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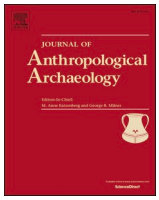

Diet, economy, and culinary practices at the height of precolonial Swahili urbanism

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ABSTRACT

Swahili cuisine is known across Africa and globally as a highly distinctive product of a cosmopolitan, coastal, urban society. Here we present a comprehensive study of precolonial Swahili diet and culinary practices at the coastal town of Songo Mnara, positioning archaeological and ethnographic understandings of cuisine in a long-term coastal tradition. We explore contemporary food cultures and then present the first direct evidence for precolonial cuisine by combining ceramic lipid residue analysis with archaeobotanical, zooarchaeological, and faunal and human stable isotopic data. Integrating these datasets produces a detailed picture of diet at the site of Songo Mnara during the peak of precolonial Swahili urbanism. Lipid residue analysis demonstrates how plant and animal products were consumed and valued in ways not discernible from plant and animal remains alone. We also note special treatment for particular foodstuffs, including an association of fish consumption with high-status spaces and vessels, and preferential management of cattle for milk. A more complex picture of urban life emerges, recognizing influences of taste, class, and culture. Our findings demonstrate the potential of multi-layered anthropological studies for exploring cuisine and urban life in coastal contexts across the globe.

1. Introduction

This paper presents multiple datasets exposing diet and culinary practice at a 14th-16th-century site on the coast of Tanzania, producing the first comprehensive approach to cuisine for the Swahili region. The study of cuisine draws together social and economic aspects of past consumption, with important ramifications for our understanding of past societies (Craig-Atkins et al., 2020; Hastorf, 2016). Beyond subsistence and diet, which focus on the procurement and consumption of available foods, cuisine invokes not just the food people ate, but the materials, skills, tastes, and knowledge to be found among a particular community (Klarich, 2010). A culinary approach is contingent on social practice and examines the care taken in the treatment of different foodstuffs to glean insights into how they might have been valued in the past. Thus, against a background of a particular crop and animal repertoire, we can explore which foods are treated in specialized ways, as a proxy for the social value and tradition attached to their consumption. Advances in molecular and chemical residue analysis of ceramics have helped drive these studies in recent years, enabling researchers to connect shifts in material culture directly to the consumption of particular foodstuffs, by which social relations were reproduced (e.g., Craig et al., 2015).

The Swahili coast of eastern Africa can offer an important contribution to this literature. As an African Islamic society of long standing, the cuisine of the last 1000 years can be seen in the context of a rich culinary tradition of Islamic and Indian Ocean cuisine, known from the

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courtly traditions of the Caliphate and from cookbooks that relate regional variants (Lewicka, 2011; Nasrallah, 2007). In an African context, there are no comparable historical documents, but regional archaeology has revealed the importance of cuisine and culinary tastes in the definition of social identities in the deeper past of eastern Africa (Grillo et al., 2020). On the Swahili coast there are only scant historical mentions of cuisine before the 19th century, although various types of food are described by sporadic visitors to the coast (see below). Based on ceramic and archaeobotanical evidence, archaeologists have argued for the social importance of elite consumption and feasting (Fleisher, 2010; Walshaw, 2010). Cuisine has not, however, been studied from the perspective of daily consumption. Instead, daily foods have been explored through approaches to 'diet' which do the important work of exploring which foodstuffs were being consumed, but cannot inform on who was eating what, where, and in which combinations. The cuisine of the contemporary Swahili coast—including modes of cooking, types of vessels used, and combinations of ingredients—is acknowledged as an important social agent today (Caplan, 2013; Rolingher, 2005; Wynne-Jones & Mapunda, 2008). In this paper, we seek to extend this understanding into the past using a multiproxy archaeological approach to reconstruct aspects of cuisine in a precolonial town.

We present multiple datasets from the 14th-16th-century CE site of Songo Mnara (Fig. 1) that together provide the first insights into daily culinary practice on the precolonial Swahili coast. Songo Mnara is one of dozens of urban settlements on the eastern African coast, many of which emerged during the early second millennium CE, linked to trade networks on the African continent and the Indian Ocean world more broadly. The precolonial 'Swahili Coast' stretches from southern Somalia to Mozambique and includes the northern coast of Madagascar, and the archaeology of many settlements on this littoral has documented a rich variety of urban forms. Songo Mnara is a compact 6–7 ha settlement, one of the best-preserved stone townscapes on the entire eastern

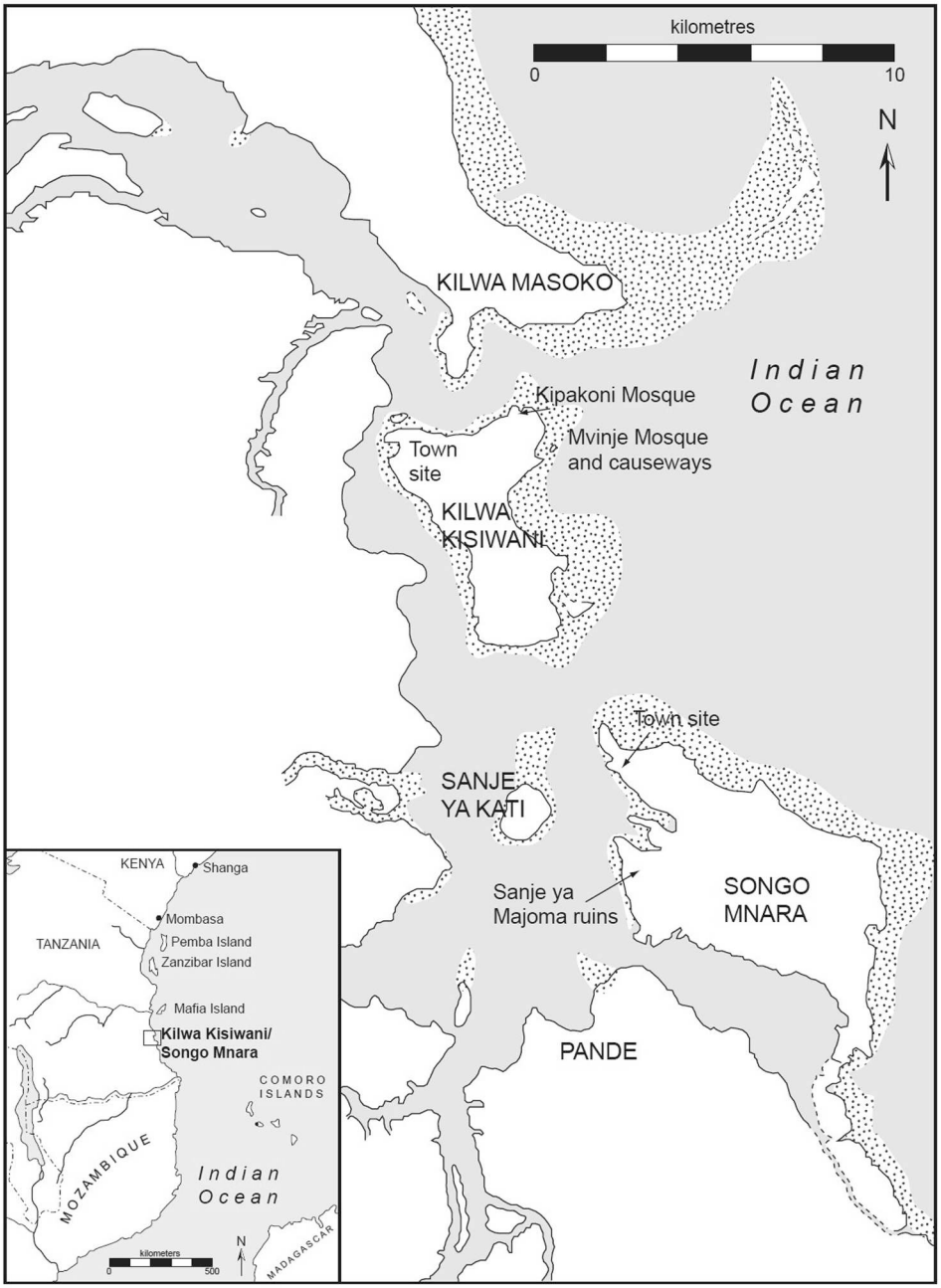

Fig. 1. Location of Songo Mnara along the eastern African coast.

African coast. The site contains the standing remains of>40 coral-built houses, six mosques, and clear demarcations of open spaces bounded by a town wall. The town was occupied from the late 14th to 16th centuries CE and emerged in the shadow of the richer and much longer-occupied site of Kilwa Kisiwani (Chittick 1974) on the island just to the north. As at Kilwa, the inhabitants of Songo Mnara were connected to long-distance exchange networks, with clear evidence of merchant houses as well as the local production of cloth, beads, and finished iron objects. The Songo Mnara Urban Landscape Project (2009–2016) focused on the use of space in the town, providing an unparalleled archaeological dataset to reveal the ways that people created and inhabited both daub structures and stone houses, yards, open spaces, and other parts of the townscape (Fleisher & Wynne-Jones, 2012; Wynne-Jones, 2013; Fleisher, 2014). One primary discovery was an area of daub structures flanking the western entrance of the site, of which five were subject to test and extensive excavation. Data from daub contexts at other coastal sites suggest that not all daub house dwellers were poor (LaViolette & Fleisher, 2009; Pawlowicz, 2019); at Songo Mnara, the residents of daub structures seem to have had access to a similar range of material culture (including imported pottery, adornments, and coinage) as their stone house neighbors.

Songo Mnara provides the most comprehensive data collected to examine Swahili cuisine to date; these data also speak to how urban cuisine developed on the edges of the Islamic world, linked to widespread coastal and Indian Ocean networks. The dataset, including ceramic, faunal, and archaeobotanical data from more than sixty excavation trenches covering 1500 m^2, allows for a reconstruction of an African cuisine, through contextual data from houses, middens, and courtyards. We conducted the analysis of archaeobotanical and zooarchaeological data in relation to activity contexts with a view towards understanding subsistence not just as a composite but as it was structured among households and other spaces of consumption. Excavation of human burials at Songo Mnara provided skeletal samples for the first characterization of human diet through stable isotope analysis for a Swahili urban site.

In this paper, we draw together the results of these analyses. Full details of the excavation and analytical methods are described in the supplementary information. First, we provide a broad overview of precolonial Swahili social practices associated with the production and consumption of food as known from historical, ethnographic, and archaeological sources from the eastern African coast. Next, we examine evidence of subsistence (defined here as procurement of available foodstuffs) and diet (selection of consumed foods) at Songo Mnara from zooarchaeological and archaeobotanical datasets along with stable isotope data from both human and animal remains. Together these datasets reveal individual diet and animal husbandry practices. Finally, we present ceramic organic residue data, tying together our understandings of subsistence, diet, and cuisine (combinations for cooking and serving food).

This is the first application of either stable isotope analysis or ceramic residue analysis at a Swahili site. The result is therefore an unparalleled study of cuisine and culinary practice in an area of coastal Africa and the Indian Ocean world that has yet to contribute to discussions of Islamic and African cuisines. Multiple lines of evidence are crucial to this understanding, as the tropical coastal context means that various terrestrial and marine food sources exist, making it difficult to paint a complete picture from any single study. By demonstrating the potential for this combined set of data, we therefore also make an argument for the use of multi-layered archaeological studies in coastal contexts across the globe.

2. Foodways on the precolonial Swahili coast

Current understandings of subsistence and diet on the Swahili coast are based on a combination of data from archaeological, historical, and ethnographic, sources. Each of these is restricted in some ways as a means of understanding dietary practices, but together they can provide a broad picture of available foodstuffs, and social practices for the region.

2.1. Archaeologies of subsistence

Faunal and botanical remains were rarely systematically collected from precolonial Swahili settlements, let alone studied, until the 1980s (Mudida & Horton, 1996; Kleppe, 2001; Walshaw, 2015; Wright et al., 1984). In the past two decades, new research on archaeobotanical and archaeofaunal datasets from the eastern African coast has increased our understanding of subsistence strategies during the last ~1500 years of settlement (Quintana Morales & Prendergast, 2017) and extended subsistence records to the Late Pleistocene (Roberts et al., 2020). Swahili communities fed themselves through a mixed range of subsistence strategies including farming, herding, fishing, and the exploitation of wild resources. Archaeobotanical data demonstrate a flexible culinary system where Asian rice and beans were slowly adopted into a fundamentally African pantry, including pearl millet and sorghum, alongside pulses and many fruits; wild foods were also collected and utilized, including baobab and weedy greens. Although imported Asian crops, such as rice, were present by the 7th century CE, these became much more abundant in the second millennium CE (Crowther et al., 2016; Walshaw, 2010; Wright et al., 1984). However, rice has so far been identified at only a restricted set of sites (Walshaw & Stoetzel, 2018). Protein from fish and wild game were gradually supplanted by greater numbers of domesticates after the start of the second millennium CE (Mudida & Horton, 1996; Prendergast et al., 2017; Quintana Morales & Prendergast, 2017). Fishing and shellfish collecting were always part of the coastal diet, with a shift towards offshore reef resources in later centuries linked to different fishing technologies (Fleisher et al., 2015; Mudida & Horton, 1996, Quintana Morales & Horton, 2014). While there is a robust body of research documenting the archaeology of subsistence practices on the Swahili coast, there are few examples of archaeological research that connects ceramic practices with dietary data (Fleisher, 2010; Walshaw, 2010), and these are focused on elite practices and feasting.

2.2. Historical texts

Histories of the eastern African coast before the 16th century are written by outsiders, travelers to the region who recorded their experiences and observations. Although they are informed by the perspectives of foreign visitors, these accounts contain a non-exhaustive set of descriptions of foodstuffs encountered and exploited. As early as the first century CE, the *Periplus Maris Erythraei* mentions the use of sewn boats and dugout canoes for fishing and catching turtles (Casson, 1989, pp. 59–60). Cattle-keeping is described by Al-Masudi (915 CE), whose testimony has been used to suggest a significant pastoralist component to early Swahili society (Horton & Mudida, 1993). An account by Al-Idrisi highlights the importance of hunting and fishing as important forms of subsistence in the 12th century (Freeman-Grenville, 1962, p. 20).

Direct historical mentions of daily foods at Kilwa and Songo Mnara are absent, but a broad view of food consumption practices can be inferred from recorded visits to other parts of the coast. Historical accounts from Al-Masudi and Ibn Battuta (1331 CE) describe foods and feasts encountered during travels to eastern Africa. Al-Masudi reports that banana, millet, and coconut were dietary staples (Freeman-Grenville, 1962, p. 16-17). Ibn Battuta provides a detailed snapshot of cuisine he experienced while treated to a feast in Mogadishu: “rice cooked with ghee placed on a large wooden dish [topped with] dishes of… chicken and meat and fish and vegetables” served with pickled lemon, ginger, mangoes, and “chillies” (Hamdun & King, 1998, p. 18). He goes on to observe that “[w]hen they eat a ball of rice they eat after it something from these salted and vinegared foods” and that meals are eaten three times a day (p. 18). In contrast, when visiting Mombasa, Ibn Battuta

observes that "there is no cultivation of grain among the people of this island: food is brought to them from the *Sawahil*. The greater part of their food is bananas and fish" (p. 22). These examples signal variation among coastal towns against a backdrop of shared food practices.

Taken together, several patterns can be observed about historical mentions of food along the Swahili coast. Wild and domesticated foods of a variety of taxa were observed in historical travel records. Early records include descriptions of subsistence activities, such as cattle-keeping and fishing, but descriptions of daily household activities are noticeably absent. Despite various accounts of specific dishes, there is no mention of the investments of time, innovation, and labor on the part of the cooks, likely to be female. These blind spots are understandable given the norms of female privacy and seclusion in some Islamic contexts; however, they represent enormous gaps to be filled through archaeological data and ethnographic inference.

2.3. Swahili ethnographies

Ethnographies help illustrate food practices on the Swahili coast from the mid-20th century to the present. While they clearly represent a schematic view of culinary practice displaced in time from the data presented here, they offer a contemporary baseline against which earlier diets and cuisine might be compared. Additionally, these ethnographic observations are often the basis for many of the models used to interpret archaeological evidence, such as distinctions in modes of governance and between classes such as elites and commoners (Kusimba 1999). Early examples of ethnographies of the eastern African coast (Grottanelli, 1955; Prins, 1965) provide detailed descriptions of the tools and practices associated with fishing out at sea, an activity primarily undertaken by men. In his broad ethnographic overview of the Swahili coast, Prins (1961) draws distinctions between the diets of wealthy and poor members of Pemban society: "[t]he latter type consists of rice, cassava, maize or sweet potatoes with curried shark and cassava foliage; the first shows a very wide variety, i.e., bread, tea, milk, sugar, rice (or, occasionally, cassava or maize), bananas, fish, fruits of the season (mostly mango), vegetable relish, and sometimes meat" (p. 61). He also lists typical kitchen utensils, including gourds for carrying liquids, many medium to large jars for storing foods, variously sized cooking pots, and straw or metal trays and earthen vessels (*bunguu*) for serving food (p. 78). These accounts describe a repertoire of tools and ingredients used in Swahili foods, and to a more limited extent, how these are combined into dishes, without mention of the skills and labor required to produce these foods.

Most early ethnographic works provide a broad picture of Swahili social practices, especially those tied to a mercantile identity (Middleton, 1992), without explicitly recognizing gendered experiences outside the male sphere (but see Caplan, 1993). Ethnoarchaeological research, in contrast, has explored gender-based practices, such as the economic role of shellfish harvesting and processing by women and children in an urban setting of Dar es Salaam, Tanzania (Msemwa, 1994) and the role of women in processing, distributing, and discarding fish in the town of Vanga and nearby fishing communities in southern Kenya (Quintana Morales, 2013). While demonstrating the historical importance of local food resources along the Swahili coast, ethnoarchaeological studies also demonstrate the variation of food procurement and processing practices across spatial and temporal scales that result from environmental and socioeconomic factors as well as consumer preferences (Ichumbaki 2014).

Ethnoarchaeology is a useful approach for investigating food-based practices by exploring patterns of production, consumption, and discard among present-day communities. For example, ethnoarchaeological research on small-scale agriculture on Pemba Island, Tanzania, generated robust models of the botanical correlates of household food production (Walshaw, 2015, Ch. 7), and highlighted the importance of household activities, primarily undertaken by women. In particular, the practice of storing grains in the husk, possibly even still on the stalk, was common within family farming houses, and led to processing waste being deposited close to—even within—houses. Storing grain on the stalk resulted in the laborious work of threshing, pounding, and winnowing on a weekly, even daily, basis by women ahead of cooking processes. Shifting these laborious food processing tasks to routine household activities helped to maximize household labor during the intense harvest period.

In sum, ethnographic sources document a variety of foods as well as cooking and harvesting tools and practices on the Swahili coast, and ethnoarchaeological research, in particular, examines the role of household activities. One of the persistent challenges in understanding the cooking and consumption of daily foods is that ethnoarchaeological research targets plant and animal-based industries separately. In contrast, an emphasis on the combination of varied ingredients through culinary practice provides a more comprehensive view of how different food procurement spheres are interconnected.

3. Diet and economy at Songo Mnara, Tanzania

In the following sections, we present multiple archaeological data sets that individually reveal various aspects of subsistence and diet but that combined with lipid residue analysis provide a more nuanced picture of daily culinary practices at Songo Mnara.

3.1. Faunal record

Zooarchaeological analysis was conducted on the fish and nonhuman tetrapod (i.e., mammal, bird, reptile) remains recovered from varied contexts across Songo Mnara. Fish dominate the faunal assemblage: despite their small size, they are more than half the total weight of remains recovered during four field seasons in 2009, 2011, 2013, and 2016 (51% of ~ 25 kg). From these field seasons a total of 22,323 fish specimens were identified (Number of Identified Specimens, NISP) representing at least 7555 individuals (Minimum Number of Individuals, MNI) (Supplementary Table 2). Remains of tetrapods were identified from three field seasons (2011–2016) and while far less numerous than fish (1417 NISP, 190 MNI), they also form an important part of the Songo Mnara economy (Supplementary Table 4). Mollusks were recovered but have not been analyzed.

There is important variation in sample sizes across different parts of the site, reflecting the intensity of excavations as well as the richness of faunal remains in domestic, private contexts (Fig. 2, Supplementary Table 1). More than half of tetrapod remains (57% by weight, 63% by NISP) were recovered in stone houses, and a smaller number (20% by weight, 14% by NISP) in daub structures. Relatively few came from more public contexts associated with the mosque, burials, or open areas. Fish remains followed a similar distribution pattern, with most fish remains recovered from stone houses (62% by weight and NISP) and middens (24% by weight, 26% by NISP), fewer fish remains recovered from daub structures (7% by weight and NSIP), and small numbers from other areas.

Bone cortical preservation is excellent, with good visibility that enabled taphonomic analysis (Supplementary Tables 3 and 5). Preservation varies across the site; remains from stone houses are in pristine condition, while those recovered in association with the daub structures, mosque, and burials are less well-preserved, with many bones exhibiting root or insect damage. There are clear signatures of food preparation: 8% of tetrapod NISP (excluding teeth and microfaunal remains) are burnt, and 9% cut-marked, with higher cut-mark rates (11%) in both stone and daub structures. Mark locations suggest culinary preparation activities: disarticulation, evisceration, and defleshing. Evidence of burning is visible on 6% of fish NISP overall, with higher rates of burned fish bones in daub structures (16%) than stone houses (5%). Fish remains exhibited low rates of cut marks overall (1% NISP).

The identified fish remains recovered from Songo Mnara are composed primarily of bony fish and a small number of cartilaginous

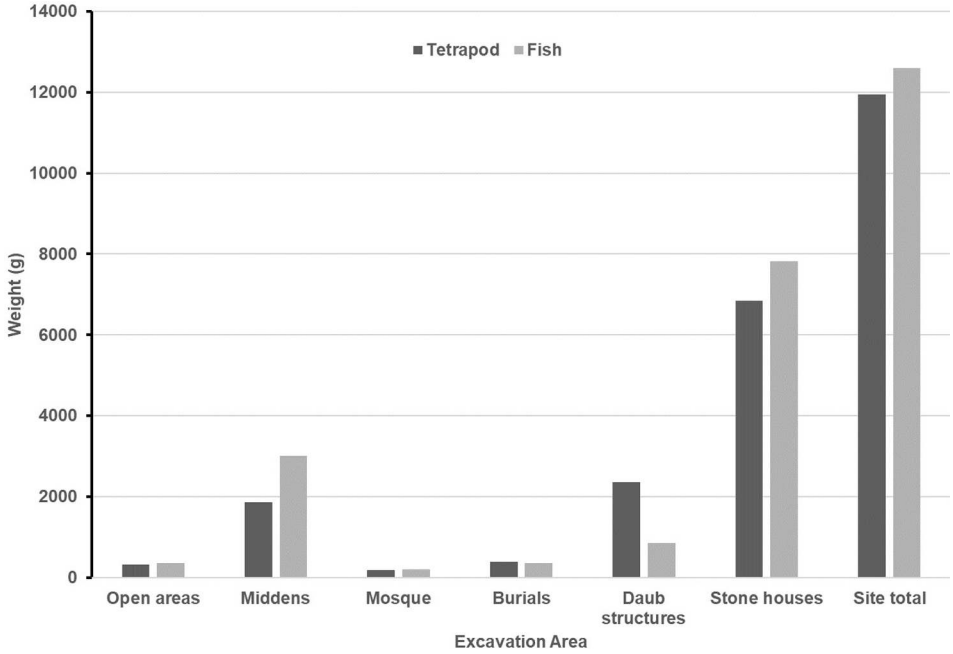

Fig. 2. Comparison of tetrapod and fish remains mass (g) across space at Songo Mnara (2009–2016 excavations).

fish, including sharks and rays (Fig. 3; Supplementary Table 2). A large portion (42% by NISP) of the bony fish assemblage is composed of three families (emperors, wolf herrings, and jacks) generally including inshore, predatory fish that feed on small fish and invertebrates. Overall, the pattern of identified fish points to a diverse fishery based on the inshore habitats found around Songo Mnara, exploiting both the protected shallow waters facing the mainland, the fringing reefs, and to a lesser extent the open sea.

Tetrapod fauna include birds and both terrestrial and marine mammals and reptiles, though overwhelmingly most remains come from domestic or commensal fauna (Fig. 4; Supplementary Table 4). The assemblage is dominated by livestock and especially caprines (sheep and goat) (NISP 180, MNI 38); by contrast cattle are comparatively rare (NISP 30, MNI 9). Fowl are the next most common group (NISP 136, MNI 34), including domestic chicken, guinea fowl, and unidentified members of the same order (Galliformes). Cut marks are commonly found on livestock and fowl. Wild bovids (NISP 22, MNI 7) are surprisingly diverse, ranging in size from dwarf antelopes to bushbuck to

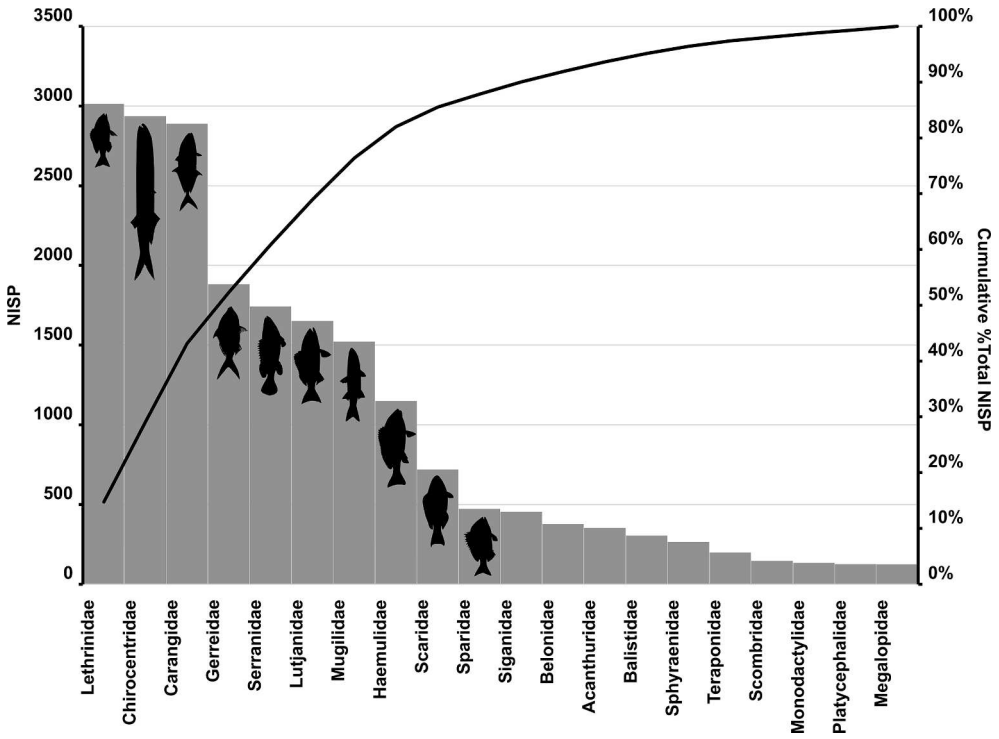

Fig. 3. Relative abundance of the top 20 bony fish families at Songo Mnara (2009–2016 excavations), using the Number of Identified Specimens (NISP). Right-hand axis and line indicate the cumulative frequency of each group.

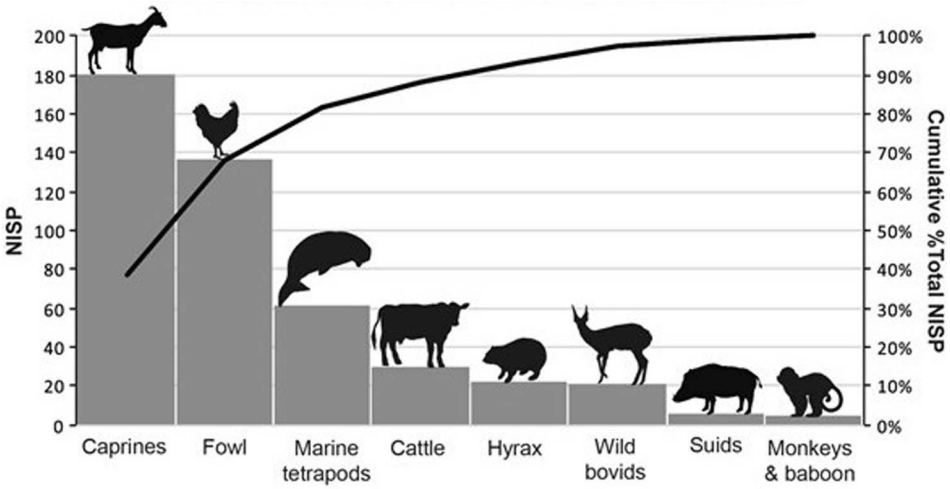

Fig. 4. Relative abundance of potential dietary taxa among tetrapods at Songo Mnara, using Number of Identified Specimens (NISP). Right-hand axis and line indicate the cumulative frequency of each group. Microfauna such as black rats and other commensal animals (domestic cats) are not considered potential dietary taxa.

eland; these game, however, are represented by few specimens per individual, suggesting they were not a critical component of diet and may, in some cases, have been transported to the site as isolated parts. Marine mammals and reptiles (NISP 62, MNI 12), including dugong and an unspecified sea turtle, are relatively more abundant than other wild game, and are frequently cut-marked, attesting to processing for meat or secondary products such as oil. Other taxa present on site include hyrax (NISP 23, MNI 10), monkeys and baboon (NISP 5, MNI 3), and unidentified suid (NISP 6, MNI 3); while these wild fauna could well have formed part of the diet, none of these remains are cut-marked, except one hyrax-sized bone. Additionally, commensal animals such as murid rodents (NISP 303, MNI 28) and domestic cat (NISP 34, MNI 7) are common at Songo Mnara but are not considered here as dietary taxa.

Out of 25 caprine specimens (MNI 15) that could be distinguished between sheep and goat, 22 (MNI 13) were identified as goat, a finding with implications for the other analyses presented in this study. Goats can feed on a wide range of plants and especially browse on C_3 plants, while sheep have higher water requirements and preferentially graze on C_4 grasses. These differences are reflected isotopically, as sheep tend to be enriched in ^{13}C relative to goats (Balasse & Ambrose, 2005; Prendergast et al., 2019). Similarly, cattle have more specific graze and water requirements than goats and are more vulnerable to disease (Gifford-Gonzalez, 2000). These advantages might help explain goats' abundance at Songo Mnara; however, mortality patterns are also key to understanding whether goats were simply more abundant among slaughtered animals.

While livestock remains are abundant, they are highly fragmented, and the skeletal portions diagnostic of an individual's sex and age-at-death were rarely preserved. When possible, specimens were assigned to broad categories (infantile, juvenile, adult, aged), based upon bone size, texture, and epiphyseal fusion; or more rarely, upon tooth eruption and wear. Narrower categories would only be possible if multiple specimens could be attributed to the same individual. An abundance of unfused postcranial elements indicates that subadults (infantile and juvenile) were common among both caprines (58% of individuals) and to a lesser extent cattle (44% of individuals). We stress that more precision might be possible—including differentiation of prime-age and older adults—if teeth were better preserved. No sex attribution was possible for any specimens. These gaps in the Songo Mnara faunal record preclude analysis of sex-specific age-at-slaughter patterns that might be indicative of milk or meat production, although there are hints that suggest cattle may have been kept alive longer than caprines, on average.

3.2. Botanical record

Macrobotanical remains of carbonized nutshell, fruitstones, seeds, and chaff at Songo Mnara suggest that inhabitants had access to both C_4 and C_3 plants (Supplementary Table 6). C_4 plant foods are represented by domesticated pearl millet, sorghum, and finger millet, all of African origin. A wide variety of C_3 food plants are found, including legumes such as cowpea, lablab, mung bean and other pulses. Other C_3 plants found at Songo Mnara include baobab, cotton, and the jujube fruit. Asian rice and coconut are two examples of C_3 plants that were probably adopted through Indian Ocean trade.

The spatial patterning of botanical remains indicates plant use practices within and between structures at Songo Mnara. Many rooms within a household yielded very few botanical residues, suggesting that floor surfaces were swept clean. Food processing, eating, and discard may have occurred in select rooms or areas in and around households. Macrobotanical and phytolith data show that in many cases routine processing ahead of cooking took place adjacent to or behind the main work/life area of a structure (McParland & Walshaw, 2015).

People who cooked and ate in daub structures seemed to have access to the same suite of plant foods as did those who inhabited stone houses, but certain households may have participated in different culinary practices. Differences exist in density of botanical remains (for example, rice grains are five times more numerous in stone households compared with daub structures) yet only around half of daub structures (50%) and stone households (57%) produced evidence for rice. Stone Houses 44 and 18 demonstrate the highest frequency of rice remains, and richer botanical assemblages overall, suggesting that foodways in these houses were potentially differentiated from the rest of the town.

4. Dietary reconstruction through human and faunal stable isotope analysis

Carbon and nitrogen stable isotope analysis of collagen extracted from human bones provides a powerful approach for directly assessing an individual average diet over a period from adolescence to death (Hedges et al., 2007). To provide a baseline for our human stable isotope and lipid residue analyses, stable isotope analysis was carried out on collagen extracted from caprines (n = 12), chickens (n = 10), cattle (n = 7), and marine fish (n = 16) as well as a range of modern and archaeological botanical remains, including sorghum, pearl millet and rice. While the caprines sampled for stable isotope analysis were undifferentiated, based on the morphological attributions described above we

infer the majority are likely goats. The results demonstrate that cattle and chicken ate more C_4 plants compared to caprines, with significant differences among the $\delta^{13}C$ values of caprines, cattle, chicken, and fish (Kruskal-Wallis, $H = 22.247$, $p < 0.001$; Fig. 5; Supplementary Table 7).

Fourteen human skeletons were excavated at Songo Mnara, from a range of locations including prominent tombs in the center of the town as well as graves outside the town walls. Excavation and sampling of these human remains was developed with and approved by members of the local community. Collagen was extracted and analyzed from the phalanges of seven human adults buried at the site (Supplementary Table 7). The resulting stable isotope values were tightly clustered ($\delta^{13}C$ = -9.0 ± 1.0‰; $\delta^{15}N$ = 11 ± 0.8‰) and showed no variation that correlated with sex or age-at-death of the individual. To estimate the proportion that each food source contributed to human diet a concentration dependent mixing model (Fernandes et al., 2014) was used with two different assumptions regarding diet-collagen enrichment (Model A and B, see Supplementary Text 1). The models were applied to the Songo Mnara individuals' mean and standard deviation to provide a crude estimation of diet across the group (Fig. 6).

Model A shows that C_4 plants and to a lesser extent cattle/chickens were likely to have made the greatest contribution by weight to diet. Here, the fish contribution to diet is lower than expected given the amount of fish bone recovered from the site. Shellfish has not been included as a separate source but could have been of greater dietary importance than fish as these animals generally have lower ^{15}N values (Yoshida et al., 2013). A much greater degree of equifinality in the dietary predictions is achieved assuming a lower diet-collagen enrichment (Model B). Here, nearly all the foods considered may have made a substantial contribution (i.e., ca. 20% by weight) although cattle/chicken and C_4 plants are still predicted to be of greater dietary significance. The dietary importance of cattle is perhaps greater than expected considering these were only a minor part of the faunal assemblage, providing the first hints that they might have been exploited for their milk. Both models highlight the major importance of plant foods to diet; C_4 plants (millets and sorghums) in particular may have been an important staple food to the inhabitants of Songo Mnara, as independently attested by the archaeobotanical evidence.

5. Investigating cuisine through organic residue analysis of pottery

Overall, the faunal and botanical records provide a picture of a society with a diverse subsistence strategy, heavily but not exclusively dependent on domesticated and marine resources. The human bone isotope data also point to a diverse diet but with a dominance of cattle/chicken and C_4 crops. While these data indicate subsistence strategies and diet, functional analyses of material culture can reveal cuisine and consumption practices. To this end, we applied molecular and isotopic analysis to lipid residues in locally produced ceramics. Ninety sherds of locally made pottery were selected from household middens from across Songo Mnara for lipid residue analysis. We considered the form, decoration, and fabric of selected sherds to avoid multiple sampling of the same vessel and to provide a representative sample of pottery types. Lipid extracts were obtained and analyzed by gas chromatography mass spectrometry (GC–MS) and GC combustion isotope ratio MS (GC-C-IRMS) using standard protocols (Craig et al., 2013). Full details of the extraction and analytical methods are described in Supplementary Text 1.

Of the 90 sherds analyzed by GC–MS, the majority contained

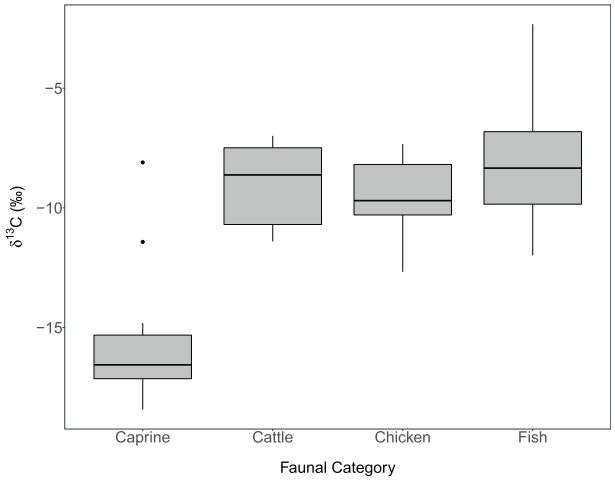

Fig. 5. Comparison of the distribution of $\delta^{13}C$ values of the principal food-providing animals found at Songo Mnara. Data available in Supplementary Table 7.

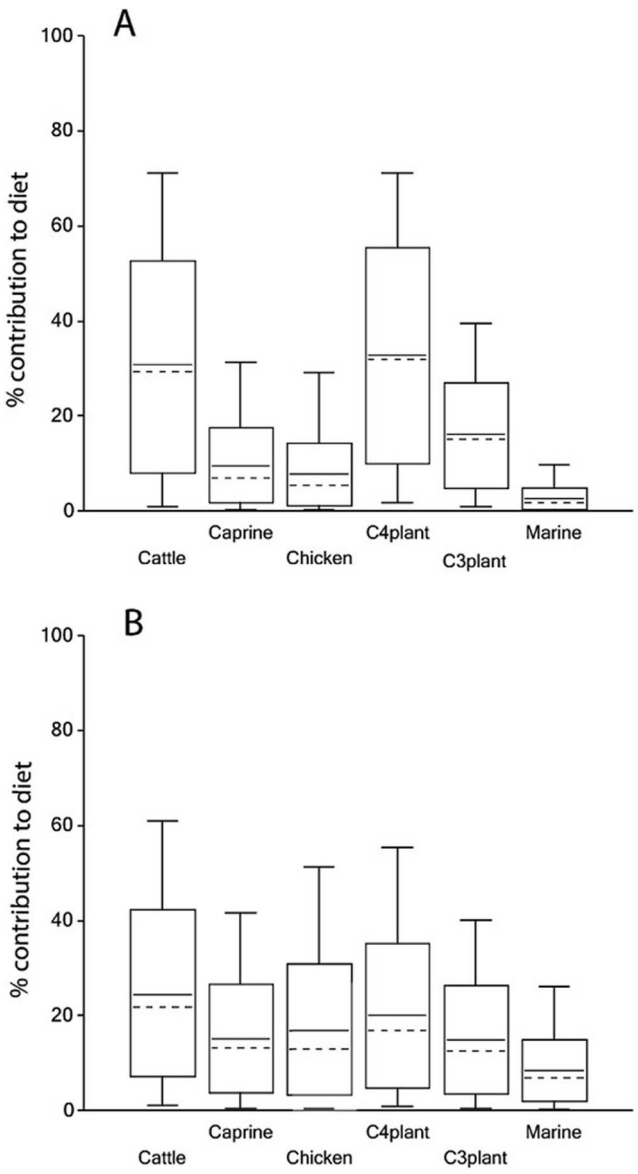

Fig. 6. Estimated contribution of foodstuffs to human diet at Songo Mnara using a Bayesian mixing model. Model **A** assumes a $\delta^{15}N_{diet\text{-}collagen}$ value of 5.5 ± 0.5‰; Model **B** assumes a $\delta^{15}N_{diet\text{-}collagen}$ value of 2.8 ± 0.5‰. The estimations (Y-axis) show the % dry weight contribution to diet. Boxes represent a 68% credible interval while the whiskers represent a 95% credible interval. The horizontal continuous line represents the estimated mean while the horizontal dashed line represents the estimated median.

interpretable amounts of lipids (90% >5μg g^{-1}). Overall, the lipid profiles were dominated by fatty acids of mid-carbon chain length ($C_{16:0}$, $C_{18:0}$). In most cases, the relatively high abundance of $C_{18:0}$ is indicative of degraded animal fats (e.g., Regert, 2011). Sixty-three samples (Supplementary Table 8) were selected for analysis by GC-C-IRMS to determine the $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids individually. Isotopic signatures are passed down the food chain from the plants to the animals that consume these plants, onto their secondary products, and ultimately, to the fats and oils absorbed into the clay fabric of the pottery. Carbon isotope values and the offset between $C_{16:0}$ and $C_{18:0}$ ($\Delta^{13}C$) have been widely used to distinguish among lipid sources, such as non-ruminant, ruminant adipose, marine, and ruminant milk fats (Copley et al., 2003; Dunne et al., 2012; 2018). Compound specific isotope analysis has also been used to distinguish plants with different photosynthetic pathways (C_3 vs. C_4), as the latter are relatively enriched in ^{13}C. This approach has been useful for the identification of millet (Heron et al., 2016) and maize (Reber et al., 2004) in prehistoric potsherds. However, the application of GC-C-IRMS to regions where C_4 and C_3 plants were variously exploited, as in this case, potentially both as an animal fodder and for direct consumption, presents a challenge, since lipids from isotopically distinct food sources create a wide range of $\delta^{13}C$ values when mixed at different concentrations (see Hendy et al., 2018).

5.1. Marine foods

The presence of marine animals (fish, shellfish, reptiles and mammals) indicates marine fauna were an important part of the diet at Songo Mnara, and if processed in pottery would be expected to leave lipid residues enriched in ^{13}C. Samples with a $\Delta^{13}C$ values between −1 and 1 ‰ and with $\delta^{13}C_{16:0}$ values of >−25‰ (Fig. 7) may indeed have been used for processing such products, although oils and fats from C_4 plants and/or C_4-fed animals (chicken and cattle) present alternative explanations. To investigate further, 77 samples were analyzed using GCMS in selective ion monitoring (SIM) mode to increase the sensitivity for the identification of biomarkers associated with aquatic oils (Copley et al. 2004). At this more sensitive level, nine samples (Supplementary Table 6) contained isoprenoid fatty acids and C_{18}, C_{20} and occasionally trace amounts of the C_{22} w-(o-alkylphenyl) alkanoic acids (APAAs) which are formed by heating of the polyunsaturated fatty acids present in aquatic oils. Notably the precursor fatty acids that produce the C_{20} and C_{22} APAAs through heating are at very low abundance in plant or terrestrial animal tissues (Bondetti et al., 2021). All the vessels with traces of APAAs contained $C_{16:0}$ and $C_{18:0}$ fatty acids relatively enriched in ^{13}C suggesting that, in these cases at least, tissues from marine organisms had been processed. Interestingly, most of these samples (5/7) were of a particular ceramic type called Wealed Ware, mostly necked jars with raised-ridge decoration on the vessel shoulder known from the 15th century at this site and at neighboring Kilwa (Chittick, 1974, pp. 327–28; see discussion below).

5.2. Meat and milk products

A portion of the $\Delta^{13}C$ values (38%) fall within the range of ruminant adipose lipids (−1 to −3.3‰), while 16% of the values are within the ranges of ruminant milk fats (<−3.3‰) and 46% fall within the range of non-ruminant fats (>−1‰), established from the analysis of modern authentic references (Fig. 7; Copley et al., 2003; Craig et al., 2012; Dunne et al., 2012). These results provide direct evidence of ruminant milk use, either as raw milk or processed into ghee, yoghurt, or cheese.

There is a negative correlation between $\Delta^{13}C$ and $\delta^{13}C_{16:0}$ values, which suggests that ruminant products were enriched in ^{13}C in this region through the consumption of wild C_4 plants or C_4 fodder, such as millet or sorghum. Because collagen isotope analysis showed cattle remains were enriched in ^{13}C compared to caprines, it is more likely that the ruminant fats present in the pots were derived from cattle than caprine products. This may seem surprising given the dominance of goats in the Songo Mnara faunal assemblage. One explanation is that ^{13}C-enriched values were derived from cattle milk products, a finding also supported by the stable isotopic analysis of human remains, which showed, based on modeling of the results, a higher contribution of cattle products to diet than predicted from faunal remains. Milk would require the use of containers for liquid manipulation. Heating of milk in ceramic vessels could also have been part of the production of fermented milk products or ghee.

Overall, mixing of C_3 plant resources, such as rice or coconut, with cattle dairy products, with cattle and fowl meat, fat, or within-bone nutrients, and with marine products, is sufficient to explain most of the data. We did not observe a clear pattern of plant-dominated lipid

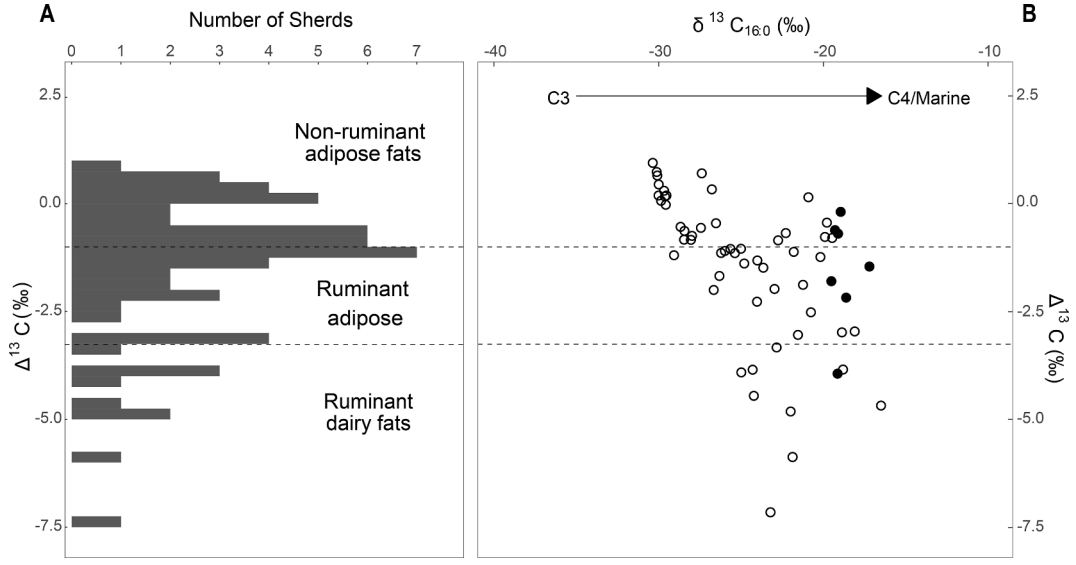

Fig. 7. A) The distribution of $\Delta^{13}C$ ($\delta^{13}C_{18:0}$ - $\delta^{13}C_{16:0}$) values obtained from Songo Mnara sherds. These are used to distinguish between non-ruminant, ruminant adipose, and ruminant dairy fats. Values were binned into equal intervals of 0.25‰. The ranges represent the mean ± 1 s.d. of the $\Delta^{13}C$ values for a global database of modern reference animal fats from Africa (Dunne et al., 2012), UK (animals raised on a pure C3 diet) (Dudd & Evershed, 1998), Kazakhstan (Outram et al., 2009), Switzerland (Spangenberg et al., 2006) and the Near East (Gregg et al., 2009). B) Plot of $\Delta^{13}C$ against $\delta^{13}C_{16:0}$ values from Songo Mnara sherds. Filled circles indicate sherds with lipids containing marine biomarkers.

residues in any of the analyzed sherds, which would be characterized by high amounts of the $C_{16:0}$ fatty acid relative to $C_{18:0}$ (typically >4 times). Therefore, it is likely that plant and animal products were regularly mixed, either together or through sequential pottery use.

6. Discussion

The combination of ceramic residue analysis with zooarchaeological, archaeobotanical, and human and faunal isotopic data sets a new benchmark for exploring culinary practices in a 14th-16th century African context, documenting not only the components of Swahili subsistence and diet, but their complex combinations in prepared foods. This approach reveals aspects of past coastal residents' taste, class, and culture embedded in everyday food practices. Elements of taste, or culinary preferences, are evident in the choices people made about which foods to eat and how to combine them, which impacted how these plants and animals were managed. The treatment of different foodstuffs in particular contexts and in association with certain types of pottery points to class-based food practices. We begin to see the outlines of past dishes encapsulating the social values and identity of coastal residents through daily practices involved in selecting, combining, and transforming local and exotic ingredients. Similarly to the way a variety of dishes, including meat and vegetable stews, pickled relishes, pilau—a spiced rice with added vegetables and meat—and coconut rice, characterize the Swahili coast cuisine today, cuisine can also be a powerful tool to understand past social practices within the quotidian, household sphere of precolonial Swahili town residents.

How foodstuffs were combined into dishes is difficult to discern through single lines of archaeological data. The outlines of Songo Mnara's urban cuisine come into focus through the informative contrasts between zooarchaeological, stable isotopic, and lipid residue results. The data presented here show that the town's inhabitants used a wide range of wild and domesticated food resources in their daily meals. Faunal assemblages are dominated by fish remains, followed by caprines (mainly goats), fowl, marine tetrapods, and cattle; botanical assemblages include C_3 and C_4 domesticates (pearl and finger millet, sorghum, Asian rice) and wild plants. We estimated the contribution of major food sources to human diet based on human bone collagen isotope data from seven individuals buried at the site. Results indicated a mixed diet with greater dietary significance of C_4 plants and cattle/chickens than marine fish, a pattern supported by the high frequencies of C_4 plant remains but contrasted by the high abundance of fish remains and comparatively low numbers of cattle bones at the site. Pottery lipid residue analysis also points to a diverse cuisine consisting of C3 plants, milk or milk products, and meats processed in locally made ceramic cookware. A wide range of ingredients were potentially cooked in pots during different episodes but also, undoubtedly, together to create complex dishes, not unlike the stews and pilau eaten today on the Swahili coast. We found no evidence for preferential access to different foodstuffs by age or sex, though we caution that the sample size is small and that this approach lacks the precision to identify subtle changes in diet. This finding contrasts with ethnographies attesting to gender- and age-based divisions of labor in food acquisition and preparation in coastal societies today (Msemwa, 1994; Quintana Morales, 2013; Walshaw, 2015), pointing to a future avenue of research exploring differences in production and consumption across social groups using multiple lines of evidence.

Historical sources describe cattle and goat/sheep herding and mention animal-based foods, including meat and ghee, but do not provide a clear picture of how frequently and in what ways these animals contributed to daily foods (e.g., Casson, 1989; Freeman-Grenville, 1962; Hamdun & King, 1998). By comparing zooarchaeological and lipid residue data, we can better envisage economic strategies and culinary practices at Songo Mnara. Zooarchaeological data indicate that caprines and especially goats were frequently slaughtered for meat, but lipid residues derived from ruminant animals fed C_3 plant diets, corresponding to goats in this context, were rarely encountered in pottery, suggesting they were processed in other ways. Indeed, roasting meat (*nyama choma*) is a popular preparation technique for goats in eastern Africa today and one supported by relatively intact, frequently burnt caprine bones at Songo Mnara. Ceramic vessels were more commonly used for milk or milk products, most likely from cattle, and zooarchaeological data suggest few cattle were slaughtered, although human bone collagen isotope data suggest cattle may have been an important component of human diet. This is consistent with ethnographic data on pastoralist herd management, which indicate that small stock like caprines—whose numbers grow at about three times the rate of large stock like cattle—are more likely to be eaten regularly, while expensive large stock are slaughtered on special occasions (Dahl & Hjort, 1976). The low frequency of cattle remains at Songo Mnara might also be explained if these large stock were largely maintained off-site—perhaps in an area with access to quality graze—and milk was transported to the site for culinary preparation and consumption, with the few cattle bones onsite corresponding to occasional slaughter for meat. Movement of cattle, cow's milk, or milk derivatives such as ghee over longer distances is another question that could potentially be explored through future research.

Documentary sources describe the values assigned to certain foods, such as the use of beef as a feasting food and fish as a daily staple (e.g., Casson, 1989; Freeman-Grenville, 1962; Hamdun & King, 1998). The lipid residues allow us to examine more closely cultural choices about cuisine and to explore the ways foodstuffs were accessed across a Swahili town. The mean $\delta^{13}C$ values of lipid residues were significantly different between Wealed Wares and other pottery types (Kruskal-Wallis Test, $H = 14.201$, $p < 0.003$). Wealed wares had fatty acids enriched in ^{13}C compared to other vessels, and 5 of the 7 vessels with molecular markers for marine foods were also Wealed Wares (Fig. 8). These pots thus seem to have a special role, linked to the spaces in stone houses and to ^{13}C-enriched foods, notably fish. All but two of the 13 Wealed Wares that were sampled came from stone houses; an alternative explanation is that fish and potentially other sources of ^{13}C-enriched foods, such as cow's milk and meat, sorghum, or millet, were preferentially prepared and consumed in stone houses. The ratio of fish to tetrapod remains was also higher in stone house contexts (Fig. 2), fitting with this culinary preference. Although the dominant narrative associated with feasting on the Swahili coast involves consuming beef, zooarchaeological evidence from the 14th-15th-century Swahili town of Vumba in southern Kenya indicated that fish were the primary food served at feasting events (Wynne-Jones, 2010, p. 426). The zooarchaeological data combined with lipid residues demonstrate that the majority of Songo Mnara residents ate fish regularly but that they may have assigned special value to fish in some contexts by processing/consuming fish in highly decorated Wealed Ware vessels.

Further insight into cuisine comes from a comparison of our results across vessel decoration types. The ceramics associated with milk products are mostly undecorated (Fig. 8), indicating that they were not associated with a specific vessel type (unlike fish and Wealed Ware), but rather were part of the repertoire of functional ceramics at the site; their distribution across both stone and daub structures supports this. This finding gives the consumption of milk products a mundane aspect, as compared to the spaces and vessels reserved for certain types of fish consumption.

Finally, the emerging culinary picture from Songo Mnara must be examined in light of the community's African and Islamic traditions. As at other Swahili coast sites (Quintana Morales & Prendergast, 2017, Prendergast et al., 2017) and even in the region today (Walsh, 2007), consumption and/or processing of *haram* animals—those whose consumption is forbidden in Islamic law, such as dugong, sea turtle, and possibly suid and monkey—is evident at Songo Mnara. The presence of these foods suggests that at least some people at Songo Mnara were practicing faith traditions outside of orthodox Islam and indicate local decisions in adopting Indian Ocean World foods and values. Although archaeological evidence of shellfish consumption, which is prohibited in

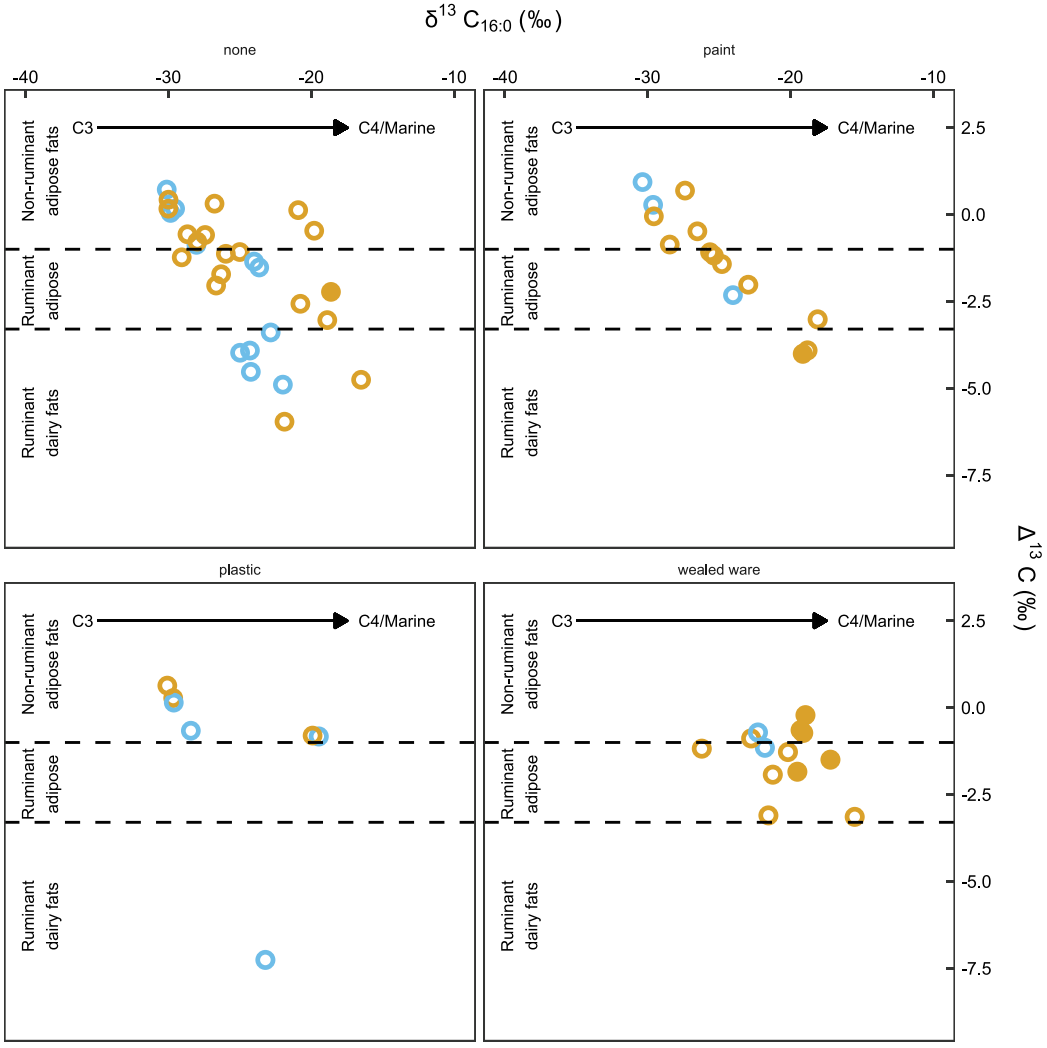

Fig. 8. Plot of $\Delta^{13}C$ against and $\delta^{13}C_{16:0}$ values from Songo Mnara pottery by principal decoration types: a) undecorated, b) paint, c) plastic, d) wealed ware. Filled circles indicate sherds with lipids containing marine biomarkers; blue circles indicate sherds from daub structures, and orange circles indicate sherds from stone houses. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

some branches of Islam, has been documented along the Swahili coast, few detailed analyses of mollusk remains exist (Faulkner et al., 2018). Future analyses of mollusk remains from Songo Mnara can help elucidate the practices and spaces associated with shellfish consumption and how these intersect with other foods. A varied assortment of foods at Songo Mnara includes locally harvested wild plants and animals, alongside African crops and foods likely integrated to the diet through Indian Ocean trading networks such as coconut and rice. The complex nature of Swahili identity connected to urban, Islamic, and African contexts is perpetually reinforced through the combination of these foodstuffs into dishes.

Integrating multiple forms of data at Songo Mnara provides a series of insights into culinary practices and consumption. We see an emerging picture of the values and tastes underlying daily food practices that sets the stage for further research beyond subsistence and diet. Evidence for the keeping of cattle for milk throws beef consumption into relief as an occasional and potentially high-status event. The dominance of fish remains is well-known from Swahili sites, but here fish consumption is recast as a component of particular spaces and forms of food preparation and consumption associated with elite practice. This unprecedented combination of faunal and botanical remains, human and animal stable isotopes, and lipid residues is more than the sum of its parts. It provides for the first time a sense of Swahili priorities about food, the ways that foodstuffs like fish and rice were pursued and singled out against a broad background of subsistence. A multiproxy approach allows us to understand past coastal inhabitants as purposeful consumers with developed culinary practices, placing into context the ways they may have produced and consumed food as part of a set of local priorities and customs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declarations

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Authors' contributions: EMQM, JF, SWJ, and OEC contributed to the study conception and design. Material preparation, data collection and analysis for various datasets was performed as follows: ceramic lipid residue analysis by EMQM and OEC; stable isotope analysis by CC (human, botanical, faunal) and EMQM (faunal); zooarchaeology by MEP (tetrapods), EMQM (fish), and OM, EN, and VO; and archaeobotany by SW. EMQM, SWJ, OEC, MEP, SW, CC, and JF contributed to the first draft of the manuscript and edited or commented on subsequent versions of the manuscript. All authors read and approved the final manuscript.

Availability of data and material: All relevant data are provided in the manuscript or Electronic Supplementary Materials.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2022.101406.

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