Hunter-gatherer technological organization and responses to Holocene climate change in coastal, lakeshore, and grassland ecologies of eastern Africa.

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Highlights:

- Relationships between Holocene ecology, climate change, and lithic technology
- New data on Holocene coastal forest hunter-gatherer adaptations
- Human-environmental interactions in lake-shore, coastal, and inland environments
- Regional diversity in hunter-gatherer and food-producer mobility and technologies in eastern Africa

Abstract: The Holocene of eastern Africa saw extreme climatic fluctuations between hyper-humid and arid conditions, which manifested differently across the region's lake basins, coastal ecotones, and terrestrial biomes. Changes to resource availability, distribution, and predictability presented different constraints and opportunities to diverse hunter-gatherer communities. Major ongoing questions concern how humans reconfigured economic, social, and technological strategies in different regional settings. The role of more stable coastal environments in these processes remains especially under-studied. Here, we examine and compare relationships between environmental change and the organization of stone tool technology at the site of Panga ya Saidi, eastern Kenya, in strata dating from c. 15-.2 ka. Located near the Indian Ocean coast, this dataset provides the first insights into Holocene human-environmental relationships in a coastal forest zone of eastern Africa. Integrating the new Panga ya Saidi environmental and archaeological records with other high-resolution records from nearby terrestrial and lacustrine zones, we take a comparative approach to address how climatic fluctuations shaped trajectories of hunter-gatherer adaptations through the Holocene. We argue that lithic technologies deployed within lake basins and coastal zones reflect more stable land-use strategies with less residential mobility compared to those associated with terrestrial foraging. All regions exhibit technological reconfigurations with the arrival of pastoralism, except for the coastal forest which appear largely consistent across the study period. Results inform ongoing debates into the resilience of recent eastern African hunter-gatherers and food-producers and provide an analogical framework for examining human-environmental dynamics deeper in time.

Keywords: Archaeology; Africa; lithic technology; hunter-gatherers; climate change; resilience

1. Introduction

Eastern Africa was an important region in the biological and cultural evolution of our species, where complex climatic change and diverse geographies presented novel challenges and opportunities to humans and our ancestors (Archer, 2020; Ashley et al., 2011; Chritz et al., 2019; Lahr and Foley, 1998, 2016; Lupien et al., 2020; McBrearty and Brooks, 2000; Potts, 1996, 2013). Reconstructing influences of climatic changes on human behaviors across eastern African environments requires both adequate data resolution and analogical models for relating archaeological signatures to specific hunter-gatherer land use strategies (Ambrose, 1986, 1998; Dale et al., 2004; Kusimba, 2005). While the Pleistocene has received more research attention, hunter-gatherer and food-producing groups living during the Holocene epoch also experienced significant climate changes across eastern Africa's interconnected ecological zones. Greater temporal and paleo-climatic resolution in the Holocene make it possible to investigate human-environmental interactions at a finer scale compared to earlier periods.

The onset of the African Humid Period (AHP)—from c. 14–4 ka—brought increased precipitation to the continent, leading to the expansion of many river, lake, and grassland ecosystems in eastern Africa (DeMenocal et al., 2000; Tierney et al., 2011). Hunter-gatherer-fisher lifeways emerged with new economic strategies and bone point technologies (Sutton, 1974, 1977). Shifts in rainfall systems through the Holocene were regionally and temporally heterogeneous, manifesting differently across diverse ecologies, and thereby presenting a mosaic of opportunities and challenges to hunter-gatherers. As northern hemisphere insolation diminished from c. 5–4 ka, the termination of AHP conditions also occurred at different paces and to varying intensities (Collins et al., 2017; de Menecol et al., 2000; Shanahan et al., 2015; Tierney et al., 2011). Hunter-gatherers adapting to changing environments further had to cope with population migrations and the spread of food production in eastern Africa from c. 5–1.5 ka (Gifford-Gonzalez, 1998, 2000; Lane, 2004; Marshall and Hildebrand, 2002; Prendergast et al., 2019; Wang et al., 2020; Crowther et al., 2018). These circumstances would have had profound impacts on how humans interacted with, moved within, and impacted landscapes. Aspects of foraging strategies, mobility, and land-use can be reconstructed from archaeological remains, particularly from stone tools which are a direct and well-preserved medium through which people interfaced with their environments (Andrefsky, 1991, 1994, 2010; Nelson, 1991; Shott 1986; Surovell 2009; Tryon and Faith, 2016).

Studies of stone tools in the eastern African Holocene have remained highly regionalized. Most work has been dedicated to identifying variation in the production of blades, backed blade segments, and other small blade tools that characterize "Later Stone Age" (LSA) technologies in the region. There has been less focus toward building comparative or diachronic models for how climatic change and environmental heterogeneity influenced hunting-and-gathering lithic economies. Additionally, a lack of climatic or archaeological data from some important regions has made it difficult to assemble such broad perspectives. Coastal and pericoastal forests represent such an example of a major eastern African ecosystem that was important for human evolution, expansion, and later social complexity, but has a relatively understudied record of Holocene forager adaptations (Beyin and Rayano, 2020; Chami, 1996, 2004; d'Errico et al., 2019; Helm et al., 2012; Kessey, 2009; Martinón-Torres et al., 2021; Shipton et al., 2018, 2021; but see Knutsson, 2019). Discovery of Panga ya Saidi cave within the coastal forest biome of eastern Kenya, presents a paired paleoecological record and rich lithic assemblage spanning the Holocene (Helm et al., 2012; Shipton et al., 2018, 2021). Panga ya Saidi datasets contribute to reconstructing foraging strategies adjacent to the eastern African coast, which can now be integrated into a comparative analysis of adaptations across a broader range of environments and geographies.

This paper presents a new technological analysis of the stone tool assemblages from the Terminal Pleistocene to Late Holocene levels at Panga ya Saidi and applies these data to infer past forms of mobility and economy. Paired with a recent paleoenvironmental data, we present hypotheses for the structure of ancient human-environmental interactions in the region through the arrival of Iron Age farmers roughly 1,000 years ago. We compare coastal patterns with those from four other regions where hunter-gatherers experienced different manifestations of Holocene climatic change: The Lake Turkana Basin of northern Kenya, the southern Great Rift Valley of Kenya, the Lake Victoria Basin, and north-central Tanzania (**Fig 1**). Consideration of technological changes and/or continuities across diverse environments experiencing major climatic changes presents new insights into the drivers for technological organization, innovation and change in eastern Africa and how these processes contributed to the diversity of hunter-gatherer lifeways globally.

2. Background

2.1 Holocene climatic change in north-eastern Africa

Northern and eastern Africa experienced climatic fluctuations as Terminal Pleistocene aridity gave way to higher but variable rainfall patterns during the AHP (DeMenocal et al., 2000; Street-Perrott et al., 1989; Tierney et al., 2011). Shifts in precessionally-forced summer insolation at this time influenced a more northerly position of the Inter-Tropical Convergence Zone (ITCZ) and a more eastern position of the Congo Air Boundary (CAB), which both drive the strength of seasonal monsoons (Bergner and Trauth, 2004; Kizza et al., 2009; Nicholson, 1996; Tierney et al., 2011, 2013). Rainfall patterns were also variable through the AHP, with shifts in solar radiation and the Indian Ocean dipole as well as movement of the CAB causing rainfall fluctuations on multiple time scales (Forman et al., 2014; Marchant et al., 2007; Tierney et al., 2011; Trauth et al., 2010). Climates fluctuated in terms of wet vs. dry, but also in terms of the seasonality and predictability of rainfall (**Table 1**).

Different combinations of these forces further conditioned regional heterogeneity, and forager lifeways showed similar regional responses. An estimated 17–50% increase in seasonal rainfall led to the expansion of rivers, lakes, and grasslands in many parts of eastern Africa, although rainfall patterning was uneven across different parts of the continent (Kutzback and Liu, 1999; see also Junginger et al., 2013; Levin et al., 2009; Tierney et al., 2011). These expanded river and lake systems provided opportunities for foragers to adopt or intensify aquatic-focused subsistence systems. Evidence for a focus on aquatic resources and the spread of barbed bone point technology (presumably for fishing/spearing) led Sutton (1977, 1979) to refer to an “Aqualithic” period of African history. The extent, timing, and impact of these broad climatic shifts were regionally heterogenous and dependent on specific local hydrology, elevation, and ecology (see Chritz et al., 2019; van der Lubbe et al., 2019), as fishing economies developed in the Lake Turkana and Lake Victoria region, while terrestrial-focused forager economies persisted in savanna and montane forest zones.

After c. 5 ka, gradual insolation forcing influenced a rapid termination of AHP climatic conditions, leading to an overall reduction in humid conditions in the tropics (deMenocal, 2008; Tierney and deMenocal, 2013; Loakes et al., 2018; Vam Rampelbergh et al., 2013). Rainfall rates dropped quickly in some regions, but environmental records across northeastern Africa indicate ecological transitions were sometimes non-linear or more protracted (Ivory and Russell, 2018; Jung et al., 2004; Neumann, 1989; van der Lubbe et al., 2017). These processes are better understood for eastern African lake basins where lake-level estimates and lake-core data are available. It is less clear how these processes impacted floral and faunal cohorts in the highland, savanna, and forest eco-systems situated further away from larger lakes. Due to the differences in the timing and intensity of AHP conditions and terminations across eastern Africa, it is necessary to consider each region’s environmental record independently, as will be done here.

2.2 Lithic technological organization and inferring human-environmental interactions

Technological trajectories depended in large part on how climate change manifested and affected local resources, but also on how populations chose to respond to perceptions about risk and planned needs at different scales. Stone tools represent the best-preserved and most direct correlate for how prehistoric groups interacted with their environment, and so archaeologically assemblages of stone tools should capture different dimensions of those interactions. This is never a straightforward endeavor and lithics form only one component of tool-use strategies that included organic technologies, which are only sometimes preserved archaeologically (e.g., d'Errico et al., 2019; Langley et al., 2016). Lithic assemblages are formed through the actions of individuals in specific places and times, with different goals, limitations, and degrees of technical skill. Depositional events are time-averaged, transformed by site-specific anthropogenic and geological processes, and all of these forces affect the attributes and morphologies of lithic artifacts (Bleed and Bleed, 1987; 189; Rezek et al., 2020). Technological change or continuity must be understood in a context of regional climate variability, but also in a complex web of individual choices and taphonomic circumstances.

Reconstructing lithic technological organization therefore requires identifying patterns in collections of stone tools that reflect general approaches to stone supply management, structure of reduction, strategy of repair, and forms of stone tool use (Andrefsky, 1991, 1994, 2010; Bamforth, 1986; Holdaway et al., 2010; Low and Pargeter, 2020; Nelson, 1991; Shea, 2020; Shott, 1986, 1989, 2018). Fundamentally, technological strategies must match the basic environmental, economic, and social needs of a tool-producing population to function as a successful adaptation (Binford, 1973, 1977, 1979; Bleed, 1986; Kelly, 1992; Torrence, 1984). Studies of technological organization seek to identify the basic structural parameters of tool-using strategies as a necessary foundation for—but not the culmination of—understanding past human-environmental interactions. Mobility forms the basis for many important human strategies, with different configurations employed depending on relative resource availability and distribution, environmental predictability, and population density (Binford, 2001; Bousman, 2005; Kelly, 2013; Porter and Marlowe, 2007). Models generally assume that hunter-gatherers practice forms of mobility, and that mobility patterns will be the primary force structuring lithic production strategies (Andrefsky, 1994; Blades, 1999; Kuhn, 1991, 2014; Parry and Kelly, 1987; Surovell, 2009; see also review in **Supplemental Text**).

3. Holocene climatic and technological change across eastern Africa

Broad comparative studies of technological organization across diverse environmental zones are needed to discern which characteristics of lithic technologies are useful for reconstructing responses to specific environmental conditions and transitions. Eastern Africa experienced complex processes of climate change through the Early (11.7–8.3 ka), Middle (8.3–4.2 ka), and Later (4.2 ka to present) phases of the Holocene epoch (after Walker et al., 2019). Climatic impacts on ecologies and human habitation are understood for only a few parts of eastern Africa, reflecting the need for expanded research. Here, we focus here a few key geographic areas where climatic and technological analyses have provided solid foundations for a comparative analysis.

3.1 Lake Turkana Basin fisher-foragers

The Lake Turkana Basin of northern Kenya experienced extreme climatic and environmental changes through the Holocene. High rainfall rates during Early Holocene AHP conditions fed the lake, and it reached sustained high-stand periods and began overflowing into the Nile River system (Bloszies et al. 2015; Garcin et al. 2011; Johnson and Malala 2009; Owen et al. 1982; van der Lubbe et al., 2017). At this time, aquatic foraging niches provided a rich resource base for hunter-gatherer–fisher populations (Robbins, 1974; Phillipson, 1977; Bartheleme, 1985; Beyin et al., 2017).

Recession of the lake and aridity-driven deflation across the basin in the Middle Holocene has led to the loss of many sites, and many more are known only from surface or near-surface scatters. Many known sites appear to be likely seasonal fishing camps with evidence of specialized targeting of a few preferred fish taxa such as catfish, Nile perch and tilapia (Prendergast and Beyin, 2018, Stewart, 1989).

Other sites like Lothagam-Lokam may reflect repeated/longer term hunter-gatherer occupations in more reliable or protected areas (Goldstein et al., 2017). These sites, and river valleys surrounding the lake, have more evidence of terrestrial hunting along with fishing (Bartheleme, 1985). After c. 9 ka, lake levels began to fluctuate, and people were increasingly tied to the lakeshore (Wright et al., 2015).

Despite shifts in climate and lake level and claims for greater economic regionalization, there is no detectable change in the organization of lithic technology around Lake Turkana from the Late Pleistocene through to the Middle Holocene. Smaller scatters are dominated by diverse cherts, as well as local volcanics and quartz (Bartheleme, 1985; Beyin, 2011; Beyin et al., 2017; Robbins, 1972; Robbins and Lynch, 1978; Lahr et al., 2016; Wright and Forman, 2011). Larger sites have greater proportions of local coarse volcanics used for both extensive expedient knapping as well as the manufacture of elongated flakes and large crescents (Robbins, 1974). High quality materials like obsidian occur in small but variable quantities (usually <5%) at fisher-hunter–gatherer sites. Core technology is primarily restricted to discoidal-radial cores for expedient flake production and un-specialized single platform cores that produced typically large and short blades and bladelets (**Supplemental Fig. 1**: a-j). Backed pieces, mostly represented by crescents, are highly variable in size. Scrapers are equally diverse and like cores they lack standardization or apparent regional styles. Inter- and intra- site variability might indicate highly flexible lifeways across the Early Holocene, or that lithic technology remained largely expedient as more economic emphasis went into organic fishing technologies best exemplified by the proliferation of barbed bone points at lakeshore sites (Barthelme, 1985; Phillipson, 1977; Wright et al., 2015). Unstandardized crescents were maintained to accommodate opportunistic terrestrial hunting and inter-personal conflict (Lahr et al., 2016).

A major technological shift in the Turkana Basin occurred after c. 5 ka, coincident with the arrival of mobile herders and an abrupt drop in lake levels and local rainfall (Ashley et al., 2014; Hildebrand et al., 2018; Forman et al., 2014; Junginger et al., 2014). Lithic assemblages at herder sites are markedly different from those of earlier fisher-hunter-gatherer, featuring predominantly obsidian and a focus on small blades and backed tools (Goldstein, 2019). Herder sites on both sides of the Lake show the same strategies of core reduction and more uniformity in blade blank and tool forms. This economy was supported by new regional exchange networks to supply obsidian across the lake (Nash et al., 2011; Ndiema et al., 2011).

As aridity increased after 4 ka, the lake retreated further, and the technological signatures of specialized pastoralism disappeared. During subsequent millennia, a mosaic of mixed herder-forager, lakeshore fisher-hunters, and agropastoralists developed around Lake Turkana (Gifford-Gonzalez, 2003; Wright et al., 2015). Few sites of this period are well studied; however, the cave of Ele Bor and the open-air fishing camp of Lopoy both demonstrate that more expedient technological strategies relying on local raw materials persisted into the Iron Age (Phillipson, 1984; Robins, 1980). This marks a return to technological patterns and possibly mobility strategies more similar to those from the Early Holocene.

3.2 Hunter-gatherers in the Central Rift Valley

The Central Rift Valley is a topographically complex zone connecting the Lake Turkana Basin in the north to the broad savanna plains of the Loita-Mara, Athi-Kapiti Plains, and the Serengeti. It contains several small lakes like Nakuru, Naivasha, and Elmenteita, although these did not appear to support the kind of focused fisher-forager economies evident around larger Holocene lakes in eastern Africa. Instead, there is an apparently wide range of terrestrial-resource-based groups occupying the Rift floor, the Rift escarpments, and surrounding highland savannas (see Ambrose, 1998; Wilshaw, 2016; Robertshaw, 1990). Few of these have been described in detail, and many were historically lumped into a succession of broad Later Stone Age industries. Lithic analyses of Pleistocene sites at Lukenya Hill in the Athi-Kapiti plains clearly demonstrate multiple divergent technological strategies, reflecting diverse mobility and land-use strategies within a small region (Barut, 1997; Kusimba, 2001; Muia, 1998; Waweru, 2001).

A large group of sites within ~25 km of Mt. Eburru in the Naivasha-Nakuru Basin have been analyzed with lithic assemblages that appear to represent a discrete set of economic strategies, referred to as "Eburran" (Ambrose, 1984, 1985, 1998, 2001; Cole, 1954, 1963; Walshaw, 2016). These assemblages primarily come from rock shelter and cave sites along the margins of montane forests along the Mau Escarpment, but with some sites at lower altitudes within the Rift Valley (Ambrose, 1980; Leakey, 1931; Cole, 1954, 1963). Communities occupying these sites relied on high-quality obsidian acquired from sources directly on Mt. Eburru, and to a lesser degree from minor sources within a 20 km range (Frahm and Tryon, 2018). People emphasized blade production in all Holocene levels, employing a distinct micro-faceting technique of preparing striking platforms (Ambrose, 1980, 1984, 1985, 1998).

Lithic assemblages in the Central Rift Valley demonstrate gradual and linear changes in tool forms that coincide with climatic shifts from the onset of the AHP through the Middle Holocene. Rainfall across the Early Holocene varied between regions but was around 260–300 mm/year greater than at present. Blades and backed pieces are largest in these earliest Holocene phases, with particularly large geometrics between 50–70 mm in length (Ambrose 1980, 1984, 2002). Scrapers in these levels are conversely small (below 30 mm in maximum length on average). From 11–6 ka, blades and backed pieces both decrease in size, whereas blade-based endscrapers become larger, though there is a preference for bi-directional organization of blade cores throughout the sequence (**Supplemental Fig 1**: k-p). Deposits dating to after 8 ka also begin to show a shift away from geometrics to other forms of backed pieces like truncations, fewer scrapers, and a disproportionate increase in tabular bipolar cores and burins (Ambrose 1984, 1998). Tool ratio changes may reflect different activities taking place at sites as the surrounding ecology changed over time. Technological shifts in core size, reduction strategy, and projectile technologies impacting crescent use are more likely to indicate general changes in foraging strategies in higher elevation zones.

By c. 6 ka rainfall had reduced by 10–20% in the Rift Valley (Hastenrath and Kutzbach 1983; Duhnforth et al. 2006) and this is associated with a rapid decrease in lake levels for Lake Naivasha and Lake Nakuru within the Central Rift, with some smaller lakes drying up completely (Olago et al., 2007, 2009). Hunter-gatherers abandoned the area, either moving out of the Rift into higher elevations. Lake levels begin to recover after 5 ka though conditions were still arid. Ambrose (1998) proposes that by this time hunter-gatherer land-use strategies began to be split between continued use of highland caves and rockshelters, and increasing occupation in lower-elevation grasslands, with differences in tool form proportions between site types. At all sites the trajectory of backed pieces becoming smaller continues. Early migrations of herders from the north had occurred by c. 5 ka (Prendergast et al., 2019), and hunter-gatherers began acquiring goat and sheep through raiding or exchange shortly thereafter (Marean, 1992). Changes in settlement patterns are attributed to a gradual adoption of animal husbandry (Ambrose 1998; Kusimba and Kusimba, 2005; Mutundu, 2010).

Pastoralism spread more rapidly once rainfall increased further and grasslands began to recover c. 3.2 ka (Ambrose and Sikes 1991). After this time, hunter-gatherer layers are overlain with those associated with new herding communities who employed very different technological traditions (Ambrose, 2001). Highland sites begin to exhibit patterns consistent with the Elmenteitan pastoralists, who produced large obsidian blades prepared with dorsal-proximal faceting, consistently small geometrics, large backed blades and end-scrapers, and very specific hierarchical core morphologies and reduction sequences (Ambrose, 2001, 2002; Goldstein, 2018; Robertshaw, 1990). Not only do these differ from early technologies, but they also appear uniformly across all Elmenteitan sites in southwestern Kenya (Goldstein, 2021). Major transformations coincident with the spread of specialized herding in the Rift mirror the pattern from the Lake Turkana Basin, although in southern Kenya high-mobility lithic strategies persist until the Iron Age (Ambrose, 1985).

3.3 Lake Victoria fisher-foragers

The Lake Victoria Basin also hosted pottery-making fisher-foragers from c 8–1 ka, referred to as the “Kansyore” traditions after their distinctive ceramic styles. Sites with Kansyore material are concentrated in riverine and lakeshore environments on the northern, eastern, and western sides of Lake Victoria, but extend at least to the Lake Eyasi Basin of central Tanzania (Dale, 2007; Prendergast, 2010). The full extent of Kansyore interaction spheres are unknown, with reports of Kansyore ceramics as far east as the Tanzanian coast (Thorp, 1992) and archaeogenetic evidence hinting at connections with the Congo Basin in the west (Wang et al., 2020).

Early occurrences of Kansyore fishing-focused adaptations around Lake Victoria date to around or just after a transition from peak AHP insolation-driven rainfall conditions to a more arid climate (Berke et al., 2012; Johnson et al., 2000). Evidence at sites dating to these early periods reflects greater reliance on land-based hunting (Dale and Ashley, 2010). Emphasis on fish and shellfish increases through the Early-to–Mid Holocene, as the climate continued to become more arid and seasonally variable (Stager et al., 2003). While Middle Holocene Kansyore sites are rare, it is probably during this time that people began transitioning to semi-delayed-return foraging strategies based around predictable seasonal resources around Lake Victoria (Dale et al., 2004). Foragers maintained longer-term seasonal occupations along the lake shore where they focused on dry-season fishing and shellfish collection leading to accumulation of dense shell middens (Prendergast, 2010; Prendergast and Lane, 2010; Robertshaw et al., 1983). River rapids were intermittently occupied by Kansyore-producers in the early rainy season to take advantage of spawning *Barbus* (Lane et al., 2006; Marshall and Stewart, 1995; Prendergast, 2010). Hunting remained important, as evidenced by Kansyore horizons at rockshelter sites away from the lake (Gabel 1969; Prendergast et al. 2007; Soper and Golden 1969). A significant change in material culture and subsistence occurs in the Later Holocene, as the climate approaches modern highly seasonal rainfall conditions and forest decline after c. 2 ka (Dale, 2007; Ssemmanda et al., 2002; Stager et al., 1997, 2003). Multi-proxy data from Kapsabet Swamp in the northwest of the Lake Victoria Basin indicate overall wetter conditions after 3 ka, but punctuated by arid episodes that highlight the increasing unpredictability and sub-regional variation of the Late Holocene that may have challenged Kansyore lifeways (Njagi et al., 2021). Responses to these conditions appears to have included greater commitment to delayed-return strategies, including acquiring livestock from surrounding herders before ultimately being integrated or replaced by pastoralists (Dale et al., 2004; Prendergast, 2010; Lane, 2004).

Kansyore sites of all periods exhibit a preference for readily available quartz but included small chert nodules and occasionally obsidian acquired through long-distance down-the-line exchange. Bipolar cores are the most common core type (as is typical of quartz industries), however the high proportion of single platform hierarchical cores and blade/bladelet debitage indicates strong emphasis on serial blade production to accommodate high logistical mobility involved in movement between lakeshore, riverine, and inland sites (Seitsonen, 2010; Siiriainen, 1977, see also **Supplemental Fig 2**: k-p). At least some of the bipolar cores represent curated late-stage blade cores, again signifying a level of curation consistent with greater mobility (Seitsonen, 2010).

The lithic technology is otherwise broadly consistent with other LSA strategies in eastern Africa. Blade blanks were used to manufacture backed pieces ranging from small crescents to larger curved- and straight-backed elements and end scrapers exhibit further evidence of long-term curation. (Seitsonen, 2010; see also Ambrose, 2001). Other typical features include a high proportion of burins, convergent backed pieces, and some unshaped flake-tools. Suspected longer-term lakeshore occupations have wider ranges of tool forms as would be expected (e.g. Surovell, 2009), with a narrow range of tools at seasonal/short-term riverine and rockshelter sites (Seitsonen, 2010).

The only discernable change over time among Kansyore assemblages is increased acquisition of obsidian in the later phases due to increased contact with herders in the Central Rift and Loita-Mara plains (Frahm et al., 2017). Otherwise, these organized semi-delayed return strategies were supported primarily by organic innovations like weirs and nets, as well as sophisticated, seasonally organized, resource collection (Dale et al., 2004; Lane et al., 2007; Prendergast, 2010). Holocene climatic changes were locally impactful, though far less extreme than those in the Turkana Basin. The relative stability of the larger Lake Victoria Basin, and access to predictable aquatic and terrestrial food resources allowed Kansyore producers to maintain a technology that supported seasonal/logistical forms of mobility that remained structurally similar through the Holocene.

Major lithic transitions along the eastern edge of Lake Victoria occurred only after c. 1.7 ka with the spread of specialized herders into the region. Hunter-gatherer–fisher levels at sites like Wadh Lang'o and Gogo Falls are overlain with strata demonstrating a stark transition to pastoralist ceramic styles, high proportions of domesticated livestock, and the characteristic obsidian-dominant lithic economy of these pastoralists (Lane et al., 2007; Seitsonen, 2010; Robertshaw, 1991). This, in part, reflects the same strategic shift to greater preparation for structured mobility across diverse ecologies that mark the spread of herding in the Turkana Basin and Central Rift (Goldstein, 2019, 2021).

3.3 Central Tanzania/Lake Eyasi Basin hunter-gatherers

There have been too few focused paleoclimatic studies within northern-central Tanzania to permit reconstruction of Holocene environmental change on a local scale. Overall shifts may have shared timing with to the nearby Lake Victoria, but only relatively as rainfall rates would likely be lower and these environments would not benefit from lake ecology feed-back mechanisms. Even so, the timing of such changes may have been different and clues from the terrestrial record in the Central Rift of Kenya indicates small-scale rainfall changes may have had large impacts on the distribution and predictability of resources exploited by Holocene foragers.

Several typically LSA lithic assemblage groups have been described for the broader Lake Eyasi region of north-central Tanzania for the Holocene (Kessey, 2005; Mehlman, 1989; Tryon and Faith, 2016). At Mumba and Nasera Caves, Kansyore pottery indicates early connections with the Victoria Basin (Prendergast et al., 2007; Tryon and Faith, 2016). It is unclear if this means there was population overlap, but patterns of raw material availability, ecology, and hunting-and–gathering strategies are different enough to merit independent consideration.

Central Tanzanian hunter-gatherer toolkits remain understood primarily in the typological terms by which they were first defined. The Early Holocene "Silale Industry" from Nasera Cave is over 95% quartz and is characterized by increasing standardization and miniaturization of tools. Geometrics are smaller and more elongate than those from Pleistocene forms (Mehlman, 1989, p. 389). Small scrapers are frequent and aside from curved- and straight-backed flakes there are very few other tool forms. Over 50% of cores are identified as bipolar forms with the remainder being a mix of single and multiple platform types (Mehlman, 1989, p. 390, see **Supplemental Fig. 2**: a, b, f, g). Many of the illustrated "bipolar" cores appear to be small pyramidal cores with late-stage bipolar reduction. This would indicate a greater reliance on hierarchical elongate core reduction that would be more typical of Holocene technologies in surrounding regions. A similar technology was recovered from Mumba Rockshelter but was not labeled as "Silale" based on differences in the microlith:scraper ratio, a slight difference in geometric width, and the presence of larger scrapers (Mehlman, 1989, p. 401–2). Lacking evidence of divergent core reduction strategies, these variations could be explained simply by different patterns of site use.

Through the Middle Holocene there is a slight shift in a few aspects of lithic assemblages. Cherts become slightly more common, but quartz still makes up ~90% of assemblages and there is no discernable change in core morphologies or reduction strategy at Nasera (Mehlman, 1989, **Supplemental Fig 2**: c-e, h, i). There is a slight reduction in the proportion of backed geometrics relative to other tool types, but with a morphology consistent with earlier horizons (Mehlman, 1989, p. 404; Tryon and Faith, 2016). Scrapers on the other hand are longer in Middle Holocene "Olmoti" layers, and tools in general are far fewer relative to the quantity of debitage and other materials (Tryon and Faith, 2016). Finally, there is a marked increase in burins and notches in Middle Holocene levels (Mehlman, 1989, p. 407).

A roughly contemporaneous set of assemblages is described from Mumba Rockshelter that is also predominantly quartz-based with a smaller chert component. Unlike at Nasera, geometrics and scrapers are highly variable in formality, morphology, and size (Mehlman, 1989:420). Proportions of scrapers, burins, and backed pieces vary dramatically between levels. Tryon and Faith (2016) present data that supports shifts toward shorter occupational spans through the Middle Holocene sequence at Nasera Rockshelter. Variation in occupational span (and likely site function) may explain many of the patterns in differential tool production, curation, and disposal behaviors, and intensity of bipolar reduction, between Middle Holocene assemblages, and also between Early and Middle Holocene technologies. One possibility is that technological patterns reflect an increase in mobility across central Tanzania during the transition to more arid and seasonally variable conditions brought on by AHP termination. There is no technological evidence to support the proposition that the "industries" previously defined for Central Tanzania represent fundamentally different strategies, but rather should be taken as reflecting different activity patterns within the same technological system until proven otherwise.

Mobile pastoralist economies are not evident in Central Tanzania until 3 ka, and after this point lithic technological systems become more diverse (Grillo et al., 2017; Prendergast et al., 2010). Sites associated with mobile herders at least as far south as Mt. Kilimanjaro demonstrate typical obsidian-based blade technologies associated with savanna-Pastoral Neolithic groups (Mturi 1986; see Ambrose 2001). In the Lake Eyasi Basin, open-air sites with Savanna Pastoral Neolithic (SPN) type ceramics feature a different lithic technology. These "Ishimijega" assemblages feature an even split of quartz and local chert, with a smaller imported obsidian component. Diversity in backed tool and scraper morphology and a high rate of combination/transformed tools and notches are features that appear retained from earlier Middle Holocene economies.

Some tool forms that were previously uncommon such as double end-scrapers and especially convergent backed pieces (elsewhere called miscellaneous microliths, or micro-drills) appear in higher frequency in the Ishimigega, and both are typical features of Pastoral Neolithic assemblages (see Goldstein, 2014, 2018; Robertshaw, 1990). There is a marked shift among the organized cores toward more pyramidal and opposed platform orientations, and more tabular single platform cores made from large flakes (Mehlman, 1989, p. 476–477). Higher rates of chert use in these assemblages are likely due to people's need to manufacture these kinds of hierarchical cores that ensured more uniform blade and bladelet products, as chert is an easier material to control than quartz. Technological features match those described for the large SPN site of Luxmanda on the Mbulu Plateau southwest of Lake Eyasi, extending the Ishimigega association with herders in both lowland and highland environs (Grillo et al., 2017).

3.5 The eastern African coast

East African coasts and pericoastal forets are less well studied in terms of Holocene hunter-gatherer adaptations, with more historical focus being on early food production and Swahili Coast trade (but see Chami, 2007; Chami and Kwekason, 2003). This has begun to change with several recent archaeological and paleoenvironmental studies mostly focused on islands (Chami, 2019; Crowther et al., 2016, 2018; Langley et al., 2016; Prendergast et al., 2016; Roberts et al., 2019; Shipton et al., 2018, 2021; see also Beyin and Ryano, 2020).

Climatic data for the equatorial coast suggest overall less pronounced climate change over the last 20 ka relative to regions of similar latitude inland or along the coast of the Horn of Africa to the north. In particular, leaf-wax data from Lake Challa suggests rainfall was largely stable from the LGM through the

Terminal Pleistocene, with additional arid phases around 12 ka, and from c. 6–5 ka, that bookend an overall wetter AHP (Tierney and DeMenocal, 2013). Environmental proxy data from cores along the Tanzanian coast similarly reflect a prolonged AHP, but one with a gradual decrease in precipitation from c. 8–5.5 ka (Liu et al., 2017). The latter study also detects a subtle increase in terrigenous sediment inputs over the last 3.5 thousand years, indicative of greater river discharge due to increased coastal rainfall (Liu et al., 2017).

Multi-proxy paleoenvironmental reconstruction for Panga ya Saidi indicate relative ecological stability during these climatic shifts (Shipton et al., 2018). Oxygen and carbon stable isotope studies show a trajectory of wetter conditions and C_3 forest expansion through the Holocene, and there are no apparent faunal turn-overs consistent with significant environmental change (Roberts et al., 2019; Shipton et al., 2018). A few non-mutually exclusive possibilities exist to explain these patterns; (1) lowland pericoastal forests were buffered from rainfall pattern changes that drove aridity elsewhere, (2) the local ecology recovered more quickly once conditions ameliorated and/or (3) rainfall fluctuations were minor and did not impact local flora and fauna.

Lithic assemblages from hunter-gatherer and food-producer contexts were well noted along the coast, though often only in small numbers (Chami, 1996, 2004; Isaac 1974; Helm et al. 2012). People inhabiting islands made use of diverse raw materials, principally quartz, as well as limestone, rhyolite, basalt, and andesite (Chami 2004; Kessy, 2009). At Kuumbi Cave, more recent excavations by Shipton et al. (2016) noted that Later and Terminal Pleistocene contexts were dominated by small quartz bipolar flakes, while the Iron Age contexts were characterized by large limestone flakes produced via freehand percussion. Earlier quartz technology might be associated with more mobile groups while Zanzibar was still connected to the mainland (Prendergast et al. 2016; Shipton et al. 2016; Chami 2004; Kessy 2009). As with the Lake Turkana record, bone tools played an important technological role in coastal environments and may be associated with more specialized and/or delayed-return foraging (d’Errico et al., 2019; Langley et al., 2016). These coastal assemblages were too small for focused technological study and represent only one component of coastal land-use that also included activities along the mainland coast and interior coastal plain (Helm et al., 2012). Panga ya Saidi therefore represents a rare opportunity to understand coastal forager activities from a large Terminal Pleistocene and Holocene lithic assemblage.

3. Panga ya Saidi

Panga ya Saidi is a large limestone cave complex, situated at the eastern edge of the Dzitsoni Uplands, approximately 150 m above sea level (**Fig 2**). The site is 15 km from the present-day coast, with the steep coastal shelf keeping this distance to within ~20 km throughout the human occupation history of the region (Roberts et al., 2019; Shipton et al., 2018). In addition to its peri-coastal setting, the environments around Panga ya Saidi include lowland tropical forests and more open savannas. Paleoenvironmental data suggest that the local environment was more forested prior to agricultural intensification in recent centuries and while the distribution of nearby grasslands would have shifted through the Holocene, its position between different environmental zones may have been one factor that drew early people to Panga ya Saidi.

Archaeological investigations have yielded a 3+ m sequence with consistent pulses of occupation over the last 78 ka yrs (Shipton et al., 2018). Previous studies have presented overviews of the site and specific details regarding the excavations, stratigraphy, and chronology (Helm et al., 2012; Shipton et al., 2013, 2018; See also **Supplemental Text**, **Supplemental Fig. 3**), tetrapod and shellfish remains from the sequence (Prendergast et al., 2017; Shipton et al., 2018; Faulkner et al. 2021), its local and regional environment (Roberts et al., 2019), and the large assemblage of beads and ornamental artifacts (d’Errico et al., 2020). Excavations have also recovered the oldest known human burial from Africa (Martinón-Torres et al., 2020) and aDNA yielding Iron Age human remains (Skoglund et al., 2017). Long term trends in lithic tools across the whole occupation sequence and Middle to Late Stone Age transitions are reviewed elsewhere (Shipton et al., 2021).

The density of diverse archaeological remains reflecting subsistence activities, symbolic behaviors, and tool manufacture indicate the site was continually important within patterns of human land-use across the Late Pleistocene and Holocene periods. The present study focusses on lithics from the Terminal Pleistocene and Holocene levels and situates them against the comparative context of lithic technology elsewhere in eastern Africa during these periods.

Paleoecological stable isotope analysis of faunal remains from the cave demonstrate that environmental changes across its occupational history were subtle, with the ecotonal character of the site consistent during each phase of occupation (Shipton et al., 2018, 2021; Roberts et al., 2019). Carbon and oxygen measurements from Terminal Pleistocene through to the Late Holocene appear to demonstrate a continuous pattern of increasing precipitation and greater C3 forest surrounding Panga ya Saidi (Roberts et al., 2019). Faunal patterns also show an increase in the proportion of browsing and frugivorous species relative to open-ecology grazers beginning in the Terminal Pleistocene and continuing through the Iron Age (Roberts et al., 2019). While more dates from this sequence are needed to better understand patterns within the Holocene, multiple lines of evidence support consistently higher forest cover around Panga ya Saidi throughout the last c. 14 ka years

4. Methods

4.1 Temporal division and sampling

Lithic material for this study was taken from Layers 1–6 of the main excavation block at Panga ya Saidi. Layers were observed to be continuous and largely homogenous across the extent of current excavations. Radiocarbon date ranges for these levels given below are based on the IntCal 2020 radiocarbon curve (Reimer et al., 2020). A full analysis of the stratigraphy is published elsewhere (Shipton et al., 2018) and the strata sampled here is presented in **Supplemental Fig. 3**.

Layers 1 and 2 are both thin horizons with small quantities of lithics, and abundant pottery dating to the last thousand years as consistent with dates from this level. Due to sample sizes and the tight temporal range these represent, they were grouped together for the purposes of this study and are considered to reflect the Iron Age. Layer 3 dates to 1242–1065 cal yr BP (1212 ± 23 ^{14}C yr BP; OxA–29285), with an increase in lithics and a marked reduction in ceramics. Due to some evidence of mixing in the upper horizons (Shipton et al., 2018), Layer 3 may reflect an intermediate zone between Late Holocene and Early-to-Mid Holocene deposition, and it is not yet clear how much time the Layer captures. In areas of small sample size for artifact analyses, Layer 3 is merged with Layers 1/2. It is elsewhere presented on its own to compare with upper and lower strata.

Below this horizon is Layer 4, and two radiocarbon dates on charcoal provide a date range of 8548–7579 cal yr BP (Shipton et al., 2021). Artifact density in this layer is relatively high and may include a greater time-depth than overlaying layers. Layer 4 is therefore considered to reflect primarily Early-Mid Holocene deposition. Layers 5 and 6 are grouped together within the same temporal unit (Shipton et al., 2018, 2021). A radiocarbon date range of 14846–14168 cal yr BP for Layer 5 (12375 ± 150 ^{14}C yr BP, OxA-30441), indicates the accumulation of these layers during the Terminal Pleistocene.

This study includes lithic material from all relevant contexts excavated between 2010 and 2017. In total, this includes 3693 artifacts weighing 25.3 kg (including fragmentary debris). Artifacts from each context/layer were first separated by raw material, with the major types being chert, quartz, and limestone. Within each raw material class, pieces were organized into categories of retouched pieces, cores, core repair, and all other debris. All flakes and flake fragments were sorted into size aggregates, and then by flake part (i.e. complete, proximal, medial, distal).

4.2 Lithic analysis

Various typological schemes have been applied in different parts of eastern Africa, making direct comparison difficult. Here, lithic artifacts were classified according to the East African Stone Tool Typology (EASTT, Shea, 2020), which preferences technological attributes over typological form and is more conducive to a study of lithic technological organization. Some tool names common in Holocene contexts are retained here, but corresponding EASTT codes are given in Tables 1–3 and in **Supplementary Data 1**.

Tool and flake analysis included the following measures: length, width, medial and distal thickness, weight following Andrefsky (2005, p. 98–102); width and thickness of striking platforms (Ambrose, 2002; Shott et al., 2000; Slater, 2016); total number of major flake scars on the dorsal surface (Lyons, 1994: 33; Magne and Pokotylo, 1981); overall curvature of the blade in the Z axis (Andrefsky 1986); and an estimate of the percentage of the dorsal flake surface that retains exterior weathered surface made to the nearest 10% interval (Andrefsky, 2005, p.106; Dibble et al., 2005). Additional details on qualitative and quantitative analyses are presented in the **Supplemental Text**.

5. Results

5.1. Tool technology

Backed pieces are the most common form of retouched artifact at Panga ya Saidi, constituting 56-67% of all tools across all layers. Crescents dominate the category forming ~40% of backed pieces (**Fig 3**). Elongate crescents sometimes called “curved backed pieces”, and triangles fall within the same length range as typical crescents. Average geometric length in Levels 1/2, 4, and 5/6 is 27–29mm, with microliths in Layer 3 being notably shorter ($n=6$, $\bar{x}=22.82$ mm), with lower cross-sectional areas (**Fig 4**). In aggregate, all geometric lengths are normally distributed around a mean of 27.95 mm (Shapiro-Wilk $W=.9744$, $p=.43$). Cross-sectional area measurements are unevenly distributed (Shapiro-Wilk $W=.9228$, $p<.05$), however geometric weights are constrained around a mean range of .75–1.25 g. This makes the Panga ya Saidi geometrics somewhat smaller than those of other regions during the Late Pleistocene, but consistent with the mean values from Early to Middle Holocene contexts in the Central Rift Valley (Ambrose, 2002).

The remainder of the assemblage consists of oblique truncations (typical of eastern African Holocene technologies) and an assortment of double oblique truncations, partially backed flakes and flake fragments. It is possible that these may represent early stage geometrics and the presence of flake segmentation products in Layers 3–6 reflects some level of *in situ* microlith production. All other tool forms are rare in the analyzed strata and are too few to discuss morphological change through time.

5.2. Core morphology

Most cores recovered from Layers 1–6 exhibit nonhierarchical organization indicative of expedient strategies of core reduction (**Table 2**). The most common forms are simple flaked pebbles and discoidal/radial cores (**Fig 5**). Discoidal cores are variable in form, including minimally flaked unifacial and bifacial pieces. Of these, 80% retain some smooth cortex on at least one face indicating that both chert and quartz examples were usually manufactured from pebbles and small cobbles. Only Layers 5/6 have a high proportion of polyhedrons, which are the smallest form of non-bipolar, non-hierarchical cores. Pebble cores, discoids made from pebbles, and multi-platform polyhedrons form, respectively, a continuum in terms of size and mass such that all may represent different stages in the expedient pebble/cobble reduction. This is supported by flake scar density estimates for different core classes which show pebble cores exhibit the least evidence of flaking, and cores with more platforms demonstrate higher rates of flaking (**Fig 6**). Radial, centripetal, and discoidal type cores have the highest flake scar densities, indicating they may result from intensive reduction of other core types.

Bipolar cores are rare in all levels except Layers 5/6, where they make up nearly two thirds of all cores. These too are most often manufactured from pebbles but in Layers 5/6 tabular and cylindrical forms made from segmented blades (elsewhere called splintered pieces, *outil escailles*, or scalar pieces) also occur. Hierarchical cores with evidence of preferential flake removals account for 23–26% of all cores in all layers except Layer 4 where they make up 38% of the core assemblage. Most hierarchical cores are chert in Holocene levels, but in the later Pleistocene (Layers 5/6) hierarchical cores are evenly split between chert and quartz. The most common form through the sequence is that of unifacial-unidirectional flake cores with a single maintained striking platform made from small pebbles (EASTT: II.B.1.a, II.B.1.b). Layers 5/6 have a high frequency of hierarchical blade cores designed to produce consistent elongate removals, including single platform, sub-pyramidal, pyramidal, and opposed platform variants. All single platform hierarchical cores are small with maximum flake release surfaces averaging 2.1 cm relative to a 3.3 cm average among bidirectional cores. Size differences between some core classes appear consistent across layers. Despite changes in the proportion of core classes and types between the Late Pleistocene and Holocene strata, overall core weight (as the best correlate for remaining utility) remains steady through time with respect to raw material (**Fig 7**). The only exception is that chert cores in Layer 3 are much smaller than they are in other layers, although this may be a product of a small sample size.

5.3. Core preparation and repair

All levels contained primary and secondary clast initiation flakes indicative of early stage core exploitation. A few chert cresting flakes throughout the sequence are the only evidence this may have occasionally included on-site preparation of hierarchical blade cores. Otherwise, cortical flakes most likely were derived from initial flaking of the discoidal and bipolar type pebble cores common in the assemblage. Proportions of early stage removals vary from 6–7.6% of all macro-debitage across the strata, except for Layer 3 wherein they account for over 11.5% of all flakes. Combined with the frequency of cores retaining high proportions of cortex, these data indicate that transport of chert and quartz pebbles to the site in preparation for lithic reduction was a significant and consistent component of toolmaking behavior at Panga ya Saidi (Shipton et al., 2018). Core repair flakes occur in low frequency through the analyzed layers (2–5% of all macro-debitage). Almost all such flakes are chert and appear to be orthogonal platform removals or tablet flakes. These forms reflect repair of unidirectional hierarchical chert cores, such as the blade and bladelet cores present in the assemblage.

5.4 Core reduction strategies

5.4.1 Use of quartz and limestone

Quartz and limestone are primarily represented in non-elongate flake debris. Both raw materials diminish in proportion relative to chert from the Terminal Pleistocene through time until the uppermost Layers 1/2 when use of these stone types increases again. Limestone is most heavily utilized in the Terminal Pleistocene Layers 5/6. A reduction in the use of these materials is also reflected in changing proportions of flake shapes through time.

The size of limestone flakes is consistent throughout the sequence until the most recent horizons in Levels 1/2, where there is a substantial increase in size and weight distributions (**Supplemental Fig 4a**). Differences in flake shapes are primarily found between Later Holocene Levels 1/2 and 3 and earlier Levels 4 and 5/6 for both limestone (Kruskal-Wallis $H\chi^2$=18/00, Hc=18.10, p<.05), and quartz (Kruskal-Wallis $H\chi^2$=8.03, Hc=8.10, p<.05). In earlier horizons, more intensive exploitation of expedient limestone cores produced a broader range of flake shapes that through time become more constrained to simple round and laterally convergent morphologies. Proportions of dorsal scar orientations also show greater diversity among limestone flakes in Layers 5/6 compared to subsequent strata when unidirectional removals are more common (χ^2=25.485, df=9, p<.05).

Use of quartz is greater in Layers 4 through 6, and throughout most Layers the assemblage is split between round flakes from expedient cores and more elongate flake forms that likely came from the kind of hierarchical quartz cores found in these Layers. Emphasis on elongate flakes is less evident in Layer 3, though this may be an artifact of the small sample size for quartz for this layer. Complete quartz flakes are significantly larger in Layers 5/6 and 3 (**Supplemental Fig 4b**). Sample size may again be affecting patterns in the more recent Layers, however the difference in flake mass between Levels 5/6 and 4 indicates a true behavioral difference in quartz use between the Terminal Pleistocene and Holocene. There is not a significant change in the orientation of quartz flaking, with unidirectional removals characterizing 70–75% of quartz flake scar patterns (χ^2=2.97, df=9, p=0.96).

5.4.2 *Chert technology*

There are no significant differences in chert flake shape through the layers (Kruskal-Wallis Hχ^2=7.35, Hc=7.35, p=.06). Chert was used in large part to produce elongate flakes, with 25–33% of all chert debris from any layer being classified as blades based on morphology and dorsal scar pattern. A combined category of blades and elongate flakes that do not meet the technical criteria for blades makes up 32-33% of all complete chert debitage (**Table 4**, **Fig 8**).

Blades make up ~37% of all debitage in Terminal Pleistocene to Early Holocene layers (4–6), with a slight decrease into the Later Holocene where blades make up 27–32% of complete specimens. Across all layers ~87% of blades are made on higher quality chert. There is no significant change over time in blade size, even though the distribution skews to slightly smaller specimens in Layers 1/2 (Kruskal-Wallis Hχ^2=5.29, Hc=5.29, p=.15) (**Fig 9**). People at Panga ya Saidi preferentially produced chert blades from unidirectional cores throughout all levels (**Table 5**). Parallel flake scars resulting from single platform cores (e.g. EASTT types *II.B.1.c/d*) are the most common form, with a consistent representation of blades with oblique scars converging at steeper angles. The latter type is twice as common in Layer 4 compared to other levels and is the only source of variation between levels (χ^2=26.06, df=9, p<.05). This type of scar pattern is more likely to result from more curated (thus lower angled) pyramidal cores or cores with convergent/alternated striking platforms.

There is no detectable variation in the size of blade striking platforms or relationships between platform size and any flake metrics among the analyzed levels (**Supplemental Fig 5**). Platform area to flake area relationships are about the same between blades and non-blade flakes, indicating no special effort to minimize blade platform striking areas to maximize core utility as seen in other parts of Kenya (e.g. in the Elmenteitan, see Ambrose, 2002, Goldstein, 2020). Platform size is a more significant predictor of length for blades than it is for flake metrics, although the correlation is still not particularly strong (Spearman's ρ=.43, r<.05).

Chert blades and flakes also share similar proportions of striking platform preparation methods (**Table 6**). Across all layers and for both blade and flake classes, ~78% of platforms lack preparation (combining both plain and winged platform types). There are significant differences among layers largely due to micro-faceted platforms being present in Layers 4 and 5/6, but then almost entirely absent from the Late Holocene strata (Chi^2=67.331, df=18, p<.05). Larger platform faceting continues into Layer 3, but then also disappears in Layers 1/2.

Among blades, there are also some relationships between striking platform type and size. Plain, winged, and micro-faceted platforms share the same surface area size range (with plain being the most variable), while faceted platforms are generally larger than all other categories and ground platforms are the smallest overall (**Fig 10**). The larger size of faceted platform blades indicates these may be related to core rotations or transformations. Ground platforms are smaller, with this preparation reducing the overall loss of available platform per blade produced. The low frequency of ground platforms is further indication that maximization of core utility was not a priority for prehistoric peoples at Panga ya Saidi.

Proximal-to-distal curvature was also recorded for chert blades. Unlike expected patterns wherein shorter blades exhibit more curvature, there is no relationship at all between blade length and blade curvature across the Panga ya Saidi assemblage (Spearman Rho=.054, p=.38). There is no evidence for consistent core design of core maintenance aimed at controlling blade curvature at any point. Blades tend to be more heavily curved in Layer 3 relative to other layers, however lacking a clear variable affecting curvature this is most likely to be due to sample size or random variation.

6. Discussion

6.1 Terminal Pleistocene-to-Holocene mobility and lithic economy at Panga ya Saidi

High quality chert formed the basis for highly formalized and consistent blade production at Panga ya Saidi. Blades were likely used for a variety of tasks, with segmenting and backing suggesting they were sometimes used as part of compound tool technology. Blades were also likely retouched into scrapers and other cutting tools used elsewhere on the landscape. Terminal Pleistocene Layers 5/6 do show greater representation both of hierarchical blade cores and bipolar cores, which could be interpreted as evidence for more emphasis on provisioning for more mobile lifeways. However, cores do not appear more intensively reduced, nor do striking-platform to flake size relationships change across layers significantly enough to indicate altering pressures on raw material curation that would suggest changes in overall mobility through time. Higher flake scar densities on expedient discoidal cores may be evidence that some proportion of these reflect late-stage transformations of hierarchical blade cores.

Lower quality local raw materials were used differently to chert. Quartz, a regionally ubiquitous material, was more-often used to supplement chert in the production of elongate flakes and blades in the Terminal Pleistocene. Quartz was used more opportunistically into the Middle Holocene, with the possibility for people returning to a more mixed hierarchical and expedient use of the material in the Later Holocene. Limestone was flaked expediently during all time periods.

Lithic technological strategies at Panga ya Saidi show evidence of behavioral change from the Terminal Pleistocene into the Holocene that may reflect a shift away from longer-term occupations in earlier times. Layers 5/6 yielded a higher frequency of chert primary and secondary flakes, and core preparation debris that is consistent with greater investment in provisioning (after Kuhn, 2014; see also Thompson et al., 2014). These layers also have relatively low frequencies of tools relative to the larger and diverse core assemblage, consistent with longer-term use of the cave during that period (Kuhn 1991; Surovell, 2009). Decreasing frequencies of expedient non-hierarchical cores could be an indicator of reduced occupational spans (Parry and Kelly, 1987; Wallace and Shea, 2006). This would be most extreme in the Middle and Late Iron Age periods when people were increasingly tied to sedentary farming villages and made use of caves primarily for ritual purposes (Helm et al., 2012; Chami, 2009; Shipton et al., 2017).

A Terminal Pleistocene to Holocene pattern of increasingly shorter-term occupations is consistent with trends across the history of the site from the last glacial maximum (Shipton et al., 2021). Analyses of core reduction strategies and flake morphologies do not suggest a technological reorganization, so these differences are more likely to reflect changes in how the technological strategies have been deployed over the last 17,000 years. This may include changing use of the cave site, or spatial shifts in activity patterns within the site over time. Panga ya Saidi is similar to nearby coastal sites (Helm et al., 2012) in that these do not show the re-organization of lithic economy associated with arrivals of food production elsewhere in eastern Africa (Ambrose, 1998, 2001; Goldstein, 2019a, 2020; Tryon and Faith, 2016). Similar consistency is observed throughout pre-food production levels in Lake Victoria fisher-forager sites

(Seitsonen, 2007) and early Holocene Lake Turkana Basin sites (Bartheleme et al., 1984; Beyin, 2007; Robbins, 1972,1974).

One major factor influencing occupation intensity at sites like Panga ya Saidi was the gradual mosaic adoption of food production along the coast, wherein wild plants and animals continued to be critically important into the Iron Age (Crowther et al., 2018; Prendergast et al., 2017). The apparent expansion of forests through the Holocene likely reflects higher rainfall, with proxy records from Panga ya Saidi indicating stable environments (Roberts et al., 2019; Shipton et al., 2018). Consistent access to rich riverine and maritime resources may have bolstered the resilience of foraging lifeways before, and through, the Iron Age. It is possible to imagine a land-use system where farming slowly replaced coastal foraging but continued logistical use of key fishing areas along rivers and coastal hill hunting camps essentially meant little overall change to mobility strategies. This may be tested by expanded work at sites elsewhere along the coast.

Low density of lithic debris combined with the low sediment accumulation rates also support shorter-term occupation at Panga ya Saidi in the Holocene. The upper strata at Panga ya Saidi are thin, with minimal natural or anthropogenic buildup. The narrow range of tool types and high proportion of backed pieces to flakes are consistent with expectations for short-term use of the cave (Barton and Riel-Salvatore, 2014; Kuhn, 1995). At the same time, only a few raw materials are present and much of this is local. If societies were overall more mobile on the landscape, we would expect a greater diversity of raw material types discarded at even short-term occupations (Surovell, 2009). High ratios of expedient flake production and lack of evidence for maximizing raw material utility in core design make it unlikely that the broader technological organization was oriented toward high mobility on the landscape.

Given current lithic evidence, Panga ya Saidi is hypothesized to be a special purpose site that was used logistically (*sensu* Binford, 1979) throughout the Holocene by populations that did not otherwise practice high rates of residential mobility. We hypothesize that hunter-gatherers moved between centralized long-term base camps and logistical camps like Panga ya Saidi, rather than traveling in large seasonal rounds or as a part of herd-following strategy (eg Barut, 1997). Movement to the coastal plains from the west would likely have resulted in access to obsidian from the Central Rift Valley, so the absence of obsidian indicates the groups using Panga ya Saidi were likely primarily based near the Indian Ocean coast. Hunter-gatherer mobility and land use is similar to that hypothesized for the Kansyore Lake Victoria fisher-foragers, wherein inland hunting was only one component of a more complex subsistence base focused on coastal ecotones. Reliance on terrestrial hunting continued to be important for coastal populations well through the Iron Age, even as agricultural products and domesticated livestock became larger components of subsistence (Crowther et al., 2018; Prendergast et al., 2017; Walsh, 2007). Hunting trips by foragers or later farmers may have occurred frequently throughout the year, were seasonally organized, and/or intensified during periods of climatic stress.

Recent genetic evidence has also revealed a long-term persistence of communities with eastern African hunter-gatherer ancestry in coastal regions, including from an individual buried in the Later Holocene strata at Panga ya Saidi (Skoglund et al., 2017). This is somewhat different from the gradual turnover in other regions associated particularly with the spread of mobile pastoralists (Prendergast et al., 2019; Wang et al., 2020) and seems to reflect the persistence of forager-fisher communities well supported by lacustrine and coastal resources over thousands of years. That these communities were resistant to admixture from incoming food-producing groups may suggest that they were thriving populations present at significant local densities. Hunter-gatherer communities like the Waata Oromo (Waliangulu) continued to be present in regions near Panga ya Saidi into recent history. These hunter-gatherer communities played an important role in trade networks connecting interior regions with the Swahili Coast and offering fallback resources to herders during droughts (Kassam and Bashuna, 2004;

Walsh, 1992). Similar exchange and economic networks may have bolstered the long-term resilience of terrestrial hunting and conservation of lithic technologies through the Late Holocene.

6.2 Relationship between technological variation, climate change, and forager resilience in Holocene eastern Africa.

With recent research contributing to an improved understanding of lithic technologies along the eastern African coast (Beyin et al., 2020; Chami, 2009; Shipton et al., 2021), it is possible to begin comparing coastal, lake-basin, and terrestrial trajectories throughout the Holocene. From the regions assessed here, two broad technological trajectories emerge: Terrestrial foragers with more variable lithic technology, and aquatic resource foragers with more consistent lithic technology.

Terrestrial foragers and those around smaller lake basins in Tanzania and southern Kenya demonstrate more variation in lithic technologies (and therefore in mobility systems and subsistence) over time and across space. For example, the Eburran technologies demonstrate continuous uni-directional change, but this pattern is isolated to a small ecotone and differs from what is known about neighboring areas like Lukenya Hill (Ambrose 1998; see also Kusimba 2001). While altitudinal zonation along the slopes of Mt. Eburru and the Mau Escarpment supported diverse plants and animals, it also made the distribution of these resources more sensitive to changes in precipitation. The human response appears to be development of more specialized technological strategies to maintain foraging strategies focused on the Rift Valley highlands.

The northern Tanzanian patterns also exhibit diachronic change and high variability between sites. In this region however, variations in tool and core type proportions appear to be best related to how specific sites are being used as part of larger seasonal rounds. In fact, the presence of Kansyore pottery at some inland Tanzanian sites could indicate that the same populations were moving or interacting between Lake Victoria and Lake Eyasi (Prendergast, 2011, 2014). A change in how sites are used is still relevant, and may indicate shifts in human-environmental interactions. This likely involved changes in overall mobility and frequency of movements between the Lake Victoria Basin and this interior zone. In addition, heterogeneity within and between rockshelter sequences may reflect dynamic changes in faunal distributions, animal migration patterns, or human hunting strategies in relation to these other variables. For example, the structure of major wildebeest migrations through this region is heavily shaped by rainfall patterns and grassland dynamics that may have changed markedly during the initiation and termination of the AHP (Holdo et al., 2009).

Forager lithic assemblage groups associated with aquatic resources from the coast and larger lake basins display greater continuity in technological organization and by proxy mobility strategies. Coastal subsistence patterns also appear relatively consistent through time, providing further evidence that forager lifeways in coastal environments were highly resilient (Crowther et al., 2016). Other regions seemingly buffered from major climate perturbations (e.g. Lake Victoria and the Indian Ocean coastal forests), display similar patterns of overall technological continuity. The Lake Turkana Basin that saw dramatic fluctuations due to the onset and decline of AHP-driven rainfall, but there is relatively little evidence for significant changes to stone tool technological organization until the arrival of herding (Goldstein, 2019)

Aquatic resource access was certainly a major factor here, but this alone cannot explain these phenomena across all environmental zones. It is more likely that lake and coastal zones also offered a confluence of riverine, mixed savanna, wetland, and sometimes forest ecologies that were all affected differently by climatic change on the local and regional scales. As some resource bases expanded while others contracted, foragers could adjust existing strategies accordingly between more options. Proximity of different biomes permitted longer-term occupations near more stable lake or coastal shores and incentivized persistence of flexible, non-specialized, technological strategies. This accounts for the lack of highly derived tool-kits, preference for local stone, and prevalence of expedient core reduction in these regions until adoption of food-production and/or iron.

Greater flexibility and more subsistence options would allow higher population densities to better endure climate stress. In combination with rates of mobility and interaction between communities, this would have implications for maintaining transmission of technological strategies over time and also for the rate of technological innovations relative to ecological change (see Collard et al., 2013, Grove, 2016; Hopkinson, 2011; Powell et al., 2009). From a deep-time perspective, this would not necessarily mean uni-directional technological intensification. As environments constantly shifted, more rapidly spreading effective responses including "re-inventing" strategies could appear in the archaeological record as the kind of overall flexibility documented for some of these coastal and lake basin regions. Climate, environment, land-use strategies, and demography would therefore be entangled in complex feed-back relationships that cannot be understood from any single set of variables. The most substantial changes in the organization of human mobility and economic strategies across eastern Africa during the Holocene resulted not directly from climatic change, but from the spread of herding and farming. Adoption of food production were also not independent of environmental influence, as these strategies can form effective adaptations to increasingly arid and unpredictable environments in eastern Africa after 5 ka (Marshall and Hildebrand, 2002). Coastal forest regions around Panga ya Saidi would not have supported mobile pastoralism, and so this transformation never occurred in the site's sequence. The later adoption of plant agriculture also appears to have had little impact on overall stone tool economies.

6.3 Wider implications for understanding variation in stone tool technology

In consideration of lithic diversity in the eastern African Holocene, a number of observations can be made that are relevant for interpreting Pleistocene patterns. Much of the local scale variation in the LSA may be explained by changing activity patterns within or between sites, rather than real strategic variation. People in the past were mobile, therefore sites should not be considered as independent data-points that reflect specific cultural adaptations, but as components of larger land-use strategies that crosscut different environments. Human capacity to change technological strategies as people move within and between regions over the course of a year, a decade, or a lifetime make it problematic to associate variation in lithic assemblages with different cultural affiliations. Regionally distinctive tool "styles" are the exception, rather than the rule, and many large areas show almost no discernable formal variation (see Shea, 2014). While the Holocene is usually interpreted as a time of greater social diversity, lithic "types" appear to be a poor proxy for assessing group identities, at least in LSA periods (see Lahr and Foley, 1994; Olaka et al., 2010). However, it should be noted that the length of otherwise typologically uniform backed crescents does seem to be a strong indicator of group-relation within western Kenya (Ambrose, 2002). While this may be correlated with different ways that groups were using crescents (i.e. as composite cutting edges vs. arrow points, see Goldstein and Shaffer, 2017), it may be that greater focus on metrology over typology will reveal some meaningful patterns in this regard.

It is important to document the sheer variability of technological strategies across regions, especially in terms of how many classic "Later Stone Age" features manifest in different environments. Seemingly more stable coastal populations maintained large components of expedient non-hierarchical technologies, calling into question what measures like proportion of backed pieces, geometrics, or other blade tools actually means in terms of human behavior. In other words, the groups most associated with specialized or delayed return subsistence demonstrate the least diagnostic and most informal lithic technologies. Interestingly, variation in geometric size and form does appear to be the most plastic trait of Holocene forager technologies. Variability in microliths may reflect greater capacity for adjusting to changing circumstances, making diversity (and not homogeneity) a better indicator of the emergence of more recent-looking tool-using strategies. Addressing these questions requires a shift away from typological studies to a greater focus on comparative metric analyses.

7. Conclusions

The Later Pleistocene to Holocene record at Panga ya Saidi in eastern Kenya provides new insights into the technological organization of LSA fisher-hunter-gatherers and Iron Age hunter-farmers. Access to diverse resource bases and relative climatic stability along the eastern African coast relative to the interior is associated with a lithic technological strategy of mixed expedient and hierarchical reduction relying on local raw materials with very little evident change over the last 15,000 years. The stone tool economy reflects land-use strategies with overall low residential mobility and likely a smaller foraging radius for groups in the region, with Panga ya Saidi serving largely as a logistical hunting base within this system. In addition, the coastal forest zone appears to be one of the only areas that did not experience a major transformation in mobility and land-use related to shifts in food production, and this merits reconsideration of the importance of coastal foragers in the heterogeneous adoption of plant agriculture (see Crowther et al., 2018; Prendergast et al., 2017) and the rise of later Swahili urbanism (Chami, 1994; Horton and Chami, 2018; Kusimba, 1999) in the coastal region.

Eastern Africa's diverse environments supported hunter-gatherer and fisher-forager populations that responded to large-scale climatic change in different ways. Comparison of lake-basin and terrestrial records with the newly reported record of Holocene coastal forest adaptations demonstrate patterns in stone tool technologies that are relevant for inferring the structure of these human-environmental interactions. Lacustrine and coastal zones are associated with more generalized Later Stone Age technologies that showing minimal diachronic variation across larger areas. Stone tool technologies are more spatially discrete in montane-savanna zones, showing more specialized local adaptations and greater fluctuation in toolkit design across time. Terrestrial foraging strategies appear to be more sensitive to climatic change, even when proxy data indicate these areas experienced climatic shifts less acutely than lake basins. Even though they faced different challenges, the long-term persistence of hunter-gatherers and foragers into the Late Holocene indicates they were often resilient to climatic and other perturbations. In some areas like Lake Turkana and at Panga ya Saidi, foraging strategies continued to be vital well after the arrival of food production.

Patterns of human-environmental interactions in Holocene eastern Africa inform research into similar phenomena earlier in the human record, and merit further research. There is a need for high-resolution dating and re-analysis of lithic assemblages for many of the key sites in all regions discussed here. To understand broader processes, more attention should be given to human lifeways within coastal and coastal forest environments. New data is necessary to test and refine the hypotheses presented here, which can only offer an initial foundation into addressing larger-scale patterns of human responses to African climate change. Examination of Holocene foragers also enhances our capacity for building structural analogies for interpreting tool diversity and technological change in other regions and time periods (*sensu* Wylie, 1988; see also Ambrose, 1986; Kusimba and Kusimba, 2005). Taking a comparative inter-regional approach offers novel insights that are not possible from site-specific studies alone and are essential to building better models for human-environmental interactions in the African past.

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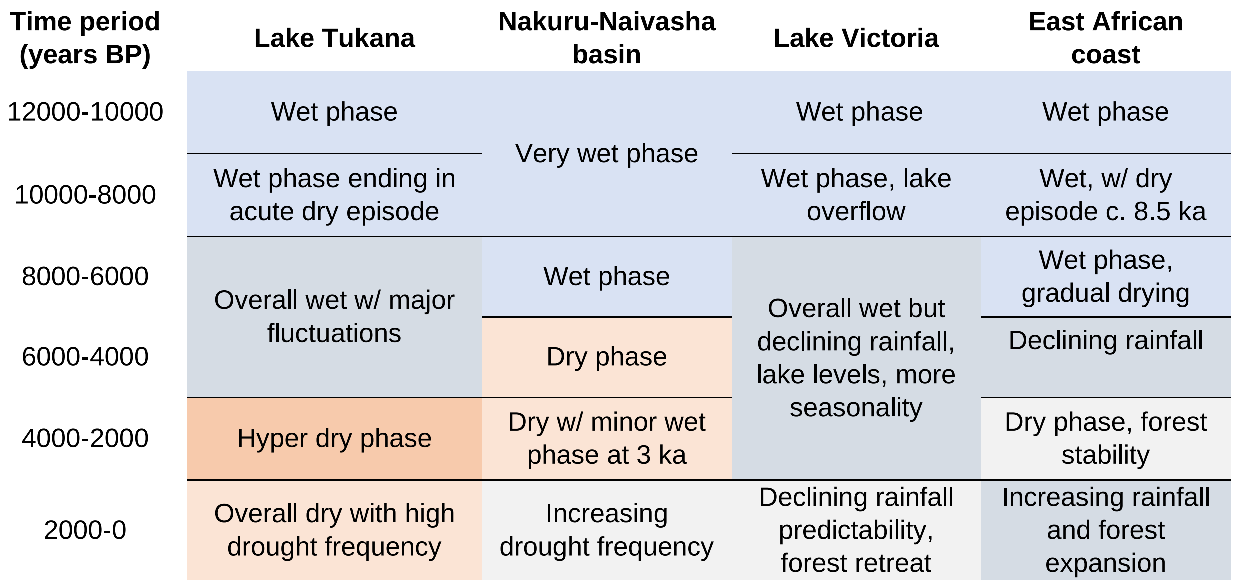
Tables and Figure Captions

Table 1. Summary of climatic changes through the Holocene at Lake Turkana (Bloszies et al. 2015; Forman et al. 2014), the Nakuru-Naivasha Basin of the Central Rift Valley (Olago et al. 2009), Lake Victoria (Johnson et al. 2000, Stager and Mayweski 1997), and the Kenya/Tanzania coast (Liu et al. 2017; Roberts et al. 2020). Direct climate data from the Lake Eyasi region of Tanzania is not available but may be inferred from Nakuru-Naivasha and L. Victoria records.



Time period (years BP)	Lake Tukana	Nakuru-Naivasha basin	Lake Victoria	East African coast
12000-10000	Wet phase	Very wet phase	Wet phase	Wet phase
10000-8000	Wet phase ending in acute dry episode		Wet phase, lake overflow	Wet, w/ dry episode c. 8.5 ka
8000-6000	Overall wet w/ major fluctuations	Wet phase	Overall wet but declining rainfall, lake levels, more seasonality	Wet phase, gradual drying
6000-4000		Dry phase		Declining rainfall
4000-2000	Hyper dry phase	Dry w/ minor wet phase at 3 ka		Dry phase, forest stability
2000-0	Overall dry with high drought frequency	Increasing drought frequency	Declining rainfall predictability, forest retreat	Increasing rainfall and forest expansion

Table 2. Retouched lithic artifacts from Layers 1-6 at Panga ya Saidi. All pieces are chert unless otherwise noted. Artifacts are sorted by named type EASTT reference (Shea 2020).

		Layers			
Type	***EASTT***	**1/2**	**3**	**4**	**5/6**
Scrapers					
Endscraper	*IX.A.1.a*			3	
Convex transverse scraper	*IX.A.1.b.i*				2
Carinated scraper	*IX.A.1.i*				1
Disc/thumbnail scraper	*IX.A.1.k*		1		
Notch tools					
Single Notch	*IX.A.2.a*		1	2	1
Backed pieces					
Crescents	*IX.B.1.a*	4	9	24*	15*
Curved backed	*IX.B.1.b*		1	6	1
Triangle	*IX.B.2.a*		2		1
Oblique truncation	*I.B.3.d*	1	5	8	7
Lateral truncation	*IX.B.3.b.1*				2
Straight backed blade	*IX.B.3.b.2*				3
Convergent backed	*IX.B.4.a*			1	
Double oblique truncation	*IX.B.4.b*		1	6	2
Other backed flake	*IX.B.6*	1	1	10	2
Derived segment	*IX.F1*		1	2	2
Fragment (ind.)			1	3	1
Total Backed		*6*	*21*	*60*	*36*
Burin					
Single burin	*IX.E.1*			4	
Dihedral burin	*IX.E.2*	1	1		
Double burin	*IX.E.3.b*				1
Combinations	*IX.G.5*			1	1
Retouched/thinned pieces	*IX.D.1*		3	6	4
Other					
Hammerstone	*X.A.1*			1	
Groundstone adze	*XI.A.1.A*		1	1	
Awl	*IX.C.3.a*				1
Handaxe	*IV.A.1*		1†		

* One specimen is quartz

† Limestone

Table 3. Inventory of cores analyzed from Layers 1-6 at Panga ya Saidi (counts given as [n chert / m quartz]).

			Layers		
	EASTT	**1-2**	**3**	**4**	**5-6**
Nonhierarchical					
Unipolar	*I.A*	2/0		1/0	1/0
Bipolar					
On pebble	*I.B.1*	1/0	3/0	2/1	10/1
Tabular (*outil escaille*)	*I.B.2*				7/0
Cylindrical (*batonnete*)	*I.B.3*	1/0			6/1
Total Bipolar		*2/0*	*3/0*	*2/1*	*23/2*
Other nonhierarchical					
Bifacial pebble core	*I.C.1*	3/1	3/0	5/0	10/0
Discoidal (unifacial)	*I.C.2.a*		3/0	2/1	9/1
Discoidal (bifacial)	*I.C.2.b*		4/0	2/1	3/1
Polyhedron	*I.C.4*	1/0		1/0	7/0
Core-on-Flake	*III.C.2*	1/2		0/4	
Total Other nonhierarchical		*5/2*	*10/0*	*10/6*	*29/2*
Hierarchical cores					
Flake					
Unifacial	*II.B.1.a*	1/1	2/1	9/0	4/3
Single platform	*II.B.1.b*			0/1	2/1
Total hierarchical flake		*1/1*	*2/1*	*9/1*	*6/4*
Blade					
Single platform	*II.B.1.c*			1/0	0/1
Convergent single platform	*II.B.1.d*	1/0			0/2
Pyramidal single platform	*II.B.1.e*				3/0
Distal opposed blade core	*II.B.2.a*			0/1	1/3
Total hierarchical blade		*1/0*	*0*	*1/1*	*4/6*
Fragment (Ind.)		0/1	1/1		0/3

Table 4. Inventory of flakes analyzed from Layers 1-6. Counts given as (n limestone/ n quartz/ n chert).

		Layer(s)			
	EASTT	**1/2**	**3**	**4**	**5/6**
Preparation flakes					
Split clast	*V.A*		0/0/1		0/0/1
Primary clast initiation	*V.B.1*	0/1/3	0/3/2	1/6/6	2/12/15
Secondary clast initiation	*V.B.2*	0/2/3	0/3/6	4/6/4	0/7/10
Tabular initiation flake	*V.C.2*			0/0/1	
Cresting flake	*V.D.1*	0/0/1	0/0/1		0/0/2
Total preparation flakes		*10*	*16*	*28*	*49*
Blades					
Noncortical	*VI.D.1*	3/1/20	0/0/19	2/4/89	7/9/144
Lateral cortex	*VI.D.2*	0/2/1	0/0/3	0/0/4	2/0/9
Distal cortex	*VI.D.3*	0/1/1	0/0/4	0/1/10	1/4/10
Lateral/ Distal cortex	*VI.D.4*	0/1/0	0/0/2	0/0/4	0/3/10
Total blades		*30*	*28*	*114*	*199*
Flakes					
Residual cortical	*VI.E.2*	0/6/10	0/4/18	1/10/27	6/20/43
Noncortical	*VI.E.3*	19/18/57	8/11/46	50/20/198	121/102/303
Total flakes		*120*	*87*	*306*	
Core repair flakes					
UHC plunging flake	*VII.C.1*	0/0/1	0/1/2	0/0/2	0/0/5
UHC tablet flake	*VII.C.2*		0/0/2	0/0/1	0/0/4
UHC platform flake	*VII.C.3*	0/1/1	0/0/2	1/0/9	0/0/13
Concavity removals	*VII.C.4/5*			0/0/2	0/0/1
Other convexity repair	*VII.D*			0/0/3	1/0/0
Total core repair flakes		*3*	*7*	*18*	*24*

Table 5. Variation in flake plan-view shape through the Panga ya Saidi sequence by raw material type.

	CHERT (n)				QUARTZ (n)				LIMESTONE (n)			
Flake Type/ Layer	**1/2**	**3**	**4**	**5/6**	**1/2**	**3**	**4**	**5/6**	**1/2**	**3**	**4**	**5/6**
Round	35	50	139	217	16	1	13	48	8	3	14	32
Elongate	31	38	117	189	12	2	20	36	3	3	4	18
Convergent	15	12	42	81	5	4	4	8	5	1	7	19
Divergent	9	4	24	34	2	3	8	7	1	0	6	15
Wide	0	2	9	11	0	0	2	3	2	1	8	13
Amorph.	3	8	30	36	2	1	3	4	1	0	7	10

Table 6. Striking platform type by layer by raw material type.

		Layer(s)			
		1/2	**3**	**4**	**5/6**
CHERT	Cortical	6	2	7	9
	Flat	59	52	205	342
	Winged	16	14	53	64
	Ground	7	5	15	41
	Faceted		20	22	30
	Micro-faceted	1	1	20	23
	Point	5	7	17	9
		1/2	**3**	**4**	**5/6**
LIMESTONE	Cortical		1	4	9
	Flat	14	6	23	98
	Winged			3	5
	Ground	2		3	5
	Faceted	1	1	6	8
	Point	3		6	14
		1/2	**3**	**4**	**5/6**
QUARTZ	Cortical	6	2	6	29
	Flat	18	13	27	49
	Winged		1	3	2
	Ground	3		1	5
	Faceted		1		1
	Point	5	4	10	12

Fig 1. Published Holocene sites with hunter-gatherer stone tool sequences showing distribution of technologies associated with Lake Turkana fisher-hunter-gatherers (FHG), Kansyore fisher-foragers (FF), Central Tanzanian hunter-gatherers (HG), and the location of Panga ya Saidi relative to other FHG sites in the coastal forests of eastern Africa. Coastal forest extent data from Conservation International; imagery and elevation data from ESRI.

Fig 2. Location and setting of Panga ya Saidi Cave: (a) Panga ya Saidi within the coastal forest zone of eastern Africa; (b) local setting of Panga ya Saidi relative to the modern coast; (c) view of Panga ya Saidi from outside the cave; (d) excavations within Panga ya Saidi.

Fig 3. Typical variation in morphology of backed crescents at Panga ya Saidi. All chert except quartz 'u'. Layer 3 (r,s,v,w); Layers 4 (a-p); Layer 5/6 (q,t,u x).

Fig 4. Dimensions of backed geometrics by geometric type and horizon, with density plots showing continuous distribution of geometric measurements by layers with no evidence of backed tools clustering by size but gradual change in cross-sectional area over time.

Fig 5. Examples of typical core forms from Panga ya Saidi; (a-b, f) discoidal (radial, bifacial); (c) discoidal (partial bi-facial); (d) single platform unidirectional; (e) single platform bladelet; (g) bifacial pebble core (quartz). Layer 1/2 (b); Layer 3 (c); Layer 4 (a,d,e); Layer 5/6 (f,g).

Fig 6. Box and jitter plot of flake scar density estimates for different core types showing higher intensities of core reduction among radial, single platform, and bidirectional cores than other core classes. Triangles represent category means, empty circles and stars reflect specimens >1 and >2 s.d. from the mode respectively. Surface area is estimated assuming as cuboids ($A=2lw+2wt+2lt$) except for pyramidal and sub-pyramidal (following $A=2\pi rh+2\pi r^2$).

Fig 7. Weight of quartz and chert cores across the analyzed sequence showing relative uniformity through time except for smaller chert cores in Layer 3. Error bars indicate range of 1 SD.

Fig 8. Morphological variation in chert blades from Panga ya Saidi reflecting alternated core morphologies (a,d,f, l), bi-directional cores (c, i, m, v) and uni-directional/convergent cores (all others). Layer 3 (m-r, s-y); Layer 4 (e, j-l); Layer 5/6 (a-d, f-I, z-aa).

Fig 9. Box and jitter plots of lengths of complete chert blades in the analyzed layers. Triangles represent sample means, open circles are outliers beyond 1 SD.

Fig 10. Striking platform area (length x width) by platform preparation type for chert blades. Triangles represent sample means, open circles are outliers beyond 1 SD, stars beyond 2 SD.

Supplemental Fig 1. Representative variation in core organization from Holocene HG contexts at Lothagam, Lake Turkana (a-j, all on lava), and the Eburran Phase 2 (k, n, o) and Phase 5 (l, m, p) levels at Maasai Gorge, Central Rift Valley. Includes discoidal-radial (a-e), bidirectional (f, k, m-p), unidirectional, rotated (l), single-platform unidirectional (h) and sub-pyramidal unidirectional (I,j). Turkana material redrawn from Robbins (1974), Eburran material redrawn from Ambrose (1985).

Supplemental Fig 2. Representative variation in core organization from Silale (a,b,f,g) and Olmoti (c-e, h, i) strata at Mumba Rockshelter, Tanzania (all quartz, except chert f, g) and Kansyore sites at Lake Victoria (j-o, all quartz). Includes bidirectional (a, f, g, i), discoidal, radial (h, j), bipolar (b-e), single platform core on flake (k), single platform unidirectional (l, m), and sub-pyramidal unidirectional (n, o). Tanzanian material redrawn from Mehlman (1989), and Kansyore redrawn from Seitsonen (2010).

Supplemental Fig 3. The Panga ya Saidi stratigraphic sequence with major phases/strata and radiocarbon date locations (a), and appearance of the upper strata that produced Pleistocene to Holocene assemblages assessed in this analysis (b,c).

Supplemental Fig 4 Box plots of flake mass by level group for complete quartz (b) and limestone (a) flakes. Open circles are outliers beyond 1 SD, stars beyond 2 SD.

Supplemental Fig 5. Box plots of chert blade striking platform area by level group, including all platform types except for point platforms. Open circles are outliers beyond 1 SD, stars beyond 2 SD.

References

Ambrose, S.H., 1980. Elmenteitan and other late Pastoral Neolithic adaptations in the central highlands of East Africa, in: Leakey, R.E., Ogot, B.A. (Eds.), *Proceedings of the Eighth Panafrican Congress of Prehistory and Quaternary Studies.* The International Louis Leakey Memorial Institute for African Prehistory, Nairobi, pp. 279–282.

Ambrose, S.H., 1984. The introduction of pastoral adaptations to the highlands of East Africa, in *From hunters to farmers: the causes and consequences of food production in Africa*, in: Clark, J.D., Brandt, S.A. (Eds.), University of California Press, Berkeley, pp. 212–239.

Ambrose, S.H., 1985. Excavations at Masai Gorge Rockshelter, Naivasha. *Azania*, *20*(1), 29–67.

Ambrose, S.H., 1986. Hunter-gatherer adaptations to non-marginal environments: An ecological and archaeological assessment of the Dorobo Model. *Sprache und Geschichte in Afrika, 7*(2), 11–42.

Ambrose, S.H., 1998. Chronology of the Later Stone Age and food production in East Africa. *Journal of Archaeological Science*, *25*(4), 377–392.

Ambrose, S. H., 2001. East African Neolithic. In *Encyclopedia of prehistory*, Springer, Boston, MA, pp. 97–109.

Ambrose, S.H., 2002. Small things remembered: origins of early microlithic industries in sub-Saharan Africa. *Archeological Papers of the American Anthropological Association*, *12*(1), 9-29.

Ambrose, S. H. and Sikes, N. E., 1991. Soil carbon isotope evidence for Holocene habitat change in the Kenya Rift Valley. *Science,* 253(5026), 1402.

Andrefsky Jr., W., 1991. Inferring trends in prehistoric settlement beahvior from lithic production technology in the southern plains. *North American Archaeologist*, *12*(2), 129–144.

Andrefsky Jr., W., 1994. Raw-material availability and the organization of technology. *American Antiquity, 59*(1), 21–34.

Andrefsky Jr., W., 2005. *Lithics: Macroscopic Approaches to Lithic Analysis* 2nd Edition. Cambridge: Cambridge University Press.

Andrefsky Jr., W., 2010. The analysis of stone tool procurement, production, and maintenance. *Journal of Archaeological Research*, *17*, 65–103.

Archer, W., 2020. Carrying capacity, population density and the later Pleistocene expression of backed artefact manufacturing traditions in Africa. *Philosophical Transactions of the Royal Society B*, *376*(1816), 20190716. https://doi.org/10.1098/rstb.2019.0716

Ashley, G.M., Ndiema, E.K., Spencer, J.Q., Harris, J.W. and Kiura, P.W., 2011. Paleoenvironmental context of archaeological sites, implications for subsistence strategies under Holocene climate change, northern Kenya. *Geoarchaeology*, *26*(6), 809-837.

Bamforth, D.B., 1986. Technological efficiency and tool curation. *American Antiquity*, 38–50.

Barthelme, J., 1977. Holocene sites north-east of Lake Turkana: A preliminary report. *Azania*, 12(1), 33–41.

Barthelme, J.W., 1985. *Fisher-hunters and Neolithic pastoralists in East Turkana, Kenya* (Vol. 254). BAR, Oxford.

Barton, C.M. and Riel-Salvatore, J., 2014. The formation of lithic assemblages. *Journal of Archaeological Science*, *46*, 334–352.

Barut, S., 1997. *Later Stone Age lithic raw material use at Lukenya Hill, Kenya* (Doctoral Dissertation, University of Illinois at Urbana-Champaign).

Bergner, A.G. and Trauth, M.H., 2004. Comparison of the hydrological and hydrochemical evolution of Lake Naivasha (Kenya) during three highstands between 175 and 60 kyr BP. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *215*, 17–36.

Berke, M.A., Johnson, T.C., Werne, J.P., Grice, K., Schouten, S. and Damsté, J.S.S., 2012. Molecular records of climate variability and vegetation response since the Late Pleistocene in the Lake Victoria basin, East Africa. *Quaternary Science Reviews*, *55*, 59–74.

Beyin, A., 2011. Recent archaeological survey and excavation around the greater Kalokol area, west side of Lake Turkana: Preliminary findings. *Nyame Akuma*, *75*(1), 40–50.

Beyin, A., Prendergast, M.E., Grillo, K.M. and Wang, H., 2017. New radiocarbon dates for terminal Pleistocene and early Holocene settlements in West Turkana, northern Kenya. *Quaternary Science Reviews*, *168*, 208–215.

Beyin, A. and Ryano, K.P., 2020. Filling the Void: a Study of Sites Characterized by Levallois and Blade Technologies in the Kilwa Basin, Coastal Tanzania. *Journal of Paleolithic Archaeology*, 1–47.

Binford, L.R., 1973. Interassemblage variability: The Mousterian and the “functional” argument. In *The Explanation of Cultural Change*, edited by C. Renfrew, pp. 227–254. London: Duckworth.

Binford, L.R., 1977. Forty-seven Trips, in Wright, R.V.S. (Ed.), *Stone Tools as Cultural Markers*. Australian Institute of Aboriginal Studies, Canberra, pp. 24–36.

Binford, L.R., 1979. Organization and formation processes: Looking at curated technologies. *Journal of Anthropological Research, 25*: 255–273.

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

Blades, B.S., 1999. Aurignacian lithic economy and early modern human mobility: new perspectives from classic sites in the Vézère valley of France. *Journal of Human Evolution*, *37*(1), 91–120.

Bleed, P., 1986. The optimal design of hunting weapons: Maintainability or reliability. *American Antiquity*, 51(4), 737-747.

Bleed, P. and Bleed, A., 1987. Energetic efficiency and hand tool design: a performance comparison of push and pull stroke saws. *Journal of Anthropological Archaeology*, *6*(2), 189–197.

Bloszies, C., Forman, S.L. and Wright, D.K., 2015. Water level history for Lake Turkana, Kenya in the past 15,000 years and a variable transition from the African Humid Period to Holocene aridity. *Global and Planetary Change*, *132*, 64–76.

Bousman, C.B., 2005. Coping with risk: Later stone age technological strategies at Blydefontein Rock Shelter, South Africa. *Journal of Anthropological Archaeology*, *24*(3), 193–226.

Chami, F.A., 2007. Diffusion in the studies of the African past: reflections from new archaeological findings. *African Archaeological Review*, *24*, 1–14.

Chami, F. 1996. The excavation of Kiwangwa Late Stone Age site, In Pwiti, G, Soper, R. (Eds.), *Aspects of African Archaeology: Papers from the 10th Congress of the Pan-African Association of Prehistory and Related Studies*, University of Zimbabwe, Harare, pp. 307–316.

Chami, F. 2009. The Longue Durée of Zanzibar and western Indian Ocean Seaboard, in Chami, F. (Ed.), *Zanzibar and the Swahili Coast From ca. 30,000 Years Ago*. EandD Vision Publishing, Dar es Salaam.

Chami, F.A., 2019. The archaeology of the Mafia Archipelago, Tanzania: New evidence for Neolithic trade links. *Studies in the African Past*, *4*.

Chami, F.A. and Kwekason, A., 2003. Neolithic pottery traditions from the islands, the coast and the interior of East Africa. *African Archaeological Review*, *20*(2), 65–80.

Chritz, K.L., Cerling, T.E., Freeman, K.H., Hildebrand, E.A., Janzen, A. and Prendergast, M.E., 2019. Climate, ecology, and the spread of herding in eastern Africa. *Quaternary Science Reviews*, *204*, 119–132.

Cole, S., 1954. The Prehistory of East Africa. *American Anthropologist*, *56*(6), 1026–1050.

Cole, S., 1963. *The Prehistory of East Africa* (2nd ed.). Macmillan, New York.

Collard, M., Buchanan, B., O"Brien, M.J., 2013. Population Size as an Explanation for Patterns in the Paleolithic Archaeological Record More Caution Is Needed, *Current Anthropology*, *54*, S388-S396.

Collins, J.A., Prange, M., Caley, T., Gimeno, L., Beckmann, B., Mulitza, S., Skonieczny, C., Roche, D. and Schefuß, E., 2017. Rapid termination of the African Humid Period triggered by northern high-latitude cooling. *Nature Communications*, *8*(1), 1–11.

Crowther, A., Faulkner, P., Prendergast, M.E., Quintana Morales, E.M., Horton, M., Wilmsen, E., Kotarba-Morley, A.M., Christie, A., Petek, N., Tibesasa, R. and Douka, K., 2016. Coastal subsistence, maritime trade, and the colonization of small offshore islands in eastern African prehistory. *The Journal of Island and Coastal Archaeology*, *11*(2), 211–237.

Crowther, A., Prendergast, M.E., Fuller, D.Q. and Boivin, N., 2018. Subsistence mosaics, forager-farmer interactions, and the transition to food production in eastern Africa. *Quaternary International*, *489*, 101-120.

Dale, D., 2007. *An archaeological investigation of the Kansyore, Later Stone Age hunter-gatherers in East Africa* (Doctoral dissertation), Washington University in St. Louis.

Dale, D. and Ashley, C.Z., 2010. Holocene hunter-fisher-gatherer communities: new perspectives on Kansyore using communities of Western Kenya. *Azania: Archaeological Research in Africa*, *45*(1), 24–48.

Dale, D., Marshall, F. and Pilgram, T., 2004. Delayed-return hunter-gatherers in Africa? Historic perspectives from the Okiek and archaeological perspectives from the Kansyore, in: Bettinger, R.L., Garvey, R., Tushingham, S. (Eds.), *Hunters and gatherers in theory and archaeology*. Springer US, New York, pp. 340-375.

deMenocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarnthein, M., Baker, L. and Yarusinsky, M., 2000. Abrupt onset and termination of the African Humid Period:: rapid climate responses to gradual insolation forcing. *Quaternary Science Reviews*, *19*, 347–361.

Dibble, H.L., Schurmans, U.A., Iovita, R.P. and McLaughlin, M.V., 2005. The measurement and interpretation of cortex in lithic assemblages. *American Antiquity*, 545–560.

Dühnforth, M., Bergner, A.G. and Trauth, M.H., 2006. Early Holocene water budget of the Nakuru-Elmenteita basin, central Kenya Rift. *Journal of Paleolimnology*, *36*(3), 281–294.

d’Errico, F., Martí, A.P., Shipton, C., Le Vraux, E., Ndiema, E., Goldstein, S., Petraglia, M.D. and Boivin, N., 2020. Trajectories of cultural innovation from the Middle to Later Stone Age in Eastern Africa: Personal ornaments, bone artifacts, and ocher from Panga ya Saidi, Kenya. *Journal of Human Evolution*, *141*, p.102737.

Faulkner, P., Miller, J.M., Quintana Morales, E.M., Crowther, A., Shipton, C., Ndiema, E., Boivin, N. and Petraglia, M.D., 2021. 67,000 years of coastal engagement at Panga ya Saidi, eastern Africa. PLoS One, 16(8), e0256761.

Forman, S.L., Wright, D.K. and Bloszies, C., 2014. Variations in water level for Lake Turkana in the past 8500 years near Mt. Porr, Kenya and the transition from the African Humid Period to Holocene aridity. *Quaternary Science Reviews*, *97*, 84–101.

Frahm, E., Goldstein, S.T. and Tryon, C.A., 2017. Late Holocene forager-fisher and pastoralist interactions along the Lake Victoria shores, Kenya: Perspectives from portable XRF of obsidian artifacts. *Journal of Archaeological Science: Reports*, *11*, 717–742.

Gabel, C., 1969. Six rock shelters on the northern Kavirondo shore of Lake Victoria. *African Historical Studies*, *2*(2), 205–254.

Garcin, Y., Melnick, D., Strecker, M.R., Olago, D. and Tiercelin, J.J., 2012. East African mid-Holocene wet–dry transition recorded in palaeo-shorelines of Lake Turkana, northern Kenya Rift. *Earth and Planetary Science Letters*, *331*, 322–334.

Gifford-Gonzalez, D., 2003. The fauna from Ele Bor: Evidence for the persistence of foragers into the later Holocene of arid north Kenya. *African Archaeological Review*, *20*(2), 81–119.

Goldstein, S., 2018. Picking up the pieces: reconstructing lithic production strategies at a Late Holocene obsidian quarry in southern Kenya. *Journal of Field Archaeology*, *43*(2), 85–101.

Goldstein, S.T., 2019. Lithic technological strategies of the earliest herders at Lake Turkana, northern Kenya. *Antiquity*, *93*(372), 1495–1514.

Goldstein, S.T., 2021. Lithic technological organization of the “Elmenteitan” early herders in southern Kenya: Implications for mobility, exchange, and climatic resilience. *Journal of Anthropological Archaeology*, 61, 101259.

Goldstein, S.T. and Shaffer, C.M., 2017. Experimental and archaeological investigations of backed microlith function among Mid-to-Late Holocene herders in southwestern Kenya. *Archaeological and Anthropological Sciences*, *9*(8), 1767–1788.

Goldstein, S., Hildebrand, E., Storozum, M., Sawchuk, E., Lewis, J., Ngugi, C. and Robbins, L.H., 2017. New archaeological investigations at the Lothagam harpoon site at Lake Turkana. *Antiquity*, *91*(360).

Grillo, K.M., Prendergast, M.E., Contreras, D.A., Fitton, T., Gidna, A.O., Goldstein, S.T., Knisley, M.C., Langley, M.C. and Mabulla, A.Z., 2018. Pastoral Neolithic settlement at Luxmanda, Tanzania. *Journal of Field Archaeology*, *43*(2), 102–120.

Grove, M., 2016. Population density, mobility, and cultural transmission. *Journal of Archaeological Science*, *74*, 75–84.

Hastenrath, S. and Kutzbach, J.E., 1983. Paleoclimatic estimates from water and energy budgets of East African lakes. *Quaternary Research*, *19*(2), 141–153.

Hildebrand, E.A., Grillo, K.M., Sawchuk, E.A., Pfeiffer, S.K., Conyers, L.B., Goldstein, S.T., Hill, A.C., Janzen, A., Klehm, C.E., Helper, M. and Kiura, P., 2018. A monumental cemetery built by eastern Africa's first herders near Lake Turkana, Kenya. *Proceedings of the National Academy of Sciences*, *115*(36), 8942–8947.

Helm, R., Crowther, A., Shipton, C., Tengeza, A., Fuller, D. and Boivin, N., 2012. Exploring agriculture, interaction and trade on the eastern African littoral: preliminary results from Kenya. *Azania: Archaeological Research in Africa*, *47*(1), 39–63.

Holdaway, S., Wendrich, W. and Phillipps, R., 2010. Identifying low-level food producers: detecting mobility from lithics. *Antiquity*, *84*(323), 185–194.

Holdo, R.M., Holt, R.D. and Fryxell, J.M., 2009. Opposing rainfall and plant nutritional gradients best explain the wildebeest migration in the Serengeti. *The American Naturalist*, *173*(4), 431–445.

Hopkinson, T., 2011. The Transmission of Technological Skills in the Palaeolithic: Insights from 574 Metapopulation Ecology, in: Roberts, B.W., VanderLinden, M. (Eds.), *Investigating Archaeological 575 Cultures: Material Culture, Variability, and Transmission*. New York, Springer-Verlag, pp. 229–244.

Horton, M. and Chami, F., 2018. Swahili Origins, in Wynne-Jones, S., LaViollete, A. (Eds.), *The Swahili World*. Routledge, Oxon, pp.135–146.

Ivory, S.J. and Russell, J., 2018. Lowland forest collapse and early human impacts at the end of the African Humid Period at Lake Edward, equatorial East Africa. *Quaternary Research*, *89*(1), 7–20.

Johnson, T.C. and Malala, J.O., 2009. Lake Turkana and its link to the Nile. In *The Nile*. Springer, Dordrecht, pp. 287–304.

Johnson, T.C., Kelts, K. and Odada, E., 2000. The Holocene history of Lake Victoria. *Ambio*, 2–11.

Jung, S.J.A., Davies, G.R., Ganssen, G.M., and Kroon, D., 2004. Stepwise Holocene aridification in NE Africa deduced from dust-borne radiogenic isotopic records. *Earth and Planetary Science Letters*, *221*, 27–37.

Junginger, A. and Trauth, M.H., 2013. Hydrological constraints of paleo-Lake Suguta in the Northern Kenya Rift during the African humid period (15–5 ka BP). *Global and planetary change*, *111*, 174–188.

Junginger, A., Roller, S., Olaka, L.A. and Trauth, M.H., 2014. The effects of solar irradiation changes on the migration of the Congo Air Boundary and water levels of paleo-Lake Suguta, Northern Kenya Rift, during the African Humid Period (15–5 ka BP). *Palaeogeography, Palaeoclimatology, Palaeoecology*, *396*, 1–16.

Kelly, R.L. 1992. Mobility/Sedentism: concepts, archaeological measures, and effects. Annual *Reviews of Anthropology,* 21, 43–66.

Kelly, R.L., 2013. *The lifeways of hunter-gatherers*. Cambridge University Press, Cambridge.

Kessy, E.T., 2005. *The relationship between the Later Stone Age and Iron Age cultures of central Tanzania* (Doctoral dissertation), Department of Archaeology-Simon Fraser University.

Kessy, E.T., 2009. Analysis of lithic artefacts from Mwanampambe and Kuumbi cave, Zanzibar in: Chami, F. (Ed.), *Zanzibar and the Swahili Coast From ca. 30,000 Years Ago*. EandD Vision Publishing, Dar es Salaam, pp.131–143.

Kizza, M., Rodhe, A., Xu, C.Y., Ntale, H.K. and Halldin, S., 2009. Temporal rainfall variability in the Lake Victoria Basin in East Africa during the twentieth century. *Theoretical and applied climatology*, *98*, 119–135.

Knutsson, K., 2019. Preliminary analysis of lithics from Kuumbi cave, Zanzibar. *Studies in the African Past*, *6*.

Kuhn, S.L., 1991. "Unpacking" reduction: lithic raw material economy in the Mousterian of west-central Italy. *Journal of Anthropological Archaeology*, *10*(1), 76–106.

Kuhn, S.L., 2014. *Mousterian lithic technology: an ecological perspective.* Princeton University Press, Princeton.

Kusimba, S.B., 1999. Hunter–gatherer land use patterns in Later Stone Age East Africa. *Journal of Anthropological Archaeology*, *18*(2), 165–200.

Kusimba, S.B., 2001. The early later stone age in East Africa: Excavations and lithic assemblages from Lukenya Hill. *African Archaeological Review*, *18*(2), pp.77–123.

Kusimba, S.B., 2005. What is a hunter-gatherer? Variation in the archaeological record of eastern and southern Africa. *Journal of Archaeological Research*, *13*(4), 337–366.

Kusimba, C.M., and Kusimba, S.B., 2005. Mosaics and interactions: East Africa 2000 B. P. to the present. In Stahl, A.B. (Ed.), *African archaeology: A critical introduction*. Blackwell Publishing, Oxford, pp. 392–419.

Lahr, M. and Foley, R.A., 1998. Towards a theory of modern human origins: geography, demography, and diversity in recent human evolution. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *107*(S27), 137–176.

Lahr, M.M. and Foley, R.A., 2016. Human evolution in late quaternary eastern Africa, in: S.C. Jones, B.A. Stewart (Eds.), *Africa from MIS 6-2.* Springer, Dordrecht, pp. 215–231.

Lahr, M.M., Rivera, F., Power, R.K., Mounier, A., Copsey, B., Crivellaro, F., Edung, J.E., Fernandez, J.M., Kiarie, C., Lawrence, J. and Leakey, A., 2016. Inter-group violence among early Holocene hunter-gatherers of West Turkana, Kenya. *Nature*, *529*(7586), 394–398.

Lane, P., Ashley, C. and Oteyo, G., 2006. New dates for Kansyore and Urewe wares from northern Nyanza, Kenya. *Azania*, *41*(1), 123–138.

Langley, M.C., Prendergast, M.E., Shipton, C., Quintana Morales, E.M., Crowther, A. and Boivin, N., 2016. Poison arrows and bone utensils in late Pleistocene eastern Africa: evidence from Kuumbi Cave, Zanzibar. *Azania: Archaeological Research in Africa*, *51*(2), 155–177.

Leakey, L.S.B., 1931). *The Stone Age cultures of Kenya Colony* (1st ed.). Cambridge University Press, Cambridge.

Levin, N.E., Zipser, E.J. and Cerling, T.E., 2009. Isotopic composition of waters from Ethiopia and Kenya: insights into moisture sources for eastern Africa. *Journal of Geophysical Research: Atmospheres*, *114*(D23).

Liu, X., Rendle-Bühring, R., Kuhlmann, H. and Li, A., 2017. Two phases of the Holocene East African Humid Period: Inferred from a high-resolution geochemical record off Tanzania. *Earth and Planetary Science Letters*, *460*, 123–134.

Loakes, K.L., Ryves, D.B., Lamb, H.F., Schäbitz, F., Dee, M., Tyler, J.J., Mills, K. and McGowan, S., 2018. Late Quaternary climate change in the north-eastern highlands of Ethiopia: A high resolution 15,600 year diatom and pigment record from Lake Hayk. *Quaternary Science Reviews*, *202*, 166–181.

Low, M. and Pargeter, J., 2020. Regional Variability in Lithic Miniaturization and the Organization of Technology in Late Glacial Southern Africa (~ 18-11 kcal BP). *Journal of African Archaeology*, 18(1), 38–66.

Lupien, R.L., Russell, J.M., Grove, M., Beck, C.C., Feibel, C.S. and Cohen, A.S., 2020. Abrupt climate change and its influences on hominin evolution during the early Pleistocene in the Turkana Basin, Kenya. *Quaternary Science Reviews*, *245*, p.106531.

Lyons, W.H., 1994. *Lithic Technology at the Hall Creek Site (35GR420B), Silvies Valley, Grant County, Oregon* (Doctoral dissertation) Washington State University.

Magne, M. and Pokotylo, D., 1981. A pilot study in bifacial lithic reduction sequences. *Lithic Technology*, *10*(2-3), 34-47.

Marchant, R., Mumbi, C., Behera, S. and Yamagata, T., 2007. The Indian Ocean dipole–the unsung driver of climatic variability in East Africa. *African Journal of Ecology*, *45*(1), 4–16.

Marean, C., 1992. Hunter to herder: Large mammal remains from the hunter-gatherer occupation at Enkapune Ya Muto rockshelter (Central Rift, Kenya). *African Archaeological Review, 10*, 65–127.

Marshall, F. and Hildebrand, E., 2002. Cattle before crops: the beginnings of food production in Africa. *Journal of World prehistory*, *16*(2), 99–143.

Marshall, F.B. and K. Stewart., 1995. Hunting, fishing and herding pastoralists of western Kenya: The fauna from Gogo Falls. *Archaeozoologia*, 7, 727.

Martinón-Torres, M., d'Errico, F., Santos, E., Gallo, A.Á., Amano, N., Archer, W., Armitage, S.J., Arsuaga, J.L., de Castro, J.M.B., Blinkhorn, J. and Crowther, A., Douka, K., Dubernet, S., Faulkner, P., Fernández-Colón, P., Kourampas, N., González García, J., Larreina, D., Le Bourdonnec, F.X., MacLeod, G., Martín-Francés, L., Massilani, D., Mercader, M., Miller, J., Ndiema, E., Notario, B., Pitarch Martí, A., Prendergast, M.E., Queffelec, A., Rigaud, S., Roberts, P., Shoaee, M. J., Shipton, C., Simpson, I., Boivin, N. & Petraglia, M.D. 2021. Earliest known human burial in Africa. Nature, 593(7857), 95-100.

McBrearty, S. and Brooks, A.S., 2000. The revolution that wasn't: a new interpretation of the origin of modern human behavior. *Journal of human evolution*, *39*(5), 453-563.

Mehlman, M. J., 1989. *Later Quaternary archaeological sequences in northern Tanzania* (Doctoral dissertation). University of Illinois at Urbana-Champaign.

Mturi, A.A., 1986. The pastoral neolithic of West Kilimanjaro. *Azania*, 21(1), 53–63.

Muia, M., 1998. *The Lukenyan Industry: A Definition* (Doctoral dissertation), University of Nairobi.

Mutundu, K. K. (2010). An ethnoarchaeological framework for the identification of Late Holocene archaeological sites in East Africa. *Azania*, 45(1), 6–23.

Nash, B.P., Merrick, H.V. and Brown, F.H., 2011. Obsidian types from Holocene sites around Lake Turkana, and other localities in northern Kenya. *Journal of Archaeological Science*, *38*(6), 1371–1376.

Ndiema, K.E., Dillian, C.D., Braun, D.R., Harris, J.W.K. and Kiura, P.W., 2011. Transport and subsistence patterns at the transition to pastoralism, Koobi Fora, Kenya. *Archaeometry*, *53*(6), 1085–1098.

Nelson, M., 1991. The Study of Technological Organization. *Archaeological Method and Theory, 3*, 57–100.

Neumann, K., 1989. Holocene vegetation of the Eastern Sahara: charcoal from prehistoric sites. *African Archaeological Review*, *7*(1), 97–116.

Nicholson, J., 1996. A review of climate dynamics and climate variability in Eastern Africa, in: Johnson, T., Odada, E. (Eds.), *The limnology, climatology and paleoclimatology of the East African lakes.* CRC Press, Milton Park, pp. 25–56.

Nicholson, S.E., 2000. The nature of rainfall variability over Africa on time scales of decades to millenia. *Global and planetary change*, *26*(1-3), pp.137–158.

Njagi, D.M., Routh, J., Olago, D. and Gayantha, K. 2021. A multi-proxy reconstruction of the late Holocene climate evolution in the Kapsabet Swamp, Kenya (East Africa). Paleogeography, Paleoclimatology, Paleoecology, 574, 110475.

Olago, D., Marshall, M., Wandiga, S.O., Opondo, M., Yanda, P.Z., Kangalawe, R., Githeko, A., Downs, T., Opere, A., Kabumbuli, R. and Kirumira, E., 2007. Climatic, socio-economic, and health factors affecting human vulnerability to cholera in the Lake Victoria basin, East Africa. *AMBIO: A Journal of the Human Environment*, *36*(4), 350–358.

Olago, D., Opere, A. and Barongo, J., 2009. Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift. *Hydrological sciences journal*, *54*(4), 765–780.

Olaka, L. A., Odada, E. O., Trauth, M. H., and Olago, D. O., 2010. The sensitivity of East African rift lakes to climate fluctuations. *Journal of Paleolimnology, 44*, 629–644.

Owen, R.B., Barthelme, J.W., Renaut, R.W. and Vincens, A., 1982. Palaeolimnology and archaeology of Holocene deposits north-east of Lake Turkana, Kenya. *Nature*, *298*(5874), 523–529.

Parry, W. J., and Kelly, K. L., 1987. Expedient core technology and sedentism, in: Johnson, J.K., Morrow, C.M. (Eds.), *The organization of core technology*. Westview Press, Boulder, CO, pp. 285–304.

Phillipson, D.W., 1977. Lowasera. *Azania*, *12*(1), 1–32.

Phillipson, D.W., 1984. Aspects of early food production in northern Kenya, in: Kryzyzaniak, L. (Ed.), *Origins and Early Development of Food-Producing Cultures in Northeastern Africa*, Polish Academy of Science, Poznan, pp. 489–495.

Porter, C.C. and Marlowe, F.W., 2007. How marginal are forager habitats?. *Journal of Archaeological Science*, *34*(1), 59–-68.

Potts, R., 1996. Evolution and climate variability. *Science*, *273*(5277), 922–923.

Potts, R., 2013. Hominin evolution in settings of strong environmental variability. *Quaternary Science Reviews*, *73*, 1-13.

Powell, A., Shennan, S., Thomas, M.G., 2009. Late Pleistocene Demography and the Appearance of 600 Modern Human Behavior, *Science*, *324*, 1298–1301.

Prendergast, M.E., 2010. Kansyore fisher-foragers and transitions to food production in East Africa: the view from Wadh Lang'o, Nyanza Province, Western Kenya. *Azania: Archaeological Research in Africa*, *45*(1), 83–111.

Prendergast, M.E., 2011. Hunters and herders at the periphery: the spread of herding in eastern Africa, in: Jousse, H., Lesur, J. (Eds.), *People and Animals in Holocene Africa: Recent Advances in Archaeozoology*, *2*. Africa Magna Verlag, Kiel, pp. 43–58.

Prendergast, M.E. and Lane, P.J., 2010. Middle Holocene fishing strategies in East Africa: zooarchaeological analysis of Pundo, a Kansyore shell midden in northern Nyanza (Kenya). *International Journal of Osteoarchaeology*, *20*(1), 88–112.

Prendergast, M.E. and Beyin, A., 2018. Fishing in a fluctuating landscape: terminal Pleistocene and early Holocene subsistence strategies in the Lake Turkana Basin, Kenya. *Quaternary International*, *471*, 203–218.

Prendergast, M.E., Luque, L., Domínguez-Rodrigo, M., Diez-Martín, F., Mabulla, A.Z. and Barba, R., 2007. New excavations at Mumba rockshelter, Tanzania. *Journal of African Archaeology*, *5*(2), 217–243.

Prendergast, M.E., Grillo, K.M., Mabulla, A.Z. and Wang, H., 2014. New dates for Kansyore and pastoral neolithic ceramics in the Eyasi Basin, Tanzania. *Journal of African Archaeology*, *12*(1), 89–98.

Prendergast, M.E., Rouby, H., Punnwong, P., Marchant, R., Crowther, A., Kourampas, N., Shipton, C., Walsh, M., Lambeck, K. and Boivin, N.L., 2016. Continental island formation and the archaeology of defaunation on Zanzibar, eastern Africa. *PloS one*, *11*(2), p.e0149565.

Prendergast, M. E., Lipson, M., Sawchuk, E. A., Olalde, I., Ogola, C. A., Rohland, N., Sirak, K., Adamski, N., Bernardos, R., Broomandkhoshbacht, N., Callan, K., Culleton, B., Eccles, L., Harper, T., Lawson, A.M., Mah, M., Oppenheimer, J., Stewardson, K., Zalzala, F., Ambrose, S., Ayodo, G., Louis Gates Jr., H., Gidna, A., Katongo, M., Kwekason, A., Mabulla, A., Mudenda, G., Ndiema, E., Nelson, C., Robertshaw, P., Kennet, D., Manthi, F., Reich, D., 2019. Ancient DNA reveals a multistep spread of the first herders into sub-Saharan Africa. *Science*, *365*(6448), eaaw6275.

Reimer, P.J., Austin, W.E., Bard, E., Bayliss, A., Blackwell, P.G., Ramsey, C.B., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M. and Grootes, P.M., 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725–757.

Rezek, Z., Holdaway, S.J., Olszewski, D.I., Lin, S.C., Douglass, M., McPherron, S.P., Iovita, R., Braun, D.R. and Sandgathe, D., 2020. Aggregates, formational emergence, and the focus on practice in stone artifact archaeology. *Journal of Archaeological Method and Theory*, 1–42.

Robbins, L.H., 1972. Archeology in the Turkana district, Kenya. *Science*, *176*(4033), 359-366.

Robbins, L. H., 1974. *The Lothagam site: A Late Stone Age fishing settlement in the Lake Rudolph basin, Kenya* (Vol. 1). Michigan State University, East Lansing.

Robbins, L.H., 1980. *Lopoy and Lothagam*. Michigan State University, Lansing.

Robbins, L.H. and Lynch, B.M., 1978. New evidence on the use of microliths from the Lake Turkana Basin, East Africa. *Current Anthropology*, *19*(3), 619-620.

Roberts, P., Prendergast, M.E., Janzen, A., Shipton, C., Blinkhorn, J., Zech, J., Crowther, A., Sawchuk, E.A., Stewart, M., Ndiema, E. and Petraglia, M., 2020. Late Pleistocene to Holocene human palaeoecology in the tropical environments of coastal eastern Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *537*, p.109438.

Robertshaw, P.T., 1990. *Early Pastoralists of Southwestern Kenya*. Memoirs of the British Institute in Eastern Africa, 11, Nairobi.

Robertshaw, P., Collett, D., Gifford, D. and Mbae, N.B., 1983. Shell middens on the shores of Lake Victoria. *Azania 18*(1), 1-43.

Seitsonen, O., 2010. Lithics use at Kansyore sites in East Africa: technological organisation at four recently excavated sites in Nyanza Province, Kenya. *Azania: Archaeological Research in Africa*, *45*(1), 49–82.

Shanahan, T.M., McKay, N.P., Hughen, K.A., Overpeck, J.T., Otto-Bliesner, B., Heil, C.W., King, J., Scholz, C.A. and Peck, J., 2015. The time-transgressive termination of the African Humid Period. Nature *Geoscience*, 8(2), 140–144.

Shea, J.J., 2014. Sink the Mousterian? Named stone tool industries (NASTIES) as obstacles to investigating hominin evolutionary relationships in the Later Middle Paleolithic Levant. *Quaternary International*, *350*, 169-179.

Shea, J.J., 2020. *Prehistoric stone tools of eastern Africa: a guide*. Cambridge University Press, Cambridge.

Shennan, S., 2001. Demography and cultural innovation: A model and its implications for the 605 emergence of modern human culture, *Cambridge Archaeological Journal*, *11*, 5–16.

Shipton, C., Crowther, A., Kourampas, N., Prendergast, M.E., Horton, M., Douka, K., Schwenninger, J.L., Faulkner, P., Quintana Morales, E.M., Langley, M.C. and Tibesasa, R., 2016. Reinvestigation of Kuumbi cave, Zanzibar, reveals later stone age coastal habitation, early Holocene abandonment and iron age reoccupation. *Azania: Archaeological Research in Africa*, 51(2), 197-233.

Shipton, C., Roberts, P., Archer, W., Armitage, S.J., Bita, C., Blinkhorn, J., Courtney-Mustaphi, C., Crowther, A., Curtis, R., d'Errico, F. and Douka, K., 2018. 78,000-year-old record of Middle and Later Stone Age innovation in an East African tropical forest. *Nature Communications*, 9(1), 1–8.

Shipton, C., Blinkhorn, J., Archer, W., Kourampas, N., Roberts, P., Prendergast, M.E., Curtis, R., Herries, A.I., Ndiema, E., Boivin, N. and Petraglia, M.D., 2021. The Middle to Later Stone Age transition at Panga ya Saidi, in the tropical coastal forest of eastern Africa. Journal of Human Evolution, 153, 102954.

Shott, M.J., 1986. Technological organization and settlement mobility: An ethnographic examination. *Journal of Anthropological Research, 42*, 15–51.

Shott, M.J., 1989. On tool-class use lives and the formation of archaeological assemblages. *American Antiquity*, *54*(1), 9–30.

Shott, M.J., 2018. The costs and benefits of technological organization: Hunter-gatherer lithic industries and beyond, in: Robinson, E., Sellet, F. (Eds.), *Lithic technological organization and paleoenvironmental change*. Studies in Human Ecology and Adaptation Vol. 9. Springer, Cham., pp. 321-333.

Shott, M.J., Bradbury, A.P., Carr, P.J., and Odell, G.H., 2000. Flake size from platform attributes: predictive and empirical approaches. *Journal of Archaeological Science*, *27*, 877–94.

Siiriäinen, A., 1977. Later Stone Age investigation in the Laikipia Highlands, Kenya: a preliminary report. *Azania*, *12*(1), 162–186.

Skoglund, P., Thompson, J.C., Prendergast, M.E., Mittnik, A., Sirak, K., Hajdinjak, M., Salie, T., Rohland, N., Mallick, S., Peltzer, A. and Heinze, A., 2017. Reconstructing prehistoric African population structure. *Cell*, 171(1), 59–71.

Slater, P., 2016. *Change in lithic technological organization strategies during the Middle and Later Stone Ages in East Africa* (Doctoral dissertation), University of Illinois at Urbana-Champaign.

Soper, R.C. and Golden, B., 1969. An archaeological survey of Mwanza region, Tanzania. *Azania*, 4(1), 15–79.

Ssemmanda, I. and Vincens, A., 2002. Vegetation changes and their climatic implications for the Lake Victoria region during the late Holocene, in Odada, E.O., Olago, D.O. (Eds.), *The East African Great Lakes: Limnology, Palaeolimnology and Biodiversity*. Springer, Dordrecht, pp. 509–523

Stager, J.C., Cumming, B. and Meeker, L., 1997. A high-resolution 11,400-yr diatom record from Lake Victoria, East Africa. *Quaternary Research*, *47*(1), 81–89.

Stager, J.C., Cumming, B.F. and Meeker, L.D., 2003. A 10,000-year high-resolution diatom record from Pilkington Bay, Lake Victoria, East Africa. *Quaternary Research*, *59*(2), 172–181.

Street-Perrott, F.A., Marchand, D.S., Roberts, N. and Harrison, S.P., 1989. *Global lake-level variations from 18,000 to 0 years ago: A palaeoclimate analysis* (No. DOE/ER/60304-H1). Oxford Univ.(UK). Geography School.

Stewart, K.M., 1989. *Fishing sites of North and East Africa in the Late Pleistocene and Holocene: Environmental change and human adaptation*. BAR.

Surovell, T.A., 2009. *Toward a behavioral ecology of lithic technology: cases from Paleoindian archaeology*. University of Arizona Press, Tuscon.

Sutton, J. E. G., 1974. The aquatic civilization of Middle Africa. *The Journal of African History*, *15*(4), 527–546.

Sutton, J.E.G., 1977. The African Aqualithic. *Antiquity*, *51*(201), 25–34.

Thorp, C., 1992. Archaeology in the Nguru Hills: Iron Age and earlier ceramics. *Azania*, *27*(1), 21–44.

Tierney, J.E. and deMenocal, P.B., 2013. Abrupt shifts in Horn of Africa hydroclimate since the Last Glacial Maximum. *Science*, *342*(6160), 843–846.

Tierney, J.E., Russell, J.M., Damsté, J.S.S., Huang, Y. and Verschuren, D., 2011. Late Quaternary behavior of the East African monsoon and the importance of the Congo Air Boundary. *Quaternary Science Reviews*, 30(7-8), 798–807.

Tierney, J.E., Smerdon, J.E., Anchukaitis, K.J. and Seager, R., 2013. Multidecadal variability in East African hydroclimate controlled by the Indian Ocean. *Nature*, 493(7432), 389–392.

Torrence, R., 1984. Monopoly or direct access? Industrial organization at the Melos obsidian quarries, in: Ericson, J.E., Purdy, B.A. (Eds.), *Prehistoric quarries and lithic production*. Cambridge University Press, Cambridge, pp. 49–64.

Trauth, M. H., Maslin, M. A., Deino, A. L., Junginger, A., Lesoloyia, M., Odada, E. O., Olago, D. O., Olaka, L. A., Strecker, M. R., and Tiedemann, R., 2010. Human evolution in a variable environment: The amplifier lakes of Eastern Africa. *Quaternary Science Reviews*, *29*(23–24), 2981–2988.

Tryon, C.A. and Faith, J.T., 2016. A demographic perspective on the Middle to Later Stone Age transition from Nasera rockshelter, Tanzania. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1698), p.20150238.

van der Lubbe, H.J.L., Krause-Nehring, J., Junginger, A., Garcin, Y., Joordens, J.C.A., Davies, G.R., Beck, C., Feibel, C.S., Johnson, T.C. and Vonhof, H.B., 2017. Gradual or abrupt? Changes in water source of Lake Turkana (Kenya) during the African Humid Period inferred from Sr isotope ratios. *Quaternary Science Reviews*, 174, 1–12.

Van Rampelbergh, M., Fleitmann, D., Verheyden, S., Cheng, H., Edwards, L., De Geest, P., De Vleeschouwer, D., Burns, S.J., Matter, A., Claeys, P. and Keppens, E., 2013. Mid-to late Holocene Indian Ocean Monsoon variability recorded in four speleothems from Socotra Island, Yemen. *Quaternary Science Reviews*, 65, 129–142.

Walker, M., Gibbard, P., Head, M.J., Berkelhammer, M., Björck, S., Cheng, H., Cwynar, L.C., Fisher, D., Gkinis, V., Long, A. and Lowe, J., 2019. Formal subdivision of the Holocene Series/Epoch: a summary. Journal of the Geological Society of India, 93(2), 135-141.

Wallace, I.J. and Shea, J.J., 2006. Mobility patterns and core technologies in the Middle Paleolithic of the Levant. *Journal of Archaeological Science*, *33*(9), 1293–1309.

Walsh, M., 1992. Mijikenda origins: A review of the evidence. *Transafrican Journal of History*, pp.1-18.

Wang, K., Goldstein, S., Bleasdale, M., Clist, B., Bostoen, K., Bakwa-Lufu, P., ... and Mercader, J., Schiffels, S., Boivin, N., 2020. Ancient genomes reveal complex patterns of population movement, interaction, and replacement in sub-Saharan Africa. *Science Advances*, *6*(24), eaaz0183.

Waweru, V.N., 2001. *Activity areas at GvJm 47, Lukenya hill an assemblage composition and site structure analysis* (Doctoral dissertation), University of Nairobi.

Wilshaw, A., 2016. The current status of the Kenya Capsian. *African Archaeological Review*, *33*(1), 13–27.

Wright, D.K., Forman, S.L., Kiura, P., Bloszies, C. and Beyin, A., 2015. Lakeside view: Sociocultural responses to changing water levels of Lake Turkana, Kenya. *African Archaeological Review*, 32(2), 335–367.

Wright, D. K., and Forman, S. L., 2011. Holocene occupation of the Mount Porr strand plain in southern Lake Turkana, Kenya. *Nyame Akuma, 76*, 47–62.

Wylie, A., 1988. ‘Simple’analogy and the role of relevance assumptions: implications of archaeological practice. *International Studies in the Philosophy of Science*, *2*(2), 134–150.