

Mozambique Stone Age Landscape: A Decade of Archaeological Research

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Abstract

Since the publication of our 2016 review mapping the Stone Age of Mozambique (Gonçalves et al., 2016), Stone Age archaeological research in the country has intensified significantly. This paper presents a comprehensive analysis of 657 Stone Age sites, including 272 newly documented sites. The recent discoveries in a total of more than 400 sites, discovered primarily through systematic survey campaigns between 2010 and 2025, represent an important increase over the 250 sites known prior to 2010, fundamentally transforming our understanding of prehistoric occupation patterns in southeastern Africa. Our analysis examines altitudinal distribution, clustering, and regional settlement patterns across the Early Stone Age (ESA), Middle Stone Age (MSA), and Late Stone Age (LSA).

Analysis reveals significant elevation differences between chronological periods, with ESA sites at lowest elevations, MSA at highest, and LSA intermediate. Multicomponent sites occupy significantly lower elevations than sites with only MSA assemblages, suggesting persistent landscape advantages at low-elevation locations such as river floodplains and coastlines. The extended analysis demonstrates that 45.8% of all sites contain MSA evidence when multicomponent assemblages are included, revealing MSA as the dominant phase and indicating maximum territorial expansion during this period. Clustering patterns intensify progressively from ESA (60% highly clustered) through MSA (76%) to LSA (81%), suggesting evolution from extensive mobility to intensive landscape use.

Provincial analysis reveals four distinct settlement zones: Maputo, Niassa, and Gaza Provinces are dominated by MSA occupations, while the Sofala Province is dominated by LSA coastal plain occupation. Also relevant are the very common multiple component sites in the Maputo province. These findings show that survey results, including mainly open-air sites, are (1) an important source of information to better understand the Stone Age, (2) significantly enhance our understanding of prehistoric human behavioral variability in Mozambique and southeastern Africa, and (3) provide crucial data for testing hypotheses about the emergence and dispersal of early *Homo sapiens*.

1. Introduction

In 2016, we published a comprehensive review of Stone Age archaeological sites in Mozambique, documenting over 300 sites dating to the Stone Age spanning from the colonial-era surveys of Santos Júnior between 1936–1956 (Santos Júnior, 1937, 1950) through the early 21st century work of Mercader (e.g., Mercader, Asmerom, et al., 2009; Mercader, Bennett, et al., 2009; Mercader et al., 2013; Mercader et al., 2012) and our own initial work in Mozambique (Gonçalves et al., 2016). That synthesis revealed Mozambique's critical position for understanding human evolution in southeastern Africa yet also highlighted significant research gaps. At the time, most known sites lacked precise chronological control, excavation data, or systematic spatial analysis. The subsequent decade has witnessed an unprecedented expansion of archaeological research in Mozambique, driven by a modest number of new field projects, enhanced survey methodologies, and growing recognition of the country's potential to address key questions about the origins and dispersal of anatomically modern humans.

Mozambique occupies a strategically significant geographical position for informing on debates about modern human origins and dispersal. The country has a tropical to subtropical climate, with a distinct wet-dry seasonality that influences resource availability and likely shaped past settlement patterns. Positioned along the southeastern African coast between latitudes 10° and 27° S, the country encompasses diverse ecological zones

from coastal plains to highland plateaus that commonly exceed 1,300 m elevation and reach over 2,400 m at Monte Binga. Its 2,500 km Indian Ocean coastline provides a potential corridor for early coastal migrations, while inland river valleys (Limpopo, Save, Zambezi, Lúrio) with extensive alluvial plains attracted human settlement throughout prehistory and offered resource-rich environments for hominin populations. Recent theoretical models emphasize the importance of coastal adaptations in the emergence of behavioral modernity (e.g., Marean, 2011; Marean, 2014), making Mozambique's coastal and near-coastal archaeological record particularly relevant to current debates.

This paper presents the first comprehensive locational analysis of all Stone Age sites for Mozambique, including both the previous known sites published by Gonçalves et al. (2016) as well as sites published in the last decade (discovered primarily between 2010 and 2025). These discoveries almost double the previously known archaeological record and provide unprecedented opportunities to examine settlement patterns, resource exploitation strategies, and environmental adaptations across the three major Stone Age phases: Early Stone Age (ESA, ~ 2.6 Ma-300 ka), Middle Stone Age (MSA, ~ 300 – 35 ka), and Late Stone Age (LSA, ~ 40 ka-2 ka). This paper also addresses the issue of settlement patterning through a comprehensive geographical analysis of Stone Age sites in Mozambique, employing both traditional single-phase categorization and an extended analysis that incorporates multiphase occupation sites.

Our analysis focuses on three key questions: (1) How do settlement patterns differ across chronological phases (ESA, MSA, LSA)? (2) What regional patterns emerge across Mozambique's diverse provinces? (3) How do these new discoveries modify our understanding of Stone Age occupation in southeastern Africa? By combining spatial analysis with chronological and typological data, we provide the first extensive characterization of prehistoric settlement strategies in this understudied yet critical region.

2. Methods

2.1 Data Collection and Site Documentation

The present study (Fig. 1) added a total of close to 300 new sites (Bicho, 2026) to the previous Gonçalves et al 2016 database, creating the new database available online (<https://doi.org/10.17605/OSF.IO/W3MEJ>). The new sites were documented through multiple research survey initiatives conducted between 2013 and 2025: the field work within two doctoral dissertation research projects, that of Marjanna Kohtamäki (Kohtamäki, 2014) and Decio Muianga (Muianga, 2025); our own surveys (NB and JH) since 2013 (e.g., Bicho, Cascalheira, André, et al., 2018; Bicho et al., 2016; Gonçalves et al., 2016) and tá's team within the much larger Carvalho's work in Gorongosa (Regala, 2024). The majority of new discoveries resulted from intensive systematic surveys in four primary regions: the Gaza and Maputo Provinces in southern Mozambique; the Save valley, incorporating both sites in the Sofala and Inhambane Provinces in central Mozambique; and the Niassa Province in northern Mozambique. Additional sites were recorded opportunistically during infrastructure development projects and heritage impact assessments.

The following variables were recorded for each site: geographic coordinates (latitude/longitude in WGS-84 datum), elevation above sea level, site type (open-air, rockshelter, cave, shell midden), chronological attribution based on lithic technology and typology, presence/absence of excavation, and bibliographic references. Site locations were verified using handheld GPS units or smart phones with high accuracy $\pm 3-10$ m (Cascalheira et al., 2017; Cascalheira et al., 2014) and cross-referenced with satellite imagery in Google Earth Pro. Cultural-

chronological attributions follow standard southern African nomenclature and were based primarily on diagnostic lithic artifacts, including, for example, Acheulean bifaces for ESA, prepared core technologies and blades for MSA, and microlithic assemblages for LSA.

For settlement analyses, we used exclusively the sites with geographic coordinates. These are 539 archaeological sites from Mozambique, of which 397 have specific chronological attributions. Sites were categorized using two analytical frameworks to examine phase distribution patterns: (1) a four-unit categorization distinguishing single phases (ESA, MSA, LSA) from multicomponent assemblages, and (2) an extended unit approach that captures all occurrences of each phase, including sites with multiple occupations. Stone Age sites without indication of the phase (i.e., without diagnostic artifacts) were not included in the analyses.

The four-unit categorization creates mutually exclusive categories: (1) ESA—sites with Earlier Stone Age evidence only; (2) MSA—sites with Middle Stone Age evidence only; (3) LSA—sites with Later Stone Age evidence only, excluding assemblages that also contain Iron Age materials; and (4) Multiple phases—sites with evidence from multiple Stone Age periods (e.g., ESA and MSA; MSA and LSA; all three phases) or sites that include post-Stone Age materials alongside LSA assemblages (e.g., LSA and Iron Age). This categorization preserves analytical clarity by distinguishing single-phase assemblages from complex, multi-period localities.

The logic behind this grouping recognizes that multicomponent sites, regardless of their specific phase combination, share a fundamental characteristic: they demonstrate repeated human use of particular landscape positions across substantial time spans. Whether a site contains ESA + MSA or MSA + LSA evidence, or whether LSA materials co-occur with Iron Age artifacts, these locations attracted multiple periods of occupation. Grouping all multicomponent assemblages together enables comparison of single-phase sites (which may represent short-term or specialized use) against persistently attractive locations. This framework provides a more comprehensive view of landscape use during each chronological period by including all archaeological manifestations, rather than only pure assemblages.

2.2 Geographical Variables

Three primary geographical variables form the core of the analysis. Elevation, derived directly from geographical coordinates at Google Earth, provides a proxy for environmental zone and ecological context. Terrain type, classified into plains/low relief, moderate hills, and hilly/mountainous categories, was calculated using terrain roughness—the standard deviation of elevation within a 5 km radius of each site. This metric captures local topographic variation, with low values (< 30 m SD) indicating plains and high values (> 70 m SD) indicating rugged terrain. Spatial clustering, quantified as the distance to the nearest neighboring site, reveals patterns of landscape use intensity, with shorter distances suggesting concentrated activity or repeated visits to favored locations.

Statistical analyses employed one-way ANOVA to test for overall differences between categories, followed by pairwise t-tests to identify specific contrasts. Significance was assessed at $\alpha = 0.05$. Descriptive statistics include means, medians, standard deviations, and interquartile ranges to characterize central tendency and dispersion in each category. Given the right-skewed distributions common in elevation and distance data, both mean and median values are reported to provide complete distributional information.

3. Results

Over 500 Stone Age sites are distributed across the Mozambique ten provinces, with concentration in Maputo (n = 254), Sofala (n = 144), Gaza (n = 118), and Niassa (n = 74) provinces (Table 1).

Open-air sites constitute the overwhelming majority (n = 512, 94.4%), with rockshelters (n = 16, 2.9%), caves (n = 12, 2.2%), and shell middens (n = 2, 0.4%) representing specialized site types in much lower frequencies. This distribution likely reflects both preservation biases (many rockshelters and some caves were located during survey, but the large majority had no sediment, partly due to guano harvesting, and partly due to natural geomorphological erosion) and prehistoric settlement preferences in this region's predominantly savanna and woodland environments.

Table 1
Site distribution by province.

Provinces	ESA	MSA	LSA	Stone Age	Multiple phase sites	Total
Cabo Delgado		1		3		4
Gaza	42	57	21	9	10	118
Inhambane	2	1	4	16	2	23
Manica	1	1	2	5		9
Maputo	92	145	126	26	122	254
Nampula	1	3	1	1	1	4
Niassa	1	35	19	28	11	74
Sofala	17	49	50	49	20	144
Tete	8	6	4	9	6	21
Zambézia			2	2		3
Total	164	298	229	148	172	654

If we look only at the locations with full geographical information (Table 2: n = 542 sites), then MSA locations (considering both single and multi-phase sites) are the most common (n = 245, 45.8%), followed by sites with LSA occupations (n = 196, 36.6%), and ESA sites (n = 94, 17.6%) Non-descriptive Stone Age sites account for 135 locations. Notably, multicomponent assemblages represent nearly one-quarter of all sites (n = 140, 25.8%), indicating that multi-phase sites are a significant feature of the archaeological landscape. These figures highlight the importance of considering mixed assemblages when assessing the archaeological record. The high proportion of these sites may reflect genuine patterns of recurrent occupation, suggesting this period witnessed maximum territorial expansion across the Mozambican landscape.

Table 2
Phase Distribution.

Phase Category	Count	Percentage (%)
ESA	94	36.6
MSA	245	45.8
LSA	196	17.6

Examination of the multiple-phase assemblages reveals diverse combinations of archaeological phases. The most common pattern is MSA-LSA co-occurrence, representing more than half of all multi-phase sites. The predominance of MSA-LSA combinations suggests these two periods are most frequently found together at the sites, which could indicate either genuine transitional occupations or preferential reoccupation of MSA localities during the LSA. A notable subset of multi-phase sites includes Iron Age materials alongside LSA components, indicating continuity of site use into more recent periods.

Multiple occupation sites may represent palimpsests resulting from recurrent occupation of favorable locations, particularly in contexts such as rockshelters or proximity to water sources. Alternatively, they may reflect post-depositional disturbance, or surface collection methodologies that aggregate materials from multiple periods, or that it is difficult to separate Stone Age phases based purely on lithic artifacts when diagnostic elements are lacking or are not clear across phases.

3.1 Elevation Patterning

Analysis of the four-unit categorization reveals statistically significant elevation differences between chronological categories (one-way ANOVA: $F = 4.43$, $p = 0.0045$). Single ESA occupation sites (Table 3) are located at the lowest elevations with a mean elevation of 135.5 m (median 102.0 m, SD 112.3 m, range 8-543 m). Single MSA locations show substantially higher mean elevation of 243.8 m (median 113.0 m, SD 302.3 m, range 0–1,388 m), representing nearly double the ESA mean. Single LSA sites fall intermediate at 188.2 m mean elevation (median 85.6 m, SD 251.1 m, range 8 – 1,608 m). Most strikingly, multicomponent sites occupy significantly lower elevations with a mean of 155.2 m (median 114.0 m, SD 149.7 m, range 8-720 m).

Pairwise comparisons show specific contrasts (Fig. 2). The ESA-MSA difference proves highly significant ($t = -2.532$, $p = 0.012$), confirming a fundamental shift toward higher elevation exploitation during the Middle Stone Age. The MSA-LSA comparison shows no significant difference ($t = 1.438$, $p = 0.152$), though means differ by 56 m, suggesting both periods utilized similar elevation ranges albeit with different emphases.

Table 3
Elevation statistics by chronological phase

Phase	Elev. Mean (m)	Elev. Range (m)	St.Dev.
ESA single	135.5	8-543	112.3
MSA single	243.8	0–1,388	302.3
LSA single	188.2	8 – 1,608 m	251.1
Multi-phase sites	155,2	8-720	149.7
ESA all sites	125.8		
MSA all sites	197.4		
LSA all sites	173.8		

Most revealing is the MSA versus multicomponent comparison ($t = 2.977$, $p = 0.0032$), demonstrating that pure MSA sites occupy significantly higher elevations than localities with evidence from multiple periods. This pattern suggests that multicomponent sites cluster in lowland positions offering persistent advantages, while single MSA assemblages extend into more diverse elevation zones including highlands that attracted less repeated occupation, and may represent specialized sites for exploiting natural resources, including raw materials.

Elevation patterns in the extended analysis partly mirror but also modify the four-unit results. All ESA sites show a mean elevation of 125.8 m (median 96.0 m), slightly lower than the single ESA group due to inclusion of low-elevation multicomponent sites. All-MSA sites, including the multicomponent locations, reveal a mean of 197.4 m (median 114.0 m), substantially lower than the single MSA component (243.8 m). All-LSA sites shows 173.8 m mean elevation (median 97.1 m), also lower than the single LSA group. Statistical testing confirms significant differences between phases (ANOVA: $F = 3.95$, $p = 0.020$), with ESA significantly lower than both MSA ($p = 0.006$) and LSA ($p = 0.036$). The extended analysis thus confirms the fundamental ESA pattern of low-elevation occupation while revealing that MSA and LSA both incorporated lower-elevation multicomponent sites alongside their higher-elevation pure assemblages, showing, thus, a much larger altitudinal range of occupation in those later Stone Age phases.

Provincial analysis reveals marked regional variation in chronological representation and elevation preferences. Maputo Province, containing 30.2% of all sites, shows particularly strong MSA and LSA representation (65.0% and 60.7% of provincial sites respectively, indicating substantial multicomponent presence), with consistently low elevations across all phases (ESA: 64.5 m, MSA: 102.8 m, LSA: 99.5 m). Gaza Province demonstrates contrasting patterns with strong ESA representation and MSA dominance (50.5%) but weak LSA (16.2%), suggesting possible abandonment or reduced use during the Later Stone Age. Niassa Province shows minimal ESA (1.4%) but substantial MSA (47.3%) with very high elevations (ESA: a single site at 576 m, MSA: mean elevation 704 m, LSA: mean elevation 608 m), indicating northern highlands were exploited primarily during the Middle Stone Age. These provincial differences illuminate regional settlement trajectories that deviate from the overall pan-Mozambican pattern, suggesting environmental or cultural factors that varied geographically across the Stone Age.

Long-term landscape denudation rates are unknown with any precision throughout the study area and have undoubtedly been varied in magnitude and distribution over the past 2 Ma. In tectonically quiescent southern Africa, long-term denudation rates may be approximated at ~ 2 cm/1000 yrs (Ritter et al., 2011). This would imply that LSA land surfaces may have been tens of centimeters higher than present surface elevations, whereas ESA land surfaces perhaps several meters higher than at present. Certainly, many artifacts recovered from surface contexts throughout the study area rest upon deflated land surfaces. But the magnitude of land-surface lowering and topographic deflation is minimal compared to the magnitude of elevation differences revealed through this analysis. Therefore, artifact distribution patterning by elevation represents real locational and behavioral patterns rather than any taphonomic bias.

3.2 Terrain Type Distribution and landscape use

Terrain type analysis reveals pronounced plains preference across all categories (Fig. 3 and Table 4) but with significant variation between phases. Single ESA occupations sites show the strongest plains focus with 98.1% in low-relief contexts and only 1.9% in moderate hills. Single MSA sites demonstrate the greatest terrain diversity, with 80.3% in plains, 15.7% in moderate hills, and 3.9% in hilly/mountainous terrain—the only chronological category with substantial representation in rugged landscapes. Single LSA sites return to strong plains preference (91.9% plains, 8.1% hills), intermediate between ESA and MSA. Multicomponent sites show 91.4% plains distribution, similar to LSA, with virtually no mountainous representation, reinforcing the pattern that repeatedly occupied locations cluster in favorable lowland terrain.

Table 4
Elevation and topographic settings

Phase	Total_sites	Elev.	Elev.	Elev.	Elev.	Elev.	Plains (n)	Hills (n)	Mountains (n)
		Mean	Median	SD	(Min.)	(Max.)			
		(m)	(m)	(m)					
ESA	93	125.8	96.0	115.6	8	576	90	3	0
MSA	252	197.4	114.0	240.5	0	1388	217	30	5
LSA	197	173.8	97.1	204.6	8	1608	179	17	1

The extended analysis, that is for each phase including both single and multicomponent sites, reveals similar patterns but with larger sample sizes strengthening the conclusions. ESA maintains 96.8% plains focus with minimal hill exploitation. MSA shows 86.1% plains, 11.9% moderate hills, and 2.0% mountains, confirming MSA as the most terrain-diverse phase even when multicomponent sites are included. LSA locations demonstrates a focus on the plains (90.9%). Chi-square testing confirms significant association between chronological period and terrain type ($\chi^2=28.4$, $df = 10$, $p = 0.002$), validating that different Stone Age phases exhibited distinct terrain preferences beyond what sampling variation alone would produce.

A similar pattern emerges from the distance to coast metric. ESA sites average 164.2 ± 34.0 km from the Indian Ocean, with all sites located inland rather than on the immediate coast. MSA populations extended significantly further inland (mean: 253.1 ± 162.7 km), including substantial occupation of the Niassa highlands over 500 km from the coast. LSA groups show intermediate distances (mean: 207.8 ± 141.1 km), though with several coastal shell midden sites indicating at least seasonal exploitation of marine resources.

The large standard deviations in MSA elevation and coastal distance reflect genuine diversity in settlement patterns rather than measurement error or chronological mixing. MSA sites occur across the full spectrum from low-elevation coastal settings (42 m elevation, 119 km from coast) to high-elevation interior plateaus (1,388 m elevation, 554 km from coast), documenting the successful adaptation of MSA populations to diverse ecological contexts.

The Niassa Province, a marked rough and hilly country, encompassing the southern terminus of the East African Rift Valley and the shores of Lake Malawi (Niassa), represents a distinct ecological zone that supported substantial MSA and some LSA populations. No ESA sites have been identified in Niassa, suggesting either that these highland environments were not occupied during the Acheulean or that ESA materials remain unrecognized in the predominantly quartz assemblages typical of the region (Bennett, 2011; Bicho, Cascalheira, Haws, et al., 2018; Bicho et al., 2016). The lack of ESA sites in Niassa exerts a strong influence over the statistical results reported above (Tables 3 and 4).

The Stone Age sites of Sofala Province exhibit the lowest mean elevation (76.4 m) and closest mean proximity to the coast, reflecting intensive occupation of the central Mozambique coastal plain and lower Save Valley. The chronological distribution shows LSA dominance, followed by MSA and ESA, suggesting either preferential preservation of later occupations or genuine intensification of settlement in this productive ecological zone during the late Pleistocene and Holocene. The relatively low ESA representation may reflect survey bias toward surface scatters, given the limited exposure of older (buried) fluvial and marine deposits on the coastal plain.

The Gaza Province shows the most balanced representation across all three phases, concentrated mostly inland in the Limpopo and Oliphant River valleys at moderate elevations (mean: 129.0 m). The ESA sites in inland Gaza include classic Acheulean assemblages with large cutting tools (LCTs) and are positioned on ancient river terraces, consistent with patterns observed across southern Africa. The strong MSA presence demonstrates the continued attractiveness of these riverine environments after the Acheulean, while LSA occupation confirms utilization through the terminal Pleistocene and Holocene.

The Maputo Province while marked by mostly MSA occupations, also has many multiphase sites. These tend to be inland, on small river terraces, that run east to the Indian Ocean. The foothills of the Lebombo mountains below 200 m seem to have been used during all three phases. Many sites are located around Changalane, as the result of intensive survey around the cave and shelters of Daimane.

3.3 Spatial Clustering Patterns

Spatial clustering analysis (Table 5), based on the linear distance from each site to its nearest neighbor, reveals progressive intensification from earlier to later periods. In the four-unit categorization (Fig. 4), single ESA sites show 60.4% highly clustered (within 1 km), indicating mixed patterns of dispersed and clustered settlement. Single phase MSA sites increase to 76.4% highly clustered, demonstrating emergence of concentrated landscape use. Single LSA sites reach 81.4% highly clustered, the highest proportion among single-phase categories, suggesting intensive occupation of favored locations. Multicomponent sites show 69.1% highly clustered, lower than single LSA locations but higher than single ESA, indicating these repeatedly occupied locations attracted visits but were not as intensively used as the most clustered LSA localities.

Table 5
Clustering results.

Phase	Total_sites	Mean distance (km)	Median distance (km)	Highly clustered (n)	Moderate cluster (n)	Dispersed (n)	Expected distance (km)	Nearest Neighbor Index
ESA	93	8.45	1.83	45	13	35	10.38	0.814
MSA	252	3.11	0.11	181	33	38	6.31	0.493
LSA	197	3.01	0.08	158	20	19	7.13	0.422

The analysis of the complete phases (Table 7) strengthens these clustering patterns through larger sample sizes. ESA shows 48.4% highly clustered with substantial dispersed component (37.6% >5 km apart), characterizing ESA settlement as relatively extensive. MSA increases to 71.8% highly clustered with median neighbor distance of only 0.11 km, revealing strong landscape concentration. LSA peaks at 80.2% highly clustered with median distance of 0.08 km—indicating sites often occur within 80 meters of each other, suggesting either seasonal reoccupation of precise localities or functionally related activity areas within broader settlement systems. This progressive clustering intensification from ESA through MSA to LSA suggests fundamental changes in mobility strategies, from extensive ranging to logistical organization to possible semi-sedentary occupation in optimal zones.

Table 7
Comparative statistics for four-unit categorization and extended unit analysis

Category	N Sites	Mean Elev. (m)	Median Elev. (m)	Plains (%)	Clustered (%)
ESA (single occupation sites)	53	135.5	102.0	98.1	60.4
ESA (all sites)	93	125.8	96.0	96.8	48.4
MSA (single occupation sites)	127	243.8	113.0	80.3	76.4
MSA (all sites)	252	197.4	114.0	86.1	71.8
LSA (single occupation sites)	86	188.2	85.6	91.9	81.4
LSA (all sites)	197	173.8	97.1	90.9	80.2
Multiple phases	139	155.2	114.0	91.4	69.1
<i>Note: Four-unit categories are mutually exclusive (ESA-only, MSA-only, LSA-only, Multiple phases). Extended categories are inclusive (all sites with evidence from each phase). Elevation in meters above sea level. Clustering percentage indicates sites within 1 km of nearest neighbor. Plains percentage indicates sites in plains/low relief terrain.</i>					

4. Discussion

4.1. Methodological Implications: Four-Unit vs Extended Analysis

Comparison of the single vs multiphase occupations reveals both convergence and divergence in interpretations. Both approaches confirm fundamental patterns: ESA occupation was concentrated at low elevations in plains contexts, MSA expanded into diverse elevations and terrain types, and LSA showed intensive clustering. However, the extended analysis including the multiphase sites substantially modifies our understanding of MSA importance—revealing it as the dominant phase affecting 47% of all sites rather than appearing comparable to ESA and LSA in site counts. This difference emerges because many multicomponent sites include MSA evidence, suggesting MSA represents a period of maximum territorial expansion across Mozambique.

The four-unit approach, by isolating single component assemblages, seems to indicate specific settlement characteristics of each phase uncontaminated by later reoccupation. Single phase MSA sites' high mean elevation (243.8 m) and terrain diversity indicate MSA populations explored varied landscapes including marginal

highlands. Single phase LSA sites' extreme clustering (81.4% within 1 km) suggests intensive use patterns possibly reflecting reduced mobility. The multicomponent category, grouping together repeatedly occupied locations, reveals these sites occupy significantly lower elevations than single phase assemblages, suggesting lowland positions offered persistent advantages—permanent water sources, raw material outcrops, or strategic positions—that attracted repeated occupation across vast time spans. The analytical choice between frameworks depends on research questions: the single-phase site approach clarifies phase-specific behaviors, while the extended analysis focuses on overall landscape use during each chronological period.

4.2. Settlement Strategy Evolution Across the Stone Age

The combined evidence suggests a nonlinear trajectory of settlement evolution from ESA through MSA to LSA. Earlier Stone Age populations practiced extensive foraging strategies focused on riverine lowlands, evident in low mean elevation (125.8–135.5 m), strong plains preference (96.8–98.1%), and mixed clustering/dispersal patterns (48.4–60.4% highly clustered). This pattern suggests high residential mobility with large foraging territories, consistent with Acheulean settlement patterns documented elsewhere in Africa. ESA technology—large bifacial tools requiring substantial raw material—may have constrained mobility or dictated settlement near stone sources in river valleys.

Middle Stone Age populations demonstrated ecological expansion into diverse environments, evidenced by increased mean elevation (197.4–243.8 m), terrain diversity (14–20% in hills/mountains, unique among Stone Age phases), and strong clustering (71.8–76.4% within 1 km). This pattern suggests a more logistical mobility strategy with central places and satellite camps, technological innovations enabling highland exploitation (prepared-core technologies producing portable cores and prepared blanks), and territorial knowledge evidenced by return visits to specific localities. The MSA, thus, represents maximum niche breadth, with populations exploiting varied elevation zones and terrain types while maintaining base camps in favored locations. The extended analysis, revealing MSA evidence at close to half of the sites, suggests this expansion was geographically extensive across the Mozambican landscape.

Later Stone Age populations show landscape intensification focusing on plains settings (90.9–91.9%) but with extreme clustering (80.2–81.4% within 1 km, median distances of 80 meters). This pattern suggests reduced residential mobility, intensive use of optimal lowland zones, and possible semi-sedentary occupation in resource-rich areas. LSA microlithic technology, at least in certain phases, allowing tool maintenance and curation, may have enabled more tethered settlement patterns by reducing the need for frequent moves to new raw material sources. The intermediate elevation position (173.8–188.2 m) suggests LSA populations selectively occupied proven locations rather than exploring the full elevation range exploited during MSA. This trajectory—from extensive ranging (ESA) through niche expansion (MSA) to intensive concentration (LSA)—reflects changing adaptations shaped by technology, demography, and social organization across hundreds of thousands of years.

4.3. Expansion of Settlement Range in the MSA

The most striking pattern emerging from our analysis is the dramatic expansion of occupied elevations and inland penetration during the MSA relative to the ESA. While ESA populations remained confined to low-elevation river valleys, MSA groups successfully colonized environments ranging from sea level to above 1,300 m, extending over 550 km inland to the Niassa highlands. This represents a fundamental shift in hominin adaptive capacity and ecological flexibility.

Several mechanisms may explain this MSA expansion. First, technological innovations associated with the MSA—particularly prepared core technologies (Levallois and related centripetal methods) allowing more efficient use of locally available raw materials—may have facilitated occupation of regions distant from high-quality lithic sources. The prevalence of quartz-based assemblages in Niassa highlands demonstrates successful adaptation to locally available, though suboptimal, raw materials. Second, the large increase in frequency of MSA over ESA sites suggests that demographic pressure may have driven territorial expansion. Third, environmental changes (such as increased aridity) may have pushed populations into previously marginal habitats. Finally, cognitive and social developments associated with the MSA may have enabled more complex logistical organization, allowing groups to exploit diverse and distant resources more effectively.

The high-elevation MSA occupation of Niassa Province deserves particular attention. Sites above 1,000 m elevation may represent adaptations to cooler temperatures, different vegetation communities, and distinct faunal assemblages compared to lowland settings. While absolute dating remains limited, Mercader's work at sites like Ngalue Cave documents MSA occupation in this region from at least ~ 150 ka (Mercader, Asmerom, et al., 2009; Mercader et al., 2008; Mercader et al., 2012) up to the LSA in Chicaza (Bicho, Cascalheira, Haws, et al., 2018). The successful occupation of these highland environments demonstrates the remarkable ecological flexibility of MSA populations and confirms that anatomically modern humans in southern Africa had already developed sophisticated adaptive strategies (e.g., Brooks et al., 2018; d'Errico et al., 2005; Henshilwood et al., 2001; Jerardino, 2016; Jerardino & Marean, 2010; Marean, 2014) well before their expansion beyond the continent.

4.4. Coastal Adaptations and the Coastal Route Hypothesis

Despite Mozambique's extensive Indian Ocean coastline and its potential significance for coastal migration routes (e.g., Bailey, 2004; Compton, 2011; Erlandson & Braje, 2015; Parkington, 2010; Stringer, 2000; Whitfield et al., 2025; Wood, 2019), our data document relatively limited Stone Age occupation of immediate coastal settings. Only two sites in our dataset are coastal shell middens, one in Cabo Delgado without any indication of phases, and one in the Maputo area with the three Stone Age phases. Mean distance to coast for all chronological phases exceeds 100 km, with ESA at 164 km, MSA at 253 km, and LSA at 208 km. There are, in fact, only 20 sites within 20 kms from the present coastline. The large majority are south of Maputo in the Boane area, related to the alluvial plain of the Tembe and the Umbeluzi Rivers, running to the Maputo Bay. Cabo Delgado, in the north, has 3 coastal sites while Nampula, Sofala, and Gaza have one site each. Seven out of 14 sites in the Maputo Bay area are multiphase locations, and the most common phase is ESA, followed by MSA.

Although there are a few sites in the coastal band, particularly in the Maputo Bay area, the pattern still seems to contrast with expectations from the 'coastal route hypothesis' for modern human dispersal, which posits that MSA populations exploited coastal resources and used shoreline corridors for long-distance movement (e.g., Marean, 2011; Marean et al., 2007). Several factors may contribute to the apparent paucity of coastal MSA sites in Mozambique. First, preservation bias is significant: sea-level changes during the late Pleistocene mean that much of the MSA coastline now lies underwater on the continental shelf, potentially obscuring a substantial coastal settlement record (Fisher et al., 2013; Fisher et al., 2010). Second, the Mozambican coast consists largely of sandy beaches and mangrove-fringed estuaries rather than the rocky headlands with wave-cut platforms and tidal pools that characterize the Cape coast of South Africa (Cawthra et al., 2018), potentially offering different (and perhaps less abundant) marine resources. Third, many of the coastal sections are covered by large

Holocene sand dunes, masking potential MSA sites. Finally, fourth, survey coverage of coastal regions remains incomplete, and targeted survey of relict beach deposits and barrier islands may yet reveal coastal MSA sites.

If the coastal record is systematically biased toward non-detection through sea-level change, geomorphological differences, and incomplete survey, then the absence of coastal MSA sites cannot be taken as evidence against coastal migration. The corollary is that the inland record cannot directly test the coastal route hypothesis either. What the inland data do demonstrate is that MSA populations had the ecological flexibility and technological capacity to exploit diverse environments well inland of any postulated coastal corridor, suggesting that inland routes through Mozambique's major river valleys were viable alternatives or complements to any coastal pathway. In any case, though not likely, this pattern may represent the prehistoric reality, and coastal adaptation was not that relevant during the MSA in Mozambique.

Nevertheless, the two documented shell middens and the sites in the Maputo Bay area, though limited in number, confirm that coastal resources were eventually incorporated into subsistence strategies, consistent with the broader southern African pattern of intensified marine exploitation that started in the MSA (Brooks et al., 2018; Jerardino & Marean, 2010; Klein & Bird, 2016; Marean, 2011; Marean, 2014; Will et al., 2019). The timing of this shift and whether it occurred gradually through the MSA in Mozambique or represents a more abrupt change remains to be determined through excavation and dating of stratified coastal sites.

4.5. Regional Patterns and Environmental Diversity

The marked differences in settlement patterns across provinces reflect both research history and genuine prehistoric adaptations to diverse environments. Niassa's distinctive high-elevation, inland occupation pattern represents successful colonization of rift valley settings with access to Lake Malawi (Niassa) and its associated resources. The lake provides permanent water, aquatic resources, and concentrations of terrestrial game, creating a productive mosaic landscape that attracted sustained human occupation. Mercader's excavations demonstrate exploitation of grass seeds, wild fruits, and other plant foods alongside game hunting, documenting a broad-spectrum MSA economy adapted to this highland environment (Mercader, Bennett, et al., 2009; Mercader et al., 2013; Mercader et al., 2008).

Gaza's concentration of ESA sites in the Limpopo and Elephant River valleys fits the classic pattern of Acheulean distribution along major watercourses in southern Africa. These river systems provided reliable water, diverse habitats in close proximity, and in addition to the local igneous rocks, fluvially transported lithic raw materials suitable for large tool manufacture. The substantial MSA occupation of Gaza suggests continuity in the attractiveness of these river valley settings through time, though with technological and likely behavioral changes reflected in the shift from Acheulean to MSA assemblages. Also, worthy of note, is the concentration of LSA locations in small tributaries running to the Oliphant river, where long LSA sequences can be found (Bicho, Cascalheira, André, et al., 2018; Bicho et al., 2023; Raja, 2020).

Save's strong LSA representation (Both Sofala and Inhambane Provinces), combined with its low elevation and close coastal proximity, may reflect genuine intensification of occupation during the late Pleistocene and Holocene as populations adapted to changing post-glacial environments. The lower Save Valley and adjacent coastal plains offered diverse resources including riverine, estuarine, and terrestrial environments in close juxtaposition. The presence of limestone bedrock south of the Save contains close to a dozen caves (in the Buxane area), some tested and proven to have intensive LSA occupation, that together with recent located LSA sites (Zimuara and Chessungalane) in the immediate northern vicinity of the Save confirm a significant LSA

occupation during the Holocene. Nevertheless, the high proportion of undifferentiated Stone Age sites indicates that much remains to be learned about the specific chronology of occupation in this promising region.

Multicomponent sites, comprising 25.8% of the dataset, provide crucial insights into landscape persistence. Their significantly lower mean elevation (155.2 m) compared to single MSA occupations (243.8 m, $p = 0.0032$) suggests certain lowland locations offered sustained advantages across Stone Age periods. Sites with evidence from all three phases show even lower mean elevation (82.2 m), including mainly large river floodplains and near-coast sites. These 'super sites' may represent optimal landscape positions attracting repeated occupation for potentially hundreds of thousands of years. Such persistent places likely offered combinations of permanent water sources, stone raw material outcrops, ecological ecotones providing diverse resources, or strategic positions for monitoring game movements.

The taphonomic objection—that multicomponent sites merely reflect surface mixing or poor chronological resolution—is weakened by the systematic geographical patterns exhibited by artifact distributions. Were multicomponent assemblages simply analytical artifacts, they should show random distribution across the landscape. Instead, they cluster systematically at low elevations in plains contexts, suggesting real behavioral significance. The low-elevation concentration implies environmental advantages that persisted through Pleistocene climate fluctuations, possibly tied to major river systems that remained active even during arid phases. Understanding these persistent sites of multi-phase habitation remains a central concern for reconstructing Stone Age landscape cognition and territorial organization.

4.6. Research Gaps and Future Directions

Despite the dramatic expansion of the known archaeological record documented in this paper, major research gaps remain. Absolute chronology is the most pressing need—fewer than 50 radiometric dates exist for the entire Stone Age sequence across all of Mozambique from half a dozen sites. Most sites have been documented only through surface reconnaissance, with no subsurface testing or excavation – out of the 657 sites, only 27 have been tested or excavated. This means that in nearly all cases, chronological attributions were based on diagnostic typological and technological features of stone tools (and thus remain tentative). In addition, artifact density and spatial patterning are unknown, and crucial data on subsistence, environment, and behavior are absent.

Several limitations constrain these interpretations. The concentration of sites in Maputo, Sofala, Gaza, and Niassa provinces (close to 90% of the dataset) likely reflects research intensity rather than prehistoric reality: many of these sites result from our own intensive surveys in Sofala, Gaza and Niassa, while Maputo has been the focus of Kohtamäki (2014) and Muianga (2025). Also, some of these occurrences represent work carried out in areas that include Mozambique's major cities and road networks. Under-sampled provinces like Nampula, Cabo Delgado, Tete, Zambezia may contain substantial undiscovered Stone Age records that could modify regional patterns. The same should be said for the Mozambique coastal strip. The absence of absolute dates for most sites means chronological assignments rely on typological assessments that may conflate temporally distinct occupations or mis-identify assemblages.

Close to a quarter of the sites, classified only as 'Stone Age', represents substantial missing data that, once refined chronologically, might alter proportions and patterns. Water proximity, inferred from low elevations but not directly measured, requires integration of hydrological data to test the assumption that lowland sites correlate, in fact, with water sources. Terrain roughness, calculated as elevation variation within 5 km, captures broad

topographic patterns but misses micro-topography that may have been archaeologically significant. Beyond elevation and water resources, incorporation of the local geology could also inform models of access to sheltered sites and lithic raw materials.

Priorities for future research should include:

- Systematic dating programs targeting stratified sites with preserved organic materials for radiocarbon dating and sediments for luminescence dating. Establishing a robust chronological framework is essential for moving beyond typological age assignments.
- Targeted excavation of rockshelters and caves in Niassa, Sofala, and Inhambane. These sites offer the best potential for preserved faunal remains, botanical materials, and stratified artifact assemblages that can address behavioral questions.
- Systematic geoarchaeological survey of major river valleys, such as the Zambeze, focusing on dating terrace formations and correlating archaeological horizons with regional environmental changes. Understanding the relationship between site distribution and past environmental conditions is crucial for interpreting settlement patterns.
- Intensive coastal survey targeting preserved dune systems, barrier islands, and particularly relict beach deposits. Testing sea-level and coastal resource exploitation hypotheses requires locating and excavating coastal MSA sites.

5. Conclusions

Archaeological survey and surface collection remain fundamental methodologies for understanding African Stone Age prehistory, particularly given the continent's vast spatial scale and limited resources for subsurface exploration and excavation. Surface assemblages provide critical data on landscape use, raw material procurement strategies, and technological variability across different environmental zones (Douglass et al., 2023; Holdaway & Fanning, 2008; Phillipson, 2005; Wandsnider & Camilli, 1992). While taphonomic processes including deflation, bioturbation, and colluvial movement can compromise stratigraphic integrity, systematic survey methodologies can document meaningful artifact distributions, revealing patterns of hominin behavior that would be invisible through excavation alone (Foley, 1982).

In East Africa, surface scatters have proven instrumental in identifying key Oldowan and Acheulean localities, with pioneering work by the Leakeys demonstrating how surface finds can guide targeted excavations (Leakey, 1971). Similarly, survey projects in the Sahara have mapped extensive Middle Stone Age and Later Stone Age distributions across now-arid landscapes, providing insights into human responses to Quaternary climate fluctuations (Cancellieri et al., 2016; Cremaschi & Di Lernia, 1998). Recent applications of GIS and spatial analysis have enhanced the interpretive potential of surface data, allowing researchers to model site formation processes and distinguish between primary and secondary contexts (e.g., Holdaway & Fanning, 2008; Oron et al., 2023; Rose et al., 2025). While surface assemblages cannot provide the chronological precision of stratified deposits, their capacity to reveal broad-scale patterns of technological change and population movement makes them indispensable for reconstructing African prehistory (McBrearty & Brooks, 2000). The present study, based primarily on survey and surface archaeological data, provides a rather extensive view on the Stone Age of Mozambique and its settlement patterns and land use.

Our data set demonstrates that choices of data aggregation and analytical approach significantly affect interpretations of Stone Age settlement patterns. The four-unit categorization, distinguishing single-phase assemblages from multicomponent sites, sheds light on specific behavioral characteristics of each chronological period while revealing that repeatedly occupied locations cluster systematically at low elevations, suggesting persistent landscape advantages. The extended unit analysis, that is, integrating the single and multicomponent sites for each phase, reveals Middle Stone Age as the dominant period affecting almost half of the sites and strengthens clustering patterns through larger sample sizes. Both frameworks converge on fundamental patterns—ESA lowland concentration, MSA ecological expansion, LSA intensive clustering—while diverging on questions of territorial extent and occupation intensity.

The geographical patterns reveal clear evolutionary trajectories. Statistically significant elevation differences between phases ($p = 0.0045$ in four-unit, $p = 0.020$ in extended analysis) confirm changing environmental preferences, with ESA lowest (125.8–135.5 m), MSA highest (197.4–243.8 m), and LSA intermediate (173.8–188.2 m). Progressive clustering intensification—from 48.4–60.4% (ESA) through 71.8–76.4% (MSA) to 80.2–81.4% (LSA) highly clustered—demonstrates fundamental changes from extensive to intensive landscape use. The ESA–MSA transition represents the most dramatic shift ($p = 0.006$ – 0.012), suggesting technological and behavioral innovations during the Middle Stone Age enabled exploitation of diverse terrain including highlands previously unoccupied.

Multicomponent sites provide unique insights into landscape persistence. Their significantly lower elevation than single phase assemblages (particularly MSA, $p = 0.0032$) indicates certain lowland locations offered sustained advantages across Stone Age periods. The sites with evidence from all three phases, all in lower altitudinal zones, represent 'persistent places' (Barton et al., 1995; Schlanger, 1992; Shaw et al., 2016) attracting human occupation for hundreds of thousands of years, likely due to permanent water sources, raw material availability, or strategic positioning. These findings help to better understand the deep human history of Mozambique while demonstrating the importance of methodological choices—between exclusive categorization and inclusive phase analysis—in reconstructing prehistoric landscapes. Future research integrating absolute dates, paleoenvironmental data, and systematic regional surveys will test and refine these interpretations, advancing understanding of Stone Age adaptations in southeastern Africa.

The intensive surveys of 2019–2025, particularly the last few years in the Save basin in the Sofala and northern Inhambane Provinces, have transformed our knowledge of Mozambique's Stone Age. However, this work also highlights how much remains unknown. The paucity of absolute dates, limited excavation data, and large areas still awaiting systematic survey mean that we are only beginning to understand the full complexity of prehistoric occupation in this region. Nevertheless, the patterns documented here provide a foundation for hypothesis testing and targeted future research.

The expanded archaeological record documented in this paper highlights Mozambique's growing significance for addressing questions about modern human origins and dispersal. The successful MSA occupation of diverse environments from coast to highland plateaus demonstrates the ecological flexibility and adaptive capacity that would have facilitated subsequent expansion beyond Africa. The temporal depth of MSA occupation, extending back to at least ~ 150 ka in the Niassa region, places these adaptations well within the timeframe of anatomically modern human origins. The geographic position of Mozambique between the dense concentration of MSA sites in South Africa and the important sites in Tanzania and Kenya makes it a critical link in understanding population movements and interactions across the subcontinent. As Mozambique emerges from decades of limited

archaeological research, it is becoming clear that the country holds crucial evidence for understanding the late stages of human evolution in Africa.

Declarations

Author Contribution

NB, JC, JR, MB and MD prepared and reviewed the manuscript; Figures were prepared by NB; All authors participated in field work and acquired data to the database.

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Figures



Figure 1

Google Earth map of Mozambique with the Stone Age sites.

Single vs Multicomponent within Each Phase

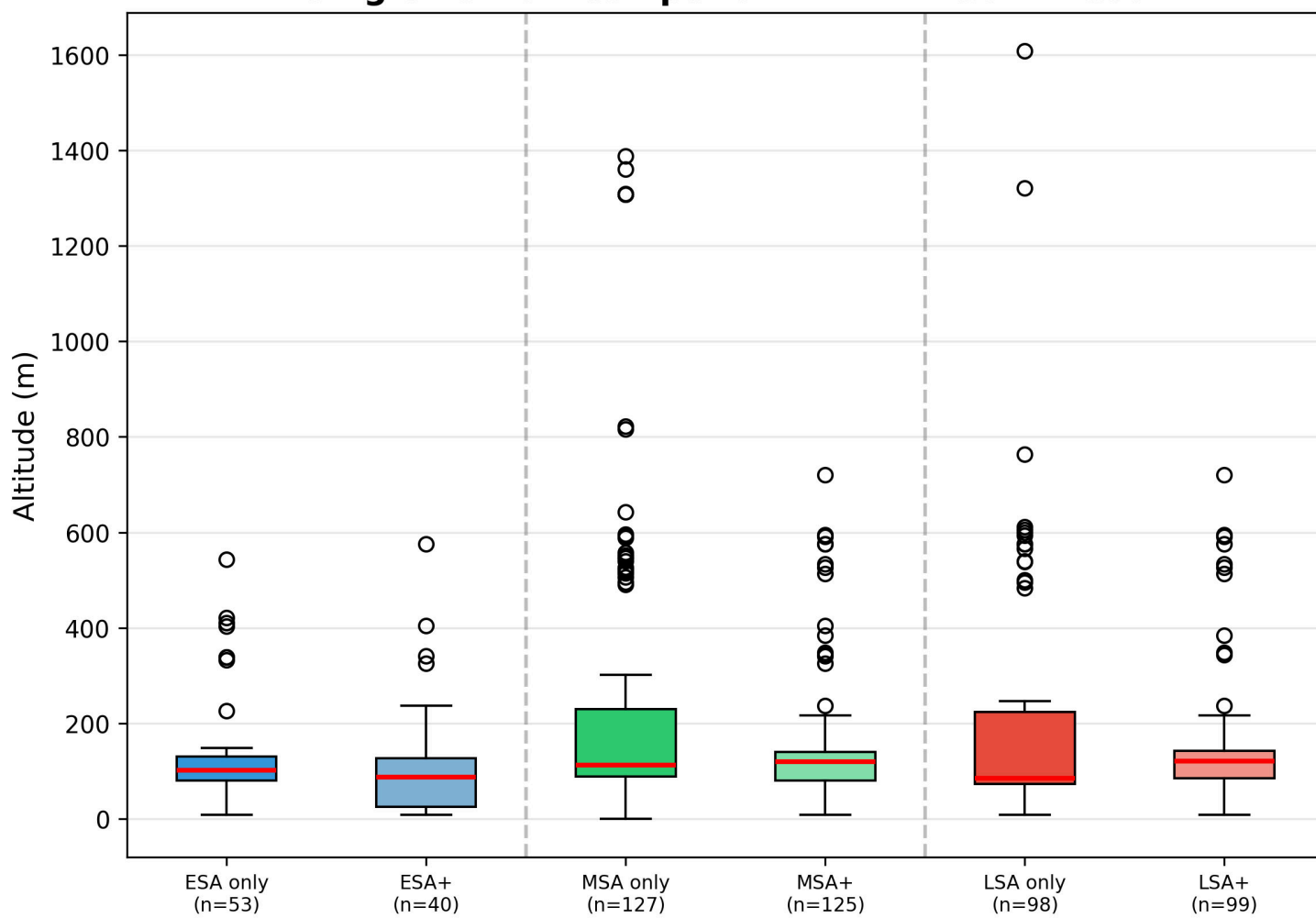


Figure 2

Box plot showing elevation for each Stone Age phase.

Terrain Type Distribution by Phase

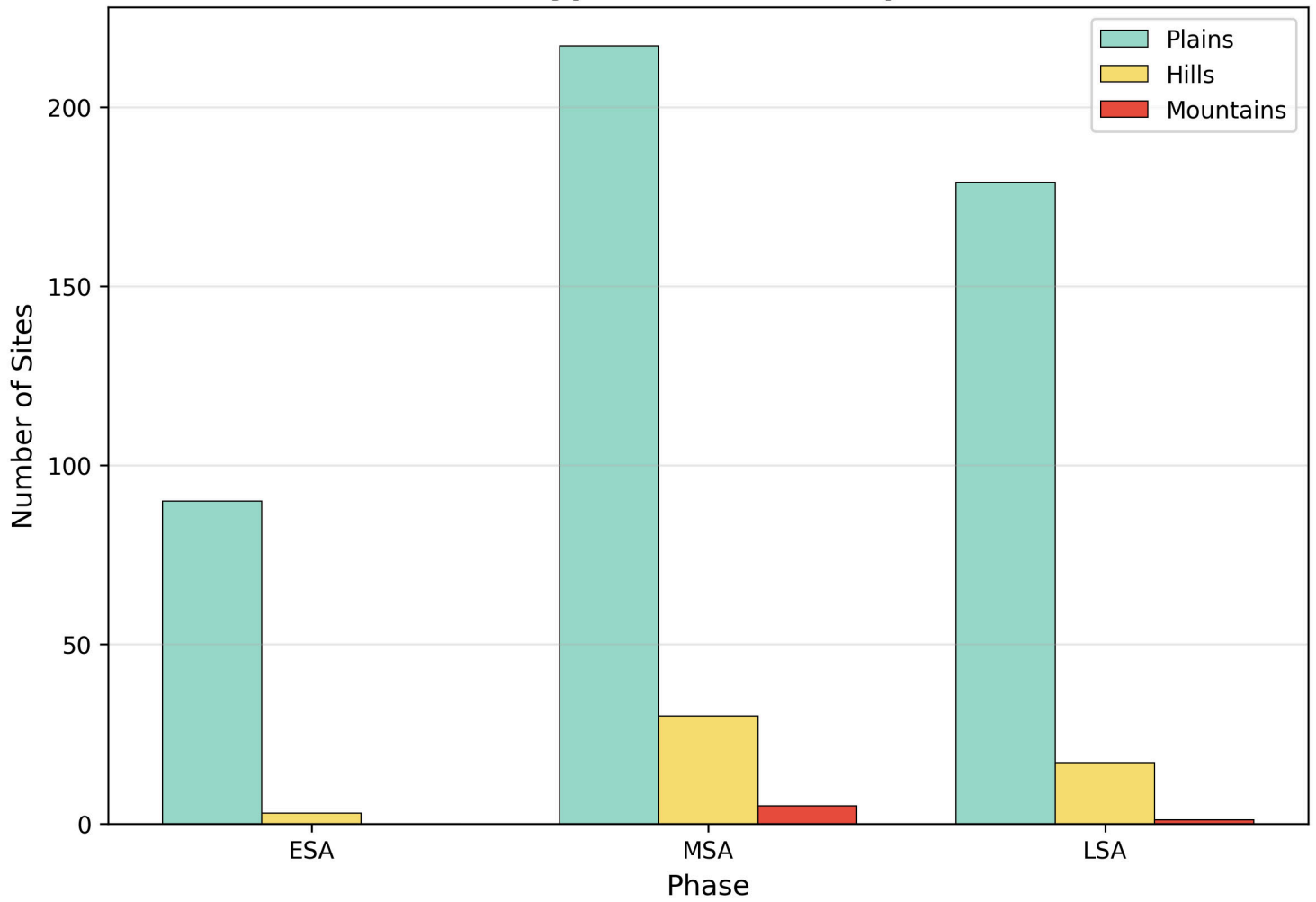


Figure 3

Site distribution by terrain type.

**Clustering Patterns by Phase
(Distance to Nearest Site)**

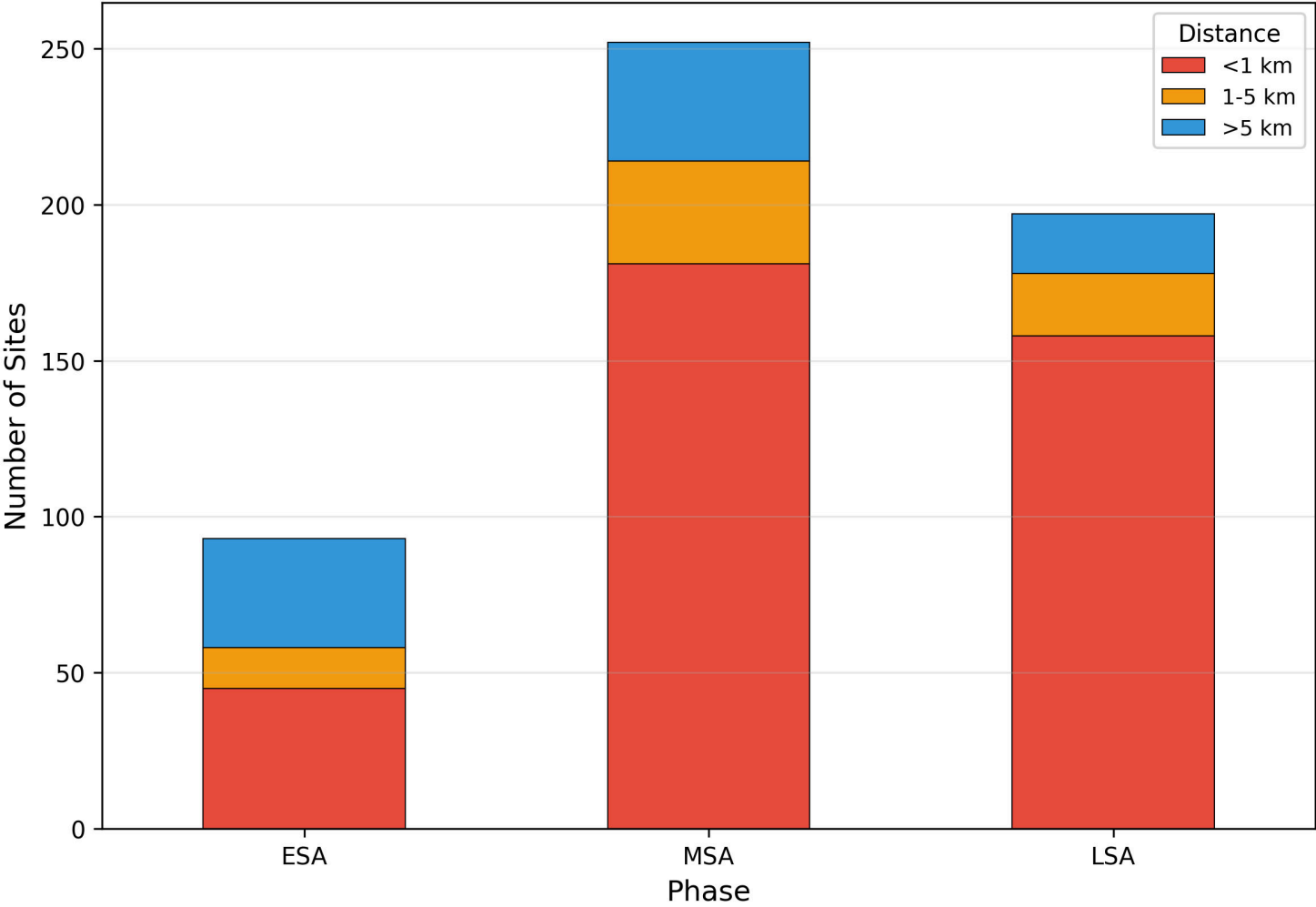


Figure 4
Clustering of Stone Age phases in Mozambique.