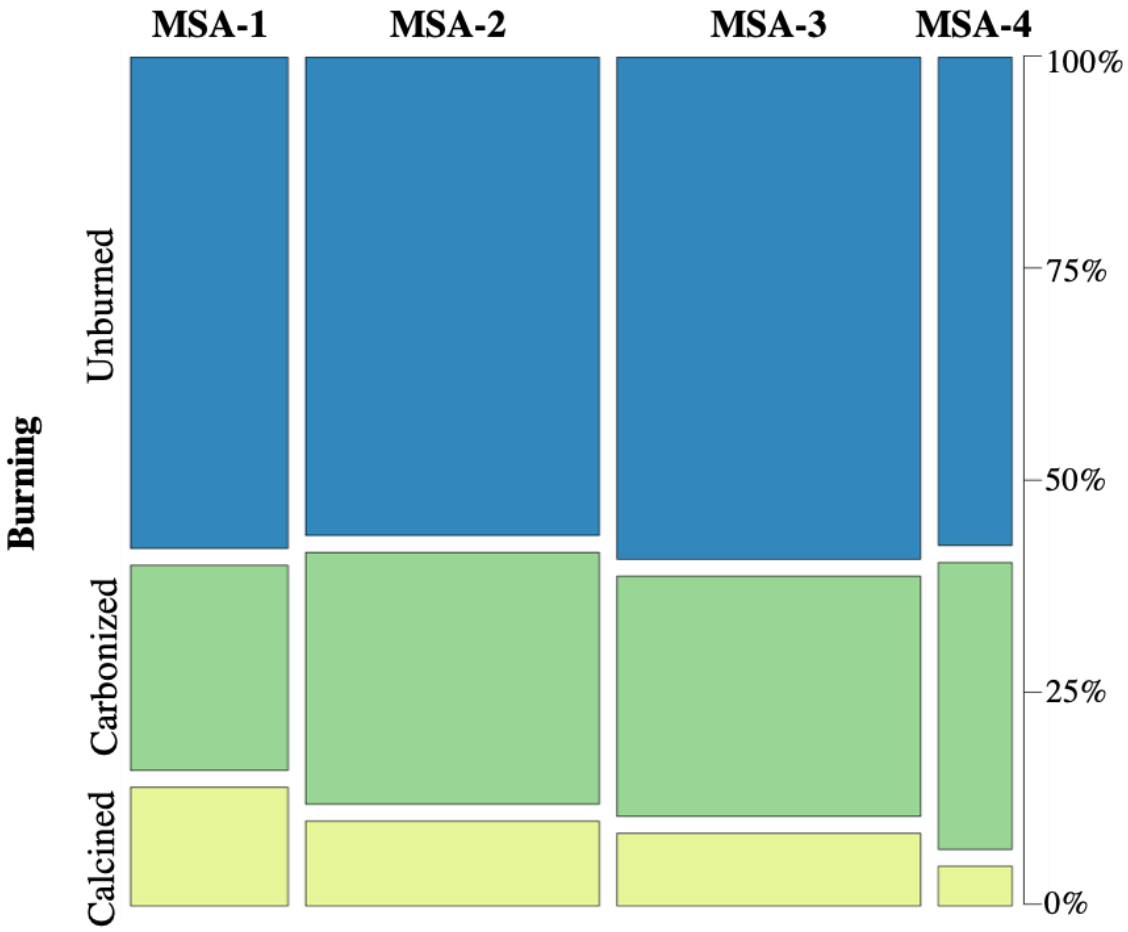

Figure 5.10 Relative frequencies (based on NISP) of unburned, carbonized, and calcined bone for the four analytical units. Bin height scales to the relative percentage of each group within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

Table 5.17 Chi-squared tests of independence between analytical units for unburned, carbonized, and calcined bone.

AU 1	AU 2	χ^2	p-value
MSA-1	MSA-2	10.85	< 0.01*
MSA-1	MSA-3	15.31	< 0.01*
MSA-1	MSA-4	23.26	< 0.01*
MSA-2	MSA-3	2.61	0.27
MSA-2	MSA-4	8.95	0.01*
MSA-3	MSA-4	7.17	0.03*

* p-value significant at $\alpha = 0.05$

Table 5.18 Partial chi-squared tests among analytical units for unburned, carbonized, and calcined bone.

Burning	MSA-1	MSA-2	MSA-3	MSA-4
Unburned	(+)	(-)	(+)	(-)
Carbonized	(-)*	(+)	(-)	(+)*
Calcined	(+)*	(+)	(-)	(-)*

(+) observed values > expected; (-) observed values < expected

* p-value significant at $\alpha = 0.05$

Bone fragmentation and fracture morphology

Approximately 80% of the terrestrial faunal specimens at SM1 are small fragments < 20 mm in maximum length, indicating that the assemblage has undergone extensive fragmentation (Table 5.19 and Figure 5.11). Although there are a handful of specimens that reach maximum lengths of 80-100 mm or more, mean fragment lengths for both mapped and water-screened specimens are well under 20 mm, while surface-collected specimens are only slightly larger than 20 mm on average (Figure 5.11). Although significant bone fragmentation is common for human-produced sites (Gifford-Gonzalez, 1989), and small average fragment sizes have been reported for other MSA sites (*e.g.,* Yellen *et al.,* 2005; Clark, 2009), assuming that humans are the primary agent of faunal accumulation and modification at SM1, it is unclear if fragmentation of this extent is common for the MSA, or if SM1 is unique in this respect. This question will be explored in more detail through comparative analyses with other MSA sites in Chapter 7.

Table 5.19 Maximum fragment length category frequencies for terrestrial fauna at SM1.

Maximum length (mm.)	NISP	% NISP
0-9	1305	30.1
10-19	2113	48.7
20-29	596	13.7
30-39	194	4.5
40-49	79	1.8
50-59	28	0.7
60-69	16	0.4
70+	5	0.1

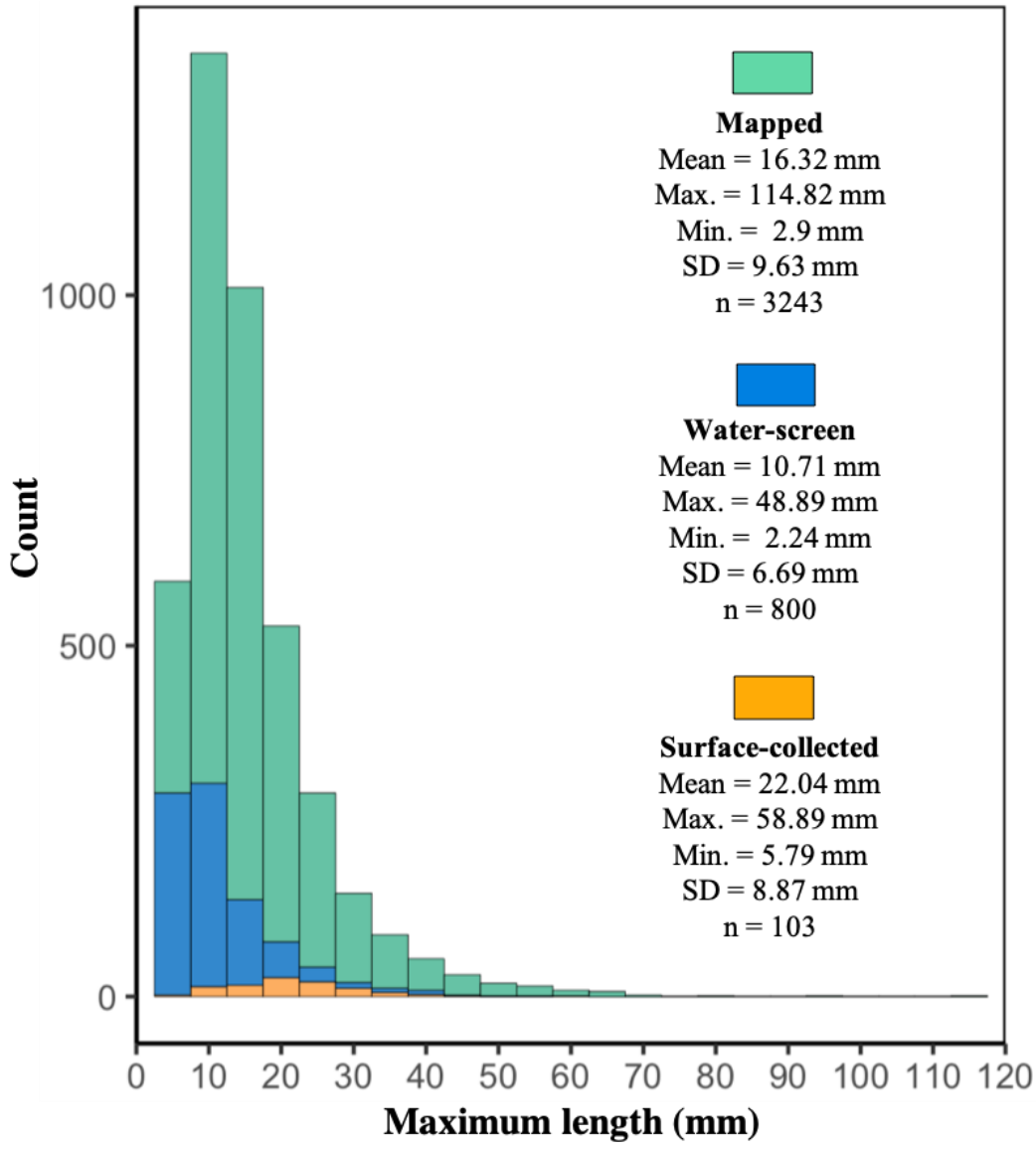

Figure 5.11 Maximum length of faunal specimens by provenience type.

When the fragmentation data are separated by CT category, bones < 20 mm in maximum length account for ~80% of specimens in CT category 1, 64% of specimens in CT 2, 32% of specimens in CT 3, and 25% of specimens in CT 4; none of the specimens in CT 5+ are < 20 mm in maximum length (Table 5.20 and Figure 5.12). Additionally, 87% of the specimens for which a CT category was not assigned (*i.e.,* all bones other than long bones) are < 20 mm in maximum length. These data clearly suggest that, at least for the long bone sample, the magnitude of fragmentation is mediated to some extent by animal body size. However, it is worth noting that when the cutoff point is shifted slightly to < 30 mm in maximum length, the specimen frequencies increase to 94% for CT 1, 86% for CT 2, 64% for CT 3, 56% for CT 4, and 50% for CT 5+, which still suggests that bones from animals of all sizes are quite small and fragmented on average. It is also important to keep in mind that the samples for CT 4 and 5+ in particular are very small (22 specimens combined), which may well affect the reliability of such comparisons for these groups.

Table 5.20 Maximum fragment lengths for terrestrial fauna by CT category.

	Maximum fragment length category								
CT category	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7+**	**% < 20 mm**
CT 1	102	269	70	17	6	2	1	1	79.3
CT 2	53	556	213	75	33	13	5	3	64
CT 3	1	51	51	34	15	4	5	-	32.3
CT 4	1	3	5	2	1	3	1	-	25
CT 5+	-	-	3	1	2	-	-	-	0
CT n/a[1]	1148	1234	254	65	22	6	4	1	87.1

[1]Cortical thickness was only measured for long bones
Maximum length categories: 0 = 0 – 9.99 mm; 1 = 10 – 19.99 mm; 2 = 20 – 29.99 mm; 3 = 30 – 39.99 mm; 4 = 40 – 49.99 mm; 5 = 50 – 59.99 mm; 6 = 60 -69.99 mm; 7+ = 70+ mm

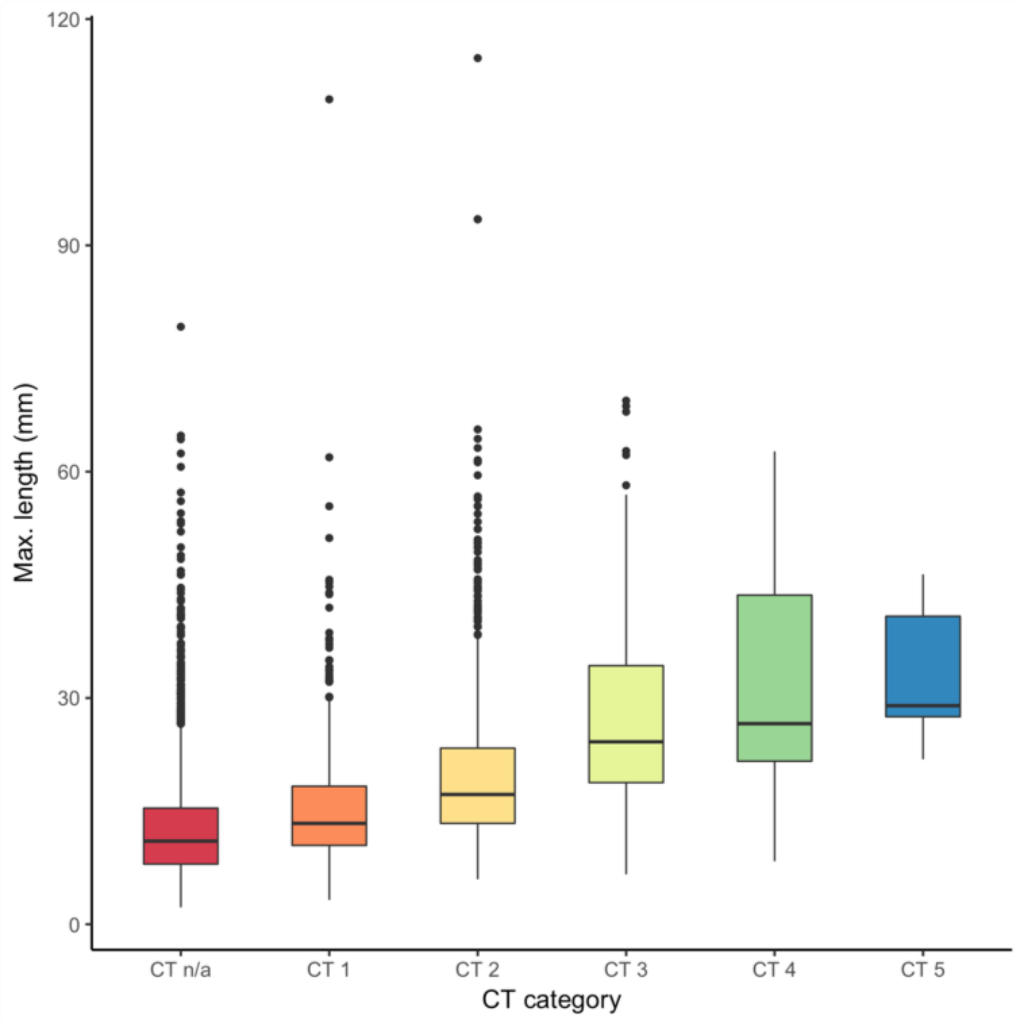

Figure 5.12 Maximum length of terrestrial fauna by long bone cortical thickness (CT) category.

Given such a high degree of fragmentation, it is perhaps unsurprising that long bone samples are dominated by small, largely non-identifiable midshaft fragments that preserve less than half of the original circumference of the shaft (Table 5.21). Just over 91% of long bone specimens are midshaft fragments, while another ~7% are near epiphysis shafts, and epiphyses represent less than 2% of the total sample. Moreover, 94.2% of fragments overall

Table 5.21 Maximum shaft circumference by long bone portion.

	Max. shaft circumference				
Long bone portion	**<50%**	**>50%**	**100%**	**NISP**	**% NISP**
Epiphysis	8	2	20	30	1.9
Near epiphysis shaft	105	1	5	111	6.9
Shaft	1410	21	45	1476	91.2
NISP	1523	24	70		
% NISP	94.2	1.5	4.3		

(and ~92% of midshafts) retain less than half the original circumference of the shaft. Interestingly, although specimens with more than half of the shaft circumference preserved represent < 6% of specimens overall, those with complete tubular shafts are almost three times more common than those with 50-99% of the shaft preserved (Table 5.21).

Separating these data by skeletal element and CT category also reveals some interesting patterns (Table 5.22). The samples are small, but humeri tend to be more fragmented than femora, with only ~35% of humeri retaining complete shafts compared to ~65% of femora. Additionally, ~80% of metapodials and both of the identified tibia fragments, all of which are from ungulates, retain less than half the original shaft circumference. All but one of the radii and ulnae, on the other hand, retain complete shafts. Although several of these elements belong to birds and a small carnivore, there is at least one of each from a size 1 or 2 bovid. If humans are largely responsible for fragmenting bones at SM1, the fact that these two bovid elements have relatively low marrow content compared to other long bones might help to explain why they retain their complete shaft circumference. Whatever the case, it is interesting to note the relatively high percentage of specimens assigned to CT category 1 (which, in this case, comprises mostly birds and a few small carnivores) that are complete tubular portions, as well as the fact that there is

only one specimen larger than size 2 that retains more than half the original shaft circumference (Table 5.22). This pattern is essentially the opposite of what would be expected if fragmentation was largely due to natural causes, an observation that will be revisited in the section on post-depositional destruction later in this chapter.

Table 5.22 Maximum shaft circumference by element and CT category.

MC	CT	COR	HM	RD/UL	FM	TB	TBT	MP	TMT	LB
	CT 1	-	-	1	-	-	1	1	-	357
	CT 2	-	5	-	3	2	-	10	-	902
<50%	**CT 3**	-	-	-	-	-	-	2	-	158
	CT 4	-	-	-	-	-	-	-	-	13
	CT 5	-	-	-	-	-	-	-	-	6
	CT 1	-	-	-	-	-	-	-	-	13
	CT 2	-	1	-	-	-	-	1	-	8
>50%	**CT 3**	-	-	-	-	-	-	-	-	-
	CT 4	-	1	-	-	-	-	-	-	-
	CT 5	-	-	-	-	-	-	-	-	-
	CT 1	5	3	8	3	-	3	2	2	36
	CT 2	-	1	-	2	-	1	-	-	1
100%	**CT 3**	-	-	-	-	-	-	-	-	-
	CT 4	-	-	-	-	-	-	-	-	-
	CT 5	-	-	-	-	-	-	-	-	-

MC = maximum circumference; CT = cortical thickness category; COR = coracoid; HM = humerus; RD/UL = radius/ulna; FM = femur; TB = tibia; MP = metapodial; TBT = tibiotarsus; TMT = tarsometatarsus; LB = non-ID long bone fragment

With respect to fracture morphology, oblique fracture angles and curved/v-shaped outlines are the most common at SM1, representing 66.6% and 41.6% of fractures, respectively (Table 5.23 and Figure 5.13). As discussed above, these fracture morphologies are most commonly associated with green bone breaks, and therefore suggest that much of the fragmentation at SM1 occurred while bones were fresh and still contained muscle, marrow, and grease that would be of interest to humans and carnivores. However, fractures with right angles (28.8%) and transverse outlines (35.2%), both of which are typically the result of dry bone breakage, are also relatively well-represented at the site. Additionally, it is worth noting that 28% of long bone fragments have oblique and right-angle fractures on opposite ends, while 22% have a curved/V-shaped break on one end and a transverse break on the other, and a combined ~40% of specimens have opposite angles and/or outlines on each end (Figure 5.14). This relatively high percentage of specimens with opposite break morphologies on each end suggests that many bones may have undergone multiple episodes of fragmentation (*i.e.,* both nutritive and non-nutritive destruction) at SM1.

Table 5.23 Fracture angle and outline frequencies.

Fracture angle	**NISP**	**% NISP**
Oblique	1692	67.1
Right	714	28.3
Oblique & right	115	4.6
Fracture outline		
Curved/V-shaped	1072	42.2
Transverse	882	34.7
Intermediate	575	22.6
Curved/transverse	14	0.6

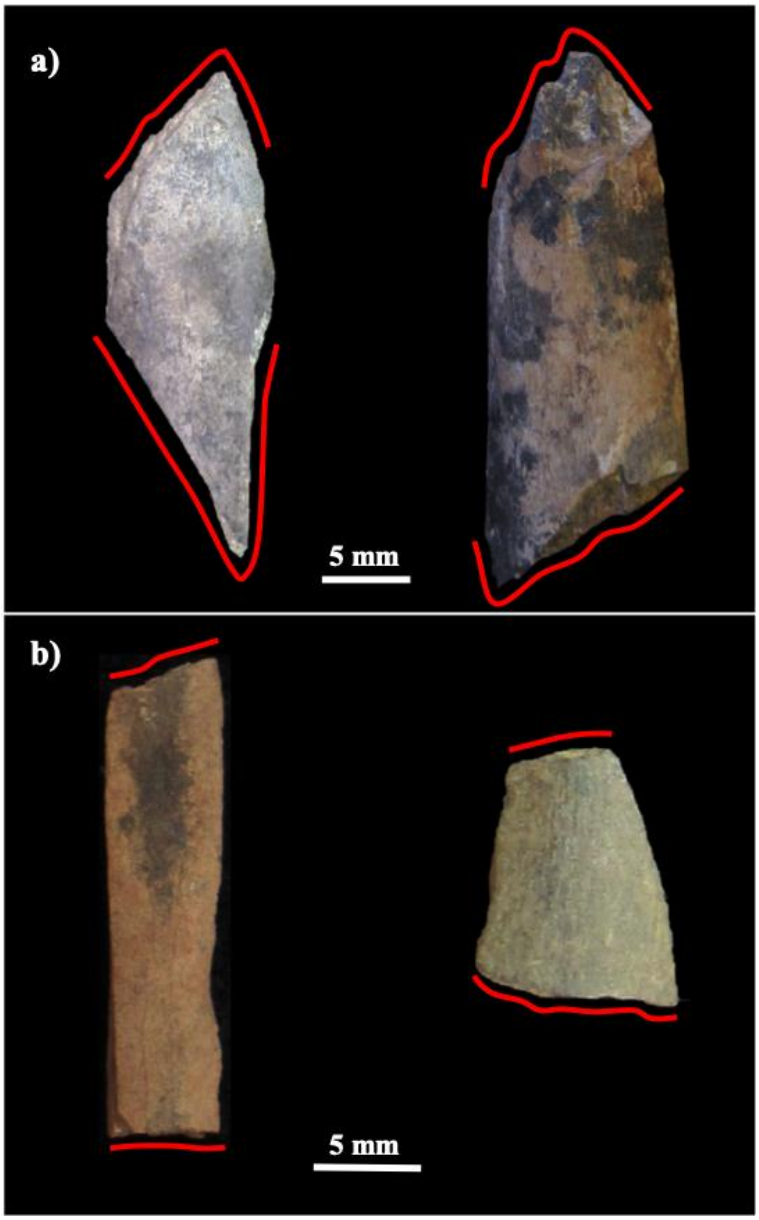

Figure 5.13 Long bone fragments with a) oblique angles and curved/V-shaped outlines (W15-9-139 and W15-11-50), and b) right angles and transverse outlines (W15-22-281a and X15-20-129). Fracture outlines highlighted in red.

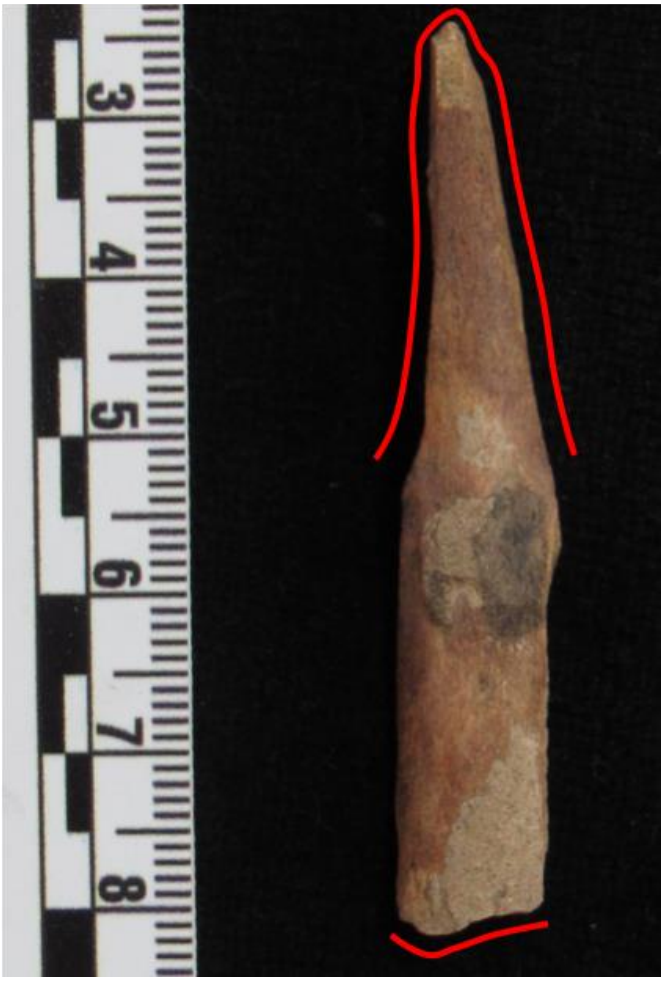

Figure 5.14 Long bone fragment (W14-16-142) with a V-shaped outline on one end (upper) and a transverse outline on the other (lower). Fracture outlines highlighted in red. Scale is in centimeters.

Background information for several comparative sites is presented in Table 5.24. The relative frequencies of fracture angles and outlines for SM1 and the comparative sites are shown in Figure 5.15a and b. (Please note that the percentages for each site in Figure 5.15 do not sum to 100%, because other fracture types, including "oblique and right" angles and "intermediate" outlines, were also recorded for the sites in question, but are not included here because they are less informative regarding the timing of bone breakage.) In terms of both fracture angle and outline frequencies, SM1 is quite similar to the Upper

Paleolithic (UP) site of Fontbregoua, at which Villa and Mahieu (1991) determined that human hammerstone percussion to access marrow was the primary cause of bone fragmentation. SM1 is also quite different from the sites of Sarrians and Bezouce, where bone breakage is mostly due to natural post-depositional damage and coarse excavation methods, respectively (Villa and Mahieu, 1991) (Figure 5.15a and b).

However, the percentages of both right-angle breaks and transverse outlines at SM1 are also much higher than those reported for experimental assemblages in which fresh bones were broken by hammerstone percussion (*i.e.,* humans only), carnivore chewing/gnawing (*i.e.,* carnivores only), or a combination of the two (humans-then-carnivores) (Marean *et al.* 2000) (Figure 5.15a and b). Although these sites represent an idealized situation in which all bones were broken fresh, which is unlikely to exist in an archaeological context, the large discrepancy between SM1 and these assemblages potentially suggests a significant amount of post-depositional bone breakage at SM1. This possibility will be explored further in the next section.

Table 5.24 Comparative sites for fracture morphology frequencies at SM1.

Site	Abbrev.	Period/Type	Cause/type of fragmentation
Sarrians	AR	UP	Postdep. processes/Non-nutritive
Bezouce	BEZ	UP	Excavation damage/Non-nutritive
Fontbregoua	FB	UP	Humans/Nutritive
Humans only	HO	Experimental	Humans/Nutritive
Carnivores only	CO	Experimental	Carnivores/Nutritive
Humans > Carnivores	H-C	Experimental	Humans-then-carnivores/Nutritive

UP = European Upper Paleolithic (~45-10 ka)
Sources: Villa and Mahieu (1991) and Marean *et al.* (2000)

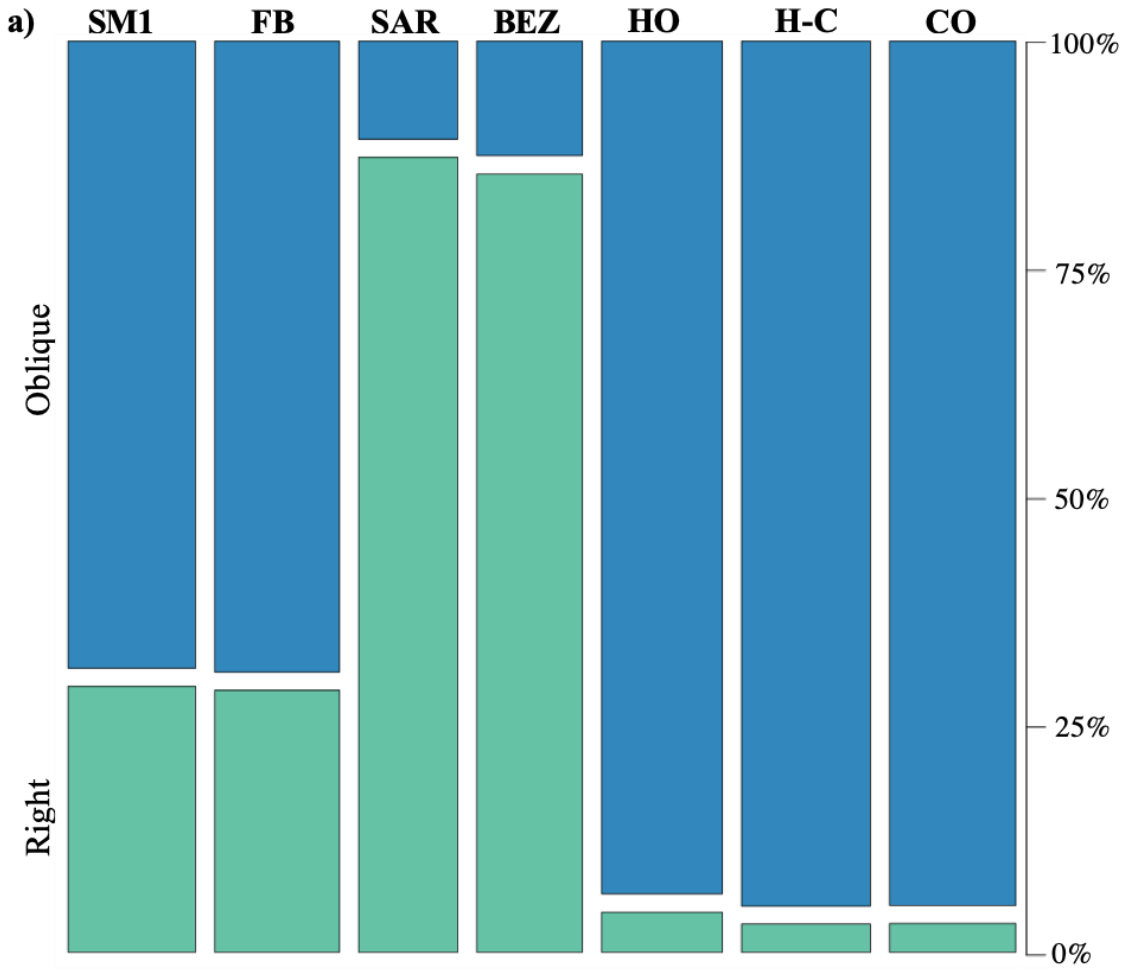

Figure 5.15 a) Fracture angle frequencies (%) for SM1, Upper Paleolithic sites, and experimental assemblages. Bin height scales to the relative percentage of oblique and right angles at each site. Bin width scales to the total percentage of oblique and right-angle fractures at each site.

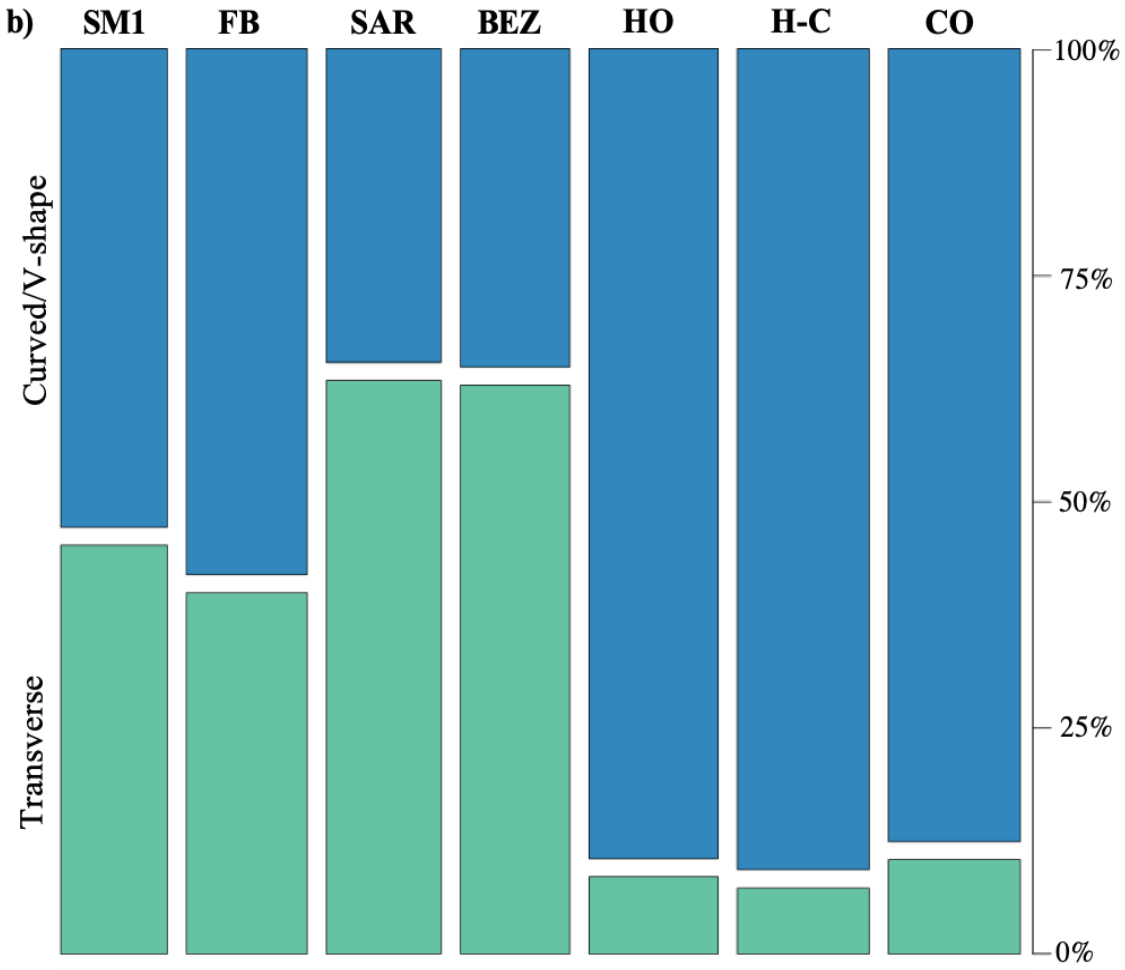

Figure 5.15, cont. b) Fracture outline frequencies (%) for SM1, Upper Paleolithic sites, and experimental assemblages. Bin height scales to the relative percentage of curved/v-shaped and transverse outlines at each site. Bin width scales to the total percentage of curved/v-shaped and transverse outlines at each site.

For analyses of fragment length between the four proposed analytical units, specimens were grouped into slightly broader categories (*i.e.,* 0-19 mm, 20-39 mm, 40-59 mm, 60+ mm) in order to increase the sample sizes for each category and avoid having groups that contained no observations in one or more analytical units. Chi-squared tests of independence indicate that the frequencies of specimens in each of the revised maximum length categories are quite similar across all four units, with none of the differences between them approaching statistical significance (Table 5.25). Chi-squared tests also document that none of the differences in fracture angle and outline frequencies between analytical units are statistically significant (Table 5.25). Once again, these data suggest that patterns of fracture morphology are very similar throughout the horizontal extent of SM.

Table 5.25 Chi-squared tests of independence between analytical units for fragment size categories and fracture morphology.

Attribute	**AU1**	**AU2**	χ^2	**p-value**
Fragment size	MSA-1	MSA-2	2.13	0.55
	MSA-1	MSA-3	3.07	0.38
	MSA-1	MSA-4	0.82	0.84
	MSA-2	MSA-3	0.73	0.87
	MSA-2	MSA-4	1.37	0.71
	MSA-3	MSA-4	2.68	0.44
Fracture angles	MSA-1	MSA-2	0.26	0.61
	MSA-1	MSA-3	2.37	0.12
	MSA-1	MSA-4	0.46	0.5
	MSA-2	MSA-3	1.5	0.22
	MSA-2	MSA-4	1.29	0.26
	MSA-3	MSA-4	3.37	0.07
Fracture outlines	MSA-1	MSA-2	1.22	0.27
	MSA-1	MSA-3	0.48	0.49
	MSA-1	MSA-4	0	1
	MSA-2	MSA-3	0.19	0.66
	MSA-2	MSA-4	0.57	0.45
	MSA-3	MSA-4	0.22	0.64

Density-mediated attrition and post-depositional destruction

Bone mineral density and skeletal portion representation

Examining correlations between bone mineral density (BMD) and element/portion representation can provide a means of assessing the extent of density-mediated destruction of bone at SM1 (Lyman, 1984, 1994; Lam *et al.* 1998, 1999). The following analyses employ all relevant identifiable skeletal elements from size 1-4 bovids at SM1. BMD values for *Connochaetes taurinus* (blue wildebeest) were chosen as the most appropriate analog for the sample overall, and bone portion definitions are defined based on the scan sites depicted in Lam *et al.* (1998, 1999). A full listing of the portion descriptions and BMD values for *Connochaetes taurinus* is provided in Appendix F.

The units of interest here are element portions, as opposed to whole elements or animal units, and most elements are divided into multiple portions with different BMD values, so each occurrence of a particular portion was treated as an individual specimen for the purpose of count data. For example, a femoral fragment that included the complete proximal epiphysis and portions of the proximal and middle shaft would be recorded four times – once each for the proximal end (head/neck), greater trochanter, proximal shaft, and midshaft. Spearman's rho (r_s) was calculated for the entire sample, as well as for each of the three main excavation blocks individually, in order to examine possible differences in density-mediated destruction between different areas of the site. Likewise, the relationship between nNISP and BMD was also examined for small (size 1 and 2) and large (size 3 and 4) bovids separately, although it should be noted that when considered alone, the sample size for the large bovids is quite small.

As the results in Table 5.26 and Figure 5.16 demonstrate, there is not a significant correlation between nNISP and BMD among any of the datasets examined here. The results for the entire dataset, excavation blocks W14 and W15 separately, and the size 1/2 bovid

sample are all very similar (Table 5.26). In each case, the correlation coefficient is ~0.14 with p-values that range between 0.4 and 0.5. When the sample from X15 is considered on its own, the correlation is negative, suggesting that less dense bone is actually more common in this excavation block, albeit only very slightly. The correlation between nNISP and BMD is much higher among the bovid size 3/4 sample and, accordingly, this is also the only dataset for which the p-value even approaches statistical significance. However, it is important to bear in mind that the size 3 and 4 bovids comprise the smallest sample, making this the least statistically robust result out of the entire group. Moreover, although it does represent the strongest relationship among the samples examined here, the p-value of 0.128 still indicates a non-significant correlation or, at best, one that is only marginally statistically significant.

Table 5.26 Spearman's rank correlation coefficient results for nNISP versus BMD.

Sample	**NISP**	**Portions[1]**	**r_s**	**p-value**
All excavation blocks	151[2]	40	0.137	0.4
W14	37	25	0.14	0.5
W15	48	24	0.143	0.51
X15	54	26	-0.027	0.9
Bovid 1/2	131	37	0.138	0.41
Bovid 3/4	15	11	0.488	0.13

[1] Unique element portions represented in the dataset
[2] Includes 5 specimens for which size body class was not determined, but which are size 1 or 2

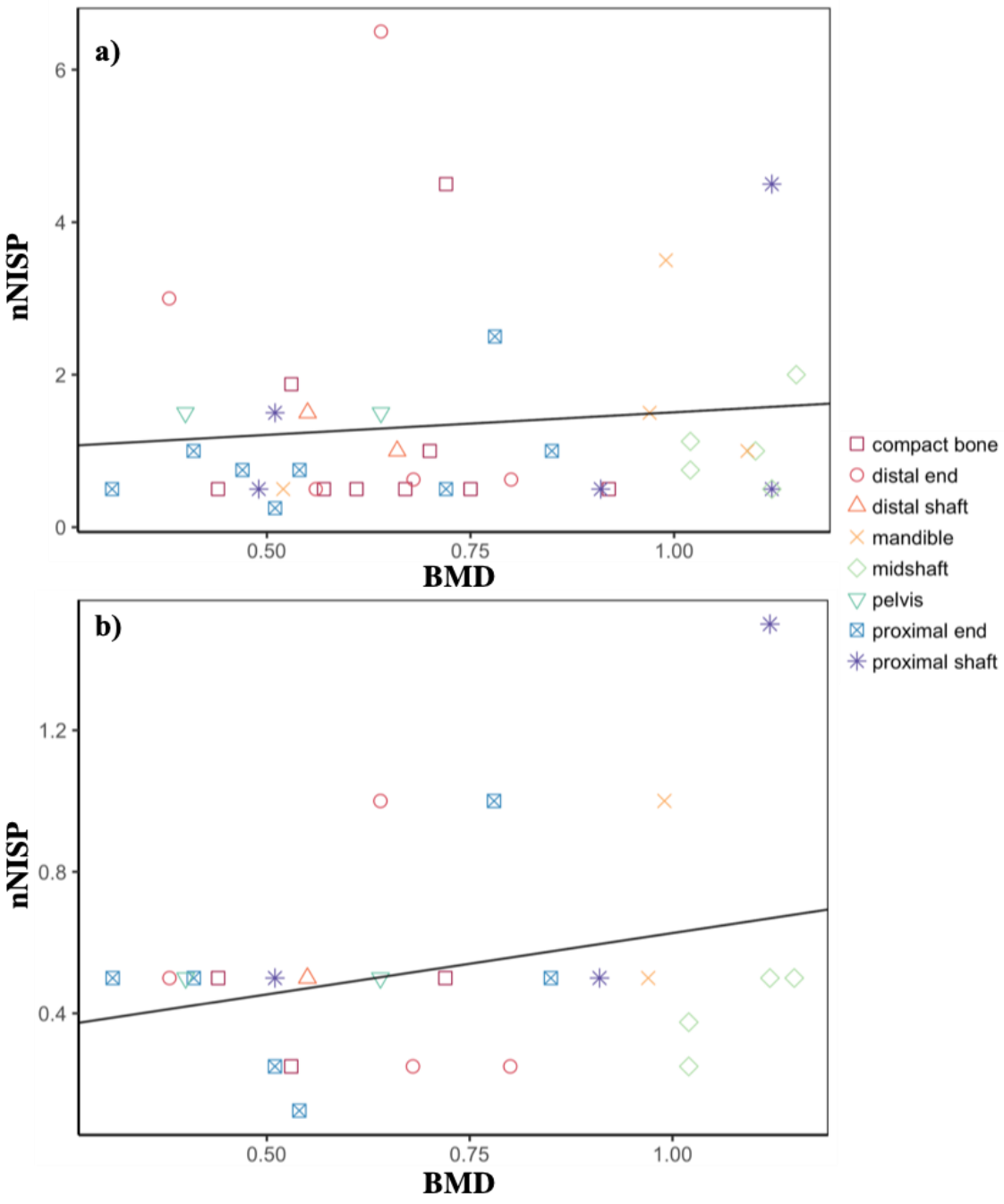

Figure 5.16 Plots of nNISP versus BMD for a) all bovid size classes and excavation blocks and b) size 1-4 bovids from excavation block W14.

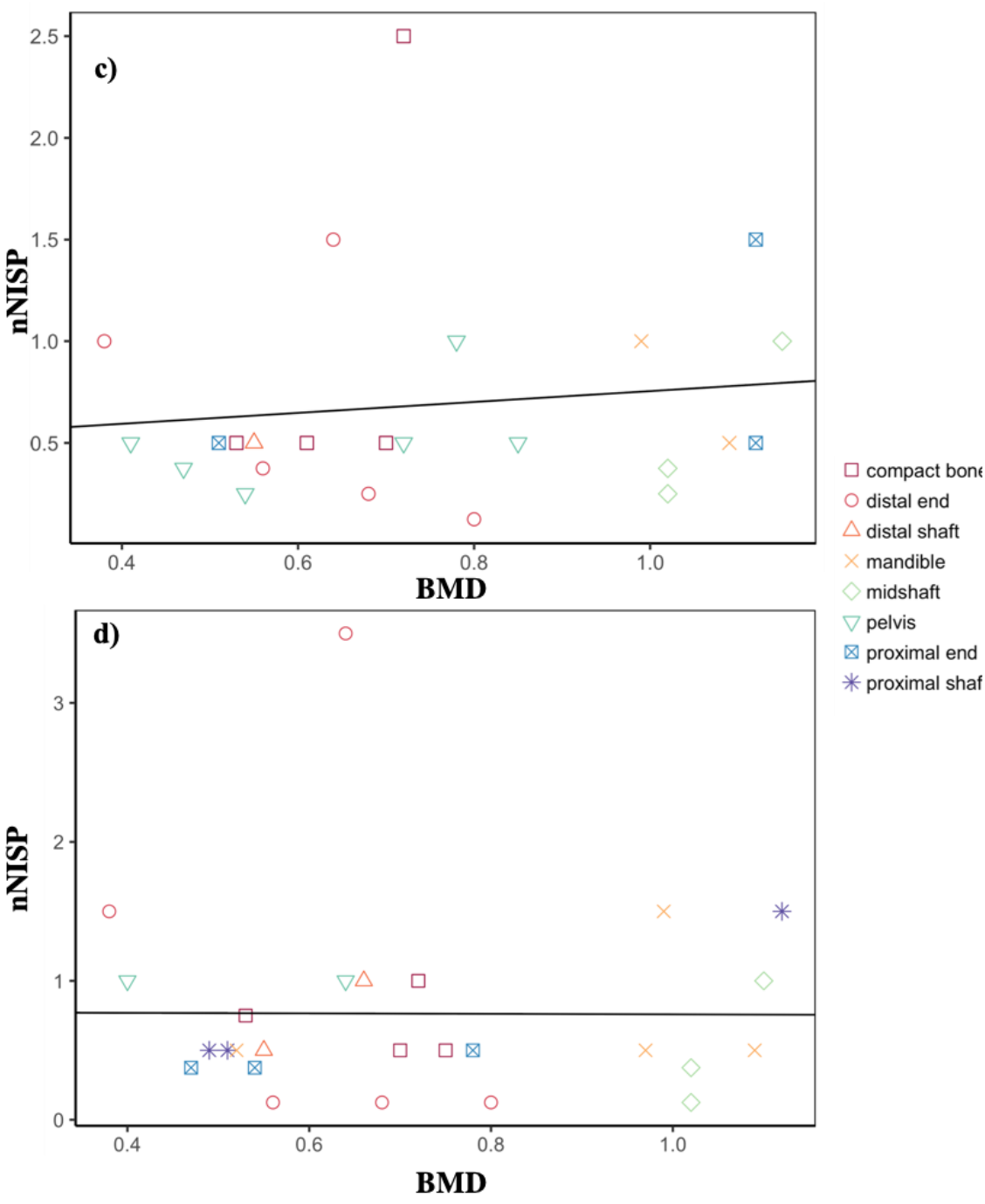

Figure 5.16, cont. Plots of nNISP versus BMD for size 1-4 bovids from c) excavation block W15 and d) excavation block X15.

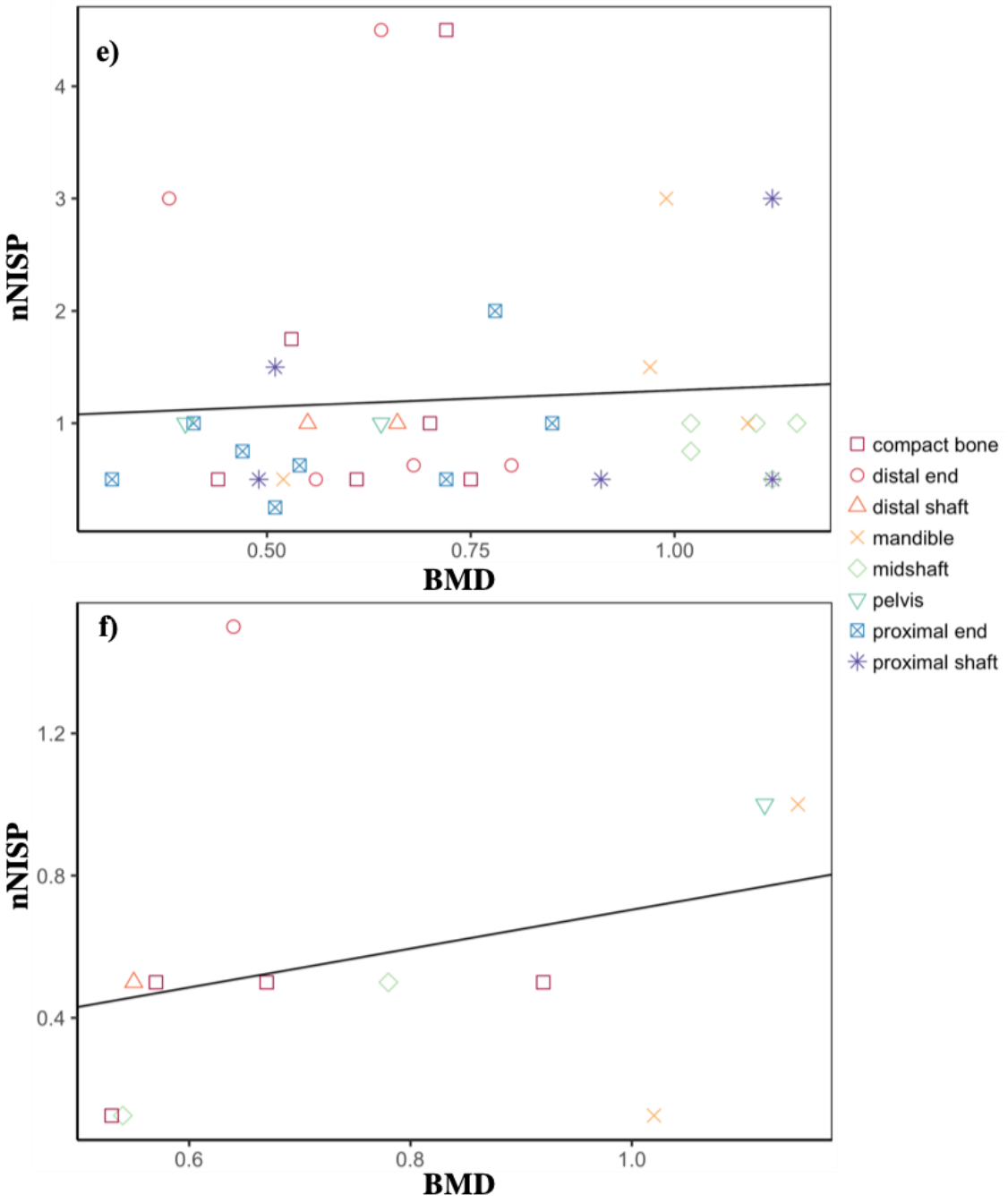

Figure 5.16, cont. Plots of nNISP versus BMD for e) size 1/2 bovids and f) size 3/4 bovids.

Completeness indices for compact bones

Examining fragmentation of compact bones offers an additional avenue by which to investigate the severity of post-depositional bone destruction at SM1 (Marean, 1991; Villa *et al.,* 2012). The Completeness Index (CI) of Marean (1991) is used here to investigate the degree of fragmentation among compact bones at SM1. In order to calculate CI, each bone was first assigned a "percentage complete" during data collection, which simply represents an estimate of the fraction remaining (out of 1) of the original bone. Next, all of the percentages for each bone (or group of bones) were summed, and the total divided by the NISP of that particular bone. Finally, a mean completeness value (*i.e.,* the CI) for each bone was produced by multiplying the dividend by 100 (Marean, 1991). The expectation is that the CI should be relatively low (*i.e.,* < 50%) for sites at which a significant degree of natural post-depositional destruction has occurred. Conversely, CI should be comparatively high for sites not impacted heavily by post-depositional destruction, regardless of whether they were produced by humans and/or carnivores (Marean, 1991).

Although Marean (1991) focused specifically on carpals and tarsals, the sample analyzed here includes sesamoids, patella, and phalanx 3, because these are also compact bones and are similar to carpals and tarsals in that they are small, relatively dense, nutrient-poor, and unlikely to be targeted by either humans or carnivores for nutritive destruction on a regular basis. The inclusion of these elements also serves to increase sample sizes, which are somewhat low across the board. Due to the relatively small sample sizes, all carpals have been grouped together, as have all tarsals except the astragalus and calcaneus.

The CI is 97.1% and 98.8% for the combined tarsals and the sesamoid/patella groups, respectively, indicating that the majority of these bones are almost completely intact at SM1 (Table 5.27 and Figure 5.17). Similarly, the CI for carpals is 78.6%, which

Table.5.27 Completeness Index for compact bones.

Element	NISP	TPC	CI
Carpals	7	5.5	78.6
Tarsals	7	6.8	97.1
Calcaneus	4	2	50
Astragalus	10	6.2	62
Phalanx 3	20	13.4	67
Sesamoids/patella	8	7.9	98.8
TPC=total percentage complete; CI=completeness index			

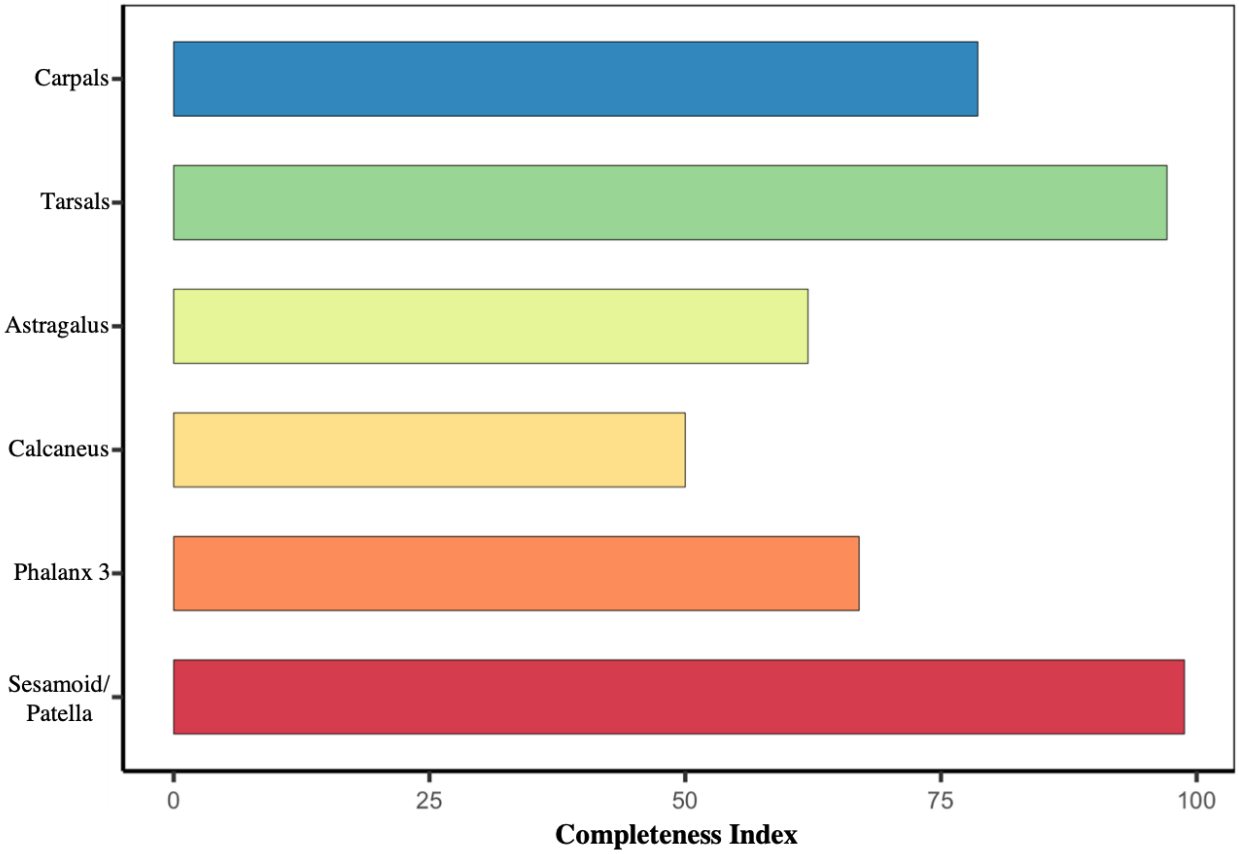

Figure 5.17 Completeness Index for compact bones.

again indicates that most of these elements are largely complete. The astragalus and phalanx 3 provide the largest samples of individual compact bones, and in both cases the CI is somewhat lower than those for the other tarsals, carpals, and the sesamoid/patella group. Nonetheless, the CI of 62% for the astragalus and 67% for phalanx 3 still document that these elements are ~2/3 complete on average, which does not suggest an extensive amount of fragmentation for either set of bones.

The calcaneus, which has a CI of 50%, was found to be the most extensively fragmented of all the compact bones analyzed here. This CI value is the only one that approaches what might be considered a substantial amount of post-depositional destruction at SM1, at least based on the data from compact bones, although it still indicates that calcanei are 50% complete on average (Table 5.27 and Figure 5.17). It is also interesting to note that, unlike the other compact bones analyzed here, the calcaneus actually contains a small marrow cavity that is potentially a target for humans and/or carnivores, and Marean (1991) actually omitted the calcaneus from his analyses of archaeological sites for this very reason. Thus, the possibility that the higher degree of fragmentation of the calcaneus may result from human and/or carnivore nutritive destruction cannot be ruled out. The fact that at least one other compact bone in the assemblage shows evidence of human processing (in the form of cut marks – see below) may further support this idea.

Due to small sample sizes and the presence of several rows in the contingency table with no observations in one or more of the analytical units, it is only possible to compare post-depositional destruction across the vertical extent of SM1 using aggregated samples that represent the "upper" and "lower" portions of the site. MSA-1 and MSA-2 were combined into a single level that consists of the upper ~1 m of the site, while MSA-3 and MSA-4 were combined into a second level that represents the lower ~0.7 m of the site. Although less than ideal, using the aggregated samples nonetheless makes it possible to

compare element portion representation across the vertical extent of the site with sample sizes that better facilitate statistical analysis (n = 70 for the "upper" level, and n = 58 for the "lower" level). Unfortunately, there are not enough identified compact bones at the site to allow for meaningful analysis of any sort of subdivided groups, so it is not possible to compare CIs between individual analytical units.

Chi-squared tests of independence between the "upper" and "lower" levels of SM1 indicate that differences in skeletal element portion representation between them are highly insignificant ($\chi^2 = 1.79$, p = 0.97). These results suggest, in turn, that the level of post-depositional destruction is quite similar across the entire vertical extent of the site. Thus, it seems likely that, were it possible to conduct such analyses, individual pairwise comparisons of MSA-1, MSA-2, MSA-3, and MSA-4 would also turn up few, if any, significant differences between them in terms of post-depositional destruction, at least as measured by the representation of different skeletal element portions in each unit

Bone surface modification

Both human and carnivore damage were observed on the terrestrial fauna from SM1. Of the 3234 specimens closely inspected for surface modification, a total of 463 cut and percussion marks were identified on 100 and 82 specimens, respectively (*i.e.,* 5.6% of the assemblage combined), and 421 carnivore tooth marks were observed on a total of 152 specimens (*i.e.,* 4.9% of the assemblage) (Table 5.28 and Figure 5.18). Given the high degree of bone fragmentation at SM1, it is perhaps not surprising that ~80-85% of specimens with cut, percussion, and tooth marks could not be identified to a specific skeletal element, although the majority of these specimens were at least identifiable as long bone shaft fragments in all three cases (Table 5.29). Samples are quite small, but of the identified portion of the assemblage that preserves human modification, long bones are

Table 5.28 Frequencies of human and carnivore surface modification at SM1.

Modification type	**# Marks**	**# Specimens**	**%Total[2]**
Cut mark	320	100	3.1
Percussion mark	143	118	3.6
Total human mod.	*463*	*182 [1]*	*5.6*
Tooth mark	421	152	
Total carnivore mod.	*421*	*152*	*4.7*
Total	**884**	**334**	**11.9**

[1]Adjusted to account for specimens with multiple mark types
[2]Out of 3234 specimens thoroughly inspected for surface modification

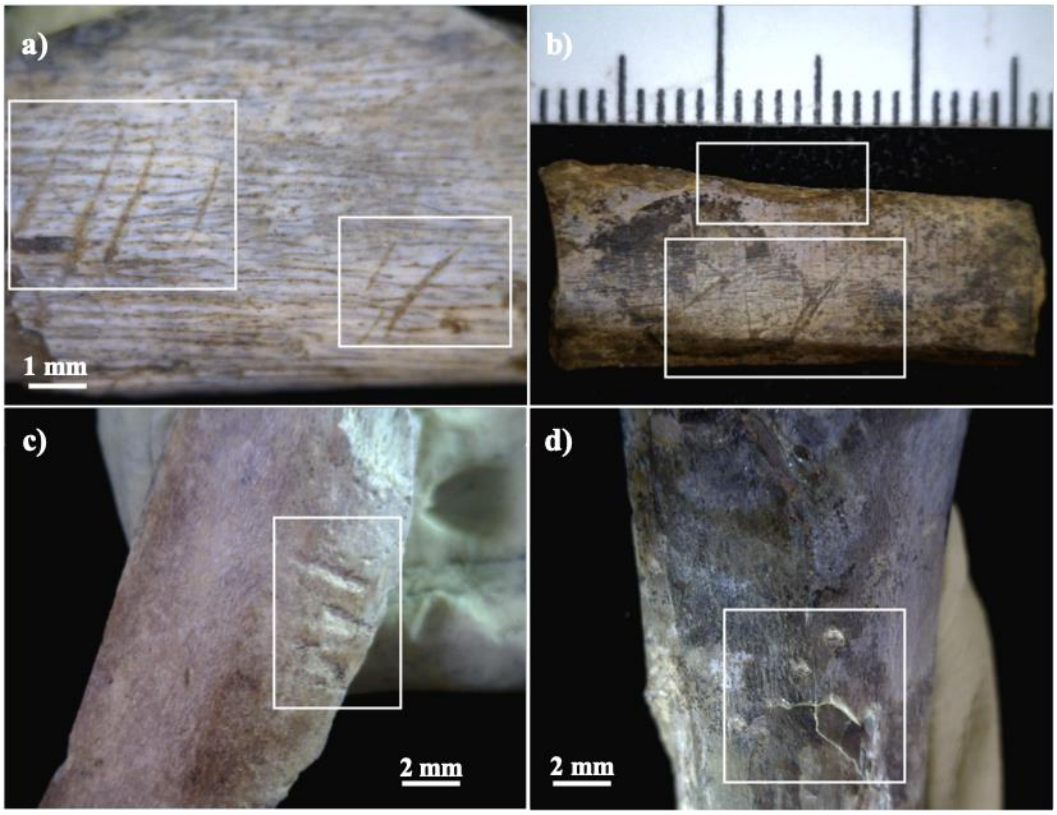

Figure 5.18 Specimens with a) cut marks (SM1-671; this specimen is also shown in Figure 5.6d), b) cut and percussion marks (X15-22-268) c) carnivore tooth furrows (SM1-665), and d) carnivore tooth punctures (W15-21-117).

Table 5.29 Counts of modified specimens by element type and percentages of modified specimens represented by each group.

Element	CM	PM	TM	% Human	% Carnivore
Cranial	-	3	1	1.6	0.7
Axial	5	1	7	2.6	4.7
Long bones	11	8	18	9.1	12
Compact bones	2	-	2	1	1.4
Long bone fragment	63	97	102	72	67.1
Non-ID bone	19	9	22	13.1	14.5
CM = cut mark; PM = percussion mark; TM = tooth mark					

more than three times as likely as other elements to have cut and percussion marks. Cut marks were also observed on several ribs, a scapula, an innominate, and two compact bones, as were percussion marks on three mandibles and a single rib. Likewise, the number of long bones with carnivore tooth marks is more than double that of any other type of element. Additional specimens bearing tooth marks include a mandible, a bird coracoid, several ribs, a thoracic vertebra, a radial carpal, and a third phalanx (Table 5.29).

The relative percentages of long bone midshaft fragments with cut, percussion, and/or carnivore tooth marks from SM1 and experimental assemblages modeling several different scenarios in which either humans (*i.e.,* human-then-carnivore: H-C) or carnivores (*i.e.,* carnivore-then-human: C-H; carnivore-then-human-then-carnivore: C-H-C) were given first access to bones are presented in Table 5.30 (Blumenschine, 1995; Capaldo 1995, 1998; Marean and Kim, 1998; Selvaggio, 1998). Some of the experimental studies only report two types of marks, so the data are presented in three different ways to facilitate direct comparisons with SM1: 1) the relative frequencies of specimens with cut, percussion, and tooth marks; 2) the relative frequencies of specimens with only percussion and tooth marks; and 3) the relative frequencies of specimens with only cut and tooth

marks. Relative frequencies were calculated by dividing the number of specimens with at least one of the mark types under consideration (*i.e.,* cut + percussion + tooth; percussion + tooth; or cut + tooth) by the total number of specimens bearing those same mark types.

Table 5.30 Relative frequencies (%) of bone surface modification at SM1 and comparative sites.

All mark types	**Site type**	**CM**	**PM**	**TM**
SM1	-	22.9	36.6	40.5
Capaldo (1998)	H - C (HS)	25.7	42.5	31.8
Selvaggio (1998)	C - H	6.5	33.3	60.2
Selvaggio (1998)	C - H - C	10.2	18.4	71.4
PM and TM only				
SM1		-	47.5	52.5
Capaldo (1998)	H - C (HS)	-	57.2	42.8
Blumenschine	H - C	-	77.2	22.8
Selvaggio (1998)	C - H	-	35.6	64.4
Selvaggio (1998)	C - H - C	-	20.5	79.5
CM and TM only				
SM1		36.2	-	63.8
Capaldo (1998)	H - C (HS)	44.6	-	55.4
Capaldo (1998)	H - C (WB)	21.7	-	78.3
Selvaggio (1998)	C - H	9.7	-	90.3
Selvaggio (1998)	C - H - C	12.5	-	87.5

Sequence of access: H - C = "humans-then-carnivores"; C - H = "carnivores-then-humans"; C - H - C = "carnivores-then-humans-then-carnivores"

CM = cut mark; PM = percussion mark; TM = tooth mark

Data from Blumenschine (1995), Capaldo (1995, 1998), Selvaggio (1998), Marean and Kim (1998)

As might be expected, SM1 is not an exact match for any of the experimental assemblages (Table 5.30 and Figure 5.19a-c). In most cases, SM1 has lower percentages of cut- and percussion-marked specimens than the H-C experimental assemblages, and SM1 actually has a slightly lower frequency of specimens with percussion than tooth marks, which does not align with any of the H-C experiments. Yet, in both of the datasets considering cut marks, cut mark frequencies at SM1 are ~2-3 times higher than those for both the C-H and C-H-C assemblages. Percentages of tooth-marked specimens at SM1 are also quite a bit lower than the C-H and C-H-C assemblages in all cases, with an average difference of 23% between SM1 and all the "carnivore-first" assemblages. Conversely, tooth mark frequencies at SM1 are only ~8% higher than the H-C experiments on average, and SM1 actually has a lower relative frequency of tooth-marked specimens than the H-C "whole bone" (Capaldo H-C (WB)) experiment (Table 5.30 and Figure 5.19a-c).

The results of chi-squared tests between assemblages for surface modification frequencies are presented in Table 5.31. Although SM1 is significantly different from all other assemblages when cut, percussion, and tooth marks are considered together, the differences with both the C-H and C-H-C assemblages are greater than with the H-C "hammerstone" (Capaldo H-C (HS)) assemblage. When only cut and tooth marks are considered, differences between SM1 and the H-C (HS) scenario are not significant. Further, a more detailed inspection of the data reveals that the significant differences between SM1 and the H-C (WB) scenario actually stem from the fact that cut-marked specimens are significantly more abundant than expected at SM1. A non-significant result is also found between SM1 and the C-H experiment when only percussion and tooth marks are considered, although closer examination of these data does indicate that percussion marks are over-represented and tooth marks under-represented at SM1 in this case, as well. Overall, SM1 appears to be more similar to the H-C assemblages, with the closest match

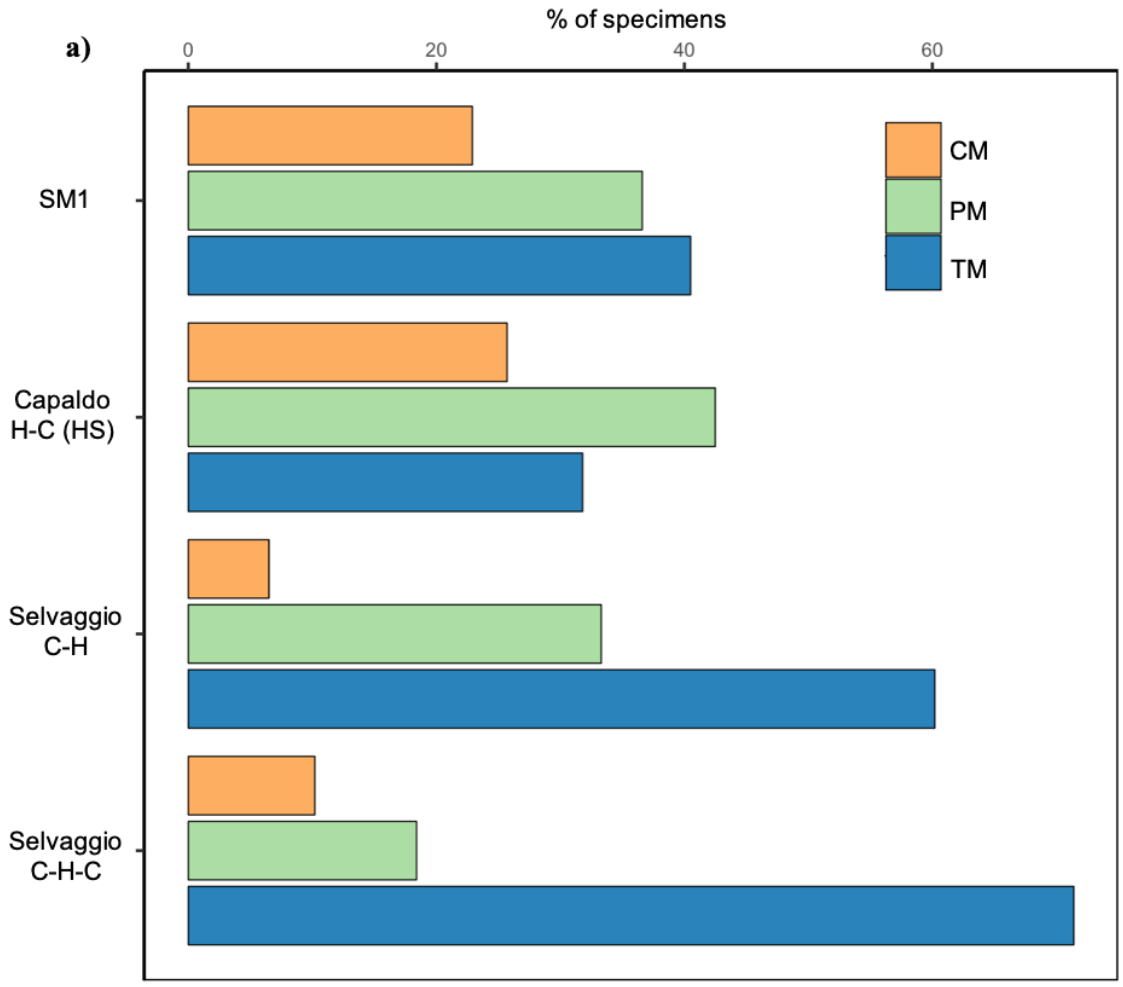

Figure 5.19 a) Relative frequencies (%) of modified specimens for SM1 and experimental assemblages. Percentages were calculated by dividing the number of specimens containing a specific mark type by the total number of specimens with at least one cut, percussion, or tooth mark. CM = cut mark; PM = percussion mark; TM = tooth mark.

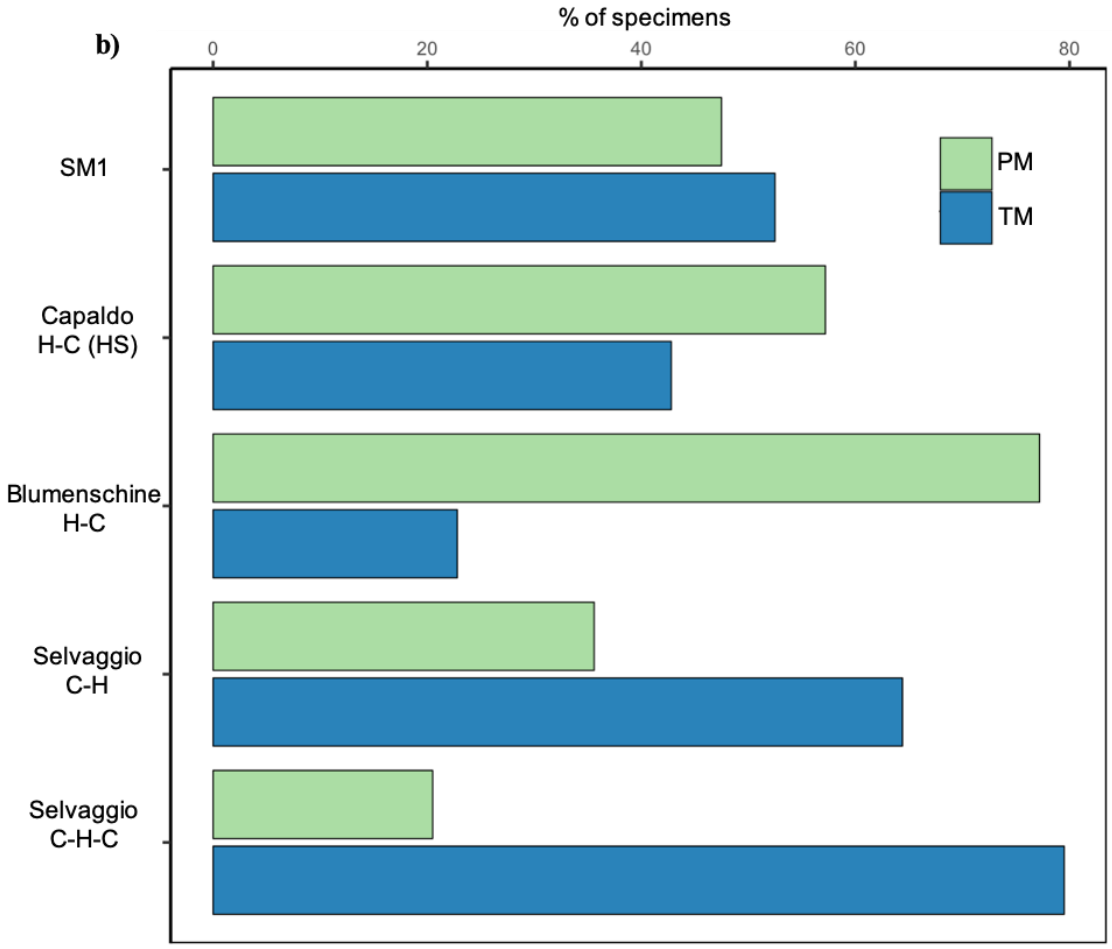

Figure 5.19, cont. b) Relative frequencies (%) of specimens with percussion and tooth marks for SM1 and experimental assemblages. Percentages for were calculated by dividing the number of specimens containing at least one percussion or tooth mark by the total number of specimens with percussion and/or tooth marks. PM = percussion mark; TM = tooth mark.

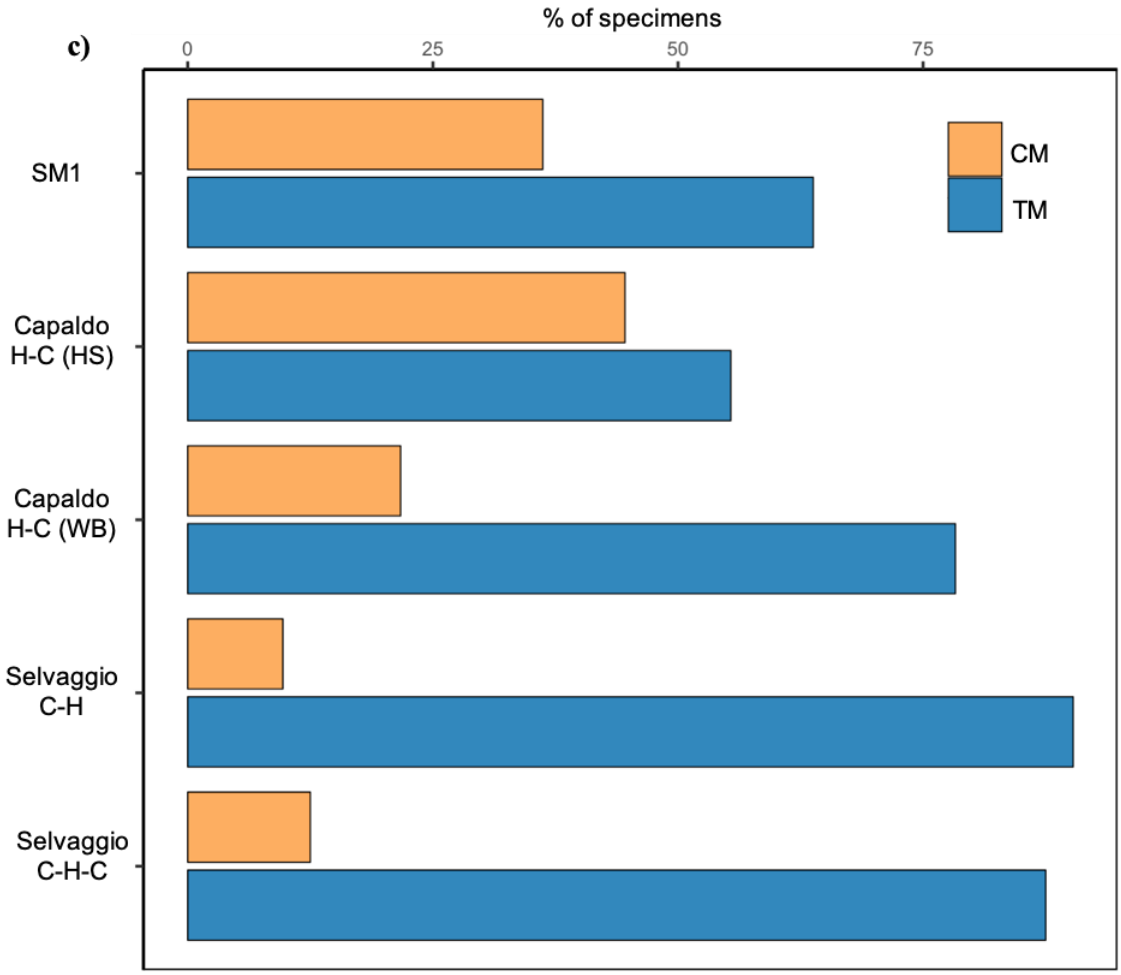

Figure 5.19, cont. c) Relative frequencies (%) of specimens with cut and tooth marks for SM1 and experimental assemblages. Percentages for were calculated by dividing the number of specimens containing at least one cut or tooth mark by the total number of specimens with cut and/or tooth marks. CM = cut mark; TM = tooth mark.

Table 5.31 Chi-squared tests of independence between SM1 and experimental assemblages for surface modification.

	All mark types		PM and TM only		CM and TM only	
Assemblage	χ^2	**p-value**	χ^2	**p-value**	χ^2	**p-value**
Capaldo H-C (HS)	5.98	0.05*	5.2	0.02*	3.24	0.07
Capaldo H-C (WB)	-	-	-	-	7.73	< 0.01*
Blumenschine H-C	-	-	34.14	< 0.01*	-	-
Marean H-C	-	-	58.54	< 0.01*	-	-
Selvaggio C-H	16.04	< 0.01*	3.44	0.06	15.38	< 0.01*
Selvaggio C-H-C	15.94	< 0.01*	10.75	< 0.01*	8.35	< 0.01*

*p-value significant at $\alpha = 0.05$

CM = cut mark; PM = percussion mark; TM = tooth mark

being to the experiment of Capaldo (1998) that modeled a scenario in which carnivores had secondary access to bones that were first defleshed and hammerstone-processed for marrow removal by humans (Tables 5.30 and 5.31 and Figure 5.19a-c).

Examining surface modification with respect to animal body size shows that specimens with human modification are more common (in both absolute and relative terms) than those with carnivore damage for specimens in most of the CT categories (Figure 5.20a and b). The only exception is CT 4, for which the three modified specimens each bear a single tooth mark. The situation is reversed for CT 5, with the sole modified specimen bearing two human cut marks. Although, the number of specimens with cut and percussion marks is generally similar for all small-to-medium-sized animals (*i.e.,* CT categories 1-3), the relative frequencies of both types of mark increase slightly with each step up, suggesting a possible correlation between animal size and human processing (Figure 5.20b). Chi-squared tests support this conclusion, and indicate significant differences between CT 1-3 for the number of cut-, percussion-, and unmarked specimens ($\chi^2 = 15.439$, $p > 0.01$). More specifically, the number of human-modified specimens is

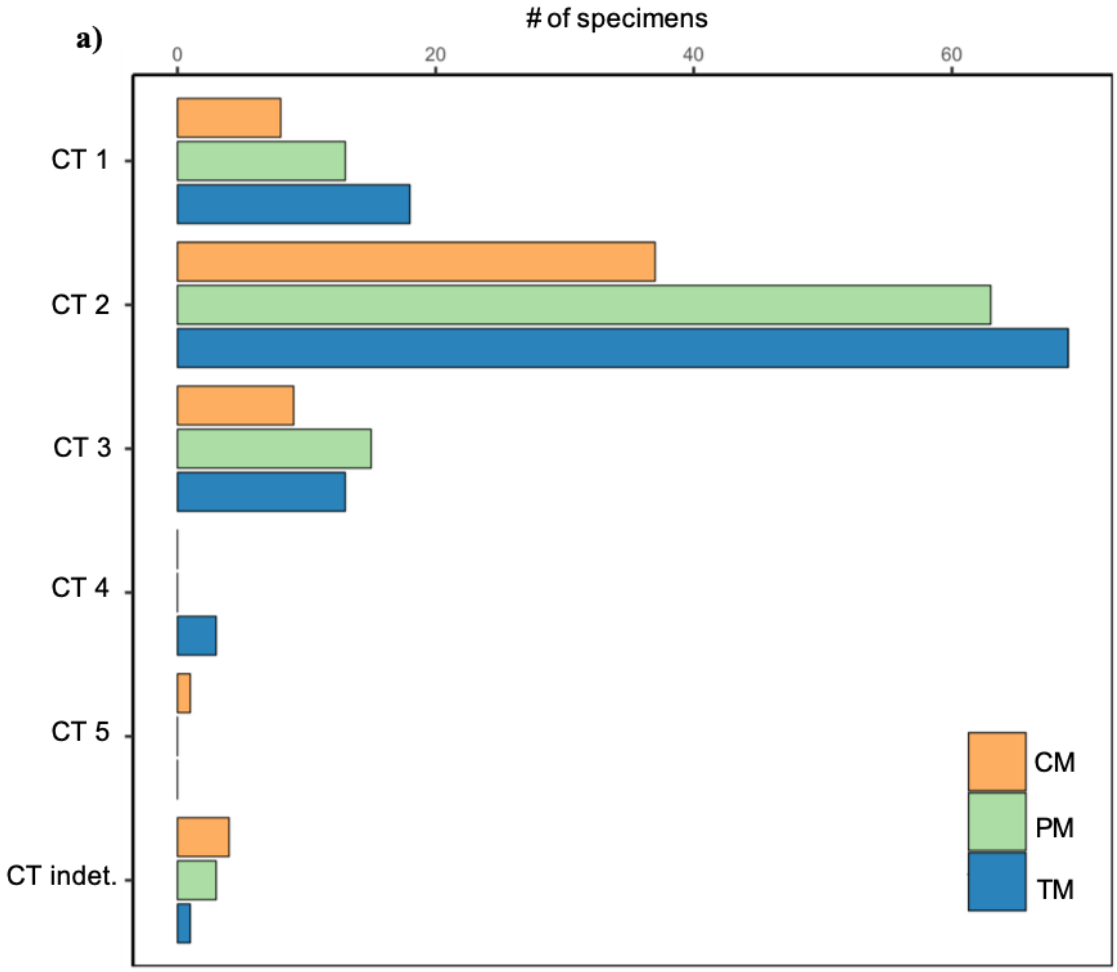

Figure 5.20 a) Raw frequencies (NISP) of specimens with surface modification for each CT category. CM = cut mark; PM = percussion mark; TM = tooth mark. CT indet. = CT category indeterminate or not relevant.

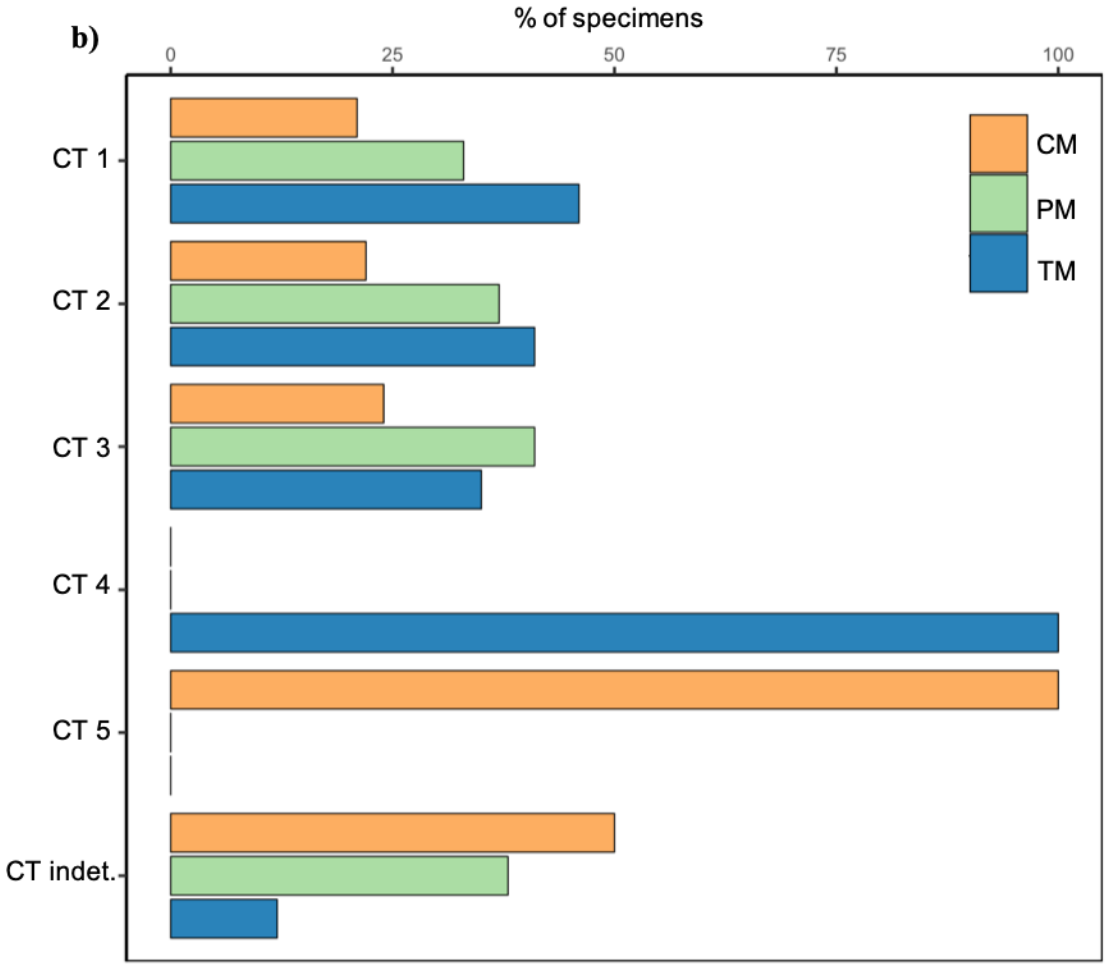

Figure 5.20, cont. b) Relative frequencies (%) of specimens with surface modification for each CT category. Percentages were calculated by dividing the number of specimens containing a specific mark type by the total number of specimens with at least cut, percussion, or tooth mark in each CT category. CM = cut mark; PM = percussion mark; TM = tooth mark. CT indet. = CT category indeterminate or not relevant.

significantly smaller than expected for CT 1, and larger than expected for CT 3. Bones with cut and percussion marks are also more common than expected for CT 2, although the relationship is not statistically significant.

Carnivore damage shows the opposite pattern, with a general decrease in the relative frequencies of tooth-marked specimens as size increases from CT 1-3 (Figure 5.20b). Chi-squared tests indicate that the number of specimens with tooth marks for CT 1 is significantly larger than expected, but that overall differences in the number of tooth-marked versus unmodified specimens between CT 1-3 are not statistically significant at $\alpha = 0.05$ ($\chi^2 = 5.42$, $p = .07$). Finally, chi-squared tests also indicate no significant differences in the numbers of human- versus carnivore-modified specimens for CT 1-3 and specimens for which CT category was indeterminate or not relevant (*i.e.,* elements other than long bones).

The relative frequencies of specimens with cut, percussion, and carnivore tooth marks are generally similar within each of the four analytical units (Figure 5.21). Human modification does appear to be somewhat over-represented in MSA-1, but chi-squared tests do not indicate significant differences between any of the units for the frequency of specimens with cut and percussion versus carnivore tooth marks (Table 5.32). This suggests that, relative to the total number of modified specimens in each unit, neither human nor carnivore modification is substantially over- or under-represented in any of the analytical units. Although the overall results are once again non-significant at $\alpha = 0.05$ ($\chi^2 = 11.85$, $p = .07$), when unmodified specimens are included (*i.e.,* human- versus carnivore-versus un-modified specimens), the results for all four analytical units combined suggest that specimens with human modification are significantly more abundant than expected in MSA-1 and less abundant in MSA-3. Additionally, there are more carnivore-modified

specimens than expected in MSA-1, MSA-2, and MSA-4, although in no case is the relationship statistically significant.

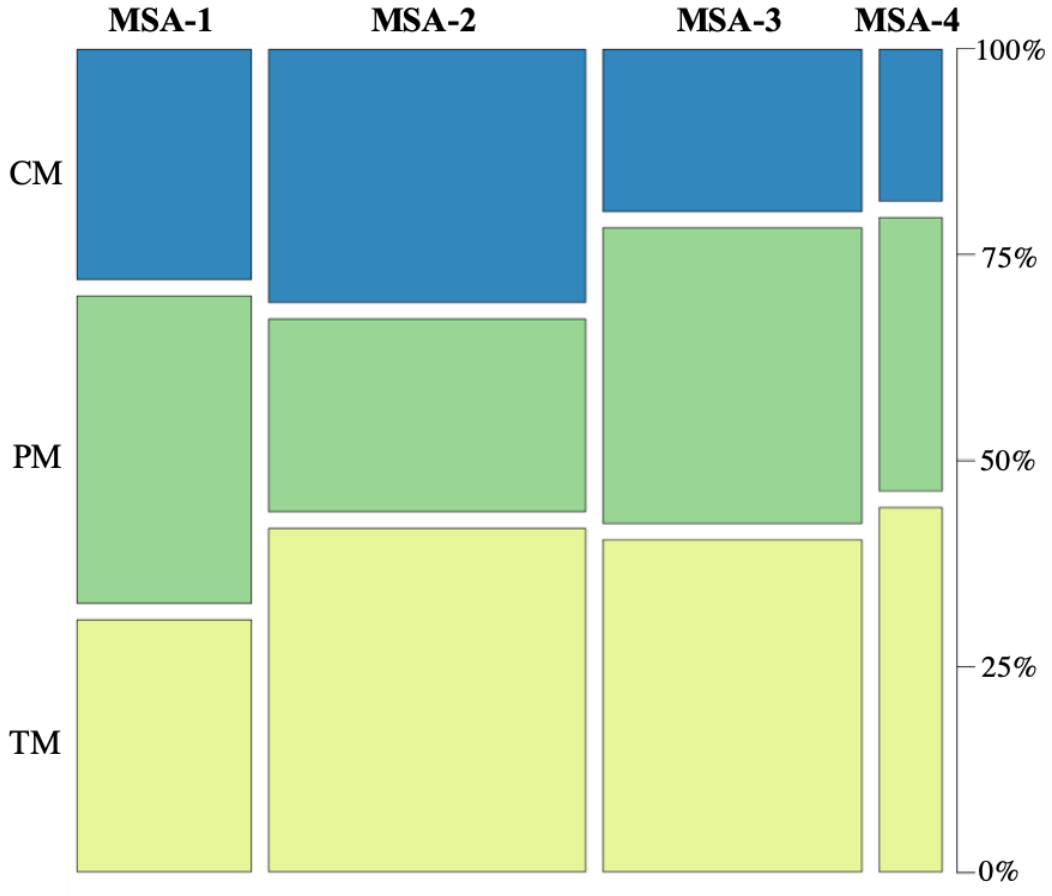

Figure 5.21 Relative frequencies (%) of specimens with surface modification in each analytical unit. Bin height scales to the relative percentage of each group within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit. CM = cut mark; PM = percussion mark; TM = tooth mark.

Table 5.32 Chi-squared tests of independence between AUs for surface modification.

AU 1	AU 2	χ^2	p-value
MSA-1	MSA-2	2.17	0.14
MSA-1	MSA-3	1.27	0.26
MSA-1	MSA-4	0.99	0.32
MSA-2	MSA-3	0.13	0.72
MSA-2	MSA-4	0	0.99

Taphonomic summary

The data presented in this section suggest that bone surface visibility and preservation are good overall at SM1. The large majority of bones are either completely unweathered or only lightly-to-moderately weathered, and the frequencies of other types of damage that can weaken bones and hinder close inspection of surfaces are generally low. The most common type of damage from post-depositional processes other than weathering is exfoliation, which occurs on just under 14% of the total specimens. The evidence for thermal alteration indicates that ~40% of the terrestrial faunal assemblage has been exposed to fire, with moderate carbonization and full calcination being the most and least common types of burned bone, respectively. Given that over half of the burned bones are only lightly-to-moderately carbonized, it seems unlikely that thermal alteration was severe enough across the entire assemblage to substantially alter patterns of bone fragmentation or complicate identification of surface modification marks. Although somewhat rare overall, the fact that 10% of specimens are calcined further indicates that many bones experienced prolonged exposure to extremely high temperatures which are often not produced by naturally-occurring fires (David, 1990; Lyman, 1994; Buenger, 2003; but see Keough *et al.,* 2015; Alvarez *et al.,* 2017).

Data on bone fragmentation document that the bones of terrestrial fauna from SM1 are extensively fragmented. Just under 80% of specimens overall are < 20 mm in maximum length, and the average fragment lengths for both mapped (16.32 mm) and water-screened (10.71 mm) specimens are well below 20 mm. When fragmentation data are analyzed using CT categories as a proxy for animal body size, there is some evidence that the magnitude of bone fragmentation is greater for smaller animals than it is for larger ones. However, it is important to keep in mind that sample sizes for animals larger than CT 3 are quite small, and regardless, at least 50% of the bones in all five CT categories are < 30 mm in maximum length, which suggests a high degree of fragmentation across the board.

Analyses of long bone fracture end morphology document an abundance of oblique angles and curved/v-shaped outlines, indicating that most bones were broken while fresh. Interestingly, right angle and transverse breaks, both of which are most commonly associated with dry bone breaks, are also fairly common. Comparative analyses further indicate that SM1 is quite similar to the human-produced UP site of Bezouce, at which fragmentation is largely due to human nutritive breakage, and significantly different from the sites of Sarrians and Fontbregoua, where non-nutritive damage is substantial. However, the frequencies of right angle and transverse breaks are still much higher at SM1 than at experimental sites produced by humans and carnivores. Particularly when coupled with the fact that ~40% of long bones have fractures indicative of both fresh and dry breaks on opposite ends, the high frequencies of right angle and transverse breaks raise the possibility that an extensive amount of non-nutritive bone destruction has occurred at SM1.

Analyses of the relationship between BMD and skeletal element portion representation in size 1-4 bovids and fragmentation of compact bones were conducted to further explore the extent of density-mediated attrition and post-depositional destruction of bone. BMD and element portion data were analyzed for the entire sample, as well as several

subsets representing different areas of the site and bovid size classes, and in no case was there a statistically significant relationship between BMD and element portion representation. Similarly, analyses employing the CI of Marean (1991) failed to document significant fragmentation of compact bones at SM1. In all but one case, the CI was > 60%, and it was between ~80-98% in three of the six cases. The lone exception is the calcaneus, for which the CI was 50%, although the sample of calcanei is quite small and this is perhaps the compact bone most likely to have been fragmented by humans and/or carnivores for nutritive purposes. When taken as a whole, the data on BMD and skeletal element representation and compact bone fragmentation appear to indicate a moderate degree of natural, non-nutritive bone destruction at most.

Finally, although the absolute frequencies of bone surface modification are relatively low overall, the identification of ~900 cut, percussion, and tooth marks on a combined 334 specimens attests to the involvement of both humans and carnivores in site formation at SM1. Given that the absolute frequencies are quite similar, these data are somewhat equivocal with respect to the identity of the primary faunal accumulator at the site. However, in all but one of the datasets examined here, human damage is more common in terms of both the number of marks and the number of modified specimens; the only exception is the subset for CT category 4 (n=16), which contained three bones with a single tooth mark and no human-modified bones.

Comparisons of the relative percentages of modified long bone shaft fragments indicate that the data that best match SM1 are from experimental assemblages modeling scenarios where humans first defleshed and/or fragmented bones for marrow removal, after which they were given to carnivores to scavenge the remaining meat and marrow. Likewise, the relative frequency of specimens with carnivore tooth marks at SM1 is much lower than either of the two experimental assemblages in which carnivores had first access

to bones, but it does fall within the range observed for several of the "human-then-carnivore" assemblages. Overall, the surface modification data further support the idea that humans are primarily responsible for faunal accumulation and modification at SM1. More specifically, these data suggest that most terrestrial faunal bones were originally introduced into the site by humans and, as would typically be expected for an open-air site, then ravaged post-discard by other non-human carnivores. Additional discussion of the potential behavioral implications of the surface modification data are provided below in the section on human and carnivore activity at SM1.

Using taphonomy to test the validity of analytical units

As previously discussed, the four analytical units defined in Chapter 4 – MSA-1, MSA-2, MSA-3, and MSA-4 – are hypothesized to represent different occupation levels within SM1. The units were delineated *post-hoc* and largely based on plots of the spatial distribution of archaeological material, so they were initially treated as hypotheses of site formation that required additional testing and validation. Thus, another goal of the taphonomic analyses in this chapter was to determine whether differences exist between proposed analytical units, which support the idea that they do in fact reflect distinct episodes of occupation. Specifically, it was hypothesized that if the analytical units do represent different occupations, there should be discernible differences in the taphonomic attributes of the material in each of them. Conversely, if all of the material derives from a single occupation, or fewer than four episodes of habitation, the taphonomic signatures should be largely the same across some or all of the analytical units.

The results of comparative analyses between analytical units for subaerial weathering, post-depositional damage, burning, fragmentation, fracture morphology, and surface modification are summarized in Table 5.33. As noted above, there are no

Table 5.33 Summary of comparative analyses among the four analytical units.

Attribute	MSA-1	MSA-2	MSA-3	MSA-4
Weathering	All units	MSA-1	MSA-1	MSA-1
Post-dep. damage[1]	MSA-4	MSA-4	MSA-4	All units
Burning	All units	MSA-1 & -4	MSA-1 & -4	All units
Fragmentation	None	None	None	None
Fracture morphology	None	None	None	None
Surface modification	None	None	None	None

[1]Dendritic etching, pocking, exfoliation, sheen, smoothing, and erosion. Analytical units listed in each row are significantly different from the unit at the top of the column for the taphonomic attribute in question. For example, MSA-1 is significantly different from all other analytical units for the frequency of weathered versus unweathered bone. Similarly, MSA-1 is significantly different from MSA-4 for the frequency of specimens with and without post-depositional damage.

significant differences between any of the units for either bone fragmentation or fracture morphology. With respect to weathering, post-depositional damage, and burning, both MSA-1 and MSA-4 are significantly different from all other units for two out of three of these attributes. MSA-1 differs significantly from all other units in terms of weathering and burning, while MSA-4 was significantly different from the other three units for post-depositional damage and burning. Interestingly, comparisons of MSA-2 and MSA-3, the units that contain the largest concentrations of bone and artifacts, do not indicate any significant differences between the two (Table 5.33).

There are several potential explanations for the similarities of the overall taphonomic characters of MSA-2 and MSA-3. It is possible that the lack of distinction

between these two units reflects the fact that they do not actually represent separate occupational levels. Instead, it may be that material from these units derives from a single occupation and has simply become rather widely dispersed through ~90 cm of depth at the site. Given the combination of vertisols in the region and marked fluctuations in rainfall and aridity between wet and dry seasons, some vertical movement among artifacts and bones at SM1 is certainly expected, and it is possible that at least some material may have experienced significant vertical displacement over the millennia since its deposition.

This expectation is at least partly borne out by bone refit studies that were undertaken in part to better understand the extent of movement within the sediment column at SM1 and which document both horizontal and vertical displacement of material at the site (Table 5.34 and Figure 5.22). However, as Table 5.34 and Figure 5.22 show, the absolute vertical distance between refit specimens is typically quite small. There is a single case in which two refit specimens are separated by a vertical distance of 22.7 cm, but no other set of two or more refits is separated by a distance greater than 5.5 cm, and the average vertical distance between bones that refit is only 2.2 cm. This suggests that the majority of specimens at SM1 have not experienced a significant amount of vertical movement within the sediment column, or at least not the ~60 bones for which refit fragments were identified. Horizontal movement of specimens appears to be much more pronounced, with an average horizontal separation of 30.8 cm between refit specimens, a maximum distance of 174.4 cm, and four additional sets of refits found between ~45-95 cm apart in the N/S or E/W plane (Table 5.34). The higher degree of horizontal movement is interesting and, in fact, probably makes sense if the analytical units represent living floors that were regularly disturbed by foot traffic and/or intentionally swept clean of debris.

Table 5.34 Maximum horizontal and vertical distance between sets of refit specimens at SM1.

Refit #	# specimens	Level(s)	HD (cm)*	VD (cm)
W13-14-3	2	37, 38	36.8	1.7
W14-3-24	2	35	47	1.2
W14-3-134	2	36	1.4	0.5
W14-3-167a	2	37	0	0
W14-4-185	2	41	14.2	0.8
W14-8-179	2	40	21.9	0.1
W14-14-81	2	34	56.4	0.7
W14-15-832	2	37	6.1	0.1
W14-16-27	2	-	23	2.3
W14-16-309	2	32	25.3	1.2
W14-17-277	2	35	7.6	0.7
W14-25-215-1	2	28, 29	6.7	1
W14-25-393	2	30	46	4.1
W14-25-411	2	30	15.9	1.2
W15-8-115-1	2	32, 33	96.3	3.4
W15-10-11	2	32	79	1.1
W15-10-39	2	33	**174.4**	0.6
W15-22-2	4	22	27.2	5.5
W15-22-5	2	22	2.8	0.7
X15-1-179	3	28	44.4	1.9
X15-2-116	2	22, 23	62	4.9
X15-9-4	3	17	13.9	1.5
X15-12-330	2	19, 24	17.9	**22.7**
X15-18-478	2	20, 21	1.3	0.5
X15-9-191	2	19	33.5	1.8
X15-20-169a	2	23, 24	10.1	1.5
X15-21-65	3	24	0	0
X15-23-124-2	2	20	23	1.3
Z13-4-84	2	21	0	0
Average distance (cm)			**30.8**	**2.2**

*Maximum distance between N or E coordinates of two refit specimens

All refit sets have at least two unique catalog numbers, but were assigned a single number for presentation here. The catalog numbers presented here are typically those of the largest/most prominent piece in the refit set.

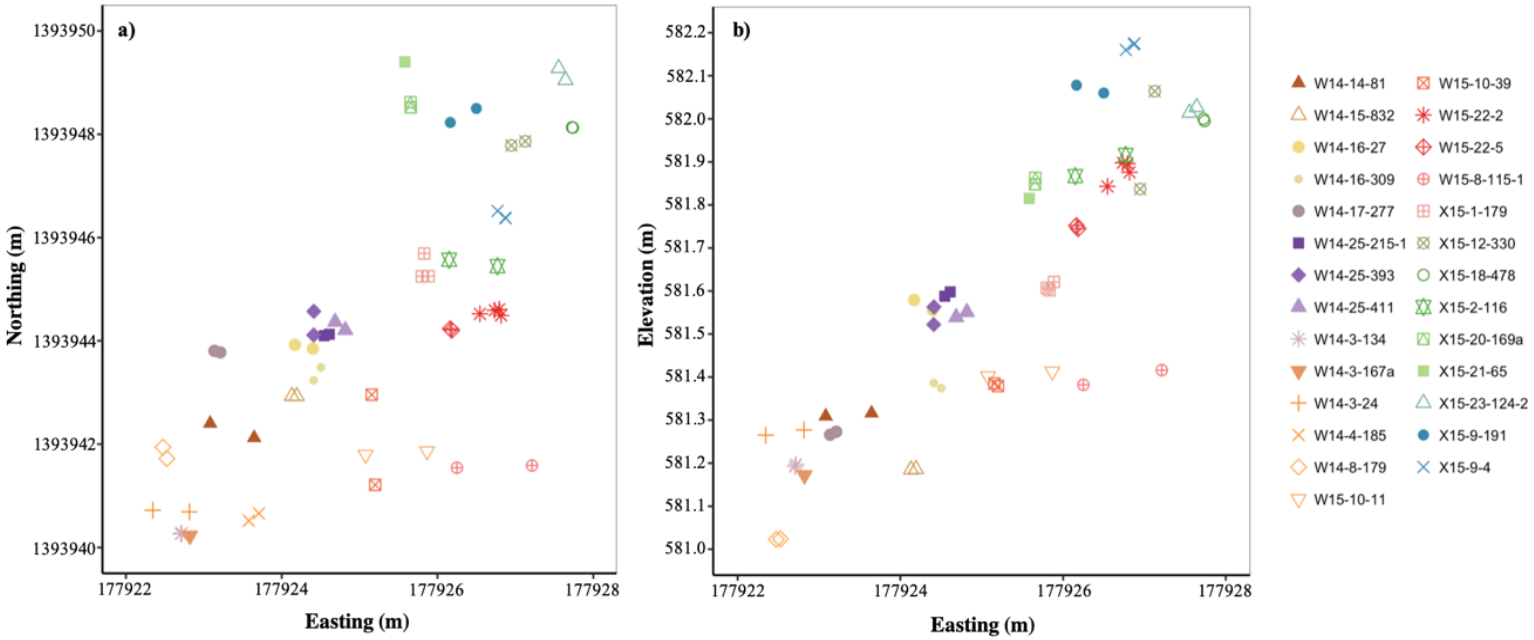

Figure 5.22 Spatial distribution of refit specimens across the a) horizontal and b) vertical extent of SM1. Specimens for which only one symbol is visible have the same easting and northing or elevation coordinates.

It is also important to keep in mind that the unconformities identified on the north wall of W14 and W15 align quite well with the boundary lines drawn between MSA-2 and MSA-3 (upper unconformity) and MSA-3 and MSA-4 (lower unconformity) (Figures 4.7 and 4.9). Moreover, this congruence exists despite the fact that the location of the unconformities was not used in the initial process of defining the surface floors (see Chapter 4). Although the unconformities were only identified within a one-meter-wide section of the N-S transects used to demarcate analytical units, the presence of what appears to be a natural boundary marker that separates MSA-2 and MSA-3 further supports the idea that the material in these units derives from different occupations.

It should also be pointed out that the analyses presented here employed aggregated groupings of the original codes for weathering, post-depositional damage, and burning in order to increase sample sizes and facilitate comparisons between analytical units. However, when the original data (*i.e.,* all six weathering codes, all seven burn codes, and all six types of post-depositional damage) are analyzed instead, the results indicate significant differences between MSA-2 and MSA-3 for weathering ($\chi^2 = 19.61$, p = .001) and erosion ($\chi^2 = 7.85$, p = 0.05), although not for burning or any of the other types of post-depositional damage. Once again, these data generally support the idea that material in each unit was deposited at different times and that each unit has a somewhat distinct preservational history.

It is also possible that there are, in fact, at least four distinct occupation levels at SM1, but the delineation of the analytical units presented here is not entirely accurate. In other words, some of the material assigned to MSA-2 may actually belong in MSA-3, and vice-versa. This would actually not be that surprising, given that it was necessary to define the analytical units on a largely *post-hoc* basis and there are several places within the site where the assignment of "floaters" (*i.e.,* artifacts and bones located in between relatively

dense clusters of material that appear to form a distinct surface) to an analytical unit was somewhat subjective (see Chapter 4). However, if this is the case, it is almost certainly only an issue for a relatively small number of specimens located on or very near to the boundaries drawn between units, and therefore seems unlikely to substantially alter the overall results of the analyses.

It may also be the case that MSA-2 and MSA-3 do represent separate occupation levels, but that the artifacts and bones within them were deposited under broadly similar (but not identical) conditions and have broadly similar (but not identical) preservational and taphonomic histories. In light of the above discussion, which highlights several other lines of evidence that point to multiple occupation levels at SM1 and suggest that MSA-2 and MSA-3 are in fact distinct from one another, this appears to be the most likely scenario. If so, then the use of taphonomic attributes would not be very effective in helping to validate MSA-2 and MSA-3 as separate units, simply because these data are very similar between the two units and are therefore not really appropriate for the task.

Ultimately, the taphonomic data appear to support the validity of the analytical units, or occupation levels, as defined in Chapter 4. There are clear differences in the taphonomic character of both MSA-1 and MSA-4 when compared to all of the other units. Additionally, although broader-scale comparisons suggest little difference between MSA-2 and MSA-3, more detailed analyses indicate that these levels also have somewhat distinct taphonomic signatures. A distinction between these two units is further supported by the position of the upper unconformity found along the north wall of W14 and W15, which provides a natural boundary between MSA-2 and MSA-3 that is very much in line with the boundaries of these units as they are defined in Chapter 4. Even if some material has been erroneously assigned to one or the other analytical unit, it very probably represents a relatively small number of items and is unlikely to substantially alter any conclusions

drawn from the overall analyses. Moreover, it certainly does not change the fact that there appears to be strong evidence for at least four different occupational events at SM1.

Finally, it is interesting to note that three of the four attributes that are likely due in large part to human behavior (*i.e.,* burning, fragmentation, fracture morphology, and surface modification) were found to be very similar across all four analytical units, while attributes resulting from natural, non-nutritive processes (*i.e.,* weathering, post-depositional damage) were found to differ significantly across multiple units in several cases. This may indicate that human behavior, at least as it relates to burning, fragmenting, and processing animal bones, remained fairly constant during different occupations of SM1, whereas natural environmental and/or preservational conditions may have been more varied over time.

HUMANS AND NON-HUMAN CARNIVORES AS AGENTS OF SITE FORMATION

The taphonomic analyses described above demonstrate that, while natural and non-nutritive destructive processes are partly responsible for patterns of bone modification at SM1, these processes likely produced only a moderate amount of damage to the terrestrial faunal assemblage. As such, humans and non-human carnivores are the only two other plausible agents of faunal accumulation and modification. The identification of cut, percussion, and tooth marks on ~10% of the terrestrial fauna provides unambiguous evidence that both humans and carnivores were involved in site formation, and more in-depth analyses largely point to humans as the primary agent of faunal accumulation and modification at SM1.

However, the surface modification data are perhaps somewhat more ambiguous than is often the case, so it is important to examine any additional evidence that can be used to evaluate whether or not humans are the primary faunal accumulator at SM1, and help

clarify the extent to which carnivores were also involved. In order to further disentangle the complex taphonomic history of the site, the following section examines several additional lines of evidence for human and carnivore activity at SM1. This section also provides further discussion of the potential implications of patterns of surface modification and skeletal element representation for MSA foraging behavior at SM1.

Human activity

Archaeological association

Information on different expectations for potential indicators at sites primarily produced by humans are presented in Table 5.35. As discussed in Chapter 4, along with an abundant terrestrial and aquatic fauna, SM1 also contains tens of thousands of chipped stone artifacts, including MSA and Levallois points, scrapers, prismatic blades, and various classes of debitage, all of which clearly and unequivocally document the presence of humans, and attest to their involvement in site formation. Moreover, artifacts and faunal remains are closely associated and relatively evenly dispersed throughout the horizontal and vertical extent of the site, and there do not appear to be any areas within the site where distinct clusters of lithics occur to the exclusion of faunal remains (or vice versa) (Figures 4.5, 4.6, and 4.9). Thus, the most parsimonious explanation for the spatial distribution of material at SM1 is that fauna and artifacts were deposited at the same time and by the same agent (*i.e.,* humans).

Burned bone

The spatial distribution of burned bone provides additional evidence to support the conclusion that humans are the primary accumulator of the terrestrial fauna at SM1 (Figure

Table 5.35 Potential expectations for sites created primarily by humans.

Evidence	Human sites
Archaeological association	Yes
Cut/percussion marks	High frequency
Tooth marks	Low frequency*
Carnivore remains	Low frequency
Axial elements and compact bones	Varies
Articular ends and near/epiphyseal frag.	High frequency
Midshaft fragments	High frequency (rel. to near-epiphyseal)
Burned bone	High frequency and intensive burning
Fresh bone breaks	High frequency
Non-human coprolites	No
Gastric etching	No

*Frequencies may be relatively high at sites where regular post-discard carnivore ravaging has taken place, as would be expected for open-air localities, but should still be much lower than primary carnivore kill and/or den sites.
Sources: Blumenschine 1988; Blumenschine and Selvaggio 1988; Villa and Mahieu 1991; Capaldo 1998; Marean et al. 2000; Pickering 2002; Villa et al. 2004; Munro and Bar Oz 2005.

5.23a and b; and see Figure 4.2 for a detailed view of the excavation grid with blocks and individual m^2 units labeled). Burned bone is distributed throughout the entire horizontal and vertical extent of the main excavation area and is found in every m^2 unit excavated to date, although there are several areas of the site in which burned bone appears to be rather heavily concentrated. There are particularly dense clusters located in units W15-22, X15-18, X15-19, and X15-20, which combined account for just under ~20% of the total burned bone at the site (Figure 5.23a). There are also noticeable concentrations in units W14-6, W14-25, and W15-8 located several meters to the south and/or west of the other clusters of burned bone. However, because many of the m^2 with the largest percentages of burned bone are also some of the most densely concentrated overall in terms of excavated material, it is worthwhile to examine the distribution of burned bone further using a unit of measure that also accounts for total sample size.

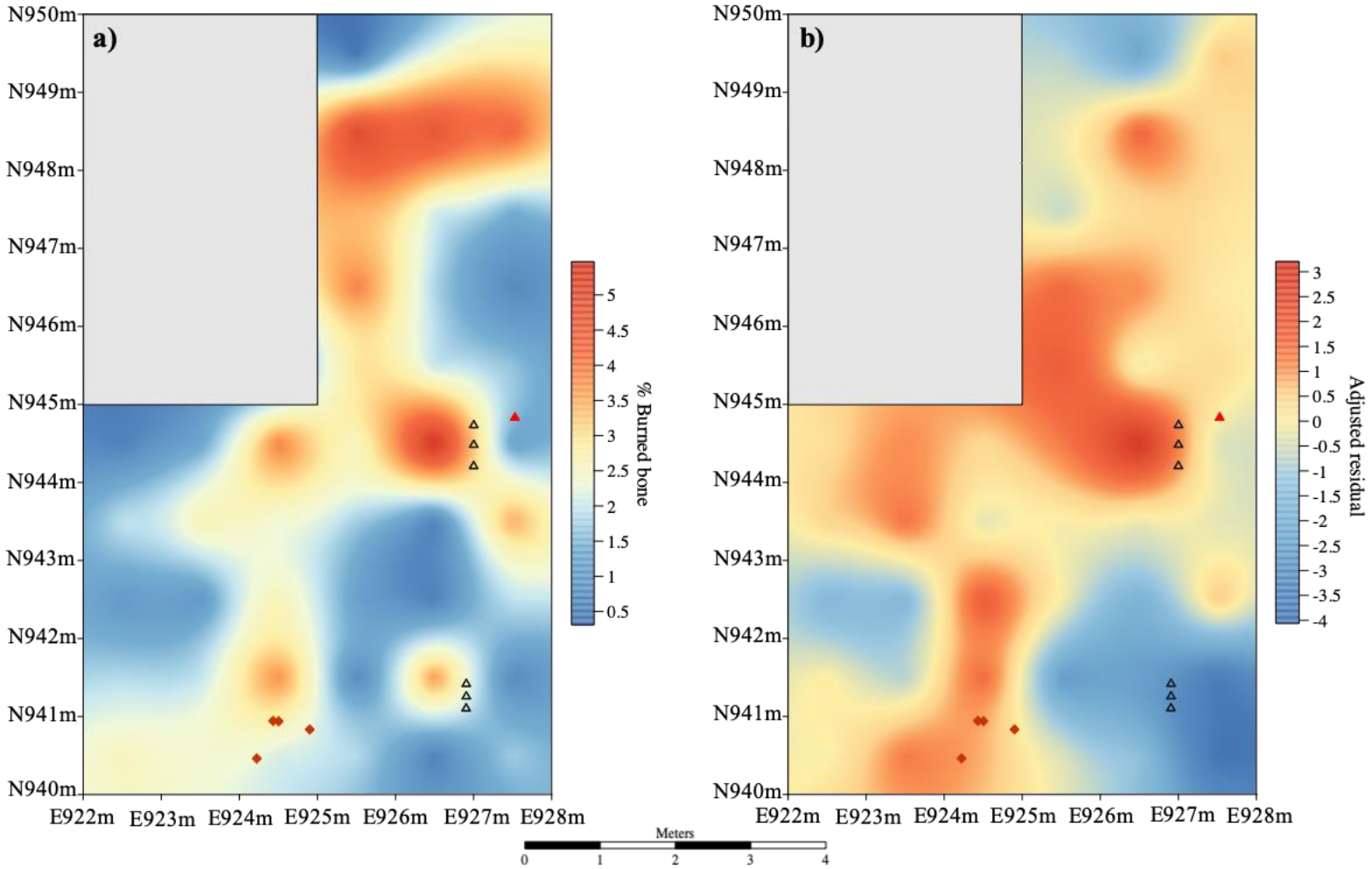

Figure 5.23 Density maps based on a) the percentage and b) adjusted residuals of burned bone for the main excavation area at SM1. Triangles = paleomagnetic samples; red indicates heated sediments. Red diamonds = burned clay. Most of the grayed-out area has not been excavated. Northing and easting values are truncated to the last three digits.

Plotting the density of burned bone based on the adjusted residuals of observed versus expected values shows that around half of the m^2 units in the site have more burned bone than expected (Figure 5.23b). Once again there are several areas within the site where the density of burned bone is comparatively quite high, and partial chi-squared tests indicate that there are multiple m^2 units where the overabundance of both burned and unburned bone are statistically significant (Table 5.36). When only calcined bone is considered, there are basically two very dense clusters – one near the center of the main excavation block in W14-25, W15-21, and X15-1, and another along the northwestern edge in X15-13 and X15-18 – both of which, unsurprisingly, overlap with areas where burned bone in general is quite abundant (Table 5.36). These data suggest that these areas are places where a large amount of material was exposed to fire, and in many cases, this involved prolonged exposure to temperatures that are much higher than those typically produced by naturally-occurring fires (David, 1990; Buenger, 2003; but see Keough *et al.,* 2015; Alvarez *et al.,* 2017). Plots of the density of burned bone within each analytical unit reveal similar patterns (Figure 5.24). There are distinct "hot spots" and "cold spots" within all of the units, and in most cases, these align with the areas where burned and unburned bone appear to be clustered in the plot of the site as a whole (Figures 5.23 and 5.24).

As discussed earlier in this chapter, the presence of burned bone, and particularly the fact that 10% of bones are calcined, is a fairly strong indicator of human activity at SM1 because naturally-occurring fires often do not burn long or hot enough to cause calcination (David, 1990; Buenger, 2003; but see Keough *et al.,* 2015; Alvarez *et al.,* 2017). The spatial patterning of burned bone across the entire site and in each of the analytical units also indicate dense concentrations of burned bone that are often ringed by areas where thermally altered specimens are much less abundant. Taken together, these data suggest: 1) significant human involvement in the process of burning bone, and 2) the possible

presence of dedicated hearth areas within the site where burning activities were concentrated. The spatial overlap between dense concentrations of burned bone, burned clay, and paleomagnetic samples indicating heated soils further supports the latter conclusion (Figure 5.23a and b). That several of the densest concentrations of burned bone show overlap between analytical units suggests that some areas of the site were continued foci for burning activity over time (Figure 5.24a-d). Additionally, these foci are shifted to slightly different parts of the occupation surface between analytical units, which would be expected for an open-air occupation that lacks the spatial constraints that often require "stacking" of hearth areas in cave sites (L.C. Todd, personal communication).

Table 5.36 Meters where counts of burned/unburned bone are significantly higher or lower than expected.

Meter	Unburned	Carbonized	Calcined
W14-7	(+)	(+)	(-)*
W14-14	(+)	(-)*	(+)
W14-15	(-)*	(+)	(+)
W14-17	(-)	(+)*	(-)
W14-25	(-)	(-)*	(+)*
W15-3	(+)*	(-)*	(-)*
W15-8	(+)*	(-)*	(-)
W15-9	(+)*	(-)	(-)*
W15-10	(+)*	(-)	(-)*
W15-12	(+)*	(-)	(-)
W15-21	(-)	(-)	(+)*
W15-22	(-)*	(+)*	(+)
X15-1	(-)*	(+)	(+)*
X15-13	(-)	(-)	(+)*
X15-18	(-)	(-)	(+)*
X15-19	(-)	(+)	(+)*
X15-20	(+)	(+)*	(-)*
X15-22	(+)*	(-)	(-)

(+) observed values > expected; (-) observed values < expected
*p-value significant at $\alpha = 0.05$

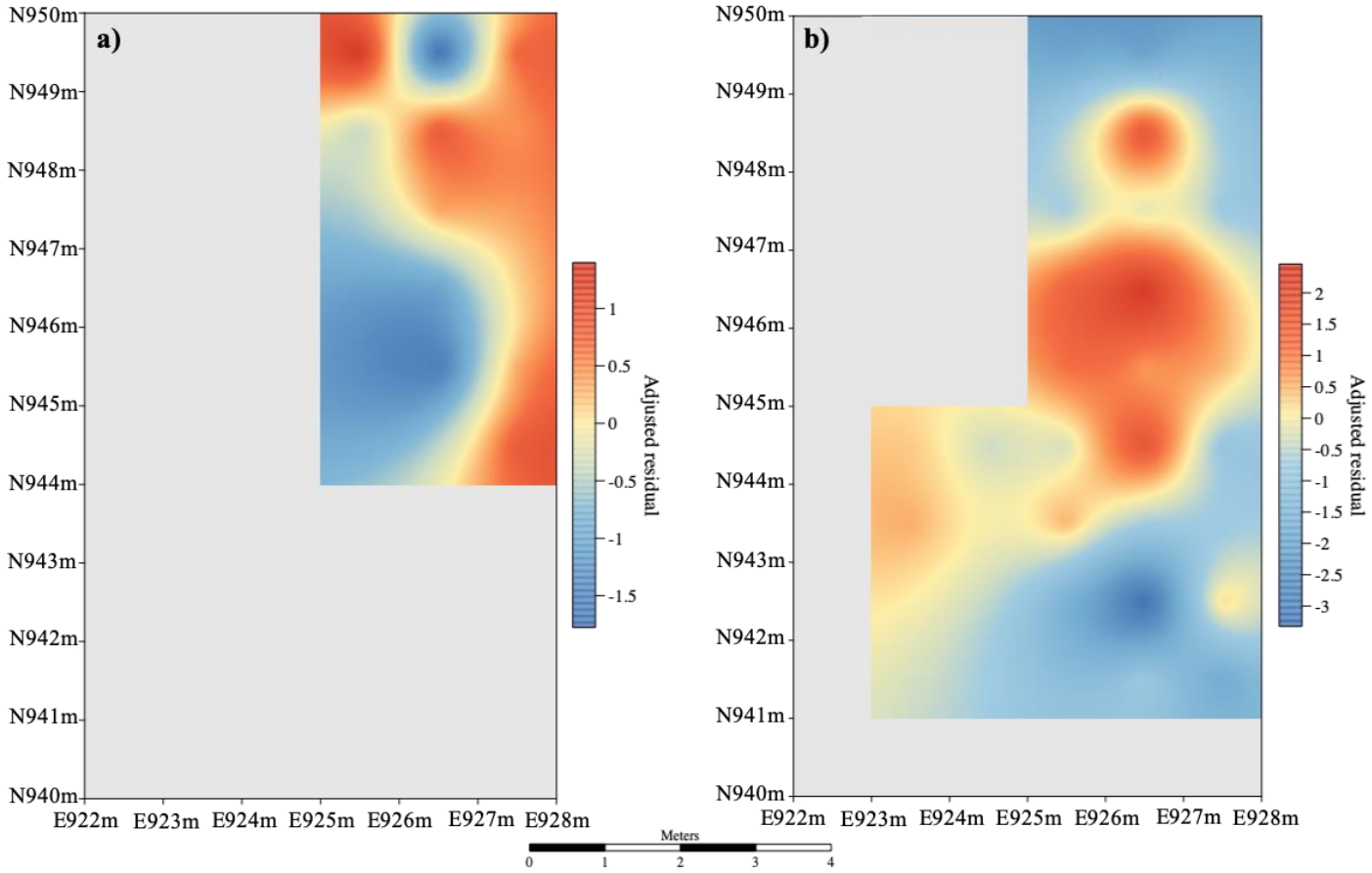

Figure 5.24 Density maps based on the adjusted residuals of burned bone for a) MSA-1 and b) MSA-2. Maps are plotted onto the full grid for the main excavation area, with areas outside a given analytical unit grayed out. Boundary lines are defined based on the last m^2 in which the analytical unit occurs in each direction. Northing and easting values are truncated to the last three digits.

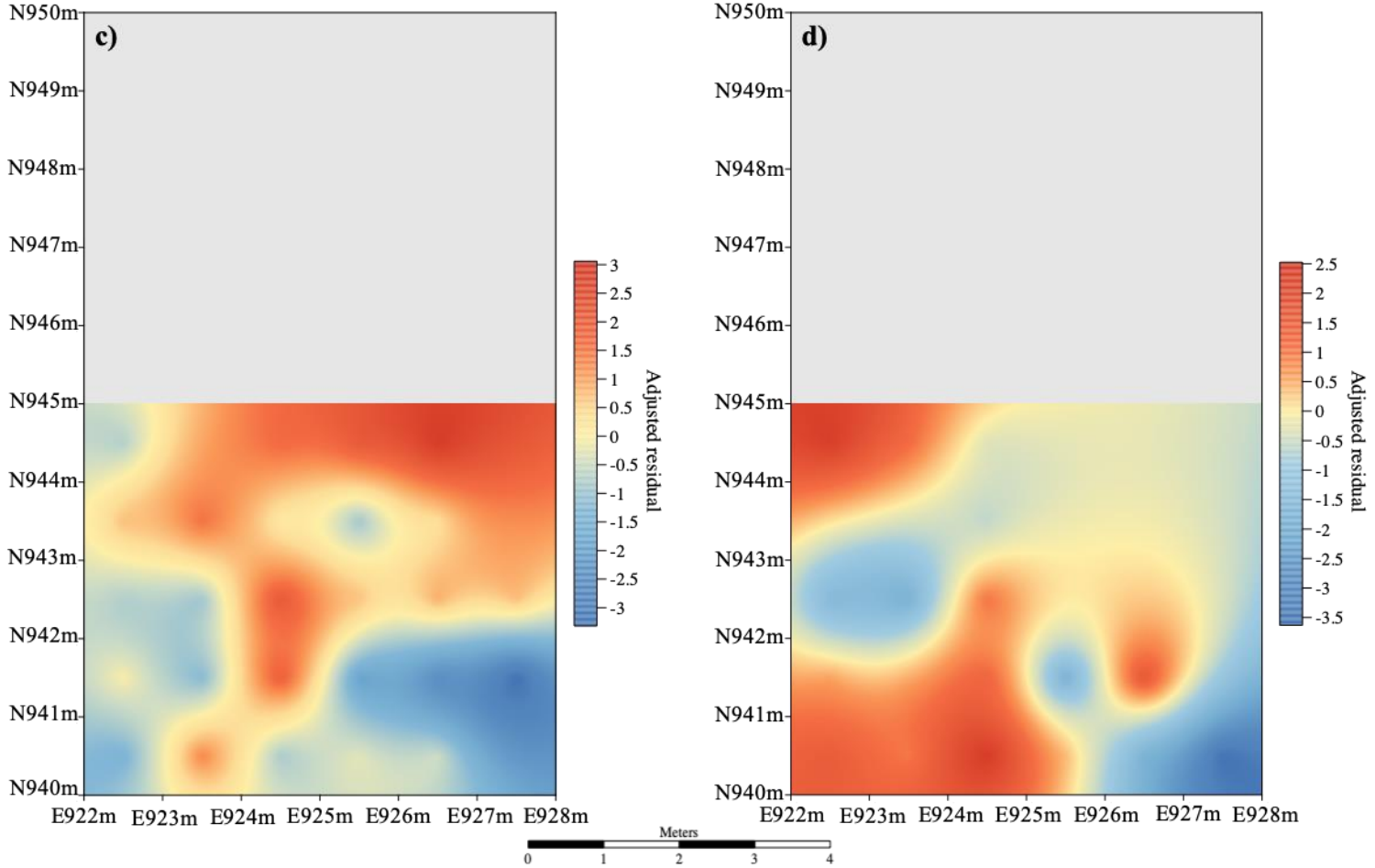

Figure 5.24, cont. Density maps based on the adjusted residuals of burned bone for c) MSA-3 and d) MSA-4. Maps are plotted onto the full grid for the main excavation area, with areas outside a given analytical unit grayed out. Boundary lines are defined based on the last m^2 in which the analytical unit occurs in each direction. Northing and easting values are truncated to the last three digits.

Faunal transport behavior

Analysis of skeletal part abundances and the relationships between element representation and economic utility may offer additional information that can help further elucidate patterns of prey selectivity, butchery practices, and faunal transport behavior by MSA humans at SM1 (Binford, 1978, 1981; Bunn, 1986; Bunn and Kroll, 1986; Metcalfe and Jones, 1988; Marean and Cleghorn, 2003; Cleghorn and Marean, 2004; Faith and Gordon, 2007). The following analyses provide a general overview of skeletal element abundance, and examine evenness values and correlations between element abundance and economic utility for the identified bovid assemblage at SM1. The standardized food utility index (SFUI) was chosen because it is a relatively simple index that describes the food utility of whole bones, as opposed to bone portions or skeletal segments (Metcalfe and Jones, 1988; Faith and Gordon, 2007). MAU is used instead of nNISP for analyses of transport strategies, so that data from SM1 are analogous to those used by Faith and Gordon (2007) to model each foraging strategy. Results are presented for both all identified elements, and only the high-survival set (Marean and Cleghorn, 2003). High-survival elements are generally considered most appropriate for this type of analysis (*e.g.,* Marean and Cleghorn, 2003; Faith and Gordon, 2007), but using only this set here reduces sample sizes by at least half in all cases and the results are quite similar regardless of which dataset is used. It is also important to point out that statistical analyses of size 3 and 4 bovids, in particular, should be viewed with appropriate caution due to their very low NISP counts (size 3 = 12; size 4 = 1).

Plots of skeletal part abundance for size class 1-4 bovids at SM1 show some interesting patterns in terms of element representation (Figure 5.25). Size 1 bovids are represented by relatively high numbers of both cranial elements (*i.e.,* horn cores and mandibles) and femora, as well as metapodials, phalanges, and compact bones. Similarly,

femora and cranial elements are the most abundant skeletal parts for size 2 bovids, and this group is also represented by both long bones of the forelimb (*i.e.,* radius and ulna), the tibia, and pelvis, as well as numerous metapodials, phalanges, and compact bones. Specimens from size class 3 bovids, on the other hand, include only fore- and hindlimb elements, while a metapodial is the only element attributed to a size 4 bovid.

When small-to-medium (size 1 & 2) and larger (size 3 & 4) bovids are grouped together in order to increase sample sizes (albeit only slightly in the case of the size 3 & 4 group), these patterns are further accentuated (Figure 5.26). From these data it is clear that size 1 & 2 bovids are relatively well-represented by cranial, axial, and appendicular elements (*i.e.,* essentially every part of a complete skeleton), with an abundance of cranial and hindlimb bones in particular. Conversely, there is a clear paucity of cranial and axial elements among size 3 & 4 bovids, which are really only represented by the proximal elements of the forelimb (*i.e.,* humerus) and the distal elements of both the fore- and hindlimb. (*i.e.,* metapodials, phalanges, and compact bones). It is also worth noting here that the plots in Figures 5.25 and 5.26 serve to highlight the point made earlier about the overall similarity of results obtained from analyses that employ nNISP and more derived measures, such as MAU. In any case, these data suggest that butchery and transport strategies may have been different for size 1 & 2 versus size 3 & 4 bovids at SM1. More specifically, it appears that size 1 & 2 bovids were more often brought back to the site mostly complete, while size 3 & 4 animals may have been butchered more extensively at kill sites, with only selected parts transported back to SM1. This possibility can be tested further by examining how evenly skeletal parts are distributed in the assemblage and the relationships between MAU and SFUI in more detail (Binford, 1978; Metcalfe and Jones, 1988; Jones and Metcalfe, 1988; Marean and Cleghorn, 2003; Faith and Gordon, 2007).

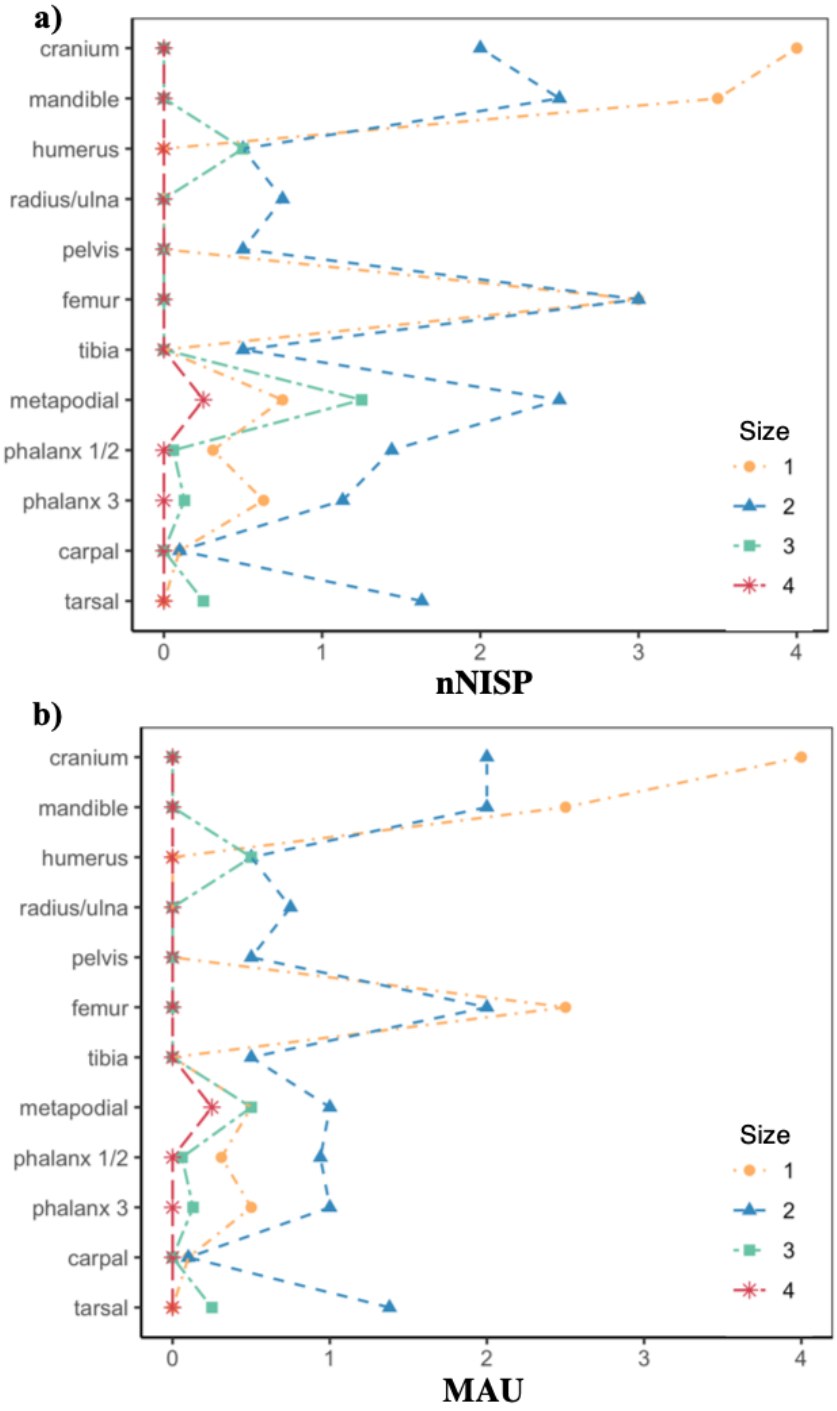

Figure 5.25 Plots of element abundance based on a) nNISP and b) MAU values for size 1-4 bovids at SM1.

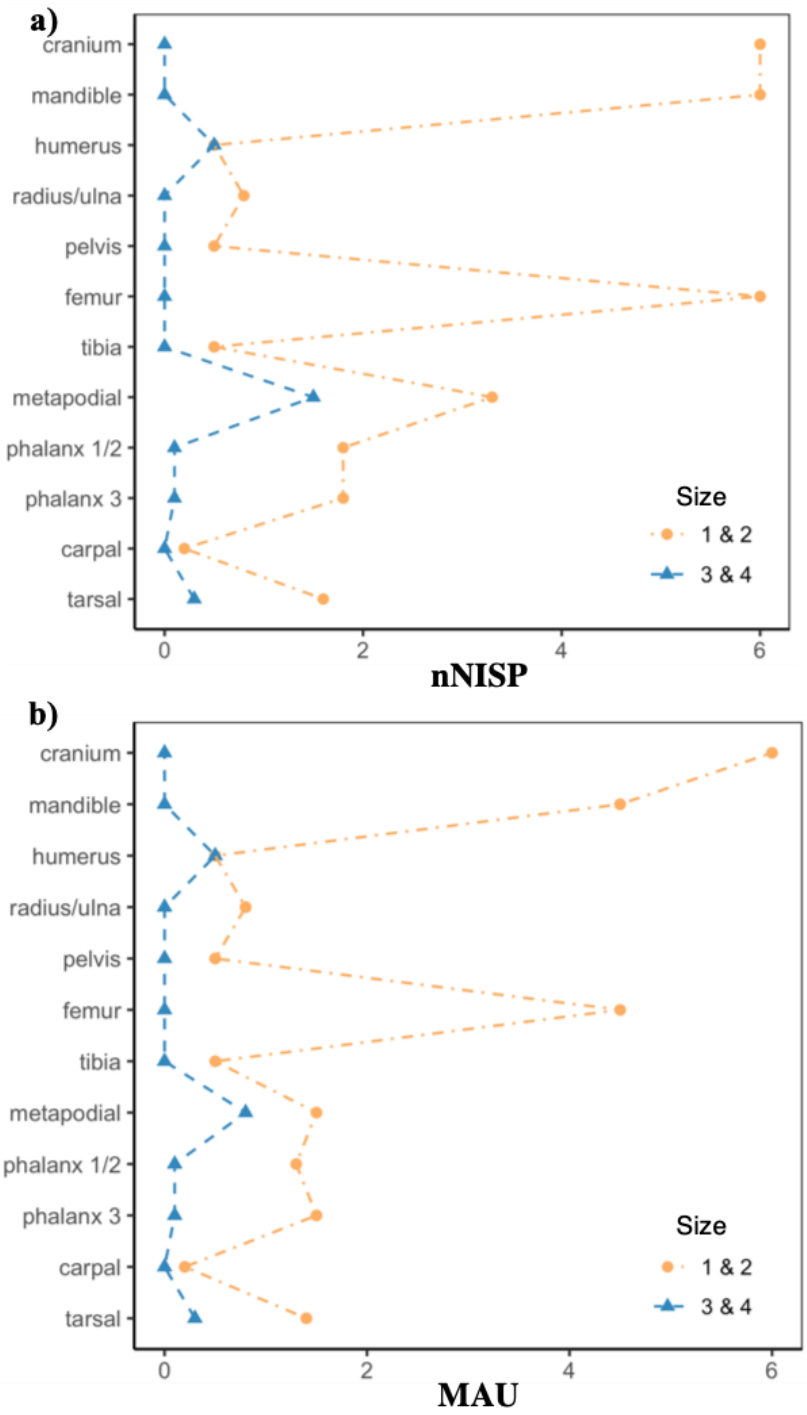

Figure 5.26 Plots of element abundance based on a) nNISP and b) MAU values for small/medium (size 1/2) and medium/large (size 3/4) bovids at SM1.

Evenness values are very similar when considering all identifiable specimens and only high-survival elements for both the full bovid assemblage (.85-.86) and size 1 & 2 bovids only (0.82-0.84) (Table 5.37). For both groups, evenness values are a good match for the unbiased strategy, in which skeletal elements are transported in direct proportion to their economic utility, and do not overlap with those for any of the other transport strategies. However, although the relationships are relatively weak and non-significant, in all four cases, the correlation between SFUI and MAU is actually negative and falls well outside the middle 95% range modeled by Faith and Gordon (2007) for an unbiased sample with MNE = 100 and MNE = 50 (Table 5.38 and Figure 5.27). Negative correlations of this magnitude are only associated with an unconstrained strategy, where body parts are transported from a kill site in direct proportion to their occurrence in the body and with no regard for economic utility, such as when whole carcasses are transported away from a kill site (Table 5.38). Conversely, what little data there are for size 3 & 4 bovids indicate a relatively good match to the gourmet strategy, which models very selective transport of only high food utility elements back to a base camp, in terms of evenness values for both the full set of elements and the high-survival set (albeit less so). Correlations were not tested for size 3 & 4 bovids due to the very small sample sizes.

Faith and Gordon (2007) demonstrate that correlations become more sensitive and less reliable when MNE $\leq$ 150, with the greatest potential for error at MNE < 50. Given that MNE = 108 for the largest sample from SM1, it is perhaps not surprising that the evenness and correlation values calculated for SM1 do not match those modeled by Faith and Gordon (2007) for any single type of transport strategy. In order to maintain samples that even approach MNE = 100 (much less 150), it is also necessary to use elements from both the high- and low-survival sets, and only one of the high-survival sets exceeds the lower threshold of MNE < 50, which again greatly increases the risk for statistical error.

Table 5.37 Evenness values for element representation and correlations between MAU and SFUI for bovids from SM1.

All elements	**MNE**	***e***	**r_s**	**p-value**
All bovids[1]	108	0.855	-0.18	0.59
Size 1 & 2	87	0.836	-0.16	0.65
Size 3 & 4	8	0.538	-	-
High-survival set				
All bovids[1]	57	0.859	-0.61	0.17
Size 1 & 2	41	0.819	-0.53	0.28
Size 3 & 4	4	0.342	-	-

[1]Includes specimens not assigned to a specific size class

Table 5.38 Evenness values and Spearman's rho (r_s) for different transport strategies modeled by Faith and Gordon (2007).

	Transport strategy	**e**	**r_s**
MNE=100	Gourmet	.451 (.34 - .569)	.904 (.667 - 1)
	Unbiased	.842 (.776 - .905)	.941 (.826 - 1)
	Bulk	.964 (.927 - .989)	.726 (.275 - .964)
	Unconstrained	.983 (.961 - .996)	.007 (-.732 - .743)
MNE=50	Gourmet	0.483 (.327 - .641)	0.893 (.577 - 1)
	Unbiased	0.859 (.767 - .937)	0.883 (.631 - 1)
	Bulk	0.95 (.899 - .987)	0.576 (-.048 - .934)
	Unconstrained	0.967 (.925 - .992)	.008 (-.710 - .741)

Values are for the mean and middle 95% range (in parentheses) for 5000 random samples modeling each type of transport strategy with MNE of 100 and 50

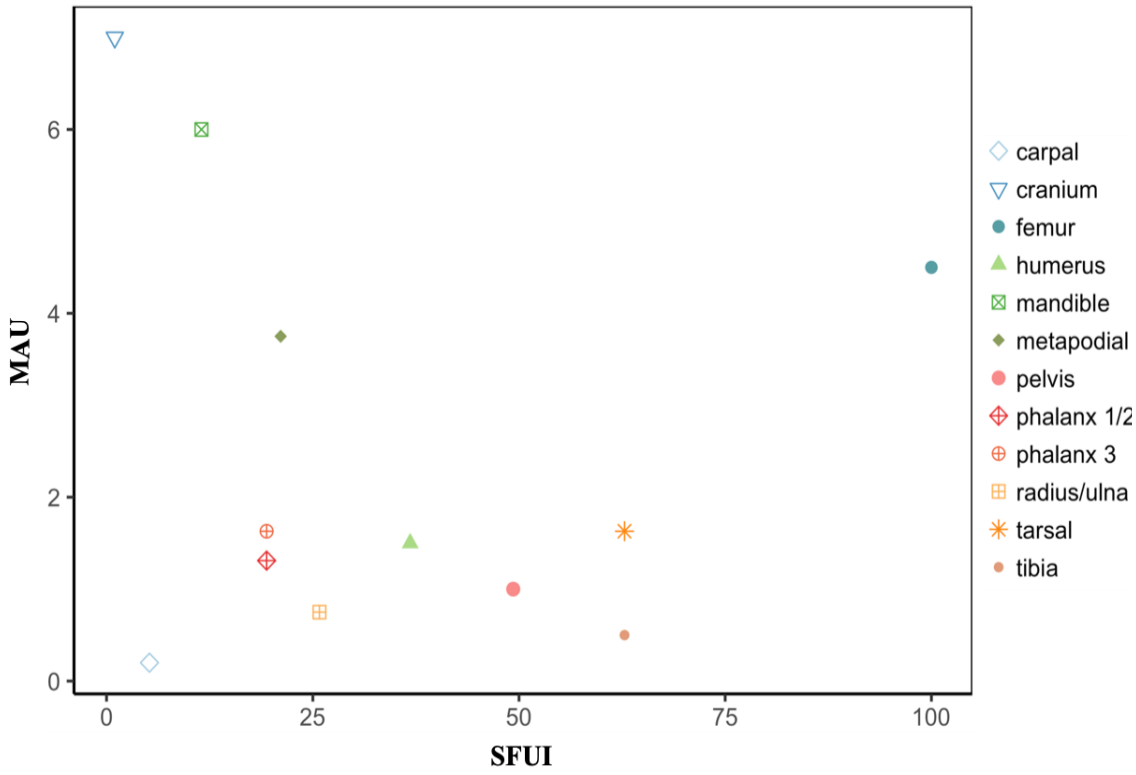

Figure 5.27 Plot of minimum animal units (MAU) versus standardized food utility index (SFUI) values for all bovids.

Further, it is likely that the evenness values are skewed downward due to the high MAU values of femora, crania (*i.e.,* horn cores), and mandibles, in particular (Figure 5.27). Most of the other bones are grouped relatively tightly along the y-axis (MAU), indicating that the assemblage is relatively evenly distributed when femora and skull elements are excluded. Likewise, the low correlations for all bovids and size 1 & 2 bovids are no doubt due, at least in part, to the over-representation of horn cores and mandibles, which are two of the lowest-ranked parts in terms of SFUI.

Analyzing previously-published data from Bunn *et al.* (1988) and O'Connell *et al.* (1988, 1990), Monahan (1998: 417) notes that skeletal transport and carcass processing decisions among the Hadza in Tanzania are guided by three primary objectives, namely to satisfy immediate hunger following the hunt, transport the largest quantity of edible food possible back to residential camps, and reduce transport costs. Monahan (1998) also summarizes several "rules" of skeletal transport behavior among the Hadza, including that: 1) animals smaller than size 3 are typically transported mostly or complete to residential camps; 2) postcranial axial elements other than ribs (*e.g.,* vertebrae, pelves) are the most commonly transported bones, regardless of animal size; and 3) easily processed (*e.g.,* ribs and limbs), heavy (*e.g.,* cranium), and/or low-ranked (*e.g.,* metapodials) elements are often discarded in the field after being stripped of meat and tissue, which is either consumed immediately or transported back to camp. The Hadza data are supported by additional ethnographic work with the Kung! San in Botswana and Nunamiut in Alaska, who were also observed to regularly transport mostly or complete carcasses of small and medium (*i.e.,* size 1 & 2) mammals back to residential sites, process larger animals more extensively in the field, and discard heads, limb bones, and other heavy and/or low-ranked elements at kill/butchery sites (Binford, 1978; Yellen, 1991).

The idea that field-processing and transport of smaller bovids at SM1 was less selective than that of larger bovids makes sense from an energetic standpoint and, given the above discussion, is also very much in line with ethnographic observations (Binford, 1978; Bunn *et al.,* 1988; O'Connell *et al.,* 1988, 1990; Yellen, 1991; Lupo, 2006). However, as already noted for the Hadza, when animals are butchered in the field they are also often defleshed and the long bones discarded in order to decrease the weight of transported items (Binford, 1978; Bunn *et al.,* 1988), which does not necessarily match the data from SM1, where humeri and metapodials are the most common elements for larger

bovids. Additionally, at least among the Hadza, the most commonly transported parts are post-cranial elements of the axial skeleton (Monahan, 1998), which makes the relative absence of such elements at SM1 difficult to explain if the Hadza are in fact an appropriate analog. However, it is possible, and perhaps likely, that these discrepancies are due at least in part to a layer of post-discard bone destruction at SM1 which is obscuring patterns of element representation that would be expected based on the Hadza data. The identification of several lines of evidence indicating a moderate degree of post-depositional fragmentation and post-discard carnivore ravaging at SM1 in the previous sections would seem to further support this conclusion.

Despite the somewhat ambiguous and seemingly contradictory results from the preceding analyses, overall the data presented in this section appear to suggest less selective transport strategies for size 1 & 2 bovids at SM1. More specifically, the fact that essentially all parts of a complete skeleton are represented for this group indicates that mostly complete or complete animals were transported back to SM1 with minimal butchery or processing at kill sites, at least in some cases. That the evenness values for size 1 & 2 bovids fall outside the modeled range for an unconstrained strategy (which essentially models complete-animal transport) is likely explained in large part by the comparatively high frequencies of femora and cranial elements, although the match with an unbiased strategy is somewhat puzzling in light of the high frequencies of horn cores and mandibles, both of which are low-value elements, and should therefore have proportionally low representation in an unbiased strategy. Alternatively, size 3 & 4 bovids may have been more extensively processed in the field, with meatier limb elements transported back to SM1 and cranial and axial elements mostly discarded at kill sites. However, given that MNE < 10 in all cases for this group, it is simply not possible to draw any definitive conclusions about faunal transport and discard strategies for size 3 and 4 bovids.

Faunal processing strategies

Cut marks are most commonly found on the middle and proximal shafts of long bones at SM1 (Table 5.39). When only specimens identified to a specific skeletal element are considered, 41.2% of cut-marked portions are long bone midshafts and 35.3% are near epiphysis (proximal) shafts, and these specimens bear 62.7% and 27.6% of the total cut marks, respectively. Cut marks on epiphyses are less common, with proximal and distal ends combined accounting for 23.5% of portions and only 10.3% of marks. However, there are also a number of non-identified long bone shaft fragments that contain cut marks and can be assigned to the midshaft category because they lack the trabecular structure expected on near epiphyseal shaft or epiphyseal fragments (Pickering and Egeland, 2006). When these specimens are included, midshaft frequencies increase to 87.3% of portions and 90.8% of marks, and the frequencies for all other portions are drastically reduced. Additionally, when all cut-marked specimens are included, midshaft fragments still account for two-thirds (67.6%) of specimens, while the majority of the rest (22.6%) are non-identifiable bones and those for which portion assignments are not relevant (*i.e.,* cranial and axial elements, phalanges, and compact bones) (Table 5.39).

Investigating the cut mark data by skeletal element and taxonomic group may offer additional insight into faunal processing activities by MSA humans at SM1 (Table 5.40). Most of the cut marks occur on specimens belonging to non-identified specimens, many of which may well have been bovids based on the taxonomic abundance data discussed at the beginning of this chapter. The elements involved here include a scapula, ribs, and several humeri. Cut marks on identified bovid specimens are confined largely to elements of the hindlimb, including the femur, metapodials, phalanges, and an astragalus. A fragment of innominate bearing cut marks was also identified as a potential match for a small bovid from the comparative collections, although the specimen did not contain any distinctive

Table 5.39 Frequencies (%) of cut-marked specimens and cut marks by element portion.

		Cut-marked portions			Cut marks		
Location	**n**	**%ID[1]**	**%ID+LB[2]**	**%Total[3]**	**%ID[1]**	**%ID+LB[2]**	**%Total[3]**
Proximal end	1	5.9	1.3	1	3.4	0.8	0.6
Proximal shaft	6	35.3	7.6	5.9	27.6	6.7	5
Middle shaft	69	41.2	87.3	67.6	62.1	90.8	67.8
Distal shaft	-	-	-	-	-	-	-
Distal end	3	17.6	3.8	2.9	6.9	1.7	1.3
Non-ID/Not relevant[4]	23	-	-	22.6	-	-	25.3

[1]Long bones identified to a specific skeletal element only

[2]Identified long bones + non-ID shaft fragments with no trabecular structure

[3]Out of total cut-marked portions/cut marks on all identified and non-ID specimens with cut marks; midshaft includes non-ID long bone fragments

[4]Non-identifiable or elements other than long bones

Table 5.40 Cut-marked specimens by skeletal element and taxonomic group.

Element	**Taxonomic group**
Scapula	Terrestrial mammal
Innominate	cf. Bovid
Rib	Terrestrial mammal
Humerus	Primate, bird, terrestrial mammal
Femur	Bovid
Tibiotarsus	Bird
Metapodial	Bovid
Phalanx	Bovid
Astragalus	Bovid
Long bone fragment	Bird, terrestrial mammal
Non-ID bone	Terrestrial mammal

landmarks by which a definitive identification could be made. Multiple bird bones, including a *N. meleagris* humerus with possible human chew marks (W14-25-001), were also found to contain cut marks. Additionally, a primate humerus with cut marks along the proximal shaft (SM1-250) was also recovered (Figure 5.28), and is perhaps one of the most interesting specimens with human modification at SM1. Primates are a fairly common occurrence in MSA faunal collections (Klein, 2009), but there are currently few (if any) published MSA sites where the primate material bears human cut or percussion marks. Thus, SM1 may well represent one of the earliest incidences of humans hunting and eating "bush meat" that has been documented to date.

There are several conclusions that can be drawn here regarding MSA faunal processing strategies at SM1. First, the high frequencies of cut-marked midshafts suggest that defleshing/fileting was the most common type of butchery activity at SM1. However, the extensive amount of fragmentation at the site should also be kept in mind when considering the high number of cut-marked midshafts relative to near epiphyseal shaft and/or epiphyseal portions. At least some of the disparity in cut-mark frequency between mid-shafts on the one hand, and near-epiphyseal shafts and epiphyses on the other, is almost certainly due to the higher density of midshafts, which makes them more likely to survive the myriad taphonomic processes that an assemblage is subject to between deposition and recovery. Nonetheless, the data indicate that the process of defleshing animal bones was a regular occurrence at SM1. Identification of cut marks on multiple near-epiphyseal shaft fragments further indicates that butchery also included disarticulation. Likewise, cut marks identified on the blade of small mammal scapula and across the sustentacular facet of a size 2 bovid astragalus (Figure 5.28c) were probably created during disarticulation of the proximal forelimb and distal hindlimb of these animals, respectively.

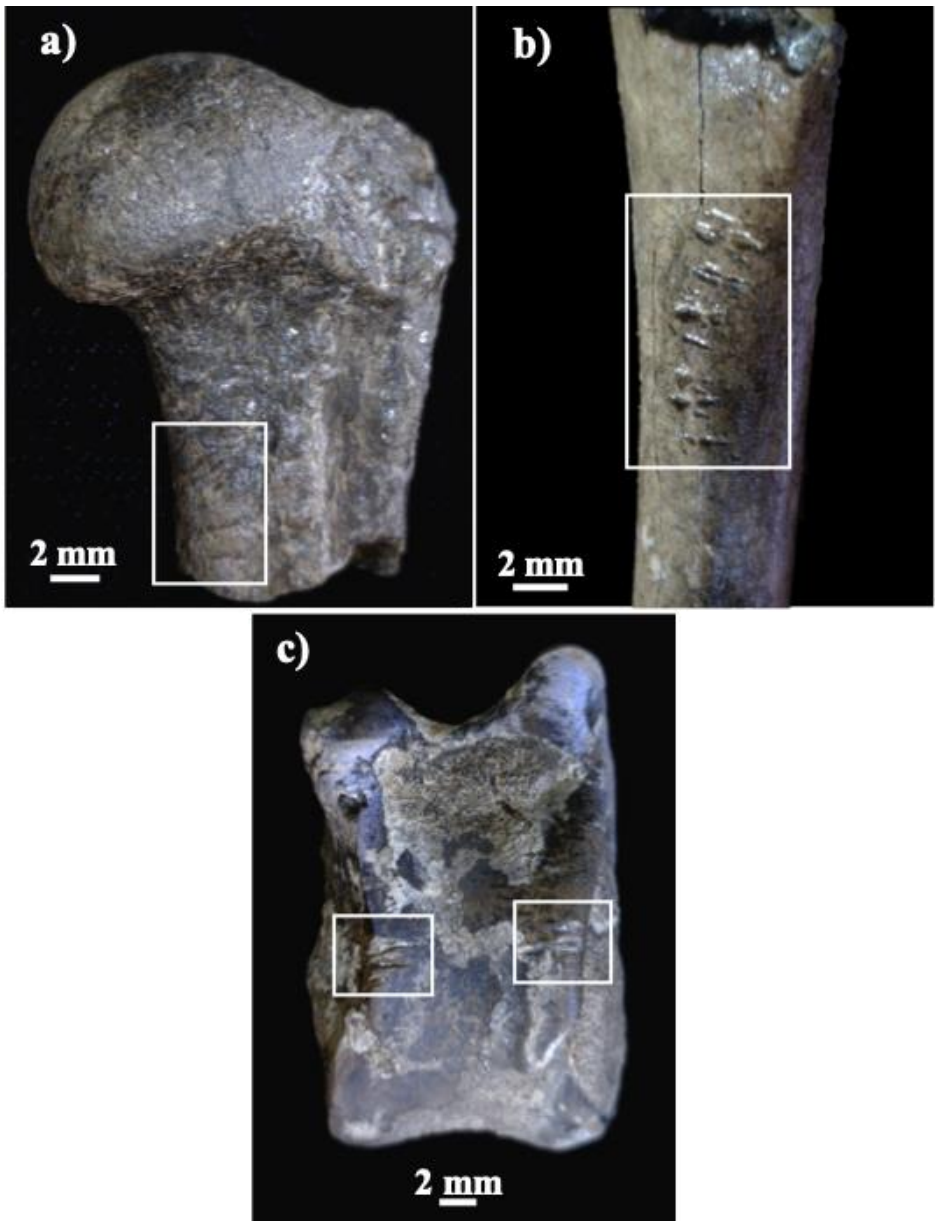

Figure 5.28 Cut-marked bones. a) Monkey humerus (SM1-250). b) *Numida meleagris* humerus with cut and possible chew marks (W14-25-001). c) Size 2 bovid astragalus (X15-13-179).

There may also be evidence for evisceration of some animals in the form of several cut-marked rib shaft fragments (Table 5.40), but these cut marks could also have been produced during activities associated with disarticulation and/or defleshing (Nilssen, 2000). The cut marks identified on several bovid metapodials and phalanges also seem likely to have resulted from skinning of these animals, although disarticulation cannot be completely ruled out as an alternative explanation for these marks. Whatever the case, there can be little doubt that multiple types of butchery activity took place at SM1. Finally, it should also be pointed out that the occurrence of marks indicating disarticulation of skeletal segments and the evidence for fileting and defleshing of bones is consistent with many animals having been brought back to the site mostly or complete.

The cut mark data also document that multiple types of prey were processed by humans at SM1, including bovids, birds, and at least one primate. All three groups have marks on one or more specimens consistent with defleshing and disarticulation, which suggests that humans had early access to these prey species through deliberate hunting. That humans hunted small-to-medium-sized bovids during the late MSA is not surprising (Clark and Plug, 2008; Clark, 2009). However, as discussed in Chapter 1, there has been debate about the extent to which MSA humans regularly exploited small, fast-moving game that likely required relatively complex technology, such as snares or traps, to capture. The monkey certainly fits within this category, and it seems quite likely that this animal was caught using a snare, trap, or perhaps a projectile weapon, and the same technology was probably also used to capture the guineafowl. Regardless, these specimens document the inclusion of small game in the MSA diet at SM1. The inclusion of small, low-ranked prey in MSA diets would also be consistent with the site having been occupied during times when terrestrial resources were relatively scarce and/or nutritionally depleted, as would be expected during the dry season in this region of Ethiopia (Speth, 1987; Clark, 2009).

Other potential indicators of non-human carnivore activity

As previously noted, the presence of carnivore tooth marks on 4.7% of bones unambiguously documents carnivore input in modifying the terrestrial fauna at SM1. Additionally, the lack of long bone epiphyses is another potential indication of carnivore activity at the site, because some mammalian carnivores are known to preferentially target the grease-rich epiphyses of long bones and remove them from sites where they have first access and those where they have scavenged human kills (Blumenschine, 1988; Marean, 1991; Marean and Spencer, 1991; Blumenschine and Marean, 1993). It is therefore important to examine other lines of evidence that may suggest that carnivores played a significant role in site formation at SM1 (Table 5.41).

Table 5.41 Potential expectations for sites created primarily by non-human carnivores.

Evidence	**Carnivore sites**
Archaeological association	No (or little)
Cut/percussion marks	Low frequency (or none)
Tooth marks	High frequency (~80% specimens)
Carnivore remains	High frequency (~20%+ MNI)
Axial elements and compact bones	Low frequency
Articular ends and near/epiphyseal fragments	Low frequency
Midshaft fragments	Low frequency
Burned bone	Low frequency
Fresh bone breaks	High frequency
Coprolites	Yes
Gastric etching	Yes
Sources: Blumenschine 1988; Blumenschine and Selvaggio 1988; Villa and Mahieu 1991; Capaldo 1998; Marean et al. 2000; Pickering 2002; Villa et al. 2004; Munro and Bar Oz 2005	

The same non-human carnivore species that preferentially target the grease in long bone epiphyses (*i.e.,* hyaenas and canids) may also destroy and/or delete other spongy axial elements, such as vertebrae, thus leading to a relative dearth of these bones at sites created primarily by carnivores (Blumenschine, 1988). Cruz-Uribe (1991) and Marean (1991) have also suggested that a low frequency of compact bones may be expected at some carnivore sites, because carpal and tarsal masses are often swallowed whole by carnivores feeding on lower limb bones, although not all authors agree that this is a reliable criterion for distinguishing human and carnivore sites (*e.g.,* Pickering, 2002). Whatever the case, axial elements are relatively common at SM1, representing ~23.8% of NISP for the total identified terrestrial assemblage, and ~22% of NISP when size 1a animals are excluded. By contrast, compact bones account for 13.5% of the total NISP, and ~15% when only size 1-4 animals are considered (Table 5.4; Appendix E). Although many authors do not explicitly define the term, Dominguez-Rodrigo (2002) describes a "low" frequency as between 5-15%, at least in terms of interpreting the number of tooth-marked specimens at a site. If the same benchmark is applied to the element abundance data from SM1, the frequency of axial elements is much greater than what can be defined as low frequency. Compact bones obviously do not exceed the 5-15% threshold, indicating that these elements are in fact rather poorly represented at SM1.

As with cut mark data, the placement of tooth marks may also offer insight into the nature and extent of carnivore involvement at SM1 (Blumenschine, 1988; Capaldo, 1998; Selvaggio, 1998). Data on tooth mark locations were not recorded as specifically as for cut marks, but it is possible to identify the basic long bone portion (*i.e.,* epiphyseal, near epiphyseal, or midshaft) on which tooth marks occur. Although the sample is small, tooth marks are most common on the epiphyses and midshafts of identified long bones, and are equally likely to occur on either of these portions (41.7% in both cases) (Table 5.42).

Table 5.42 Frequencies of tooth-marked specimens and tooth marks by element portion.

		Tooth-marked portions			Tooth marks		
Location	**n**	**%ID[1]**	**%ID+LB[2]**	**%Total[3]**	**%ID[1]**	**%ID+LB[2]**	**%Total[3]**
Epiphysis	5	41.7	4.4	3.3	31.6	4.1	2.9
Near epiph. shaft	4	16.7	3.5	2.6	10.5	2.1	1.4
Middle shaft	105	41.7	92.1	69.1	57.9	93.8	65.1
Non-ID/Not relevant[4]	38	-	-	25	-	-	30.6

[1]Long bones identified to a specific skeletal element only

[2]Identified long bones + non-ID shaft fragments with no trabecular structure

[3]Percentage of all tooth-marked portions/individual tooth marks for the entire assemblage (*i.e.*, ID and non-ID specimens); midshaft includes non-ID long bone fragments

[4]Non-identified or elements other than long bones

However, if non-identifiable fragments are included, the percentage of tooth-marked midshafts (92.1%) is dramatically higher, and much higher than that of near epiphyseal shafts or epiphyseal ends. When all carnivore-modified specimens are considered, the frequency of tooth-marked midshafts is still ~70% (Table 5.42).

Considering only the identified assemblage, the frequency of midshaft portions with tooth marks is somewhat low for sites primarily created by carnivores (Capaldo, 1998; Selvaggio, 1998), and falls within the range observed by Blumenschine (1988) for simulated open-air hominin sites. Conversely, when shaft fragments not identified to a specific element are included, the frequency of tooth-marked midshaft fragments for long bones is in line with expectations for sites where carnivores have first access to carcasses (Blumenschine, 1988, 1995). It is possible that the over-representation of tooth-marked midshafts is due in part to a bias against near-epiphyseal shafts and epiphyses due to

extensive fragmentation and the moderate amount of post-depositional destruction that took place at SM1. If so, then it may be that the lower frequencies of tooth-marked specimens observed among identifiable long bones only (41.7%) are actually similar to those that were originally present at the site, although there is no way to empirically test this position with the available data. Nonetheless, the tooth-mark data indicate that, at least in some cases, non-human carnivores at SM1 had access to carcasses with enough meat left on the long bones to make them attractive the species in question (Table 5.42).

Finally, several other possible indicators for non-human carnivores as a primary accumulator of faunal remains include a lack of archaeological associations, low frequencies of burned bone overall and intensive burning in particular, a relatively high frequency of carnivore remains (≥ 20% of NISP), the presence of coprolites, and/or the occurrence of gastric etching on bones (Table 5.41) (Pickering, 2002; Villa *et. al.,* 2004). Of course, not all of these expectations will be met at every site produced primarily by carnivores, but it certainly seems telling that basically none of them are observed at SM1. As already discussed, archaeological material is abundant at SM1 and, with few exceptions, there is a clear spatial association between artifacts and faunal remains throughout the entire horizontal and vertical extent of the site. Moreover, ~40% of the terrestrial fauna is burned, and 10% of that sample is either partially or fully calcined.

No definitive instances of gastric etching were documented and no coprolites have been recovered, although this is perhaps the least likely of the expectations to be met on a regular basis. Specimens with sheen and erosion, two of the primary diagnostic characteristics of gastric etching, represent ~11% and 9% of bones, respectively, but there are only a handful of bones where the two co-occur, which is likely to happen in the case of bones with gastric etching. Moreover, it cannot be assumed that all, or even most,

instances of sheen and/or erosion are actually gastric etching because there are a number of other processes that can cause this type of damage (Thompson, 2006).

Summary of human and carnivore activity

When examining all of the data for human and carnivore involvement in site formation at SM1, the majority of the evidence clearly points to much more extensive input by humans than by non-human carnivores (Table 5.43). This conclusion is supported by the close association of artifacts and faunal remains, the presence and spatial distribution of burned bone, and calcined bone in particular, and the fact that many faunal specimens bear clear evidence of human modification in the form of cut and percussion marks. Skeletal part profiles further indicate that MSA humans likely transported at least some of the smaller (*i.e.,* size 1 & 2) animals back to the site as nearly- or complete carcasses. Although the skeletal element sample from larger bovids (*i.e.,* size 3 & 4) is limited, the available data suggest that these animals may have been more extensively butchered in the field with only select parts brought back to SM1. The cut mark data document that animals of various sizes were butchered at SM1, and that all stages of butchery (*i.e.,* evisceration, skinning, disarticulation, and fileting) likely took place at the site. The surface modification data also document that humans processed small game, likely obtained by hunting, trapping, and/or perhaps small projectile weaponry, and may provide one of the oldest records of humans eating another primate, in this case a monkey of the genus *Chlorocebus.*

The presence of tooth marks also documents some, albeit limited, carnivore involvement in site formation at SM1. The location of tooth marks further indicates that carnivores sometimes had access to long bones with muscle and tissue still remaining on the middle shaft. It seems likely that many of these marks result from secondary scavenging

Table 5.43 Summary of terrestrial faunal analyses at SM1 and the most likely faunal accumulator based on multiple lines of evidence.

Evidence	**SM1**	**Most likely accumulator[1]**
Archaeological association	Yes	Humans
Cut/percussion marks	5.6% (total); 59.5% (relative)	Humans
Tooth marks	4.9% (total); 40.5% (relative)	Carnivores
Carnivore remains	>1%	Humans
Axial elements and compact bones	22.4% & 13.8%	Humans?
Articular ends and near/epiphyseal fragments	>4%	Carnivores?
Midshaft fragments	High frequency	Humans
Burned bone	39.6%; 10% calcined	Humans
Fresh bone breaks	High	Humans or carnivores
Coprolites	No	Humans
Gastric etching	No	Humans

[1]Considering only humans and mammalian carnivores as primary agents of faunal accumulation and modification

of bones that were not fully defleshed by humans, but it is also possible that carnivores had primary access to bones in some cases. The lack of epiphyseal ends and somewhat low frequencies of compact bones at the site may also be evidence of carnivore involvement, although these data are somewhat ambiguous in the absence of other clear and corroborating indications of carnivore activity. Ultimately, aside from the relatively rare tooth marks, there is essentially no other unambiguous evidence of substantial non-human carnivore input at SM1.

CONCLUSION

This chapter has presented the results of zooarchaeological, taphonomic, and behavioral analyses of the terrestrial fauna from SM1. Generally speaking, the faunal assemblage is well-preserved, with good surface visibility and minimal natural surface damage overall. The faunal remains represent a modestly diverse collection of terrestrial mammals, birds, reptiles, and amphibians, with bovids being the most abundant taxonomic group by far. All of the animals identified at the site are still extant in the region today, and their ecological preferences suggest generally similar terrestrial ecosystems and habitats around SM1 in the past and present. The overall rarity of sheen, smoothing, and erosion on most of the terrestrial faunal specimens, as well as the presence of thousands of tiny bone fragments and chipped stone flakes (see Chapter 4), indicate that the SM1 assemblage is largely *in-situ* and is not primarily the result of fluvial accumulation. Analyses of bone fragmentation indicate a moderate amount of natural post-depositional breakage, and the presence of carnivore tooth marks document limited carnivore involvement in site formation. However, the preponderance of the evidence clearly indicates humans as the primary agent of faunal accumulation and modification, including: the sheer density and close association of archaeological and faunal material; the presence of calcined bone and

the spatial distribution of burned bone, which indicates possible dedicated hearth areas; extensive bone fragmentation, which can be shown not to simply result from natural breakage; and the presence of human cut and percussion marks, the frequencies of which are rather low, but nonetheless higher than those of carnivore tooth marks.

MSA humans appear to have focused largely on hunting and trapping small-to-medium-sized bovids, but also took a variety of prey of all sizes, including larger bovids, birds, and even monkeys. Quantitative analyses are ambiguous on the question of specific transport strategies, but several lines of evidence indicate that many animals were brought back to the site mostly-complete or complete. Accordingly, data on the placement of cut and percussion marks suggests that all types of butchery activity took place on-site. Overall, SM1 appears to have been a longer-term base camp, where MSA people brought the animals they hunted and trapped, in order to process and consume them. Further, analyses of taphonomic attributes across the four analytical units proposed in Chapter 4, combined with *in-situ* evidence for multiple depositional surfaces on the north wall of W14 and W15, strongly suggest that the site represents a base camp that was occupied repeatedly during the late MSA and that the material within it represents the remains of multiple episodes of occupation.

Chapter 6: The aquatic fauna

INTRODUCTION

That SM1 contains a diverse assemblage of terrestrial mammals, birds, and reptiles will come as no surprise to researchers interested in the MSA, because many of the same taxa are common at other MSA sites across Africa (*e.g.,* Assefa, 2000; Marean *et al.*, 2000; Thompson, 2008; Clark, 2009; Hutson, 2012a; Faith, 2013). However, the presence of abundant fish and mollusks at SM1 is unusual for an MSA site, and particularly one located hundreds of kilometers inland. Although many coastal MSA sites, and particularly those in South Africa, contain numerous fish, shellfish, and other aquatic fauna (*e.g.,* Henshilwood *et al.,* 2001; Avery *et al.,* 2008; Jerardino and Marean, 2010), there are far fewer inland sites with large collections of freshwater aquatic taxa (*e.g.,* Brooks *et al.,* 1995; Yellen *et al.,* 1995; Yellen *et al.,* 2005). Moreover, Katanda (~90 ka) is currently the only other inland MSA site where there is evidence that a large assemblage of riverine fish remains are likely human-accumulated (Brooks *et al.,* 1995; Yellen *et al.,* 1995). Thus, the fossil fish and mollusks from SM1 document a rare occurrence for the MSA, and one that is rarer still if they are shown to be collected and processed by humans.

The present chapter deals with the aquatic fauna from SM1, with a primary focus on analysis of the fish remains. Mollusks will also be discussed with reference to taxonomic representation and specimen counts, but are not analyzed in detail. Throughout this chapter, the fish from SM1 will be compared to a sample of 377 fish bones of similar age from the Kibish Formation that were analyzed for this study using the same recording system for the SM1 fish. The Kibish fish are primarily naturally accumulated (Trapani, 2008), so the taphonomic character of this assemblage can serve as a baseline for helping to determine

whether or not the SM1 fish result largely from natural die-offs. More detail on the sample composition, collection, and recording procedures of the Kibish fossil fish is available in Chapter 3, Appendices B and C, and the original analysis by Trapani (2008). One of the main goals of previous work on the Kibish fish was to determine the taxonomic composition of the fossil fish community in the ancient Omo River, so the collection strategy was geared towards larger and easily identifiable material (Trapani, 2008). Thus, comparisons with SM1 were not made in cases where the Kibish Formation fish were deemed unlikely to be representative of expectations for an unbiased natural assemblage in which all elements were collected without regard to size and/or identifiability (*e.g.,* analyses of fish body size and bone fragmentation). Although the Kibish fish are likely to be an appropriate analog for a naturally-accumulated assemblage, all comparative analyses should be viewed in light of the manner in which the fossils were collected.

The data and analyses presented in this chapter are relevant to Hypothesis 1 regarding the primary faunal accumulator(s) at SM1, Hypothesis 2 and Hypothesis 3, which deal with riverine foraging and seasonal site use, respectively, and Hypothesis 4 about SM1 preserving evidence of multiple occupations. Once again, the results of all analyses will be discussed in more general terms throughout the chapter and summarized in the last section. All of the results from preceding chapters will then be synthesized and placed into more specific context with regard to hypothesis-testing in Chapter 8.

TAXONOMY AND PALEOECOLOGY

Taxonomic representation

The following discussion of taxonomic representation for fish and mollusks is based on a total of 3590 specimens recorded for this study. NISP, MNE, and MNI counts

for the fish, as well as a basic NISP count for the mollusks are presented in Table 6.1. In Table 6.1, the NISP count for "Indet. fish" includes 360 bones that were identified to element but not taxon, as well as 797 specimens not identified to element or taxon. Likewise, the MNE count for this group includes specimens not identified to a specific taxon. As is common in studies of archaeological fish collections (*e.g.,* Stewart, 1989; Zohar, 2003), all bones of the neurocranium, mandible, hyoid, and suspensorium are considered separate specimens for the purposes of NISP counts even if they were found in articulation with one another. The frequencies of each fish taxon as a percentage of NISP, MNE, and MNI for the sample of specimens identified to both taxon (at the level of family or lower) and skeletal element are presented in Table 6.2. A full inventory of the fish remains by taxon and skeletal element is provided in Appendix G. As with the terrestrial fauna, comparisons with modern fish collections at the National Museum of Ethiopia indicate that all of the identifiable material derives from extant genera that are still present in the Shinfa River today (Table 6.1) (Tewabe, 2008; Tewabe *et al.,* 2010).

Of the 3163 fossil fish specimens, 2362 (74.7%) were identifiable to at least a broad category of skeletal element, while 2002 (69.9%) were identifiable to a taxonomic order and 1794 (56.8%) to the level of family or lower. However, these numbers are somewhat inflated by the inclusion of ~1300 small and nondescript fragments of dermal cranial shields (*i.e.,* "headplate") and dorsal/pectoral spine shafts that were nonetheless identifiable as belonging to the family Clariidae or the order Siluriformes (catfish). When these fragments are excluded, there are a total of 736 specimens identified to both skeletal element and taxonomic order, of which 696 could be assigned to a family, and 660 were further identifiable to a particular genus (Table 6.1; Appendix G). Although emphasis was not placed on making identifications below the level of genus, the following discussion will reference species that were either identified definitively, or were found to be the best

Table 6.1 Fish and mollusk taxonomic representation at SM1.

Taxon	NISP	MNE	MNI
Siluriformes			
Bagridae			
Bagrus docmak/bajad	62	42	6
Clariidae			
Clarias gariepinus	440	217	28
Clariidae indet.[1]	1102	-	-
Claroteidae			
Auchenoglanis biscutatus	4	3	1
Mochokidae			
Synodontis schall/serratus	81	43	12
Schilbeidae			
Schilbe intermedius	34	20	5
Indet. catfish	208	26	9
Cypriniformes			
Cyprinidae			
Labeo sp.	24	22	2
Labeobarbus sp.	11	10	1
Labeo/Labeobarbus sp.	36	27	1
Perciformes			
Cichlidae			
Oreochromis niloticus	4	4	1
Indet. fish	1157	174	-
Mollusks	427	-	-
Total	**3590**	**588**	**66**

[1]Generic headplate fragments for which MNE and MNI were not calculated

Table 6.2 Percentage of total[1] NISP, MNE, and MNI for fish at SM1.

Taxon	% NISP	% MNE	% MNI
Siluriformes			
Bagrus	8.9	10.8	10.5
Clarias[2]	63.2	55.9	49.1
Auchenoglanis	0.6	0.8	1.8
Synodontis	11.6	11.1	21.1
Schilbe	4.9	5.2	8.8
Cypriniformes			
Labeo	3.4	5.7	3.5
Labeobarbus	1.6	2.6	1.8
Labeo/Labeobarbus	5.2	7.0	1.8
Perciformes			
Oreochromis	0.6	1.0	1.8

[1]Based on specimens identified to the level of family or lower

[2]Does not include generic headplate fragments

match based on modern comparative material and therefore represent the most likely candidate taxon for the fish from SM1. Outside of this section, however, all discussions will be of generic or higher-level taxonomic groups. In all but one case, the fish families identified at SM1 are represented by only a single genus, so these two groupings are basically interchangeable, and are employed as such throughout the chapter.

Siluriform catfish, of which there are five families, make up the majority of the identified fish from SM1, and account for 89.2% of NISP, 83.8% of MNE, and 91.2% of MNI. Similarly, taxonomic representation within this group is skewed towards just three of the taxa. Family Clariidae is represented by *Clarias gariepinus* (African sharp-toothed catfish), which is by far the most abundant fish at the site and makes up 63.2% of NISP for specimens identified to a specific element at the level of family or below. If generic headplate fragments are included, Clariidae accounts for ~86% of specimens identified at

least to family. It is difficult to make a distinction between *Clarias* and the closely related genus, *Heterobranchus,* on the basis of cranial shield morphology alone, but given that no other elements were identified as belonging to *Heterobranchus,* it is likely that the most, if not all, of these specimens are also from *C. gariepinus* (Tables 6.1 and 6.2). As such, from this point forward, all of the clariid material will simply be referred to as belonging to *Clarias.*

Family Mochokidae is the next most abundant taxon and makes up 11.6% of NISP for the identified sample. Two species are likely present, *Synodontis schall* (wahrindi) and *S. serratus* (shield-head squeaker), although a distinction was not made between the two for most identifications. Similarly, Bagridae accounts for 8.9% of NISP and is represented by two closely-related species, *Bagrus docmak* (semutundu/silver catfish) and *B. bajad* (black Nile/silver catfish), although *B. docmak* appears to be somewhat more common. Schilbeidae is also present, with the most likely species being *Schilbe intermedius* (butter catfish), and represents 4.9% of NISP. Claroteidae is represented by *Auchenoglanis biscutatus* (yellow spiny catfish), which was identified on the basis of four bones that make up < 1% of the total NISP. An additional 208 specimens, a large majority of which are very small fragments of dorsal or pectoral spine shaft, were also identified as belonging to the order Siluriformes, but could not be classified more specifically (Tables 6.1 and 6.2).

Cypriniformes (*i.e.,* carps and barbs) are represented by a single family, Cyprinidae, and two genera, *Labeo* and *Labeobarbus,* which combined represent 11% of NISP. The most likely candidate species for the *Labeo* material are *L. forskalii* and/or *L. niloticus* (carp; 3.4% of NISP), while there are several possible candidates for the *Labeobarbus* specimens (yellowfish/barb; 1.6% of NISP), including *La. bynni, La. crassibarbis, La. degeni, La. intermedius,* and/or *La. nedgia* (Tewabe, 2008). Another 36 specimens (5.2% of NISP) were identified as belonging to Cyprinidae, but could not be

classified to a more specific taxon. Extant species of *Labeo* and *Labeobarbus* are generally similar in terms of their ecology and habitat preferences, so discussions from this point forward will often consider all of the cyprinids as a single group (referred to as either *Labeo/barbus* or Cyprinidae), although they are treated separately for analyses of taxonomic diversity. Several bones from the family Cichlidae were also recovered. All of the specimens are from *Oreochromis niloticus* (Nile tilapia) and they represent 0.6% of NISP (Tables 6.1 and 6.2).

In addition to the fish, excavations also recovered a total of 427 fossil mollusk specimens (Table 6.1). The majority of this material consists of relatively small fragments of mollusk shell that are difficult to identify to a particular species. Several of the larger specimens were identified as likely belonging to *Etheria elliptica* (Nile bivalve/Nile oyster), a species of the family Etheriidae. Several more fragments were also identified as *Chambardia wahlbergi* and/or *C. rubens* (bivalve mollusk), both of which are members of family Iridinidae (Kappelman *et al.,* 2014). Additionally, there are a number of very small shells that belong to *C. aegyptiaca* (bivalve mollusk: J. Kappelman and D. Graf, personal communication). As with the fish taxa present at SM1, all of these mollusk species are extant in the region and are found in the modern Shinfa River.

Comparisons with modern fish communities

Data from stable isotope studies (see Chapter 4) and the taxonomic makeup of the terrestrial faunal assemblage (see Chapter 5) indicate that terrestrial ecosystems at SM1 in the late MSA were very similar to those present in the region today. The above discussion of the species composition of the fish fauna also indicates similar biotic communities of the modern and paleo-Shinfa River (see below for more information on this point). Thus, it stands to reason that the modern fish population from the Shinfa River should provide a

suitable analog for comparing patterns of taxonomic representation at SM1 to the expected natural abundances of fish taxa in the Shinfa River during the late MSA.

In his study of fish diversity in the Blue Nile Basin, Tewabe (2008; Tewabe *et al.,* 2010) non-selectively sampled fish from four rivers in the region around SM1 during both the wet and dry season, and identified a total of 20 species from 12 genera and 8 families in the Shinfa River alone (out of 27 species, 17 genera, and 12 families in all four rivers combined) (Appendix H). The Shinfa River sample did not include *Auchenoglanis biscutatus, Brycinus macrolepidotus*, or *Marcusenius cyprinoides* (Tewabe, 2008), but all three species were collected by Mr. Tewabe in the Shinfa River when he later worked with our Blue Highways Project (Kappelman *et al,* 2014). Thus, the modern Shinfa River actually has at least 23 species, 14 genera, and 9 families of fish. Conversely, only 8 genera from 7 families were identified at SM1, which indicates that, although all of the taxa from SM1 are still extant in the Shinfa River, they do not represent the full range of diversity in the naturally-occurring fish population (Tewabe, 2008; Kappelman *et al.,* 2014). Specifically, there are several species of *Hydrocynus* (tigerfish), *Alestes* (silversides), and *Brycinus* (tetra) from the family Characidae, as well as two species of *Mormyrus* (electric/elephant-snout fish) from the family Mormyridae, that live in the Shinfa River today and were likely also present in the river during the late MSA, but are nonetheless absent from SM1.

Importantly, there are also very clear differences between the frequencies of the taxa represented at SM1 and their natural abundances in both the modern Shinfa River and other temporary rivers in the region that were sampled by Tewabe (2008; Tewabe *et al.,* 2010) (Figure 6.1). In all four of the modern rivers (and in most rivers and lakes in northern and western Ethiopia in general), cyprinids are the most abundant fish and represent

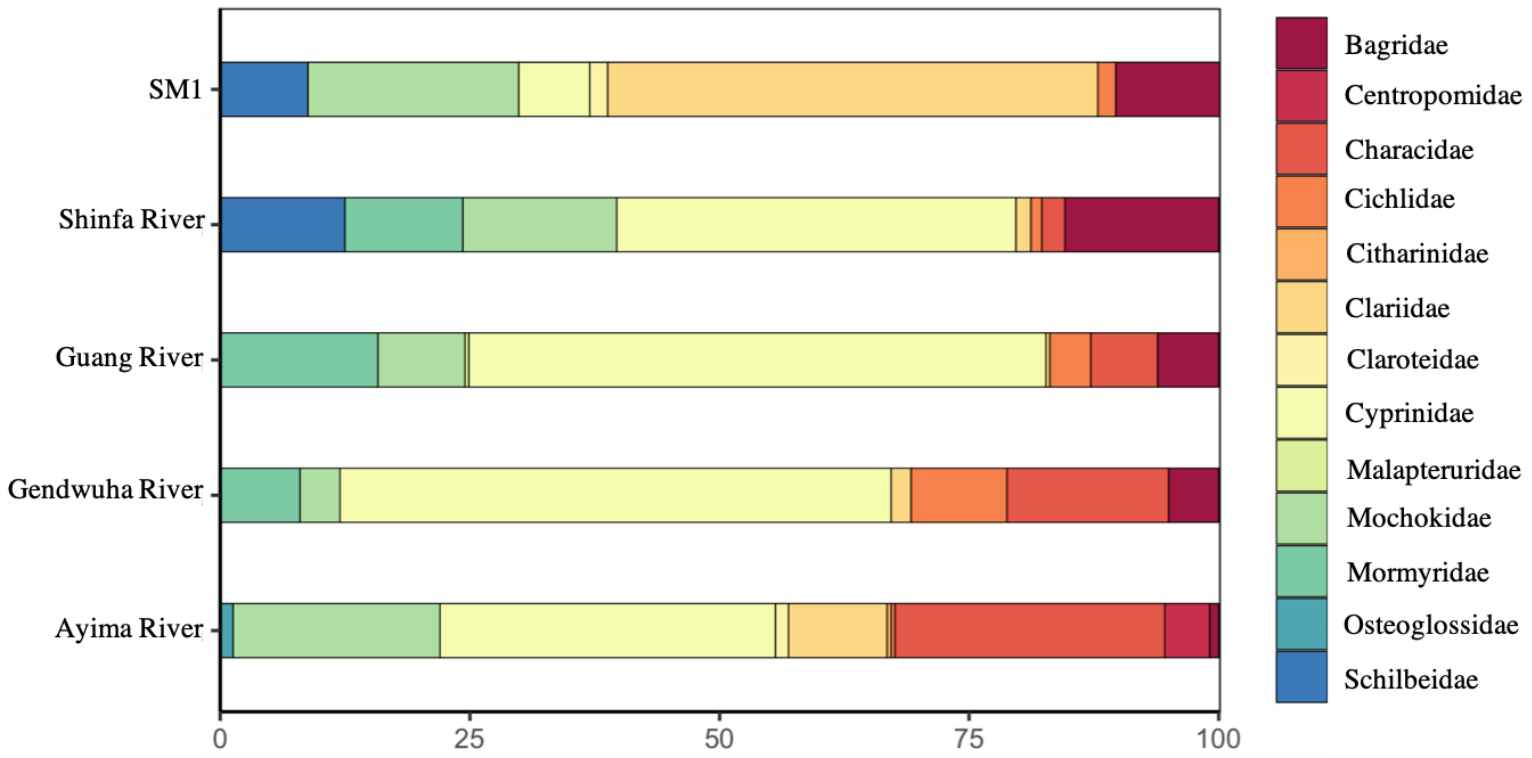

Figure 6.1 Taxonomic representation for fish from SM1, the modern Shinfa River, and other temporary rivers in the Blue Nile basin. Data for the Shinfa, Guang, Gendwuha, and Ayima rivers from Tewabe (2008).

between ~35-60% of the total catch, but this group accounts for only 7% of MNI at SM1 (Figure 6.1, Table 6.2, and Appendix H). Further, Clariidae (*i.e., Clarias* and *Heterobranchus,* although the latter is much rarer) is one of the least abundant taxa in all of the modern rivers, in sharp contrast to SM1 where *Clarias* dominates the assemblage by any measure available and makes up just under half (49.1%) of the total MNI. The frequencies of Bagridae (*i.e., Bagrus)* and Mochokidae (*i.e., Synodontis*) at SM1 are more similar to the modern rivers overall; yet, compared to the Shinfa River specifically, Bagridae appears to be under-represented while Mochokidae is over-represented. Chi-squared tests document that differences in overall taxonomic representation between SM1 and the modern Shinfa River are statistically significant (χ^2 = 123.71, p-value = <.01). Partial chi-squares further document that *Clarias* is significantly over-represented, and cyprinids under-represented, at SM1 relative to the modern river.

Taxonomic diversity

When considering the sample of specimens identified to at least the level of genus (n = 660), NTAXA = 8 for the fossil fish from SM1, while the reciprocal of the Simpson Index (1/D) = 2.14, evenness (*e*) =.58, and the Shannon Index (H) = 1.16 (Table 6.3). The relatively low value for 1/D indicates that one genus, or perhaps a few genera, tend to dominate the assemblage in terms of abundance, while the mid-range value of *e* similarly suggests a relatively uneven assemblage. Likewise, the low value of H indicates that the fossil fish assemblage from SM1 is not very heterogeneous. It seems apparent that these results are primarily due to the over-representation of *Clarias* within the assemblage, although the relatively high frequencies of *Bagrus* and *Synodontis* are likely also a contributing factor here, at least to some extent.

Table 6.3 Diversity indices for SM1, Kibish Formation, and the modern Shinfa River.

Taxon/Assemblage	NTAXA	1/D	*e*	H
Genus				
SM1	8	2.14	0.56	1.16
Shinfa River	12	6.44	0.79	1.96
Kibish Formation	9	2.96	0.61	1.34
Family				
SM1	7	1.35	0.32	0.62
Shinfa River	8	4.24	0.79	1.65
Kibish Formation	9	3.33	0.64	1.41

NTAXA = total number of genera or families; 1/D = reciprocal of the Simpson Index; *e* = evenness; H = Shannon Index

Analyzing the data at the level of family results in a slight decrease in richness to NTAXA = 7, from which 1/D is calculated as 1.35, a value that approaches the minimum limit for this index and suggests that a single taxon is dominant within the assemblage. Likewise, the evenness value of 0.32 documents a highly uneven distribution of individuals among the seven families present, while the extremely low value of H = 0.62 (values typically range between ~1.5 – 3.5) further indicates an assemblage with very low heterogeneity. Clearly, the patterns observed here are produced in large part by the extremely high frequencies of Clariidae compared to all other families when the mostly non-descript cranial shield fragments - the vast majority of which, again, belong to *Clarias* - are included. The relatively large samples of *Synodontis* (*i.e.,* Mochokidae) and *Bagrus* (*i.e.,* Bagridae) are not increased by examining the data at the family level, so these values now contribute far less to maintaining some degree of evenness in the assemblage, meaning that *Clarias* (*i.e.,* Clariidae) alone is primarily the dominant taxon.

Comparisons with data on from the natural fish community in the modern Shinfa River reveal further patterns related to taxonomic diversity at SM1. Diversity indices for

the modern fish were calculated based on data for the 272 fish sampled from the Shinfa River by Tewabe (2008). At the level of family, NTAXA = 8 for the fish from the modern Shinfa River, and 1/D = 4.24, *e* = 0.79, and H = 1.65. Analyzing these data at the level of genus results in an increase to NTAXA = 12, and slightly higher values of 6.44 and 1.95 for 1/D and H, respectively, while the value of *e* remains the same at 0.79 (Table 6.3). In both cases, these results indicate that, compared to the fossil fish from SM1, the natural fish community in the modern Shinfa River is taxonomically richer, much more evenly distributed, less dominated by a singly family or genus, and quite a bit more heterogeneous (Table 6.3). In other words, patterns of taxonomic diversity for the SM1 fossil fish assemblage are very different from the natural structure of the fish community present in the Shinfa River today.

The data for the fish from the Kibish Formation are actually rather similar to SM1 when analyzed at the level of genus (Tables 6.3). Working at the generic level, NTAXA = 9, and 1/D = 2.96, *e* = 0.61, and H = 1.34. As with SM1, these values indicate an assemblage that is relatively uneven, not very heterogeneous, and somewhat dominated by one or a few genera, although the dominance is not nearly as pronounced as it is at SM1. Furthermore, in this case the dominant taxa are *Lates* (Nile perch) and *Synodontis,* rather than just *Clarias,* although *Clarias* is still relatively common in the collection. Analyzing the data at the family level (NTAXA = 9; 1/D = 3.33; *e* = 0.64; H = 1.41) increases the contribution of Clariidae (*i.e., Clarias*), and therefore reduces the dominance of Latidae (*i.e., Lates*) and Mochokidae (*i.e., Synodontis*) somewhat, and results in a slightly more even and heterogeneous assemblage overall. This is in contrast to SM1, where the family-level analysis only amplified the dominance of *Clarias* in the assemblage (Tables 6.3 and 6.4).

These data suggest that the SM1 fish fauna is fairly similar to the Kibish collection in terms of taxonomic diversity overall, although the dominance of a single taxon is much

more pronounced at SM1 at both the generic and family level. Additionally, the Kibish fish are characterized by a pattern in which there are two somewhat predominant taxa (*Lates* and *Synodontis*), as opposed to just one overwhelmingly dominant taxon (*Clarias*) at SM1. It is also important to bear in mind that, given the collection strategy for the Kibish Formation material, the taxonomic abundances in the Kibish fish assemblage may not necessarily match those that would be expected if naturally-accumulated fish fossils from the Omo River were collected non-selectively. Nonetheless, the data presented above do not suggest significant differences between SM1 and the Kibish assemblage in terms of overall diversity, or at least not for taxonomic richness (NTAXA), evenness (*e*), or heterogeneity (H).

Table 6.4 Percentage of NISP, MNE, and MNI for fish taxa from the Kibish Formation.

Taxon	**% NISP**	**% MNE**	**% MNI**
Characiformes			
Hydrocynus	0.3	0.5	3.1
Cypriniformes			
Barbus	1.3	2.2	3.1
Osteoglossiformes			
cf. Gymnarchus	3.2	5.6	3.1
Perciformes			
Lates	37.7	55.3	28.1
Polypteriformes			
cf. Polypterus	1	1.1	6.3
Siluriformes			
Bagrus	2.2	3.4	12.5
Clarias[1]	8.3	3.9	9.4
Schilbe	2.6	0.6	3.1
Synodontis	43.4	27.4	31.3

[1]Does not include generic headplate fragments

Values based on raw data collected for this study only.

Paleoecology of the fossil fish

Many of the fish taxa recovered from SM1 are common at late Pleistocene riverine and lacustrine sites in northern and eastern Africa and, following Van Neer (1989, 2004), they can essentially be divided into two groups. The first group includes fish that can tolerate adverse conditions (*i.e.,* high salinity, low oxygen, and/or high carbon-dioxide concentrations), albeit to varying degrees, and typically live in shallow and/or brackish water (Van Neer, 1989, 2004). In riverine environments, these fish may spend considerable time out on the floodplain, and all of them at least enter the floodplain for the purposes of spawning, which often takes place during the rainy season when river waters are high and rich with food and nutrients. The second group consists of fish that are typically more sensitive to adverse water conditions and spend more time in open water further away from the shoreline of lakes and rivers. These taxa also often spawn during the high-water stands of the rainy season, but many of them do so in open water. Those that do migrate into the shallows or onto the floodplain only stay for a brief period, after which they return to open water (Van Neer, 1989, 2004).

Most of the fish from SM1 are from the first group of "flood-plain dwellers" (Van Neer, 1989, 2004). *Clarias* has accessory organs that allow it to breathe air, so this taxon can withstand conditions of very low oxygen and high concentrations of carbon dioxide, and may at times even leave the water to move across dry land for several hundred meters (Fish, 1956; Golubtsov *et al.,* 2002; Van Neer, 2004). *Clarias* is primarily a demersal (*i.e.,* bottom-dwelling/-feeding) fish and its species can inhabit a range of ecosystems, from shallow-water swamps to deep-water offshore habitats in the middle of lakes, but they are most commonly found in littoral inshore habitats (Stewart, 1989). *Clarias* is also known to migrate through shallow flooded grasslands on a regular basis and is one of the first fish to venture out into the shallowest parts of the floodplain at the onset of the rainy season, where

spawning take places in water that is often < 10 cm deep (Fish, 1956; Holl, 1968; Dadebo, 2000; Van Neer, 2004). Both juveniles and adults spend much of the breeding season on the floodplain and both eventually make their way into the main channel as waters begin to recede near the end of the rainy season, although juveniles often stay out on the floodplain longer than adults (Van Neer, 2004). Fish that do not migrate to the main channel before the connection is broken are confined to shallow floodplain pools, which continue to evaporate throughout the dry season and may or may not dry up completely before the rains return the following year (Van Neer, 2004). Given its ability to breathe atmospheric oxygen, *Clarias* has the potential to survive longer than many other fish in these ever-evaporating and increasingly deoxygenated pools (Fish, 1956; Stewart, 1989).

The other two siluriform taxa with a clear preference for inshore habitats and tolerance for more adverse conditions are *Schilbe* and *Auchenoglanis* (Schwartz, 1983; Stewart, 1989; Golubtsov *et al.,* 2002). Species of *Schilbe* may range throughout the horizontal and vertical extent of the water column, but are most commonly found away from open-water areas of rivers and lakes (Schwartz, 1983; Stewart, 1989; Golubtsov *et al.,* 2002). *Auchenoglanis* is a demersal fish that spends most of the time near the floor of lakes and river channels in relatively shallow water, and is often found in muddy floodplain swamps (Jubb, 1967). As with *Clarias,* in riverine environments, the majority of breeding activity for both *Schilbe* and *Auchenoglanis* takes place in shallow pools outside the main river channel on the floodplain, where individuals may stay for an extended period of time during the rainy season (Golubtsov *et al.*, 2002).

Oreochromis inhabits the littoral or sublittoral zones of lakes and rivers, although in some places they may also venture into deeper open-water habitats for part of the year (Bruton and Boltt, 1975). *Oreochromis* species do not have the special air-breathing apparatus of *Clarias,* but do have other physiological (*e.g.,* hemoglobin) and anatomical

(*e.g.,* gill structures) adaptations that allow them to tolerate poor-quality habitats, and these fish are often found in very shallow brackish water (Avella *et al.*, 1993). Similar to *Clarias, Oreochromis* breeding often occurs in water < 50 cm deep and, although individuals may spawn throughout the year, the peak of breeding activity is usually during the rainy season (Van Neer, 2004; Kwarfo-Apegyah *et al.,* 2010). The cyprinid genera *Labeo* and *Labeobarbus* are also tolerant of relatively low-quality water conditions, albeit perhaps not as resilient as *Clarias* and *Oreochromis* (Stewart, 1989; Golubtsov *et al.* 2002; Van Neer, 2004). Once again, these are demersal fish that primarily occupy inshore habitats, but some taxa may also enter open-water zones for at least part of the year (Van Neer, 2004). Regardless, most species migrate to shallow waters near the shoreline and/or out onto the floodplain to spawn, which they typically do at the height of the rainy season (Dadebo *et al.,* 2003; Van Neer, 2004).

Bagrus is the only fish from SM1 that is firmly in the "open-water" group (Ita, 1978; Van Neer, 2004). *Bagrus* is a demersal fish found primarily in deep water, often at depths of 15 m or more in lakes and rivers in eastern Africa (Stewart, 1989). Adults spend very little time outside open-water zones for a large part of the year (Stewart, 1989; Van Neer, 2004). Individuals do migrate inshore to breed during the rainy season when rivers and lakes are bank-full or overflowing, and spawning usually takes place in shallow water near the shoreline, but some individuals may also enter the floodplain to spawn. In either case, the time spent inshore is typically quite limited and adults usually return to the open water of the main lake or river channel rather quickly (Van Neer, 2004). Conversely, juveniles often remain in shallow inshore environments or move out onto the floodplain for a period of time, where food and shelter from predators are more readily available (Van Neer, 2004).

Synodontis is also considered one of the "open-water" forms by Van Neer (1989, 2004), although it is more difficult to generalize habitat preferences for this taxon than it is for those discussed above (Golubtsov *et al.,* 2002). *Synodontis* is one of the most speciose genera of freshwater fish in Africa and includes species that are both pelagic (*i.e.,* spending much of the time near the middle of the water column, well below the surface but well above the floor) and demersal, and which occupy both deep and shallow water habitats (Schwartz, 1983; Stewart, 1989; Laleye *et al.,* 2006). Some species of *Synodontis* are also better-suited to conditions of low oxygen and high salinity than others, making them more amenable to spending larger amounts of time in low-quality environments (Van Neer, 2004). Additionally, large numbers of these fish are known to regularly migrate into the floodplain during the rainy season in order to spawn (Van Neer, 2004). However, they are included in the open-water group because many species do not spend extended amounts of time on the floodplain, and individuals typically return to the main lake body or river channel after a brief period of time (Van Neer, 2004).

Much like the terrestrial fauna, the makeup of the fossil fish assemblage from SM1 does not indicate significant differences in the paleoecology of the modern and paleo-Shinfa River. In fact, given that all of the identified species from the site are still present in the modern river today, it seems likely that the overall hydrological and biological characteristics were very similar between the modern and ancient river systems. These data are also potentially important for understanding the behavioral implications of fish taxonomic representation at SM1. More specifically, the fact that many of the fish taxa present would have inhabited different parts of the river, and had distinct and often seasonally-determined patterns of spawning behavior, may be useful for determining how and/or when fish were caught (Van Neer, 2004). For example, the methods used to catch inshore fish such as *Clarias* may differ from those required to obtain open-water species

like *Bagrus*, and the predominance of *Clarias* may be at least partly related to its uniquely high tolerance for living in shallow, deoxygenated water (Stewart, 1989). Once again, these points will be returned to in the section on human activity below.

SKELETAL ELEMENT REPRESENTATION

The following section provides a summary of skeletal part representation in the context of the broader discussion of the general characteristics of the fossil fish assemblage from SM1. Additional discussion of bone fragmentation, survivorship, and the potential behavioral correlates of these data will be provided in subsequent sections. A full catalog of skeletal elements by taxonomic group is provided in Appendix G. A schematic diagram showing the different anatomical regions referred to in the following sections is also presented in Figure 3.1.

Patterns of element representation among the fossil fish from SM1 are essentially reversed compared to those observed for the terrestrial fauna (Table 6.5). When all identified and non-identified specimens are considered, cranial elements (49%) are the most abundant, representing just under half the sample. Postcrania (16.3%) and vertebrae (9.5%) make up just over 25% of the assemblage combined, while the remaining ~25% of specimens are not identifiable to a specific skeletal element. When non-identifiable elements are excluded, the proportions rise to 65.5%, 21.7%, and 12.8% for cranial, postcranial, and vertebral elements, respectively (Table 6.5).

Bones of the neurocranium are by far the most common cranial bones, and the most abundant elements overall, due in large part to the very high number of generic *Clarias* cranial shield, or headplate, fragments. Median fin elements, oromandibular bones, and vertebrae are also well-represented, and all three are actually more abundant than neurocrania if generic headplate fragments are not included. Almost all of the median fin

Table 6.5 Fish skeletal element representation from SM1 by taxon, anatomical region, and skeletal structure.

Region/ Structure	***Auch.***	***Bagrus***	***Clarias***	**Clariidae**	***Schilbe***	***Synod.***	**Silur.**	**Cyprin.**	***Oreochr.***	**Indet.**	**%NISP**	**%Total**
Cranial	-	*21*	*287*	*1102*	*1*	*6*	*1*	*23*	*2*	*107*	*65.5*	*49.0*
Neurocranium	-	1	114	1102		6	1		-	42	53.5	40.0
Oromandibular	-	5	128	-	1	-	-	2	2	20	6.7	5.0
Hyoid	-	14	39	-	-	-	-	5	-	5	2.7	2.0
Opercular	-	1	6	-	-	-	-	2	-	3	0.5	0.4
Branchial	-	-	-	-	-	-	-	-	-	37	1.6	1.2
Pharyngeal	-	-	-	-	-	-	-	14	-	-	0.6	0.4
Postcranial	*3*	*15*	*124*	-	*24*	*75*	*175*	*1*	*1*	*94*	*21.6*	*16.2*
Appendicular	-	-	11	-	-	11	3	-	-	47	3.0	2.3
Median fin	3	15	113	-	24	64	172	1	1	47	18.6	13.9
Vertebral	*1*	*26*	*29*	-	*9*	-	*32*	*47*	*1*	*159*	*12.8*	*9.6*
Non-ID	-	-	-	-	-	-	-	-	-	*797*	-	*25.2*
NISP	4	62	440	1102	34	81	208	71	4	1157		

Auch = *Auchenoglanis; Synod.* = *Synodontis;* Silur. = Siluriformes; Cyprin. = Cyprinidae; *Oreochr.* = *Oreochromis;* Indet. = indeterminate

elements are catfish spines, with all but one of the identified specimens being pectoral spines; the single other specimen is a *Synodontis* dorsal spine base. Additionally, there are 168 fragments of spine shaft for which a definitive distinction between pectoral/dorsal was not made, but based on the predominance of pectoral spines in the identified material (and of *Clarias* overall, which does not have dorsal spines), it seems likely that most of these are also pectoral spines. The other 47 median fin elements are fin rays, a handful of partial articulated fins that were only identifiable as belonging to teleost fish, and an *Oreochromis* pterygiophore. The oromandibular elements are dominated by mandibles, most of which belong to *Clarias* and *Bagrus,* although several palatines, a few maxillary tooth plates, and several small cyprinid pharyngeal teeth were also recovered. Additionally, both precaudal and caudal vertebrae are present at SM1, but in many cases, identifications did not emphasize distinguishing between the two, so it is not really possible to provide a more detailed breakdown of the frequency of each type of vertebra (Table 6.5).

Examining the frequency of bones from the broader anatomical regions by taxon also underscores some patterns of element representation at SM1 (Table 6.6). As already noted, even when generic headplate fragments are excluded, *Clarias* is dominated by cranial elements (66.3% of NISP). Several other cranial elements are also relatively well-represented for *Clarias*, including the mandibular bones, hyoid bar, palatine, and quadrate (in that order). Common postcranial bones (28.6% of NISP) include appendicular elements, such as the cleithrum, supracleithrum, and coracoid, and pectoral spines of the median fin group, while vertebral elements are quite rare and only make up 5.1% of the material assigned to *Clarias* (Tables 6.5 and 6.6).

Cranial bones, represented by a mere six neurocranial fragments, represent only 7.4% of the identified *Synodontis* material, which is somewhat puzzling given that this genus also has a dense, dermal-plated cranial shield. Postcranial elements make up the

Table 6.6 Frequency (% of NISP) of fish bones from SM1 from each anatomical region, expected frequency (%) in a complete skeleton, and results of chi-squared tests for differences between observed and expected frequencies.

	Cranial[1]		Postcranial		Vertebral[2]			
Taxon	**SM1 %**	**Exp. %**	**SM1 %**	**Exp. %**	**SM1 %**	**Exp. %**	χ^2	**p-value**
Auchenoglanis	-	58.3	75	5.7	25	36	-	-
Bagrus	34.4(-)*	58.3	24.6(+)*	5.7	41	36	18.35	<.01
Clarias	66.3	58.3	28.6(+)*	5.7	5.1(-)*	36	42.25	<.01
Schilbe	2.9(-)*	58.3	70.6(+)*	5.7	26.5	36	106.8	<.01
Synodontis	7.4(-)*	58.3	92.6(+)*	5.7	-	36	152.26	<.01
Labeo/barbus	15.8(-)*	69.4	1.8(-)*	10.3	82.5(+)*	20.3	47.63	<.01
Oreochromis	50	65.6	25	19	25	15.4	-	-

[1]Does not include generic headplate fragments or pharyngeal teeth.

[2]Does not include weberian apparatus.

(+)* = observed significantly greater than expected; (-)* = observed significantly less than expected

All expected proportions based on data from Zohar (2003; Zohar *et al.*, 2008).

Proportions for Siluriformes based on *Clarias*, with one median fin element added for fish with dorsal spines.

other 92.6% of *Synodontis* bones, and no vertebrae were definitively identified as belonging to this taxon. It is once again the case that postcranial material consists almost entirely of cleithra and pectoral spines, but a single dorsal spine shaft base was also recovered. Element representation for *Schilbe* is also largely skewed towards postcranial elements (70.6%), all of which are fragments of pectoral spine bases and/or shafts. However, in the case of *Schilbe*, cranial representation is even lower (2.9%) and vertebral elements are relatively common (26.5%) (Tables 6.5 and 6.6).

Element representation for *Bagrus* is more evenly spread out across the three anatomical regions. Vertebrae (41.9%) are the most common type of element, followed by cranial elements (33.9%), and postcrania (24.2%). Among cranial elements, the mandible and hyoid bar are the most abundant, while all of the postcranial bones are pectoral spines. Vertebrae (66.2%) are the most common elements for the cyprinid genera *Labeo* and *Labeobarbus,* as well, and cranial elements (32.4%) are also relatively well-represented among these genera. In this case, more than half of the cranial specimens are pharyngeal teeth, rather than actual cranial bones, although several opercula, hyomandibulae, and quadrates were also recovered. If pharyngeal teeth are excluded, the proportions of cranial and vertebral elements are 15.8% and 82.5%, respectively. The single identified postcranial element (1.4% with teeth; 1.8% without teeth) is a fin spine belonging to *Labeobarbus.* Finally, of the four specimens assigned to *Oreochromis,* two are cranial (50%: quadrates), one is postcranial (25%: pterygiophore), and one is vertebral (25%: vertebral centrum) (Tables 6.5 and 6.6).

In all cases, the overall frequencies of cranial, postcranial, and vertebral elements observed at SM1 are significantly different from the expected frequencies in a complete fish skeleton (Table 6.6). More specifically, cranial elements are under-represented in most cases, and significantly so in four out of the five taxa that have samples reasonably large

enough to allow for meaningful analysis. The only exception to this pattern is *Clarias,* for which cranial elements are actually over-represented, although the difference between observed and expected frequencies is not statistically significant. However, including generic headplate fragments increases the percentage of cranial elements to ~91% and produces a highly statistically significant difference with the expected frequency of 58.3% in a complete *Clarias* skeleton (Table 6.6).

Postcranial elements are over-represented in four out of five taxa (Table 6.6). This is particularly true for *Synodontis* and *Schilbe,* both of which are dominated by postcranial elements, despite an expectation of only 5.7% in a complete fish. The percentages of postcranial elements for *Bagrus* and *Clarias* are quite a bit lower, but nonetheless also significantly different than expected. However, the inclusion of generic headplate fragments drops the proportion of postcranial bones to ~8% for *Clarias*, which is still higher than the expectation of 5.7%, but the difference is no longer statistically significant. Once again, there is a single exception, *Labeo/barbus,* for which postcranial elements are substantially rarer than expected. Finally, vertebrae are generally under-represented in the collection, and significantly so in *Clarias.* Conversely, both *Bagrus* and *Labeo/barbus* have more vertebrae than expected, and the difference is highly significant for *Labeo/barbus* (Table 6.6).

The modest overabundance of *Clarias* cranial elements is not necessarily surprising given the very durable nature of *Clarias* cranial shields, and this pattern is actually quite common at late Pleistocene and Holocene archaeological sites across Africa (Greenwood, 1968; Stewart, 1989, Van Neer 1989, 2004; Van Neer and Lesur, 2004). However, it is not clear that differences in density are sufficient to fully explain the over-representation of *Clarias* neurocranial elements relative to all of the other taxa at the site. This is particularly true with regard to the almost complete lack of cranial elements from

Synodontis, which is also a "shield-headed catfish" and the second most abundant genus at the site. The paucity of *Synodontis* cranial bones may also be at least partly related to the generally smaller size of many individuals, although the recovery of elements belonging to a number of very small fish, including several *Synodontis* specimens, suggests that size is not the only factor at play here (see below).

The overall dominance of *Clarias* in the collection may also be explained, at least in part, by the robust nature of some of the most common elements found at SM1 (*e.g.,* pectoral spines, angular/dentary, hyoid) in this taxon. Yet, the pectoral (and dorsal) spines of *Bagrus, Synodontis,* and *Schilbe* are also quite robust, as are the mandibular bones (*i.e.,* angular/dentary) of *Bagrus*, in particular. If these taxa were introduced into the site at the same frequencies as *Clarias,* it is likely that at least some of the other postcranial elements, especially pectoral and dorsal spines, would have survived in higher numbers, even if the cranial elements were more susceptible to destruction by humans and/or other non-human processes than those of *Clarias*.

As already discussed, *Clarias* ranks very low in terms of species abundance in the modern Shinfa River, with *Bagrus, Synodontis,* and *Schilbe* all being more than twice as common in the samples collected by Tewabe (2008; Tewabe *et al.,* 2010). This is also the case for the 76 fish collected from the Shinfa River by our Blue Highways Project research teach, which includes Mr. Tewabe, of which only two are *Clarias*. If species diversity was at all similar in the past, then the dominance of *Clarias* cannot simply be assumed to result from the natural distribution of species in the paleo-Shinfa River. The relative paucity of cranial elements and almost complete lack of postcrania among *Labeo/barbus* is also interesting, given that cyprinids are the most abundant fish in the modern Shinfa River (and in most bodies of water throughout western and central Ethiopia). At least part of the reason for the lack of cyprinid cranial bones at SM1 almost certainly relates to the relatively

delicate nature of these elements when compared to those of *Clarias* and other "shield-headed" catfish. However, if cyprinids were introduced into the site in similar numbers to *Clarias,* it is still difficult to explain why more robust cyprinid elements, such as vertebrae and fin spines, are not much more common at SM1.

Thus, although taphonomic biases against smaller fish and/or those with less robust skeletons are no doubt partly responsible for the over-representation of *Clarias* at SM1, taphonomy alone is likely insufficient to account for both the over-representation of *Clarias* and under-representation of most other taxa at the site. Even if *Clarias* bones do survive at much higher rates than those of other taxa, the simple fact that *Clarias* is rather uncommon in the modern Shinfa and other river(s) in the region, particularly compared to cyprinids and several other catfish taxa, appears to argue against the idea that the predominance of this taxon at SM1 results entirely from natural processes and/or taphonomic filters. All of these points will be returned to below, after the results of taphonomic analyses have been presented.

FOSSIL FISH BODY SIZE

Data on fossil fish body size can potentially provide insight into a number of aspects of site formation at SM1, including whether or not the fish are more likely to represent a natural (*i.e.,* non-human) or human accumulation and the season in which they were captured (Gifford-Gonzalez *et al.,* 1999). Assuming that humans are responsible for collecting the fish, body size data can also provide information about the fishing methods and practices (*e.g.,* selective versus non-selective; shoreline vs open-water), the season of capture (*i.e.,* wet, dry, or both), and the nutritive and total body mass contribution of fish in the diet. Previous work has shown that the size of fossil fish can be accurately estimated using regression equations derived from analyses of the relationships between various

osteometric measurements and body size in modern reference samples (*e.g.,* Casteel, 1976; Stewart, 1989; Grouard, 2001; Zohar, 2003; Van Neer and Lesur, 2004; Prendergast, 2010; Prendergast and Beyin, 2017). There are a number of techniques that can be used to accomplish this task, although two of the most widely-used methods involve linear regression or logarithmic "power-curve" analyses (Desse and Desse-Berset, 1996; Grouard, 2001; Van Neer and Lesur, 2004). Importantly for the current study, reliable estimates can be generated from both species-specific equations, as well as equations calculated for higher-level taxonomic groupings (Desse and Desse-Berset, 1996; Van Neer and Lesur, 2004).

Estimates of fossil fish body size at SM1 were generated using equations derived from linear regression analyses of a sample of 76 modern fish caught in the Shinfa River between 2010 and 2016. Details on the modern fish sample from the Shinfa River are provided in Chapter 3. Only taxa found at SM1 were included in regression analyses. The same osteometric measurements taken on the fossils were recorded for the modern fish, and each measurement was regressed against the total length of the fish (TL: length from the most anterior point of the snout to the most posterior point on the tail, measured at the time of capture) to determine which were the most likely to provide reliable estimates of TL for the fossil fish. All variables were log-transformed and the residuals for each model were tested for normality using Shapiro-Wilk tests. Models for which the residuals were not normally distributed after transformation were excluded from further analysis. For all measurements, analyses were run at all possible taxonomic levels (*i.e.,* genus, family, order, and/or class), and only equations indicating a strong and significant correlation with TL (*i.e.,* adjusted $r^2 > 0.7$ and p-value < 0.05) were considered for further use.

When choosing the best predictive equation for each fossil, it was assumed that: 1) the equation should be from a sample that includes the taxon in question; and 2) the most

appropriate equation would be the one with the highest correlation from the lowest taxonomic group possible. For example, assuming similar correlation values and sample sizes, a regression equation from analyses of modern *Clarias* individuals would be the first choice for predicting TL for a fossil *Clarias* specimen. In the absence of an appropriate *Clarias*-specific equation, an equation derived from only siluriform catfish would be preferred over one for a sample that included both catfish and other taxa. Further, the estimate could be obtained using an equation generated from analyses of *Clarias,* Siluriformes, and/or all fish, but not for *Bagrus, Synodontis,* or Cyprinidae, which are groups that do not include *Clarias.*

Sample size was also taken into consideration, although all of the samples used to create predictive equations were limited by the number of modern fish with both body size and osteometric data available. Samples range from 8-35 individuals (mean = 18), but over half of the estimated TL values are based on equations generated from samples of 20+ fish (Appendix I). When possible, TL estimates based on a relatively small number of modern fish (*i.e.,* $n < 20$) were also compared to estimates using equations for the same variable generated from larger samples. For example, sample sizes for analyses of all fish taxa together range from 31-35 for different variables in the modern collection, while those for cyprinids are between 10-13 individuals. Thus, TL estimates for fossil cyprinid specimens were generated using both cyprinid-specific equations and equations derived from the same variables for the "all fish" group (*i.e.,* the only other equation that would include, and therefore be relevant to, cyprinids), and the two were compared. Differences between values compared in this way were generally minimal (*i.e.,* ~1-3 cm), and in ~80% of the cases it was determined that the value reported here was likely to be the more conservative (*i.e.,* smaller) one, meaning that the data presented below might reasonably be considered minimum estimates in many cases. Even so, given the general similarity of most estimates,

the overall analyses and interpretations would almost certainly be the same, regardless of which estimate was used. A full catalog of the measurements used to create predictive equations, sample sizes, summary statistics, and all TL estimates for fossil fish is provided in Appendix I.

In addition to TL, the body mass (BM) of fossil fish was also estimated. Estimates were first generated using equations derived from the modern Shinfa River fish collection in the same way described above for TL. There is also extensive published work in which the relationship between fish length and body mass has been investigated for all of the species present at SM1 (*e.g.,* Willoughby and Tweddle, 1978; Bayley, 1982; Britton and Harper, 2006; Laleye, 2006; Laleye *et al.*, 2006). As such, linear regression and/or allometric equations describing the length-weight relationship in the relevant taxa were also collected from the literature in order to estimate BM for the SM1 fish. BM estimates based on analyses of the Shinfa collection and from the published equations were found to be quite similar overall. However, only around half of the modern Shinfa fish have BM data recorded, and *Bagrus* is the only taxon below the level of family with more than ~10 individuals that were weighed at the time of capture. The equations derived from the literature, by contrast, were all species-specific and most were generated from analyses with much larger sample sizes. Thus, the following discussion of fossil fish BM is based on estimates generated using the published equations, and the values presented are the mean BM estimate in kilograms from all the equations used for a particular fossil. Details on the equations and all BM estimates for the fish from SM1 are provided in Appendix I.

Finally, it should be pointed out that body size estimates were calculated using all available elements for any taxon, so most taxa include estimates based on several different elements, and all fossil specimens were treated as if they came from different individuals. It is not uncommon for researchers to estimate fossil fish size using NISP-based samples

that outnumber MNI estimates and to include calculations from multiple different elements in order to maximize the number of archaeological specimens available for analysis (*e.g.,* Van Neer and LeSur, 2004; Prendergast and Beyin, 2017). Nonetheless, it is important to note here because it raises the possibility that some individuals may have been double-counted and leads to sample sizes (which theoretically represent the number of individual fish analyzed) that are higher than the MNI counts provided earlier in the chapter.

In the modern fish sample, TL estimates for the same individual produced using different elements and equations were found to be quite similar in most cases so it seems unlikely that potential double-counting would significantly alter the overall range of TL and BM values. The mean values could be differentially affected if, for example, large fish were more often double-counted than small fish (or vice-versa), although it also seems unlikely that this would drastically change the overall result. It is also important to remember that: 1) by definition, MNI is an estimate of the smallest possible number of individuals at a site; and 2) for a variety of reasons discussed in Chapter 3, MNI values at SM1 are likely depressed, and perhaps significantly so in many cases. Thus, despite the possible interdependence of some specimens, the 103 presumed individuals for which body size was estimated here likely still underestimate the actual number of fish present at SM1. Nonetheless, the data and discussion in the following section should be taken with appropriate caution, and the full dataset is provided in Appendix I for more detailed examination by any interested readers.

Size reconstructions of fossil fish

Analyses of the length of fossil fish at SM1 are based on a total of 103 specimens for which TL could be reliably estimated. Analyses of the BM of fossil fish are based on a

sample of 99 fish for which relevant osteometric data and appropriate equations were available. Because weight data were calculated using genus-specific equations from the literature, BM was not estimated for specimens of indeterminate generic status. Unfortunately, there are too few specimens with size estimates to carry out analyses on any aggregate other than the full sample, so it is not possible to investigate differences in size representation across analytical units as was done for the terrestrial fauna.

Fossil fish at SM1 range in TL from just over ten centimeters to almost a meter in length (Table 6.7 and Figure 6.2). The distribution of body sizes for the sample as a whole is essentially unimodal, but with a small peak along both the left and right tails. Additionally, the overall distribution is skewed slightly to the right of center, with an average TL for the entire sample of 45 cm. Fossil fish range in BM from less than 50 grams to over four kilograms (Table 6.7). Once again, the weight data are distributed unimodally for the entire sample but the skew is decidedly to the left of center, with a long right tail caused by several specimens that are relatively quite large (Figure 6.3). With one possible exception, which will be discussed in more detail below, the distribution of within-taxon TL and BM values are also unimodally distributed, indicating that many of the specimens in each group are generally similar in size.

Estimated TL values for *Clarias* range between 32-82 cm, with a mean length of 51 cm for all specimens in this taxon. Although the TL distribution is unimodal overall, *Clarias* is responsible for the small right tail peak just noted, which occurs between 70-75 cm (Figure 6.2). Approximately 10% of the *Clarias* specimens are 70+ cm long, including the largest specimen in the assemblage, which is estimated to have measured 82 cm from head to tail, while just under half the *Clarias* individuals are at least 50 cm long. In terms of BM, *Clarias* has the highest within-taxon variation, which is not surprising given that *Clarias* is much better-sampled than any of the other genera. The *Clarias* sample also

Table 6.7 Total length (TL) and body mass (BM) estimates for fish from SM1.

		TL (cm)		BM (kg)	
Genus	**NISP**	**Mean**	**Range**	**Mean**	**Range**
Bagrus	9	56	39 - 74	1.8	0.5 - 3.9
Clarias	61	51	32 - 82	1.2	0.2 - 4.4
Synodontis	20	25	12 - 49	0.4	<.1 - 2.6
Labeo/barbus	7	42	24 - 50	0.8	0.2 - 1.2
Oreochromis	2	41	41	1.1	1.1
Indet.	4	43	21 - 61	-	-
Total	**103**	**45**	**12 - 82**	**1.1**	**< 0.1 - 4.4**

includes one of the smallest fish in the assemblage, which is estimated to weigh just ~0.2 kg, as well as the largest fish overall, which is estimated to have been 4.4 kg (Figure 6.3). There are two other *Clarias* specimens that weigh ~3-4 kg, although the distribution is skewed noticeably leftward, and the majority of individuals weigh between 1-2 kg. The mean weight for a *Clarias* specimen is 1.2 kg (Table 6.7).

Bagrus TL values are skewed slightly toward the right side of the unimodal distribution. Accordingly, there are several medium-to-large-sized *Bagrus* individuals at the site, including two with estimated TL of 74 cm and 62 cm, and five more that are estimated to be over 50 cm long. The remaining two fish of this genus have estimated TL values of ~39 cm and ~48 cm, respectively. Although the sample is much smaller, the mean estimated length of 56 cm for *Bagrus* specimens is slightly greater than that for *Clarias* (Table 6.7 and Figure 6.2). With respect to BM, *Bagrus* contains the second-largest fish overall, with an estimated weight of 3.9 kg, and once again the mean weight of *Bagrus* specimens, 1.8 kg, is actually 0.6 kg higher than that of *Clarias.* The distribution in this case has a slight leftward skew.

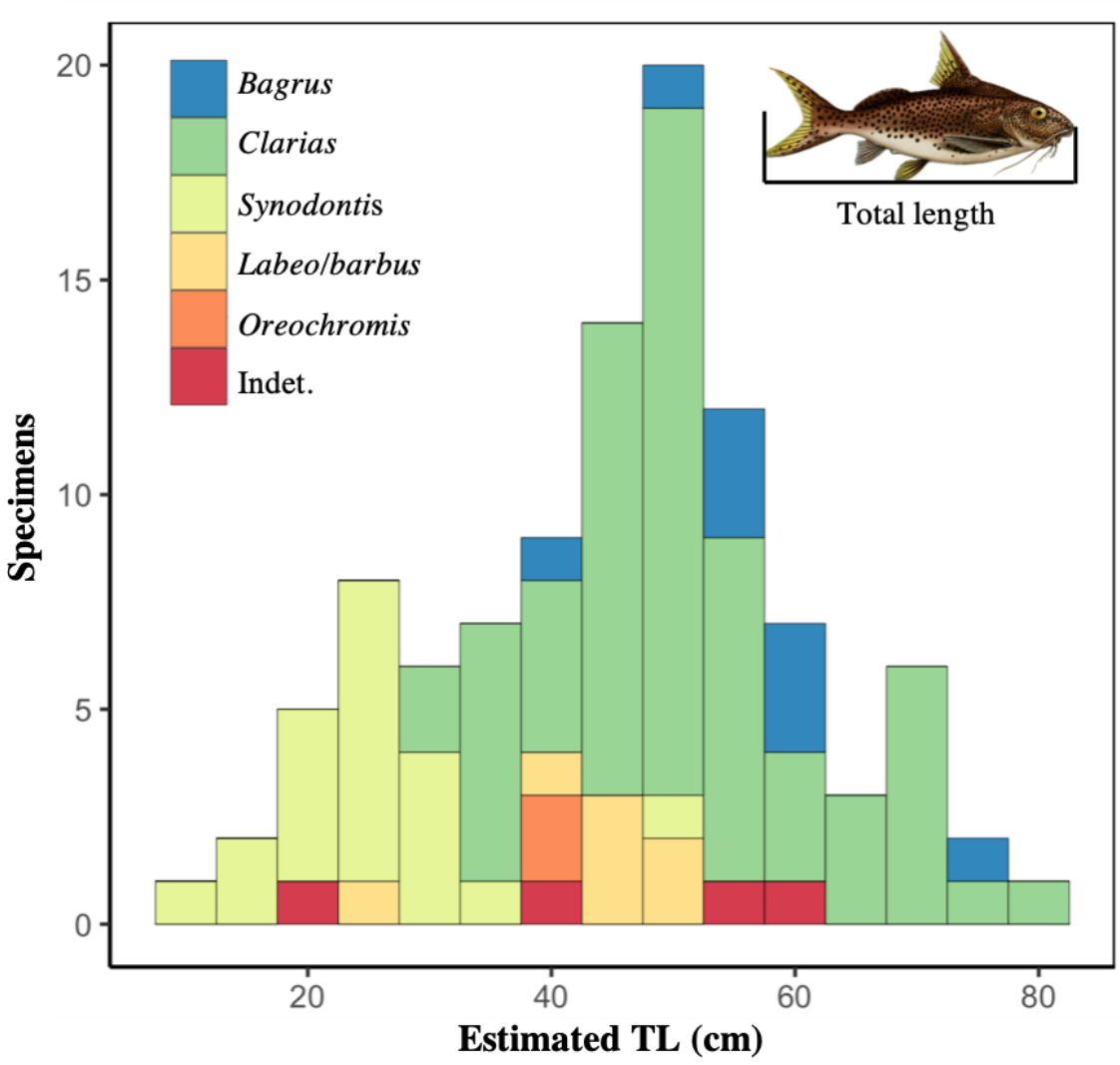

Figure 6.2 Size distribution of fish from SM1 based on total length (TL) estimates. Fish image courtesy of wikimedia.org.

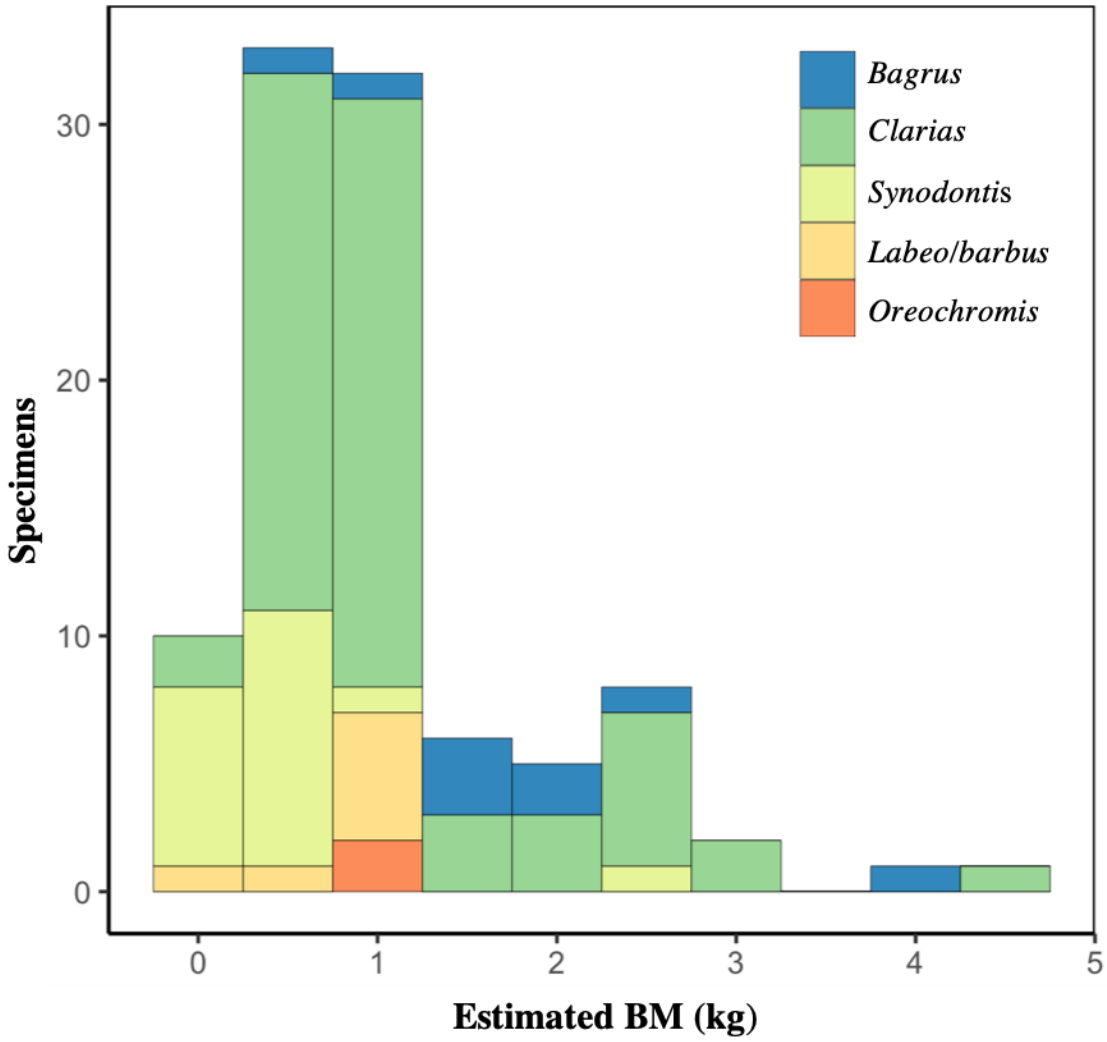

Figure 6.3 Size distribution of fish from SM1 based on body mass (BM) estimates.

The distribution of *Synodontis* TL and BM values are both leftward skewed with a long right tail caused by a single fish that is quite a bit longer and heavier than all of the rest, although the effect is slightly more pronounced for BM than for TL (Figures 6.2 and 6.3). *Synodontis* specimens range from 12-49 cm in TL, but there are actually only three specimens > 30 cm long. As such, the mean TL for *Synodontis* of 25 cm is much closer to the lower end of that range (Table 6.7). The range of BM values for *Synodontis* is rather broad, with the smallest fish estimated to weigh just over 0.04 kg (by far the smallest fish in the assemblage) and the largest 2.6 kg (Table 6.7 and Figure 6.3). However, as noted above, there are actually no other *Synodontis* individuals estimated to weigh > 0.8 kg, and 70% of the specimens have estimated weights between 0.2-0.6 kg. The mean BM for *Synodontis* is 0.4 kg.

Like *Bagrus,* the unimodal distribution of TL for the *Labeo/barbus*, or cyprinid, specimens is skewed towards the right. Yet, similar to *Synodontis*, the cyprinids are also somewhat shorter overall compared to the *Clarias* and *Bagrus* specimens, despite the fact that several of them are still quite sizeable. The largest individual cyprinid specimen is estimated to be 50 cm, and the smallest just 25 cm long, with a mean TL of 42 cm for all of the cyprinid fish. The BM of cyprinids ranges between 0.2-1.2 kg, although the values are skewed towards the higher end of that range, and the average cyprinid weighs ~0.8 kg.

There are only two *Oreochromis* specimens, but technically they also have a unimodal distribution since both occur in the same bins in Figures 6.2 and 6.3. These specimens are estimated to have been 41 cm in length and both of them are estimated to have weighed 1.1 kg (Table 6.7). Finally, there were four specimens (three opercula and one quadrate fragment) that were not assigned to a genus, but for which it was still possible to estimate TL using equations based on analyses of the full sample of modern fish. The TL estimates for these individuals range from ~20-60 cm, with a mean of 43 cm (Table 6.7

and Figure 6.2). With only four specimens, it is difficult to be definitive, but these fish appear to have a somewhat bimodal distribution, with two individuals < 40 cm long and two individuals > 50 cm long. As already noted, BM was not estimated for these specimens.

Analyzing the body size data in groups based on the size classes of Stewart (1989) helps to further clarify some interesting patterns (Figure 6.4). To begin with, it is clear from Figure 6.4 that, while TL does vary rather widely, the majority of fossil fish from SM1 are between ~30-50 cm (~47%) or 50-85 cm (~35%) long. Moreover, when coupled with data on the life history of the fish taxa at SM1, the body size data indicate that, although both juveniles and adults are present in the assemblage, fish of lengths that would be attained by sexually mature adults appear to be far more common.

Clarias gariepinus typically reaches sexual maturity at lengths of ~30-40 cm, although mature females as small as ~20 cm have also been observed (Willoughby and Tweddle, 1978; Golubtsov *et al.,* 2002). If 35 cm (*i.e.,* a point in the middle of the higher end of that range) is taken as the cutoff for sexual maturity, the data in Figure 6.4 still suggest that more than half of the *Clarias* individuals are likely to have been adults. The complete absence of *Clarias* in the two smallest classes indicates that even the subadult individuals are unlikely to have been very small juveniles, given that juvenile fish would likely be under 20 cm for the first year of life and would certainly not be expected to attain lengths of 30 cm (Holl, 1968; Willoughby and Tweddle, 1978). Additionally, although they can reach maximum lengths of up to ~150 cm, the *Clarias* individual with an estimated TL of 82 cm would likely be at the higher end of the body size range in most populations and would have been a relatively large fish (Golubtsov *et al.*, 2002).

Many of the *Bagrus* specimens also appear to have been fairly sizeable adults (Figure 6.4). *B. docmak* reaches maturity by at least 40 cm, although it is not uncommon to find mature individuals of ~20-25 cm (Rinne and Wanjala, 1983). Further, body size for

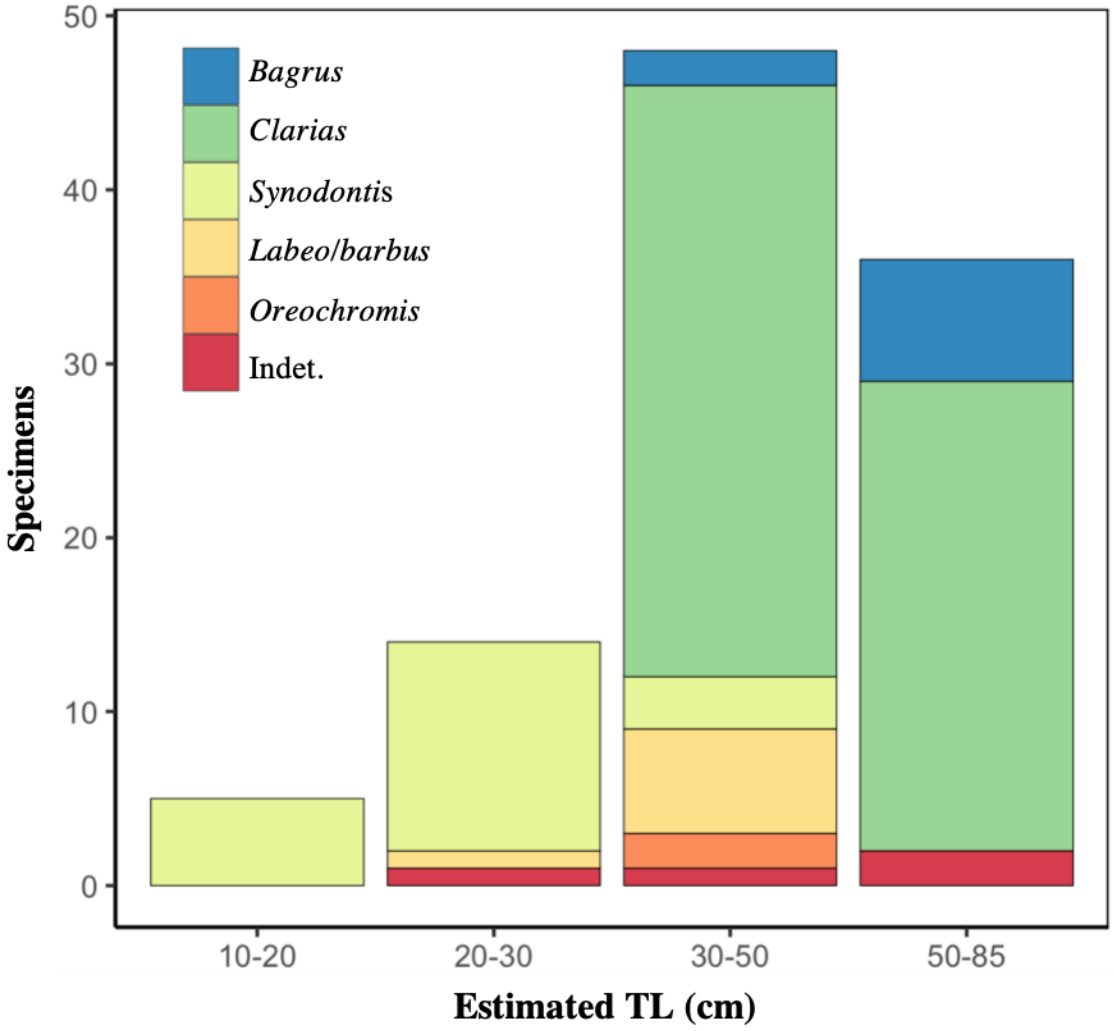

Figure 6.4 Estimated total length (TL) of fish from SM1 by size class (Stewart, 1989).

this taxon typically tops out at around ~90-110 cm, meaning that the two specimens with TL estimates of ~60-75 cm may have been some of the larger individuals in the river (Golubtsov *et al.,* 2002). Once again, there are no *Bagrus* specimens estimated to have been less than 30 cm in TL, which suggests that there are few if any juveniles present at SM1. The *Synodontis* specimens are much smaller on average than those of both *Clarias* and *Bagrus*, which is not surprising, given that adults of this genus typically measure

between ~20-35 cm, with a mean of ~21 cm at maturity and a maximum size of ~50-60 cm (Golubtsov *et al.,* 2002; Laleye *et al.,* 2006; Prendergast *et al.,* 2017). Thus, as with *Clarias* and *Bagrus,* the majority of the *Synodontis* specimens appear to have been adults **(**Golubtsov *et al.,* 2002), although several fish in the smallest size category (< 10 cm) does indicate the presence of some juveniles in the *Synodontis* sample (Figure 6.4).

Much of the *Labeo* and *Labeobarbus* material is also probably from fairly sizeable adult fish (Figure 6.4). Both *Labeo niloticus* and *Labeobarbus bynni* mature at lengths of ~20-30 cm and are recorded to reach maximum lengths of ~60-80 cm in some parts of east Africa **(**Kolding, 1989; Golubtsov *et al.,* 2002). Thus, once again, the cyprinid specimen with an estimated TL of ~50 cm was likely not only fairly large overall but may also have been one of the larger fish of its kind in the river at that time. There are only two *Oreochromis* specimens, both of which have estimated TL values of 41 cm, suggesting somewhat smaller fish which were nonetheless nearly half a meter in length and much larger than the average length of ~19 cm at maturity (Prendergast and Beyin*,* 2017).

The body size data indicate a relatively large range of variation in terms of both TL and BM for the fossil fish from SM1. However, most individuals are of sizes near the middle or higher end of the range for TL (Figure 6.3). The opposite appears to be true of the BM data, with most of the individuals weighing ~1 kg, even though the largest individuals weigh ~4-4.5 kg (Figure 6.4). These data indicate that the SM1 assemblage is largely composed of sexually mature adult fish. As already noted, it is probable that taphonomic filters have destroyed many of the smallest and least robust fish bones that once existed at the site. However, the presence of bones belonging to very small individuals from several taxa indicates that the predominance of medium- and, to a lesser extent, large-sized sized fish is not entirely due to taphonomic bias against smaller, more delicate bones (Table 6.7 and Appendix I) (Prendergast and Beyin, 2017). Assuming the fish are human-

collected (see below), the focus on medium-to-large-sized individuals could suggest that MSA fishing practices were selective and preferentially targeted individuals that were relatively easy to catch and could supply a generous amount of meat to the diet. Locals in the region today regularly consume fingerling fish whole (Tewabe, 2008; Kappelman *et al.,* 2014), so human collection may actually also help explain the relative lack of very small fish at SM1.

BONE SCATTER FREQUENCY

As discussed in Chapter 3, the bone scatter frequency (BSF) of fish remains can vary widely between natural and human-produced sites, so BSF alone is not necessarily sufficient to distinguish between the two cases (Gifford-Gonzalez *et al.,* 1999; Zohar, 2003; Zohar *et al.,* 2008). However, combined with other lines of evidence, a relatively high BSF (*i.e.,* 1+) can provide additional support for human agency in accumulating fossil fish, whereas a very low BSF (*i.e.,* <.1) is more likely to indicate a naturally-accumulated assemblage (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994; Gifford-Gonzalez *et al.,* 1999).

Data for both the raw BSF (*i.e.,* the total number of fish bones per m^2) and BSF standardized by the depth of fish-bearing sediments (sBSF: BSF/total depth in cm) for all m^2 units in the main excavation area at SM1 are presented in Table 6.8. The raw BSF values have a broad range of 2-225 bones/m^2, but are generally high across the board, with an average of 66.5 fish bones/m^2 for the entire main excavation area. The sBSF values are obviously quite a bit lower, ranging between 0.2-5.9 bones/m^2 (Table 6.8). Nonetheless, approximately 80% of units have sBSF values of 1+, while 30% have a sBSF of 2-6 bones/m^2. Similarly, none of the sBSF values are as low as the BSF values reported by Stewart (1989, 1991) for natural fish bone accumulations around Lake Turkana, and the

average sBSF for the entire main excavation area and all three excavation blocks are much higher than these natural assemblages (Table 6.8 and Figure 6.5).

Table 6.8 Fish bone scatter frequency (BSF) and standardized bone scatter frequency (sBSF) for all m^2 units in the main excavation area at SM1.

Sq. meter	Depth (cm)	BSF[1]	sBSF[2]	Sq. meter	Depth (cm)	BSF[1]	sBSF[2]
W14-3	27.8	26	0.9	W15-13	25.7	36	1.4
W14-4	28.1	36	1.3	W15-18	47.3	62	1.3
W14-5	31.5	31	1.0	W15-19	34.8	22	0.6
W14-6	33.4	78	2.3	W15-20	38.9	77	2.0
W14-7	36.1	45	1.2	W15-21	44.7	102	2.3
W14-8	32.5	24	0.7	W15-22	63	121	1.9
W14-13	38.8	58	1.5	W15-23	58.2	42	0.7
W14-14	44.1	20	0.5	X15-1	57.1	98	1.7
W14-15	36.4	63	1.7	X15-2	59.7	61	1.0
W14-16	41.5	77	1.9	X15-3	35.4	67	1.9
W14-17	23.3	30	1.3	X15-8	38.8	28	0.7
W14-18	42	39	0.9	X15-9	56	90	1.6
W14-23	26.5	10	0.4	X15-10	36.4	94	2.6
W14-24	33.3	28	0.8	X15-11	41.6	88	2.1
W14-25	57.3	173	3.0	X15-12	31.8	94	3.0
W15-1	32.1	191	6.0	X15-13	33.2	82	2.5
W15-2	19.2	66	3.4	X15-18	36.3	104	2.9
W15-3	40.2	69	1.7	X15-19	42.7	225	5.3
W15-8	27.4	31	1.1	X15-20	53.5	86	1.6
W15-9	35.2	57	1.6	X15-21	8.8	2	0.2
W15-10	29.4	56	1.9	X15-22	31	103	3.3
W15-11	29.7	33	1.1	X15-23	16.7	41	2.5
W15-12	22.1	26	1.2	**Mean**	**-**	**66.5**	**1.8**

[1]BSF = total # fish bones/m^2 *(i.e.,* raw sample size)

[2] sBSF = BSF standardized by the total depth of the fish-bearing portion of the m^2

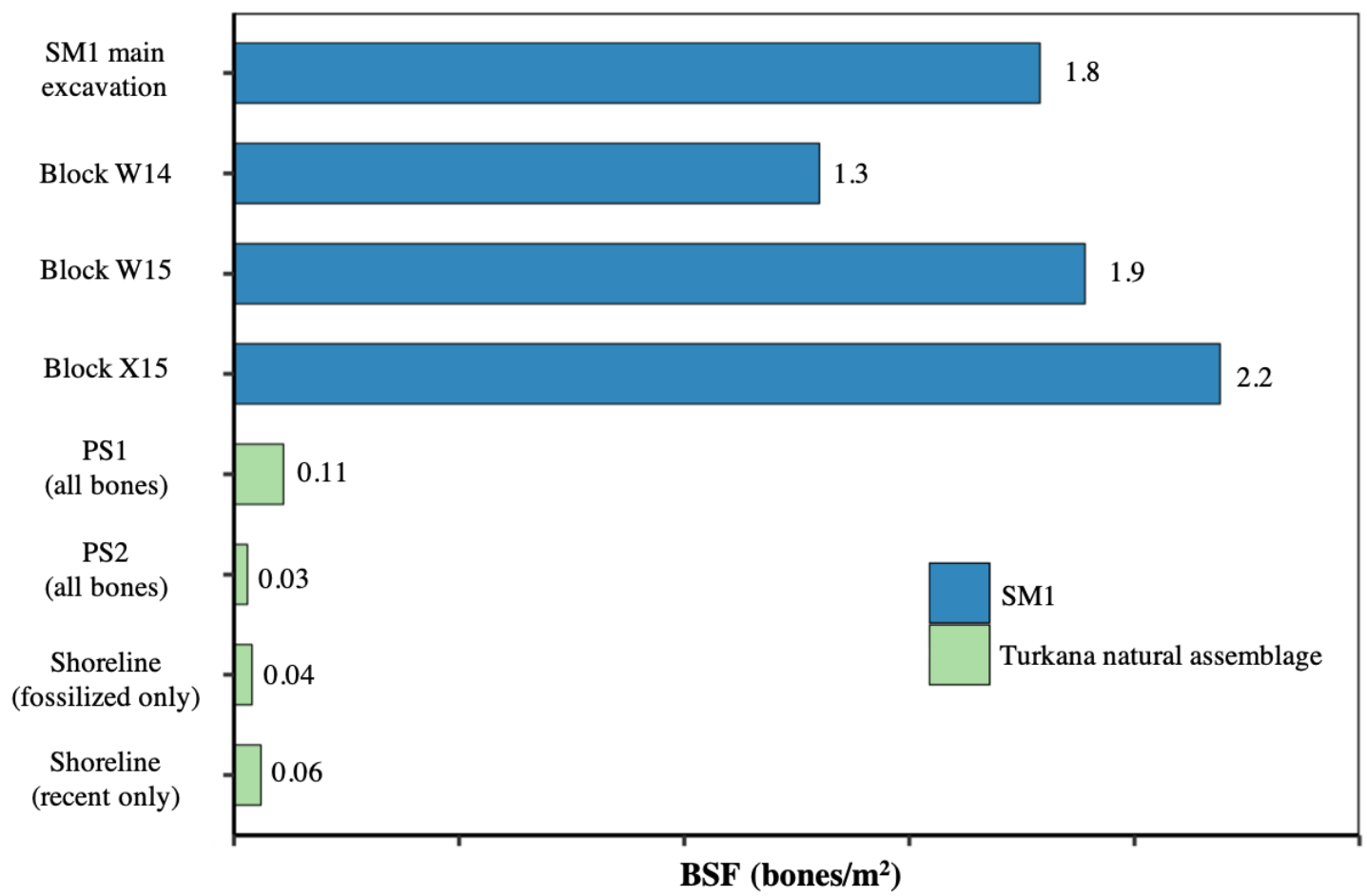

Figure 6.5 Fish bone scatter frequency (BSF) for SM1 and natural assemblages around Lake Turkana collected by Stewart (1989, 1991). Values for SM1 are the averages of sBSF (BSF standardized by sediment volume) for the entire main excavation area and each excavation block. The Lake Turkana sites are surface-collected natural bone scatters reported in Stewart (1989, 1991).

Data on the BSF and sBSF for each of the four analytical units are presented in Table 6.9. There are multiple m^2 within each analytical unit, so the BSF here is simply the total number of fish bones in the unit divided by the total number of m^2 within it that contain fish bones. Likewise, the sBSF values in this case are standardized by both the area and the depth (*i.e.,* the volume) of sediment within the analytical unit. The units tend to slope to the south and often fluctuate widely in depth across their horizontal extent, so using the total depth would likely significantly overestimate the volume of sediment within each unit. As such, the average depth across the entire analytical unit, calculated as the maximum depth of each m^2 divided by the total number of m^2 in the unit, was used to standardize the BSF by volume instead of the total depth of the entire analytical unit.

Once again, the raw BSF values are quite high across the board, with a range of 16.7-50.4 bones/m^2, and an average of 33.5 bones/m^2. The sBSF values are much smaller and range between 1.4-2.6 bones/m^2, with an average of 2.0 bones/m^2. BSF and sBSF are highest in MSA-1 and lowest in MSA-4, and generally speaking there seems to be a decline in the density of fish bone moving from unit-to-unit deeper into the sediment column, although the differences between MSA-2 and MSA-3 are small and MSA-3 actually has a slightly higher sBSF than MSA-2. Nonetheless, all of the sBSF values are at least an order of magnitude higher than those from the natural assemblages around Lake Turkana (Table 6.9 and Figure 6.5).

Table 6.9 Fish bone scatter frequency for each analytical unit at SM1.

AU	n	Sq. meters	Depth (cm)	BSF[1]	sBSF[2]
MSA-1	705	14	19.6	50.4	2.6
MSA-2	985	28	20.2	35.2	1.7
MSA-3	919	29	16.1	31.7	2.0
MSA-4	318	19	12.2	16.7	1.4

[1]BSF = total # of fish bones/total # of m^2

[2]sBSF = total # of fish bones/(total # m^2 * mean m^2 depth for AU)

TAPHONOMY OF THE FOSSIL FISH

The same agents that can bias analyses of terrestrial fauna are also of interest for the fish from SM1. The following section will explore many of the same taphonomic attributes that were investigated for the terrestrial fauna in Chapter 5. As discussed in Chapter 3, in many cases the criteria and methods used to assess the various taphonomic attributes of interest have been modified in order to make them specifically applicable to fish bones. Similar to the previous chapter, analyses of fish bone surface preservation and modification typically exclude specimens not recovered *in-situ* and/or those that were too small (*i.e.,* < 10 mm) to reliably assess these features. The fish from the Kibish Formation are used for comparison with a natural assemblage in several cases. Taphonomic data for the Kibish Formation fish can be found in the tables in Appendix J.

Bone deposition and surface preservation

The fossil fish bones from SM1 preserve a range of colors (Figure 6.6). A large majority of bones are dark (49.5%) or medium (24.6%) brown, while gray (6.4%), light brown (5.9%) and black (5.0%) are also relatively common. The remaining colors, including white (3.6%), gray-brown (3.5%), beige (0.8%), and orange/red-mottled brown (0.7%), represent > 10% of the total assemblage combined. Some of the gray and white bones are actually calcined, meaning that their light coloration is not necessarily due to staining caused by natural depositional and/or preservational conditions. The fact that ~85% of bones are varying shades of black or brown, and ~75% of them are medium or dark brown, indicates that the majority of specimens were deposited and preserved under similar conditions (Stewart, 1989).

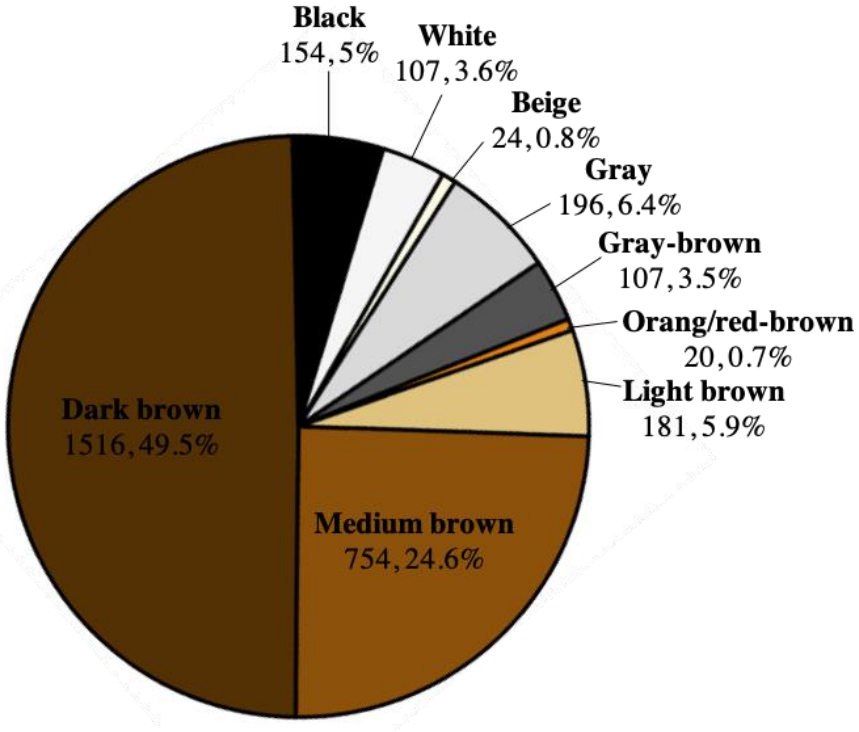

Figure 6.6 Specimen counts and relative frequencies of each color category for fossil fish bones from SM1.

The fish from the Kibish Formation also come in a range of colors, with variations of brown being the most common (Figure 6.7) In this case, dark brown is once again the most common color, but it is not as predominant as at SM1, and medium and light brown are also much less common. Additionally, gray-brown, orange/red-mottled brown, and black are much more common in the Kibish Formation assemblage than at SM1. The pattern of fish bone coloration for the Kibish Formation collection also appears to be less uniform overall, suggesting that these fish were deposited and preserved under a more varied set of conditions than the fish from SM1 (Figures 6.6 and 6.7).

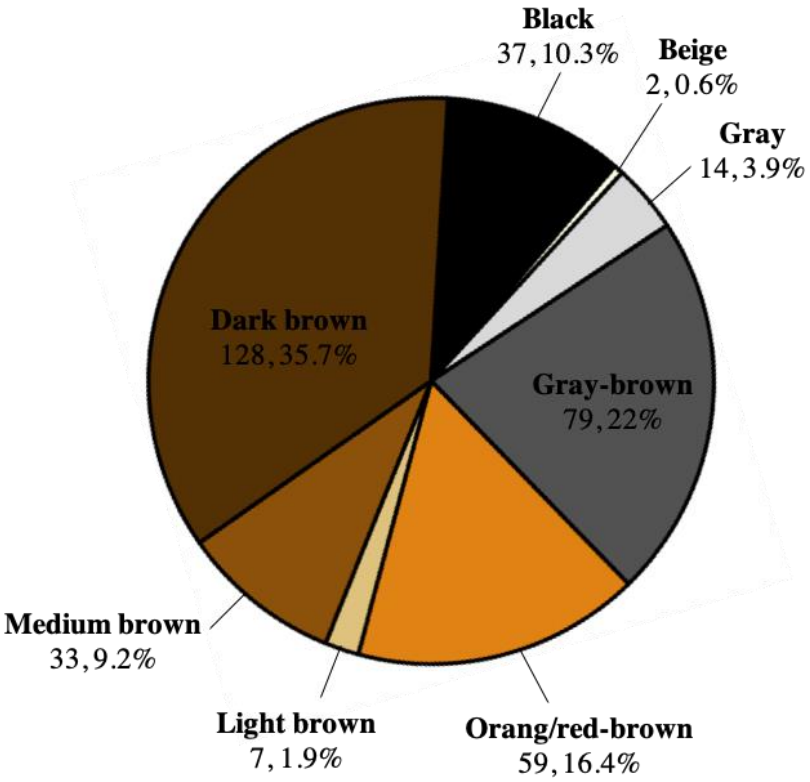

Figure 6.7 Specimen counts and relative frequencies of each color category for fossil fish bones from the Kibish Formation.

As with the terrestrial fauna, overall bone surface visibility and preservation is good for the fossil fish from SM1 (Table 6.10). Most (90-100%) of the preserved bone surface is visible for over 80% of the sample, while over 90% of specimens have at least half their surface visible. Specimens with severely limited (≤ 20%) surface visibility represent a very small portion of the assemblage (Table 6.10). Just under 49% of bones were classified as weathering stage 0 (48.5%), indicating bone that essentially looks fresh and undamaged, while another 40.6% are in weathering stage 1, with cracking, friability, crumbling, and/or other damage confined to less than half the observable surface (Table 6.11 and Figure 6.8). The majority of remaining specimens (8.9%) were in stage 2, while very few bones (2%) were classified as stage 3, the most severe category of weathering damage.

Table 6.10 Bone surface visibility for fish from SM1.

Surface visible	n	% specimens
10-20%	88	3.5
30-40%	79	3.2
50-60%	96	3.9
70-80%	151	6.1
90-100%	2068	83.3

Table 6.11 Frequencies of weathering and specimens from SM1 with post-depositional (PD) damage.

Weathering category	n	%
0	582	48.5
1	487	40.6
2	107	8.9
3	24	2.0
Post-depositional damage		
Dendritic etching	3	0.3
Pocking	35	2.9
Exfoliation	206	16.8
Erosion	114	9.3
Sheen	220	18.0
Smoothing	7	0.6

Dendritic etching, pocking, and smoothing were all observed on < 3% of relevant specimens; erosion is somewhat more common, but still limited to < 10% of fish bones (Table 6.11 and Figure 6.9). Exfoliation and sheen are the most common types of post-depositional damage, and were observed on ~17% and 18% of specimens, respectively. Yet, in both cases, most specimens were coded as a 1 for both the extent (exfoliation = 96%; sheen = 77%) and severity (exfoliation = 97%; sheen = 81%) of the damage, meaning that the damage was localized and of modest severity, at best, for the majority of the bones.

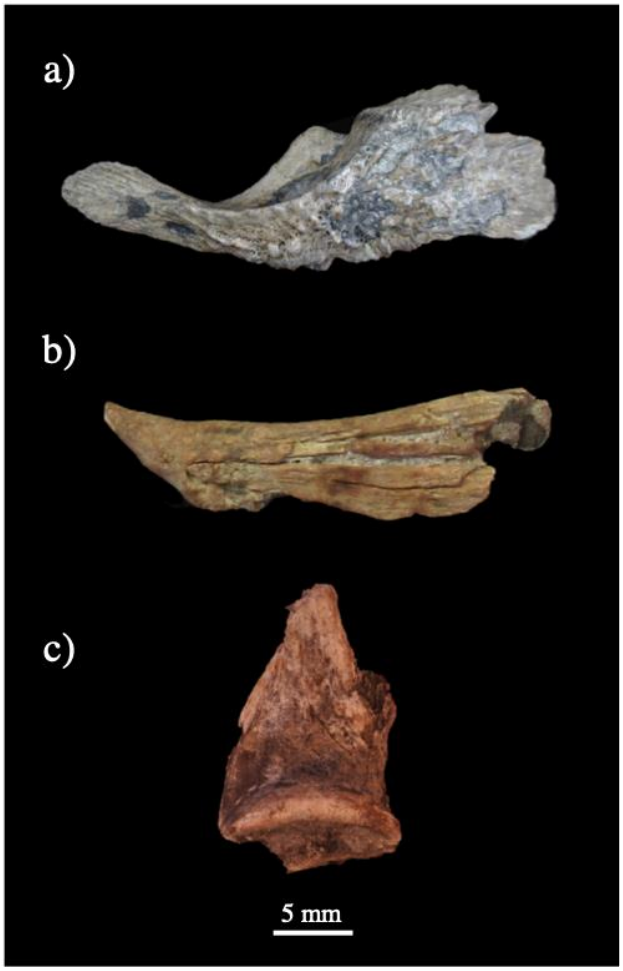

Figure 6.8 Weathering stages on fossil fish bones from SM1. a) Unweathered *Clarias* interorbital (stage 0; W14-16-160). b) Lightly weathered *Clarias* ceratohyal (stage 1; W14-25-483). c) Heavily weathered *Bagrus* pectoral spine base (stage 3; W14-13-68).

There are also only a handful of specimens where sheen and smoothing were observed to overlap, which might be expected if, for example, the damage was caused by fluvial transport of the bones (Stewart, 1989; Thompson, 2006). The idea that most bones were not fluvially transported into the site is also supported by the lack of smoothed specimens overall (Table 6.11). Finally, most bones displayed the effects of only one of the categories in this variable, so there is not a lot of overlap between specimens bearing different types

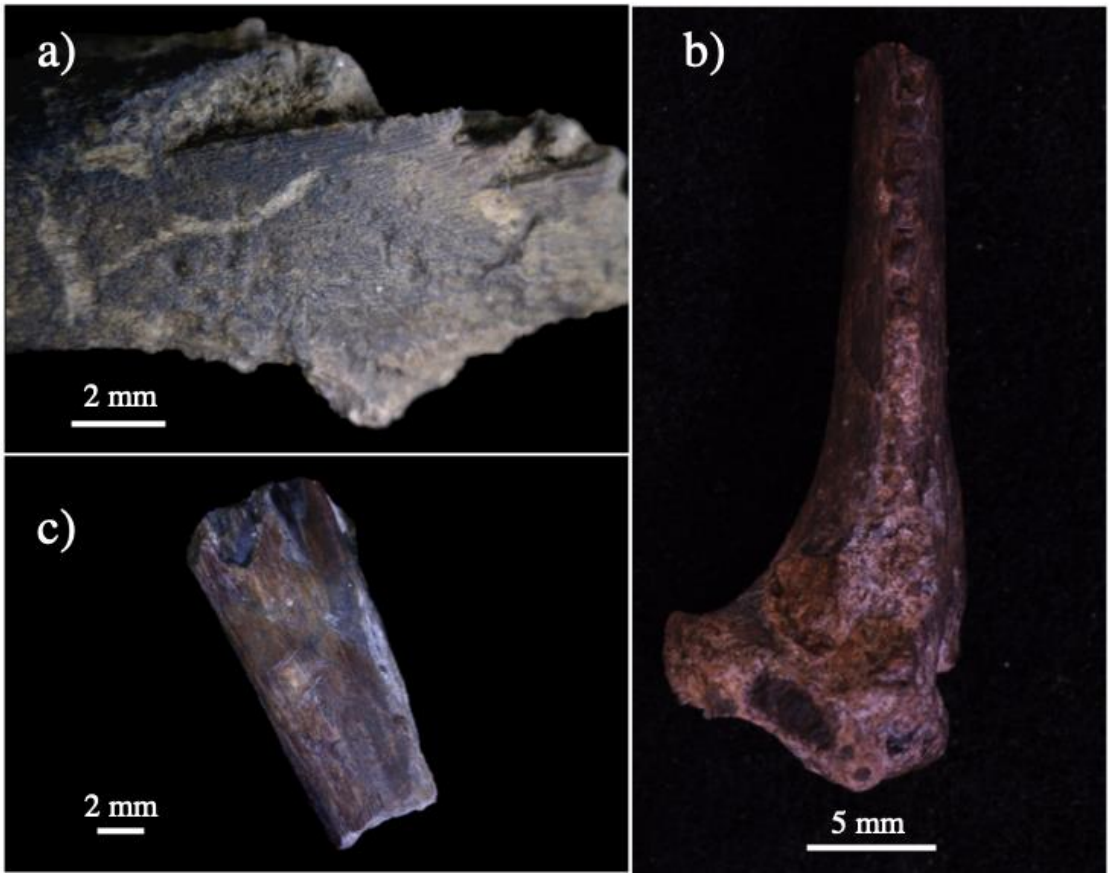

Figure 6.9 Fish specimens from SM1 with post-depositional damage. a) *Clarias* parasphenoid with pocking (W15-3-75). b) *Clarias* pectoral spine with exfoliation along the shaft and erosion around the edges of the base (W15-1-148a). Fish cleithrum fragment with sheen (X15-23-127).

of post-depositional damage. Thus, although no single category of damage occurs on more than 18% of bones, ~40% of specimens do display some type of post-depositional damage. As already discussed, in the majority of cases the damage was very limited in both its extent and severity.

Chi-squared tests of independence indicate significant differences between the fish from SM1 and the Kibish Formation for the frequencies of both weathering and post-depositional damage (Table 6.12). There are proportionally more weathered bones among the fish from SM1 than for the naturally-accumulated fish from the Kibish Formation. By

Table 6.12 Chi-squared tests of independence between SM1 and Kibish Formation for weathering and post-depositional processes.

Attribute	χ^2	p-value
Weathering	4.62	0.03*
Post-depositional processes	39.74	< 0.01*
*p-value significant at $\alpha = 0.05$		

contrast, however, the Kibish Formation sample has significantly higher frequencies of post-depositional damage than were observed at SM1. In fact, specimens displaying post-depositional damage are ~1.5 times more common in the Kibish sample than they are at SM1, and the two most common types of damage (exfoliation and sheen) were both observed on ~30% of specimens (Appendix J). The higher instances of weathering at SM1 may actually make more sense if SM1 is human-accumulated, as bones deposited in a natural setting (*i.e.,* underwater) would likely experience less subaerial exposure and be covered by sediment more rapidly than bones deposited on the surface of the ground at an archaeological site. Likewise, the expectation would generally be for less fluvial transport in a human versus natural assemblage, so the fact that sheen and smoothing, both of which are often the result of waterborne transport, are more prevalent in the Kibish Formation fish is generally in line with the idea that the fish from SM1are primarily the result of human behavior.

The relative frequencies of weathered versus unweathered specimens and those with and without post-depositional damage for the four proposed analytical units at SM1 are depicted in Figure 6.10a and b. Chi-squared tests indicate significant differences for the proportions of weathered versus unweathered specimens between MSA-1 and MSA-3, as

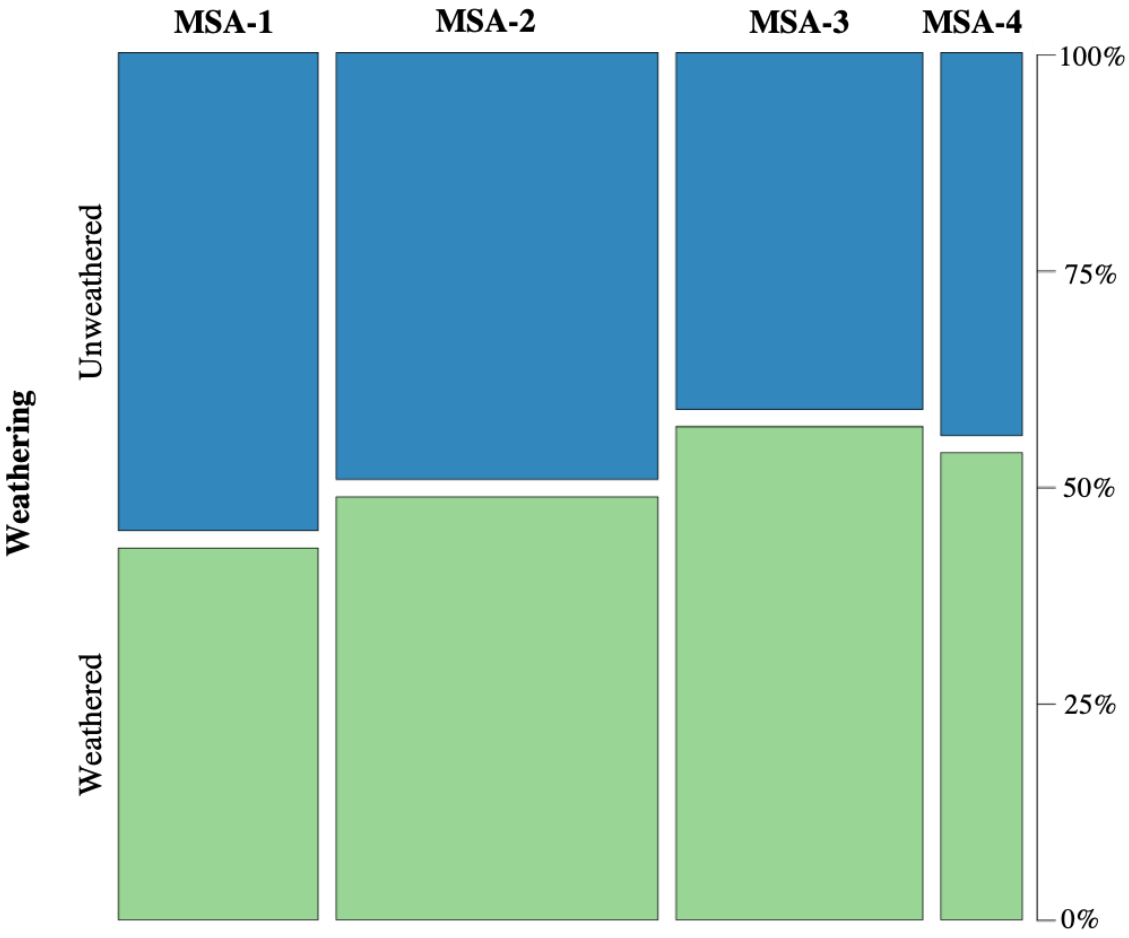

Figure 6.10 a) Frequencies (%) of weathering for the four analytical units at SM1. Bin height scales to the relative percentage within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

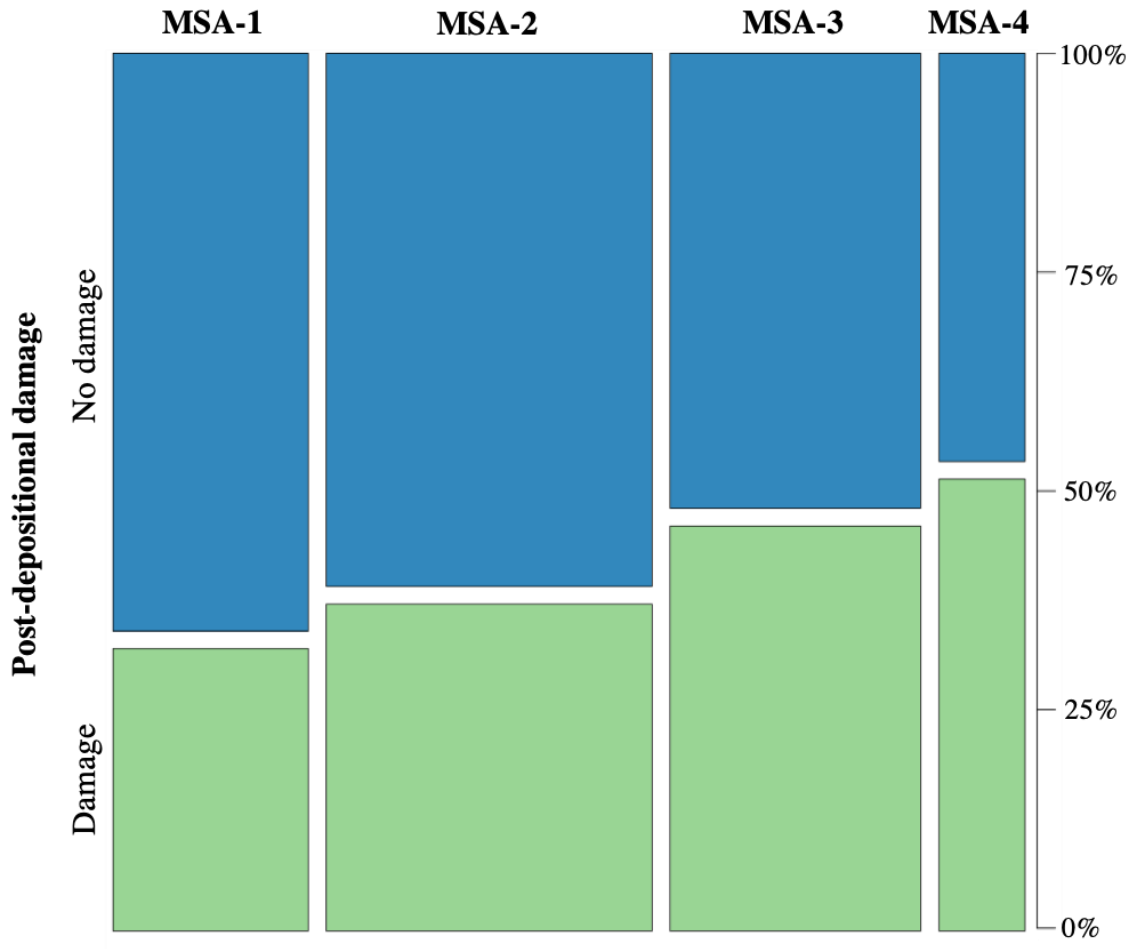

Figure 6.10, cont. b) Frequencies (%) post-depositional damage for the four analytical units at SM1. Bin height scales to the relative percentage within the analytical unit. Bin width scales to the percentage of total specimens (*i.e.,* for all units combined) that occurs in each analytical unit.

Table 6.13 Chi-squared tests of independence between analytical units for weathering and post-depositional processes.

		Weathering		Post-dep. processes	
AU1	**AU2**	χ^2	**p-value**	χ^2	**p-value**
MSA-1	MSA-2	2.2	0.14	1.74	0.19
MSA-1	MSA-3	11.72	< 0.01*	12.09	< 0.01*
MSA-1	MSA-4	3.54	0.06	12.57	< 0.01*
MSA-2	MSA-3	4.89	0.03*	6.19	0.01*
MSA-2	MSA-4	0.76	0.39	7.53	0.01*
MSA-3	MSA-4	0.21	0.65	0.84	0.36
*p-value significant at α = 00.05					

Table 6.14 Partial chi-square tests among analytical for weathering and post-depositional processes.

Weathering	**MSA-1**	**MSA-2**	**MSA-3**	**MSA-4**
Unweathered	(+)*	(+)	(-)*	(-)
Weathered	(-)*	(-)	(+)*	(+)
Post-dep. processes				
No damage	(+)*	(+)	(-)*	(-)*
Damage	(-)*	(-)	(+)*	(+)*
*p-value significant at α = 0.05				

well as MSA-2 and MSA-3 (Table 6.13). Partial chi-squared tests further indicate that in both cases the differences stem in part from a significant over-representation of weathered specimens, and under-representation of unweathered ones, in MSA-3 (Table 6.14). Additionally, MSA-1 has substantially more unweathered specimens than expected, which is also contributing to the significant result in Table 6.13. In terms of the six other types of post-depositional damage, both MSA-3 and MSA-4 are significantly different from MSA-1 and MSA-2, while the two other comparisons indicate non-significant differences (Table 6.13). As with weathering, these results arise from the fact that damaged specimens are

significantly overabundant in both MSA-3 and MSA-4, while undamaged ones are over-represented in MSA-1 and MSA-2, and significantly so in the former (Table 6.14).

These data generally suggest that surface preservation is better in MSA-1 and MSA-2, and that specimens in MSA-3 and MSA-4 may have spent more time exposed on the surface and/or been more subject to the various processes that produce exfoliation, pocking, erosion, smoothing, sheen, and etching. Additionally, MSA-3 and MSA-4 are deeper and older than MSA-1 and MSA-2, so somewhat poorer preservation in these two lower-most units may result from the material within them having spent a longer period of time within the sediment column. Yet, in the case of weathering stages, a closer look at the data reveals that for ~75% of the weathered specimens in MSA-3 and MSA-4 the weathering is localized and not severe. It is also important to remember that analyses for the site as a whole suggest good surface preservation overall, and categories indicating minimal weathering, post-depositional damage (*i.e.,* codes 0 and 1), and surface exposure far outnumber those indicating severe damage (*i.e.,* stages 2+) in all analytical units. Thus, the fact that specimens with these attributes are overabundant in MSA-3 and MSA-4 *relative* to MSA-1 and MSA-2, does not necessarily mean that preservation is exceptionally poor in MSA-3 and MSA-4 overall (and this does not, in fact, appear to be the case).

Thermal alteration

Of the 1615 fish specimens that were either clearly unburned or calcined, 22.4% were locally-to-fully calcined, while the other 77.6% of bones showed no signs of burning damage (Figure 6.11 and Table 6.15). When the 1306 specimens coded as “indeterminate”, based on very dark brown or black coloration that could not be confidently identified as carbonization rather than oxide-staining, are included, the frequency of clearly unburned

Table 6.15 Frequencies of burned fish bone at SM1.

Burn category	n	% Specimens[1]	% Total[2]
Unburned	1253	77.6	42.9
Localized calcination	175	10.8	6
Moderate calcination	126	7.8	4.3
Full calcination	61	3.8	2.1
Burning indet.	1306	-	44.7

[1]Out of 1615 specimens coded as unburned or calcined

[2]Out of 2921 specimens coded as unburned, calcined, or indeterminate

See Chapter 3 for more detail on burn category definitions

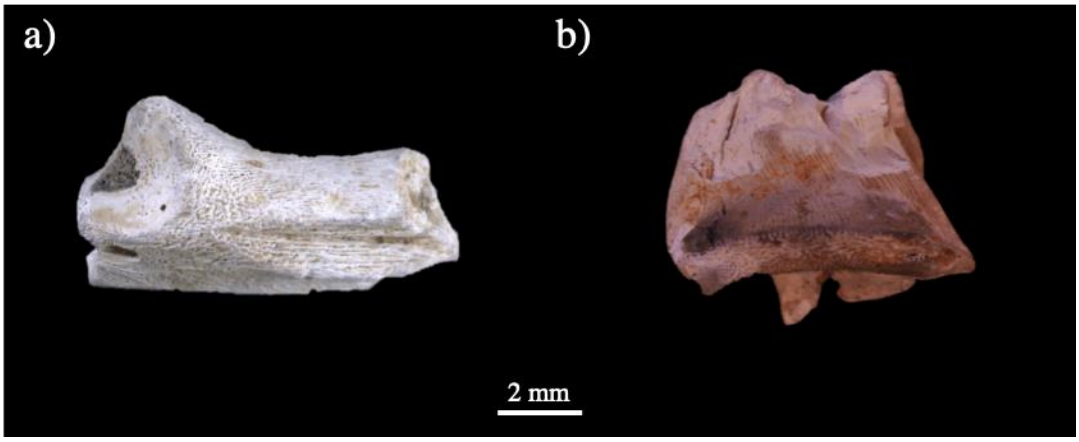

Figure 6.11 Calcined fish bones. a) *Clarias* mandible (angulo-articular) fragment (X15-3-160-1). b) *Synodontis* pectoral spine base (W15-23-153).

specimens is 42.9%, and the frequency of calcined fish bone is 12.4% at SM1. This value is quite similar to that for calcined bone among the terrestrial fauna (~10%), and the absolute number of calcined fish bones (n=362) is actually slightly higher than that for terrestrial fauna (n=341). These values contrast sharply with the naturally-accumulated fish from the Kibish Formation, where ~90% of specimens are unburned, and none were definitively identified as having been burned. Approximately 5% of the Kibish specimens

did display a grayish color for which burning could not be ruled out as a possible cause, but even if all of these specimens were calcined, which is unlikely, the frequency of burned fish bones at SM1 would still be at least twice as high as that of the Kibish Formation fish. Further, given the likelihood that some of the "indeterminate" bones from SM1 are carbonized, this difference may actually be much larger.

Evidence of burning on fish bones is distributed across all of the taxa present at SM1 (Table 6.16). For specimens identified to at least the level of family, chi-squared tests indicate no significant differences in the proportions of unburned versus burned specimens in each fish taxon for the sample as a whole (χ^2 = 2.05, p-value = .84). Within this subsample, *Clarias* accounts for 84.6% of the burned bones, while all the other taxa represent ~5% or less of specimens. When the entire assemblage is considered, over 90% of the burned specimens are from *Clarias* (45.9%), indeterminate fish (31.2%), and indeterminate catfish (14.9%), while all other taxa make up less than 3% of the sample each. Partial chi-squared tests indicate that burned bones are under-represented among *Clarias, Schilbe,* and *Labeo/barbus*, and over-represented for *Bagrus* and *Synodontis*, although in no case are the differences between observed and expected values statistically significant (Table 6.17).

Burning was also observed on bones from all anatomical regions and skeletal structures at SM1 (Table 6.18). Within the burned sample, bones of the neurocranium (34.5%), median fin (25.4%), and specimens that could not be identified to a specific skeletal element (19.6%) are the most common. Vertebrae (13.8%) and oromandibular elements (5%) are also relatively abundant, while elements from all other skeletal structures make up 2.9% of burned specimens combined, and none accounts for more than 0.8% of the total sample alone. Chi-squared tests indicate significant differences in the

Table 6.16 Frequency (NISP) of burned fish bone from SM1 by taxon, anatomical region, and skeletal structure.

Element	*Bagrus*	*Clarias*	*Schilbe*	*Synod.*	Silur.	Cyprin.	*Oreochr.*	Indet.	% Total
Cranial	*3*	*134*	-	-	-	-	-	*12*	***41.2***
Neurocranium	-	122	-	-	-	-	-	3	**34.5**
Oromandibular	2	11	-	-	-	-	-	5	**5**
Hyoid	-	1	-	-	-	-	-	1	**0.6**
Opercular	1	-	-	-	-	-	-	-	**0.3**
Branchial	-	-	-	-	-	-	-	3	**0.8**
Postcranial	*2*	*29*	*3*	*9*	*45*	-	-	*4*	***25.4***
Appendicular	-	1	-	-	-	-	-	1	**0.6**
Median fin	2	28	3	9	45	-	-	3	**24.8**
Vertebral column	*5*	*2*	*1*	-	*9*	*6*	*1*	*26*	***13.8***
Non-ID	-	-	-	-	-	-	-	*71*	***19.6***
%Total	**2.8**	**45.6**	**1.1**	**2.5**	**14.9**	**1.6**	**0.3**	**31.2**	
%NISP[1]	**5.1**	**84.6**	**2.1**	**4.6**	**-**	**3.1**	**0.5**	**-**	

[1]For burned specimens identified to the level of Family or below

Table 6.17 Partial chi-squared tests between fish taxa at SM1 for unburned versus burned bone.

Burning	***Bagrus***	***Clarias***	***Schilbe***	***Synodontis***	**Cyprinidae**
Unburned	(-)	(+)	(+)	(-)	(+)
Burned	(+)	(-)	(-)	(+)	(-)
Auchenoglanis and *Oreochromis* not included due to small sample sizes.					

Table 6.18 Partial chi-squared tests between anatomical regions for unburned versus burned fish bone from SM1.

Burning	**Cranial**	**Postcranial**	**Vertebral**
Unburned	(+)*	(-)*	(-)
Burned	(-)*	(+)*	(+)
*p-value significant at $\alpha = 0.05$			

number of burned versus unburned specimens across the three anatomical regions ($\chi^2 = 27.9$, p-value < 0.01), with burning significantly over-represented for postcrania, and median fin bones specifically, and under-represented for cranial elements, especially among the neurocranium and hyoid bones (Table 6.18).

The results of chi-squared tests for differences in the frequencies of burned versus unburned fish bones in each of the four analytical units are presented in Table 6.19. Most of the units are quite similar overall, although MSA-4 is significantly different from both MSA-2 and MSA-3 for the frequency of burned fish bones. In both cases, this is due to the fact that burned specimens are significantly under-represented in MSA-4. Burned fish bones are also more abundant than expected in both MSA-2 and MSA-3, although not significantly so. Conversely, there are fewer than expected burned fish bones in MSA-1, but once again the difference between observed and expected values is statistically non-significant (Table 6.20).

Table 6.19 Chi-squared tests of independence between analytical units for unburned versus burned fish bone.

AU1	AU2	χ^2	p-value
MSA-1	MSA-2	3.73	0.29
MSA-1	MSA-3	3.6	0.31
MSA-1	MSA-4	5.07	0.17
MSA-2	MSA-3	1.83	0.61
MSA-2	MSA-4	7.89	0.05*
MSA-3	MSA-4	7.96	0.05*
*p-value significant at $\alpha = 0.05$			

Table 6.20 Partial chi-square tests between analytical units for unburned versus burned fish bone.

Burning	MSA-1	MSA-2	MSA-3	MSA-4
Unburned	(+)	(-)	(-)	(+)*
Burned	(-)	(+)	(+)	(-)*
*p-value significant at $\alpha = 0.05$				

Bone fragmentation

Maximum specimen length

Much like the terrestrial fauna, the fossil fish assemblage from SM1 consists largely of small fragments of bone (Figure 6.12). Although there are several bones that are quite large, the vast majority of specimens (90%) are < 20 mm in maximum length (ML), while those > 40 mm make up slightly less than 1% of the total collection. Accordingly, the mean fragment lengths for mapped, water-screened, and surface-collected fish specimens are all < 15 cm. Mean fragment length for mapped material is 13.65 mm, despite this sample containing the largest specimen in the entire faunal collection, a partial (~75% complete)

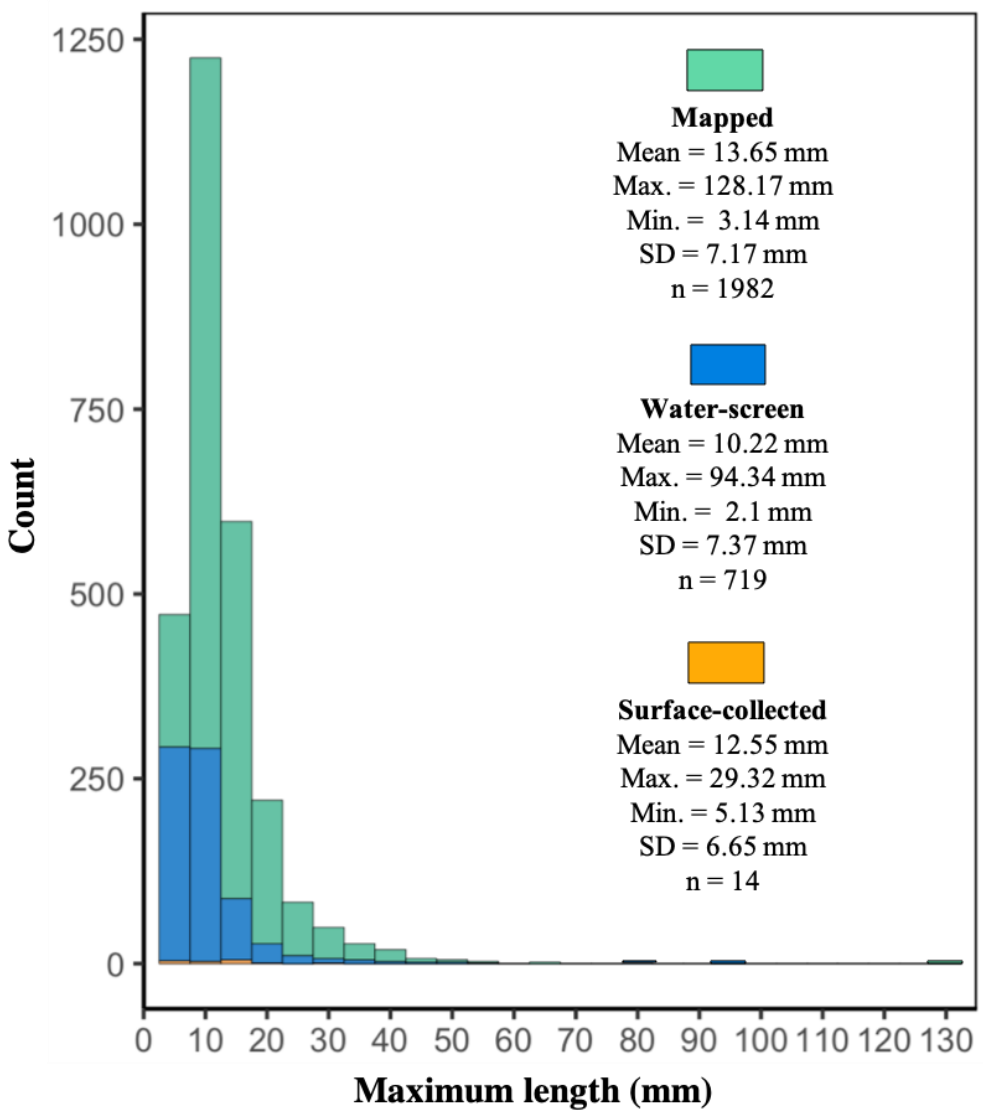

Figure 6.12 Maximum length of fish specimens from SM1 by provenience type.

Clarias neurocranium that measures 128 mm from cranial to caudal end. Unsurprisingly, water-screen specimens are slightly smaller overall, with a mean length of 10.22 mm, but it is worth noting that the two next-largest fish bones, a *Clarias* mandible (in three pieces) and neurocranium fragment (ML = 94.34 mm and 81.89 mm, respectively), are both from

the water-screened material. There are only 16 surface-collected fish bones, which have a mean length of 12.55 mm and a maximum of only ~30 mm (Figure 6.13).

As is clear from Table 6.21, the occurrence of very small fragments is observed for elements from all anatomical regions and skeletal structures. Just under 90% of cranial bones are less than 20 mm in ML, while another ~10% are between 20-40 mm long. As will be discussed in more detail below, the vast majority of the small neurocranial specimens are the non-descript fragments of *Clarias* cranial shield, which average 10.6 mm in length. All but one of the 50+ mm specimens are cranial elements, including several partial *Clarias* neurocrania and mandibles and a single *Bagrus* hyoid. There are no postcranial specimens longer than 40 mm, and 93% of them are < 20 mm in ML. Vertebral centra are not included in Table 6.21, but all of the hypurals measure < 20 mm, as well. Finally, it is probably not surprising that the non-identifiable portion of the assemblage is also dominated by very small fragments, although there are several sizeable specimens among this material, including the only other very large fish bone not mentioned above, which in this case measures between 50-60 mm (Table 6.21).

The ML data from Kibish Formation are quite different, with very few specimens < 10 mm long and the majority of specimens between ~15-55 mm in maximum length (Figure 6.13 and Table 6.22). Mean fragment length for the entire Kibish Formation sample is 41.2 mm, with a minimum of 8.04 mm for a non-identified fish scale and a maximum of 204 mm for a very large *Lates* neurocranium. Nearly 25% of the Kibish specimens are ≥ 50 mm long, and ~8% of them are ≥ 90 mm in maximum length (Figure 6.13 and Table 6.22). It is once again important to bear in mind that the collection strategy for the Kibish material was specifically focused on easily identifiable elements (Trapani, 2008), which almost certainly introduced some level of bias towards larger-sized specimens in this sample. This also means that the data for the Kibish fish are not necessarily representative

of what would be expected for a naturally-accumulated assemblage from the Omo River for which all elements, regardless of size and/or identifiability, were collected. Nonetheless, these data indicate some very clear differences in bone fragmentation between SM1 and the Kibish Formation, at least with respect to overall fragment size.

Table 6.21 Maximum length categories for fish bones from SM1 by skeletal region.

	Maximum length (mm)					
Region/Structure	**0-9.99**	**10-19.99**	**20-29.99**	**30-39.99**	**40-49.99**	**50+**
Cranial	*625*	*694*	*118*	*39*	*15*	*8*
Neurocranium	574	559	78	25	9	4
Oromandibular	31	79	23	6	3	2
Hyoid	3	25	16	8	3	2
Opercular	2	9	1	-	-	-
Branchial	15	22	-	-	-	-
Postcranial	*257*	*214*	*26*	*7*	-	-
Appendicular	16	33	14	6	-	-
Median fin	241	181	12	1	-	-
Vertebral[1]	*1*	*7*	-	-	-	-
Non-ID	*230*	*498*	*52*	*14*	*1*	*1*
Total	**1113**	**1413**	**196**	**60**	**16**	**9**
%	**39.7**	**50.3**	**7**	**2.1**	**0.6**	**0.3**

[1]Hypurals only; vertebral centra not included

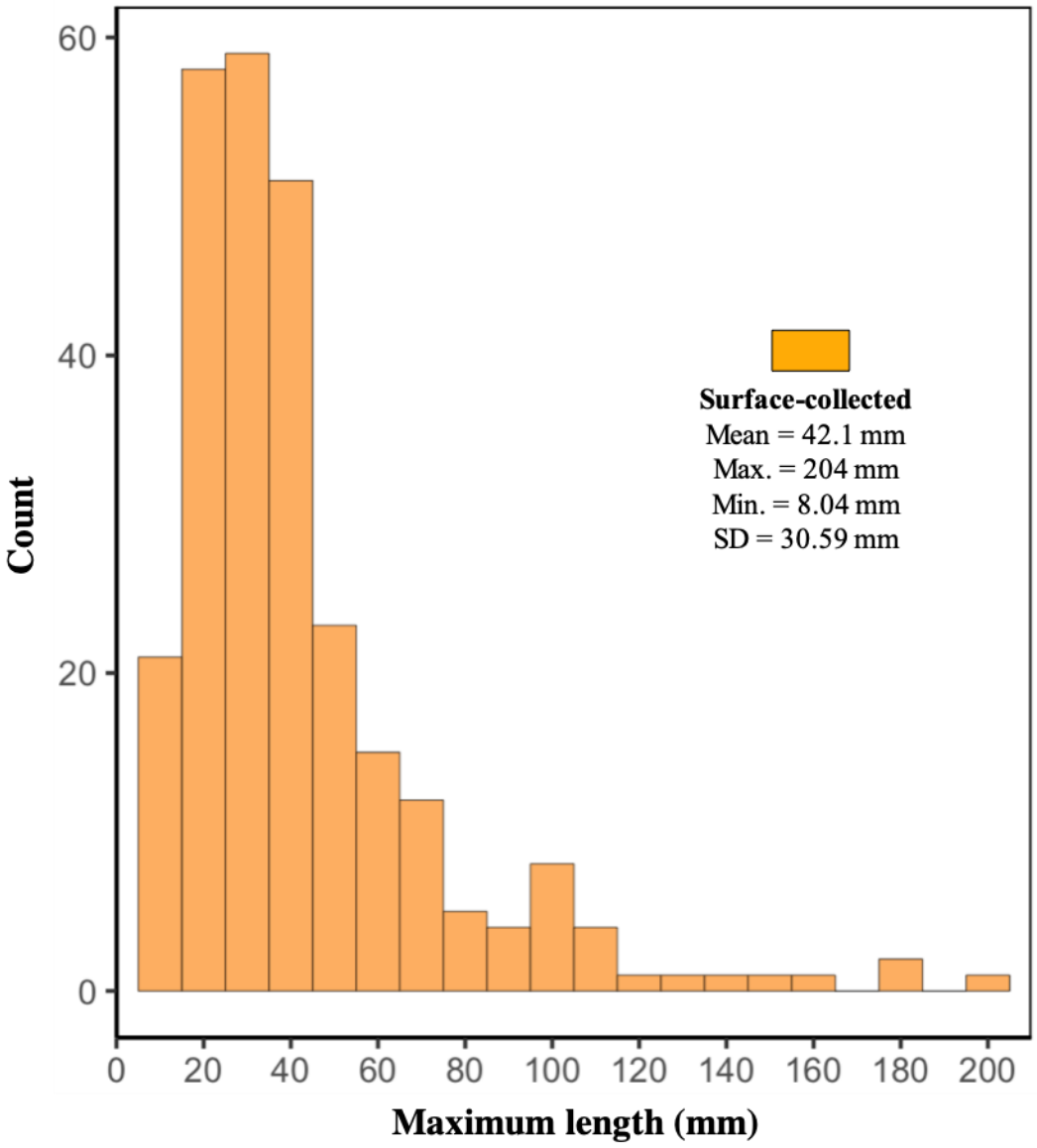

Figure 6.13 Maximum length of fish skeletal specimens from Kibish Formation.

Table 6.22 Maximum length category frequencies for fish from the Kibish Formation.

Max. length (mm)	n	%
0-9.99	3	1.1
10-19.99	52	19.4
20-29.9	58	21.6
30-39.99	52	19.4
40-49.99	37	13.8
50-59.99	20	7.5
60-69.99	10	3.7
70-79.99	11	4.1
80-89.99	4	1.5
90-149.99	17	6.4
150-209.99	4	1.5

The results of chi-squared tests of independence for maximum length categories between the four proposed analytical units at SM1 are presented in Table 6.23. In order to maximize sample sizes, particularly among larger specimens, fragment length categories were aggregated into three groups representing small (0-19.99 mm), medium (20-39.99), and large (40+ mm) fragments. As the results in Table 6.23 document, chi-squared analyses indicate that differences in the frequency of small, medium, and large fragments of fish bone between all of the analytical units are statistically non-significant. This is very similar to the terrestrial fauna, for which there were also no significant differences in fragment length categories among the four analytical units.

Table 6.23 Chi-squared tests of independence between analytical units for maximum fragment length of fish bones.

AU1	AU2	χ^2	p-value
MSA-1	MSA-2	1.97	0.37
MSA-1	MSA-3	4.78	0.09
MSA-1	MSA-4	2.19	0.34
MSA-2	MSA-3	0.93	0.63
MSA-2	MSA-4	1.46	0.48
MSA-3	MSA-4	2.18	0.34

Fragmentation and Survivorship Indices

The preceding section demonstrates that fish bones at SM1 are extensively fragmented. Yet, based on the body size data, there are clearly a number of rather small individuals in the fish assemblage, so it is possible that at least some of the small specimens represent bones that are actually relatively complete. Thus, it is worthwhile to assess fragmentation further using variables specifically meant to measure the actual completeness of the bones (Zohar *et al.,* 2001, 2008). It is also of interest to examine whether or not the apparent over-representation of different taxa and/or elements as discussed in previous sections is potentially due, at least in part, to differential fragmentation and/or post-depositional destruction. In other words, are there differences in the extent of fragmentation between different taxa, anatomical regions, or skeletal structures, which might indicate that NISP counts have been significantly (and artificially) inflated for one group relative to another? Indices of fragmentation (FI) and survivorship (SI) are used to accomplish these tasks for the fish from SM1 (Zohar *et al.,* 2001, 2008; Zohar, 2003). The following analyses employ all fish specimens for which a percentage completeness value (see below) was recorded. In this case, comparisons were not made

with the fish from the Kibish Formation because it is not clear that patterns of fragmentation in this sample are actually representative of the expectations for a natural assemblage (see above). The generic term "skeletal part" is used in the following descriptions because all of the analyses described below can be undertaken for anatomical regions, skeletal structures, and/or individual elements.

As noted in Chapter 3, the FI expresses the percentage of the original bone represented by the recovered fossil. Thus, the FI is essentially the functional equivalent for fish of the "percentage complete" value used to calculate the CI for compact bones in Chapter 5. Values for specimen completeness were recorded in 10% increments and the FI is expressed as one of three categories that represent slight (specimen 80-100% complete), moderate (specimen 40-70% complete), and heavy (specimen 10-30% complete) bone fragmentation. Additionally, FI was standardized using a weighted mean index (WMI) of fragmentation based on the NISP for all 10 completeness categories (Zohar *et al.,* 2001; Zohar, 2003). The WMI is calculated as: $WMI = \Sigma(W_i * x_i)/100$, where W_i is the value of the completeness category (*i.e.,* 10-100, in increments of 10) and x_i is the percentage of NISP in the category for the taxon and skeletal part in question (Zohar *et al.,* 2001). For example, in the SM1 assemblage, NISP = 13 postcranial bones that could only be identified as generic fish, with five (38.5%) that are 10% complete, five (38.5%) in the 20% category, and three (23.1%) in the 30% category. The calculation for WMI is therefore: ((38.5*10) + (38.5*20) + (23.1*30))/100, and the resulting value of 18.5 represents the mean percentage completeness (weighted by the NISP in each completeness category) for the total sample of postcranial bones from fish not identified to a particular taxonomic group.

The survivorship index (SI) represents the number of observed versus expected bones for a particular skeletal part and taxon (Zohar *et al.,* 2001, 2008), and is calculated as: $x^{obs} / (x^{exp} * x^{total})$, where x^{obs} is the NISP for the skeletal part, x^{total} is the total NISP for

the taxon, and x^{exp} is the expected value for the skeletal part, based on the number of bones that comprise the part and the total number of bones in a complete skeleton (*i.e.,* x^{exp} = # of bones in skeletal part/total # of bones in skeleton). For example, following the classification system used here, there are a total of 175 bones in the complete skeleton of *Clarias,* and 63 bones that comprise the vertebral column. At SM1, NISP = 18 for *Clarias* vertebrae and 415 for *Clarias* overall, so the SI for *Clarias* vertebrae is: 18/((63/175)*415) = 0.12. (There are 25 *Clarias* specimens not included in the sample, so NISP = 415 instead of 440 to match the sample used to create WMI values). The resulting value expresses the ratio of observed to expected *Clarias* vertebrae at SM1, based on the total number of *Clarias* bones recovered from the site. Accordingly, values < 1 indicate that the skeletal part is under-represented at the site, while values > 1 document an over-representation (Zohar *et al.,* 2001, 2008). In the example just given, the SI of 0.12 suggests that *Clarias* vertebrae are much less common than expected at SM1.

Finally, WMI, SI, and MNI can be used in combination to assess the relationships between fragmentation and survivorship, and to determine the potential for a high amount of natural post-depositional destruction in the fish assemblage (Zohar *et al.,* 2001, 2008). As just noted, skeletal parts with SI > 1 are over-represented relative to the NISP for a given taxonomic group. If a part with a high SI also has a low WMI (*i.e.,* < ~50), its high frequency in the collection may result more from extensive fragmentation than it does from an actual overabundance of the part itself (Zohar *et al.,* 2001). In other words, as SI (*i.e.,* skeletal part abundance) increases and WMI (*i.e.,* skeletal part completeness) decreases, the possibility of different fragments from the same part being counted twice and artificially inflating NISP for that skeletal part also increases (Zohar, 2003). Similarly, if there is a strong negative correlation between SI and WMI for the assemblage as a whole, it would suggest this problem may be pervasive throughout the entire collection.

Assuming a negative correlation between WMI and SI, this issue can be explored further by examining the relationship between WMI and MNI, because MNI counts should be less sensitive to double-counting than the NISP data on which the SI is based. If over-representation is due mostly to extensive fragmentation, the expectation here is that WMI and MNI should be correlated, and skeletal parts with low WMI (*i.e.,* low completeness or high fragmentation) should also have low MNI values. This would indicate that, for a given high-frequency skeletal part, the possibility that NISP is inflated by double-counting (*i.e.,* interdependence) cannot be ruled out, because it cannot be shown that many of the fragments are actually from different skeletal parts and individuals (Zohar *et al,* 2001; Zohar, 2003). Conversely, the implication for skeletal parts with low WMI values and relatively high MNI counts is that, despite extensive fragmentation, there are in fact numerous unique occurrences of the skeletal part within the site; or, put another way, the over-representation of the part is real and not due to artificial inflation of NISP counts. These analyses may also bear on questions of the faunal accumulator because a close correlation between skeletal part abundance and fragmentation better fits the expectations for natural (*i.e.,* non-selective) post-depositional destruction and, in turn, a naturally-accumulated collection of fish bones (Zohar *et al,* 2001).

The FI values for the eight skeletal structures comprising the cranial, postcranial, and vertebral regions of the fish skeleton are depicted in Figure 6.14. For all but two of the skeletal structures in each region, over 50% of bones are heavily fragmented (*i.e.,* mostly incomplete), meaning that only 10-30% of the original bone was recovered. The two exceptions are the hyoid and vertebrae, for which only 47.6% and 40.8% of specimens, respectively, are heavily fragmented. Fragmentation is particularly extensive among the opercular series, bones of the median fin, and appendicular elements. Over 90% of specimens from all three of these structures are heavily fragmented, and none of them have

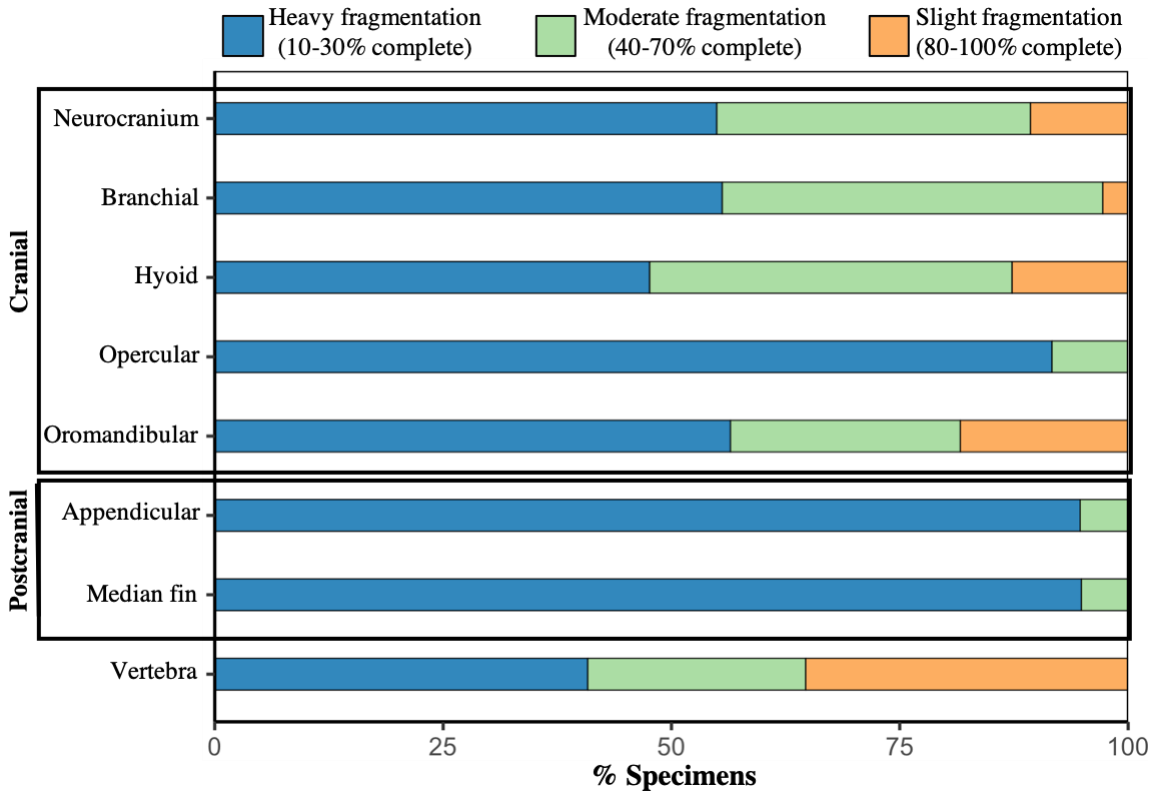

Figure 6.14 Frequency (%) of fragmentation index (FI) categories of fish from SM1 by anatomical region and skeletal structure. Does not include generic headplate fragments.

any specimens in the slightly fragmented category. The high degree of fragmentation is not necessarily surprising for opercula, which are typically fairly thin and delicate relative to other elements, except perhaps for the small portion of the bone comprising the articular surface for the hyomandibular. Extensive fragmentation of bones in the median fin group, which here consists almost entirely of catfish pectoral spines (fin rays and fragments were not coded for completeness in most cases), is more surprising, because catfish spines are typically relatively dense and quite durable. There are also very few lightly fragmented, or mostly complete, branchial elements (*i.e.,* branchiostegals, because no other branchial

elements were recovered), although in this case the percentage of moderately fragmented specimens is much higher, and the percentage of heavily fragmented ones much lower, than for opercula, median fin, and appendicular elements.

Between ~35-40% of bones from the neurocranium and hyoid region are moderately fragmented, and these regions also have fairly high proportions (~11-13%) of bones that are only slightly fragmented, at least compared to branchial, opercular, appendicular, and fin elements. There are relatively fewer oromandibular and vertebral elements in the moderately fragmented category, and these groups also have the highest frequencies of lightly fragmented specimens. For the vertebral column, ~60% of bones are only moderately (23.9%) or slightly (35.3%) fragmented, making vertebrae the best-preserved elements overall, followed by bones of the hyoid (52.6% moderately or slightly fragmented). For the oromandibular elements, the somewhat higher incidence of lightly fragmented specimens is not matched by moderately fragmented ones, and this structure actually has the highest frequency of heavily fragmented specimens outside opercula, fins, and appendicular elements. Thus, overall levels of fragmentation are actually quite similar for neurocrania, branchiostegals, and oromandibular bones, despite the higher frequency of lightly fragmented specimens among the latter (Figure 6.14).

It is also worth noting that the data in Figure 6.14 do not include the 1102 non-descript *Clarias* cranial shield fragments, because these specimens were not identifiable to a specific element, and it was therefore not possible to estimate the percentage of the original bone remaining. All of these specimens would almost certainly belong in the heavy or moderate fragmentation categories, and the very small size of most of them suggests that the vast majority would be in the former (Table 6.21). As such, had it been possible to include the generic headplate fragments in the FI data, it is very likely that the frequencies

of heavily and moderately fragmented specimens for neurocrania would be much higher and more similar to those for opercula, fins, and appendicular elements.

Levels of fragmentation are very similar across *Bagrus, Clarias, Schilbe,* and the other fish remains not identified to taxon (Figure 6.15). For all of these groups, ~15-20% of bones are only slightly fragmented, ~20-25% are moderately fragmented, and ~60-65% are heavily fragmented. Fragmentation is much more extensive among *Synodontis* and non-identified catfish, with ~90% of elements being heavily fragmented in both groups. For *Synodontis,* the high levels of fragmentation are almost certainly due in part to the small overall size of many of the individual fish from this genus (see above). Conversely, heavy fragmentation among generic catfish bones is largely due to the fact that this sample consists primarily of small fragments of dorsal and pectoral spine shafts that could not be identified more precisely because there was not enough of the original element remaining. (It is also worth pointing out that heavy fragmentation, in turn, is why many of these elements could not be identified more specifically.) Levels of fragmentation among *Labeo/barbus* are much lower than the other groups, with ~40% of specimens being slightly fragmented and another ~20% only moderately fragmented. Once again, this makes sense in light of the fact that 80% of the *Labeo/barbus* bones (n = 57; 12 pharyngeal teeth/rows are not included) are vertebrae, which are the best-preserved elements overall (Figures 6.14 and 6.15).

The WMI and SI values for each anatomical region and skeletal structure by taxon are presented in Table 6.24. The majority of WMI values are < 50% for both the broader cranial and postcranial regions, and the skeletal structures that make up each of them, suggesting high levels of overall fragmentation across all elements and taxa for these skeletal parts. The only exceptions are for cranial elements in *Synodontis* and *Schilbe,* although in both cases WMI does not actually exceed 50% and the calculation is based on

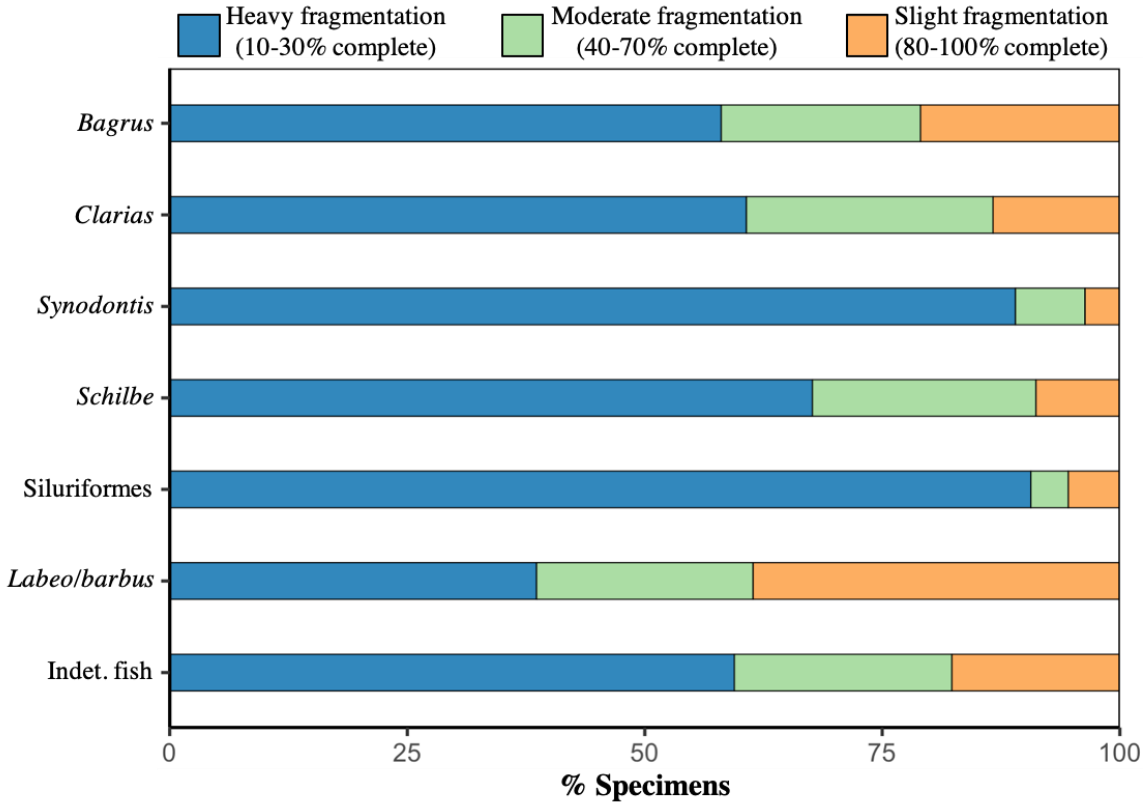

Figure 6.15 Frequency (%) of fragmentation index (FI) categories of fossil fish from SM1 by taxon. Does not include generic headplate fragments.

a very small sample of specimens (NISP = 6 for *Synodontis* and NISP = 1 for *Schilbe*). WMI values for the cranial region and its component structures range from 20-50%, with an average of 39.2% for the region overall. Postcranial WMI values are even lower, ranging between 18.5-30%, with an average of 24.2% for the entire region. Unsurprisingly, the WMI values for vertebral elements, which comprise both an anatomical region and a skeletal structure, are much higher, with a minimum of 44.7%, a maximum of 66.7%, and an average of 57.2%.

Given the discussion of element representation presented earlier in the chapter, the fact that SI values present basically the opposite pattern is also unsurprising (Table 6.24).

Table 6.24 WMI and SI values for anatomical regions and skeletal element structures by taxonomic group at SM1.

Region/ Structure	*Bagrus*		*Clarias*		*Synod.*		*Schilbe*	
	WMI	**SI**	**WMI**	**SI**	**WMI**	**SI**	**WMI**	**SI**
Cranial	*36.2*	*0.6*	*41.2*	*1.1*	*50*	*0.1*	*50*	*0.1*
Neurocranium	30	0.1	37.4	0.9	50	0.3	-	-
Oromandibular	28	0.8	44.5	2.9	-	-	50	0.3
Hyoid	40.7	2.8	41.5	1.2	-	-	-	-
Opercular	20	0.5	26.7	0.4	-	-	-	-
Branchial	-	-	-	-	-	-	-	-
Postcranial	*26.7*	*3.9*	*22.8*	*5.4*	*22*	*16.5*	*25*	*12.4*
Appendicular			19.1	0.6	29.1	3	-	
Median fin	26.7	14.2	23.1	24.5	20.8	47.1	25	41.4
Vertebral	*50.5*	*1.1*	*65.5*	*0.1*	*-*	*-*	*66.7*	*0.7*

Region/ Structure	**Silur.**		**Cyprin.**		**Indet.**		**Mean**	
	WMI	**SI**	**WMI**	**SI**	**WMI**	**SI**	**WMI**	**SI**
Cranial	*-*	*-*	*27.8*	*0.2*	*29.8*	*0.5*	*28.8*	*0.4*
Neurocranium	-	-	-	-	24.5	0.5	24.5	0.5
Oromandibular	-	-	20	0.4	22.7	0.4	21.4	0.4
Hyoid	-	-	32	1.3	44	0.3	38.0	0.8
Opercular	-	-	25	1	16.7	0.3	20.9	0.7
Branchial	-	-	-	-	35.3	0.7	35.3	0.7
Postcranial	*13.3*	*14.8*	*30*	*0.1*	*18.5*	*0.4*	*24.3*	*0.3*
Appendicular	10	0.3	-	-	18.5	0.8	18.5	0.8
Median fin	13.4	48.6	30	0.6	-	3.9	30.0	2.3
Vertebral	*50.9*	*0.4*	*59.6*	*4.3*	*43.9*	*2.5*	*51.8*	*3.4*

In other words, survivorship is lowest among cranial elements and highest among postcranial elements, potentially suggesting a negative correlation between WMI and SI for the assemblage as a whole. Correlation tests confirm that this is indeed the case, although the correlation is weak and not significant at $\alpha = 0.05$ ($r^2 = -0.09$, p-value = 0.07). Nonetheless, the existence of a negative correlation between WMI and SI raises the possibility that over-representation of at least some skeletal elements at SM1 is largely due to high levels of fragmentation. This is particularly true for postcranial elements, such as pectoral spines, for which WMI values indicate that elements are only ~25% complete on average and SI values are extremely high in many cases (Table 6.24).

In order to investigate this possibility further, the relationships between WMI and MNI were also examined (Zohar *et al.,* 2001). Once again, the results indicate a weak and non-significant relationship between WMI and MNI ($r^2 = 0.01$, p-value = 0.65) and, as Table 6.25 demonstrates, the expected pattern for a site in which high skeletal part frequencies are largely due to heavy fragmentation is not met for many of the most common elements at SM1. Of the ten skeletal elements with the highest MNI, six of them have WMI values between 13-35%, indicating that they are quite fragmentary on average. By contrast, several of the bones with relatively high WMI values (~50-60%), namely vertebral elements, also have low values of MNI. Clearly this pattern does not hold for all of the elements within the site, and the comparisons are perhaps complicated by the fact that there are very few elements with "high" WMI values (*i.e.,* > 50%, with almost all of them vertebrae) and MNI values are relatively low in all cases. Nonetheless, that many of the most common elements in terms of MNI, including *Clarias* and *Synodontis* spines, *Clarias* neurocrania, and several *Clarias* oromandibular bones, are also some of the most extensively fragmented, indicates that their over-representation cannot simply be attributed to heavy fragmentation or post-depositional destruction (Table 6.25)

Table 6.25 WMI and MNI values for fish skeletal elements from SM1.

Taxon	Element	WMI	NISP	MNI
Clarias	Mandible	51.7	85	28
Clarias	Spine	23.1	118	25
Clarias	Palatine	33.8	23	14
Clarias	Quadrate	26.3	19	14
Synodontis	Spine	20.7	65	12
Clarias	Hyoid	43.2	39	11
Clarias	Interorbital 2	57.8	14	10
Clarias	Neurocranium	33.8	76	10
Siluriformes	Spine	13.4	168	9
Clarias	Vertebra	65.5	18	7
Synodontis	Cleithrum	29.1	11	6
Bagrus	Hyoid	40.6	12	6
Schilbe	Spine	25.0	24	5
Bagrus	Spine	26.7	15	5
Indet. fish	Urohyal	44.0	5	5
Indet. fish	Vertebra	43.9	151	4
Indet. fish	Cleithrum	20.0	8	4
Clarias	Opercle	26.7	6	4
Labeo/barbus	Vertebra	59.6	47	3
Labeo/barbus	Hyomandibular	32.0	5	3
Clarias	Urohyal	35.0	4	3
Clarias	Interorbital 4	34.0	5	2
Bagrus	Mandible	28.0	5	2
Clarias	Cleithrum	18.0	5	2
Indet. fish	Dentary	20.0	10	2
Siluriformes	Cleithrum	10.0	3	2
Clarias	Coracoid	22.5	4	2
Synodontis	Neurocranium	49.9	6	2
Siluriformes	Vertebra	50.9	32	1
Bagrus	Vertebra	50.5	24	1
Schilbe	Vertebra	66.6	9	1
Bagrus	Hyomandibular	15.0	2	1
Indet. fish	Coracoid	16.0	5	1
Indet. fish	Opercle	16.7	3	1

Differences in the frequency of slightly, moderately, and heavily fragmented specimens are statistically significant between all pairs of analytical units except MSA-1 versus MSA-2 and MSA-3 versus MSA-4 (Table 6.26). Levels of fragmentation are higher in MSA-1, where slightly fragmented specimens are significantly under-represented, and MSA-2, in which heavily fragmented specimens are significantly over-represented (Table 6.27). Conversely, MSA-4 has significantly more slightly fragmented specimens than expected and significantly fewer heavily fragmented ones. Both heavy and moderate fragmentation are also under-represented, and slight fragmentation over-represented, in MSA-3, although in all three cases the associations are insignificant (Table 6.27).

Table 6.26 Chi-squared tests of independence between analytical units for fragmentation index categories of fish at SM1.

AU1	**AU2**	χ^2	**p-value**
MSA-1	MSA-2	4.36	0.11
MSA-1	MSA-3	7.89	0.02*
MSA-1	MSA-4	15.08	< 0.01*
MSA-2	MSA-3	5.99	0.05*
MSA-2	MSA-4	14.97	< 0.01*
MSA-3	MSA-4	4.46	0.11
*p-value significant at $\alpha = 0.05$			

Table 6.27 Partial chi-square tests between analytical units for fragmentation index categories of fish at SM1.

Fragmentation	**MSA-1**	**MSA-2**	**MSA-3**	**MSA-4**
Slight	(-)*	(-)	(+)	(+)*
Moderate	(+)	(-)	(-)	(+)
Heavy	(+)	(+)*	(-)	(-)*
*p-value significant at $\alpha = 0.05$				

Surface modification

Out of 1909 fish bones that were inspected for surface modification, cut or tooth marks were identified with high confidence (HC) on a total of 26 specimens (1.4%) (Table 6.28 and Figure 6.16). Another 52 (2.9%) specimens had cut, percussion, or tooth marks that were identified with medium confidence (MC), which means that they were deemed to represent probable instances of each type of modification, but lacked one or more of the criteria used to make definitive identifications (*e.g.,* Blumenschine *et al.,* 1996; Willis *et al.,* 2008; Archer and Braun, 2013; Willis and Boehm*,* 2014). While there is perhaps no reason to assume that percussion marks on fish should differ substantially from those on terrestrial mammals, very little work has actually tested this idea empirically, and there are currently few published morphological criteria for identifying hammerstone percussion marks specifically on fossil fish (but see Archer and Braun, 2013). As such, all percussion marks on fish bones from SM1 were recorded as MC for the current study.

No specimens were observed to contain more than one type of modification, and the majority (~75%) of bones have only 1-2 marks each, although there are several on which a relatively high number (~5-11) of cut or tooth marks were observed. Although frequencies are quite low overall, these data nonetheless contrast once again with the Kibish Formation where only three modified specimens (1%) were recorded, all of which have one or two MC tooth marks each. An additional 27 specimens had non-identifiable marks, which in some cases consisted of linear striations that were noted as possible cut/scrape, tooth, and/or digestion marks. However, for many of these specimens, the striations appeared to be quite shallow and occurred in dense patches across much of the bone surface, suggesting that they were more likely the result of natural processes, such as trampling.

Table 6.28 Frequencies of surface modification for fish from SM1.

Modification	Marks	% Marks	Specimens	% Spec.	%Total
Human	*90*	*40.7*	*34*	*43.6*	*1.8*
HC cut	25	11.3	9	11.5	0.5
MC cut	57	25.8	17	21.8	0.9
MC percussion	8	3.6	8	10.3	0.4
Carnivore	*131*	*59.3*	*44*	*56.4*	*2.3*
HC tooth	53	24	17	21.8	0.9
MC tooth	78	35.3	27	34.6	1.4
Total	221		78		4.1
HC = high confidence; MC = medium confidence					

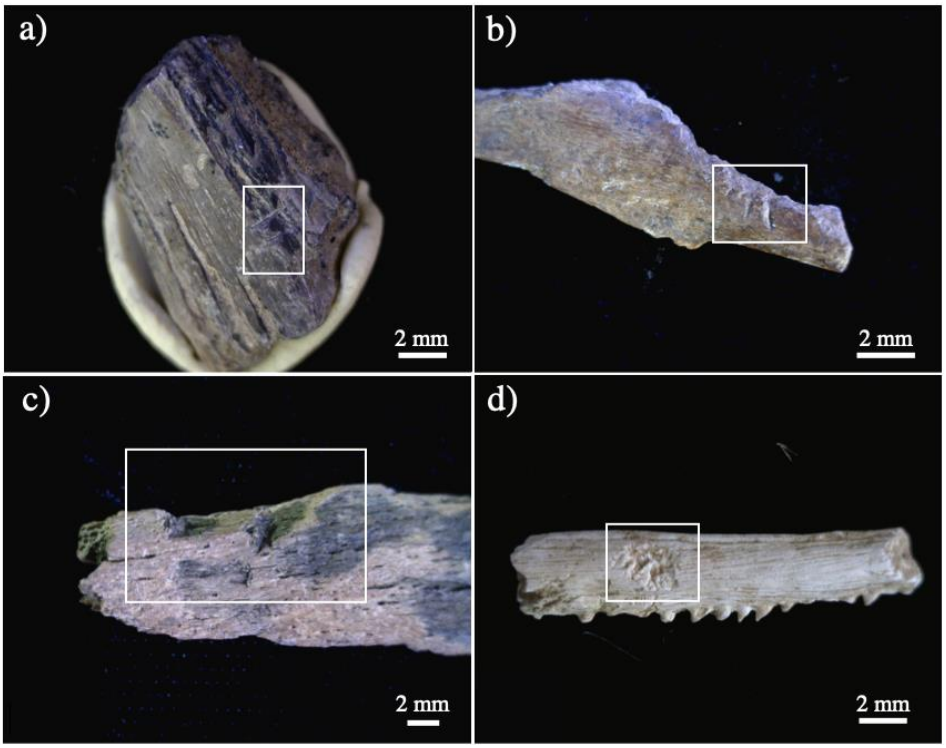

Figure 6.16 Fish bones with high- (HC) and medium-confidence (MC) human modification. a) Non-identified fragment (W14-6-296) with HC cut marks. b) Non-identified fragment (W14-16-385) with HC cut marks. c) Neurocranium fragment (W15-23-71) with MC chop marks. d) *Clarias* pectoral spine (X15-18-398) with MC percussion mark; the very small size of this mark is one of the factors that led to its MC classification.

High confidence (HC) carnivore modification (n = 17 specimens and 53 marks) is approximately twice as common as HC human modification (n = 9 specimens and 25 marks) at SM1 (Table 6.28). By contrast, frequencies of MC carnivore (n=27 specimens and 78 marks) and human (n=25 specimens and 63 marks) modification are actually much more similar. Accordingly, overall frequencies are also more similar, with human damage accounting for ~41% of marks and 44% of modified specimens, while carnivore damage makes up the remaining ~59% of marks and ~56% of modified specimens (Table 6.28).

Considering both HC and MC marks, approximately 39% of surface-modified specimens are cranial elements, while ~29% are postcranial bones, and the other 33% are not identifiable to a particular skeletal element; no modifications of any kind were observed on elements of the vertebral column (Table 6.29; see Figure 3.1 and Appendix D for anatomical region classifications). Cut-marked specimens are evenly spread across postcranial and non-identifiable elements, with each accounting for 38.5% of the sample. Cut-marked postcranial elements include catfish spines (n=2), as well as a cleithrum, and a coracoid. The remaining 23% of cutmarks are found on cranial elements, including a parasphenoid, an interorbital, a dentary, a quadrate, and several fragments of *Clarias* cranial shield. Likewise, 50% of the MC percussion marks are located on catfish spines, while another 37.5% occur on cranial shield fragments and a single oromandibular element. Tooth marks are most heavily concentrated on cranial elements, and neurocranial fragments in particular. Additionally, two ceratohyals and a mandible fragment were also tooth-marked. Postcranial elements with tooth marks (18.4%) are much less common, and include catfish spines, a cleithrum, and a coracoid. The remainder of tooth-marked specimens (34.1%) are non-identifiable fragments (Table 6.29).

With respect to the taxonomic distribution of surface-modified specimens, marks were found on bones belonging to *Clarias* (47.4%), fish of indeterminate taxonomic status

(47.4%), *Synodontis* (3.8%), and *Bagrus* (1.4%) (Table 6.30). Specimens not identified to taxon (53%) account for the largest percentage of bones with human damage, followed by *Clarias* (41.2%), and *Synodontis* (5.8%). No *Bagrus* elements were found to have human modification. *Clarias* (51.2%) and indeterminate fish (43.2%) also account for the vast majority of specimens with carnivore modification, while *Synodontis* (2.3%) and *Bagrus* (2.3%) make up just under 5% of the carnivore-modified sample combined (Table 6.30).

Table 6.29 Surface modification[1] frequencies (%) for fish bones from SM1 by anatomical region and skeletal structure.

Region/Structure	**CM**	**PM**	**TM**	**Total**
Cranial	*23*	*37.5*	*47.7*	*38.5*
Neurocranium	15.4	25	40.9	30.8
Oromandibular	7.6	12.5	2.3	5.1
Hyoid	-	-	4.5	2.6
Postcranial	*38.5*	*50*	*18.2*	*28.2*
Appendicular	7.7	-	4.5	5.1
Median fin	30.8	50	13.6	23.1
Non-ID	*38.5*	*12.5*	*34.1*	*33.3*

[1]Includes high- and medium-confidence marks

CM = cut mark; PM = percussion mark; TM = tooth mark

Table 6.30 Surface modification[1] frequencies (%) for fish from SM1 by taxon.

Taxon	Human[2]	Carnivore	Total
Bagrus	-	2.3	1.4
Clarias	41.2	52.2	47.4
Synodontis	5.8	2.3	3.8
Indet. fish	53	43.2	47.4

[1]Includes high- and medium-confidence marks
[2]Includes cut and percussion marks

Taphonomic summary

Taphonomic analyses of the fossil fish from SM1 indicate similar depositional contexts, and good surface visibility and preservation overall for most of the assemblage. Just under 75% of the bones are medium-to-dark brown in color, while over 85% of the specimens fall within four of the nine color categories, indicating that the majority of fish bones were deposited and preserved under largely similar environmental and taphonomic conditions. These data contrast with the fish from the Kibish Formation, for which the specimens are more evenly distributed across a similar number of color index categories. The majority (~90%) of fish bones from SM1 also have most or all of the preserved surface visible. Heavy bone weathering is minimal, with ~90% of specimens appearing fresh or having only localized damage. Less than 20% of specimens display any one type of post-depositional damage, although it also worth noting again that there is not much overlap among damaged specimens, so 40% of the bones actually display some type of post-depositional damage. Yet, in over 90% of cases, the damage occurs on less than half of the observable surface and does not severely impact its overall integrity.

When the 1300+ specimens coded as indeterminate because it was not possible to confidently distinguish between carbonization and dark staining are included, over 10% of the fish bones at SM1 are calcined (this increases to > 20% if only specimens coded as unburned or calcined are considered). Burning was observed across all taxonomic groups, anatomical regions, and skeletal structures. Although the majority of burned bones were from *Clarias,* generic siluriform catfish, and indeterminate fish, overall levels of burning were not significantly different between the five most common taxa. Conversely, there were substantial differences in the proportions of burned versus unburned specimens between anatomical regions, with burning significantly more common than expected for postcranial elements and less so for cranial elements.

As with the terrestrial fauna, the data indicate extensive fragmentation among the fish bones at SM1. Just under 40% of bones are < 10 mm in maximum length, while another ~50% are between 10-20 mm long. Bones > 40 mm long are exceedingly rare and represent < 1% of the total assemblage. Analyses of FI indicate that a majority of elements from most anatomical regions and skeletal structures are heavily fragmented, and in all but one case the proportion of slightly fragmented (*i.e.,* mostly complete) specimens is < 20%. Vertebrae are the one exception, and have both the highest frequency of slight fragmentation (~35%), as well as the lowest frequency of heavy fragmentation (~40%). Unsurprisingly, given the FI data, the WMI values indicate that elements of the cranial and postcranial regions are ~40% and ~25% complete on average, respectively. Once again, vertebrae fare better, and are ~60% complete on average, although this is still only slightly higher than the 50% mark that previous authors have deemed to indicate high levels of fragmentation in a fish bone assemblage (Zohar *et al.,* 2008).

In accordance with the analyses of skeletal part representation presented earlier in this chapter, the SI data suggest that cranial elements are generally under-represented,

while postcranial elements, and catfish spines in particular, are significantly over-represented. The negative correlation between WMI and SI indicates that the overabundance of postcranial elements is potentially due primarily to natural post-depositional destruction. However, the lack of correlation between WMI and MNI, and the fact that many of the most fragmented elements (*e.g.,* spines, oromandibular bones) also have some of the highest MNI values, indicates that they are actually much more abundant than expected and their over-representation does not simply result from artificially-inflated NISP values.

Both human and carnivore damage were observed on the fish bones from SM1 and, much like the terrestrial fauna, the overall frequencies are low (and quite a bit lower than the terrestrial fauna, in fact). The relative rarity of human and carnivore damage is not necessarily surprising, given that 1) marks are probably less likely to preserve on fish bones than on terrestrial mammals, and 2) frequencies of modified specimens are often quite low at both modern fish camps and archaeological fishing sites in Africa and elsewhere (Stewart, 1989, 1991; Butler, 1996; Gifford-Gonzalez *et al.,* 1999; Willis *et al.,* 2008; Willis and Boehm, 2014; Prendergast and Beyin, 2018).

Cut and tooth marks that could be identified with a high degree of confidence occurred on ~1.5% of specimens overall, while another 2.5% of specimens had damage deemed most likely to be cut, percussion, or tooth marks. Cranial elements are the most commonly modified overall. Approximately half of the specimens with tooth marks are cranial, while another ~20% are postcranial. Human damage shows the opposite pattern, with ~40% of specimens from the post-cranial region and ~25% from the cranial region. In both cases, the remaining ~30-35% of modified specimens are non-identifiable fragments. Finally, *Clarias* and non-identified fish account for ~95% of the modified specimens, while the remaining ~5% are *Bagrus* and *Synodontis*.

Using taphonomy to test the validity of analytical units

The results of comparative analyses among the four analytical units for weathering, post-depositional damage, burning, and fragmentation are summarized in Table 6.31; unfortunately, even when MC specimens were included, samples were not large enough to allow for statistical comparisons of surface modification frequencies between units. Unlike the terrestrial fauna, there are no cases in which comparative analyses indicate significant differences between a given unit and all of the others (Table 5.32 and Table 6.31). Yet, much like the terrestrial fauna, fragment length categories were again found not to differ significantly between any of the analytical units. The only other instances where comparisons indicate no significant differences between a given analytical unit and all of the others are burning in MSA-1 and weathering in MSA-4 (Table 6.31).

There are several patterns of association and dissociation in the data presented in Table 6.31. Specifically, there are no cases in which MSA-1 and MSA-2 are significantly different from one another, and only one in which MSA-3 and MSA-4 were found to differ significantly for the taphonomic attribute in question. These data suggest the possibility that fish material in the upper levels (*i.e.,* MSA-1 and MSA-2) may not actually derive from different occupational events and, similarly, that material from the lower levels (*i.e.,* MSA-3 and MSA-4) may have also been deposited at or around the same time. Clearly, if this is the case, and the upper and lower levels are actually part of the same aggregates, it would imply that the analytical units as defined here have been delineated incorrectly. Interestingly, though, a somewhat opposing pattern was observed among the terrestrial fauna, with MSA-2 and MSA-3 being the only two units found not to differ significantly for any of the taphonomic attributes that were examined in that case.

Table 6.31 Summary of comparative analyses among the four analytical units.

Attribute	MSA-1	MSA-2	MSA-3	MSA-4
Weathering	MSA-3 & -4	MSA-3	MSA-2	None
Post-dep. damage	MSA-3 & -4	MSA-3 & -4	MSA-1 & -2	MSA-1 & 2
Burning	None	MSA-4	MSA-4	MSA-2 & -3
Fragmentation[1]	None	None	None	None
Frag. Index	MSA-3 & -4	MSA-3 & -4	MSA-1 & 2	MSA-1 & -2

[1] Maximum fragment length categories

Analytical units listed in each row are significantly different from the unit at the top of the column for the taphonomic attribute in question for fish from SM1. For example, MSA-1 is significantly different from MSA-3 and MSA-4 for the frequency of weathered versus unweathered bone. Similarly, MSA-1 is significantly different from MSA-3 and MSA-4 for the frequency of specimens with and without post-depositional damage.

On the one hand, the fact that significant differences exist between MSA-1 and MSA-2 versus MSA-3 and MSA-4 in the taphonomic data for terrestrial fauna, does not support the idea that the four units represent only two (*i.e.,* upper and lower) occupational episodes and should be re-aggregated. On the other hand, it is somewhat puzzling that the patterns of association and dissociation would be reversed for terrestrial fauna and fish because regardless of the primary accumulator, the bones in both groups that occur in the same area of the site were almost certainly deposited around the same time and subject to similar taphonomic conditions. Thus, it seems likely that differences in the structure and preservational qualities of terrestrial fauna versus fish bones are the most plausible explanation for the apparent inconsistencies. Additionally, despite having identical names and encoding very similar information, the taphonomic variables were defined (*e.g.,* weathering) and/or recorded (*e.g.,* burning) somewhat differently for fish and terrestrial fauna, which may also be contributing to the apparent discrepancies in the taphonomic results for each group.

Whatever the case, the chi-squared comparisons document significant differences between at least two pairs of analytical units for four out of the five taphonomic attributes analyzed for the fish bones from SM1. Moreover, although the patterns of association are reversed in some ways, there is still a lot of overlap in the results for terrestrial fauna and fish (Tables 5.32 and 6.31). Additionally, when the results for the four variables that overlap between terrestrial fauna and fish are combined, all four of the analytical units are significantly different from at least one of the others for all of the taphonomic attributes except for maximum fragment length categories (Table 6.32). There is also no case among the combined results in which two units are not significantly different from each other for at least one of the four taphonomic attributes other than fragmentation. Thus, particularly when combined with results from the terrestrial fauna, comparisons of the taphonomic data for fish among the proposed analytical units once again support the hypothesis that the units do, in fact, represent distinct occupational events.

Table 6.32 Combined results of taphonomic comparisons among the four analytical units for terrestrial fauna and fish from SM1.

Attribute	**MSA-1**	**MSA-2**	**MSA-3**	**MSA-4**
Weathering	All units	MSA-1 & -3	MSA-1 & -2	MSA-1
PD processes	MSA-3 & -4	MSA-3 & -4	All units	All units
Burning	All units	MSA-1 & -4	MSA-1 & -4	All units
Fragmentation[1]	None	None	None	None

[1]Maximum fragment length categories.

Analytical units listed in each row are significantly different from the unit at the top of the column for the taphonomic attribute in question for terrestrial fauna and/or fish from SM1. For example, MSA-1 is significantly different from all other units for frequency of weathered versus unweathered bone. Similarly, MSA-1 is significantly different from MSA-3 and MSA-4 for the frequency of specimens with and without post-depositional damage.

DO THE FISH FROM SM1 REPRESENT A NATURAL OR HUMAN ACCUMULATION?

Several lines of evidence that are useful in distinguishing between natural and human-accumulated fish remains, and the expectations for each type of site, are listed in Table 6.33. These include taxonomic abundance and diversity, skeletal part representation, body size distribution, fragmentation, bone scatter frequency, and association with other evidence of human activity, all of which were explored for SM1 in the preceding sections of this chapter and/or previous chapters of this dissertation. The results of those analyses are summarized in Table 6.34, with respect to whether they indicate the fish from SM1 are more likely to represent human or non-human accumulation.

As discussed in Chapter 4, much like the terrestrial fauna, fish bones are found in abundance throughout most of the horizontal and vertical extent of the main excavation area at SM1. Moreover, fish remains are closely associated with thousands of chipped stone artifacts, possible hearth features, and thousands of terrestrial faunal bones throughout the site, as all features resulting primarily from human behavior (see Chapter 5). The fact that ~10% of fish bones are calcined further suggests human involvement in fish capture and processing. Given that naturally-deposited fish remains would be expected to most often occur in an aquatic setting, the likelihood of bones being burned in a naturally-occurring wildfire is reduced compared to terrestrial fauna. As noted in Chapters 3 and 5, natural fires often do not burn long or hot enough to calcine bones, so calcination in and of itself is potentially a strong, but not necessarily unequivocal, indication of human activity. Despite their relative rarity, the presence of human cut (and likely percussion) marks are an additional unambiguous indicator that humans processed fish at SM1 (Table 6.34).

Taxonomic abundances at SM1 also diverge significantly from those observed for modern fish communities in the Shinfa River and several other temporary rivers in the surrounding region (Table 6.34). While it may be unreasonable to expect fish community

Table 6.33 Expectations for natural and human-accumulated fish assemblages.

Evidence	Human accumulation	Natural accumulation
Archaeological association	Yes	No
Cut marks	Possibly	No
Burned bone	Yes	No
Scatter	High	Low (average of .06 bones/m^2 at L. Turkana)
Taxonomic abundance	Variable, but usually differs from natural abundances	Similar to natural abundances
Taxonomic diversity	Variable, but usually lower than natural fish community	Variable, but often similar to natural fish community
Skeletal representation	Differs from complete skeleton	Similar to complete skeleton
Skeletal robusticity	Potentially high representation of less robust taxa	Under-representation of less robust taxa
Body size	Often limited range, biased towards medium-sized fish	Wide range; smaller fish may be absent
Fragmentation	High overall; high cranial fragmentation	Low
MNI versus fragmentation	No correlation between MNI and fragmentation	Correlation between MNI and fragmentation
Tooth marks	No	Possible

Sources: Stewart (1989, 1991); Butler (1993, 1996); Stewart and Gifford-Gonzalez (1994); Gifford-Gonzalez *et al.* (1999); Zohar *et al.* (2001); Zohar (2003)

Table 6.34 Summary of fossil fish analyses at SM1 and the most likely type of accumulation based on multiple lines of evidence.

Evidence	**SM1**	**Most likely type of accumulation?**
Archaeological association	Yes	Human
Cut marks	Yes	Human
Burned bone	Yes	Human
Bone scatter frequency	Relatively high	Natural or human
Taxonomic abundances	Significantly different from the Shinfa River and other rivers in the region	Human
Taxonomic diversity	Lower than modern Shinfa River	Natural or human
Skeletal element proportions	Significantly different from complete skeleton in most cases	Human
Skeletal robusticity	Less robust taxa significantly under-represented	Natural?
Body size	Ranges from ~20-80 cm; mostly small/medium-sized fish	Human
Fragmentation	Very high in general; high cranial fragmentation	Human
MNI versus fragmentation	No correlation between MNI and fragmentation	Human
Tooth marks	Yes	Natural (not human)

structure in the paleo-Shinfa River to mirror exactly that of the modern river, there is also no apparent reason to assume that it would have been substantially different. To the contrary, all of the aquatic taxa recovered from SM1 are still extant in the river today, which suggests broad similarities between the ancient and modern riverine ecosystems. As noted above, the same is true of the terrestrial fauna, which also suggests a large degree of continuity in terrestrial environments now and in the past. Given how significantly taxonomic representation at SM1 differs from that of the modern river, particularly with respect to the dominance of *Clarias* and paucity of cyprinids, it seems very likely that the frequencies of taxa at SM1 are also quite different from the natural fish community in the ancient river, which is the expectation for a human-produced site (Table 6.33).

The body size distribution of fossil fish, which ranges from ~20-80 cm, but is largely dominated by medium-sized fish (*i.e.,* TL = 30-60 cm; BM = 1-1.5 kg), is also a better match for a human accumulation of fish bones. A naturally-accumulated assemblage would generally be expected to contain a wider range of body sizes and, in many cases, to be biased towards larger and more robust individuals whose bones would be more resistant to natural destructive forces (Tables 6.33 and 6.34). Similarly, patterns of skeletal element representation at SM1 are significantly different from those expected for a complete fish skeleton in almost every case (Table 6.34). Once again, this is not the general expectation for a natural fish accumulation, in which the frequencies of different skeletal elements should more closely match their frequencies in a complete skeleton (Table 6.33). Patterns of bone fragmentation at SM1 – namely a high degree of fragmentation overall, extensive fragmentation of cranial elements, including very dense catfish cranial shields and spines, and a lack of correlation between fragmentation and element abundance – are also indicative of a human-produced assemblage, rather than a natural one.

The possible exception here is the significant over-representation of sturdier taxa and elements, which is perhaps more indicative of a natural assemblage (Tables 6.33 and 6.34). Specifically, the under-representation of fragile elements (*e.g.,* cyprinid neurocrania) relative to more robust bones (*e.g.,* catfish spines and cranial shields) does indeed suggest some amount of taphonomic bias against, and post-depositional destruction of, thin and fragile fish bones at SM1. Similarly, the predominance of *Clarias* is also likely due in part to the overall robust nature of the *Clarias* skeleton compared to many of the other taxa found at the site, particularly *Labeo, Labeobarbus,* and *Oreochromis*. However, for a number of reasons already discussed in both the current and several previous sections, the observed patterns of taxonomic and skeletal representation at SM1 are unlikely to result from natural processes and taphonomic bias alone, and almost certainly also reflect human preferences and behavior.

Results from several other lines of evidence are not necessarily as clear-cut, but nonetheless generally point to humans as the primary agent of accumulation for the fish from SM1 (Table 6.34). Raw BSF values are several orders of magnitude higher than those recorded for natural fish scatters around Lake Turkana. Yet, the modern fish scatters are surface collections, while the excavated material from SM1 also has a component of depth, which is unlikely to be represented in the surface scatters. When the BSF values for SM1 are standardized for depth (sBSF), the values are much lower across the board, although they are still at least an order of magnitude higher than the natural sites in many cases. Furthermore, even the lowest sBSF values at SM1 do not overlap with the natural fish bone scatters recorded by Stewart (1989, 1991) around Lake Turkana. By contrast, the sBSF values from SM1 are well within the range of values documented by Zohar *et al.* (2008) for natural bone scatters excavated along the shoreline of Lake Kinneret in Israel. Thus, the BSF/sBSF data alone are not unequivocal in supporting the idea that humans are

primarily responsible for accumulating the fish bones at SM1. Nevertheless, when combined with numerous other lines of evidence of human involvement, the generally high BSF and sBSF values provide additional support for humans as the primary accumulator of the SM1 fish (Tables 6.33 and 6.34).

Generally speaking, both NTAXA and all three diversity indices suggest that, compared to the modern fish community in the Shinfa River, the SM1 fish are quite a bit less diverse, heterogeneous, and evenly distributed. This fits the expectation of lower taxonomic diversity at human-created sites relative to the natural fish community in the river or lake from which the fish derive (Table 6.34). Yet, although the index values are lower at SM1 in every case, this interpretation is complicated by the fact that SM1 is actually quite similar to the naturally-accumulated fish from the Kibish Formation in terms of overall diversity, heterogeneity, and evenness. As such, the taxonomic diversity data are also somewhat more ambiguous with respect to determining agents of accumulation.

The presence of other carnivore tooth marks unequivocally documents the involvement of non-human agents in accumulating and modifying the fossil fish bones from SM1. Carnivore tooth marks are actually more common than human modification in terms of both the number of modified specimens and individual marks. However, as discussed in Chapter 5, there is essentially no additional evidence to indicate that carnivores played a significant role in site formation at SM1. Moreover, the terrestrial (*e.g.,* big cats, hyaenas, canids, mustelids, viverrids) and aquatic (*e.g.,* crocodiles) carnivores that may have created the tooth marks are unlikely to have accumulated such a concentration of fish bones in the same way that, say, hyaenas might create a dense accumulation of bones from terrestrial prey species in their den sites. In other words, the fish remains do not represent a non-human carnivore kill or den site, and are unlikely to have resulted primarily from carnivore activity. Thus, although carnivores were undeniably involved,

they were almost certainly peripheral to the primary accumulating agent, which is most likely either natural death or human activity, with some predation and/or subsequent scavenging by carnivores in either case. It bears repeating, then, that the rest of the evidence from the site leans decidedly more toward the latter than the former (Tables 6.33 and 6.34).

The data presented in the preceding sections strongly indicate that the fish from SM1 are primarily the result of human activity. This includes the close spatial association of fish bones, abundant chipped stone artifacts, and other archaeological features, as well as the presence of burned bone and specimens with human modification. Similarly, patterns of taxonomic abundance, skeletal representation, and body size distribution are all quite different from those expected for a naturally-accumulated collection of fish bones. Data on bone scatter frequency and taxonomic diversity are somewhat more equivocal, but when combined with the numerous other lines of evidence indicating human involvement, these factors also point to a human-created site. The presence of tooth marks unambiguously documents that non-human carnivores were also involved in site formation with respect to the fossil fish. However, their involvement appears to have been quite limited, and likely consisted mostly of scavenging on fish remains leftover after human processing and consumption (Table 6.34).

MSA Fishing Behavior at SM1

Having established that the fish from SM1 are primarily the result of human activity, it is now important to examine the potential implications of the results presented in previous sections for: 1) specific techniques of fish capture and processing behavior; and 2) overall MSA foraging strategies at SM1.

Traditional fish procurement technology and methods

Stewart (1989) notes seven types of fishing technology that are widespread across many parts of Africa, most of which are at least several hundred years old, and probably substantially older, including: thrust and stationary basket-traps, weirs, nets, spears/harpoons, hook/gorge and line, and plant poisons. In certain situations, fish are also often caught using nothing more than bare hands (Stewart, 1989, 1991). Perhaps with the exception of fish hooks, harpoon points, and basket-traps, the other implements listed above are not overly complex from a technological standpoint, and some of them (*e.g.,* plant poisons, bare hands), require little or no technology at all. Moreover, these types of fishing gear are often created from grasses, wood, bone, and other perishable materials that, unfortunately, typically do not preserve in the archaeological record. Additionally, and once again with the exception of hook-and-line fishing and harpooning, all of these technologies often entail communal fishing by groups that may consist of men, women, and/or children (Stewart, 1989; Kappelman *et al.,* 2014). As such, fishing is often an activity that relies on relatively simple technology and is a way for members of essentially all ages to contribute productively to the daily food requirements of the group.

However, not all fishing activity is created equal and, in Africa and elsewhere, the practicality, productivity, location, methods, and implements of fish capture are largely dependent on several factors, including the time of year, water levels, and specific habitat types (*e.g.,* riverine versus lacustrine versus floodplain) (Stewart, 1989; Belcher, 1998). In most cases, fishing during the rainy season in lakes and rivers across eastern Africa is typically unproductive and difficult, because water levels are higher, waterways are much more turbulent, and fish are generally in poorer condition due to the onset of the breeding cycle, during which they often go for long periods without eating (Stewart, 1989; Van Neer, 1989). Catching open-water taxa, such as *Bagrus* and *Lates*, is particularly challenging, as

it typically requires relatively complex technology and maneuvers, such as spearing or harpooning them from high banks and bluffs overhanging deep water, running hook-and-lines from the shore well out into open water, and/or taking boats out in unfavorable conditions (Stewart, 1989; Prendergast and Beyin, 2017).

In some areas it is possible to catch taxa such as *Labeobarbus* and *Clarias* during the wet season using nets and/or weirs placed in littoral inshore habitats near river mouths, where they tend to congregate in large numbers during upriver spawning migrations (Stewart, 1989). Additionally, in places where rivers regularly overflow their banks, taxa that spawn in shallow water out on the floodplain are vulnerable to capture with nets, spears, clubs, or even bare hands for at least part of the wet season (Stewart, 1989; Van Neer, 2004). This is especially true of *Clarias,* for which spawning regularly takes place in extremely shallow water, and courtship and mating behavior involves loud tail-slapping and extended periods of lethargy that makes them particularly conspicuous and easy to catch out on the floodplain (Van Neer, 2004). Nonetheless, the rainy season is typically the least productive time of year for freshwater fishing in the lakes and rivers of eastern Africa (Stewart, 1989).

By contrast, fishing during the dry season is often a much more practical and fruitful endeavor (Stewart, 1989). Dry season fish procurement typically occurs: 1) during seasonal migrations along continually receding main waterways; and/or 2) in shallow pools isolated from the main waterway, in which fish left behind are trapped until the connection to the main water body is restored at the start of the next rainy season (Stewart, 1989; Van Neer, 2004). In flowing water, weirs and basket-traps may be used to catch catfish, cyprinids, cichlids, and other taxa that tend to congregate in shallow, vegetated areas (Stewart, 1989). Numerous methods and implements may be used to target *Clarias, Bagrus, Synodontis, Labeo, Labeobarbus*, and other taxa in isolated dry season pools, including basket traps,

nets, and spears, all of which can be employed somewhat more selectively than during the wet season (Stewart, 1989). Depending on the depth of the pool, fish are often simply clubbed and/or caught with bare hands during this time of year in shallow waterholes (Stewart, 1989; Van Neer, 2004). Likewise, if the pool is shallow enough, plant poisons may be used to stun smaller fish, which can then be scooped up by hand after floating to the surface (Tewabe, 2008; Kappelman *et al.,* 2014).

In sum, fishing is often a communal activity that can be undertaken by group members of all ages using a variety of technology and methods. That many of these methods and implements are widespread across Africa and are possibly quite ancient attests to their relative simplicity and efficacy of use (Stewart, 1989). Moreover, although fishing can technically be undertaken at any time of year, the location, manner, and methods of fishing activity are highly dependent on specific ecological, hydrological, and climatic conditions, as well as on the behavior and habitat preferences of the fish being caught (Stewart, 1989).

Fish procurement at SM1

The modern Shinfa River rarely overflows its banks and does not have an extensive floodplain habitat similar to the Nile and many other rivers in Africa (Kappelman *et al.,* 2014). If the paleo-Shinfa River was similar to the modern river, it is likely that if any fishing activity at SM1 occurred during the wet season, it probably consisted primarily of using nets, weirs, or baskets in a non-selective manner to exploit littoral, inshore habitats (Stewart, 1989). *Clarias, Synodontis, Labeo,* and *Labeobarbus* are all relatively well-adapted to shallow-water habitats, and all undertake large-scale migrations at or near the onset of the rainy season, so any of these methods could have been used to catch these taxa from the shoreline as they moved upstream (Stewart, 1989, 1991). Catching open-water

taxa like *Bagrus* during this time of year likely would have required the use of spears/harpoons or hook-and-line setups (Stewart, 1989, 1991), and there is currently no evidence for either harpoons or other specific fishing tackle at SM1. In any case, our local informants in the region around SM1 have told us that they do not typically engage in wet season fishing today, and the prospect that a substantial amount of fishing occurred during the wet season in the late MSA at SM1 also seems quite improbable.

As detailed in Chapter 4, the highly seasonal rainfall regime and specific geomorphology of the modern Shinfa River are such that it is very difficult and impracticable to undertake significant fishing activity during much of the wet season, when the river is fast-flowing and bank-full (Kappelman *et al.,* 2014). Stable isotope and faunal analyses indicate that the ancient climatic conditions, habitats, and ecological rhythms were largely analogous to modern ones, so there is good reason to assume the same factors that inhibit wet season fishing today were also present in the past (Nachman *et al.,* 2011, 2015; Plummer *et al.,* 2019; see above and Chapter 5). Local Gumuz and Amhara people living in the region around SM1 today restrict fishing activity primarily to the dry season when water levels are receding and the river is eventually reduced to a series of isolated waterholes, and it is reasonable to posit that MSA people would have behaved in much the same way (Tewabe, 2008; Tewabe *et al.,* 2010; Kappelman *et al.,* 2014). Thus, it is also reasonable to assume that, much like today, the majority of fishing activity at SM1 almost certainly occurred in the dry season, in large part because this would have been the time of the year when it was most practical, productive, and in fact possible to do so.

It is feasible that taxa such as *Clarias, Synodontis, Labeo,* and *Labeobarbus* were exploited using weirs and basket-traps as they moved back downstream in the Shinfa River early in the dry season when the water was still flowing in the channel (Stewart, 1989). However, the period of flow cessation for the modern Shinfa River, and other temporary

rivers in the region, is relatively short, and once the rains end, flows cease, and the increasingly disconnected dry-season pools begin to form (Kappelman *et al.,* 2014). It is most probable that much of the fish procurement activity during the late MSA occurred in these isolated dry season pools, simply because the river was reduced to a series of disconnected waterholes during much of this period.

Fishing in dry-season waterholes could have been accomplished using a variety of methods (Stewart, 1989, 1991; Tewabe, 2008; Tewabe *et al.,* 2010). When pools were still relatively large and deep, basket-traps, nets, and/or spears may have been used to target many of the taxa found at SM1 in shallow areas along the edge of the waterline (Stewart, 1989). As evaporation continued and the dry season wore on, the same fish may have been speared, clubbed, and even caught with bare hands in the increasingly smaller and shallower pools (Stewart, 1989; Tewabe, 2008; Kappelman *et al.,* 2014). Likewise, nets drawn and dragged across all or part of a waterhole may have been used as a more non-selective manner of dry season fish capture (Stewart, 1989). Once pools became shallower and more restricted, plant poisons may also have been used to procure smaller fish in much the same way that local people catch fingerlings in the river today (Tewabe, 2008; Tewabe *et al.,* 2010). Importantly, all of these methods could have been effectively employed by men, women, and children, with most of them involving implements that are unlikely to be preserved in the archaeological record (Stewart, 1989; Tewabe, 2008; Tewabe *et al.,* 2010; Kappelman *et al.,* 2014). Moreover, none of these methods requires the types of relatively complex technology (*e.g.,* fish hooks, harpoon points, boats) often posited as a requirement for systematic fishing behavior in the past (*e.g.,* Klein, 2009), while collection with bare hands would actually require no technology at all.

Dry season fishing may also help explain the predominance of *Clarias* at SM1 and the low frequency of other taxa that may have been much more common in the river overall

(*e.g.,* cyprinids). It is not unusual for assemblages from late Pleistocene and Holocene fishing sites in Africa, and earlier sites (*i.e.,* < ~15-20 ka) in particular, to contain abundant *Clarias* remains (Stewart, 1989, 1991; Brooks *et al.,* 1995; Yellen *et al.,* 1996; Gautier and Van Neer, 1989; Van Neer, 1989; Van Neer, 2004). In many cases the abundance of *Clarias* is attributed to early humans exploiting this taxon on the floodplain during the wet season when they congregate in large numbers in shallow water, and are quite conspicuous and easy to capture (Van Neer, 1989, 2004).

The overabundance of *Clarias* at SM1 is probably also related to its propensity for shallow water, albeit perhaps in a somewhat different context. As evaporation progressed throughout the dry season, the isolated pools in which fish and other aquatic fauna were trapped would have become increasingly small and crowded, and the water itself warmer, more saline, and less oxygenated. Although many of the other taxa recovered from SM1 can tolerate shallow, saline, and oxygen-poor habitats to varying degrees, *Clarias* was likely the best-equipped of the species currently known at the site to survive as such conditions intensified over the long and arid dry season (Greenwood, 1968; Van Neer, 1989). In fact, the lungfish, *Protopterus,* which can actually survive total desiccation of pools by burrowing into the mud, is probably the only fish common to rivers in this part of Africa that is better-suited than *Clarias* to spend extended periods in such hostile habitats (Fish, 1956; Greenwood, 1968; Van Neer, 1989). However, this fish is not known from SM1, and has not been collected in the Shinfa River or other trunk tributaries of the Blue Nile in this part Ethiopia (Tewabe, 2008; Tewabe *et al.,* 2010).

The important point here is that the particularly high tolerance for *Clarias* to withstand very harsh water conditions may have contributed to making it one of the most readily available fish for MSA people to exploit from isolated dry season waterholes around SM1. Moreover, this may have been especially true at the height of the dry season,

when some pools were completely depleted and many of those that remained were probably quite inhospitable to fish and other aquatic fauna that lacked a robust tolerance for adverse water conditions. As on the floodplain, *Clarias* (and other fish) remaining in the shallow dry season pools would have been easy prey for MSA humans using basket-traps, nets, spears, clubs, plant poisons, or even simply their bare hands.

Finally, the fish left behind on the floodplain and in dry season pools often tend to be smaller individuals, because larger fish typically return to the main channel much sooner after spawning and/or migrate downstream earlier as water flows begin to recede (Stewart, 1989, 1991; Van Neer, 2004). Thus, the fact that many of the fish from SM1 are of medium body size also aligns with the notion that the majority of fishing took place in dry season pools. It is possible, although seemingly quite unlikely, that some limited wet season fishing occurred, and that the handful of rather large individuals (e.g., ~70-80 cm in TL) were caught from the shoreline at this time. It is also equally plausible, and perhaps more so, that larger individuals were procured during the dry season, perhaps on their way back downstream soon after the rains ceased and flows began to wane, or shortly after complete flow cessation when waterholes were still fairly large and deep. Whatever the case, the bulk of the evidence suggests that fishing was primarily a dry season activity at SM1.

Fish processing and consumption at SM1

As with terrestrial fauna, patterns of element representation, fragmentation, and human modification can provide insight into overall site structure and use, and fish transport and processing behavior at SM1 (Stewart, 1989, 1991; Butler, 1993; Stewart and Gifford-Gonzalez, 1994; Belcher, 1998; Gifford-Gonzalez *et al.,* 1999). The presence of cranial, postcranial, and vertebral remains among most taxa suggests that many fish were transported back to SM1 mostly or complete, and that most or all processing activity often

took place at the site. This, in turn, suggests that SM1 was a short- or long-term base camp, rather than a temporary use fishing site (Stewart and Gifford-Gonzalez, 1994; Gifford-Gonzalez *et al.,* 1999).

The idea that whole fish were brought back to the site makes intuitive sense, given that SM1 was probably never more than a few hundred meters from the paleo-Shinfa River, and all of the fish were presumably caught somewhere along this river in the general vicinity of the site. Likewise, the notion that SM1 was a longer-term residential camp and not simply a temporary hunting/fishing camp makes sense, given all of the other evidence for intensive occupation of the site, namely tens of thousands of pieces of chipped stone, regular on-site stone tool production, thousands of terrestrial faunal remains, and possible dedicated hearth areas. Furthermore, human surface modification marks were identified on elements from all three anatomical regions and burning was observed on bones from all anatomical regions and skeletal structures, which also suggests that complete fish were transported back to the site for processing and consumption.

It is possible that some of the differences in skeletal part representation between taxa are the result of differential processing. Specifically, taxa other than *Clarias*, for which neurocranial elements are exceedingly rare, may have had the heads removed and discarded off-site, and only the bodies brought back to camp. However, because modern fishers often remove all or part of the vertebral column along with the head when fish are processed (Gifford-Gonzalez *et al.,* 1999; Van Neer, 2004), it is potentially difficult to explain why vertebrae are relatively well-represented for cyprinids, *Bagrus,* and *Schilbe* at SM1 if this was the case in the past. Likewise, decapitation is not necessarily consistent with the fact that other skeletal structures and elements from the cranial region (*e.g.,* hyoid elements, opercula, pharyngeal teeth) represent ~30% of the total NISP for both *Bagrus* and the cyprinids. Additionally, as already noted, it is likely that the discrepancy in neurocranial

representation between *Clarias* and other taxa is at least partly related to taphonomic bias against smaller and more fragile taxa and elements at the site.

After being brought back to SM1, fish would have been processed and either prepared for immediate consumption (*e.g.,* roasted, boiled, or perhaps simply eaten raw) and/or dried for storage and later consumption (Stewart, 1989; Belcher, 1998; Van Neer, 2004; Kappelman *et al.,* 2014). The introduction of whole fish into the site is technically consistent with all of these activities, although fish are typically only dried and stored when there is a surplus, such as when a group has harvested greater numbers of fish from the floodplain than can be consumed at one time and part of the yield is thus available to preserve for later (Van Neer, 1989, 2004). A surplus seems implausible for SM1, given that most fishing probably occurred in the dry season when, generally speaking, groups are much more likely to experience periods of resource stress and intensification, rather than overabundance, in this part of equatorial eastern Africa (Speth, 1987).

There is also no evidence at SM1 for the types of ceramic storage vessels that are needed to store dried fish for an extended period, and which are known from numerous Holocene fishing sites across eastern and northern Africa (Van Neer, 2004; Prendergast, 2010). Yet, dried fish sold in local markets in the region around SM1 can keep for at least several days without the use of dedicated storage vessels (J. Kappelman, personal communication), so the lack of ceramic technology does not necessarily rule out the possibility that fish were dried and preserved at SM1. Thus, it is entirely possible that at least some of the fish from SM1 were dried to eat later, although without long-term storage vessels, it seems probable that consumption still took place in the relatively near-term, perhaps over a few days or a week (*i.e.,* as opposed to several weeks or months). However, given the probable focus on fishing during the dry season when terrestrial food resources may have been poorer in quality and/or more difficult to come by, it seems very likely that

just as many, if not more, of the fish were brought back to SM1 for essentially immediate consumption.

Cut marks located on a cleithrum and a coracoid, which are consistent with disarticulation of the head from the rest of the body, support the idea of fish being brought to SM1 for immediate consumption, since catfish are often dried whole (*i.e.,* retaining the head) (Zohar, 2003; Van Neer, 2004; Prendergast, 2010). Cut marks on several cranial elements may also indicate processing fish for immediate consumption (Belcher, 1998). Likewise, the presence of cut and possible percussion marks on catfish spines, and the extensive fragmentation of the spines overall, indicates that humans intentionally fractured them while processing fish (Kappelman *et al.,* 2014; and see above). Belcher (1998) and Gifford-Gonzalez *et al.* (1999) note that fishermen regularly broke and removed spines to prevent injury when processing fresh fish for short-term consumption in the fish markets of Pakistan and at fishing camps around Lake Turkana. Likewise, the pied kingfisher (*Ceryle rudis*), which is common around SM1 today and often hunts small fish in waterholes, is known to regularly smash juvenile catfish against stumps in order to unlock and break the spines, so the fish may then be swallowed whole (Kappelman *et al.,* 2014). However, Zohar (2003) also observed that fishermen in Panama regularly fragmented and removed the spines of marine catfish dried and stored for later distribution and consumption.

Thus, fracturing catfish spines is potentially in line with immediate consumption of both small and large fish, and with drying and storage of medium- and larger-sized fish. Regardless, heavy fragmentation of the robust pectoral and dorsal spines, as well as the presence of several catfish cleithra with broken spines still articulated (Figure 6.17), is highly indicative of human processing activity at SM1 (Belcher, 1998; Gifford- Gonzalez *et al.,* 1999; Zohar, 2003). Similarly, the small size of *Clarias* cranial shield fragments

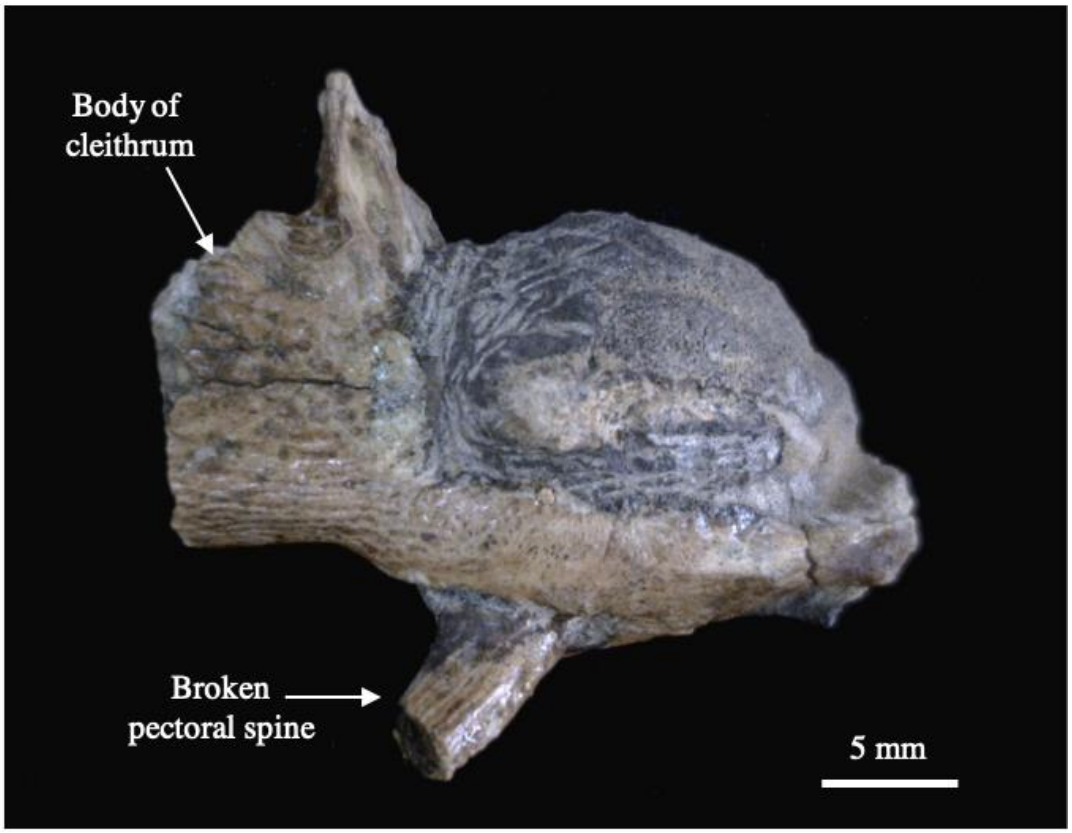

Figure 6.17 Synodontis cleithrum fragment from SM1 with broken pectoral spine still in articulation (W14-25-536).

(mean maximum length = 10.6 mm), in particular, is very much consistent with the heads being smashed for removal and consumption of the brain, which is also common at fishing sites and residential camps around Lake Turkana (Stewart, 1989, 1991; Gifford-Gonzalez *et al.,* 1999). Once again, since catfish are often dried with the head on, this activity would generally be more in line with fish being consumed fresh and not dried for long-term storage and later consumption.

Burning was observed on elements from all three anatomical regions and eight skeletal structures, which suggests that at least some fish were roasted whole, although it is also possible that some bones were burned after being discarded into or around hearth

areas. Roasting might also help explain the lack of *Clarias* vertebrae at SM1, as previous authors have noted that siluriform vertebrae in general are naturally fragile and, particularly after exposure to fire, more susceptible to post-depositional destruction than the sturdier vertebrae of other taxa, as well as other more robust catfish elements (Stewart, 1989, 1991; Stewart and Gifford-Gonzalez, 1994). If fish were often brought back to the site whole, then it stands to reason that *Clarias* vertebrae would have been quite numerous, and there is no reason to think that vertebrae would have been treated substantially differently from any other fish bones (*e.g.,* discarded elsewhere for some reason). Likewise, cranial elements are well-represented for *Clarias,* and it seems very unlikely that the vertebrae, but not the head, would have been removed off-site before the fish were transported back to SM1.

It is possible that roasting simply weakened the *Clarias* vertebrae that were originally brought into the site to the point that only a few of them survived into the present day. Yet, this potential explanation is complicated by the fact that the vertebrae of both *Bagrus* and *Schilbe,* which are also siluriform catfish, are comparatively well-represented at SM1. Additionally, Siluriformes in general account for ~67% of the total identified vertebrae at SM1, a proportion that is lower than their overall representation in terms of NISP, but nonetheless quite high. It is also possible that more *Clarias* vertebrae are actually present at the site, but were not identifiable, or at least not identified, as such. In summary, the available evidence suggests that at least some fish were roasted whole at SM1, but the question or whether or not this behavior has any bearing on *Clarias* vertebral representation remains unclear.

Fishing and seasonal foraging behavior at SM1

Another important point about riverine fishing and foraging at SM1 has to do with the implications of this behavior for overall MSA foraging strategies and the scheduling of resource acquisition at the site. The sheer number of fish bones and mollusk shell fragments (~45% of the total fauna by NISP) at the site suggests that exploiting aquatic resources was not a rare activity for the MSA people living at SM1, or one that they undertook only on an opportunistic basis. Rather, the evidence presented in this chapter indicates that riverine fishing and foraging was a significant part of the MSA adaptive strategy at SM1, and involved active, intentional, and systematic targeting of mostly medium-sized fish that would have provided a substantial amount of nutritive content for the SM1 people. Riverine food resources clearly represented a significant portion of the subsistence base when SM1 was occupied, and it is probable that occupation of the site was structured around the seasonal availability of aquatic food resources in the paleo-Shinfa River. MSA people likely returned to SM1 repeatedly during the dry season, when they knew that the isolated waterholes would contain fish, mollusks, and other aquatic food resources that were concentrated in patches that were spatially constrained, densely-packed, and relatively easy to exploit by group members of all ages.

CONCLUSION

This chapter has presented analyses of the fossil fish from SM1. The overall picture provided by these data is one of an assemblage that was largely deposited under similar conditions, buried rapidly, and is generally in good condition in terms of surface visibility and preservation. There are at least seven families of fish present at the site, and the collection is largely dominated by siluriform catfish, and *Clarias* in particular. All of the

fossil fish taxa are found in the modern Shinfa River, suggesting a general continuity between the ancient and modern riverine ecosystems.

Taphonomic analyses document that non-human carnivores and other natural processes were involved in site formation, but that their involvement was limited in scope. The vast majority of the evidence – including archaeological association, spatial distribution, taxonomic and skeletal part representation, body size distribution, burning, fragmentation, and surface modification – points to humans as the primary agent of accumulation and modification for the fish bones from SM1. As with the terrestrial fauna, these data also suggest that SM1 was a longer-term residential camp, and that the site preserves evidence of multiple episodes of occupation.

Fish capture probably took place largely in isolated waterholes during the dry season using spears, bows and arrows, nets, basket-traps, plant poisons, and/or even bare hands; there is currently no independent evidence for the former technologies at SM1, although some of the points discussed in Chapter 3 may well have been used as projectile points. Some fish may have been butchered away from SM1, but many were transported back to SM1 mostly complete or complete, and processed on-site. Processing appears to have involved smashing the catfish pectoral and dorsal spines and fragmenting neurocrania to remove the brains for consumption. Some of the fish may well have been dried for storage and later use, but most of them were probably prepared for essentially immediate consumption, and many fish were likely roasted whole before being consumed.

Importantly, the data in this chapter indicate that MSA foraging strategies at SM1 involved regular and systematic exploitation of fish, and perhaps other riverine food resources such as mollusks, as well. In other words, the site preserves evidence of riverine foraging adaptations in the Horn of Africa during the late MSA. Moreover, MSA foraging behavior at the site appears to have been intentionally structured around a distinct seasonal

pattern. Specifically, part of the yearly foraging round was scheduled around the availability of abundant fish and other aquatic food resources in the Shinfa River during the dry season. These are significant findings, the importance and implications of which will be discussed in more detail in Chapter 8.

Chapter 7: Comparisons of SM1 with other MSA sites

INTRODUCTION

The goal of this chapter is to determine if aspects of bone preservation and modification at SM1 are unique among other MSA open-air and cave sites. Additionally, it is of interest to examine if broader patterns of similarity and difference exist between open-air versus cave sites in general, because these data may be informative about whether or not it is appropriate to apply the same criteria to interpretations of taphonomy and foraging behavior at each type of site. In other words, is it reasonable to expect SM1 and other open-air sites to have taphonomic characteristics that are similar to cave sites with respect to the variables commonly used to document patterns of human and non-human modification and reconstruct human behavior?

For example, if weathering and other surface damage are regularly more severe at SM1 and other open-air sites than at cave sites, it stands to reason that surface modification marks may be less visible and/or more difficult to identify with confidence at open-air sites (Thompson, 2005). Similarly, if SM1 and other open-air sites generally have higher levels of fragmentation, the ratio of marks to bone fragments would more likely be artificially depressed at open-air sites than cave sites (Abe *et al.,* 2002). Therefore, in this example, open-air sites would generally be expected to have lower frequencies of cut and percussion marks even if they were intensively occupied and contain large collections of fauna that were hunted, processed, and consumed by humans. It then follows that applying expected criteria based on experimental work and previous studies of MSA cave sites (*e.g.,* that significant human involvement should result in high frequencies of cut and percussion marks) to open-air sites may produce inaccurate behavioral interpretations (*e.g.,* that low frequencies of cut and percussion marks necessarily indicate limited human involvement). As already discussed in Chapter 3, it is important to consider this possibility, because most

of the MSA sites where detailed taphonomic analyses have been undertaken are located in caves. Thus, expectations for common interpretive criteria (*e.g.,* frequencies of: human and carnivore modification, fracture angles and outlines, burned bone) are based primarily on data from cave sites (Thompson and Henshilwood, 2011; Hallett, 2018; Hutson, 2018) and/or experiments that do not necessarily account for the various taphonomic factors that can influence an archaeological assemblage (*e.g.,* Capaldo, 1998; Selvaggio, 1998).

Comparative data for the analyses presented below are from ten MSA sites located in Ethiopia, Morocco, and South Africa (Table 7.1). General descriptions of the fauna from Aduma A2 (A2) and Aduma A8A (A8A) are presented in Yellen *et al.* (2005), but the taphonomic data collected for this study have not been previously published. Data for Contrebandiers Cave (CBC), Blombos Cave (BBC), and Pinnacle Point 13B (PP13B) are taken from original datasets shared by E. Hallett (CBC) and J. Thompson (BBC and PP13B), although analyses of all three sites are also available in the literature (Thompson, 2008, 2010; Thompson and Henshilwood, 2011; Hallett, 2018). Data for Bundu Farm (BF) and Pniel 6 (Pn6: Hutson, 2012a, 2018), Porc Epic (PE: Assefa, 2002, 2006), Die Kelders Cave 1 (DK1: Marean *et al.,* 2000), and Sibudu Cave (SC-HP and SC-MSA: Clark, 2009, 2011; Clark and Ligouis, 2010) were collected from published accounts of each site. Fish are absent, rare, or not reported for most of the comparative sites, so fish bones are excluded from the analyses presented below. Various combinations of sites are used for different analyses based on the availability of data for the variables of interest.

Like SM1, most of the comparative sites were intensively occupied and are places where MSA humans spent substantial amounts of time on multiple occasions. The possible exceptions here are the four open-air sites, BF, Pn6, and perhaps A2 and A8A (Yellen *et al.,* 2005; Hutson, 2018). In all four cases, faunal remains are in clear association with lithics, but published accounts report that other direct evidence of human involvement (*e.g.,*

Table 7.1 Names, abbreviations, stratigraphic levels, location, and approximate ages for comparative MSA sites.

Open-air sites	**Levels**	**Country**	**Age (ka)**	**Source(s)**
Aduma A2 (A2)	-	Ethiopia	~80-100	1
Aduma A8A (A8A)	-	Ethiopia	~80-100	1
Bundu Farm (BF)	-	S. Africa	~245	2
Pniel 6 (Pn6)	-	S. Africa	~243-300	2
Cave sites				
Porc Epic (PE)	all levels	Ethiopia	~35-80	3
Contrebandiers Cave (CBC)	V, IV, 4a-d, 5a-c, 6a-c	Morocco	~95-126	4
Blombos Cave (BBC)	MSA 1-3	S. Africa	~70-100	5
Pinnacle Point (PP13B)[1]	1-7	S. Africa	~91-174	6
Die Kelders 1 (DK1)	10 & 11	S. Africa	~65-80	7
Sibudu Cave (SC-HP; SC-MSA)[2]	HP; post-HP MSA 1 & 2	S. Africa	~57-65	8

[1] Units 1-7 following Thompson (2008, 2010)

[2] HP = Howiesons Poort

Sources: 1 - Yellen *et al.* (2005); 2 - Hutson (2018); 3 - Assefa (2006); 4 - Hallett (2018); 5 - Thompson (2010); 6 - Thompson and Henshilwood (2011); 7 - Marean *et al.* (2000); 8 - Clark (2011), Clark and Ligouis (2010)

archaeological features, cut and percussion marks, calcined bone) are rare or absent. Nonetheless, humans were clearly involved in site formation to some extent at all four sites, even though their presence may have been more ephemeral and activity less extensive than at the other sites (Yellen *et al.,* 2005; Hutson, 2018).

Since the primary goal of these comparative analyses was to examine overall taphonomic similarities and/or differences between SM1 and the other MSA sites, all of the data from SM1 were treated as a single aggregate for comparisons. This was also necessary because subsamples for each analytical unit at SM1 were not always large

enough for meaningful statistical analysis. Likewise, the data for most of the comparative sites were treated as a single sample. In some cases, this was necessary because there are no explicitly defined stratigraphic units or levels for the site (*e.g.,* A2, A8A, BF, Pn6), or data for individual units or levels were not available for all the attributes of interest (*e.g.,* PP13B) (Yellen *et al.,* 2005; Thompson, 2010; Hutson, 2018).

In other cases (*e.g.,* DK1, BBC, CBC), it was deemed appropriate to aggregate the individual levels within a site because they span relatively narrow durations of time, and/or human behavior and environmental conditions appear to have been roughly similar across most or all of the levels (Marean *et al.,* 2000; Thompson, 2010; Dibble *et al.,* 2013; Hallett, 2018). The one exception is SC, where the Howieson's Poort (SC-HP) and post-HP MSA (SC-MSA) levels were analyzed separately with regard to the frequency of burned bone. Although these levels represent a temporal span of only ~7-10 kyr combined, there are substantial differences in human technology and behavior between the HP and post-HP levels that likely correspond to variability in environmental conditions, and which warrant their consideration as separate units (Clark, 2011).

The analyses in this chapter are directly relevant to Hypothesis 5, which posits that SM1 is unique among MSA sites for certain aspects of taphonomy and site formation processes, and is particularly distinct from cave sites. The taphonomic variables investigated here relate to various aspects of bone preservation, surface modification, and nutritive and non-nutritive fragmentation (Table 7.2). These variables were chosen, in part, based on the availability of comparative data in the literature, and because they all have the potential to influence behavioral interpretations (*e.g.,* weathering, post-depositional damage, and burning can obscure surface modification marks) or are direct indications of human or carnivore activity (*e.g.,* cut, percussion, and tooth marks). There are differences among sites in the way that the data were collected and/or presented for several variables,

Table 7.2 Taphonomic variables for comparative analyses.

Taphonomic attribute	Process(es) of interest
Weathering	Surface preservation; subaerial exposure
Post-depositional damage	Surface preservation; post-dep. transport
Burning	Bone preservation; mechanical weakening
Fragmentation	Human and carnivore behavior; post-dep. destruction
Fracture morphology	Timing of fragmentation
Surface modification	Human and/or carnivore behavior

which means the original data could not be compared directly in all cases. For example, the same 0-6 coding scheme was used to record burning at SM1, A2, A8A, BBC, and PP13B, but burning was recorded based on the percentage of surface affected at CBC (Thompson, 2008; Hallett, 2018). Further, reported counts for SC are of unburned/lightly, moderately, and heavily burned specimens, and published data from PE are simply for burned versus unburned bone (Assefa, 2002; Clark and Ligouis, 2010).

As such, differences between sites were initially assessed based on the presence or absence of damage (*e.g.,* unburned versus burned bone), rather than on more specific groupings for each attribute (*e.g.,* unburned versus carbonized versus calcined bone). However, when warranted and possible, comparisons were also made at finer scales for some variables. Finally, NISP counts are listed for all analyses because in many cases different criteria were used to define the samples (*e.g.,* teeth and tooth fragments were excluded from analyses of weathering and burning because weathering codes are not relevant to teeth, and the burning stage was not coded for many of the teeth from SM1, but these specimens were included in analyses of fragmentation), so sample sizes vary between analyses.

COMPARATIVE TAPHONOMY AT SM1 AND OTHER MSA SITES

Weathering

SM1 has a lower frequency of weathered bone than all of the other open-air sites, and is most similar to A2 and A8A in this respect, albeit less so in the latter case (Figure 7.1 and Table 7.3). Compared to SM1, weathering is far more common at BF and Pn6, neither of which have any completely unweathered specimens. The frequencies of weathered bone at all of the cave sites is also quite different from SM1, although the pattern of association is actually reversed between BBC, PP13B, and DK1 (*i.e.*, the South African caves), and PE and CBC (*i.e.*, the caves outside South Africa). Weathered bone is exceedingly rare at BBC, PP13B, and DK1, and therefore much less frequent than at SM1 in all cases, while PE and CBC both have higher percentages of weathered specimens than SM1 (Figure 7.1 and Table 7.3).

Chi-squared tests of independence indicate that A2 is the only comparative site where the frequencies of unweathered and weathered bone are not significantly different from SM1 (Table 7.4). However, it is important to bear in mind that the sample from A2 is somewhat small (n = 97), which may affect the reliability of chi-squared tests. Additionally, fragments < 10 mm in maximum length were excluded for A2 and A8A, in order to maintain strict comparability with the data from SM1 as presented in earlier chapters. When these specimens are included, differences between SM1 and A2 are statistically significant, although A2 is still the most similar site to SM1 overall. By contrast, results for all of the other sites are basically identical regardless of whether or not fragments < 10 mm are included.

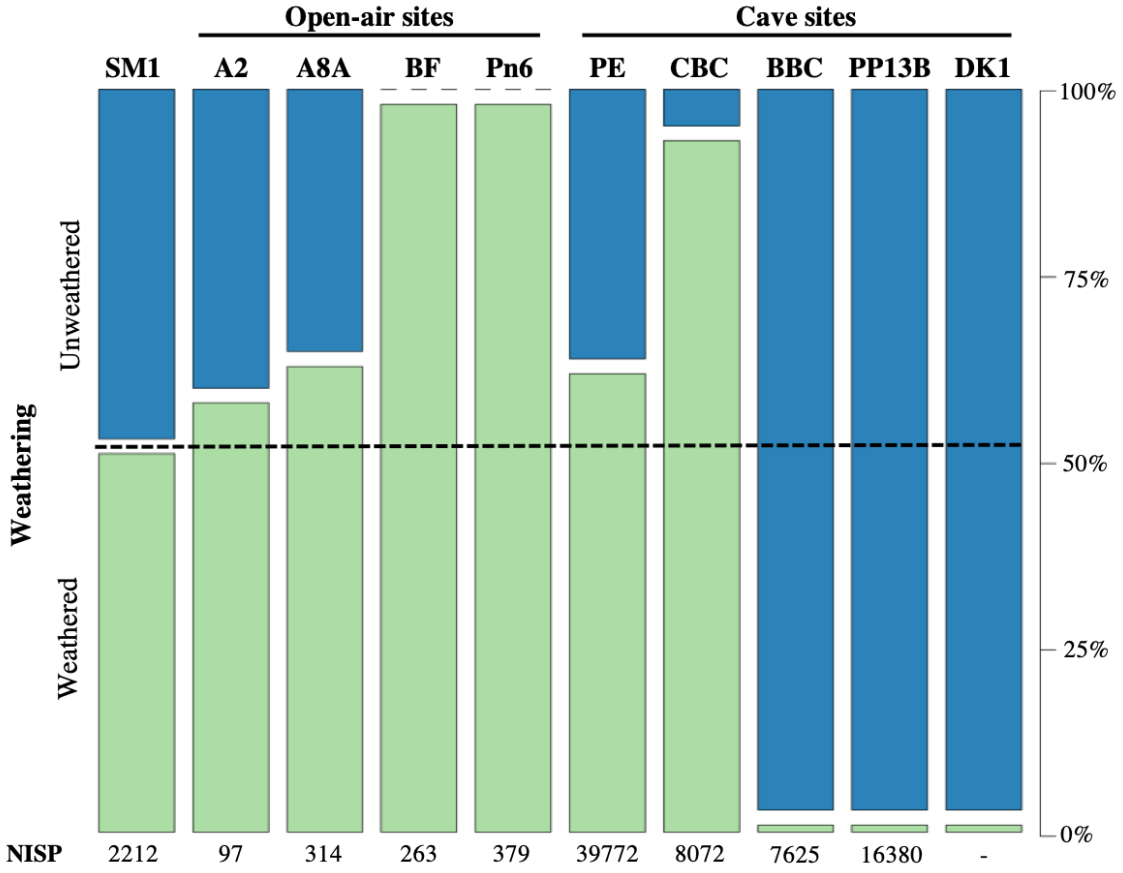

Figure 7.1 Relative frequencies (%) of unweathered versus weathered bone at SM1 and comparative sites. Surface-collected specimens and those < 10 mm excluded for SM1, A2, and A8A. Dotted line denotes the break between categories for SM1. Abbreviations are listed in Table 7.1.

Table 7.3 Relative frequencies (%) of unweathered versus weathered bone at SM1 and comparative sites.

Site	Type	Unweathered	Weathered
SM1	Open-air	47.8	52.2
Aduma A2 (A2)	Open-air	41.2	59.8
Aduma A8A (A8A)	Open-air	36	64
Bundu Farm (BF)	Open-air	0	100
Pniel 6 (Pn6)	Open-air	0	100
Porc Epic (PE)	Cave	36.6	63.4
Contrebandiers (CBC)	Cave	5	95
Blombos Cave (BBC)	Cave	99.8	0.2
Pinnacle Point (PP13B)	Cave	98.9	1.1
Die Kelders 1 (DK1)	Cave	99.9	0.1

Table 7.4 Chi-squared tests of independence between SM1 and comparative sites for frequencies of unweathered versus weathered bone

			Significant associations for SM1	
Site	χ^2	**p-value**	**Unweathered**	**Weathered**
Aduma A2 (A2)	1.37	0.24	None	None
Aduma A8A (A8A)	14.38	< 0.01*	(+)	(-)
Bundu Farm (BF)	217.65	< 0.01*	(+)	(-)
Pniel 6 (Pn6)	306.16	< 0.01*	(+)	(-)
Porc Epic (PE)	110.78	< 0.01*	(+)	(-)
Contrebandiers (CBC)	1754.83	< 0.01*	(+)	(-)
Blombos Cave (BBC)	4424.26	< 0.01*	(-)	(+)
Pinnacle Point (PP13B)	7689.77	< 0.01*	(-)	(+)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site
Cave sites italicized.

For BBC, PP13B, and DK1, the significant result is due to the fact that weathered bone is substantially over-represented across the board at SM1 compared to these sites (Table 7.4) (Specimen counts were not available for DK1, but a highly significant difference with SM1 can be assumed given its similarity to BBC and PP13B in Figure 7.1.) Even if the data are viewed at a finer scale (*e.g.*, unweathered versus light/moderate versus heavy weathering), all categories of weathered bone are substantially more common than expected at SM1 relative to the South African cave sites. Conversely, the opposite is true for A8A, BF, and Pn6, where weathered bone is significantly over-represented compared to SM1. Differences for PE and CBC are also due to higher frequencies of weathered bone at these sites relative to SM1 (Table 7.4). In this case, though, some interesting details emerge when these data are examined at a finer scale.

Sorting the data by unweathered (stage 0), lightly or moderately weathered (stages 1-2), and heavily weathered (stages 3-4) specimens, it is clear that the vast majority of weathering at PE and CBC falls in the light-to-moderate category (Figure 7.2). In fact, at CBC, ~90 % of bones are in weathering stage 1, while weathering stages 2 and 3 make up another ~5% of the sample combined (the other 5% of bones are unweathered). Additionally, at PE and CBC, specimens in the light-to-moderate category are proportionally more common than at SM1 and, accordingly, SM1 also has relatively more heavily weathered bones (Figure 7.2). Partial chi-squared tests further indicate that, for both PE and CBC, lightly-to-moderately weathered specimens are significantly over-represented compared to SM1, while heavily weathered bones are significantly over-represented at SM1. Thus, although SM1 has a lower frequency of weathered specimens than PE and CBC overall and, generally speaking, a fairly low frequency of heavily weathered specimens, it appears that the damage among the weathered sample is somewhat more severe at SM1 than at the two cave sites (Figures 7.1 and 7.2).

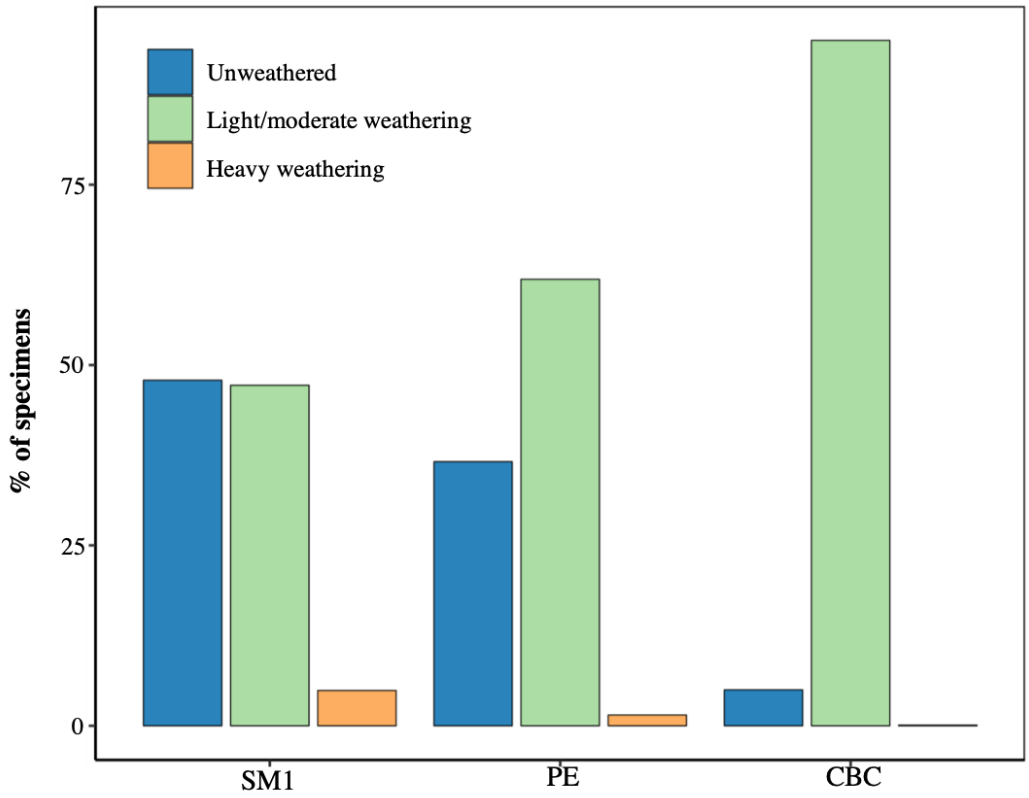

Figure 7.2 Relative frequencies of unweathered (stage 0), lightly/moderately weathered (stages 1 and 2), and heavily weathered (stages 3 and 4) specimens at SM1 and two of the cave sites, Porc Epic (PE) and Contrebandiers Cave (CBC).

Post-depositional damage

Comparative data on dendritic etching, pocking, exfoliation, sheen, and smoothing were available for A2, A8A, CBC, BBC, and PP13B. The percentages of specimens with at least one of the five types of damage and those with no post-depositional damage for SM1 and the comparative sites are depicted visually in Figure 7.3 and listed in Table 7.5. Once again, SM1 is quite different from A8A, CBC, and PP13B for this aspect of bone surface preservation. Moreover, as with weathering, the data indicate higher frequencies of

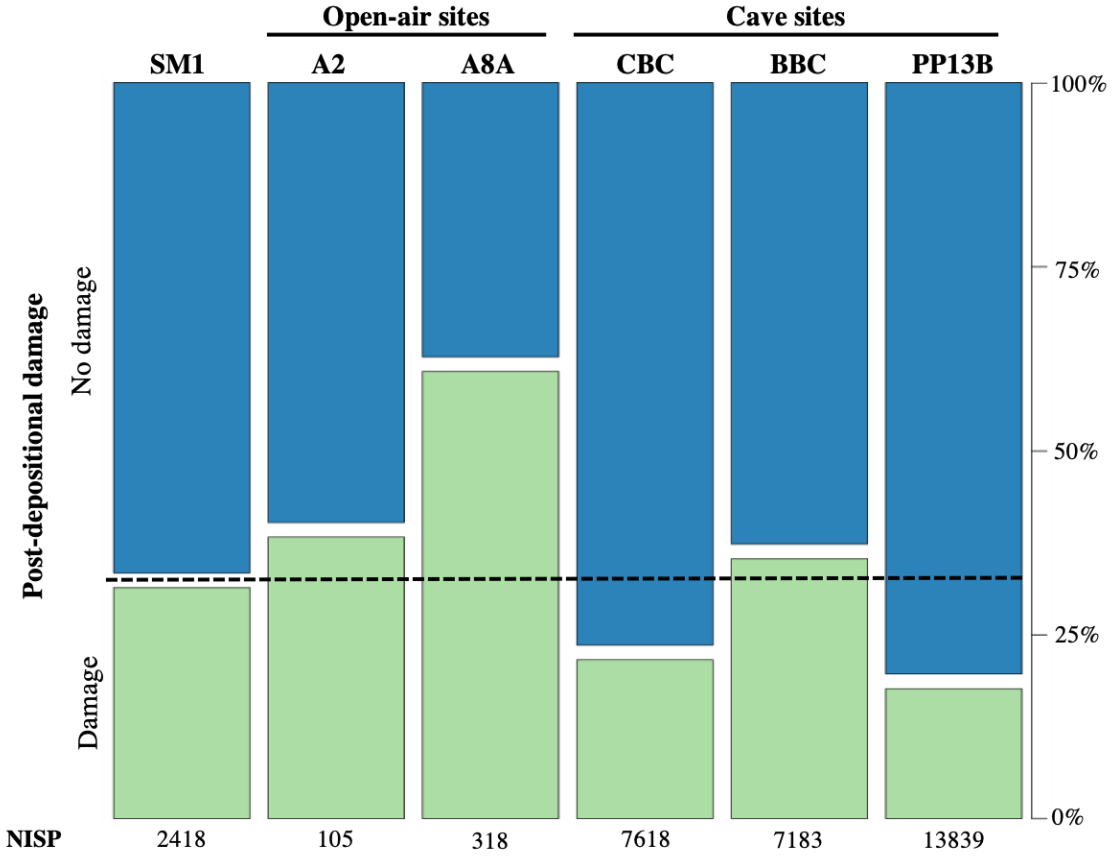

Figure 7.3 Relative frequencies (%) of specimens with and without post-depositional damage at SM1 and comparative sites. Dotted line denotes the break between categories for SM1. Specimens < 10 mm excluded for all sites. Abbreviations listed in Table 7.1.

Table 7.5 Relative frequencies (%) of specimens with and without post-depositional damage at SM1 and comparative sites.

Site	Type	%No damage	% Damaged
SM1	Open-air	68.2	31.8
Aduma A2 (A2)	Open-air	61	39
Aduma A8A (A8A)	Open-air	37.6	62
Contrebandiers (CBC)	Cave	77.6	22.4
Blombos Cave (BBC)	Cave	64.4	35.6
Pinnacle Point (PP13B)	Cave	81.8	18.2

damage at A8A and lower frequencies of damage at PP13B when compared to SM1. This trend is reversed for CBC, which has a higher frequency of weathered bones than SM1, but actually has a lower percentage of bones with various types of post-depositional damage. SM1 is again most comparable to A2 for the frequency of specimens with post-depositional damage and, in this case, also BBC, although it is worth noting that both sites have slightly higher percentages of damaged specimens than SM1 (Figure 7.3 and Table 7.5).

Despite the apparent similarity with both A2 and BBC, chi-squared tests indicate that A2 is the only site for which the differences with SM1 are not statistically significant (Table 7.6). As expected, the results for CBC and PP13B are due to the fact that damaged specimens are over-represented, and undamaged ones under-represented, at SM1 compared to these sites, while the opposite is true for A8A and BBC. That damaged specimens are more common than expected at BBC is driven largely by a high frequency of exfoliation, with 73% of damaged bones, and 26% of the total specimens in the sample analyzed here, having exfoliated surfaces (Table 7.7). In contrast, at A8A the overabundance of damaged specimens results largely from a relatively high number of bones with sheen (~63% of damaged specimens; ~39% of total specimens) and smoothing (~44% of damaged specimens; ~27% of total specimens) (Table 7.7).

Relatively high frequencies of exfoliation are also observed at CBC (93% of damaged specimens; 21% of total specimens) and PP13B (~73% of damaged specimens; 13.3% of total specimens), suggesting this may be a relatively common feature of cave sites (Table 7.7). Exfoliation is also common at SM1, A2, and A8A, although the relative percentages are not nearly as high as for the cave sites, because all other types of damage except dendritic etching are also much more abundant at the open-air sites. SM1, A2, and A8A all have high frequencies of sheen, in particular, and smoothing is also quite frequent

Table 7.6 Chi-squared tests of independence between SM1 and comparative sites for specimens with and without post-depositional (PD) damage

			Significant associations for SM1	
Site	χ^2	**p-value**	**No PD damage**	**PD damage**
Aduma A2 (A2)	2.13	0.14	None	None
Aduma A8A (A8A)	114.32	<.01*	(+)	(-)
Contrebandiers (CBC)	85.13	<.01*	(-)	(+)
Blombos Cave (BBC)	11.43	<.01*	(+)	(-)
Pinnacle Point (PP13B)	233.17	<.01*	(-)	(+)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site
Cave sites italicized

Table 7.7 Frequencies (%) of specimens with each type of post-depositional damage at SM1 and comparative sites

	SM1		**A2**		**A8A**	
Damage	**%Dam.[1]**	**%Total**	**%Dam.[1]**	**%Total**	**%Dam.[1]**	**%Total**
Dendritic	3.3	1.1	0.0	0.0	0.0	0.0
Pocking	22.3	7.7	12.2	4.8	11.6	7.2
Exfoliation	38.9	13.5	34.1	13.3	14.6	9.1
Sheen	29.8	10.3	24.4	9.5	63.3	39.5
Smoothing	10.1	3.5	46.3	18.1	43.7	27.4
	CBC		**BBC**		**PP13B**	
Damage	**%Dam.[1]**	**%Total**	**%Dam.[1]**	**%Total**	**%Dam.[1]**	**%Total**
Dendritic	6.9	1.6	13.2	4.7	1.1	0.2
Pocking	0.0	0.0	7.4	2.6	3.9	0.7
Exfoliation	93.3	21.0	73.0	26.0	72.9	13.3
Sheen	2.1	0.5	8.5	3.0	8.7	1.6
Smoothing	3.1	0.7	5.3	1.9	20.1	3.7

[1]Percentage of specimens with post-depositional damage; percentages do not sum to 100% because some specimens have more than one type of damage.
Specimens < 10 mm in maximum length excluded for all samples.
Abbreviations listed in Table 7.1.

at A2 and A8A. That sheen and smoothing are more prevalent at SM1, A2, and A8A than the cave sites is not that surprising, given that all three are located in riverine environments, and both sheen and smoothing are often associated with exposure to, and/or transport by, running water (Lyman, 1994; Thompson, 2005; Fernandez-Jalvo and Andrews, 2016). The particularly high frequencies of smoothing at A2 and A8A suggest that many of the bones from these sites were subject to some degree of water-borne transport.

Thermal alteration

The frequencies of unburned and burned bone at SM1 were compared to eight other MSA sites, but the HP and post-HP MSA layers at SC were analyzed separately, so nine pairwise comparisons were actually performed. Out of these nine comparisons, burned bone is proportionally more abundant at SM1 in five cases, and less abundant at SM1 in the remaining four cases (Figure 7.4 and Table 7.8). With respect to other open-air sites, both A2 and A8A have higher percentages of burned bone than SM1, but the reverse is true for BF, at which burned specimens are exceedingly rare. Both SC-HP and SC-MSA also have higher frequencies of burned bone than SM1, while burning is less frequent at all the other cave sites compared to SM1 (Figure 7.4 and Table 7.8).

Chi-squared tests indicate that differences between SM1 and all of the comparative sites for the frequency of unburned versus burned bone are highly significant (Table 7.9). For BF, PE, CBC, BBC, and PP13B, this result is due to the fact that burned bone is significantly less common, and unburned bone more common, at these sites when compared to SM1. Conversely, A2, A8A, SC-HP, and SC-MSA all have significantly more burned bone and less unburned bone than SM1. It is also possible to analyze these data at a finer scale for A2, A8A, BBC, and PP13, using the frequency of carbonized and calcined

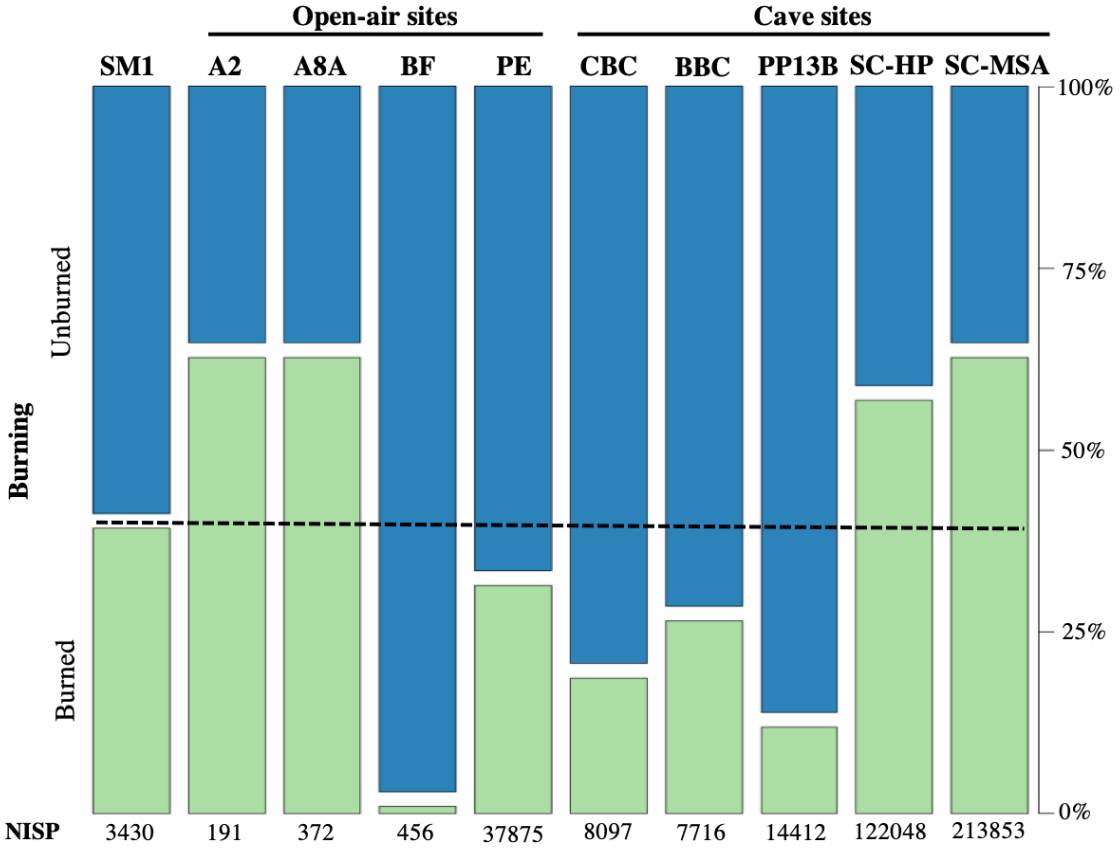

Figure 7.4 Relative frequencies (%) of unburned versus burned bone at SM1 and comparative MSA sites. Surface-collected specimens excluded for SM1, A2, and A8A. Abbreviations listed in Table 7.1.

specimens within the burned sample. Examining the data in this way reveals that the frequency of calcined specimens at SM1 is higher than at all four of the other sites and, interestingly, BBC and PP13B (*i.e.,* the cave sites) are actually more similar to SM1 than A2 and A8A (*i.e.,* the open-air sites) in this respect (Figure 7.5). For BBC and PP13B, this finding simply indicates that burning is both more frequent and more severe overall at SM1, albeit by a much smaller margin for BBC (Figures 7.4 and 7.5).

Table 7.8 Relative frequency (%) of unburned versus burned bone at SM1 and comparative sites.

Site	Type	Unburned	Burned
SM1	Open-air	62.3	37.7
Aduma A2 (A2)	Open-air	35.6	64.4
Aduma A8A (A8A)	Open-air	36.2	63.8
Bundu Farm (BF)	Open-air	98.7	1.3
Porc Epic (PE)	Cave	68	32
Contrebandiers (CBC)	Cave	81.3	18.7
Blombos Cave (BBC)	Cave	72.7	27.3
Pinnacle Point (PP13B)	Cave	88	12
Sibudu HP (SC-HP)	Cave	41.6	58.4
Sibudu post-HP MSA (SC-MSA)	Cave	35.9	64.1

Table 7.9 Chi-squared tests of independence between SM1 and comparative sites for frequencies of unburned versus burned bone.

			Significant associations for SM1	
Site	χ^2	**p-value**	**Unburned**	**Burned**
Aduma A2	45.15	< .01*	(+)	(-)
Aduma A8A	79.38	< .01*	(+)	(-)
Bundu Farm	256.87	< .01*	(-)	(+)
Porc Epic	81.49	< .01*	(-)	(+)
Contrebandiers (CBC)	562.05	< .01*	(-)	(+)
Blombos Cave (BBC)	167.45	< .01*	(-)	(+)
Pinnacle Point (PP13B)	1268.69	< .01*	(-)	(+)
Sibudu HP (SC-HP)	486.01	< .01*	(+)	(-)
Sibudu post-HP MSA (SC-MSA)	878.93	< .01*	(+)	(-)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site
Cave sites italicized.

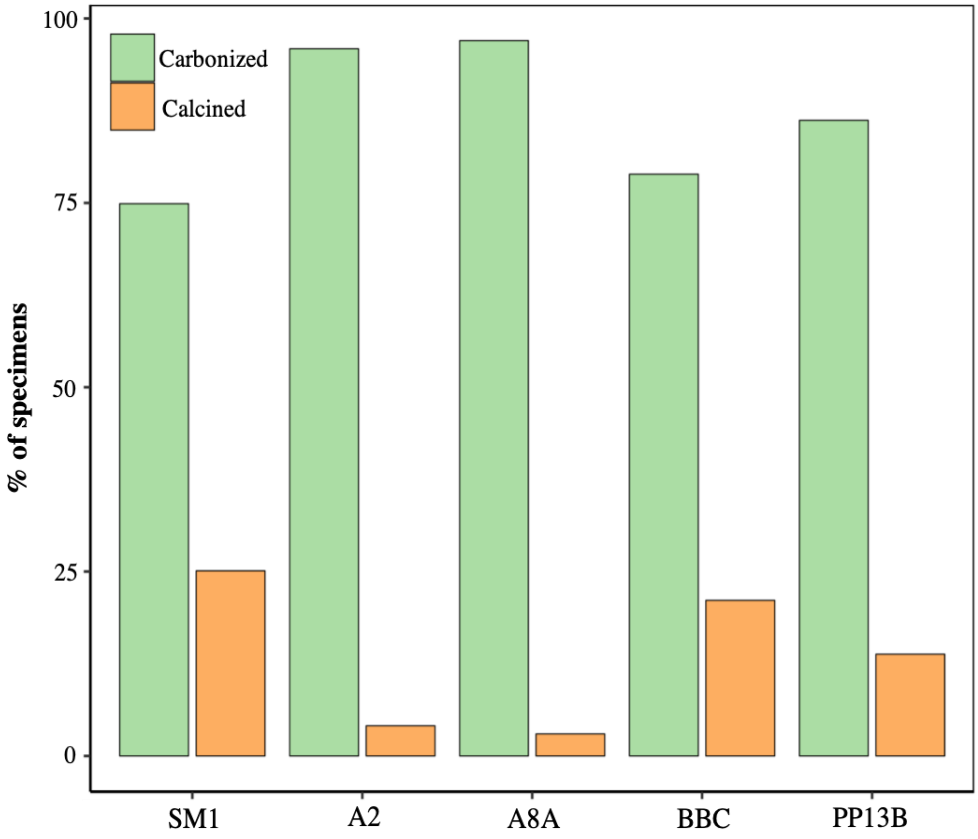

Figure 7.5 Relative frequencies (%) of carbonized and calcined bone at SM1, Aduma A2 (A2), Aduma A8A (A8A), Blombos Cave (BBC), and Pinnacle Point 13B (PP13B). Percentages based on total burned specimens only.

For A2 and A8A, the intensity of burning actually appears to be much lower than at SM1, despite the fact that A2 and A8A have higher frequencies of burned bone overall (Figure 7.5). This conclusion is further supported by the fact that the maximum burning stage observed at both A2 and A8A is localized calcination, while SM1 contains specimens at all three levels of calcination, including 164 moderately and fully calcined bones (Table 5.16). Additionally, many of the bones from A2 and A8A had a uniform dark brown color which, at least in some cases, may have actually resulted from chemical staining rather

than burning. As such, it is possible that the percentage of carbonized specimens given here for A2 and A8A and, by extension, the frequency of burned bone overall at these two sites, is actually an overestimate. That calcined bone is substantially more abundant at SM1 potentially indicates a weaker human imprint on the fauna from A2 and A8A. In fact, given that almost all of the bones are only carbonized, it is possible that much of the burning at A2 and A8A is actually the result of natural fires rather than human activity.

Fragmentation

As already discussed in Chapters 5 and 6, with very few exceptions, the bones of terrestrial fauna and fish are extensively fragmented at SM1, and humans are the most likely source for most of the fragmentation. Moreover, at first glance, it appears that the sheer extent of bone fragmentation may be one of the more distinctive and unique features of the site. In order to test this possibility further, maximum specimen length (ML) data from SM1 were compared to A2, A8A, CBC, BBC, and PP13B (*i.e.,* all sites for which raw data on fragment size were available) as a proxy for the general extent of bone fragmentation at each site.

Histograms of ML and basic summary statistics for SM1 and each of the comparative sites are depicted in Figures 7.6-7.10 and listed in Table 7.10. Several points stand out from inspection of these data. First, mean ML at SM1 is smaller than all of the comparative sites, with a maximum difference of 14.39 mm between A8A and SM1, and minimum difference of 2.35 mm between SM1 and A2. The average difference in ML between SM1 and all the comparative sites is 10.33 mm. Second, BBC and PP13B, both of which have specimens measured at 1 mm long, are the only comparative sites where the minimum specimen length is smaller than at SM1. Likewise, the largest specimens at A8A, CBC, BBC, and PP13B are between ~90-225 mm larger than those at SM1 and, on average,

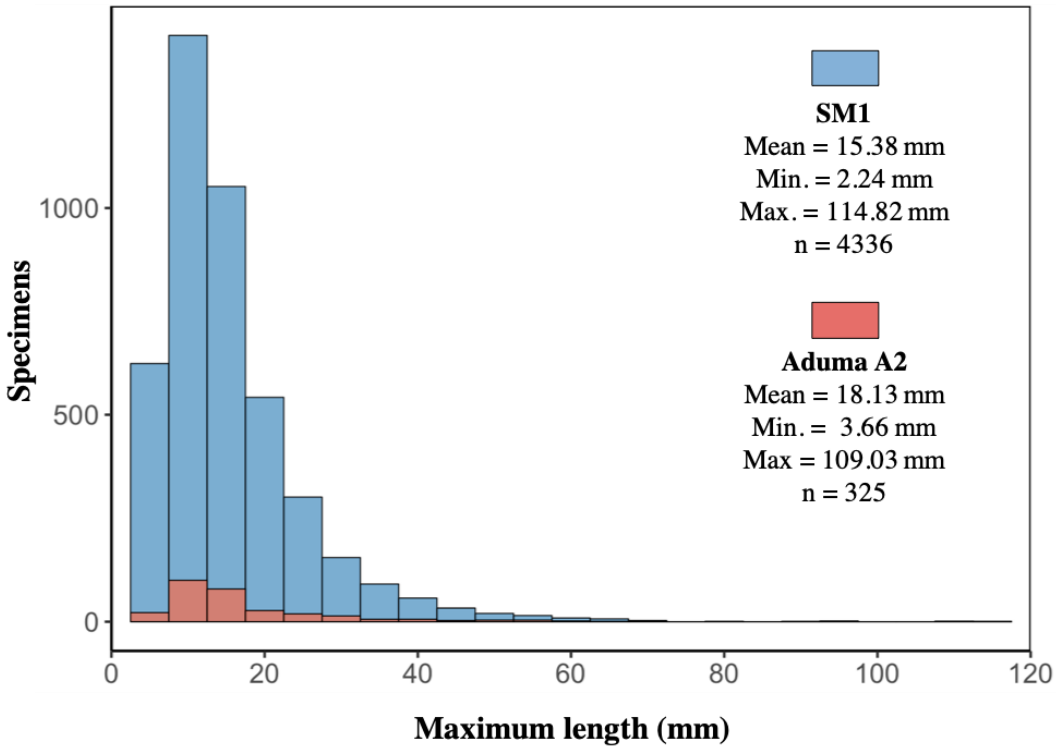

Figure 7.6 Maximum length of terrestrial faunal specimens from SM1 and A2

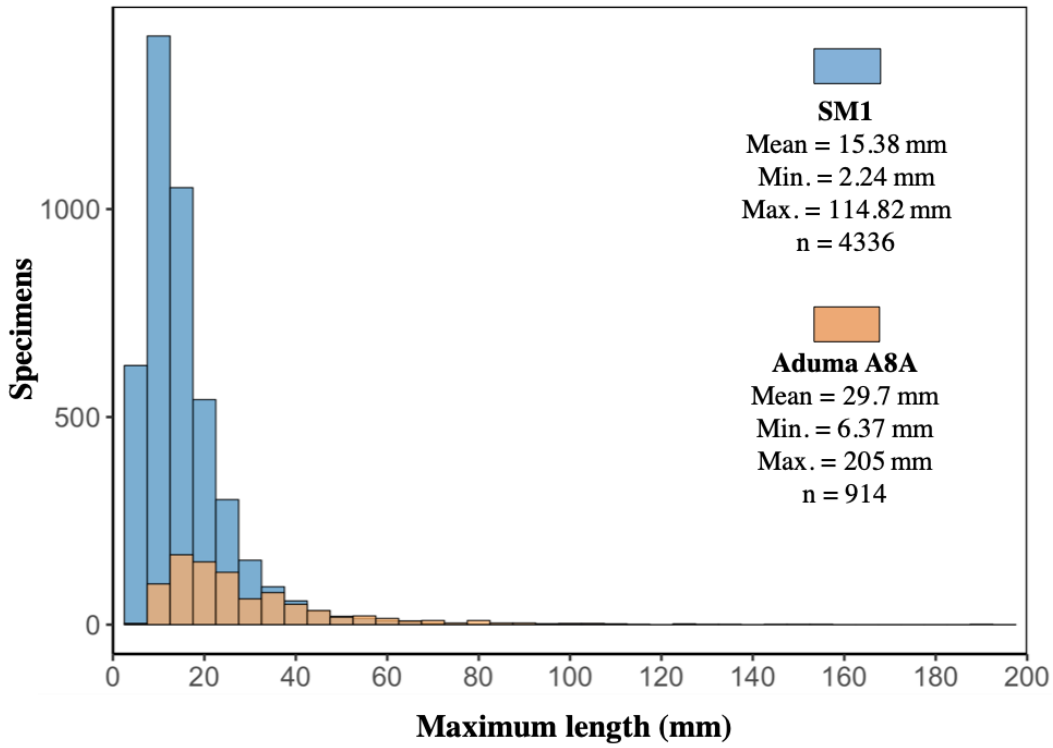

Figure 7.7 Maximum length of terrestrial faunal specimens from SM1 and A8A. One very large (i.e., 200+ mm) specimen from A8A not plotted here.

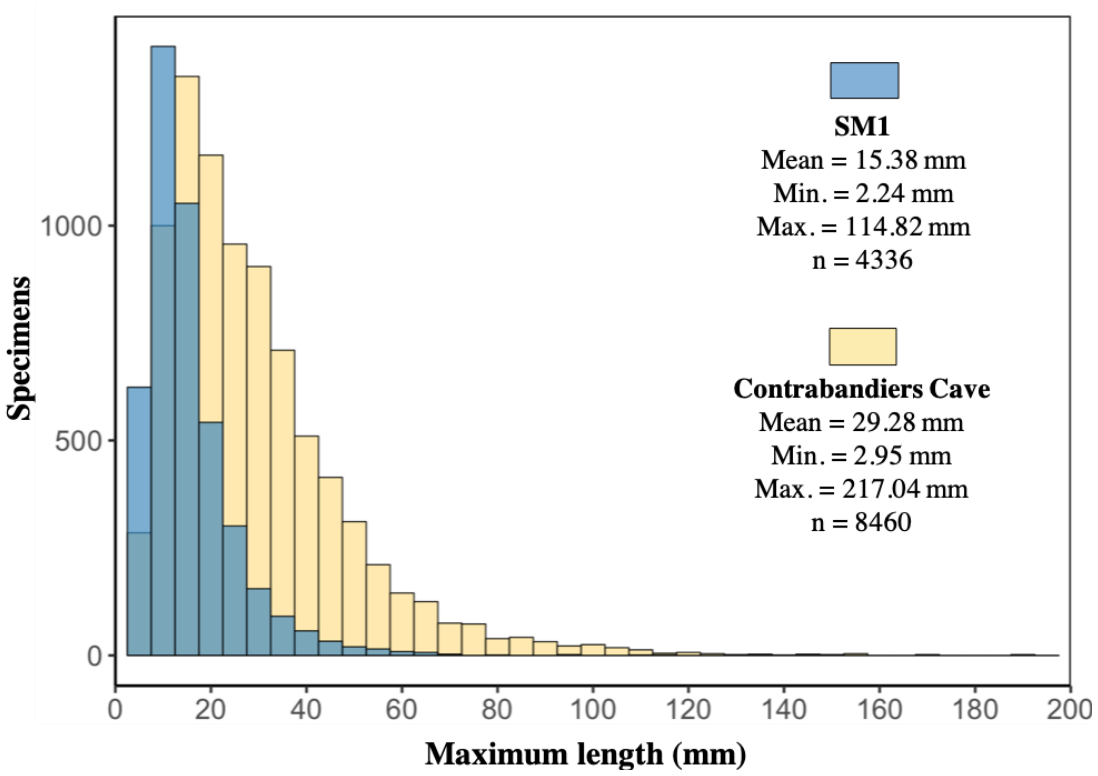

Figure 7.8 Maximum length of terrestrial faunal specimens from SM1 and CBC. Three very large (*i.e.,* 200+ mm) specimens from CBC not plotted here. Blue bars for SM1 are slightly transparent so that the first two bars for CBC are also visible behind them.

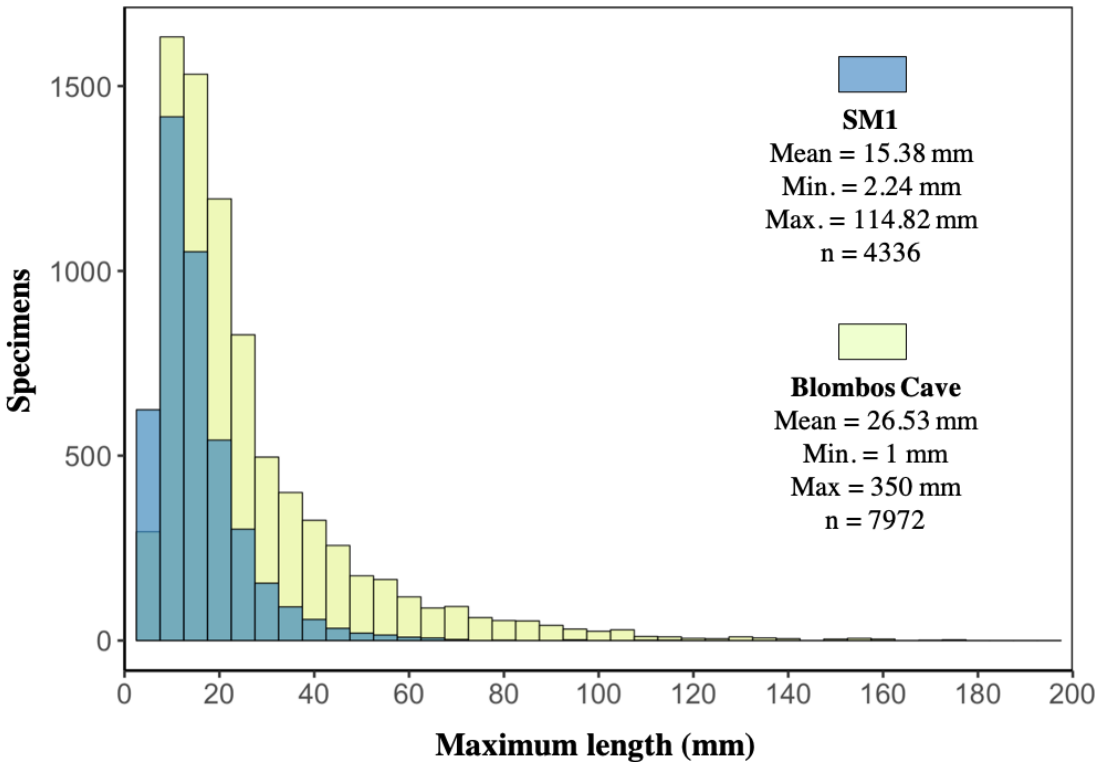

Figure 7.9 Maximum length of terrestrial faunal specimens from SM1 and BBC. Four very large (*i.e.,* 200+ mm) specimens from BBC not plotted here. Blue bars for SM1 are slightly transparent so that the first bar for BBC is also visible behind them.

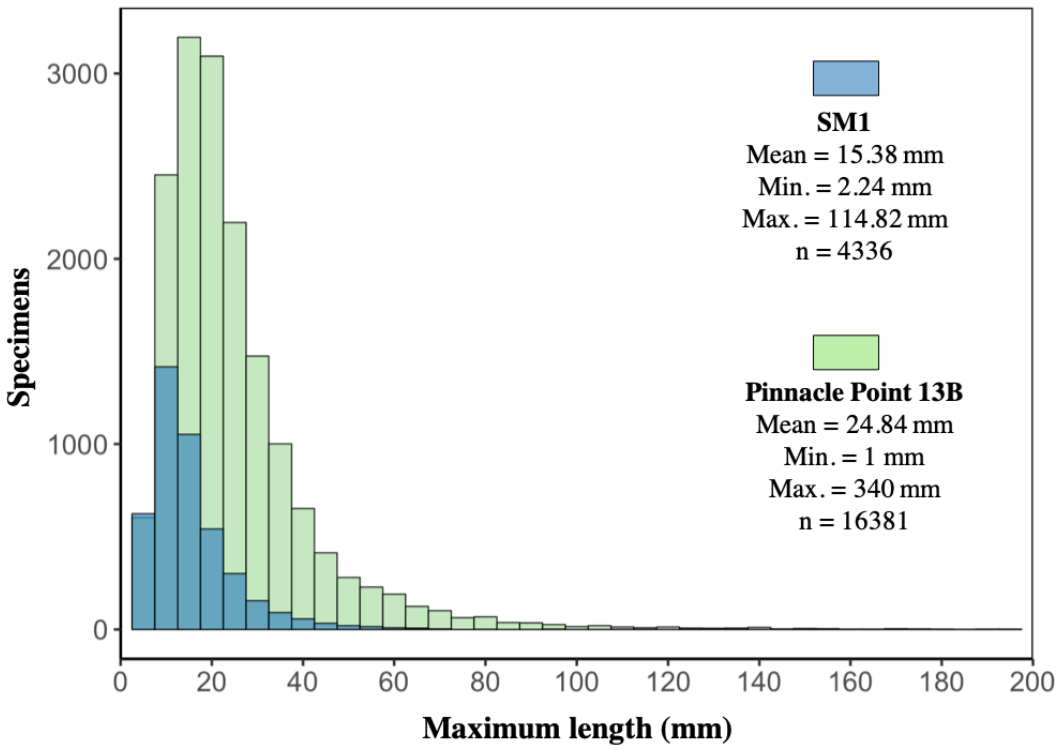

Figure 7.10 Maximum length of terrestrial faunal specimens from SM1 and PP13B. Nine very large (*i.e.,* 200+ mm) specimens from PP13B not plotted here. Blue bars for SM1 are slightly transparent so that the first bar for PP13B is also visible behind them.

Table 7.10 Summary statistics for terrestrial faunal specimen length at SM1 and comparative sites.

		Fragment size (mm)		
Site	**Type**	**Mean**	**Min.**	**Max.**
SM1	Open-air	15.38	2.24	114.82
Aduma A2	Open-air	18.13	3.66	109.03
Aduma A8A	Open-air	29.77	6.37	205
Contrebandiers Cave	Cave	29.28	2.95	217.04
Blombos Cave	Cave	26.53	1	350
Pinnacle Point 13B	Cave	24.84	1	340

the largest specimens at these sites are ~163 mm longer than those at SM1. Generally speaking, then, the data in Figures 7.6-7.10 and Table 7.10 do suggest that SM1 is unique compared to the other sites in having an unusually high degree of fragmentation, at least as measured by overall specimen lengths. This possibility can be investigated further by examining the frequency of specimens in different size categories.

There is a wide range of variation in ML across the six sites and, as just discussed, many of the comparative sites have specimens that far exceed the ML observed at SM1. Thus, rather than use the 10-mm-interval categories employed in Chapters 5 and 6, specimens were instead sorted into small (< 20 mm), medium (20-60 mm), and large (60+ mm) categories for the analyses presented here. Grouping specimens in this way makes it possible to assess overall levels of fragmentation between sites, while ensuring that all categories have sufficient sample sizes for each site. Using small, medium, and large groups also makes the analyses more manageable, and the interpretations more straightforward, than they would be if numerous 10-mm-interval (or even 20- or 30-mm-interval) categories were employed.

Unsurprisingly, SM1 has a much higher frequency of small fragments, and a much lower frequency of both medium and large fragments, than most of the comparative sites (Table 7.11 and Figure 7.11). It should be noted here that all mammal, reptile, bird, and amphibian specimens from each site were included, so some of the specimens in the samples analyzed here are partial or complete elements, and not fragments *per se*. The only exception is A2, which has very similar percentages of both small and medium fragments to SM1, as well as the next-lowest frequency of large fragments after SM1.

Chi-squared tests indicate that differences in the frequency of fragment size categories between SM1 and all of the comparative sites are statistically significant (Table 7.12). In the case of A2, there is no significant difference for the number of small- or medium-sized fragments, but large fragments are significantly over-represented compared to SM1. For A8A, CBC, BBC, and PP13B, the associations for all three size categories are significant, with small fragments less common than expected, and medium and large fragments more common than expected, at these sites relative to SM1. These data once again support the position that SM1 has an unusually high frequency of very small specimens, particularly compared to A8A and the three cave sites (Figure 7.11 and Tables 7.11 and 7.12). Given that most of the specimens with ML < 20 mm, in particular, are almost certainly tiny fragments of bone and tooth in all cases (*e.g.,* rather than complete microfaunal elements), this indicates that SM1 also has distinctively high levels of fragmentation relative to the comparative sites.

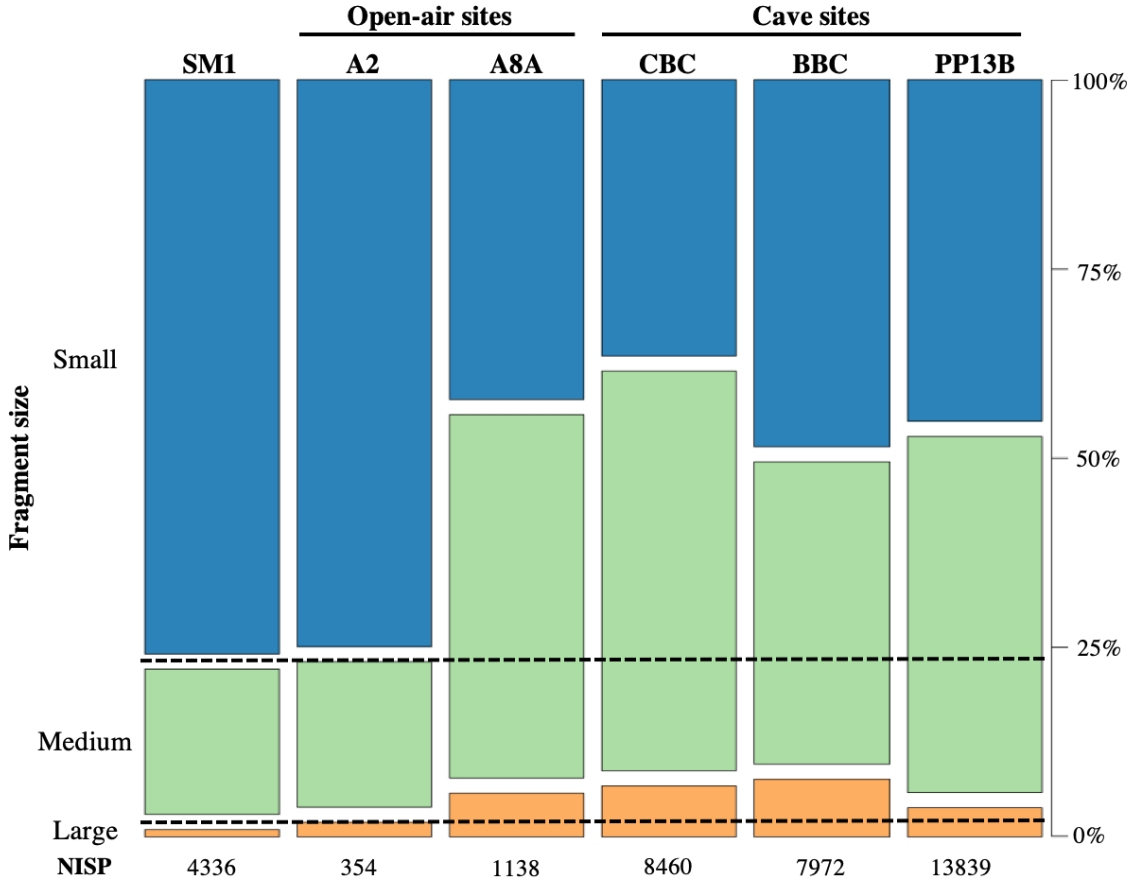

Figure 7.11 Relative frequencies (%) of small (<20 mm), medium (20-60 mm), and large (60+ mm) fragments at SM1 and comparative sites. Abbreviations listed in Table 7.1.

Table 7.11 Relative frequency (%) of small, medium, and large fragments at SM1 and comparative sites.

Site	Type	Small	Medium	Large
SM1	Open-air	78.8	20.7	0.5
Aduma A2 (A2)	Open-air	77.7	20.3	2.0
Aduma A8A (A8A)	Open-air	44.5	49.9	5.6
Contrebandiers (CBC)	Cave	38.2	55.1	6.7
Blombos Cave (BBC)	Cave	50.6	41.6	7.8
Pinnacle Point 13B (PP13B)	Cave	46.7	49.0	4.3
Small = < 20 mm; Medium = 20-60 mm; Large = 60+ mm				

Table 7.12 Chi-squared tests of independence between SM1 and comparative sites for fragment size categories.

			Significant associations for SM1		
Site	χ^2	**p-value**	**Small**	**Medium**	**Large**
Aduma A2 (A2)	12.3	< .01*	None	None	(-)
Aduma A8A (A8A)	589.5	< .01*	(+)	(-)	(-)
Contrebandiers (CBC)	1931.9	< .01*	(+)	(-)	(-)
Blombos Cave (BBC)	1017.4	< .01*	(+)	(-)	(-)
Pinnacle Point 13B (PP13B)	1439.7	< .01*	(+)	(-)	(-)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site
Small = < 20 mm; Medium = 20-60 mm; Large = 60+ mm
Cave sites italicized.

Long bone fracture morphology

Comparative analyses of long bone fracture angle and outline frequencies may also reveal important information about differences in the nature and/or timing of fragmentation at SM1 and other MSA sites (Villa and Mahieu, 1991; Marean *et al.,* 2000). Comparisons with experimental assemblages created by humans and non-human carnivores in Chapter 5 suggest that frequencies of fractures with right angles and transverse outlines at SM1, both of which indicate non-nutritive breakage, may be quite a bit higher than typically expected for sites where fragmentation is largely nutritive. The pattern at SM1 also appears to contrast rather sharply with previous studies of several MSA cave sites, where human nutritive destruction is the primary cause of fragmentation and the overwhelming majority of long bones have fractures with oblique angles and curved/v- shaped outlines, which are typical of fresh bone breakage (Marean *et al.,* 2000l Assefa, 2002; Thompson, 2010; Thompson and Henshilwood, 2011).

As might be expected from the above discussion, the cave sites of PE, PP13B, and DK1 all have much lower frequencies of fractures with right angles, and correspondingly higher frequencies of fractures with oblique angles, than SM1 (Table 7.13 and Figure 7.12). Right angle fractures are also less frequent, and oblique angles more frequent, at BBC than they are at SM1, although in this case the percentages are actually quite similar between the two sites. CBC is an outlier among the cave sites in having many more fractures with right angles and far fewer with oblique angles, relatively speaking, than SM1. Likewise, all of the open-air sites have frequencies of right-angle fractures that are either similar to (*e.g.,* A8A) or higher than (*e.g.,* A2, BF, Pn6) SM1; accordingly, the frequencies of oblique fracture angles at these sites are also similar to or lower than those at SM1 (Table 7.13 and Figure 7.12).

Table 7.13 Relative frequencies (%) of fracture angle and outline types at SM1 and comparative sites.

		Fracture angles		**Fracture outlines**	
Site	**Type**	**Oblique**	**Right**	**Curved/V**	**Transverse**
SM1	Open-air	69.8	30.2	54.2	45.8
Aduma A2 (A2)	Open-air	59.5	40.5	57.9	42.1
Aduma A8A (A8A)	Open-air	73	27	59.3	40.7
Bundu Farm (BF)	Open-air	55.5	44.5	77.1	22.9
Pniel 6 (Pn6)	Open-air	64.7	35.3	78.7	21.3
Porc Epic (PE)	Cave	96.3	3.7	95.7	4.3
Contrebandiers (CBC)	Cave	53.4	46.6	53.3	46.7
Blombos Cave (BBC)	Cave	71.4	28.6	76.7	23.3
Pinnacle Point 13B (P13B)	Cave	78.5	21.5	79.1	20.9
Die Kelders 1 (DK1)	Cave	79.7	20.3	79.3	20.7
Percentages based on specimens with oblique and right angles and curved/V-shaped and transverse outlines only.					

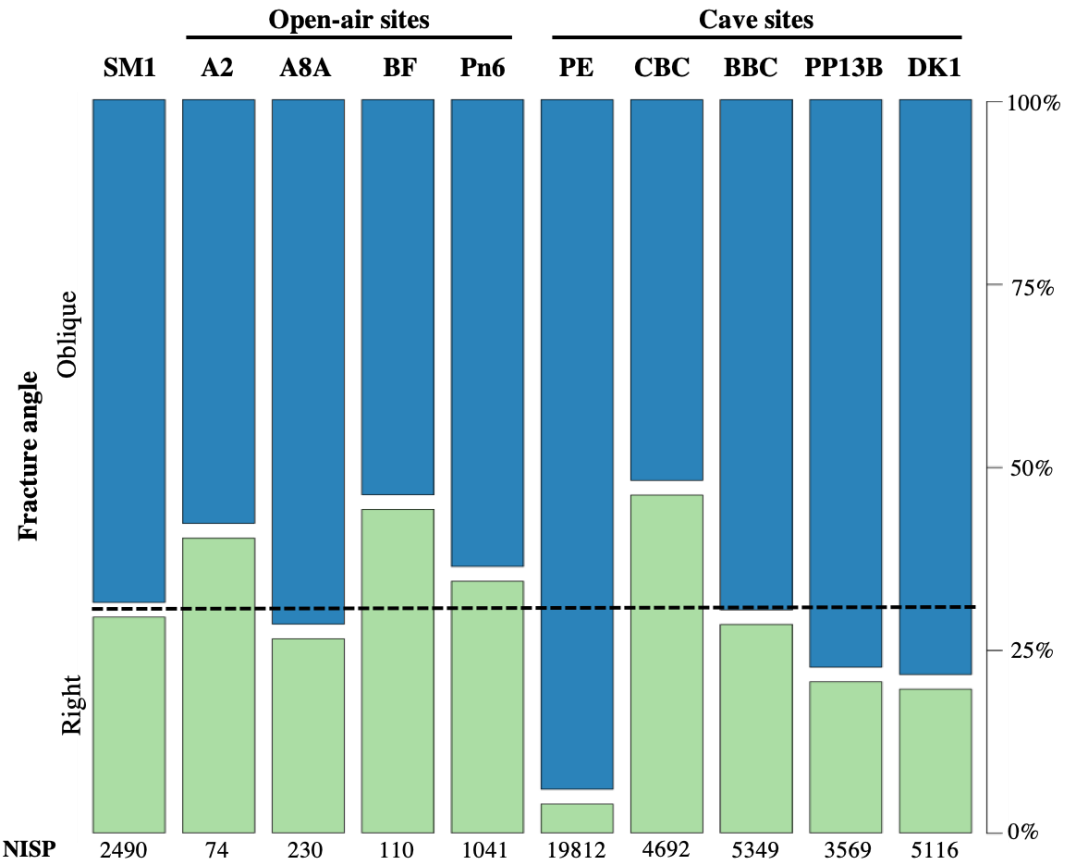

Figure 7.12 Relative frequencies (%) of long bones with oblique versus right fracture angles at SM1 and comparative MSA sites. All percentages sum to 100%. Abbreviations listed in Table 7.1.

When fracture outlines are considered, the pattern is similar for cave sites (Table 7.13 and Figure 7.13). PE, BBC, PP13B, and DK1 all have substantially lower frequencies of transverse outlines (*i.e.,* the morphology associated with non-nutritive breakage), and higher frequencies of curved/v-shaped outlines (*i.e.,* the morphology typical of nutritive breakage), than SM1. Once again, CBC is the outlier among the cave sites, and in this case actually has frequencies of curved/v-shaped and transverse outlines that are almost identical to SM1, although transverse outlines are still slightly less common at SM1 (and

curved/v-shaped outlines correspondingly more common). Additionally, transverse outlines are less frequent, and curved/v-shaped outlines more frequent, at all of the open-air sites relative to SM1. This is particularly interesting for A2, BF, and Pn6, because the opposite pattern was observed among these sites for fracture angles. In other words, compared to SM1, all three of these sites have higher frequencies of the fracture angle morphology indicative of non-nutritive breakage, but lower frequencies of the fracture outline morphology typical of non-nutritive breakage (Figure 7.13).

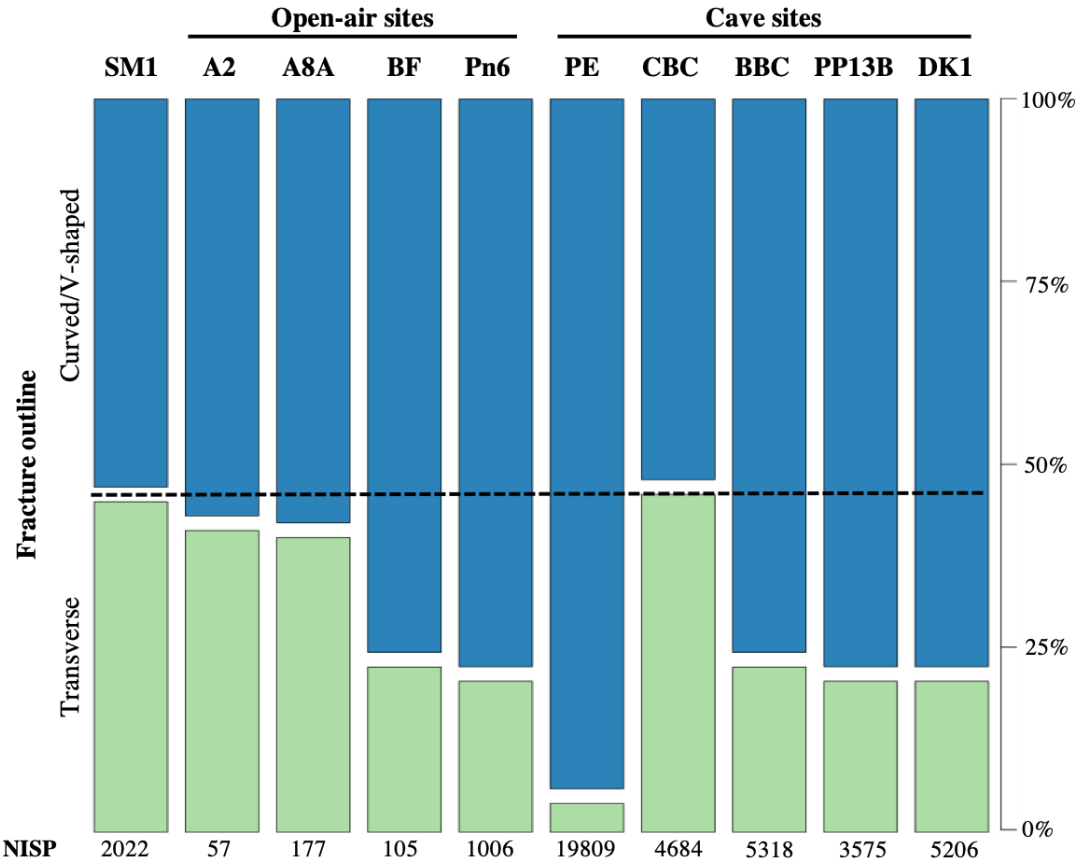

Figure 7.13 Relative frequencies (%) of long bones with curved/v-shaped versus transverse fracture outlines at SM1 and comparative MSA sites. All percentages sum to 100%. Abbreviations listed in Table 7.1.

Chi-squared tests indicate that BF, Pn6, PE, CBC, PP13B, and DK1 are all significantly different from SM1 with respect to frequencies of oblique- and right-angle fractures (Table 7.14). Conversely, the differences in fracture angle frequencies between SM1 and A2, A8A, and BBC are all non-significant. Oblique angles are significantly more common, and right angles less common, than expected at SM1 when compared to the open-air sites of BF and Pn6, and the cave site of CBC, while the opposite is true for PE, PP13B, and DK1. A similar pattern is observed for fracture outline frequencies, with all of the sites being significantly different from SM1 except A2, A8A, and a single cave site, although in this case it is CBC rather than BBC (Table 7.15). Moreover, all of the significant differences are now in the same direction, and reflect the fact that transverse fracture outlines are substantially over-represented, and curved/v-shaped outlines correspondingly under-represented, at SM1 compared to BF, Pn6, PE, BBC, PP13B, and DK1 (Figure 7.13 and Table 7.15).

Table 7.14 Chi-squared tests of independence between SM1 and comparative sites for fracture angle frequencies.

			Significant associations for SM1	
Site	χ^2	**p-value**	**Oblique**	**Right**
Aduma A2 (A2)	3.18	0.07	None	None
Aduma A8A (A8A)	0.88	0.35	None	None
Bundu Farm (BF)	9.57	< .01*	(+)	(-)
Pniel 6 (Pn6)	8.57	< .01*	(+)	(-)
Porc Epic (PE)	2474.24	< .01*	(-)	(+)
Contrebandiers (CBC)	181.88	< .01*	(+)	(-)
Blombos Cave (BBC)	1.83	0.18	None	None
Pinnacle Point 13B (PP13B)	57.85	< .01*	(-)	(+)
Die Kelders 1 (DK1)	90.97	< .01*	(-)	(+)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site.
Cave sites italicized.

Table 7.15 Chi-squared tests of independence between SM1 and comparative sites for fracture outline frequencies.

			Significant associations for SM1	
Site	χ^2	**p-value**	**Curved/V**	**Transverse**
Aduma A2 (A2)	0.17	0.68	None	None
Aduma A8A (A8A)	1.52	0.22	None	None
Bundu Farm (BF)	20.33	< .01*	(-)	(+)
Pniel 6 (Pn6)	171.07	< .01*	(-)	(+)
Porc Epic (PE)	4220.45	< .01*	(-)	(+)
Contrebandiers (CBC)	0.42	0.52	None	None
Blombos Cave (BBC)	354.8	< .01*	(-)	(+)
Pinnacle Point 13B (PP13B)	381.94	< .01*	(-)	(+)
Die Kelders 1 (DK1)	457.92	< .01*	(-)	(+)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site
Cave sites italicized.

Surface modification

Examining frequencies of human (*i.e.,* cut + percussion marks) and non-human carnivore (*i.e.,* tooth marks) surface modification reveals striking contrasts between: 1) SM1 and all of the cave sites; and 2) open-air and cave sites in general. When comparing the frequency of modified specimens as a percentage of the total sample, SM1 has much lower frequencies of human and carnivore modification overall than all three of the cave sites for which data were available (Figure 7.14 and Table 7.16). More specifically, CBC (20.1%), BBC (21.4%), and PP13B (30.5%) all have percentages of human modified specimens that are approximately three to five times higher than SM1 (6.7%). Likewise, all three cave sites have slightly higher frequencies of carnivore modification (CBC = 5%; BBC = 7.9%; PP13B = 5.5%) than were observed at SM1 (4.7%). Conversely, both human and carnivore damage are quite rare at the four other open-air sites (A2, A8A, BF, Pn6),

and both types of modification are therefore much less common than at SM1. Carnivore damage is also slightly more common than human damage at A2, A8A, and BF, while Pn6 has equal percentages of each type of modification. However, any interpretations of surface modification frequencies at A2, A8A, BF, and Pn6 should be taken with appropriate caution and viewed as tentative at best because of the very small samples of specimens with identified modification marks for all four of these sites (Figure 7.14 and Table 7.16).

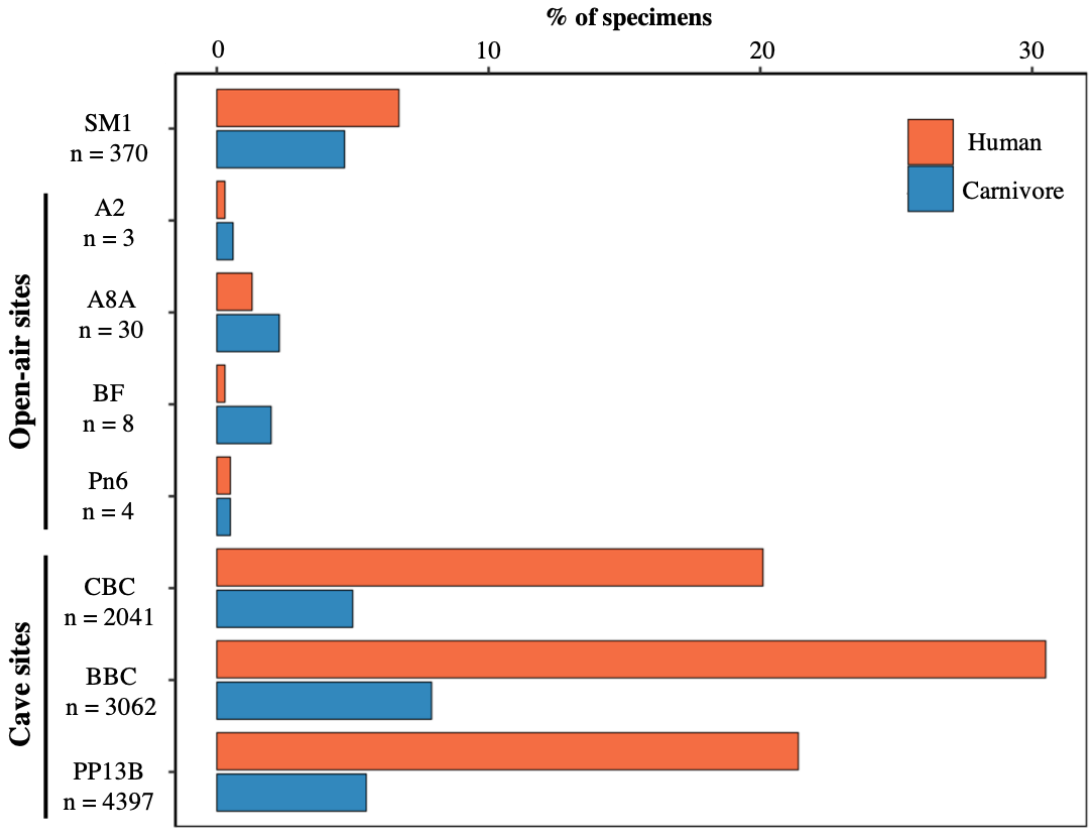

Figure 7.14 Frequencies (%) of total specimens with human and carnivore damage for SM1 and comparative sites. Frequencies were calculated by dividing the number of specimens with human and/or carnivore damage (n) by the total number of specimens examined for each site. Specimens with multiple mark types are counted once for each type of modification. Abbreviations listed in Table 7.1.

Table 7.16 Frequencies (%) of specimens with human and carnivore modification at SM1 and comparative sites.

			%Total[1]		%Modified[2]	
Site	**Type**	**NISP**	**HM**	**TM**	**HM**	**TM**
SM1	Open-air	3234	6.7	4.7	58.9	41.1
Aduma A2 (A2)	Open-air	325	0.3	0.6	33.3	66.7
Aduma A8A (A8A)	Open-air	834	1.3	2.3	36.7	63.3
Bundu Farm (BF)	Open-air	344	0.3	2	12.5	87.5
Pniel 6 (Pn6)	Open-air	419	0.5	0.5	50	50
Contrebandiers (CBC)	Cave	8106	20.1	5	80	20
Blombos Cave (BBC)	Cave	7968	30.5	7.9	79.4	20.6
Pinnacle Point 13B (PP13B)	Cave	16383	21.4	5.5	79.5	20.5

[1]Percentage out of total specimens analyzed (NISP)
[2]Relative percentage of modified specimens only
HM = cut + percussion marks; TM = tooth marks

The surface modification data present a somewhat different picture when the relative percentages of human and carnivore damage are considered among the modified sample only, rather than as a percentage of total specimens (Figure 7.15 and Table 7.16). In this case, SM1 is actually much more similar to CBC, BBC, and PP13B with respect to the frequency of specimens with human cut and percussion marks, although all three of the comparative sites still have ~20% higher frequencies of human-modified specimens than SM1. Accordingly, the percentage of specimens with carnivore tooth marks at SM1 is now ~20% higher than it is at CBC, BBC, and PP13B, as well. Unsurprisingly, the relative frequencies of human-modified specimens are much higher at SM1 than at A2, A8A, BF, and Pn6, and SM1 therefore also has a lower relative frequency of carnivore modification than all four of these sites. However, it is once again important to bear in mind the very small sample sizes for A2, A8A, BF, and Pn6 when interpreting these comparisons (Figure 7.15 and Table 7.16).

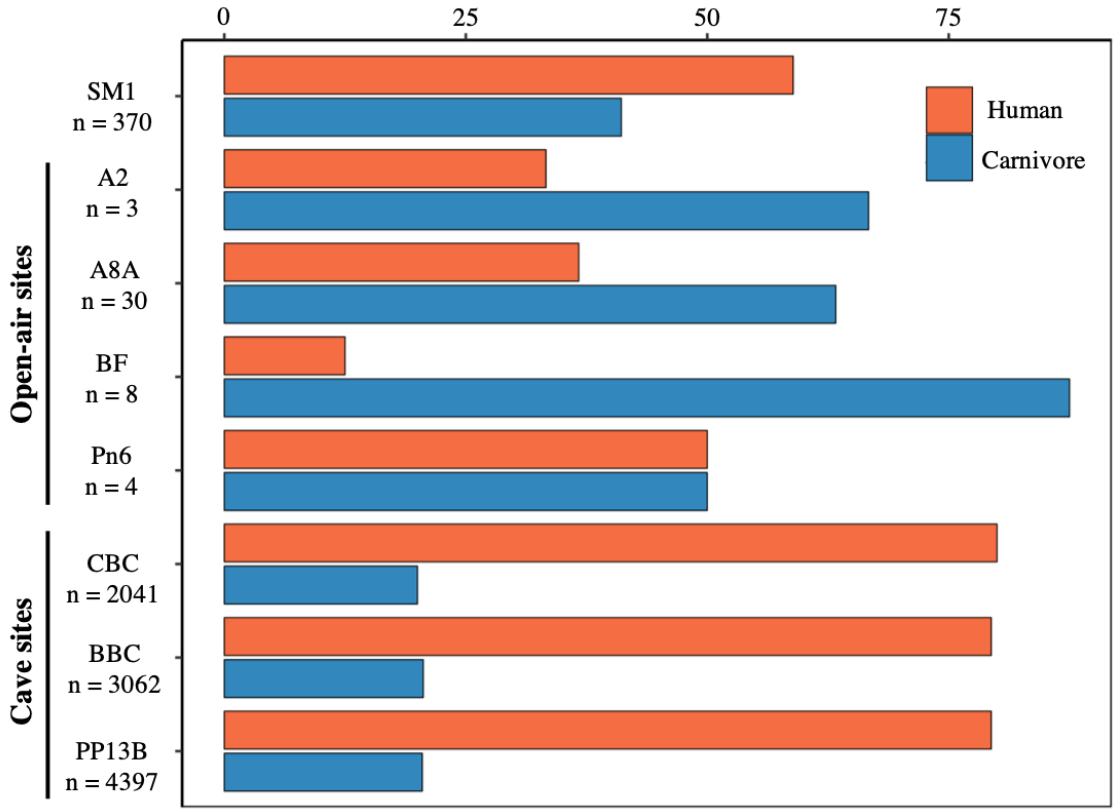

Figure 7.15 Relative frequencies (%) of specimens with human and carnivore damage for SM1 and comparative sites. Frequencies were calculated by dividing the number of specimens with human or carnivore modification by the total number of modified specimens (n) for each site. Specimens with multiple mark types are counted once for each type of modification. Abbreviations listed in Table 7.1.

Chi-squared tests indicate significant differences between SM1 and all three of the cave sites for frequencies of specimens with human versus carnivore damage (Table 7.17). Unfortunately, the samples of modified specimens for A2, A8A, BF, and Pn6 were not large enough to permit further statistical analysis, although there are clearly substantial differences between these sites and SM1 for the frequencies of both human and carnivore

modification. When compared to the cave sites, all of the significant results are due to the fact that SM1 has fewer specimens than expected with human cut and percussion marks, and more specimens than expected bearing carnivore tooth marks. When cut, percussion, and tooth marks are considered separately (*i.e.,* cut and percussion marks are not pooled into "human modification"), carnivore tooth marks are still significantly under-represented at CBC, BBC, and PP13B when compared to SM1 (Table 7.18). Cut and percussion marks are also both more common than expected at BBC relative to SM1, but the association is only significant in the case of percussion marks. Percussion marks are actually significantly under-represented at CBC relative to SM1, while the same is true of cut marks at BBC (Table 7.18). Nonetheless, the overall interpretation, that the number of specimens with identified surface modification is generally higher at the cave sites than SM1, and often by quite a large margin, obviously remains the same. This conclusion can clearly be extended to all of the other open-air sites examined here, as well.

Table 7.17 Chi-squared tests of independence between SM1 and comparative sites for frequencies of specimens with human and carnivore modification.

			Significant associations for SM1	
Site	χ^2	**p-value**	**Human**	**Carnivore**
Aduma A2 (A2)	-	-	N/A	N/A
Aduma A8A (A8A)	-	-	N/A	N/A
Bundu Farm (BF)	-	-	N/A	N/A
Pniel 6 (Pn6)	-	-	N/A	N/A
Contrebandiers (CBC)	76.5	< .01*	(-)	(+)
Blombos Cave (BBC)	77.42	< .01*	(-)	(+)
Pinnacle Point 13B (PP13B)	82.64	< .01*	(-)	(+)

*p-value significant at $\alpha = 0.05$
(+) = significantly over-represented at SM1 relative to comparative site; (-) = significantly under-represented at SM1 relative to comparative site.
Cave sites italicized.

Table 7.18 Significant associations for individual mark types at the three cave sites compared to SM1.

Site	CM	PM	TM
Contrebandiers (CBC)	(+)*	(-)*	(-)*
Blombos Cave (BBC)	(+)	(+)*	(-)*
Pinnacle Point 13B (PP13B)	(-)*	(+)*	(-)*
*Difference in observed versus expected significant at $\alpha = 0.05$ (+) = over-represented at comparative site; (-) = under-represented at comparative site CM = cut mark; PM = percussion mark; TM = tooth mark			

Summary of comparative analyses

Differences between SM1 and comparative sites

The results of comparative analyses are summarized in Tables 7.19 and 7.20. In both tables, each row corresponds to one of the taphonomic attributes that were examined in the previous sections, while each column corresponds to one of the open-air (Table 7.19) and cave (Table 7.20) sites compared to SM1. Cases where chi-squared tests indicate significant differences between SM1 and the comparative site for the variable in question are labeled with "(+)" or "(-)", while "*NS"* denotes that differences between the two sites for a given variable are not significant; a dash represents instances where no chi-squared test was performed either because data were not available for the comparative site or sample sizes were too small. The symbol (+) indicates that the attribute of interest is significantly more common than expected at the comparative site relative to SM1; (-) indicates that the attribute is significantly less common at the comparative site relative to SM1. For example, the (+) in the first row of the A8A column in Table 7.19 means that weathered bone is significantly over-represented at A8A compared to SM1, while the (-) in the first row of Table 7.20 under BBC indicates the opposite conclusion for this site.

Table 7.19 Summary of chi-squared test results between SM1 and open-air sites and the direction of differences for the taphonomic attributes of interest.

Attribute	**A2**	**A8A**	**BF**	**Pn6**
Weathered bone	*NS*	(+)	(+)	(+)
Post-depositional damage	*NS*	(+)	-	-
Burned bone	(+)	(+)	(-)	-
Small fragments (< 20 mm) (*i.e.*, high fragmentation)	*NS*	(-)	-	-
Medium and/or large fragments (20+ mm)	(+)	(+)	-	-
Right fracture angles (*i.e.*, non-nutritive breakage)	*NS*	*NS*	(+)	(+)
Transverse fracture outlines (i.e., non-nutritive breakage)	*NS*	*NS*	(-)	(-)
Human modification	(-)[1]	(-)[1]	(-)[1]	(-)[1]
Carnivore modification	-	-	-	-

[1]Result inferred; chi-squared tests not performed due to lack of data or small sample

(+) = attribute significantly over-represented at comparative site relative to SM1;
(-) = attribute significantly under-represented at comparative site relative to SM1

Abbreviations listed in Table 7.1

Table 7.20 Summary of chi-squared test results between SM1 and cave sites and the direction of differences for the taphonomic attributes of interest.

Attribute	**PE**	**CBC**	**BBC**	**PP13B**	**DK1**	**SC-HP**	**SC-MSA**
Weathered bone	(+)	(+)	(-)	(-)	(-)[1]	-	-
Specimens with PD damage	-	(-)	(-)	(-)	-	-	-
Burned bone	(-)	(-)	(-)	(-)	-	(+)	(+)
Small fragments (< 20 mm) (*i.e.*, high fragmentation)	-	(-)	(-)	(-)	-	-	-
Medium and/or large fragments (20+ mm)	-	(+)	(+)	(+)	-	-	-
Right fracture angles (*i.e.*, non-nutritive breakage)	(-)	(+)	*NS*	(-)	(-)	-	-
Transverse fracture outlines (i.e., non-nutritive breakage)	(-)	*NS*	(-)	(-)	(-)	-	-
Human modification	-	(+)	(+)	(+)	-	-	-
Carnivore modification	-	(-)	(-)	(-)	-	-	-

[1]Result inferred; chi-squared tests not performed due to lack of data or small sample

(+) = attribute significantly over-represented at comparative site relative to SM1;
(-) = attribute significantly under-represented at comparative site relative to SM1

Abbreviations listed in Table 7.1

A2 and A8A are the only two sites where differences with SM1 are not significant for more than one of the attributes investigated here (Tables 7.19 and 7.20). Chi-squared tests document that differences between SM1 and A2 are non-significant for all variables but burning and fragmentation (Table 7.19). However, although sample sizes for A2 were too small to permit chi-squared tests, there are also clearly substantial differences in surface modification frequencies between the two sites. Nonetheless, A2 in particular appears to be quite similar to SM1 overall, at least with respect to the taphonomic variables examined here. A8A is more similar to SM1 than any of the remaining sites, but fracture angle and outline frequencies are actually the only two variables for which differences with SM1 are not statistically significant. The two other open-air sites, BF and Pn6, are significantly different from SM1 for all variables for which data were available. Like A2, samples of modified specimens from A8A, BF, and Pn6 were too small for chi-squared tests, but all three sites are also quite different from SM1 with respect to surface modification frequencies (Table 7.19). Among the cave sites, BBC and CBC are quite similar to SM1 for fracture angle and fracture outline frequencies, respectively (Table 7.20). However, both sites were significantly different from SM1 for all of the other taphonomic attributes tested. Likewise, PE, PP13B, DK1, SC-HP, and SC-MSA (*i.e.,* the rest of the cave sites) are significantly different from SM1 for all of the variables examined in each case (Table 7.20).

With respect to specific taphonomic attributes, burning, fragmentation, and surface modification are the only three variables for which SM1 is significantly different from all of the comparative sites, but there is not necessarily a clear pattern to the direction of differences (Tables 7.19 and 7.20). For example, compared to SM1, burned bone is significantly less common at BF, PE, CBC, BBC, and PP13B, but significantly more common at A2, A8A, and both levels of SC. The same is true of surface modification, with

CBC, BBC, and PP13B all having higher total frequencies than SM1, and A2, A8A, BF, and Pn6 all having much lower total frequencies than SM1. Similarly, when all sites are considered together, there is also no clear pattern to the direction of differences with SM1 for weathering, post-depositional damage, or fracture angle morphology among the sites for which significant associations were found (Tables 7.19 and 7.20).

Fracture outline morphology and bone fragmentation are the two variables that seem to be an exception to this pattern (or, perhaps more appropriately, the lack thereof). In the case of fracture outlines, the frequency of transverse outlines is significantly higher (and curved/v-shaped outlines lower) at SM1 than all other sites except A2 and A8A, neither of which were significantly different from SM1 for this variable. Thus, SM1 appears to have an unusually high number of transverse long bone fracture outlines, in particular, at least compared to most of the other MSA sites investigated here. With respect to fragmentation, small fragments (< 20 mm) are over-represented at SM1 relative to all of the comparative sites, and for all sites but A2, this difference is highly statistically significant (Tables 7.19 and 7.20). Likewise, medium (20-60 mm) and large (60+ mm) specimens are over-represented at all of the other sites compared to SM1, and the associations are highly significant for both categories at CBC, BBC, and PP13B, and for large specimens at A2. Thus, the extensive amount of bone fragmentation at SM1 appears to be the one taphonomic attribute of the site for which there is a clear, consistent, and significant pattern of difference with all of the other open-air and cave sites. In other words, the very high degree of fragmentation at SM1 appears to be a unique aspect of the site, and one that sets it apart from all of the others examined here, regardless of site type, ecological setting, or geographical location.

Additionally, it should be emphasized that the faunal assemblage analyzed here for SM1 includes only a small portion of the total specimens recovered from water-screened

matrix. As noted in Chapter 4, the water-screened material far outnumbers mapped specimens at the site, and actually makes up the bulk of the total fauna recovered from SM1 to date. The mean fragment length for water-screened bones and teeth recorded for this study is ~10 mm (Figures 5.9 and 6.12), while water-screened chipped stone typically averages ~3-7 mm long (L.C. Todd, personal communication), so there is little doubt that most of the bones not analyzed here would also be very small fragments. Thus, including the currently unrecorded material from SM1 would not only increase the sample sizes by tens of thousands of specimens, but would also almost certainly serve to further emphasize the extensive amount of fragmentation that has taken place at the site.

Differences between open-air and cave sites

At least some of the differences that appear to lack consistent patterning discussed above (*i.e.,* when all comparative sites were considered together) actually become somewhat more intelligible when the data are examined by site type. For example, the differences in surface modification can actually be sorted between open-air and cave sites (Tables 7.19 and 7.20). More specifically, when compared to SM1, the cave sites CBC, BBC, and PP13B have significantly higher total frequencies of surface modification, and higher relative frequencies of human damage among the modified specimens (Table 7.20). Conversely, the open-air sites A2, A8A, BF, and Pn6 have lower total frequencies of modified specimens than SM1, and higher relative frequencies of carnivore modification. Interestingly, SM1 and the open-air sites A2, A8A, BF, and Pn6 are also much more similar to each other in terms of surface modification frequencies than any of them are to cave sites CBC, BBC, and PP13B (all three of which are almost identical to each other in this respect).

Similar patterning is also observed for fracture angle frequencies, with right fracture angles being more common at the open-air sites of BF and Pn6 compared to SM1, while right angle fractures are much less frequent at the cave sites of PE, BBC, PP13B, and DK1 (Tables 7.19 and 7.20). Moreover, SM1 and the open-air sites A2, A8A, BF, and Pn6 are all similar in having relative frequencies of oblique and right fracture angles that range between ~55-75% and ~25-45%, respectively. This finding is in contrast to the cave sites of PE, BBC, PP13B, and DK1, which are also quite similar to each other and all have generally higher frequencies of oblique angles (~70-95%) and correspondingly lower frequencies of right angles (~5-30%) (Table 7.13).

Likewise, small bone fragments (*i.e.,* < 20 mm) make up ~80% of the analyzed samples for both SM1 and A2, while this category does not represent more than ~51% of the specimens at CBC, BBC, or PP13B. However, A8A does not fit the potential pattern for open-air sites here and actually looks more similar to the cave sites in terms of fragment category frequencies. The percentages of weathered bone are also similar at SM1 and two of the open-air sites, A2 and A8A, and weathering is far more common at all three of these open-air sites than it is at the South African cave sites of BBC, PP13B, and DK1, where weathered bone is exceedingly rare (Table 7.3). PE and CBC are outliers among the caves in having higher frequencies of weathered bone than SM1, although as discussed earlier, heavy weathering is actually relatively more common at SM1, and the majority of specimens at PE and CBC are only lightly-to-moderately weathered. The other two open-air sites, BF and Pn6, have no unweathered bone and are therefore quite different from SM1, A2, and A8A, but these sites nonetheless also have much higher frequencies of weathering than all six of the cave sites (Table 7.3).

Thus, at least among several of the taphonomic variables examined here, there appear to be some consistent patterns of differences between open-air and cave sites.

Examining the average frequency of weathering, post-depositional damage, burning, fragmentation, fracture angles and outlines, and surface modification at open-air and cave sites further supports this conclusion (Figure 7.16 and Table 7.21). In all cases, the open-air sites have higher average frequencies of surface damage and burning that can obscure or delete cut, percussion, and tooth marks, and structurally weaken bones, making them more vulnerable to post-depositional destruction. Accordingly, bones with right fracture angles and transverse fracture outlines, both of which are typical of non-nutritive breakage, are also generally more abundant at the open-air sites. That fragments < 20 mm in maximum length are 1.5 times more common on average at the open-air sites further suggests that overall bone fragmentation is typically more extensive in open-air settings than caves. Given all of the above, it is perhaps unsurprising that the cave sites have a substantially higher average frequency of specimens with identified modification than the open-air sites (Figure 7.16 and Table 7.21).

As discussed previously (and confirmed in the preceding sections of this chapter), although fauna at A2, A8A, BF, and Pn6 are clearly associated with archaeological material and bear some evidence of human activity, the signature is relatively weak and the extent of human involvement in faunal accumulation is somewhat ambiguous at all three sites. As such, there is perhaps a case to be made that, for example, total frequencies of modified specimens are low at the open-air sites examined here simply because many of them were occupied less intensively than the three cave sites in this analysis. However, the same cannot be said of SM1, which was occupied intensively and repeatedly during the late MSA and where humans are primarily responsible for accumulating and modifying both terrestrial and aquatic faunal remains. When SM1 alone is used as a proxy for an intensively-occupied open-air MSA site, the overall pattern and direction of differences

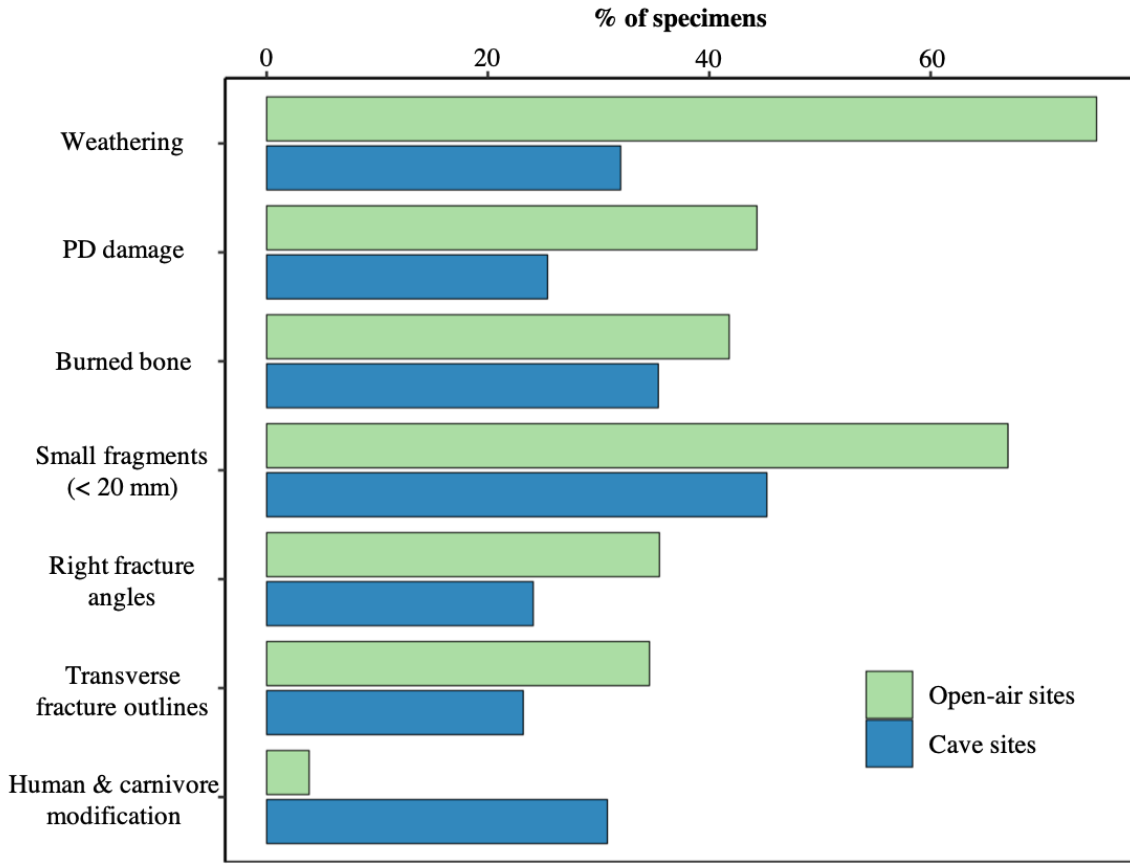

Figure 7.16 Average frequencies (%) of taphonomic attributes at MSA open-air and cave sites.

Table 7.21 Average frequencies (%) of taphonomic variables at open-air and cave sites.

Attribute	Open-air	Cave
Weathered bone	75.0	32.0
Specimens with PD damage	44.3	25.4
Burned bone	41.8	35.4
Small fragments (< 20 mm)	67.0	45.2
Right fracture angles	35.5	24.1
Transverse fracture outlines	34.6	23.2
Modified specimens	3.8	30.8

with the cave sites remain the same, although there are differences in the magnitude (Figure 7.17). Moreover, when SM1 is compared to averages for all the other open-air sites and the cave sites separately: 1) the direction of difference with the caves is always the same for SM1 and the other open-air sites; and 2) the absolute magnitude of difference is smaller between SM1 and the open-air sites for five out of the nine attributes (Figure 7.17).

The analyses presented above indicate that SM1 is more similar overall to the other open-air sites than to the cave sites, and that the open-air sites are more similar to each other than they are to the cave sites. Moreover, to answer a question that was posed at the beginning of this chapter, the data presented here suggest that it may not be reasonable to expect largely similar signatures of human behavior at both open-air and cave sites even if occupational intensity and the extent of human involvement are similar, because open-air settings may often be expected to have poorer surface preservation, higher frequencies of burned bone, and more extensive fragmentation than sites located in more sheltered settings, such as caves and rock shelters. Likewise, and quite probably as a direct result of the attributes listed above, open-air sites may also often be expected to have lower frequencies of specimens with *identifiable* cut, percussion, and tooth marks than the average cave site. The emphasis is on identifiable here to stress that, at many open-air sites, the number of modified specimens that originally existed may be substantially underestimated by the number that are actually recorded.

Thus, it seems likely that the criteria for interpreting human behavior and other taphonomic processes at open-air and cave sites (*e.g.,* fracture angle and outline frequencies, bone fragmentation, frequencies of modified specimens) may be somewhat different in many cases. For example, the data analyzed here suggest that it is reasonable to expect frequencies of ~20+% of total specimens to bear human modification marks at cave sites where humans are the primary agent of faunal accumulation and modification.

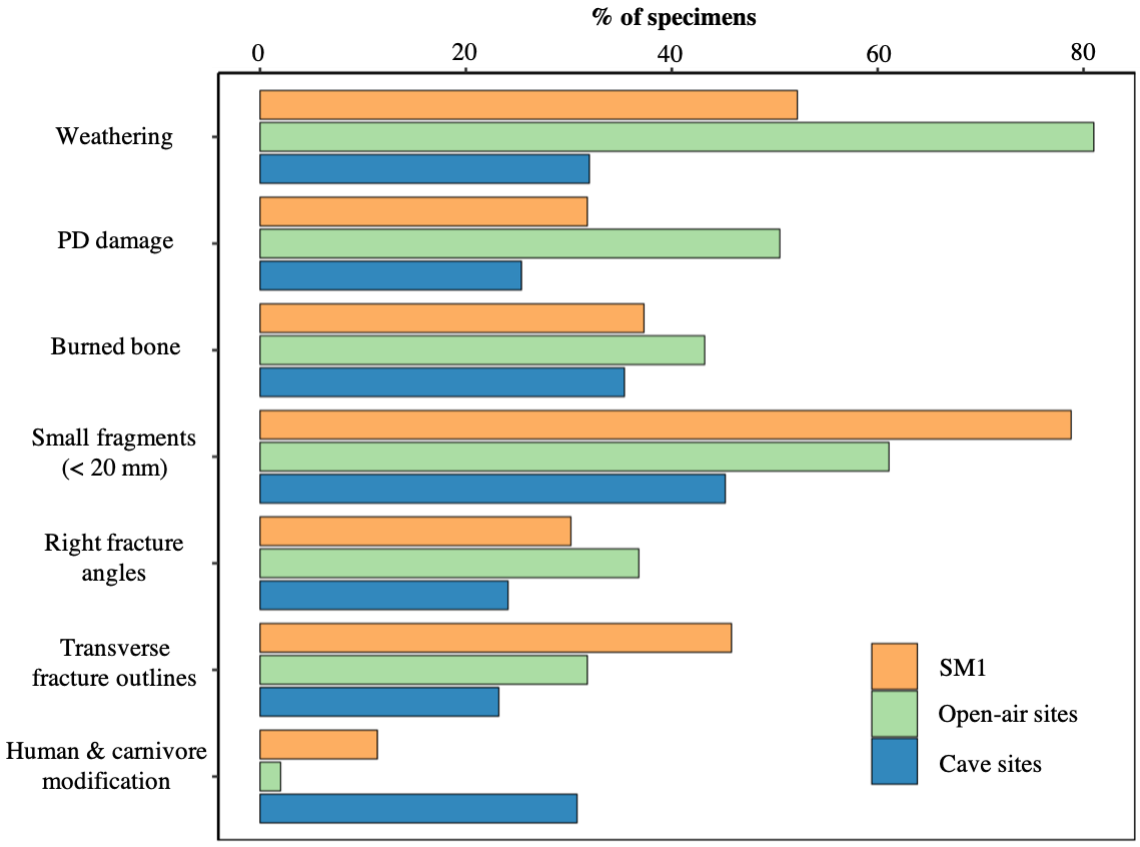

Figure 7.17 Frequencies (%) of taphonomic attributes at SM1 and average frequencies (%) for other MSA open-air (not including SM1) and cave sites.

However, the same expectation may well be unreasonable when applied to the average open-air site, given that none of those analyzed here have frequencies anywhere near 20% of total specimens, including SM1, which has been shown to be a long-term and intensive occupation, much like the cave sites to which it was compared.

Similarly, when interpreting the amount of destruction among skeletal elements at a cave site, there appears to be good reason to expect very high frequencies (*e.g.,* 70+%) of long bones with oblique fracture angles and curved/v-shaped outlines in cases where

most of the fragmentation was nutritive. Obviously, if similar frequencies of oblique angles and curved/v-shaped outlines were observed at an open-air site, this would also indicate extensive nutritive destruction. Yet, the data in this chapter suggest that this expectation may be too high for the average open-air site, even if the majority of fragmentation is the result of humans butchering meat and extracting marrow from the bones. For SM1, it was established previously that much of the fragmentation was, in fact, nutritive, but that frequencies of transverse outlines were inflated at least in part because many of the bones had likely undergone multiple (*i.e.,* both nutritive and non-nutritive) episodes of destruction (see Chapter 5). Thus, the expectation that ~70+% of specimens will have curved/v-shaped outlines seems entirely reasonable for most of the cave sites, but is not necessarily appropriate for SM1, and possibly other open-air sites, even in cases where extensive nutritive breakage has occurred (Table 7.13 and see Chapter 5).

Obviously, behavioral interpretations are not made in a vacuum, and analysts do not typically use only one variable to investigate a given taphonomic attribute for a site (*e.g.,* assessing the extent of nutritive versus non-nutritive destruction based only on long bone fracture morphology) or uncritically apply strict cut-off points when making interpretations (*e.g.,* < 70% right angles automatically indicates low levels of nutritive fragmentation). However, as discussed in detail above and in Chapter 3, a set of general guidelines for what is to be expected from sites based on the primary accumulator and various other factors has been developed through experimental and field research over the last several decades, which has significantly advanced our understanding of site formation processes, taphonomy, and human behavior in the archaeological record (*e.g.,* Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Marean, 1991; Villa and Mahieu, 1991; Capaldo, 1998; Selvaggio, 1998; Marean *et al.*, 2000; Pickering, 2002; Marean and Cleghorn, 2003; Villa *et al.,* 2004; Munro and Bar Oz, 2005; Assefa, 2006;

Thompson, 2010; Clark, 2011; Thompson and Henshilwood, 2011; Hallett, 2018; Hutson, 2018).

However, experimental scenarios (*e.g.,* human and carnivore modification: Capaldo, 1998; Selvaggio, 1998; patterns of fracture morphology: Marean *et al.,* 2000) often do not (or cannot) account for the types of taphonomic factors that may be more prevalent at open-air sites (*e.g.,* weathering, post-depositional damage, burning) and can influence interpretations of human behavior. Moreover, for the MSA specifically, most of the previous taphonomic research has been undertaken at cave sites, many of which are in South Africa and all but one of which are located in coastal settings. This is important, because the circumstances of bone deposition and preservation are likely to be quite different in cave and open-air settings, and perhaps at coastal versus interior sites, as well. This, in turn, raises the possibility that particular signatures of human activity and/or natural destruction will also often differ substantially between cave and open-air sites, even if occupational intensity and human behavior were largely similar overall. As such, it is necessary to understand if and how sites in different settings might differ systematically, in order to develop and apply the most appropriate criteria, and ensure robust and reliable behavioral interpretations, in each case.

CONCLUSION

This chapter has presented the results of comparative analyses between SM1 and several other MSA open-air and cave sites from Ethiopia, Morocco, and South Africa. The primary goal was to determine if particular aspects of bone preservation, fragmentation, and modification at SM1 are unique compared to other MSA sites. Additionally, the

question of whether or not there are discernible patterns of difference in the taphonomic character of open-air versus cave sites more generally was also explored.

The analyses in this chapter document that SM1 is significantly different from the majority of the comparative sites for most of the variables examined here. The most similar sites to SM1 overall are A2 and A8A, two open-air sites from the Aduma region in Ethiopia, which had non-significant differences with SM1 for five (A2) and two (A8A) of the eight variables analyzed. Additionally, the cave sites of CBC in Morocco and BBC in South Africa also had non-significant differences with SM1 for one variable each. The other open-air and cave sites were significantly different from SM1 in all analyses for which relevant data were available. Thus, SM1 does appear to be unique compared to most of the other sites, although there is not a clear pattern of difference for most of the variables when all the comparative sites are considered together. In other words, for most attributes, there were some comparative sites that had higher frequencies than SM1 and others that had lower frequencies than SM1. However, the data suggest that bones at SM1 are more extensively fragmented overall than those at the open-air sites of A2 and A8A and the cave sites of CBC, BBC, and PP13B (*i.e.,* all the comparative sites for which it was possible to analyze this variable). Likewise, SM1 appears to have a distinctly high frequency of transverse fracture outlines compared to the open-air sites of BF and Pn6, and caves sites PE, CBC, BBC, PP13B, and DK1. By contrast, differences in the frequency of transverse outlines at SM1 and the other two open-air sites of A2 and A8A are not significant.

The patterns of difference sort out more clearly according to site type (*i.e.,* open-air versus cave). SM1 appears to be more similar to the other open-air sites than to the cave sites, and all of the open-air sites seem to be more similar to each other overall than any of them are to the cave sites. The pattern is not universal, and there are significant differences among SM1 and the other open-air sites, particularly BF and Pn6, for many of the variables

that were examined. Yet, when compared to the averages for the other open-air sites and the cave sites, SM1 always differs from the average cave site in the same direction as the average open-air site, and the magnitude of the differences is more often smaller between SM1 and the other open-air sites. These data warrant caution in applying the same taphonomic criteria and expected signatures of human behavior to both open-air and cave sites.

Chapter 8: MSA foraging behavior at SM1

INTRODUCTION

The following chapter will: 1) discuss the results of hypothesis-testing and draw conclusions regarding the five research hypotheses discussed in Chapter 3; 2) synthesize the data and analyses presented in Chapters 4-7 in order to provide an overall reconstruction of MSA terrestrial and aquatic foraging strategies at SM1; 3) place foraging behavior at SM1 within a broader context of the MSA in Africa; and 4) offer concluding remarks and ideas for future directions of study related to the issues investigated in this dissertation.

HYPOTHESIS TESTING

Five research hypotheses, the alternative scenarios, and expectations for each were detailed in Chapter 3, and tested using various faunal, taphonomic, behavioral, and comparative data in Chapters 4-7 (Table 8.1). The following section will discuss the results presented in the previous chapters specifically within the context of testing the five hypotheses and the research questions associated with each of them.

Hypothesis 1: Terrestrial and aquatic fauna at SM1 were primarily collected by MSA humans. Data presented in Chapters 4-6 strongly support the position that the majority of the fauna from SM1, including terrestrial mammals, reptiles, birds, amphibians, and fish, were primarily collected and modified by MSA humans (Table 8.1). The evidence in support of this conclusion includes: 1) the close association of faunal material with thousands of chipped stone artifacts and other archaeological features; 2) the presence of abundant burned boned and particularly the fact that ~10-15% of the bones of both terrestrial fauna and fish are calcined; 3) the spatial distribution of burned bone and

Table 8.1 Research hypotheses, overall conclusion (*i.e.,* supported or not supported), and chapters containing relevant data for each.

Number	Hypothesis	Conclusion	Chapters
1	Terrestrial and aquatic fauna at SM1 were primarily collected by MSA humans	Supported	4, 5, & 6
2	MSA people at SM1 engaged in systematic riverine fishing and foraging behavior.	Supported	4 & 6
3	MSA foraging strategies at SM1 involved structured seasonal exploitation of dense and predictable riverine resources during the dry season.	Supported	5, 6, & 7
4	SM1 was a base camp and preserves evidence of multiple discrete episodes of occupation during the late MSA.	Supported	4, 5, & 6
5	SM1 is unique among MSA sites, and particularly distinct from cave sites, for taphonomic attributes commonly used to interpret human foraging behavior	Supported	7

artifacts, which suggests possible dedicated hearth areas within the site where burning activity was concentrated; and 4) the presence of human cut and percussion marks on the bones of terrestrial mammals, birds, and fish, which are an unequivocal indication of human involvement in processing both terrestrial and aquatic fauna from SM1.

Conversely, the data provide little support for the alternative scenario, which is that carnivores and/or other non-human agents and processes are primarily responsible for accumulating and modifying the animal bones from SM1. There is evidence that the bones of terrestrial fauna and fish were subject to some degree of post-depositional destruction, but this is not at all surprising given their age and the context of deposition; in fact, a finding

that little or no post-depositional destruction had occurred would have been much more unexpected and potentially more difficult to explain. In both cases, the extent of natural bone destruction is moderate at best, and it was demonstrated that human nutritive processing was likely responsible for the overall patterns of bone destruction and fragmentation.

Likewise, carnivore tooth marks on the bones of terrestrial mammals, reptiles, birds, and fish are a definitive signal that non-human carnivores were involved to some degree in faunal modification at SM1. However, carnivore remains occur at frequencies much lower than expected for primary carnivore sites, while other evidence that would indicate significant carnivore activity, such as coprolites or bones with definitive evidence of gastric etching, are completely lacking at SM1. Thus, the most parsimonious explanation for the majority of tooth marks at the site is that carnivores were mostly scavenging bones left behind by humans, and were not responsible for accumulating the bones at the site.

Hypothesis 2: MSA people at SM1 engaged in systematic riverine fishing and foraging behavior. Data in Chapters 4 and 6 provide the supporting evidence for Hypothesis 2 (Table 8.1). The sheer number of fish bones and mollusk shell fragments at SM1 is such that if the aquatic fauna is shown to be largely human-collected, then there can be little doubt that MSA people were regularly exploiting aquatic food resources, and this was not an activity that they engaged in only rarely or on an opportunistic basis. Thus, the expectation here was that most or all of the criteria posited for Hypothesis 1 would strongly or unambiguously indicate that humans were the primary accumulator of the fossil fish bones. The analyses in Chapter 6 tested 12 criteria that can be used to distinguish natural versus human collection of fish bones, of which eight strongly indicate humans as

the primary accumulator of the fish, while two others also suggest human collection, but are somewhat more equivocal in their support.

Specific supporting evidence for Hypothesis 2, which was presented in Chapters 4 and 6, includes: 1) the close association of fish bones and archaeological material; 2) the presence of calcined fish bone; 3) patterns of taxonomic, skeletal part, and body size representation that differ substantially from those expected for natural accumulations of fish bone; 4) extensive fragmentation that appears to be largely non-random and is not correlated with measures of faunal abundance, and therefore more likely to be the result of human activity rather than natural destruction; 5) heavy fragmentation of catfish neurocrania and spines; and 6) the presence of human cut and probable percussion marks.

The alterative scenario is that SM1 people did not regularly capture or eat fish, that fish are naturally-accumulated, and that most of the damage is due to non-human agents and processes. As already noted, there is some evidence for a moderate amount of non-human surface damage and post-depositional destruction of the fish bones, but the overall patterns suggest that humans are primarily responsible for most of the modification to the fish. Likewise, patterns of taxonomic representation, and the overabundance of *Clarias* in particular, are almost certainly mediated to some extent by taphonomic filters, but likely also result in part from human selectivity for fish that can be procured with relatively simple methods in shallow-water, near-shore settings, and dry season waterholes. Once again, tooth marks document that non-human carnivores had some access to the fish bones, but there is no indication that carnivores are primarily responsible for accumulating or modifying the fish from SM1.

Hypothesis 3: MSA foraging strategies at SM1 involved structured seasonal exploitation of dense and predictable riverine food resources during the dry season. Support for Hypothesis 3 derives from data presented in Chapters 5-7 (Table 8.1). As already discussed at length, there is good reason to assume that the SM1 people did not regularly engage in fishing and riverine foraging during the wet season because these activities would have been impractical, unproductive, and perhaps even dangerous, during this time of year. As such, documenting that fish are largely human-collected, which in turn indicates systematic riverine fishing and foraging at SM1, provides one of the strongest lines of support for dry season occupation of the site. Several other lines of evidence that may indicate resource intensification were also posited, including high frequencies of small and/or low-ranked prey (*i.e.,* increased diet breadth), intensive processing of faunal remains, and regular utilization of both high- and low-value skeletal parts, which may also support this hypothesis.

Both the body size and CT category data indicate that small animals (*i.e.,* size class 1a and 1, CT category 1) are abundant at SM1. These animals include bovids, monkeys, carnivores, hares, murid rodents, lizards, snakes, frogs, and guineafowl, most of which would typically be considered small, agile, and low-ranked prey in circumstances of low or moderate resource stress. Moreover, although evidence for human processing of smaller animals is limited, there are cut and/or percussion marks on humeri from a small monkey (SM1-250) and a guineafowl (W14-25-001, which also contains possible human chew marks), and it is likely that many of the other small mammals, reptiles, and birds were also human prey items. The fact that MSA diets included abundant fish, which may also be considered low-ranked prey if terrestrial prey is abundant and readily-available, generally fits with the expectations for increased diet breadth at SM1, as well.

There is also evidence that the SM1 people transported many animals back to the site whole which would be expected in situations where resource-stressed humans were attempting to maximize the amount of tissue, marrow, and grease available from the animals they hunted, caught, and processed. However, most of the evidence for whole carcass transport comes from small-to-medium-sized animals, many of which may also be transported whole under conditions of normal resource stress, simply because it is often easier to do so. The extensive amount of bone fragmentation at SM1, which is largely human-caused and is observed for both terrestrial fauna and fish, is also potential evidence for "hyper-processing" of faunal material. The occurrence of cut and/or percussion marks on metapodials and phalanges further indicates that even low-value skeletal parts were processed for meat and marrow. Thus, there are several lines of evidence that are consistent with the type of resource intensification that would be expected during periods of high resource stress, which are most likely to occur during the dry season in this part of eastern Africa (Speth, 1987).

When all of these data are combined, the evidence for systematic exploitation of riverine food resources and probable signs of resource intensification provide rather robust support for the hypothesis that SM1 was often occupied in the dry season during the late MSA. It is entirely possible that MSA people also visited the site during the wet season, but the data suggest that dry season occupation may have been more common. Use of the site during the dry season, in turn, suggests that its occupation revolved to some extent around the availability of fresh water and riverine food resources, which were likely widely available and much easier to access during this time of year (see below).

Hypothesis 4: SM1 was a base camp and preserves evidence of multiple discrete episodes of occupation during the late MSA. Data in support of Hypothesis 4 are presented in Chapters 4, 5, and 6 (Table 8.1). It was hypothesized that SM1 preserves evidence of multiple occupations, perhaps occurring over a period of several thousand years or more, rather than a single episode of occupation. As a part of this hypothesis, it was also posited that SM1 most likely represents a longer-term residential base camp that was occupied intensively over a period of days, weeks, or even months, as opposed to a logistical (*e.g.,* kill-butchery, fishing/fish-processing) site where activity was task-specific and the human presence was short-lived.

Support for this hypothesis was provided through analyses of multiple taphonomic attributes between four proposed analytical units (*i.e.,* occupation levels) that were defined in Chapter 4, and the validity of which were tested using taphonomic variables in Chapters 5 and 6. For both terrestrial fauna and fish, significant differences were found between multiple analytical units for many of the taphonomic variables examined. Moreover, all of the analytical units are significantly different from each of the others for at least two of the taphonomic attributes among terrestrial fauna and/or fish. Thus, the expectation for the alternative scenario, which postulated that taphonomic characteristics should be similar across most or all of the analytical units if they represent a single occupational event, was clearly not met. It should also be pointed out here that four analytical units, or occupation levels, is likely a minimum for SM1. Visual inspection of the material plotted in Figures 4.8 and 4.9 suggests the possibility of several occupation layers that were not identified using the method of delineation employed here. However, the inclusion of new data and/or a finer-scale technique for delineating different layers in future studies may make it possible to distinguish additional occupation levels within the site.

Additional supporting evidence for SM1 as a base camp rather than a logistical site includes: 1) the presence of tens of thousands of pieces of chipped stone, including debitage from all steps in the tool-making process; 2) the co-occurrence of abundant artifacts and faunal remains; 3) the presence of possible dedicated hearth features and fully calcined bone (which requires intensive heating over extended periods of time, for example, after bone is swept into a hearth during floor cleaning); 4) evidence that humans regularly transported complete or mostly complete carcasses of terrestrial mammals and fish back to the site; and 5) evidence that all aspects of faunal butchery, processing, and preparation took place at SM1 (*e.g.,* skinning, evisceration, disarticulation, fileting, and marrow processing of terrestrial mammals; butchery of fish and processing of neurocrania for brain removal; cooking both terrestrial fauna and fish). Once again, there is no support for the alternative hypothesis that SM1 was a very short-term logistical site.

Hypothesis 5: SM1 is unique among MSA sites, and particularly distinct from cave sites, with respect to taphonomic attributes that are important for interpreting early human behavior and foraging strategies. Evidence in support of Hypothesis 5 is presented in Chapter 7. The expectation here is simple: that chi-squared tests will indicate significant differences between SM1 and comparative sites, and cave sites in particular, for frequencies of weathering, post-depositional damage, burning, bone fragmentation, long bone fracture morphology, and surface modification, all of which are important criteria used to help guide interpretations of site formation and human behavior in the past. The alternative is also straightforward, and states that SM1 is actually quite similar to other MSA sites for most or all of these attributes, so chi-squared tests should indicate few if any significant differences among sites. The data in Chapter 7 document that SM1 is significantly different from 80-100% of the comparative sites in each analysis for all of the

variables except long bone fracture angles and outlines, for which SM1 is different from ~68% of sites in both cases. These data clearly support the position that SM1 differs from the comparative sites for most of the variables examined, although bone fragmentation, which appears to be unusually extensive at SM1, is the only variable for which there was a clear pattern to the direction of differences between SM1 and all of the comparative sites.

The analyses in Chapter 7 also support the idea that SM1 is quite dissimilar from the cave sites overall, and that SM1 and the other open-air sites are more similar to each other than any of them are to the cave sites (and vice versa). These data suggest that open-air sites may generally be expected to have poorer surface preservation, higher levels of fragmentation, more post-depositional destruction, and lower frequencies of specimens with identifiable surface modification marks than cave sites, even in cases where occupational duration, intensity, and human behavior are similar. This indicates the possibility of systematic differences in bone preservation and taphonomy at open-air versus cave sites, and suggests caution in assuming that the same interpretive criteria can be applied in the same ways to both types of site.

Summary of hypothesis testing

Although the results were not always unequivocal, in each case the majority of data were found to support the hypotheses of site formation and human behavior at SM1 presented in Chapter 3 (Table 8.1). More specifically, the results of hypothesis testing indicate that: 1) humans are primarily responsible for accumulating and modifying both terrestrial and aquatic fauna at SM1; 2) MSA foraging strategies at SM1 involved regular riverine fishing and foraging; 3) occupation of SM1 was seasonally-structured and the site was occupied most often during the dry season; 4) SM1 preserves evidence of multiple episodes of occupation and was a residential base camp; 5) SM1 has a unique taphonomic

history and is significantly different from other MSA open-air and cave sites for several variables related to bone preservation and modification, with extensive fragmentation being one of the most distinctive taphonomic aspects of the site; and 6) systematic differences in taphonomic character may exist between open-air and cave sites, which warrant caution in applying the same criteria to interpret taphonomy and human behavior at these two types of site. Given the above conclusions, it is now possible to synthesize the data presented in previous chapters into a single overarching interpretation of MSA foraging strategies at SM1, and to place human behavior at the site within the broader context of the late MSA in Africa.

SM1 AND LATE PLEISTOCENE HUMAN BEHAVIOR IN AFRICA

MSA foraging strategies at SM1

The data presented in this dissertation document sophisticated foraging behavior among the MSA people living at SM1 which included regular exploitation of both terrestrial and aquatic faunal resources. Terrestrial foraging strategies involved hunting a diverse array of prey species, with a focus on small-to-medium-sized (*i.e.,* size class 1 and 2) bovids in particular. Larger (*i.e.,* size 3+) bovids were also taken at times, albeit perhaps with less regularity than size 1 and 2 animals. The only animals larger than size 2 identified to date at SM1 are bovids, so there is currently no direct evidence for the acquisition of other large prey species, but there is also no obvious reason to assume that humans would not or could not have taken these animals when given the opportunity.

Terrestrial foraging behavior at SM1 also involved exploitation of small, agile taxa, many of which may have been caught using snares, traps, and/or projectile weapons. There is direct evidence of human processing on at least one small monkey and several

guineafowl bones, and ~10-15% of long bone specimens with cut and percussion marks are from CT category 1 (*i.e.,* ≤ 19 kg), which includes both microfauna (*i.e.,* hares, rodents, lizards, snakes, frogs, small birds) and small-bodied macrofauna (*e.g.,* monkeys, small bovids, large birds). The fact that microfauna and small macrofauna make up between ~30-40% of the assemblage, depending on whether the body size class or CT data are used, further suggests that these taxa were more than just occasional prey items for MSA humans living at SM1.

Once acquired, larger animals may have been processed more extensively in the field, while small-to-medium-sized animals were often brought back to the site mostly complete or complete. All manner of butchery activity, including evisceration, skinning, defleshing, and disarticulation, took place on-site at SM1, and once cleaned of muscle and tissue, most marrow-bearing bones were also hammerstone-processed for the marrow stores within them. In many cases, processing activity likely involved extensive butchery and heavy fragmentation (*i.e.,* "hyper-processing") of both high- and low-value elements in order to extract all available meat, marrow, and/or grease. It is even possible that at least some of the dry bone breakage at the site may have resulted from humans re-processing previously-discarded bones during particularly acute periods of resource stress, but there is currently no way to empirically test this possibility.

Riverine foraging strategies at SM1 involved intensive exploitation of fish, and possibly aquatic reptiles, although the few identified crocodile bones at the site do not contain direct evidence of human processing. It seems likely that SM1 people regularly exploited riverine mollusks, as well, although specific evidence for this behavior has not been presented here. Fishing behavior involved capturing multiple species of siluriform catfish, including *Clarias, Synodontis, Bagrus,* and *Schilbe,* as well as the cyprinids *Labeo* and *Labeobarbus,* and the cichlid *Oreochromis.* Although patterns of taxonomic and

skeletal element representation are almost certainly mediated to some degree by taphonomic filters that have sorted out some of the smaller fish with less robust skeletons, MSA fishers nonetheless appear to have had a preference for several species of catfish, including *Clarias, Synodontis,* and *Bagrus* (in that order). Likewise, there is a large range of variation in the size and weight of the fish that were caught, but there seems to have been a particular focus on small-to-medium-sized individuals, ranging from ~25-50 cm in total length and ~1-1.5 kg in body mass.

Most of the fish taxa found at SM1 are well-adapted for spending large amounts of time in shallow water and near-shore habitats. Fishing activity may have involved netting and/or spearing of individuals from the shoreline during the wet season or very early in the dry season when the river was flowing. However, it is much more likely that the majority of fishing took place during the height of the dry season, just as it does today, and that fish were primarily caught in the continually evaporating and increasingly disconnected waterholes using relatively simple technology, such as nets, basket-traps, spears, and plant poisons, or with no technology at all, using bare hands. As with terrestrial fauna, once they were caught, some fish may have been partially processed and/or consumed in the field. However, many fish were transported back to the site whole, where they were often, but perhaps not always, processed for immediate consumption.

Fish processing was intensive, and often involved extensive fragmentation of elements from most anatomical regions, with the possible exception of the vertebral column. Processing behavior also likely included breaking and removing catfish spines to avoid injury during subsequent butchery activity. Catfish spines can cause painful punctures, which may then be exacerbated by the release of poisons and/or the introduction of harmful skin toxins into the wound that can cause even more serious injury (Mann, 1991; Wright, 2009; Kappelman *et al.,* 2014). Thus, it is not really surprising that SM1 people

would regularly break the spines while processing fish for consumption, and similar behavior has been observed among both human fishermen and birds (Belcher, 1998; Gifford-Gonzalez *et al.,* 1999; Zohar, 2003; Kappelman *et al.,* 2014). In many cases, neurocrania were also often fragmented by humans, likely to kill the fish and/or access the brains for consumption. Although much of the evidence for this activity comes from thousands of tiny cranial shield fragments from *Clarias,* in particular, there is seemingly no reason to assume that other fish would not also have been processed in the same way. In fact, heavy fragmentation of the neurocrania of fish with less robust cranial bones (*e.g., Labeo, Labeobarbus, Oreochromis*) would likely have made them more susceptible to further natural destruction, and may therefore help explain the relative absence of neurocranial elements for taxa other than *Clarias.* Once processed, the bodies of many of the fish were probably roasted whole over an open fire. It is possible that boiling and/or other preparation techniques were also practiced, although there is currently no definitive evidence that this is the case. Likewise, it is also entirely plausible that at least some of the fish were sun- and/or smoke-dried and preserved for somewhat longer-term consumption.

SM1 foraging behavior within the context of the MSA

The apparent focus on small-to-medium-sized terrestrial animals at SM1 may be somewhat unique for the MSA, and the inclusion of numerous small, agile species is particularly interesting, given previous arguments that MSA people did not or could not take such taxa on a regular basis (*e.g.,* Klein, 2000). As noted previously, given what is currently known about MSA foraging behavior, it is not necessarily surprising that SM1 people hunted a variety of mammals, birds, and other terrestrial vertebrates of various sizes (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Faith, 2008; Wadley, 2010). However, the fact that systematic riverine fishing and foraging was also a part of

MSA foraging strategies at SM1 is undoubtedly important and unique in the context of a late Pleistocene site in Africa that pre-dates ~25 ka (McBrearty and Brooks, 2000; Van Neer, 2004).

Documenting systematic riverine food resource use at SM1 is significant in its own right, because the ~90 ka site of Katanda located along the banks of the Semliki River in DRC is currently the only other MSA site where there is evidence for similar fishing behavior (Brooks *et al.,* 1995; Yellen *et al.,* 1996). Moreover, after Katanda, there appears to be a ~65-70 kyr hiatus in such behavior, with the next-oldest dedicated fishing sites dating to ~20-25 ka at Ishango in DRC (and just upriver from Katanda), White Paintings in Botswana, and Wadi Kubanniya in Egypt (Gautier and Van Neer, 1989; Stewart, 1989; Peters, 1990; Robbins *et al.,* 1994). Thus, the new data presented here from SM1 helps to fill in this gap in the archaeological record of systematic aquatic food resource use and early riverine foraging adaptations in the late Pleistocene, and suggests that the "hiatus" in such behavior between ~90-25 ka may be more apparent than it is real.

Accordingly, the evidence from SM1 demonstrates that Katanda is not simply a rare "one-off" site, and instead documents that early riverine adaptations were more widespread than previously known. In more general terms, documenting regular fishing and riverine foraging at SM1 is also significant because it provides additional evidence that runs counter to previous assertions that MSA people either did not or could not systematically exploit aquatic resources (*e.g.,* Klein, 2009). Although the idea that MSA people were inherently less capable hunters and foragers than their LSA counterparts has now fallen out of favor with many researchers (*e.g.,* McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Faith, 2008; Shea, 2011), gathering direct evidence to support this claim is nonetheless important.

The identification of systematic riverine adaptations at SM1 is also important because of the implications it has for seasonal scheduling of overall foraging behavior at the site. As already noted, the fact that fish and mollusks represent ~45% of the total fauna at SM1 indicates that aquatic resources were a significant part of the subsistence base for the MSA people living at the site, and likely rivaled terrestrial resources in terms of importance, at least during the time of year when SM1 was occupied. As such, there is good reason to posit that MSA foraging strategies at SM1 involved deliberate seasonal partitioning of the yearly foraging round based, in part, on the availability of abundant fish, mollusks, and other riverine food resources (*i.e.,* reptiles, mammals, and/or plant foods) during the dry season. In other words, part of the yearly foraging round was scheduled around visits to SM1 during the dry season specifically, when it was known that fish, mollusks, and other aquatic food resources would be densely concentrated and relatively easy to exploit in the receding river flows and isolated waterholes.

The river waterholes would also typically have been the only source of freshwater during the dry season, a dependable supply of which would obviously be a requirement for any group of human foragers living in the area. Any water-dependent bovids, as well as other terrestrial and avian fauna, would need to visit waterholes daily to drink, making it possible to hunt and trap terrestrial game around them, as well. Thus, the waterholes would have represented dense and predictable resource patches in terms of both food and freshwater during the dry season (Kappelman *et al.,* 2014). Conversely, habitats farther removed from the river were probably more inhospitable, with the terrestrial animals in poorer condition during this time of year, and extended periods of foraging away from a river or lake would require the capacity to transport freshwater (*e.g.,* in animal hide pouches or ostrich eggshell "canteens"). It is certainly possible that the SM1 people possessed such technology, but there is currently no definitive evidence from the site to confirm this idea.

Either way, foraging at a distance from the river would almost certainly have been more difficult and less productive during the dry season.

By contrast, during the wet season, freshwater would have been readily available at basically any point along the course of the Shinfa River, as well as in other rivers, streams, seasonal lakes, and perhaps even away from rivers and lakes in the form of rainfall and/or fresh puddles. Hunting and foraging farther out from the river would therefore have been much easier during the wet season, at least from the standpoint of maintaining a steady supply of drinkable water. However, the increased availability of water in the river would be accompanied by a sharp decline in its productivity as a foraging patch for food resources. For reasons discussed in detail in Chapters 4 and 6, soon after the onset of the "big rains" it seems safe to assume that it would have become impractical, if not essentially impossible, to continue fishing and foraging in the river as a meaningful part of the subsistence strategy throughout the rest of the wet season.

The wider availability of water with returning river flows would also have the effect of "de-concentrating" terrestrial game from spatially-limited areas around waterholes, so it is likely that hunting and foraging at greater distances from the river would have actually been necessary during the wet season simply because terrestrial prey would have been more widely dispersed across the landscape at this time. Thus, wet season foraging strategies may have entailed more varied patterns of group mobility overall. While it is possible that SM1, which was probably a longer-term residential base camp, was occupied throughout the year, it seems equally plausible that foragers would have moved around more often between shorter-term sites during the wet season, perhaps similar to those recently discovered along the high terraces several kilometers to the north and east of SM1, and much farther out from the main channel of the modern Shinfa River (Porter *et al.,* 2018).

The important point here is that the available evidence indicates that MSA people intentionally and efficiently scheduled foraging activity based on specific seasonal climatic conditions and ecological rhythms in the Blue Nile Basin. More specifically, regardless of what happened during the wet season, the yearly foraging round of the MSA people living at SM1 was structured in part around the availability of abundant and localized aquatic food resources in the paleo-Shinfa River during the dry season. Once again, this is in direct contrast to previous claims that MSA people were incapable of such behavior, or at least less capable than LSA foragers, however outmoded such arguments may be today.

Finally, SM1 appears to be very similar to other "early" (*i.e.,* > ~10-15 ka) fishing sites in Africa, where groups: 1) exploited a rather limited range of fish species, most of which generally prefer littoral and/or inshore habitats and are relatively easy to capture at certain times of the year; 2) engaged in fishing and aquatic foraging on a seasonal basis; and 3) relied heavily on terrestrial fauna and other food resources for much of the year when fish were not available (Van Neer, 1989, 2004; Stewart, 1989; Yellen *et al.,* 1995). However, unlike SM1, the fishing behavior postulated for many of the other early (*i.e.,* ≥ 20-25 ka) fishing sites along interior rivers and lakes across Africa usually involves floodplain capture in the wet season, particularly of species that spend considerable time on the floodplain during spawning runs (Stewart, 1989; Van Neer, 1989, 2004). Likewise, SM1 also currently lacks barbed bone harpoon points, which are found at many of the other early fishing sites in eastern, northern, and southern Africa (Yellen, 1998). Nonetheless, SM1 fits quite well into the general pattern observed at the oldest fishing sites in Africa, including Katanda, Ishango, Wadi Kubanniya, and White Paintings (Gautier and Van Neer, 1989; Stewart, 1989; Peters, 1990; Robbins *et al.,* 1994; Yellen *et al.,* 1995). That the specific technology and/or fishing behaviors may differ somewhat between SM1 and other sites probably speaks more to the behavioral flexibility of late Pleistocene humans than it

does to any inherent differences in the actual foraging strategies and capabilities of the groups living at each site.

CONCLUSIONS AND FUTURE DIRECTIONS

This dissertation has presented zooarchaeological, taphonomic, behavioral, and comparative analyses of SM1, a late MSA open-air site located along the Shinfa River in northwestern Ethiopia. The Shinfa River is a major tributary of the Blue Nile River, and SM1 is situated in a region of the Horn of Africa where the two major hypothesized routes of human dispersal out of Africa converge. Although it is not suggested that people from SM1 actually dispersed out of Africa, it is reasonable to suggest that groups traveling along either of the two major proposed dispersal routes were likely adapted to environmental conditions and ecological rhythms similar to those present in the Blue Nile Basin (and other arid and highly seasonal lowland regions in the Horn of Africa) during the late MSA. As such, data from SM1 potentially speak to the types of adaptive strategies that early human groups brought with them as they dispersed out of Africa and across the rest of the Old World, and the behaviors which facilitated the success of these dispersals.

Data presented in the previous chapters documents that MSA people regularly exploited a wide range of terrestrial and aquatic species at SM1, with a particular focus on small-to-medium-sized terrestrial mammals and siluriform catfish, namely *Clarias.* The identification of riverine adaptations at SM1 is particularly significant, and makes it only the second site older than ~25 ka where systematic riverine fishing and foraging behavior is well-documented. The site is also important because it provides evidence that the behavioral adaptations of the SM1 people were finely attuned to the extremes of seasonality in the Blue Nile Basin, and their yearly foraging schedule was structured around specific

ecological rhythms associated with life in a temporary river ecosystem in an arid and highly fluctuating environment.

This study provides the first in-depth zooarchaeological *and* taphonomic analysis of a late MSA open-air site in eastern Africa. Currently, there is only one other project of this nature to examine taphonomy at open-air sites (Hutson, 2012, 2018a, 2018b), and only two others that have undertaken similar work at sites outside of South Africa (Assefa, 2002, 2006; Hallett, 2018). Thus, an important goal for future research will be to continue to expand the current sample of MSA sites with detailed faunal and taphonomic studies to include a more diverse range of ecogeographical locations and more sites in open-air settings. This includes study of the tens of thousands of artifacts and faunal remains from water-screened matrix at SM1 that were not analyzed for this study, but which have the potential to provide additional important information about the site and its MSA inhabitants. The need for more research at open-air MSA sites is further underscored by the results of the comparative analyses in Chapter 7 which suggest that open-air and cave sites differ in systematic ways, an observation that should be taken into account when using common taphonomic and other criteria to interpret early human behavior in the archaeological record.

There is also a need for data from more sites located along temporary rivers in the seasonal environments of the Blue Nile Basin, as well as other areas of Africa and elsewhere. This type of habitat is fairly ubiquitous across Africa, Arabia, and many other parts of both the Old and New World, and additional data will make it possible to determine whether the behavioral adaptations observed at SM1 are unique, or are common to sites in similar settings elsewhere across the globe. Identifying similar adaptations at other sites, and particularly other late MSA sites in the Horn of Africa, would lend even more weight

to the "dry-season siphon" idea that was discussed at the end of Chapter 4, and which is generally supported by the data from SM1.

The SM1 people were apparently very well-adapted for survival in extremely hot and arid conditions throughout the extended dry season in the Blue Nile Basin, and part of their dry season foraging strategy probably entailed moving intermittently between sites like SM1 that were located along rivers, perhaps centered around productive waterholes. Moreover, this behavior may have ultimately involved traveling significant distances, either one way or back and forth, during the extended ~6-8-month-long dry season in the Blue Nile Basin. Documenting broadly similar behavior in other groups living along temporary rivers in highly seasonal environments in the Horn and elsewhere in Africa would: 1) indicate that such an adaptive strategy is not unique to the specific geological, hydrological, and/or environmental conditions of SM1 and the Shinfa River; and 2) suggest that increasing aridity may have actually promoted population movement during the late MSA in some regions.

This intriguing possibility is seemingly counterintuitive at first glance, and stands in contrast with the much more commonly-held notion that dispersals through what are today the most arid regions of northeastern Africa and Arabia were only possible during warmer, wetter periods when "green corridors" existed along river courses in these regions (e.g., Drake *et al.,* 2011; Foley et al., 2013; Grove *et al.,* 2015; Timmerman *et al.,* 2016; Lamb *et al.,* 2018). There is no doubt that more equitable climatic intervals would have been favorable for large-scale, long-distance population movements, and the discussion here is not meant to argue this point. However, the evidence from SM1 suggests that drier climatic regimes may have acted to drive and/or facilitate dispersal behavior in a manner that equitable climates did not. This hypothesis deserves serious consideration and further examination.

The comparative analyses in Chapter 7 also emphasize the continued need for standardized methods of collecting and presenting faunal, taphonomic, and other data from MSA sites in order to allow broader comparisons among a greater number of sites. A larger and more diverse sample of MSA sites with detailed faunal and taphonomic data, collected and presented in ways that facilitate large-scale comparisons, will make it possible to build a broader comparative framework and expand our understanding of site formation processes and human behavior in a wider variety of geographical, ecological, and depositional contexts. A broader and more extensive comparative framework, in turn, is necessary for understanding the full range of variability in early human behavior and adaptive strategies in the MSA of Africa.

APPENDICES

Appendix A: Element codes and descriptions

Table A1. Element codes and descriptions for terrestrial fauna.

Code	Description
COR	Coracoid
CRN	Cranial bone
CRP	Carpal
FM	Femur
HC	Horn core
HM	Humerus
LB	Long bone fragment
MP	Metapodial
MR	Mandible
OES	Ostrich eggshell
PH1/2	Phalanx 1/2
PH3	Phalanx 3
PT	Patella
PV	Pelvis
RB	Rib
RD	Radius
SAC	Sacrum
SCAP	Scapula
TB	Tibia
TFR	Tooth fragment
TRS	Tarsal
TTH	Tooth
UL	Ulna
UN	Non-ID bone
VT	Vertebra

Table A2. Element codes and descriptions for fish.

Code	Description	Code	Description
ANP	Anterior nuchal plate	PNP	Posterior nuchal plate
ART	Angulo-articular	POPER	Preopercle
BOCC	Basioccipital	PRAT	Proatlas
BRSTG	Branchiostegal	PROT	Prootic
CERAT	Ceratohyal	PSPH	Parasphenoid
CLTH	Cleithrum	PSPN	Pectoral spine
COR	Coracoid	PTER	Pterotic
DENT	Dentary	PTTH	Pharyngeal tooth
DSPN	Dorsal spine	PTYG	Pterygiophore
EXOCC	Exoccipital	PVOM	Prevomer
FIN	Fin ray/fragment	QUAD	Quadrate
FN	Frontal	RB	Rib
FSPN	Fin spine	SCLTH	Supracleithrum
HYOM	Hyomandibular	SCUT	Indet. neurocranium or cranial shield fragment
HYPO	Hypohyal	SOCC	Supraoccipital
HYPUR	Hypural	SPHEN	Sphenotic
IO	Interorbital	SPINE	Pectoral/dorsal spine fragment
LETH	Lateral ethmoid	TPL	Tooth plate
METH	Mesethmoid	URO	Urohyal
MNP	Medial nuchal plate	VOM	Vomer
MX	Maxilla	VT	Vertebra
OPER	Operculum	WEB	Weberian apparatus
OSPH	Otosphenotic	NON-ID	Non-identifiable bone
PAL	Palatine		

Appendix B: Background information on comparative sites from Aduma and the Kibish Formation

ADUMA SITES

The Aduma region encompasses a ~15 km^2 area wedged in between the Pliocene-aged Dulu Ali basaltic massif (to the east) and the Awash River floodplain (to the west) in the Afar Rift of east-central Ethiopia (Haile-Selassie *et al.,* 2004; Yellen *et al.,* 2005). John Kalb first prospected the Aduma area in 1976 and noted that Acheulean handaxes were visible on the surface (Yellen *et al.,* 2005). More extensive investigation of the region began in 1992, when members of the Middle Awash Research Project discovered an MSA pavement at the southern end of the Ardu Beds, a series of conical, silty/sandy hills from which most of the Aduma fossil and archaeological material derives (Yellen *et al.,* 2005). Further investigation over the next six years turned up numerous MSA archaeological and paleontological deposits, as well as four hominin fossils (ADU-VP-1/1, ADU-VP-1/2, ADU-VP-1/3, and ADU-VP-1/6) attributed to early modern *H. sapiens* (Haile-Selassie *et al.,* 2004). A number of different radiometric methods (*e.g.,* $^{40}Ar/^{39}Ar$, TL, OSL, U-series, AAR, ^{14}C) have been employed to date the Aduma fossils and MSA deposits, each with somewhat different, and sometimes conflicting, results (Yellen *et al.,* 2005). Nonetheless, the bulk of the evidence suggests that most of the archaeological sites and the human fossils at Aduma date to the late MSA, ~80-105 ka (Haile-Selassie *et al.,* 2004; Yellen *et al.,* 2005).

Much of the archaeological and faunal material from Aduma derives from eight sites investigated between 1993-1998, and known as A1, A2 VP1/1, A2 VP1/3, A4, A5, A8, A8A, and A8B (Yellen *et al.,* 2005). In addition to the hominin fossils, which were found at A2 VP1/1 and VP1/3, these sites have produced 10 assemblages, several of which contain abundant vertebrate and invertebrate fauna, and associated chipped stone artifacts

(Yellen *et al.,* 2005). Controlled excavation was undertaken at A1, A2 VP1/1, A4, A5, A8, and A8A, while A2 VP1/3 and A8B were only surface collected (Yellen *et al.,* 2005). In most cases, sediments were dry-screened through 3-mm mesh screens, although screen size did vary on occasion and not all sediments were sieved (Yellen *et al.,* 2005). Based on published accounts and an initial inspection of the Aduma collection at the National Museum in Addis Ababa, a decision was made to focus comparative analyses for the current project on two sites – A2 VP1/1 and A8A (both ~80-100 ka) – which have abundant and/or relevant fauna for comparison with SM1.

Along with several hominin cranial fragments, A2 VP1/1 has also produced a rather large collection of faunal material (n=3000+) (Haile-Selassie *et al.,* 2004; Yellen *et al.,* 2005). The hominin fossils were found along with a small scatter of lithics and faunal remains on the ground atop an erosional surface left behind by what was once a series of Ardu hills. Following collection of the hominin cranial fragments, the erosional surface was prospected and sediment was screened. Two years later, a step trench was put in along the hillside immediately adjoining the exposed erosional surface and several 1 m^2 units were opened directly beneath the location of the hominin fossils (Yellen *et al.,* 2005). Mammalian taxa at A2 VP1/1 include hippopotamus, reedbuck, waterbuck, bushbuck, warthog, genet, and lesser canerat. As with the other sites, crocodile bones are present and, in this case, rather abundant (n=113) (Yellen *et al.,* 2005). There is also a single bone attributed to *Anhinga* (anhinga) or possibly *Phalacrorax* (cormorant), two genera of water birds. *Clarias* dominates the fish remains and the collection in general (90% of total in both cases), but a small number of (*Labeo)Barbus* remains were also recovered. Additionally, there are two genera of bivalve mollusk (*Unio* sp. and *Achatines* sp.) and one univalve taxon (*Melanoides* sp.) present (Yellen *et al.,* 2005).

Abundant fauna (n=3100) were also recovered from A8A, which consists of a slightly raised, elliptical pediment measuring ~17x5 m. Systematic surface prospecting preceded controlled excavation, which involved several .5 m^2 test pits put in at either end of the pediment, as well as an additional 14 squares that were subdivided into 20 cm^2 units and excavated by stratigraphic unit into the pediment. Excavated sediment was dry-screened (Yellen *et al.,* 2005). Mammals present at A8A include hippopotamus, reedbuck, waterbuck, bushbuck, indeterminate alcelaphine and bovine bovids, and warthog. Once again, crocodile and *Clarias* catfish are also present and, similarly to A2 VP1/1, *Clarias* accounts for ~90% of the identifiable faunal remains. Additionally, it is worth noting that definite cut marks are present on several hippopotamus bones and that a handful of specimens, including a crocodile vertebra, bear evidence of non-human carnivore damage (Yellen *et al.,* 2005).

The presence of hippopotamus, crocodile, and catfish at both sites, as well as (*Labeo*)*Barbus* and aquatic bivalve and univalve mollusks at A2 VP1/1, strongly indicate the presence of a significant source of water in the immediate vicinity of the Aduma sites. The presence of anhinga/cormorant, both of which are water birds that live in swampy, riverine environments, and lesser canerat, which often occupy marshy habitats, further supports this conclusion (Kingdon, 2015). Moreover, *Clarias* and Bohor reedbuck suggest a rather extensive floodplain environment, and waterbuck are also known to inhabit floodplains and/or well-watered woodlands (Stewart 1994; Yellen *et al.,* 2005; Clark and Plug 2008). As such, the fauna, along with other geological and paleoenvironmental data, indicate MSA people at Aduma lived within or along the fringes of a riverine ecosystem, which consisted of a river large enough to support multiple aquatic taxa of all sizes with a broad and possibly heavily vegetated floodplain, which was likely adjacent to woodland

and/or more open grassland habitats that would support water-dependent grazers (Yellen *et al.,* 2005).

The Aduma sites were chosen for comparison, in part, because of their geographical and temporal proximity to SM1. Further, there are a number of other similarities between SM1 and the Aduma sites that appear to make them ripe for comparative analysis. As discussed above, the Aduma sites were likely located either within or at the fringes of a local riverine ecosystem, and therefore derive from an ecological context which is at least broadly similar to SM1 in that respect. The fact that a number of animal taxa, including reduncine bovids, warthog, crocodile, *Clarias* catfish, and bivalve mollusks, are common to both sites may well be a reflection of this ecological similarity, and generally supports the idea that the sites are from broadly comparable settings. Additionally, as with SM1, much of the Aduma fauna was recovered *in-situ* through controlled excavation and is closely associated with archaeological material indicative of human presence.

Despite these similarities, there are also a number of differences between SM1 and the Aduma sites, and the reasons for them are not immediately clear. For example, although fragment sizes are comparable between SM1 and at least some Aduma sites (*e.g.,* A2 VP1/1), the cause(s) of fragmentation at each site may not be entirely analogous. Much of the fragmentation at Aduma is attributed to calcrete infiltration and other post-depositional processes (Yellen *et al.,* 2005), whereas initial indications from SM1 suggest fragmentation is largely human-caused or, at the least, not post-depositional (see below). Further, the effects of alluvial and colluvial processes and surface re/exposure may be more pronounced at Aduma than at SM1, given that signs of abrasion and surface erosion are somewhat prevalent at Aduma. In particular, many of the mammal bones at Aduma display eroded surfaces and/or are covered in calcrete, making identification and inspection for surface modification difficult, and hindering attempts to reconstruct human behavior from the

faunal remains (Yellen *et al.,* 2005). In fact, A8A is the only site where definite cutmarks have been observed, and although patterns of fragmentation are generally consistent with carnivore activity, conclusive carnivore damage is only present on three bones from two sites (A8 and A8A) (Yellen *et al.,* 2005). As such, while the presence of lithic artifacts provides a clear anthropogenic signal, the history of faunal accumulation and alteration is rather ambiguous (Yellen *et al.,* 2005). This is in contrast to SM1, where material was likely deposited and buried relatively rapidly, surface abrasion/erosion and calcrete formation are not overly common, and preliminary observations provide more substantial evidence for both human and carnivore involvement in the accumulation and alteration of faunal remains.

Given the probable general similarity of riverine ecosystems at SM1 and Aduma, and the fact that the Aduma sites and SM1 are comparable in many ways, but at the same time display several potentially meaningful differences, comparative analyses can be used to examine possible reasons for similarities and differences between sites in terms of taxonomy, taphonomy, and behavior (albeit probably to a lesser extent), while at least partly controlling for differences in habitat. The Aduma fauna has been previously analyzed and described (Yellen *et al.,* 2005), and there is seemingly no reason to doubt the validity of the original identifications and measurements. As such, data collection for this project was aimed primarily at gathering taphonomic and other data needed for comparison with SM1, which have not been previously collected and/or are not currently available in the published literature.

KIBISH FORMATION

The Kibish Formation is a ~100 m thick series of sedimentary units, running along the Omo River and the base of the Nkalabong Mountains in the east and bounded by the

Kibish River to the west, in the lower Omo River Valley of southern Ethiopia (Butzer, 1969; Butzer *et al.,* 1969; McDougall *et al.,* 2005; Brown and Fuller, 2008). The formation has five major subdivisions known as (from oldest to youngest) Members I, II, III, IVa, and IVb, which span the last ~240 ka and consist of primarily fluvial/deltaic (Members I, II, and III) and lacustrine (Members IVa and IVb) sediments, interbedded with volcanic tuffs and local conglomerates (Butzer, 1969; Butzer *et al.,* 1969; Brown and Fuller, 2008). The Kibish Formation rose to paleoanthropological prominence in 1967 when a team from the Kenyan National Museums led by Richard Leakey, working as part of the International Paleontological Research Expedition to the Omo River, discovered hominin fossils, dubbed Omo I, II, and III, near the top of Member I (Day, 1969, Leakey, 1969; Fleagle *et al.,* 2008). Omo III has received little attention beyond its initial description in 1969 (Fleagle *et al.,* 2008). Omo I and Omo II, on the other hand, have been the subject of continued study and controversy over the past 45+ years, and have figured prominently in debates about modern human origins (Fleagle *et al.,* 2008; Pearson *et al.,* 2008a; Rightmire, 2008).

Work resumed at the Kibish Formation between 1999-2003, when an international, multidisciplinary team of scientists embarked on a new set of expeditions with the aim of resolving the provenance and dating of the Omo I and II fossils, clarifying and verifying the original geological and stratigraphic assessments, and recovering additional faunal and archaeological material (Shea *et al.,* 2007; Fleagle *et al.,* 2008). One of the most significant aspects of this work was to obtain new age estimates for Omo I and II, which are now securely dated at ~195 ± 5 ka based on $^{40}Ar/^{39}Ar$ analysis of alkali feldspar crystals from a volcanic tuff just below the level containing the fossils (McDougall *et al.,* 2005, 2008). As such, Omo I and II are now known to be considerably older than even the earliest previous estimates (~130 ka), and are currently two of the oldest known modern *H. sapiens* fossils

in the world (Klein, 2009). This later work also recovered several additional elements belonging to the Omo I skeleton, as well as four other cranial and postcranial fossils that derive from two newly discovered sites (Pearson *et al.,* 2008a, 2008b). These investigations also significantly increased the amount of MSA archaeological and faunal material that is now available from the Kibish Formation (Assefa *et al.,* 2008; Fleagle *et al.,* 2008; Shea, 2008).

Archaeological and paleontological work during the 1999-2003 expeditions involved survey and excavation of previously known sites and new localities (Shea *et al.,* 2007; Assefa *et al.,* 2008b; Shea, 2008). Systematic surface survey entailed gridding of the surface to be prospected and methodical recovery of material, and excavations were often preceded by this type of controlled surface collection (Shea, 2008). Systematic excavations employed m^2 grids and were carried out using hand tools, and sediment was commonly screened through 50-mm mesh (Shea, 2008). However, while much of the work was carried out in systematic fashion, a large amount of surface-collected material was not collected systematically (Assefa *et al.,* 2008b; Shea, 2008; Trapani, 2008). Importantly, although some faunal remains were recovered during excavation, the majority of the fauna were surface-prospected from 122 localities in Members I, III, and IV, with collection procedures often varying by locality (Assefa *et al.,* 2008b; Shea, 2008; Trapani, 2008). Cranial and postcranial material was recovered, but collection generally concentrated heavily on more readily identifiable cranial elements. For ungulates, the primary focus was often on skulls, horn cores, mandibles, and teeth, with calcanei and astragali also heavily targeted (Assefa *et al.,* 2008b). Collection strategies for fish remains were similarly concentrated on identifiable bones and exhaustive attempts were not made to collect every element from common taxa (Trapani, 2008). Conversely, because they were relatively rare,

specimens from non-ungulate terrestrial taxa were always collected when encountered (Assefa *et al.,* 2008b).

The Kibish Formation faunal collection includes numerous terrestrial and aquatic taxa (Assefa *et al.,* 2008b; Louchart, 2008; Trapani, 2008). Mammalian fauna are dominated by bovids (represented by numerous taxa of all size classes from at least 9 tribes), which make up 60%+ of the samples across all stratigraphic units (Assefa *et al.,* 2008b). Equids (cf. Grevy's zebra and cf. Burchell's zebra) and suids (warthog, giant forest hog, red river hog) are also relatively abundant and somewhat diverse, while carnivores and primates are apparently quite rare (NISP = 1 hyaena and NISP = 1 baboon, respectively. Other mammalian fauna include elephant, giraffe, rhinoceros, hippopotamus, porcupine, mongoose, cane rat, and mole-rat (Assefa *et al.,* 2008b). Many of the taxa in the assemblage are suggestive of relatively open grassland-shrubland environments (*e.g., Gazella*, *Damaliscus, Equus*).

However, the presence of giant forest hog (*Hylochoerus meinetzhageni*), duiker (*Cephalophus*), bushbuck (*Tragelaphus scriptus*), reedbuck (*Redunca redunca*), cane rat (*Thryonomys swinderianus*), and other taxa also indicates more closed forested environments and moist grasslands (Assefa *et al.,* 2008b). Remains of hippopotamus and crocodile also indicate a relatively substantial source of water in the area, a conclusion supported by the numerous fish and water-birds that have also been recovered (Assefa *et al.,* 2008b; Louchart, 2008; Trapani, 2008). Fish are one of the most common types of vertebrate fauna, and are represented by species of *Gymnarchus, Barbus, Hydrocynus, Clarias, Synodontis, Schilbe, Tetraodon,* and *Lates,* as well as several other taxa identified only to family level or higher (Trapani 2008). Birds include pelicans, herons, anhingas, and guinea fowl (Louchart 2008).

The fish remains from the Kibish Formation fauna were chosen for comparison with the fish from SM1, in part, due to the temporal (particularly Member III) and geographic proximity to SM1. Additionally, the Kibish fish derive from open-air sites and are largely paleontological (as opposed to archaeological), so these specimens should provide a reasonable example of a naturally-accumulated fish assemblage from the late MSA. As such, comparative analyses will allow for examination of similarities and differences in taxonomy, taphonomy, and preservational state between the two assemblages, in order to help determine if the fish assemblage from SM1 is more similar to a natural or human accumulation. However, the collection strategy, which focused on large and identifiable specimens, and presorted nature for the Kibish Formation fauna is likely to have influenced the composition of the fish assemblage in ways that may make it inappropriate for some comparative analyses. This point is discussed in more detail in Chapters 3 and 5. As alluded to above, taxonomic inventories and other basic data have already been published and/or collected for much of the Kibish fauna (Assefa *et al.,* 2008b; Louchart, 2008; Trapani, 2008). Therefore, data collection for this project focused primarily on taphonomic and other basic data that are not currently available in the literature and are necessary for comparisons with SM1.

Appendix C: Taxon and element counts for Aduma A2, Aduma A8A, and the Kibish Formation

Table C1. Basic taxon and element abundance data for terrestrial fauna from Aduma A2. Includes only specimens recorded specifically for this study.

Element	**Bird**	**Bovid size 1**	**Bovid size 2**	**Bovid size 3**	***Crocodylus***	**Rodent**	**Vertebrate size 1a**	**Vertebrate size 1**	**Vertebrate size 2**	**Vertebrate size 3**	**Vertebrate size 4**	**Vertebrate size indet.**
CRN												1
MR						2	1					
TTH					5	5						
HM						1	1					
RD			2									
IM		1					1					
FM			1	1	1	1						
MP							1					1
PH	1		2				1			1		
CPB			1				2		1			
RB								1	2			
VT		2				1	7		2	2	2	
LB							2					51
TFR					1							2
NON-ID												215
NISP	1	3	6	1	7	10	16	1	5	3	2	270

Table C2. Basic taxon and element abundance data for terrestrial fauna from Aduma A8A. Includes only specimens recorded specifically for this study.

Element	***Kobus* sp. (size 2)**	**Bovid size 2**	**Bovid size 3**	**Bovid size 4**	**Bovid size indet.**	***Phacochoerus***	***Hippopotamus* sp.**	***Crocodylus***	**Indet. reptile**	**Vertebrate size 1**	**Vertebrate size 2**	**Vertebrate size 3**	**Vertebrate size 4**	**Vertebrate size 5**	**Vertebrate size indet.**
CRN		3					2	9				1	1		
MR	1	1				1		1							1
TTH						1	7	2							
HM								1							
RD			2				1								
IM										1	1	1			
FM							2				1				
MP		3													
PH												1			
CPB		1	1	1							4	3		1	2
RB							6				9	9	7		3
VT							2	2			1		1	5	
LB											1	1	1	4	129
TFR		3			3		10								18
NON-ID									1		2	8	5	1	624
NISP	1	11	3	1	3	2	30	15	1	1	19	24	15	11	777

Table C3. Basic taxon and element abundance data for fish from Aduma A2. Includes only specimens recorded specifically for this study.

Element	***Clarias***	**(*Labeo*)*Barbus***	**Non-ID**	**Total**
ART	17		2	19
BRSTG	6		9	15
CERAT	13		2	15
CLTH	4		4	8
DENT	5	1		6
SPINE	1			1
FN	3		1	4
HYPO	3		3	6
IO	7		3	10
METH	8			8
SCUT	10		171	181
OPER	2			2
PAL	3			3
PSPH	9		3	12
PSPN	82		7	89
PVOM	1			1
RB	1		3	4
SOCC			1	1
SPINE			7	7
SPHEN	1			1
TPL			2	2
TTH		18		18
URO	7			7
VOM	1			1
VT	16		19	35
WEB			1	1
NON-ID	1		167	168
NISP	201	19	405	625

Table C4. Basic taxon and element abundance data for fish from Aduma A8A. Includes only specimens recorded specifically for this study.

Element	***Bagrus***	***Clarias***	**Non-ID**	**Total**
ANG		6		6
BOCC		1		1
CERAT		5		5
CLTH			1	1
DENT		3		3
FN		3	2	5
IO		7		7
LETH		1		1
METH		11	1	12
SCUT	1	19	154	174
OPER			1	1
PSPH		7	1	8
PSPN		9	1	10
PVOM		4		4
QUAD		1		1
RB			1	1
SPINE			2	2
SPHEN			1	1
TPL			1	1
WEB		1		1
NON-ID			58	58
NISP	1	78	224	303

Table C5. Taxon and element abundance data for fish from the Kibish Formation. Includes only specimens recorded specifically for this study.

Element	*Bagrus*	*Clarias*	*Schilbe*	*Synodontis*	Siluriformes	*(Labeo)Barbus*	*Hydrocynus*	*Lates*	cf. *Gymnarchus*	cf. *Polypterus*	Non-ID fish
ANG	1	1						4			
ANP				3							
BOCC				2				1			2
CERAT		2						1			
CLTH				4	2			2			2
COR		1									1
DENT	2	1						11			
DSPN	4			9	11						43
EXOCC				3				1			1
FSPN											13
FN		1	1	4				2			1
HYOM								1			
SPINE				31							
SPINE											7
IO		2									
LETH		4	2	8				2			2
MR	0	0						0			
MX											1
MNP				1							
METH		8	1	4				1			1
SCUT		30	0	0	6					2	0
NON-ID								2		1	5
SCUT											36
SCUT				4							
OPER											1
PAL								1			
PSPH		1	1	5				1			1
PSPN		1		26	4						4
PNP				6							
					444						

PMX		1						2			2
POPER								1			
PVOM		5	1	4				2			2
PRAT		1		3				1			
QUAD								3			
RB											1
SCALE											1
SPHEN			1	6				2			2
SOCC				9				1			1
TTH						4	1		10		2
TPL								1			6
VT					1			71			12
VOM			1	4				4			
NISP	7	26	8	136	24	4	1	118	10	3	150
MNE	6	7	1	49	20	4	1	99	10	2	99
MNI	4	3	1	10	11	1	1	10	1	2	32

Appendix D: Fish skeletal element classification and expected proportions for complete skeletons

Table D1. Anatomical region (bold), skeletal structure (italics), and element groups for fish bones from SM1 following a slightly modified version of systems used in Wheeler and Jones (1989) and Zohar (2003) [1].

Cranial	**Cranial (cont.)**
Neurocranium	*Opercular*
Basioccipital	Operculum
frontal	*Branchial*
Interorbital	Branchiostegal
Lateral ethmoid	*Pharyngeal*
Mesethmoid	Pharyngeal tooth[2]
Otosphenotic	**Postcranial**
Parasphenoid	*Appendicular*
Prevomer	Cleithrum
Prootic	Coracoid
Pterotic	Supracleithrum
Sphenotic	Rib[2]
Supraoccipital	*Median fin*
Vomer	Dorsal/pectoral spine
Oromandibular	Fin ray
Angulo-articular	Fin spine
Dentary	Pterygiophore
Maxilla	**Vertebral**
Palatine	Proatlas
Quadrate	Weberian apparatus
Hyoid	Hypural
Ceratohyal	Vertebra
Hypohyal	
Hyomandibular	
Urohyal	

[1] Table lists only elements recovered from SM1

[2] Not included in analyses of region/structure/element representation

Table D2. Expected frequencies for anatomical regions and skeletal structures in a complete fish skeleton.

	Cyprinidae		Cichlidae		Siluriformes	
Region/Structure	**NISP**	**%**	**NISP**	**%**	**NISP**	**%**
Cranial	154	69.4	128	65.6	102	58.3
Neurocranium	51	23	48	24.6	42	24
Oromandibular	20	9	20	10.3	18	10.3
Hyoid	16	7.2	16	8.2	14	8
opercular	8	3.6	8	4.1	6	3.4
Branchial	59	26.6	36	18.5	22	12.6
Postcranial	23	10.3	37	19	10	5.7
Appendicular	16	7.2	16	8.2	8	4.6
Median fin	7	3.1	21	10.8	2 or 3	1.1
Vertebral column	45	20.3	30	15.4	63	36
Total	**222**	**-**	**195**	**-**	**175**	**-**
Average for Siluriformes based on *Clarias gariepinus* Data from Zohar (2003: 21)						

Appendix E: Terrestrial fauna taxon and element counts from SM1

Table E1. Taxon and element abundance data for ungulates from SM1.

Element	*Aepyceros sp.*	*Gazella sp.*	Antilopini size 1/2	Reduncini/ Tragelaphini size 2	Bovid size 1	Bovid size 2	Bovid size 3	Bovid size 4	Bovid size indet.	*Phacochoerus sp.*
HC		2			7	4			2	
MR	1	2	1		4	5			3	
TTH			1	2	1	4	1		20	1
HM						1	1		1	
RD						1				
UL						2				
VT						1				
PV						1			1	
FM		1			5	6				
TB						1				
MP					3	10	5	1	10	
PH					10	32	2			
CPB					2	14	2			
NISP	1	5	2	2	32	82	11	1	37	1
MNE	1	4	2	2	28	61	8	1	17	1
MNI	1	1	1	2	4	5	1	1	1	1

Table E2. Taxon and element abundance data for small mammals from SM1.

Element	*Felis lybica*	Carnivora size 1a/1	*Chlorocebus sp.*	*Lepus sp.*	*Hystrix sp.*	Gerbilinae	Murinae	Rodentia indet.
MR						4	3	1
TTH		1	2		1	3	2	8
HM			1					4
RD		2	1					
VT								2
SAC								1
FM			1					1
TB								1
MP	1	1						
PH1/2	2							
TRS				1				3
LB								1
NISP	3	4	5	1	1	7	5	22
MNE	3	4	5	1	1	7	5	17
MNI	1	3	1	1	1	2	2	2

Table E3. Taxon and element abundance data for reptiles and amphibians from SM1.

Element	*Crocodylus niloticus*	Serpentes	Varanidae	Reptilia indet.	Anura
RD					7
VT	1	3	1		
PV					2
FM				1	
PH1/2	2				
LB					1
NISP	3	3	1	1	10
MNE	3	3	1	1	9
MNI	1	1	1	1	4

Table E4. Taxon and element abundance data for birds from SM1.

Element	*Numida meleagris*	*Struthio camelus*	Aves indet.
COR	6		
HM	2		
RD			2
UL	3		
VT			3
RB			1
FM	1		
TBT	2		3
TMT	2		
PH	2		5
LB			128
UN			1
OES		178	
NISP	18	178	143
MNE	15	-	14
MNI	3	-	2

Table E5. Element abundance data for terrestrial fauna not identified to a specific taxon.

Element	Vertebrate size 1a	Vertebrate size 1	Vertebrate size 2	Vertebrate size 3	Vertebrate size indet.
CRN					1
MR			2		1
TTH	4	1			
SCAP	2		1		1
HUM	2	2			3
VT	12	4	3	1	7
RB	3	5	7		32
SAC	1				
PV	1		1		
FEM	1		1		2
TB	1				1
MP			2		1
PH1/2	22	2	7		
PH3	1				
CARP	2	2	1		
TARS		1	4		
CPB	4	1	2		
LB	6	2			1521
TFR	2				242
NON-ID	4				2134
NISP	68	20	31	1	3946
MNE	49	11	20	1	11
MNI	2	1	3	1	1

Appendix F: Element portion descriptions and bone mineral density (BMD) values for Connochaetes taurinus

Table F1. Element portions and density values from Lam *et al.* (1999)*.

Taxon	Element	Portion	BMD
Connochaetes taurinus	Mandible	symphysis	0.52
Connochaetes taurinus	Mandible	diastema	1.09
Connochaetes taurinus	Mandible	horizontal ramus	0.99
Connochaetes taurinus	Mandible	condyle	0.97
Connochaetes taurinus	Innominate	acetabulum	0.64
Connochaetes taurinus	Innominate	pubis shaft	0.4
Connochaetes taurinus	Humerus	proximal shaft	0.49
Connochaetes taurinus	Humerus	middle shaft	1.1
Connochaetes taurinus	Ulna	alconeal process/radial notch	0.85
Connochaetes taurinus	Femur	proximal end	0.41
Connochaetes taurinus	Femur	proximal shaft 1	0.51
Connochaetes taurinus	Femur	distal shaft	0.66
Connochaetes taurinus	Femur	distal end	0.38
Connochaetes taurinus	Femur	greater trochanter	0.31
Connochaetes taurinus	Patella	any part	0.44
Connochaetes taurinus	Tibia	proximal shaft/crest	0.91
Connochaetes taurinus	Tibia	middle shaft	1.12
Connochaetes taurinus	Intermediate carpal	any part	0.7
Connochaetes taurinus	Calcaneus	proximal end	0.57
Connochaetes taurinus	Calcaneus	body	0.92
Connochaetes taurinus	Calcaneus	sustentaculum	0.67
Connochaetes taurinus	Calcaneus	distal end	0.75
Connochaetes taurinus	Astragalus	any part	0.72
Connochaetes taurinus	Naviculo-cuboid	any part	0.61
Connochaetes taurinus	Metacarpal	proximal end	0.72

Connochaetes taurinus	Metacarpal	proximal shaft	1.12
Connochaetes taurinus	Metapodial	proximal end	0.78
Connochaetes taurinus	Metapodial	proximal shaft	1.12
Connochaetes taurinus	Metapodial	middle shaft	1.15
Connochaetes taurinus	Metapodial	distal shaft 2	0.55
Connochaetes taurinus	Metapodial	distal end	0.64
Connochaetes taurinus	Phalanx 1	proximal end	0.54
Connochaetes taurinus	Phalanx 1	middle shaft	1.02
Connochaetes taurinus	Phalanx 1	distal end	0.8
Connochaetes taurinus	Phalanx 2	proximal end	0.47
Connochaetes taurinus	Phalanx 2	distal end	0.56
Connochaetes taurinus	Phalanx 3	any part	0.53
*Includes only portions used for this study			

Appendix G: Fish taxon and element counts for SM1

Table G1. Taxon and element abundance data for siluriform catfish from SM1.

Skeletal structure	Element	*Auchenoglanis*	*Bagrus*	*Clarias*	*Schilbe*	*Synodontis*	Siluriformes indet.
Neurocranium	BOCC		1	10			
	FN			25		2	
	IO			19			
	LETH			4			
	METH			10		2	
	OSPH					1	
	PSPH			14			
	PVOM			6			
	PROT			1			
	PTER			3			
	SPHEN			4			
	SOCC			2		1	
	VOM			1			
	SCUT			1117			1
Oromandibular	ART			40	1		
	DENT		5	45			
	QUAD			19			
	MX			1			
	PAL			23			
	PHAR						
	TPL						

Hyoid	CERAT		9	31			
	HYPO		3	3			
	URO			4			
	HYOM		2	1			
Opercular	OPER		1	6			
Appendicular	CLTH			5		11	3
	COR			4			
	SCLTH			2			
Median fin	SPINE	3	15	113	24	64	172
Vertebral	PRAT		1	6			
	VT	1	24	16	9		32
	WEB		1	7			
	NISP	4	62	1542	34	81	208
	MNE	3	42	217	20	43	26
	MNI	1	6	28	5	12	9

Table G2. Taxon and element abundance data for cyprinids, cichlids, and non-identified fish from SM1.

Skeletal structure	**Element**	***Labeo***	***Labeobarbus***	**Cyprinidae**	***Oreochromis***	**Indet. fish**
Neurocranium	BOCC					2
	FN					1
	IO					4
	PSPH					9
	SCUT					26
Oromandibular	ART					1
	DENT					10
	QUAD	2			2	1
	MX					2
	PHAR	10		4		
	TPL					6
Hyoid	URO					5
	HYOM	3	2			
Opercular	OPER			2		3
Branchial	BRSTG					37
Appendicular	CLTH					8
	COR					5
	RB					34
Median fin	FIN					47
	FSPN			1		
	PTYG				1	
Vertebral	HYPUR					8
	PRAT					1
	VT	9	9	29	1	148
	WEB					2

Non-ID	NON-ID					797
	NISP	24	11	36	4	1157
	MNE	22	10	27	4	174
	MNI	2	1	1	1	-

Appendix H: Fish taxonomic abundance in the modern Shinfa River and other Blue Nile tributaries in the NW lowlands of Ethiopia

Table H1. Fish count data for the modern Shinfa River and other Blue Nile tributaries from Tewabe (2008).

Taxon	Shinfa	Ayima	Gendwuha	Guang
Characiformes				
Characidae				
Alestes baremoze	4	9	-	-
Brycinus macrolepidotus	-*	2	20	3
Brycinus nurse	1	10	-	-
Hydrocynus forskalii	1	39	29	15
Cypriniformes				
Citharinidae				
Citharinus latus	-	1	-	-
Cyprinidae				
Labeo forskalii	22	13	40	36
Labeo niloticus	36	36		1
Labeobarbus bynni	4	2	28	11
Labeobarbus crassibarbis	1	-	3	3
Labeobarbus degeni	18	7	2	12
Labeobarbus intermedius	11	9	63	63
Labeobarbus nedgia	17	8	30	28
Mormyriformes				
Mormyridae				
Marcusenius cyprinoides	-*	-	-	-
Mormyrus caschive	3	-	-	-
Mormyrus hasselquisti	-	-	3	16
Mormyrus kannume	29	-	21	26
Osteoglossiformes				
Osteoglossidae				
Heterotis niloticus	-	3	-	-
Perciformes				
Latidae				
Lates niloticus	-	10	-	-

Cichlidae				
Oreochromis niloticus	3	1	29	11
Siluriformes				
Bagridae				
Bagrus bajad	20	-	1	-
Bagrus docmak	22	2	14	16
Clariidae				
Clarias gariepinus	3	20	6	-
Heterobranchus longifilis	1	2	-	1
Claroteidae				
Auchenoglanis biscutatus	-*	3	-	-
Malapteruridae				
Malapterus electricus	-	-	-	1
Mochokidae				
Synodontis schall	32	28	3	13
Synodontis serratus	10	18	9	10
Schilbeidae				
Schilbe intermedius	34	-	-	-

*Species not sampled by Tewabe (2008), but caught in the Shinfa River during subsequent sampling undertaken as part of the Blue Highways project.

Appendix I: Regression results, equations, and body size estimates for fossil fish from SM1

Table I1. Summary statistics and equations used to predict the total length (TL) of fossil fish from SM1.

Taxon	Element	Variable	n	r^2	Equation	TL estimates for:
Bagrus	HYOM	BAS	12	0.92	1.36+.7*log(x)	*Bagrus* (2)
Cyprinidae	HYOM	BAS	13	0.9	1.26+.75*log(x)	*Labeo/barbus* (3)
Siluriformes	HYOM	BAS	21	0.9	1.34+.71*log(x)	*Clarias* (1)
All fish	MR	BAS	33	0.81	1.17+.54*log(x)	-
Siluriformes	MR	BAS	20	0.75	1.16+.55*log(x)	*Clarias* (35)
All fish	OPER	HAS	35	0.86	1.09+.66*log(x)	Indet. (3)
Bagrus	OPER	HAS	11	0.95	.92+.88*log(x)	-
Cyprinidae	OPER	HAS	13	0.9	1.01+.91*log(x)	*Labeo/barbus* (2)
Siluriformes	OPER	HAS	21	0.85	1.07+.68*log(x)	-
Bagrus	OPER	BAS	11	0.97	1.21+.84*log(x)	*Bagrus* (1)
Cyprinidae	OPER	BAS	13	0.89	1.21+.65*log(x)	-
Siluriformes	OPER	BAS	21	0.93	1.23+.76*log(x)	*Clarias* (6)
Bagrus	PSPN	BH	11	0.99	1.01+.9*log(x)	*Bagrus* (5)
Siluriformes	PSPN	BH	30	0.29	1.13+.56*log(x)	-
Synodontis	PSPN	BH	8	0.93	.6+1.06*log(x)	*Synodontis* (20)
All fish	QUAD	HAS	31	0.86	1.19+.79*log(x)	*Oreochromis* (1); Indet. (1)
Bagrus	QUAD	HAS	12	0.9	1.23+.7*log(x)	-
Cyprinidae	QUAD	HAS	10	0.83	1.15+.86*log(x)	-
Siluriformes	QUAD	HAS	20	0.86	1.22+.73*log(x)	*Clarias* (19)
All fish	QUAD	BAS	31	0.69	1.2+.5*log(x)	*Oreochromis* (1)
Bagrus	QUAD	BAS	12	0.96	.92+.8*log(x)	-
Cyprinidae	QUAD	BAS	10	0.92	1.07+.95*log(x)	*Labeo/barbus* (2)
Siluriformes	QUAD	BAS	20	0.63	1.21+.48*log(x)	-

All fish collected from the Shinfa River near SM1 between 2010-2016

BAS = breadth of articular surface; HAS = height of articular surface; BH = base height

Table I2. Equations used to estimate body mass (kg) for fossil fish from SM1.

Taxon	n	Equation[1]	Source[2]
Clarias gariepinus	19	W=.0032*TL^3.214	2
Clarias gariepinus	4814	log(W)=3.136*log(TL)-2.3396	5
Clarias gariepinus	187	W=.007906*TL^2.97401	3
Bagrus bajad	50	W=.00908*TL^2.999	1
Bagrus docmak	16	W=.005286*TL^3.149	3
Synodontis schall	50	W=.00869*TL^3.266	1
Synodontis schall	1314	log(W)=-4.212+2.832*log(TL)	4
Synodontis schall	2513	W=.014813*TL^2.8325	3
Schilbe intermedius	9262	W=0.006871*TL^3.02009	3
Labeo sp.	105	W=.00724*TL^3.073	1
Labeo cylindricus	359	W=.0105*TL^3.010	2
(Labeo)Barbus bynni	69	W=.00278*TL^3.444	1
Oreochromis niloticus	18	W=.033035*TL^2.79907	3

[1]W = weight (g); TL = total length (cm)
[2]Source: 1 = Bayley (1982: 485); 2 = Britton and Harper (2006: 335); 3 = Laleye (2006: 332); 4 = Laleye *et al.* (2006: 196); 5 = Willoughby and Tweddle (1978: 519)

Table I3. Fossil fish from SM1 used for total length and body mass estimates.

Catalog #	Genus	Element	Variable	Value (mm)
X15-11-154	Bagrus	OPER	HAS	2.80
W14-18-230	Bagrus	HYOM	BAS	2.84
W14-16-111	Bagrus	HYOM	BAS	3.43
W15-21-68	Bagrus	PSPN	BH	6.42
W15-10-101	Bagrus	PSPN	BH	6.75
W14-13-68	Bagrus	PSPN	BH	6.86
W14-15-321	Bagrus	PSPN	BH	7.10
SM1-737-1	Bagrus	PSPN	BH	7.43
W14-25-825	Bagrus	PSPN	BH	9.01
W15-23-54-1	Clarias	MR	BAS	4.11
X15-1-42	Clarias	MR	BAS	4.13
X15-19-294	Clarias	MR	BAS	5.16
X15-19-362	Clarias	MR	BAS	5.25
W15-1-83	Clarias	MR	BAS	5.28
X15-19-470	Clarias	MR	BAS	5.27
X15-10-76	Clarias	MR	BAS	5.46
X15-3-160-1	Clarias	MR	BAS	5.51
X15-2-216	Clarias	MR	BAS	6.58
X15-12-75	Clarias	MR	BAS	6.82
W15-13-57	Clarias	MR	BAS	6.85
W14-25-427	Clarias	OPER	BAS	3.30
X15-19-640	Clarias	QUAD	HAS	3.59
X15-23-195a	Clarias	MR	BAS	7.44
W15-3-65	Clarias	MR	BAS	7.80
SM1-670	Clarias	MR	BAS	7.84
W15-13-65	Clarias	MR	BAS	7.89
X15-23-104	Clarias	MR	BAS	7.87
X15-12-145	Clarias	QUAD	HAS	3.98
X15-9-99	Clarias	MR	BAS	8.11
W15-23-54a	Clarias	QUAD	HAS	4.01
W15-9-28	Clarias	MR	BAS	8.29
X15-11-497	Clarias	MR	BAS	8.48
W15-18-394	Clarias	MR	BAS	8.78
W15-3-175	Clarias	MR	BAS	8.79

X15-19-525	Clarias	QUAD	HAS	4.27
SM1-550	Clarias	MR	BAS	9.00
W15-1-145	Clarias	MR	BAS	9.00
X15-12-79	Clarias	QUAD	HAS	4.34
SM1-601	Clarias	MR	BAS	9.32
W14-25-365	Clarias	MR	BAS	9.30
X15-10-138	Clarias	MR	BAS	9.29
W15-2-103	Clarias	MR	BAS	9.46
X15-9-182	Clarias	OPER	BAS	4.12
W14-15-82	Clarias	MR	BAS	9.59
X15-12-242	Clarias	QUAD	HAS	4.61
W14-23-111	Clarias	MR	BAS	10.05
W15-13-57-4	Clarias	MR	BAS	10.09
W15-3-228	Clarias	MR	BAS	10.22
X15-18-290	Clarias	MR	BAS	10.46
X15-23-206	Clarias	QUAD	HAS	4.92
W14-25-384	Clarias	QUAD	HAS	4.98
W14-13-1	Clarias	MR	BAS	11.13
W15-23-70	Clarias	MR	BAS	11.32
W14-13-51	Clarias	QUAD	HAS	5.15
X15-9-82	Clarias	QUAD	HAS	5.18
X15-20-79-1	Clarias	QUAD	HAS	5.42
X15-23-60	Clarias	QUAD	HAS	5.57
W14-8-184	Clarias	QUAD	HAS	5.75
X15-19-188	Clarias	QUAD	HAS	6.04
X15-22-300	Clarias	OPER	BAS	5.57
W15-11-139-1	Clarias	HYOM	BAS	4.64
W15-3-335	Clarias	QUAD	HAS	6.74
W15-22-2	Clarias	MR	BAS	16.55
W15-23-35b	Clarias	OPER	BAS	6.23
X15-22-222	Clarias	QUAD	HAS	7.18
X15-3-192-2	Clarias	OPER	BAS	6.48
W14-17-212	Clarias	OPER	BAS	6.49
X15-8-126-1	Clarias	QUAD	HAS	7.52
W15-23-30	Clarias	QUAD	HAS	7.8
W15-18-358	Clarias	QUAD	HAS	8.97
W14-6-293-3	Synodontis	PSPN	BH	2.92
W15-23-206	Synodontis	PSPN	BH	3.99

W14-15-111	Synodontis	PSPN	BH	4.04
W15-1-2b	Synodontis	PSPN	BH	4.37
W14-18-71	Synodontis	PSPN	BH	4.45
W14-25-493	Synodontis	PSPN	BH	4.76
W14-6-293	Synodontis	PSPN	BH	5.04
X15-22-220a	Synodontis	PSPN	BH	5.19
W15-19-71	Synodontis	PSPN	BH	5.34
W15-8-12c	Synodontis	PSPN	BH	5.45
W15-23-153	Synodontis	PSPN	BH	5.52
W15-9-115	Synodontis	PSPN	BH	5.64
W15-9-49b	Synodontis	PSPN	BH	5.65
W14-6-313	Synodontis	PSPN	BH	5.69
W14-13-36	Synodontis	PSPN	BH	6.24
W15-19-55	Synodontis	PSPN	BH	6.28
W14-7-99	Synodontis	PSPN	BH	6.61
W15-3-367	Synodontis	PSPN	BH	6.74
W15-8-78	Synodontis	PSPN	BH	7.43
W15-21-209	Synodontis	PSPN	BH	10.73
X15-11-478-2	Labeobarbus	HYOM	BAS	1.48
X15-1-42-1	Labeo	QUAD	BAS	3.46
X15-1-361	Labeo	HYOM	BAS	3.15
W14-7-231	Labeo	OPER	HAS	4.93
W15-10-57	Labeo	QUAD	BAS	4.32
W15-11-155	Labeo	HYOM	BAS	3.65
W14-5-175	Labeo/barbus	OPER	HAS	5.65
X15-19-377	Oreochromis	QUAD	BAS	6.55
X15-1-138	Oreochromis	QUAD	HAS	3.44
W14-5-865-2	Indet.	OPER	HAS	2.18
X15-22-235	Indet.	OPER	HAS	5.44
X15-2-135	Indet.	OPER	HAS	9.27
SM1-734-51	Indet.	QUAD	HAS	5.62

Table I4. Estimated total length (TL) and body mass (BM) for fossil fish from SM1.

Catalog #	Genus	TL (cm)	BM (kg)
X15-11-154	*Bagrus*	39	0.52
W14-18-230	*Bagrus*	48	0.99
W14-16-111	*Bagrus*	54	1.49
W15-21-68	*Bagrus*	55	1.52
W15-10-101	*Bagrus*	57	1.74
W14-13-68	*Bagrus*	58	1.82
W14-15-321	*Bagrus*	60	2.00
SM1-737-1	*Bagrus*	62	2.26
W14-25-825	*Bagrus*	74	3.87
W15-23-54-1	*Clarias*	32	0.22
X15-1-42	*Clarias*	32	0.22
X15-19-294	*Clarias*	36	0.32
X15-19-362	*Clarias*	36	0.34
W15-1-83	*Clarias*	36	0.34
X15-19-470	*Clarias*	36	0.34
X15-10-76	*Clarias*	37	0.36
X15-3-160-1	*Clarias*	37	0.36
X15-2-216	*Clarias*	41	0.49
X15-12-75	*Clarias*	42	0.53
W15-13-57	*Clarias*	42	0.53
W14-25-427	*Clarias*	42	0.54
X15-19-640	*Clarias*	43	0.58
X15-23-195a	*Clarias*	44	0.61
W15-3-65	*Clarias*	45	0.66
SM1-670	*Clarias*	45	0.67
W15-13-65	*Clarias*	45	0.67
X15-23-104	*Clarias*	45	0.67
X15-12-145	*Clarias*	46	0.69
X15-9-99	*Clarias*	46	0.70
W15-23-54a	*Clarias*	46	0.70
W15-9-28	*Clarias*	46	0.73
X15-11-497	*Clarias*	47	0.76
W15-18-394	*Clarias*	48	0.80

W15-3-175	*Clarias*	48	0.81
X15-19-525	*Clarias*	48	0.81
SM1-550	*Clarias*	48	0.84
W15-1-145	*Clarias*	48	0.84
X15-12-79	*Clarias*	49	0.85
SM1-601	*Clarias*	49	0.89
W14-25-365	*Clarias*	49	0.89
X15-10-138	*Clarias*	49	0.89
W15-2-103	*Clarias*	50	0.92
X15-9-182	*Clarias*	50	0.92
W14-15-82	*Clarias*	50	0.94
X15-12-242	*Clarias*	51	0.97
W14-23-111	*Clarias*	51	1.01
W15-13-57-4	*Clarias*	52	1.02
W15-3-228	*Clarias*	52	1.04
X15-18-290	*Clarias*	53	1.09
X15-23-206	*Clarias*	53	1.12
W14-25-384	*Clarias*	54	1.15
W14-13-1	*Clarias*	54	1.21
W15-23-70	*Clarias*	55	1.24
W14-13-51	*Clarias*	55	1.24
X15-9-82	*Clarias*	55	1.26
X15-20-79-1	*Clarias*	57	1.40
X15-23-60	*Clarias*	58	1.48
W14-8-184	*Clarias*	60	1.60
X15-19-188	*Clarias*	62	1.79
X15-22-300	*Clarias*	63	1.87
W15-11-139-1	*Clarias*	65	2.11
W15-3-335	*Clarias*	67	2.29
W15-22-2	*Clarias*	68	2.39
W15-23-35b	*Clarias*	68	2.44
X15-22-222	*Clarias*	70	2.65
X15-3-192-2	*Clarias*	70	2.69
W14-17-212	*Clarias*	70	2.70
X15-8-126-1	*Clarias*	72	2.94
W15-23-30	*Clarias*	74	3.19
W15-18-358	*Clarias*	82	4.39
W14-6-293-3	*Synodontis*	12	0.04

W15-23-206	*Synodontis*	17	0.11
W14-15-111	*Synodontis*	18	0.12
W15-1-2b	*Synodontis*	19	0.15
W14-18-71	*Synodontis*	19	0.16
W14-25-493	*Synodontis*	21	0.20
W14-6-293	*Synodontis*	22	0.23
X15-22-220a	*Synodontis*	23	0.26
W15-19-71	*Synodontis*	24	0.28
W15-8-12c	*Synodontis*	24	0.30
W15-23-153	*Synodontis*	24	0.31
W15-9-115	*Synodontis*	25	0.33
W15-9-49b	*Synodontis*	25	0.34
W14-6-313	*Synodontis*	25	0.34
W14-13-36	*Synodontis*	28	0.46
W15-19-55	*Synodontis*	28	0.47
W14-7-99	*Synodontis*	30	0.55
W15-3-367	*Synodontis*	30	0.59
W15-8-78	*Synodontis*	33	0.80
W15-21-209	*Synodontis*	49	2.56
X15-11-478-2	*Labeobarbus*	24	0.17
X15-1-42-1	*Labeo*	38	0.57
X15-1-361	*Labeo*	43	0.81
W14-7-231	*Labeo*	44	0.85
W15-10-57	*Labeo*	47	1.08
W15-11-155	*Labeo*	48	1.14
W14-5-175	*Labeo/barbus*	50	1.25
X15-19-377	*Oreochromis*	41	1.05
X15-1-138	*Oreochromis*	41	1.09
W14-5-865-2	Indet.	21	-
X15-22-235	Indet.	38	-
X15-2-135	Indet.	54	-
SM1-734-51	Indet.	61	-

[1]BM = mean of estimates in Table I6

Table I5. All total length (TL) estimates for fossil fish from SM1.

		TL (cm) estimate from equation for:				
Catalog #	**Genus**	**BAG**	**SYN**	**SIL**	**CYP**	**ALL**
X15-11-154	*Bagrus*	39	-	37	-	-
W14-18-230	*Bagrus*	48	-	46	-	-
W14-16-111	*Bagrus*	54	-	52	-	-
W15-21-68	*Bagrus*	55	-	38	-	-
W15-10-101	*Bagrus*	57	-	39	-	-
W14-13-68	*Bagrus*	58	-	40	-	-
W14-15-321	*Bagrus*	60	-	40	-	-
SM1-737-1	*Bagrus*	62	-	41	-	-
W14-25-825	*Bagrus*	74	-	46	-	-
W15-23-54-1	*Clarias*	-	-	31	-	32
X15-1-42	*Clarias*	-	-	32	-	32
X15-19-294	*Clarias*	-	-	36	-	36
X15-19-362	*Clarias*	-	-	36	-	36
W15-1-83	*Clarias*	-	-	36	-	36
X15-19-470	*Clarias*	-	-	36	-	36
X15-10-76	*Clarias*	-	-	37	-	37
X15-3-160-1	*Clarias*	-	-	37	-	37
X15-2-216	*Clarias*	-	-	41	-	41
X15-12-75	*Clarias*	-	-	42	-	42
W15-13-57	*Clarias*	-	-	42	-	42
W14-25-427	*Clarias*	-	-	42	-	-
X15-19-640	*Clarias*	-	-	42	-	43
X15-23-195a	*Clarias*	-	-	44	-	44
W15-3-65	*Clarias*	-	-	45	-	45
SM1-670	*Clarias*	-	-	45	-	45
W15-13-65	*Clarias*	-	-	45	-	45
X15-23-104	*Clarias*	-	-	45	-	45
X15-12-145	*Clarias*	-	-	45	-	46
X15-9-99	*Clarias*	-	-	46	-	46
W15-23-54a	*Clarias*	-	-	46	-	46
W15-9-28	*Clarias*	-	-	46	-	46
X15-11-497	*Clarias*	-	-	47	-	47
W15-18-394	*Clarias*	-	-	48	-	48

W15-3-175	*Clarias*	-	-	48	-	48
X15-19-525	*Clarias*	-	-	48	-	49
SM1-550	*Clarias*	-	-	48	-	48
W15-1-145	*Clarias*	-	-	48	-	48
X15-12-79	*Clarias*	-	-	48	-	49
SM1-601	*Clarias*	-	-	49	-	49
W14-25-365	*Clarias*	-	-	49	-	49
X15-10-138	*Clarias*	-	-	49	-	49
W15-2-103	*Clarias*	-	-	50	-	50
X15-9-182	*Clarias*	-	-	50	-	-
W14-15-82	*Clarias*	-	-	50	-	50
X15-12-242	*Clarias*	-	-	51	-	52
W14-23-111	*Clarias*	-	-	51	-	51
W15-13-57-4	*Clarias*	-	-	52	-	52
W15-3-228	*Clarias*	-	-	52	-	52
X15-18-290	*Clarias*	-	-	53	-	53
X15-23-206	*Clarias*	-	-	53	-	55
W14-25-384	*Clarias*	-	-	54	-	55
W14-13-1	*Clarias*	-	-	54	-	54
W15-23-70	*Clarias*	-	-	55	-	55
W14-13-51	*Clarias*	-	-	55	-	57
X15-9-82	*Clarias*	-	-	55	-	57
X15-20-79-1	*Clarias*	-	-	57	-	59
X15-23-60	*Clarias*	-	-	58	-	60
W14-8-184	*Clarias*	-	-	60	-	62
X15-19-188	*Clarias*	-	-	62	-	64
X15-22-300	*Clarias*	-	-	63	-	-
W15-11-139-1	*Clarias*	-	-	65	-	-
W15-3-335	*Clarias*	-	-	67	-	70
W15-22-2	*Clarias*	-	-	68	-	67
W15-23-35b	*Clarias*	-	-	68	-	-
X15-22-222	*Clarias*	-	-	70	-	74
X15-3-192-2	*Clarias*	-	-	70	-	-
W14-17-212	*Clarias*	-	-	70	-	-
X15-8-126-1	*Clarias*	-	-	72	-	76
W15-23-30	*Clarias*	-	-	74	-	78
W15-18-358	*Clarias*	-	-	82	-	88
SM1-731/2/5-24	*Clarias*	-	-	18	-	-

W14-6-293-3	*Synodontis*	-	12	25	-	-
W15-23-206	*Synodontis*	-	17	29	-	-
W14-15-111	*Synodontis*	-	17	29	-	-
W15-1-2b	*Synodontis*	-	19	31	-	-
W14-18-71	*Synodontis*	-	19	31	-	-
W14-25-493	*Synodontis*	-	21	32	-	-
W14-6-293	*Synodontis*	-	22	33	-	-
X15-22-220a	*Synodontis*	-	23	34	-	-
W15-19-71	*Synodontis*	-	24	34	-	-
W15-8-12c	*Synodontis*	-	24	35	-	-
W15-23-153	*Synodontis*	-	24	35	-	-
W15-9-115	*Synodontis*	-	25	36	-	-
W15-9-49b	*Synodontis*	-	25	36	-	-
W14-6-313	*Synodontis*	-	25	36	-	-
W14-13-36	*Synodontis*	-	28	38	-	-
W15-19-55	*Synodontis*	-	28	38	-	-
W14-7-99	*Synodontis*	-	29	39	-	-
W15-3-367	*Synodontis*	-	30	39	-	-
W15-8-78	*Synodontis*	-	33	41	-	-
W15-21-209	*Synodontis*	-	49	51	-	-
X15-11-478-2	*Labeobarbus*	-	-	-	24	-
X15-1-42-1	*Labeo*	-	-	-	38	29
X15-1-361	*Labeo*	-	-	-	43	-
W14-7-231	*Labeo*	-	-	-	44	35
W15-10-57	*Labeo*	-	-	-	47	33
W15-11-155	*Labeo*	-	-	-	48	-
W14-5-175	*Labeo/barbus*	-	-	-	49	39
X15-19-377	*Oreochromis*	-	-	-	-	41
X15-1-138	*Oreochromis*	-	-	-	-	41
W14-5-865-2	Indet.	-	-	-	-	21
X15-22-235	Indet.	-	-	-	-	38
X15-2-135	Indet.	-	-	-	-	53
SM1-734-51	Indet.	-	-	-	-	61

Table I6. All body mass (BM) estimates for fossil fish from SM1.

		BM estimate using equation from				
Catalog #	**Genus**	**1**	**2**	**3**	**4**	**5**
X15-11-154	*Bagrus*	0.52	-	0.52	-	-
W14-18-230	*Bagrus*	0.98		1.01	-	-
W14-16-111	*Bagrus*	1.45		1.53	-	-
W15-21-68	*Bagrus*	1.47		1.56	-	-
W15-10-101	*Bagrus*	1.68		1.80	-	-
W14-13-68	*Bagrus*	1.76		1.88	-	-
W14-15-321	*Bagrus*	1.92		2.07	-	-
SM1-737-1	*Bagrus*	2.18		2.35	-	-
W14-25-825	*Bagrus*	3.66		4.07	-	-
W15-23-54-1	*Clarias*		0.21	0.23	-	0.23
X15-1-42	*Clarias*		0.21	0.23	-	0.23
X15-19-294	*Clarias*		0.31	0.33	-	0.34
X15-19-362	*Clarias*		0.32	0.34	-	0.35
W15-1-83	*Clarias*		0.32	0.34	-	0.35
X15-19-470	*Clarias*		0.32	0.34	-	0.35
X15-10-76	*Clarias*		0.34	0.36	-	0.37
X15-3-160-1	*Clarias*		0.35	0.36	-	0.38
X15-2-216	*Clarias*		0.48	0.48	-	0.51
X15-12-75	*Clarias*		0.51	0.52	-	0.55
W15-13-57	*Clarias*		0.52	0.52	-	0.55
W14-25-427	*Clarias*		0.53	0.54	-	0.57
X15-19-640	*Clarias*		0.57	0.57	-	0.61
X15-23-195a	*Clarias*		0.59	0.59	-	0.63
W15-3-65	*Clarias*		0.64	0.64	-	0.69
SM1-670	*Clarias*		0.65	0.65	-	0.69
W15-13-65	*Clarias*		0.66	0.65	-	0.70
X15-23-104	*Clarias*		0.66	0.65	-	0.70
X15-12-145	*Clarias*		0.68	0.67	-	0.72
X15-9-99	*Clarias*		0.69	0.68	-	0.73
W15-23-54a	*Clarias*		0.69	0.68	-	0.73
W15-9-28	*Clarias*		0.72	0.71	-	0.77
X15-11-497	*Clarias*		0.75	0.73	-	0.79
W15-18-394	*Clarias*		0.79	0.78	-	0.84

W15-3-175	*Clarias*		0.80	0.78	-	0.85
X15-19-525	*Clarias*		0.80	0.79	-	0.85
SM1-550	*Clarias*		0.83	0.81	-	0.88
W15-1-145	*Clarias*		0.83	0.81	-	0.88
X15-12-79	*Clarias*		0.84	0.82	-	0.88
SM1-601	*Clarias*		0.88	0.86	-	0.93
W14-25-365	*Clarias*		0.88	0.86	-	0.93
X15-10-138	*Clarias*		0.88	0.86	-	0.93
W15-2-103	*Clarias*		0.91	0.88	-	0.96
X15-9-182	*Clarias*		0.91	0.88	-	0.96
W14-15-82	*Clarias*		0.93	0.90	-	0.98
X15-12-242	*Clarias*		0.96	0.92	-	1.01
W14-23-111	*Clarias*		1.01	0.97	-	1.06
W15-13-57-4	*Clarias*		1.02	0.97	-	1.07
W15-3-228	*Clarias*		1.04	1.00	-	1.09
X15-18-290	*Clarias*		1.09	1.04	-	1.14
X15-23-206	*Clarias*		1.12	1.07	-	1.18
W14-25-384	*Clarias*		1.16	1.10	-	1.21
W14-13-1	*Clarias*		1.21	1.15	-	1.27
W15-23-70	*Clarias*		1.25	1.18	-	1.31
W14-13-51	*Clarias*		1.25	1.18	-	1.31
X15-9-82	*Clarias*		1.26	1.19	-	1.32
X15-20-79-1	*Clarias*		1.41	1.32	-	1.47
X15-23-60	*Clarias*		1.50	1.40	-	1.56
W14-8-184	*Clarias*		1.62	1.50	-	1.68
X15-19-188	*Clarias*		1.82	1.67	-	1.88
X15-22-300	*Clarias*		1.90	1.74	-	1.97
W15-11-139-1	*Clarias*		2.16	1.96	-	2.23
W15-3-335	*Clarias*		2.34	2.11	-	2.41
W15-22-2	*Clarias*		2.45	2.20	-	2.52
W15-23-35b	*Clarias*		2.51	2.25	-	2.58
X15-22-222	*Clarias*		2.72	2.43	-	2.80
X15-3-192-2	*Clarias*		2.76	2.46	-	2.83
W14-17-212	*Clarias*		2.77	2.47	-	2.85
X15-8-126-1	*Clarias*		3.04	2.68	-	3.11
W15-23-30	*Clarias*		3.30	2.90	-	3.37
W15-18-358	*Clarias*		4.58	3.93	-	4.65
W14-6-293-3	*Synodontis*	0.03		0.02	0.08	

W15-23-206	*Synodontis*	0.10		0.05	0.20
W14-15-111	*Synodontis*	0.10		0.05	0.20
W15-1-2b	*Synodontis*	0.13		0.06	0.26
W14-18-71	*Synodontis*	0.14		0.07	0.27
W14-25-493	*Synodontis*	0.18		0.08	0.33
W14-6-293	*Synodontis*	0.21		0.10	0.39
X15-22-220a	*Synodontis*	0.24		0.10	0.43
W15-19-71	*Synodontis*	0.26		0.11	0.47
W15-8-12c	*Synodontis*	0.28		0.12	0.50
W15-23-153	*Synodontis*	0.30		0.13	0.52
W15-9-115	*Synodontis*	0.32		0.13	0.55
W15-9-49b	*Synodontis*	0.32		0.13	0.56
W14-6-313	*Synodontis*	0.32		0.14	0.56
W14-13-36	*Synodontis*	0.45		0.18	0.75
W15-19-55	*Synodontis*	0.46		0.18	0.76
W14-7-99	*Synodontis*	0.55		0.22	0.89
W15-3-367	*Synodontis*	0.59		0.23	0.94
W15-8-78	*Synodontis*	0.82		0.31	1.27
W15-21-209	*Synodontis*	2.94		0.92	3.82
X15-11-478-2	*Labeobarbus*	0.17			
X15-1-42-1	*Labeo*	0.53	0.61		
X15-1-361	*Labeo*	0.76	0.87		
W14-7-231	*Labeo*	0.80	0.91		
W15-10-57	*Labeo*	1.01	1.15		
W15-11-155	*Labeo*	1.07	1.21		
W14-5-175	*Labeo/barbus*	1.17	1.32		
X15-19-377	*Oreochromis*			1.05	
X15-1-138	*Oreochromis*			1.09	

Source: 1 = Bayley (1982: 485); 2 = Britton and Harper (2006: 335); 3 = Laleye (2006: 332); 4 = Laleye *et al.* (2006: 196); 5 = Willoughby and Tweddle (1978: 519)

Appendix J: Taphonomic data for fish from the Kibish Formation

Table J1. Weathering stage frequencies for fish from the Kibish Formation.

Weathering stage	n	%
0	147	56.1
1	84	32.1
2	31	11.8
3	0	0

Table J2. Frequencies of specimens with post-depositional damage for fish from the Kibish Formation.

Damage	n	%
Dendritic etching	1	0.4
Pocking	9	3.4
Exfoliation	84	31.9
Erosion	37	14.1
Sheen	74	28.1
Smoothing	8	3
Any damage	100	61.3

Table J3. Frequencies of burned bone for fish from the Kibish Formation.

Burn stage	n	%
Unburned	337	93.6
Calcined	0	0
Indet.	23	6.4

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