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The Evolution of Long-Range Hunting with Stone-Tipped Weapons During the Afrotropic Middle Stone Age: A Testable Framework Based on Tip Cross-Sectional Area

Yonatan Sahle [1,2,*] and Marlize Lombard [3]

[1] Department of Archaeology, University of Cape Town, Rondebosch, Cape Town 7701, South Africa
[2] Department of History and Heritage Management, Arba Minch University, Arba Minch P.O. Box 21, Ethiopia
[3] Palaeo-Research Institute, University of Johannesburg, P.O. Box 524, Auckland Park, Johannesburg 2006, South Africa; mlombard@uj.ac.za
* Correspondence: yonatan.sahle@uct.ac.za

Abstract: In the Afrotropic biogeographic realm, with its diverse and high-density mammal population, early humans may have been hunting with stone-tipped weapons since ~500,000 years ago. Being able to hunt effectively from a distance has several important adaptive advantages. Yet, until now, African long-range javelin hunting remained unexplored as intermediate between short/medium-range, hand-delivered and long-range, mechanically projected weapons. Insights gained from a new Afrotropic comparative dataset with 950 weapon tips of known use—including several javelin types—provide a contextually appropriate middle-range tool for assessing the probable effective hunting ranges of Middle Stone Age points. We use a novel application of the ballistically relevant tip cross-sectional area (TCSA) statistic to define contact, short-, medium-, long- and maximum-range hunting and discuss the adaptive advantages for each. The approach is applied to suggest developments and variations in the best-fit hunting ranges of 5597 stone points from 62 Middle Stone Age Afrotropic assemblages. By aligning our results with the Marine Isotope Stage (MIS) record we hypothesize that effective long-range (~20–30 m) hunting with stone-tipped weapons was probably not practiced by ≥MIS 8, and that experimentation with long-range javelins—similar to those used by contemporary Ethiopian hunters—over these distances may have started during MIS 6, becoming part of the everyday Afrotropic hunting arsenal by the end of MIS 5.

Keywords: points; hunting javelins; bow-and-arrow; spearthrower-and-dart; adaptive advantages

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1. Introduction

There is little doubt that launching stone-tipped weapons accurately and forcefully enough to pierce the hides of prey animals from a distance had important adaptive advantages for early human hunters. It has been suggested that spearthrowers-and-darts or bows-and-arrows represent the only 'true' long-range Stone Age weaponry (e.g., [1]). Some researchers also found that reports of terrestrial javelin hunting were rare, and that trying to distinguish between hand-thrown and thrusting/stabbing spears may not be meaningful, because both represent 'short-range' hunting wherein javelins were thought to have an average range of 7.8 m only ([2], p. 18). Milks et al. [3] showed that wooden spears, comparable to those from Schöningen in Germany, dating to ~300 ka, can be thrown with 25% accuracy from ~10–15 m. The authors did not, however, demonstrate that these can penetrate animal hides when thrown by humans from such distance. The accuracy of experimental wooden spears increased to 58% when thrown from only 5 m [3] and can cause serious damage up close [4]. Two groups from the Afrotropics were reported to have hunted with wooden spears—the Bubi of Bioko Island (Equatorial Guinea), and the Mbuti (Democratic Republic of Congo)—although it is unclear from the limited ethnographic data whether some of these wooden spears were thrown at prey animals or used only for thrusting [5]. Experiments with wooden spears launched horizontally with a machine from <2 m suggest that they can attain high kinetic energy and penetrate hide but not bone [5]. The known wooden spears are thus best suited for contact or short-range hunting. Our focus is on the effective hunting ranges of Middle Stone Age stone-tipped weaponry from the Afrotropics that are meant to pierce the hides of prey animals from longer distances.

In their attempt to identify early long-range hunting in eastern Africa, Brooks et al. [6] found that points from Aduma, Ethiopia, dating to ~90–80 ka, fall within American ethnographic spearthrower-dart and large arrowhead ranges, and that dimensions decrease through time. Sahle and Brooks [7] subsequently reported on morphometric aspects, hafting traces, and impact damage patterns of the Aduma points affirming a shift between ~100 ka and ~80 ka from short-range spear technologies to long-range projectiles comparable to American spearthrower-darts. Sisk and Shea [8] also used a comparative morphometric approach to suggest that stone points from Porc-Epic (~50–40 ka) were used to tip long-range projectiles such as American spearthrower darts. Kappelman et al. [9] proposed bow hunting with tips comparable to North American arrowheads at Shinfa-Metema in Ethiopia by ~74 ka, based on tip cross-sectional geometry and micro-wear data. A combination of macro-fracture, use-wear and micro-residue analyses demonstrated that small backed pieces in southern Africa were used as arrow tips and barbs [10–12].

Despite the availability of much data on African arrowheads, and no ethno-historical or archaeological records of American-like spearthrowers in the Afrotropics, none of the existing studies considered the potential use of hunting javelins. Neither did they use African weapon-tip data for comparative purposes. Instead, the interpretations of African stone-tipped weaponry were based solely on the dimensions of North American arrowheads (n = 118), spearthrower dart tips (n = 40), and experimental stone points (n = 28) [13–15]. Yet, during the last few centuries, and still today in some contexts, Afrotropic hunters used/use a range of hunting javelins, bimanual thrusting spears, assegais (single-handed stabbing spears), and bows-and-arrows [16,17]. Lombard et al. [17] further demonstrated that hypothesizing about American-like dart hunting in sub-Saharan Africa based on tip morphometrics is impossible once javelin hunting is considered. Currently, the best prediction for spearthrower use in Africa is that it may have happened in the northern African Palearctic or Saharo-Arabian zoogeographic realm during a green-Sahara phase, instead of the biodiverse Afrotropics [18].

Comparative morphometric studies, based on large samples of southern African hafted weapon tips of known use (see Lombard et al. [17] for discussion about metal vs stone tips in the TCSA context) support a hypothesis wherein long-range javelin hunting, in tandem with stabbing/short-range assegais, may have been practiced since MIS 6 (191–130 ka), and bow hunting by ~71–59 ka in the region [19,20]. Schoville et al. [21] concurred with an interpretation of long-range hunting by ~71–59 ka while remaining unsure about the delivery system (see also [22,23]). Use-trace and morphometric data indicated that points from Gademotta, Ethiopia, may have been used as javelin tips by >279–105 ka [24], but in the absence of a javelin-tip reference collection, temporal variability in weapon use at this site-complex could not be resolved.

Based on a suite of use-trace (macro-fracture, micro-wear, and residue) analyses, we know that some pointed and backed artefacts from Middle Stone Age contexts were used as hafted tips and/or barbs for hunting weapons (SOM Table S1). Of course, this interpretation does not exclude potential alternative uses such as scraping and cutting [25–27]—but our focus here is hunting. Discussion of hunting technologies demands following specific protocols that speak directly to the development of hunting traces that can be easily missed [28–31]. For example, it is futile to ignore point fragments, broken tips and reams of experimental evidence in a macro-fracture analysis. Similarly, approaches focusing on edge-damage cannot detect the small surface striations that sometimes develop on weapon tips, and the recognition of animal residues is not always straightforward. Most use-trace methods are appropriate for generating small-scale, tool- and context-specific evidence of African Pleistocene hunting [7,24,29,32], but not for analyzing thousands of artefacts across vast spatiotemporal boundaries required to hypothesize about broad evolutionary trends in tip design for best-fit ballistic probability [17,33,34]. Importantly, they cannot provide data about hunting range, which is the purpose of the present investigation.

The tip cross-sectional area (TCSA) method provides a ballistic statistic—with velocity-distance implications—for the maximum sectional area of a weapon tip that opens a hole in the skin/hide for the projectile to enter a target's body [33]. With contextually appropriate, and statistically robust standardized TCSA ranges, large samples can be processed with minimum error. Such studies provide directly comparable quantitative datasets for building broad, testable hypotheses about weapon-assisted hunting through time and across space [19,34]. Even though such approaches cannot determine whether each individual artefact was hafted and used for hunting (for that, detailed use-trace work is required), they are effective tools for probable/best-fit ballistic interpretations of artefact classes that are clearly associated with hunting economies and known to have been used as weapon tips (SOM Table S1; SOM Data S1).

Afrotropic Middle Stone Age assemblages represent bona fide hunter-gatherer populations for whom hunting was a key techno-behavioral component, often resulting in large assemblages of faunal remains (e.g., [35]). These assemblages cover the full range of animal sizes, from size 1 (<18 kg) to size 5 (>1000 kg) (see SOM Data S1 for examples). Direct evidence of hunting with stone-tipped weapons come from Klasies River in South Africa where the tip of a stone point was found embedded in the vertebra of an extinct giant buffalo dated to ~100 ka ([36]; SOM Table S1). It is therefore reasonable to accept that some pointed stone artefacts were made for hunting during the Afrotropic Middle Stone Age, and contesting such function begs an explanation of how humans hunted animals during this phase.

American weaponry or laboratory experiments are in many ways disconnected from Afrotropic hunting reality. A real-life, contextual middle-range proxy for assessing the evolution of Afrotropic hunting can be gained directly from African hunters and their weapons. We, therefore, use recent self-collected African information and data (see [16,17] [the Supplementary materials to these papers contain full datasets regarding dimensions, materials, etc.]), for adapting the TCSA method to primarily assess variation in hunting range, with the underlaying weapon-delivery systems being of secondary concern. We present data for 5597 stone points and backed microliths representing 62 assemblages from 34 Middle Stone Age sites across the Afrotropics. Most of the eastern African artefacts were newly measured by one of the coauthors; we also present TCSA data for assemblages from several sites for the first time. Previously published TCSA data are re-analyzed and interpreted using the new hunting-range TCSA framework. Our research question is threefold:

- Can we generate a feasible chronology for the evolution of long-range, stone-tipped weapons in the Afrotropic?
- Was there spatiotemporal variability in the use of hunting ranges during the Middle Stone Age?
- If so, can we suggest testable hypotheses about the different adaptive advantages?

2. Materials and Methods

Recent work documented ethnographic hunting javelin types and the distances they can be thrown at [16]. Such 'maximal distance' relates more to modern target shooting, or sporting competitions [33], than to Afrotropic hunting. 'Effective distance', on the other hand, is a hunting concept representing the average range over which hunters deliver their weapons with the necessary accuracy and force [33]. Importantly, effective hunting in the Afrotropics is often not associated with deep-penetrating lethality at first strike. Instead, the general aim is to wound an animal with several/many strikes so that it becomes weakened and exhausted. In most instances, it is then killed with a spear thrust to the jugular (the authors' personal observations of traditional African hunting). For the purposes of this paper, we revisited African javelin hunters to record their preferred-effective hunting ranges (Table 1).

Table 1. Ethiopian hunting javelins and their maximal vs effective ranges.

Weapon Type	Local Names	Users	General Use	Maximal Distance	Effective Distance
Heavyweight-multipurpose spears/javelins	Golda gina, bambele baqe	Elite hunters	Ceremonial dances symbolizing elite-hunting status, and striking at cornered, large and dangerous prey such as buffaloes, large antelopes, bush pigs and forest hogs.	≤27 m	Contact, <10 m
Heavyweight hunting javelins	Koisha gina, dimoyi baqe	Competent, experienced hunters	Killing large prey and predators (e.g., hyaenas) from a greater distance.	33–40 m	≤13 m
Long-narrow-tipped hunting javelins	Mechamia/ganchiria gina, guruchek baqe	Any hunter	Ambush hunting, inflicting wounds from a distance, or wounding large, difficult-to-catch prey that is then tracked and killed at close-range with a heavier weapon.	≥40 m	~19 m
Versatile hunting javelins	Tsinka gina, bodoy baqe	All adult hunters	Considered to have superior velocity and efficiency, for long-range throwing to startle, divert, wound/kill startled animals	≥50 m	~27 m
Light-weight hunting javelins	Boda gina, donkoche baqe	Novice hunters	Target practice on small prey, e.g., duikers, porcupines, or bushbucks around the camp	25–40 m	not for adult hunting

The preferred-effective hunting distances reported here for Afrotropic hunting javelins clearly demonstrate that not all javelins can be thought of as short-range weapons. Especially the effective range of the Ethiopian versatile javelins compare favorably to long-range dart-and-spearthrower hunting that is most effective at ~20–30 m and fall just short of bow-hunting that is effective up to ~30–45 m [18,37–41]. We therefore use a scheme of five approximate effective hunting ranges to explore the best-fit distances from which Afrotropic Middle Stone Age weapons may have been used, i.e.:

- Contact hunting (thrusting/stabbing): Weapons generally do not leave the hands of hunters, e.g., bimanual thrusting spears, or heavyweight-multipurpose/ceremonial javelins.
- Short-range hunting: Weapons can be used in contact (single-handed stabbing), but can also be thrown effectively up to ~10 m, e.g., heavier assegais or heavyweight javelins.
- Medium-range hunting: Weapons are thrown effectively at ~11–19 m, e.g., long-narrow-tipped javelins or smaller assegais.
- Long-range hunting: Weapons are projected effectively over ~20–30 m, e.g., versatile Ethiopian javelins or those of the southern African San hunters.
- Hunting at maximum range: Weapons used at a maximum effective range of >30 m, e.g., bow hunting.

Larger projectiles usually contend with greater air resistance or drag during flight (e.g., [38,42,43]), constraining velocity and distance. Sitton et al. [44] demonstrated that stone points with smaller TCSA values travel at greater velocity compared to those with larger TCSA values when similarly propelled (see also [45]). Smaller/lighter projectiles or weapon tips therefore generally represent greater velocity and increased distance so that weapon velocity is a suitable proxy for hunting distance [33], and the TCSA metric can be used to hypothesize about effective hunting ranges. We first used the Kruskal-Wallis H test (non-parametric one-way ANOVA) on the TCSA data of 950 Afrotropic weapon tips for which the approximate effective hunting ranges are known (SOM Data S2), resulting in a significant difference (H = 768.2; $p < 0.001$) between the TCSA distributions of the five hunting-range categories. The test shows general group differences, but not differences amongst the various hunting ranges. The results of a Mann-Whitney pairwise test further demonstrate that each of the hunting ranges is significantly different in their TCSA distributions from the other at $p < 0.001$ (Table 2). Based on these results, we use the ethno-historical weapon tips from the Afrotropics to set new TCSA standards for the probable hunting ranges of pointed stone artefacts (Table 2).

Table 2. Upper half: Statistical test results, demonstrating that each of the weapon-tip ranges is significantly different from the other at $p < 0.001$. Lower half: TCSA standards for probable effective hunting distances based on existing/historical African weapon-tip use (SOM Data S2; for more detailed data, also on shaft dimensions, see [16,17]).

Results of the Mann-Whitney Pairwise Test					
Distance	**Contact *n* = 21**	**≤10 m *n* = 181**	**~11–19 m *n* = 99**	**~20–30 m *n* = 310**	**≥30 m *n* = 339**
Contact *n* = 21		<0.001	<0.001	<0.001	<0.001
≤10 m *n* = 181	<0.001		<0.001	<0.001	<0.001
~11–19 m *n* = 99	<0.001	<0.001		<0.001	<0.001
~20–30 m *n* = 310	<0.001	<0.001	<0.001		<0.001
≥30 m *n* = 339	<0.001	<0.001	<0.001	<0.001	
TCSA Standards for Probable/Best-Fit Preferred-Effective Hunting Distances					
TCSA Standard	**Hunting Range**	**Mean mm^2**	**SD mm^2**	**Range mm^2**	**Median mm^2**
Contact *n* = 21	Contact	284	88	>195 (provisional)	261
≤10 m *n* = 181	Short-range	151	43	108–194	140
~11–19 m *n* = 99	Medium-range	95	23	72–118	96
~20–30 m *n* = 310	Long-range	61	21	40–82	60
≥30 m *n* = 339	Maximum-range	23	15	8–38	21

We highlight that the sample size of contact-weapon tips ($n = 21$) is probably too small to be robust, and the value of >195 mm^2 is therefore a provisional standard only. For known Afrotropic thrusting-spear tips, the range is 195–372 mm^2. For comparative reference, eight European wooden spears, most effectively used as contact/close-range spears, have a mean TCSA of 643 mm^2 with a standard deviation of 235 mm^2, and a median of 583 mm^2 [17]. For this study we included stone points with TCSA values <500 mm^2 in the contact-hunting category but excluded rare points with values >500 mm^2 as outliers.

We use the median statistic for the general interpretation of TCSA results, because it is affected less by outliers in skewed data than the mean statistic, hence representing the predominant trend within an assemblage more accurately. We use the percentage of points in each of the assemblages studied that fall within the distinct TCSA ranges [18,19], to assign them to the respective hunting distance categories. Due to the presence of overlaps or gaps in the respective ranges (Table 2), the calculated percentages do not necessarily add up to 100. For example, there is a 10 mm^2 overlap between the TCSA ranges of short-range (108–194 mm^2) and medium-range (72–118 mm^2) weapons. Points with TCSA values could be used in either hunting-weapon category, as they do in real-life scenarios. Such pieces are thus included in the percentages calculated for each of these groups with overlapping TCSA values. As a result, the sum of the percentages per group for a given assemblage may not add up to 100.

When exploring intra-assemblage variation, we use the <15% threshold as the lower end of a spectrum focused on manufacturing either larger or smaller pieces, further minimizing the outlier effect. To highlight potential fitness consequences in an evolutionary context, we used Shea's [46] occasional-habitual-obligatory scheme wherein we interpret:

- As *occasional* a frequency of 15–32%: Occasional hunting ranges would hypothetically occur irregularly as an optional strategy that has negligible fitness consequences if it is not used. Thus, individuals or groups may gain fitness benefits from hunting at these ranges, but not much more than those who do not [46] (p. 206).
- As *habitual* a frequency of 33–65%: Habitual hunting ranges are mainstream, used with variable regularity and have variable evolutionary consequences. Thus, Individuals or groups hunting at these ranges reap fitness rewards differently than those who hunt from other ranges or who don't hunt. The benefits fluctuate spatiotemporally and contextually [46] (p. 209).
- As *obligatory* a frequency of ≥66%: The success of obligatory hunting ranges is otherwise difficult or impossible to obtain. It probably has serious short-term fitness consequences. Individuals or groups who do not hunt from these ranges in a specific socio-ecological context may suffer serious adverse consequences [46] (p. 204).

To generate a feasible chronology for the evolution of long-range stone-tipped weaponry, assess spatiotemporal variability, and suggest testable adaptive advantages throughout the Afrotropic Middle Stone Age, we amassed as much data as possible. Notwithstanding our best efforts, our analysis was constrained by a shortage of suitable published data and access to data/assemblages outside of Ethiopia and southern Africa. Hopefully this bias can be overcome in future, but unless researchers working in Africa publish their raw morphometric data or are more collaborative towards data-sharing/access to assemblages we can only work with what we have. We also constrained our samples to Afrotropic assemblages with ≥20 points and published dates or relative age estimates (Figure 1; SOM Table S2) and draw attention to the fact that many assemblages not included here have too few well-contextualized pointed artefacts to work with. Assemblages from the same sites with different age estimates, but within the same MIS stage are provided with [A, B, C, D] appendages to distinguish between them (see also SOM Table S2). Our rigorous sampling strategy allows us to interpret our results according to MIS stages for broad spatiotemporal discussion. For assemblages with age estimates spanning multiple MIS stages, we repeated the results for each stage they may fall in, which allowed us to assess possible best-fit scenarios or to highlight continuity across MIS boundaries.

We focus on the Afrotropics (Figure 1), because some of the oldest suggested evidence for the use of stone-tipped hunting weapons comes from this biogeographic realm [24,47]. It therefore provides a meaningful context for developing large-scale, data-based hypotheses about the evolution of long-range hunting with such weapons. Out of the 29 Köppen-Geiger climate zones, the Afrotropics contains more than half [48]. This corresponds with biodiversity data wherein, apart from the Neotropic, the Afrotropic biogeographic realm is richest in mammal species diversity and density (Figure 1 [49,50], and see list in Churchill [2] Table 1.2).

Biogeographic realm	Mammal species (n)	Species density (km²)
Neotropical	1617	85.1
Afrotropical	1572	71.1
Palearctic	1162	21.5
Indomalayan	954	12.7
Nearctic	697	30.4
Australasian	527	61.4

Figure 1. (**Top**): Archaeological sites in the Afrotropics from which assemblages were included in this study (SOM Table S2). (**Bottom**): Biogeographic realms in Miklos Udvardy's system (base map adapted from: Carol, CC BY-SA 3.0, http://creativecommons.org/licenses/by-sa/3.0/ (accessed on 17 June 2024) with data for mammal species and density added by ML from Burgin et al. [51].

3. Results

3.1. MIS 12-8

We only have three assemblages with ≥20 pointed artefacts (n = 250) dating to >243 ka. Cumulatively, the TCSA results suggest that if pointed stone tips were used for hunting, contact hunting was probably habitual with 49% of all the tips falling within this category (Table 3). These hominins may have also hunted habitually at close-range (38%), but the longer hunting ranges are all represented below the 15% threshold. This trend is most strongly expressed in the oldest assemblage from Kathu Pan, South Africa, where contact hunting may have been habitual (58%) and short-range weapons were starting to be so (34%). The TCSA results of the oldest Gademotta MIS 8 [A] assemblage from Ethiopia suggest that short-range hunting (48%) was preferred (more frequent) over contact hunting (34%), and that both were habitual. In addition, these hunters may have experimented occasionally with medium-range weapons (18%). During the subsequent Gademotta MIS 8 [B] phase, short-range hunting and contact hunting remain habitual (38%) while being supported occasionally by medium-range hunting at 27%.

Table 3. TCSA statistics and frequencies of probable hunting ranges for MIS 12-8 assemblages (see SOM Data S3 for point TCSA data). Note: Percentages do not add up to 100, because of overlaps/gaps in ranges see Table 2. Interpretative scheme: 15–32% = occasional, 33–65% = habitual, ≥66% = obligatory hunting distances.

Assemblage	TCSA (mm^2) Summary Statistics				% Probable Hunting Range (TCSA Ranges in mm^2)									
					Max. ≥30 m		Long ~20–30 m		Medium ~11–19 m		Short ≤10 m		Contact	
	n	Mean	SD	Median	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Kathu Pan, MIS 12	148	219	80	207	0	0	3	2	13	9	51	34	86	58
Gademotta, MIS 8 [A]	65	178	83	162	0	0	7	11	12	18	31	48	22	34
Gademotta, MIS 8 [B]	37	181	91	172	0	0	4	11	10	27	14	38	14	38
Cumulative MIS 12-8	**250**	**202**	**85**	**193**	**0**	**0**	**14**	**6**	**35**	**14**	**96**	**38**	**122**	**49**

3.2. MIS 6

The oldest MIS 6 assemblage, Rooidam 2, is the only one with a feasible proportion of stone tips suited for occasional long-range hunting (18%). Contact hunting (38%) was, however, likely preferred and habitual, with medium- and short-range hunting occasionally practiced (Table 4). The TCSA results for the older Florisbad MIS 6 [A] point assemblage suggest that both short-range (51%) and contact (48%) weapons may have been used habitually. During the younger Florisbad MIS 6 [B] phase, both weapon ranges are still habitual, but hunters may now have preferred weapons best suited for contact hunting (51%) over short-range hinting (37%), and occasionally included hunting with medium-range weapons. The MIS 6 assemblage from Pinnacle Point 13B has a relatively high proportion of tips that indicate a preference for habitual short-range hunting (61%), and occasional medium-range hunting (27%). This trend wherein short-range hunting is habitual and preferred is echoed at Klasies River with 65% of its pointed artefacts falling in this category. Here, such hunting was also occasionally supported by medium-range hunting (20%), but different from Pinnacle Point, also by occasional contact hunting (18%). At Olieboomspoort, the TCSA results suggest that short-range hunting (47%) was likely habitual, supported by occasional contact (27%) and medium-range hunting (30%) (Table 4).

Table 4. TCSA statistics and frequencies of probable hunting ranges for MIS 6 assemblages (see SOM Data S3 for point TCSA data). Note and interpretative scheme same as for Table 3.

Assemblage	TCSA (mm^2) Summary Statistics				% Probable Hunting Distance (Range in mm^2)									
					Max. ≥30 m		Long ~20–30 m		Medium ~11–19 m		Short ≤10 m		Contact	
	n	Mean	SD	Median	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Rooidam 2, MIS 6	130	170	101	150	3	2	24	18	31	24	30	23	50	38
Florisbad, MIS 6 [A]	63	200	68	189	0	0	0	0	4	6	32	51	30	48
Pinnacle Point 13B, MIS 6	51	139	50	132	0	0	6	12	14	27	31	61	7	13
Olieboomspoort, MIS 6	79	158	75	139	0	0	7	9	24	30	37	47	21	27
Klasies River, MIS 6	71	159	59	150	0	0	3	4	14	20	46	65	13	18
Florisbad, MIS 6 [B]	70	208	85	198	0	0	4	6	11	16	26	37	36	51
Cumulative MIS 6	**464**	**173**	**81**	**158**	**3**	**1**	**44**	**9**	**98**	**21**	**202**	**44**	**157**	**34**

3.3. MIS 5

For seventeen of the 25 assemblages, short-range hunting appears to have been habitual during MIS 5 (Table 5). This is, however, not the case for the oldest Klasies River MIS 5e [A] assemblage with an age estimate of >110 ka. Here the TCSA results suggest that only long-range weaponry (35%) was in habitual use, supported by the occasional use of maximum- and medium-range weaponry at 29% and 21%, respectively. During the MIS 5d glacial sub-stage, peaking at ~109 ka, the three Klasies River assemblages that indicate habitual short-range hunting (33–50%) also show habitual contact hunting (35–46%). Of these, the Klasies River MIS 5d [C] assemblage also contains artefacts that suggest the occasional use of long-range weaponry (17%), and the Klasies River MIS 5d [D] assemblage the occasional use of medium-range hunting (17%). The Makgadikgadi MIS 5d assemblage from Botswana suggests a preference for habitual contact hunting (43%), occasionally supported by short- and medium-range hunting (29% and 24%). The only MIS 5d assemblage in which medium-range weapons (50%) seem to have been preferred over short-range ones (42%) is that of Gademotta in Ethiopia. The Halibee assemblage, also in Ethiopia, spans the MIS 5d-c transition, and here contact hunting (43%) seems to have been habitual, and short-range weapons (32%) used occasionally.

Table 5. TCSA statistics and frequencies of probable hunting for MIS 5 assemblages (see SOM Data S3 for point TCSA data). Note and interpretative scheme same as for Table 3.

Assemblage	TCSA (mm^2) Summary Statistics				% Probable Hunting Distance (Range in mm^2)									
					Max. ≥30 m		Long ~20–30 m		Medium ~11–19 m		Short ≤10 m		Contact	
	n	Mean	SD	Median	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Prospect Farm, MIS 5-3?	85	144	73	142	4	5	16	19	18	21	37	44	18	20
Klasies River, MIS 5e [A]	48	88	79	62	14	29	17	35	10	21	3	6	6	13
Klasies River, MIS 5d [B]	236	189	94	183	11	5	19	8	29	12	78	33	110	47
Makgadikgadi, MIS 5d	21	183	92	182	0	0	1	5	5	24	6	29	9	43
Klasies River, MIS 5d [C]	46	188	111	175	3	7	8	17	5	11	16	35	20	43
Klasies River, MIS 5d [D]	823	180	76	168	2	0.2	46	6	144	17	412	50	295	36
Gademotta, MIS 5d	24	118	39	108	1	4	2	8	12	50	10	42	2	8
Halibee, MIS 5d-c	47	216	106	202	0	0	2	4	6	13	15	32	20	43
Pinnacle Point 13B, MIS 5c	40	163	77	144	0	0	3	8	10	25	21	53	10	25
Hollow Rock Shelter, MIS 5c [A]	30	150	72	141	1	3	3	10	7	23	19	63	5	17
Bushman Rock Shelter MIS 5c-a	166	146	81	130	6	4	30	18	42	25	60	36	43	26
Pinnacle Point 5-6, MIS 5c	86	151	78	135	1	1	10	12	19	22	41	48	20	23
Aduma, MIS 5c	22	194	108	156	0	0	0	0	9	41	8	36	7	32
Aduma, MIS 5c-b	35	110	45	94	0	0	10	29	17	49	12	34	3	9
Aduma, MIS 5a	25	93	62	73	2	8	12	48	8	32	4	16	2	8
≠Gi Pan, MIS 5a	294	185	62	171	0	0	0	0	19	6	192	65	102	35
Sibudu Cave, MIS 5a [A]	24	103	66	84	1	4	9	38	12	50	7	29	2	8
Diepkloof, MIS 5a	46	128	64	116	1	2	12	26	16	35	19	41	7	15
Blombos Cave, MIS 5a	28	107	54	95	1	4	9	32	13	46	11	39	1	4
Hollow Rock Shelter, MIS 5a-4	56	132	56	119	0	0	8	14	21	38	28	50	7	13
Shinfa-Metema, MIS 5a	26	93	23	99	0	0	7	27	19	73	7	27	0	0
Apollo 11, MIS 5a	33	182	105	153	1	3	4	12	7	21	15	45	11	33
Sibudu Cave, MIS 5a [B]	32	117	53	102	0	0	10	31	14	44	11	34	4	13
Mumba, MIS 5a-4	170	156	64	144	0	0	9	5	51	30	99	58	33	19
Umhlatuzana, MIS 5a	39	89	31	92	3	8	13	33	22	56	8	21	0	0
Cumulative MIS 5	**2482**	**165**	**81**	**150**	**52**	**2**	**260**	**10**	**536**	**22**	**1141**	**46**	**725**	**29**

Between the MIS 5c (peaking at 96 ka) and MIS 5a (peaking at 82 ka) sub-stages the TCSA of six assemblages suggest a combination of habitual short- and medium-range weapon use. These are the Aduma MIS 5c, Aduma MIS 5c-b, Hollow Rock Shelter MIS 5a-4, Diepkloof MIS 5a, Blombos Cave MIS 5a, and Sibudu Cave MIS 5a [B] assemblages (Table 5). Contact hunting seems to have been practiced occasionally throughout this period, except at ≠Gi Pan where a more habitual (35%) use is indicated. The Pinnacle Point 13B MIS 5c assemblage suggests that short-range hunting was practiced habitually (53%) while medium-range, and contact hunting were both occasional (25%). In all the other MIS 5c assemblages (i.e., Hollow Rock Shelter MIS 5c [A], Bushman Rock Shelter MIS 5c-a, Pinnacle Point 5-6 MIS 5c, and Aduma MIS 5c), this same combination of medium-range, short-range and contact hunting seems to have been in play. Hunting with short-range weapons is habitual (36–63%), supported by occasional contact hunting (17–32%), and at Bushman Rock Shelter the additional occasional use of long-range weapons (18%) is indicated. The TCSA results of the Aduma MIS 5c-b transitional assemblage suggest that contact weapons were not used; instead tips best-suited for medium-range weapons (49%) were preferred and habitual, supported by the habitual use of short-range weapons (34%) and the occasional use of long-range ones (29%).

The trend towards longer hunting ranges becomes increasingly apparent during MIS 5a (peaking at 82 ka). Weapon tips best suited for medium-range hunting are now preferred in five of the eleven assemblages, i.e., Sibudu Cave MIS 5a [A], Blombos Cave MIS 5a, Shinfa-Metema MIS 5a, Sibudu Cave MIS 5a [B], and Umhlatuzana MIS 5a (44–73%) (Table 6), and at Shinfa-Metema, Ethiopia, the use of such weapons may have been obligatory (73%). Seven assemblages have TCSA results that suggest that, in addition to short- and medium-range weaponry, hunters now supplemented their arsenals with long-range weapons. In the contexts of the Aduma MIS 5a, Sibudu Cave MIS 5a [A], and Umhlatuzana MIS 5a assemblages long-range hunting becomes habitual (33–48%), and it plays an occasional role in the Diepkloof MIS 5a, Blombos Cave MIS 5a, Shinfa-Metema MIS 5a, and Sibudu Cave MIS 5a [B] assemblages at 27–32%. The ≠Gi Pan MIS 5a assemblage is the only one that lacks artefacts suited for medium- or long-range hunting. Here habitual short-range hunting (65%) seems to have been preferred, supported by habitual contact hunting (34%). Contact hunting is only indicated for two other MIS 5a assemblages: Diepkloof MIS 5a and Mumba MIS 5a-4, at 15% and 19%, respectively (Table 5).

3.4. MIS 4

Apart from the K'one and White Paintings Shelter assemblages, all the bona fide MIS 4 assemblages contain backed pieces that are connected to Afrotropic weapon use. The TCSA results for the assemblages from this period suggest a preference for long-range and maximum-range hunting (Table 6). Hunting at maximum range may have been obligatory at Umhlatuzana (78%) and habitual at Pinnacle Point 5-6 (48%). At Pinnacle Point 5-6 it may have been supported by long- and medium-range hunting (26% and 18%, respectively), but at Umhlatuzana it may have been the only viable option. At Rose Cottage Cave, Klein Kliphuis, Sibudu Cave, Klipdrift and Apollo 11 hunting at maximum range was probably habitual (39–58%). At White Paintings Shelter, Diepkloof and Klasies River people made weapon tips best suited for habitual long-range hunting (41–48%). Only at K'one does contact hunting seem to have been the preferred habitual strategy (38%), perhaps supported occasionally by weapons suited for short-, medium- and long-range hunting (19–29%). Also at Prospect Farm, Kenya, where short-range hunting (44%) may have been the preferred and only habitual strategy, there are TCSA indications for medium- and long-range hunting (19–21%).

Of the assemblages that span the MIS 4-3 transition, the TCSA results for Rose Cottage Cave suggest a preference for habitual long-range hunting (60%), supported by habitual medium-range (43%), and occasional short-range hunting (17%). The other three MIS 4-3 transitional assemblages all show a preference for habitual short-range hunting (38–60%). At Border Cave, habitual short-range hunting (38%) seems to have been supplemented with habitual contact hunting (33%), as well as with occasional medium- and long-range hunting (19–27%), at Umhlatuzana with occasional medium-range (25%) and contact hunting (15%), and at Sibudu Cave with occasional long-range, medium-range, and contact hunting (16–30%) (Table 6).

Table 6. TCSA statistics and frequencies of probable hunting for MIS 4 assemblages (see SOM Data S3 for point TCSA data). Note and interpretative scheme same as for Table 3.

Assemblage	TCSA (mm^2) Summary Statistics				% Probable Hunting Distance (Range in mm^2)									
					Max. ≥30 m		Long ~20–30 m		Medium ~11–19 m		Short ≤10 m		Contact	
	n	Mean	SD	Median	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Prospect Farm, MIS 5-3(?)	85	144	73	142	4	5	16	19	18	21	37	44	18	20
Pinnacle Point 5-6, MIS 4	88	57	58	35	42	48	23	26	16	18	7	8	4	5
Makgadikgadi, MIS 4	46	286	91	280	0	0	0	0	2	4	5	11	40	87
Rose Cottage Cave, MIS 4	84	47	32	39	41	49	27	32	15	18	4	5	0	0
White Paintings Shelter, MIS 4	29	94	31	88	0	0	12	41	17	59	10	34	0	0
Klein Kliphuis, MIS 4	135	52	30	44	53	39	52	39	24	18	6	4	0	0
Sibudu Cave, MIS 4	219	51	44	36	112	51	69	32	28	13	21	10	3	1
Diepkloof, MIS 4	132	58	30	53	42	32	63	48	36	27	13	10	0	0
Klipdrift, MIS 4	31	42	25	35	18	58	11	35	0	0	1	3	0	0
Klasies River, MIS 4	56	59	36	47	18	32	25	45	11	20	8	14	0	0
Apollo 11, MIS 4	57	56	44	51	27	47	18	32	6	11	7	12	1	2
Umhlatuzana, MIS 4	232	24	21	17	181	78	19	8	7	3	4	2	0	0
K'one, MIS 4	21	163	48	153	1	5	4	19	4	19	6	29	8	38
Border Cave, MIS 4-3	52	178	100	153	0	0	10	19	14	27	20	38	17	33
Umhlatuzana, MIS 4-3	20	148	59	150	0	0	2	10	5	25	12	60	3	15
Sibudu Cave, MIS 4-3	44	144	75	140	0	0	7	16	13	30	25	57	7	16
Rose Cottage Cave, MIS 4-3	35	78	33	75	2	6	21	60	15	43	6	17	0	0
Cumulative MIS 4	**1366**	**74**	**74**	**48**	**478**	**35**	**379**	**28**	**232**	**17**	**192**	**14**	**99**	**7**

3.5. MIS 3

The results for the Prospect Farm, MIS 5-3? Assemblage, and the four South African MIS 4-3 transitional assemblages also pertain to this section, and we do not repeat those results. For all the bona fide MIS 3 assemblages, medium-range hunting is indicated (Table 7). TCSA results for the Mumba MIS 3 [A], Nasera, Porc-Epic, Goda Buticha, Umhlatuzana, Gorgora MIS 3 [A], and Mumba MIS 3 [B] assemblages suggest that such hunting was practiced habitually in these contexts (33–57%). The Sibudu Cave, Fincha Habera, Gorgora MIS 3 [B] and [C], and Holley Shelter results suggest occasional use of medium-range weaponry (18–30%). For several MIS 3 assemblages short-range hunting was also habitual, and perhaps even preferred, e.g., Sibudu Cave, Mumba MIS 3 [A], Gorgora MIS 3 [A] and [C] (34–60%). In the context of Gorgora MIS 3 [B] and Holley Shelter, it may have been obligatory (58–67%), and the only other feasible strategy was occasional medium-range hunting (21–22%). Habitual long-range hunting is suggested for the Nasera, Porc-Epic, Fincha Habera and Goda Buticha assemblages (33–50%), and at both Porc-Epic and Fincha Habera long-range hunting may have been the preferred strategy. Occasional long-range hunting is indicated for the Sibudu Cave, Mumba MIS 3 [A], Gorgora MIS 3 [C], and Mumba MIS 3 [B] (15–25%) assemblages. At Nasera in Tanzania, our results suggest occasional hunting at maximum range (17%) with stone-tipped weaponry during the period, and Fincha Habera is the only MIS 3 context in which hunters probably practiced a combination of habitual long-range (45%) hunting paired with hunting at maximum range (36%) (Table 7).

Table 7. TCSA statistics and frequencies of probable hunting for MIS 3 assemblages (see SOM Data S3 for point TCSA data). Note and interpretative scheme same as for Table 3.

Assemblage	TCSA (mm²) Summary Statistics				% Probable Hunting Distance (Range in mm²)									
					Max. ≥30 m		Long ~20–30 m		Medium ~11–19 m		Short ≤10 m		Contact	
	n	Mean	SD	Median	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Prospect Farm, MIS 5-3?	85	144	73	142	4	5	16	19	18	21	37	44	18	20
Border Cave, MIS 4-3	52	178	100	153	0	0	10	19	14	27	20	38	17	33
Umhlatuzana, MIS 4-3	20	148	59	150	0	0	2	10	5	25	12	60	3	15
Sibudu Cave, MIS 4-3	44	144	75	140	0	0	7	16	13	30	25	57	7	16
Rose Cottage Cave, MIS 4-3	35	78	33	75	2	6	21	60	15	43	6	17	0	0
Sibudu Cave, MIS 3	100	119	66	104	9	9	23	23	33	33	34	34	14	14
Mumba, MIS 3 [A]	317	126	47	120	3	1	46	15	122	38	190	60	26	8
Nasera, MIS 3	24	78	36	79	4	17	8	33	11	46	4	17	0	0
Porc-Epic, MIS 3	403	94	51	81	21	5	181	45	152	38	109	27	14	3
Fincha Habera, MIS 3	22	51	20	43	8	36	10	45	4	18	0	0	0	0
Goda Buticha, MIS 3	20	81	35	78	1	5	10	50	10	50	3	15	0	0
Umhlatuzana, MIS 3	23	125	48	108	0	0	3	13	11	48	11	48	2	9
Gorgora, MIS 3 [A]	21	133	41	120	0	0	1	5	9	43	12	57	2	10
Gorgora, MIS 3 [B]	24	139	42	143	0	0	3	13	5	21	14	58	2	8
Gorgora, MIS 3 [C]	93	126	51	121	1	1	20	22	28	30	45	48	12	13
Mumba, MIS 3 [B]	28	109	45	101	1	4	7	25	16	57	11	39	2	7
Holley Shelter, MIS 3	45	144	49	136	0	0	5	11	10	22	30	67	6	13
Cumulative MIS 3	**1356**	**119**	**60**	**108**	**50**	**4**	**373**	**27**	**476**	**35**	**573**	**42**	**124**	**9**

4. Discussion

We know of no hunter groups in the Afrotropics that rely only on a single weapon type or hunting range. Instead, historical and current hunters all use an array of weapons 'each according to need and fashion' [40] (see also [16,52,53]). The results presented above demonstrate how our approach is able to highlight probable variation in the hunting ranges and stone-tipped arsenals of ancient Afrotropic hunters. Such variation may indicate adaptive advantages in variable socio-ecological contexts. We started out with a three-pronged research question: (a) Can we generate a feasible chronology for the evolution of long-range, stone-tipped weapons in the Afrotropic? (b) Was there spatiotemporal variability in the use of hunting ranges during the Middle Stone Age? (c) If so, can we suggest testable hypotheses about the different adaptive advantages? Before we address these questions, we find it imperative to highlight how our current study reinforced or constrained previous interpretations about the development of long-range hunting in the Afrotropic Middle Stone Age.

4.1. Previous Interpretations of Long-Range Hunting Tested and Constrained

Previous suggestion for the early use of javelins [24] suffered from the lack of African comparative data. We rectified this here, showing that before ~280 ka, hunters at Gademotta probably used short-range weapons habitually, similar to the Ethiopian heavyweight hunting javelins. They still did so by ~280–260 ka, but now started to also experiment occasionally with medium-range javelins, similar to the Ethiopian long-narrow-tipped ones. Early javelin hunting in the Gademotta Middle Stone Age is therefore supported but does not include hunting with long-range javelins. Javelin hunting was also suggested for southern Africa by ~191–130 ka [18]. Our results suggest habitual hunting with short-range weapons resembling heavier southern African assegais or Ethiopian heavyweight hunting javelins, supported by occasional medium-range hunting. We found a possible indication of occasional long-range weapon use, with tips such as those of the Ethiopian versatile- or the southern African San javelins, in only one assemblage dating to this phase. Thus, again javelin hunting is supported, but long-range hunting is not necessarily implied.

Long-range spearthrower-and-dart hunting was inferred for the Aduma ~90–80 ka context [6,7]. Our results support an interpretation of occasional long-range javelin hunting by ~91 ka without having to invoke American hunting weapon systems. By ~80 ka, hunting with long-range javelins, similar to the Ethiopian versatile ones, seems to have been habitual at Aduma. Using our approach, we did not find support for maximum-range hunting at Shinfa-Metema by ~74 ka (but see [9]). Instead, our results suggest that medium-range hunting with weapons reminiscent of the Ethiopian long-narrow-tipped hunting javelins is the most parsimonious ballistic interpretation. Long-range and/or bow hunting was also suggested for southern Africa by ~71–59 ka [19,21], which is supported by our TCSA results. Long-range hunting is inferred to have existed at Porc-Epic ~50–40 ka [8]. Our results confirm habitual long-range hunting with weapons more similar to the versatile Ethiopian hunting javelins than to American-like spearthrower darts for this context.

4.2. Chronology of Long-Range, Stone-Tipped Weapons in the Afrotropics

With the TCSA statistic as a middle-range tool, we used Afrotropic weapons with known, real-life, effective hunting ranges to interpret the probable hunting ranges of a large quantity of Middle Stone Age pointed artefacts. This approach resulted in the following working chronology for the evolution of long-range, stone-tipped weapon use in the Afrotropics:

- ≥MIS 8 glacial (≥243 ka): Hunters before ~464 ka used contact weapons whilst starting to experiment with throwing them over short distances of up to ~10 m. Such short-range hunting with stone-tipped weapons became part of mainstream hunting behavior by MIS 8 (~300–243 ka). By that time, hunters started to experiment with medium-range hunting by throwing their weapons over distances of up to ~19 m. Currently, true long-range stone-tipped weapons that can be used effectively over distances of ~20–30 m do not seem to have been part of the Afrotropic arsenal before or during MIS 8.
- MIS 7 interglacial (~243–191 ka): No data meeting our chronological and sample size criteria.
- MIS 6 glacial (~191–130 ka): Short-range hunting with stone-tipped weapons remains part of the strategy, but this is relatively consistently paired with both contact- and medium-range hunting. These hunters may have used two or three spear/javelin types according to circumstance. In some instances, they started to experiment with long-range javelins. Whilst javelin hunting is indicated, long-range hunting was not a mainstream hunting strategy during MIS 6.
- MIS 5 (~130–71 ka): This stage is characterized by alternating interglacial and glacial sub-stages. The MIS 5 hunters seem to have continued with the three-weapon arsenal wherein up to the MIS 5c interglacial sub-stage (peaking at ~96 ka), short-range hunting was often mainstream. Subsequently, there is a shift at several sites towards medium-range hunting becoming a mainstream strategy. During the final MIS 5a interglacial substage (peaking at ~82 ka), long-range hunting becomes mainstream in tandem with medium-range hunting at some sites. MIS 5 is therefore the first time during which long-range hunting weapons became part of the everyday Afrotropic hunting arsenal.

- MIS 4 glacial (~71–57 ka): During this phase, long-range javelin hunting becomes regularly paired with hunting at maximum distance (e.g., bow hunting) in southern Africa. This geographic patterning is preliminary because dated Middle Stone Age assemblages with backed artefacts from elsewhere in the Afrotropics were not available for our study. It is, however, reasonable to hypothesize that MIS 4 Afrotropic hunters were able to hunt effectively across all the effective ranges to fit their respective needs, ecologies, and socio-cultural traditions.
- MIS 3 interstadial (~57–29 ka): Hunting at maximum distance with stone-tipped weaponry becomes rare during this stage. Instead, there is a general return to mainstream hunting with a combination of long-, medium- and short-range spears/javelins, especially in southern Africa. That said, after ~40 ka bone points similar to those used by southern African San hunters as arrowheads appear in greater numbers at several sites (e.g., [54,55]). The seeming reversion in stone-tipped hunting weaponry may thus in part reflect a shift in the use of arrow-tip materials, instead of a socio-cognitive regression. If this was the case, preservation issues may hamper our ability to detect Afrotropic maximum-range hunting post-MIS 4. The apparent reversion may also reflect the geographical range expansion (e.g., from the Rift Valley into ecotonal margins and montane habitats) and adaptive plasticity suggested for this period in such regions with very diverse ecogeographic features [56–58].

The above represents our best-fit, broad, and parsimonious chronology for the evolution of long-range, stone-tipped weapon use in the Afrotropics. It speaks to a co-evolutionary hypothesis wherein the evolution of long-range hunting was a relatively long, incremental, multi-faceted, and continuous process, with the technical aspects thereof probably invented and re-invented throughout the last 500 ka. Apart from the lithic record, other characteristics would have also contributed to the human ability to hunt from a distance. For example, the evolution of the human 'throwing arm and shoulder' (e.g., [59]), which would have played a role in our ability to cast long-range javelins effectively. Accurate long-range hunting also requires the necessary visuospatial integration, that synchronizes "inner and outer functional processes, organizing spatial, temporal, and social interactions between the brain, body, and environment" [60]. Palaeo-neurological studies suggest that this capacity was probably within the current modern human range only by ~100 ka (e.g., [61]).

All these aspects developed at different rates during different stages throughout human evolution, needing to come together with the archaeological record to allow for a robust chronological interpretation. It is our current hypothesis that experimentation with long-range weapons became feasible (physically, cognitively, and technologically) since MIS 6, but that it was the variable climatic conditions of MIS 5 that pushed it into a mainstream Afrotropic hunting behavior. Being thus prepared, the challenges of the MIS 4 glacial then stimulated the development of bimanual, mechanically projected weapons that are effective at distances of >30 m. Once this stage was reached, Afrotropic hunters had the capacity to invent, reinvent, produce, and use the full stone-tipped weapon arsenal across all hunting ranges according to their respective socio-ecological contexts.

4.3. Spatiotemporal Variability in Hunting Ranges During the Afrotropic Middle Stone Age

In the section above we provided a simplified temporal scheme, but our results section demonstrated intra- and inter-assemblage variability in Middle Stone Age hunting ranges. Some of this variation may reflect specific ecological, demographic and/or social settings. We cannot explore each of the 66 assemblages in detail here—some of that is planned for future research—and we acknowledge the lack of data for large portions of the Afrotropics. Instead, we use the K'one (Amhara, Ethiopia) and Sibudu Cave (KwaZulu-Natal, South Africa) MIS 4 assemblages to illustrate how certain aspects may contribute to inter-assemblage variability in stone-tipped weaponry and hunting ranges.

In the Ethiopian Rift Valley, ~12 km west of Lake Besaka, gully erosion exposed horizontal beds of alluvium, volcanic ash, and fossil soils [62,63], one of which contained the small assemblage of obsidian points included in our study (Figure 2). The open-air site at ~1600 m.a.s.l. in a geologically active landscape >400 km away from the nearest coastline, is currently located in a savanna (open-canopied) woodland, nestled between montane forests. During the MIS 4 glacial the vegetation was probably scrubland, with access to pockets of savanna woodland [64]. Although undated, Kurashina [65] and Clark and Williams [62] placed the assemblage in the loam of the arid upper Pleistocene at ~70–60 ka [66].

Figure 2. Top left: A satellite image of the immediate K'one landscape today with the caldera plateau to the east and a land bridge separating the larger and smaller calderas northeast of the site (red pin) that may have functioned as a natural game funnel. Top right: The steep-walled caldera rim. Bottom left: The Middle Stone Age excavation on the flank of the K'one volcanic edifice (Site photos by Williams [63]). Bottom right: Points from the K'one MIS 4 context.

K'one was probably an obsidian knapping station, where Kurashina (1978) recognized three high-density patches of flaked stone artifacts, indicating prolonged or intense stone knapping activity, perhaps by several knappers. Only rejected or lost pieces would remain on the workshop floor, but these (at least partly) represent artefacts manufactured at the site [65], to be transported and used elsewhere. The K'one obsidian source is temporally and geographically the most widely represented source in MIS 6 to MIS 3 assemblages across the Afar and Main Ethiopian Rift [67]. Depending on how long their obsidian collecting and knapping sessions lasted, the knappers may have hunted near the site. Our results suggest that tips best suited for contact hunting was the preferred and only tips in habitual use at K'one during MIS 4.

Today, Ethiopian hunters use weapons with such tips to strike at cornered, large and dangerous prey [16]. The narrow corridor ~3 km northeast of K'one, cutting through the caldera plateau (Figure 2), would provide the opportunity to trap passing herds. The landscape is also conducive of driving hunts with medium/long-range javelins, sending animals to plummet over the plateau edge onto the scrubland where they could be killed from up close. Habitual long-range hunting, or maximum-range bow hunting may not have provided adequate adaptive advantages on this cold and arid landscape or may have been too costly and/or cumbersome to maintain for the people who visited the site for short stays to collect raw-material for knapping. For example, bow staves and strings operate under tension and are weather sensitive, so that they may snap in extreme cold and arid conditions, increasing risk of wear and failure and costing much in maintenance [68,69]. As an open-air site, K'one has poor organic preservation so that there is not much fauna to assess these hypotheses, but if it was very cold or frozen during MIS 4 bow-hunting may have been difficult on this landscape.

By contrast, Sibudu is a large rock shelter, with a deep occupational sequence and excellent organic preservation ~15 km inland of the Indian Ocean at ~100 m.a.s.l. (Figure 3). The riverine habitat below the site was likely relatively persistent throughout the Middle Stone Age, and the mosaic of surrounding habitats could support a wide range of fauna [70]. MIS 4 botanical remains imply elevated levels of water availability and humidity in a closed forested environment with a woodland/savanna landscape in the vicinity [71,72]. According to Clark [73] Sibudu provides the largest MIS 4 faunal sample for South Africa, representing a diverse prey range (indicated as HP in SOM Data S1).

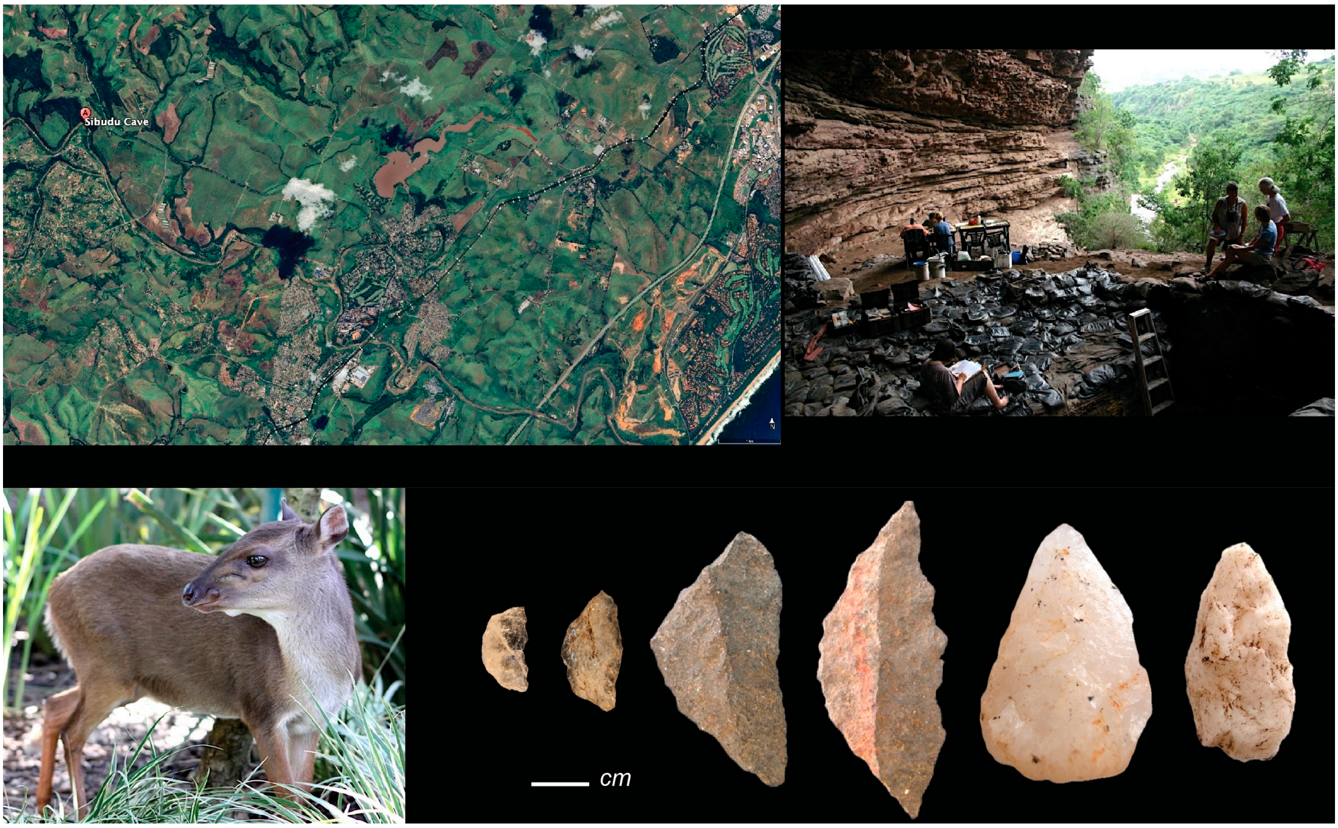

Figure 3. (**Top left**): The greater Sibudu Cave landscape today. (**Top right**): View of the surrounding landscape from within the large rock shelter. (**Bottom left**): A blue duiker, the most hunted species during MIS 4 at Sibudu (photo Derek Keats, CC BY-SA 2.0). (**Bottom right**) backed artefacts and quartz points used for hunting at Sibudu (for use-wear and residue analyses of these artefacts see [11,12]).

The most common species-level identifications are the blue duiker and bushpig, both of which prefer forested habitats, and taphonomic data confirm humans as the primary contributors [73]. Blue duiker (Figure 3) may have been captured using nets or remote capture technology such as traps or snares (e.g., [70]), but some Mbuti hunters hunt duikers—an important species in their dietary ecology—with unpoisoned arrows. Individual bow hunting is their habitual pattern, but they often also hunt in groups with their bows and arrows. Terashima [74] sees such group hunting as an archery activity with socio-economic implications wherein at least five or six hunters are needed to be effective, most Mbuti archer bands therefore consist of five to twelve families. The same hunters also use spears and/or javelins for hunting large animals such as elephant and buffalo, the yield of which is great if successful. Hunting large game with spears/javelins, however, involves such great risk that the Mbuti only do it occasionally and in a group [75].

Our TCSA results indicate that hunting at maximum range was probably the preferred and habitual strategy practiced at Sibudu during MIS 4. Bow hunting could be effective for a variety of animal sizes, including the small blue duiker, and is supported for the MIS 4 at Sibudu by use-trace and residue analysis, as well as experimental work (e.g., [11,12]). This flexible strategy—in terms of range, prey type, ecology and group size [18]—seems to have been a mainstream behavior amongst the Sibudu MIS 4 hunters. Similar to the Mbuti forest hunters, regular bow hunting in the forests around Sibudu may have afforded them certain adaptive advantages—more so than hunting from other ranges or with other stone-tipped weapons. Resembling current San hunters from southern Africa who always carry leather bags containing a bow-and-arrows and a spear/javelin so that they are prepared for any type of hunting (e.g., [53]), our TCSA results suggest that the Sibudu hunters too may have had their long-range javelins at the ready.

By MIS 4, all Afrotropic populations were modern *Homo sapiens*. We may therefore assume that both groups had well-developed throwing arms/shoulders (e.g., [59]), the neuro-cranial morphology for visuospatial integration over a distance (e.g., Bruner et al. [61,76]), and the neuro-genetic adaptations to pay attention in the complex ways necessary for bow hunting [77]. We therefore used these two assemblages with very different TCSA results to highlight how other factors may have contributed to such concurrent variability in hunting ranges and weaponry. These factors may include, amongst other things: (a) Whether assemblages come from open-air or sheltered deposits; (b) site function; (c) ecological conditions; (d) geography (topography, elevation, distance from a coastline); (e) organic preservation; and (f) group size.

4.4. Adaptive Advantages of the Different Hunting Ranges

Each of the hunting ranges increases the space between hunter and prey animal by ~10 m, which may have had broad spatiotemporal as well as specific contextual adaptive advantages. For example, bimanual thrusting spears (with or without stone tips) used for contact hunting currently represent the oldest recognizable, purpose-made hunting weapons. They were used by Neanderthals and/or *Homo heidelbergensis* in Eurasia, and both *Homo heidelbergensis* and *Homo sapiens* in the Afrotropics. Their sharpened tips (wood or stone) would allow for wounding and weakening prey animals more effectively, compared to attacking prey with un-modified objects. Hunters can apply their full bodily force to these robust weapons, doing maximum damage up close. Afrotropic thrusting spears are ~2 m long, so that used as a contact weapon there is still more than an arm's length between hunter and prey. Any kind of spear hunting, especially contact and short-range hunting, is ineffective and very dangerous for the lone hunter. Early spear hunting therefore required group hunting, and for many types of large game, return rates increase meaningfully when hunting occurs in a group [78]. Group hunting demands the development of some social cooperation, a key feature in human evolution (e.g., [79]). Our TCSA analysis highlights contexts wherein contact hunting in group may have played occasional, habitual, or obligatory roles through time and across the Afrotropics.

Short-range hunting weapons, resembling the heavier southern African assegais or Ethiopian heavyweight hunting javelins, are dual-purpose. They are sturdy enough to stab directly into an animal without losing the weapon, but could also be thrown effectively up to ~10 m. What is more, because their shaft diameters are small enough to allow effective single-handed use, hunters can carry a second weapon or shield as backup or protection. Having a single weapon that can both stab and be thrown would further stimulate strategic planning and cooperation within a hunting party. The communal success of such dual-purpose, social weapon-use strategies may explain why stone points resembling heavyweight assegais are so prevalent and spatiotemporally well represented in the Middle Stone Age Afrotropics—and why they remained a preferred hunting and warfare weapon until recent times [16,17]. During MIS 3 it may have become obligatory to conduct short-range hunting with such weapons at sites such as Gorgora in Ethiopia and Holley Shelter in South Africa, indicating that similar hunting success was difficult for these hunters to obtain with other stone-tipped hunting strategies. Alternatively, their socio-cultural contexts may have caused them to suffer serious adverse consequences, such as difficulty in finding mates for pair bonding or lack of social status, if they were not successful in the social, short-range hunting forays.

Medium-range hunting, with weapons such as the Ethiopian long-narrow-tipped hunting javelins and smaller assegais from South Africa, is especially useful for wounding animals during ambush hunting from distances of up to 19 m. They bring with them a meaningful increase in the distance between hunter and prey with less risk of danger/injury. Their relatively small shaft diameters also means that hunters can now carry up to three backup javelins in their non-throwing hands. Such hunting still relies on group hunting with its socio-cultural implications. In many instances throughout the Afrotropic Middle Stone Age our TCSA results indicate habitual combinations of short-range and medium-range hunting. For such groups it may imply an increased specialization in structured group hunting, wherein different hunters carried different weapons for their respective roles during the hunt, stimulating collective strategizing and risk management.

Our work with current javelin hunters shows that true long-range hunting, at distances that reach that of American dart hunting, can be achieved with hunting javelins. Such hunting further increases the effective hunting distance but does not necessarily require the invention of a mechanical propulsion technology. Yet, by being able to hunt from distances similar to those reached by American spearthrowers, Churchill and Rhodes [1] predicted that Middle Stone Age hunters were able to broaden their prey range and change their prey-choice economics. For example, long-range hunting is more effective on open landscapes, allowing hunters to exploit new hunting grounds and prey types, widening their subsistence economics and diet breadth [1]. The relative safety associated with long-range hunting of up to ~30 m, also allows for smaller hunting parties, compared to other spear/javelin hunters. Hunting-group sizes can thus become more flexible, and able to wax and wane with changes in ecological carrying capacity and social-organization patterns.

The adaptive advantages of bow hunting were recently summarized ([18] and references therein). First, it allows for maximum-range hunting in open and/or desert landscapes but can also be used over shorter distances in closed forested ecologies. Whilst spear/javelin/dart hunting is most effective for disadvantage and ambush hunting, bow hunting is effective for disadvantage, ambush, approach, pursuit and encounter hunting. Many arrows can be carried in a quiver during a hunting foray, allowing for more shots per trip, longer search times, and distance running. Bows can be re-loaded and fired multiple times in quick succession, from a concealed position, increasing the success rate for small groups and individual hunters. Bow hunting has a relatively high success rate, so that large sharing groups are unnecessary. Cumulatively, the adaptive advantages of bow hunting allow for complete flexibility in group size, prey type, landscape and movement across most ecological boundaries.

We suggest that these hypotheses about the adaptive advantages of the different hunting ranges are all testable from different angles for most of the assemblages presented in this study. Such work may include contextual use-trace studies, the alignment of hunting ranges with faunal assemblages, the assessment of landscapes and ecologies in terms of best-fit hunting ranges, and the estimation of group sizes and mobility—to name but a few.

Lastly, hunting with stone-tipped weaponry, although important during the Middle Stone Age, was not necessarily an obligatory behavior. Animal proteins can be gained through foraging (e.g., eggs, insects, reptiles), fishing and seafood gathering, or scavenging. Our results, however, show that it was a flexible, habitual practice throughout the Afrotropic Middle Stone Age wherein hunters could adapt their hunting ranges and weapons to reap the best fitness rewards within their specific biocultural and socio-ecological settings. This would be similar to Shea's [46] (p. 209) example of cooking as a habitual behavior amongst living humans, wherein: "Cooking is something people do more or less constantly with variable periodicity and intensity. One can microwave, roast, fry, or boil pretty much any foodstuff or eat it raw, but the costs of using one or another such method and the calories one obtains by doing so vary situationally".

5. Conclusions

With this contribution we demonstrated that it is not necessary to invoke American-like spearthrower-and-dart hunting to discuss the evolution of long-range hunting in Africa. Instead, in the most comprehensive study of its kind to date, we used knowledge gained from current/recent Afrotropic hunters and the data of their weapon tips as a more appropriate middle-range proxy for hypothesizing about Middle Stone Age point assemblages from the same biogeographic realm. We confirmed that the range of some African hunting javelins can match the approximate effective distances of spearthrower-darts in real-life hunting contexts—representing true long-range hunting. However, we also showed that not all 'javelins' are equal, and that some may have served dual stabbing-throwing purposes or represent medium-range hunting. The new hunting-range TCSA approach provides a statistically robust scheme to distinguish between stone tips best suited for each hunting range ballistically. No hunters from the Afrotropics are known to use a single weapon or hunting range only. We therefore used an approach that facilitates thinking about proportional use of different weapon tips and their associated best-fit hunting ranges within each assemblage. Considering these proportions in occasional-habitual-obligatory terms highlighted probable adaptive advantages associated with the weapon sets used in each context that can now be tested with future research.

Whilst many factors had to come together for humans to be able to practice long-range hunting with stone-tipped weapons effectively, the summary of our results show that: (a) long-range hunting with stone-tipped weapons was probably not practiced in the Afrotropics before or during MIS 8 that ended by ~243 ka; (b) experimentation with long-range javelins—similar to those used by current Ethiopian hunters—may have started during MIS 6 after ~191 ka; and (c) such hunting probably became part of the everyday Afrotropic hunting arsenal by the end of MIS 5 at ~85 ka. Lastly, it is important to consider that each hunting range and weapon-delivery system comes with its own adaptive advantages. Thus, the human ability to hunt over long- or maximum-range distances with stone-tipped weapons did not necessarily always replace hunting over shorter distances. Instead, since MIS 4, it provided Afrotropic hunters with the full spectrum of hunting ranges and stone-tipped weaponry to hunt effectively in all socio-ecological settings.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/quat7040050/s1, SOM Table S1: Examples of use-trace and direct evidence for the use of pointed and backed stone artefacts from the Middle Stone Age as tips and/or barbs for hunting weapons; SOM Table S2. Assemblages, age estimates and associated MIS stages for stone point assemblages included in this study arranged from the oldest to the youngest. Assemblages from the same sites with different age estimates, but within the same MIS stage are provided with [A, B, C, D] appendages to distinguish between them. See Figure 1 for site location and SOM 3 for TCSA data; SOM Data S1: Some Middle Stone Age Afrotropic faunal assemblages; SOM Data S2: Weapon tips of known range used to set TCSA hunting-range standards; SOM Data S3: Assemblages in cluded in this study with TCSA values in mm^2.

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