Supplementary Information for

No sustained increase in zooarchaeological evidence for carnivory after the appearance of *Homo erectus*

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Datasets and Methods

The number of modified bones from each zooarchaeological assemblage in Dataset S1 was recorded from published literature. This number includes bones with high confidence (see below) bone surface modifications (cut and/or percussion marks) but does not include other indications of butchery activity such as percussion notches, bone flakes, or fracture patterns. In cases where a zooarchaeological assemblage has been analyzed and published by multiple researchers or research groups, we have used the number of modified bones reported in the most recent publication (e.g. for FxJj50, Koobi Fora—Domínguez-Rodrigo, 2002 (1)), or the publication(s) which included the most comprehensive study of butchered bones (e.g. for DK 3, Olduvai Gorge—Potts, 1988 (2), since Potts was also able to study the equids which were not included in later analyses; for FLK Zinj, Olduvai Gorge—Blumenschine, 1995 (3) for percussion marks and Bunn and Kroll 1986 (4) for cut marks). When the exact number of butchered bones was not specified in the relevant publication (e.g. KGA 10 in Echassoux, 2012 (5) and BOU-VP-12 in de Heinzelin et al., 1999 (6)), we included only those bones for which the butchery marks were described in detail or included in publication figures.

For each assemblage, BP evaluated the confidence of the researchers who published the data (low, medium, or high) in identifying bone modifications as butchery (cut and/or percussion) marks, and we excluded low confidence butchery marks from our analysis. We did not make our own judgements on whether particular marks represent butchery marks, but rather we excluded from our analyses possible butchery marks from four sites for which the researchers themselves expressed low confidence. These include:

- **A.L. 666, Ethiopia**: Kimbel et al. (1996: 557) (7) state, “Some specimens preserve traces of carnivore and possibly hominid-induced modification. The excavated faunal remains are limited to three specimens, including a fragment of a small bovid scapula that exhibits what may be a stone tool cut mark.”

- **Lokalalei 1A, West Turkana, Kenya**: Kibunjia (1994:165) (8) states, “In the entire assemblage, only two specimens, both recovered in situ, have what may be stone tool cut marks. These are a thoracic vertebra of a size 2 bovid and a near-epiphysial long bone shaft fragment from a size 2 mammal. The possible cut-mark on the latter specimen is located on the cortical surface, away from the epiphysial end. In addition, a long bone shaft fragment of a size 1 or 2 mammal has a possible percussion groove and a carnivore tooth pit. The bone fragment itself resembles an “anvil wedge”, a characteristic product of hammerstone breakage of long bones.”

- **FxJ18IH from Koobi Fora, Kenya**: Bunn (1997:412) (9) states, “One of the limb shaft fragments from a size-3 mammal has probable cut marks on it.”

- **Naiyena Engol 2, Kenya**: Roche et al. (2018:64) (10) state, “Marks on bones are rare and all are from surface shaft fragments. One mark is attributed to a carnivore, two are dissolution pits (from insect/termite action, or roots), and one is attributed tentatively to hominin action on a shaft from a size 3 bovid. This has short parallel striations, disymmetric in section with one relatively abrupt side, and is interpreted as chop marks produced by several blows inflicted with a sharp stone tool.”

Because multiple stratigraphically identifiable levels from the same site are sometimes published separately, and discrete levels could in some cases reflect discrete occupational horizons, we followed the conventions of each publication in keeping levels separate when they were published separately.
We analytically combined multiple levels within a site and conducted distinct sets of analyses (i.e., sites versus levels) in an effort to control for variation in publication strategy.

JR compiled a presence-absence matrix of fossil mammal assemblages from eastern African Plio-Pleistocene paleontological sites spanning the same temporal (3.4-1.2 Ma) and spatial (Ethiopia, Kenya, and Tanzania) extent as our zooarchaeological dataset (see Table S2 and Dataset S2). Almost all assemblages derive from species-level taxonomic lists (see references in Table S2) of geological members and submembers (e.g., the Okote Member of the Koobi Fora Formation, Kenya, the Kada Hadar 2 submember of the Hadar Formation, Ethiopia). Confirmation of species occurrences (n=487 species total) for each assemblage were cross-referenced when possible (e.g., by other publications or consultation with experts in the systematic paleontology of a particular group), and all taxonomic names were updated following the treatments in Werdelin and Sanders (2010) or using more recent publications when possible. Each assemblage was assigned a minimum and maximum age based on absolute dating methods and, very rarely, biochronological or other correlative methods. Because the vast majority of fossil species occurrences cannot be dated more precisely than the assemblages from which they derive, species are assumed to be present throughout the published time interval of the overall assemblage.

Analytical Ages and Binning

Minimum and maximum ages for zooarchaeological levels based on dated stratigraphic marker beds were obtained from numerous references in Dataset S1. When authors indicated an interpreted age for a level based on stratigraphic scaling, we accepted this analytical age. When authors did not provide an analytical age, we used the midpoint between the minimum and maximum ages as our analytical age. We divided the period from 3.4 – 1.2 Ma into bins with a duration of 100 kyr. If the analytical age of a site fell on the boundary between intervals, it was assigned to the younger bin. In order to treat the paleontological assemblages in an analogous way to the zooarchaeological sites, the bin interval was considered “closed” on the maximum age side and “open” on the minimum age side. Thus, a paleontological assemblage with a maximum age equal to the minimum age of a bin was considered to belong to that bin, but a paleontological assemblage with a minimum age equal to the maximum age of a bin was excluded from that bin.

Proxies for carnivory and paleontological sampling

As our proxies for the amount of evidence of carnivory in each bin, we summed the total number of published modified bones across all levels (totalmod) and counted the number of discrete zooarchaeological sites (nsites) and levels (nlevels).

As proxies for how well the fossil record has been sampled across the region, we calculated the number of paleontological sites (npaleo) and the taxonomic richness (richness) of large (>18 kg) mammal species represented in the fossil record. It is well documented that sampling effort is a major determinant of observed species richness in fossil samples, with greater sampling effort (e.g., more specimens, more localities) leading to the recovery of more species (11–14). It follows that time bins with elevated species richness have yielded more fossils and/or more fossil-bearing localities. Our expectation is that this translates to greater potential for preservation and recovery of zooarchaeological assemblages.
We note that the use of richness as a proxy for paleontological sampling effort assumes that the shape of the underlying species abundance distribution (SAD) is consistent across time bins (i.e., different SADs will yield different richness values for a given number of sites or fossils). If a time bin’s SAD is more even, this would inflate richness for a given number of sites/fossils (11), which would cause the residual evidence of carnivory (REC) to decrease, assuming that the carnivory proxy value stays the same. On the contrary, a less even SAD would cause REC to increase. Therefore, the only way temporal changes in the underlying SAD would distort what would otherwise be a sustained REC increase after 1.9 Ma is if the valleys in Fig. 3 coincided with times of more even SADs. This is an extremely specific bias, which we have no a priori reason to believe to be true.

**Treatment of regression data**

We square root transformed all variables to more closely approximate linear relationships between the dependent and independent variables and used ordinary least squares (OLS) to quantify the linear relationship between each of the paleontological sampling predictors (richness and npaleo) and each of the zooarchaeological proxies for carnivory (totalmod, nsites, nlevels) summarized in Fig. 2 and Table S1. These regressions were not constrained through the origin because while we expect richness and zooarchaeological sampling effort to be positively correlated, it is possible for there to be zero evidence for carnivory even when richness is not zero (see the pre-2.6 Ma interval in Fig 2).

The time interval from 3.4 – 2.6 Ma was excluded from these regressions and all subsequent analyses because all but one time bin contain no evidence of hominin carnivory. Species richness is a better predictor than npaleo for all three carnivory proxies, so we focus on richness as our best metric of paleontological sampling. Residuals from these regressions served as our proxies for carnivory relative to paleontological sampling given in Fig. 3. The better performance of richness as a predictor of carnivory proxies as compared to npaleo is likely because richness is a more sensitive metric of sampling effort than npaleo. For example, the addition of one paleontological assemblage adds 1 to npaleo, regardless of whether the paleontological assemblage contains 2 previously unsampled species (contributing 2 to richness) or 50 previously unsampled species (contributing 50 to richness). For this reason, npaleo is a cruder proxy of sampling effort than richness.

For the analyses of site size, we regressed nlevels against nsites, totalmod against nsites, and totalmod against nlevels. All variables were square root transformed prior to these regressions to more closely approximate linear relationships. These regressions were constrained to pass through the origin because these are all nested zooarchaeological variables, so totalmod must equal zero when nlevels=0 and nlevels must equal zero when nsites=0.

**Sensitivity analysis**

In order to evaluate the impact of time bin duration on our analyses, we re-ran all analyses with time bins increasing from 80 kyr to 200 kyr in 5 kyr increments. The resulting REC values are plotted in Figure S2. The major temporal patterns are preserved, regardless of which bin width is used.
Lithics versus modified bones

Because stone tools are an important part of hominin dietary adaptations, we collected all available published data on the count of lithics (excluding shatter/debitage) from the same 59 levels for which the zooarchaeological data derive (see citations in Dataset S1). We tabulated the total number of stone tools from each level as a simple metric capturing the overall size of the lithic record. We then regressed the total number of modified bones in each 100-kyr bin against the count of lithics in each bin. The results of this regression are provided in Fig S4 (p=0.005, r²=0.501, slope=0.167).

Code to make plots and run regressions

The code for creating most plots and running the regressions is available on WAB’s github account at https://github.com/wabarr/carnivory-prevalance-public Figure S2 is the only figure not directly produced by this distributed code, as to do so would require the unwieldy distribution of 25 distinct datasets which would differ only in the bin width used.

Supplementary Text

Hominin taxonomic diversity in the Pleistocene

There were at least four hominin species (15) in eastern Africa at 1.9 Ma, so it is unclear that H. erectus was the only, or even the primary, hominin modifying bones with stone tools. Despite this taxonomic diversity, if H. erectus exhibited elevated levels of carnivory, we would expect this shift to be visible in the record as an increase in numbers of modified bones, sites, or site levels in younger intervals when controlling for the intensity of paleontological sampling. If another hominin species was highly carnivorous prior to 1.9 Ma, and then reduced its carnivory behavior after 1.9 Ma, this could potentially mask increasing carnivory behavior by H. erectus, but this is a highly speculative scenario for which there is no evidence.

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Fig S1. Scatter plots showing three carnivory proxies (count of published levels, count of zooarchaeological sites, and total number of modified bones) against species richness and the count of paleontological assemblages (paleontological sampling proxies) for the period 2.6 – 1.2 Ma. All variables are square root transformed. OLS regression lines are shown as dashed lines, and regression statistics are summarized in Table S1. Points represent time bins, which are labeled with their midpoint age (in Ma).
Fig. S2.
Time series of REC using different time bin durations from 80 kyr to 200 kyr.
Scatterplot of A) total number of modified bones against the number of published site levels, B) total number of modified bones against the number of published zooarchaeological sites, and C) the number of published site levels as a function of the number of zooarchaeological sites. Residuals from these regressions are shown in main text Figure 4. All variables are square root transformed. Regressions are constrained to pass through the origin. Points represent time bins, which are labeled with their midpoint age (in Ma).
Fig S4. Scatterplot of the total count of modified bones against the total lithic count within each bin. Both variables are square root transformed. The blue line shows the OLS regression line (p=0.005, $r^2=0.501$, slope=0.167). Each point is labeled with the age of the midpoint of the bin (in Ma).
Table S1.
Regression summaries of three carnivory proxies as a function of two paleontological sampling proxies. Note: these results include the total number of paleontological sites (npaleo), which is not discussed in the main text. All variables are square root transformed prior to regression.

| model                          | $R^2$ | p-value | slope   | intercept  |
|-------------------------------|-------|---------|---------|------------|
| totalmod_sqrt ~ richness_sqrt | 0.40  | 0.02    | 4.19    | -35.26     |
| totalmod_sqrt ~ npaleo_sqrt   | 0.36  | 0.02    | 9.10    | -14.99     |
| nsites_sqrt ~ richness_sqrt   | 0.36  | 0.02    | 0.33    | -1.84      |
| nsites_sqrt ~ npaleo_sqrt     | 0.16  | 0.15    | 0.51    | 0.27       |
| nlevels_sqrt ~ richness_sqrt  | 0.44  | 0.01    | 0.48    | -3.19      |
| nlevels_sqrt ~ npaleo_sqrt    | 0.27  | 0.06    | 0.87    | -0.40      |
Table S2.
Geographic information, dates, and references for the paleontological assemblages used to calculate our sampling proxies. A full species-by-time presence-absence dataset is provided in Dataset S2.

| Country | Fossil Unit | Lat | Long | Sequence | Min. Age | Max. Age | Mean Age | Age Ref(s.) | Faunal Ref(s.) |
|---------|-------------|-----|------|----------|----------|----------|----------|-------------|----------------|
| Tanzania | Bed I       | -2.98 | 35.30 | Olduvai Gorge | 1.80     | 2.04     | 1.92     | (16)        | (17-28)        |
| Tanzania | Bed III     | -2.98 | 35.30 | Olduvai Gorge | 0.80     | 1.20     | 1.00     | (29)        | (19,20,24,26,30,31) |
| Ethiopia | Boolihanan  | 11.15 | 40.32 | Busidima Fm. | 1.50     | 1.70     | 1.60     | (32)        | (32)           |
| Ethiopia | Burtele     | 11.30 | 40.30 | Woranso-Mille | 3.30     | 3.50     | 3.40     | (33)        | (33)           |
| Kenya    | Chari       | 4.00  | 36.37 | Koobi Fora Fm. | 0.75     | 1.38     | 1.07     | (34)        | (35,36)       |
| Ethiopia | Danauli     | 11.10 | 40.58 | Busidima Fm. | -        | -        | 2.00     | (37)        | (37)           |
| Ethiopia | Dark Paleosol | 11.15 | 40.32 | Busidima Fm. | 0.90     | 1.40     | 1.15     | (32)        | (32)           |
| Ethiopia | DD2         | 11.10 | 40.58 | Hadar Fm. | 3.22     | 3.22     | 3.22     | (38)        | (25,37,39,40) |
| Ethiopia | DD3         | 11.10 | 40.58 | Hadar Fm. | 3.20     | 3.22     | 3.21     | (38)        | (25,37,39,40) |
| Ethiopia | Gafura      | 11.60 | 40.80 | Mille-Logya | 2.91     | 3.13     | 3.02     | (41)        | (41)           |
| Ethiopia | Gombore I   | 9.56  | 39.11 | Melka Kunture | 1.60     | 1.70     | 1.65     | (30)        | (42)           |
| Ethiopia | Gurumahá    | 11.40 | 40.90 | Lee Adoyta Basin | 2.75     | 2.82     | 2.79     | (43)        | (43-46)       |
| Ethiopia | Hata        | 10.15 | 40.33 | Bouri Fm. | 2.50     | 2.50     | 2.50     | (47)        | (47-49)       |
| Kenya    | Kaitio      | 3.93  | 35.77 | Nachukui Fm. | 1.55     | 1.87     | 1.71     | (34)        | (36)           |
| Kenya    | Kaiyumung   | 2.90  | 36.05 | Nachukui Fm. | 3.00     | 3.50     | 3.25     | (50)        | (51)           |
| Kenya    | Kalochoro   | 3.93  | 35.77 | Nachukui Fm. | 1.87     | 2.33     | 2.10     | (34)        | (25,36)       |
| Kenya    | Kantis      | -1.39 | 36.72 | Kantis | 3.40     | 3.50     | 3.45     | (52)        | (52)           |
| Kenya    | KBS         | 4.00  | 36.37 | Koobi Fora Fm. | 1.53     | 1.87     | 1.70     | (34)        | (25,36)       |
| Ethiopia | KH1         | 11.10 | 40.58 | Hadar Fm. | 3.11     | 3.20     | 3.16     | (38)        | (25,37,39,40) |
| Ethiopia | KH2         | 11.10 | 40.58 | Hadar Fm. | 2.95     | 3.11     | 3.03     | (38)        | (25,37,39,40) |
| Ethiopia | Konso 1     | 5.30  | 37.40 | Konso Fm. | 1.80     | 1.90     | 1.85     | (53)        | (53)           |
| Ethiopia | Konso 2     | 5.30  | 37.40 | Konso Fm. | 1.70     | 1.80     | 1.75     | (53)        | (53)           |
| Ethiopia | Konso 3     | 5.30  | 37.40 | Konso Fm. | 1.50     | 1.60     | 1.55     | (53)        | (53)           |
| Ethiopia | Konso 4     | 5.30  | 37.40 | Konso Fm. | 1.40     | 1.50     | 1.45     | (53)        | (53)           |
| Country | Location          | Depth (m) | Age (Ma) | Thickness (m) | Age (Ma) |
|---------|-------------------|-----------|----------|---------------|----------|
| Ethiopia | Konso 5           | 5.30       | 1.30     | 1.35          | 53       |
| Ethiopia | Konso 6           | 5.30       | 0.70     | 1.00          | 53       |
| Ethiopia | Lee Adoyta        | 11.40      | 2.58     | 2.63          | 43       |
| Kenya   | Lokalalei         | 3.93       | 2.33     | 2.43          | 34       |
| Tanzania| Lower Bed II      | -2.98      | 1.74     | 1.77          | 54       |
| Kenya   | Lower Lomekwi     | 3.93       | 3.13     | 3.29          | 34, 53   |
| Ethiopia| Maka’amitalu      | 11.10      | 2.97     | 3.21          | 34, 35   |
| Ethiopia| Mb B              | 5.00       | 2.27     | 2.30          | 34, 35   |
| Ethiopia| Mb C              | 5.00       | 1.87     | 2.07          | 34, 35   |
| Ethiopia| Mb D              | 5.00       | 1.76     | 1.82          | 34, 35   |
| Ethiopia| Mb E              | 5.00       | 1.53     | 1.65          | 34, 35   |
| Ethiopia| Mb F              | 5.00       | 1.38     | 1.46          | 34, 35   |
| Ethiopia| Mb G              | 5.00       | 1.00     | 1.19          | 34, 35   |
| Ethiopia| Mb H              | 5.00       | 1.68     | 1.72          | 16, 56   |
| Ethiopia| Mb J              | 5.00       | 2.82     | 2.98          | 34, 53, 26 |
| Ethiopia| Mb K              | 5.00       | 0.75     | 1.03          | 34, 36   |
| Ethiopia| Mb L              | 5.00       | 1.30     | 1.43          | 34, 36   |
| Tanzania| Middle Bed II     | -2.98      | 3.21     | 3.27          | 57       |
| Kenya   | Middle Lomekwi    | 3.93       | 1.38     | 1.46          | 34, 35   |
| Kenya   | Nariokotome       | 3.93       | 1.00     | 1.19          | 34, 35   |
| Ethiopia| Nefuraytu         | 11.30      | 3.21     | 3.27          | 57       |
| Kenya   | Okote             | 4.00       | 1.38     | 1.46          | 34, 25, 36 |
| Ethiopia| Seraitu           | 11.60      | 2.49     | 2.70          | 41, 41   |
| Ethiopia| SH1               | 11.10      | 3.40     | 3.41          | 38, 25, 37, 39, 40 |
| Ethiopia| SH2               | 11.10      | 3.35     | 3.38          | 38, 25, 37, 39, 40 |
| Ethiopia| SH3               | 11.10      | 3.33     | 3.34          | 38, 25, 37, 39, 40 |
| Ethiopia| SH4 DD1           | 11.10      | 3.22     | 3.28          | 38, 25, 37, 39, 40 |
| Country   | Location          | Latitude | Longitude | Formation          | Age 1 | Age 2 | Age 3 | Ref 1 | Ref 2 |
|-----------|-------------------|----------|-----------|--------------------|-------|-------|-------|-------|-------|
| Kenya     | South Turkwel     | 2.90     | 36.05     | Nachukui Fm.       | 3.20  | 3.58  | 3.39  | (58)  | (25,28) |
| Kenya     | Tulu Bor          | 4.00     | 36.37     | Koobi Fora Fm.     | 2.64  | 3.44  | 3.04  | (34)  | (25,36) |
| Tanzania  | Upper Bed II      | -2.98    | 35.30     | Olduvai Gorge      | 1.20  | 1.74  | 1.47  | (54)  | (54)  |
| Kenya     | Upper Burgi       | 4.00     | 36.37     | Koobi Fora Fm.     | 1.87  | 2.00  | 1.94  | (34)  | (25,36) |
| Kenya     | Upper Lomekwi     | 3.93     | 35.77     | Nachukui Fm.       | 2.53  | 2.82  | 2.68  | (34)  | (25,36) |
| Tanzania  | Upper Ndolanya    | -3.20    | 35.20     | Ndolanya Beds      | 2.66  | 2.66  | 2.66  | (59)  | (60)  |
| Ethiopia  | Uraitele          | 11.60    | 40.80     | Mille-Logya        | 2.44  | 2.49  | 2.46  | (41)  | (41)  |
| Ethiopia  | Usno              | 4.50     | 36.00     | Usno Fm.           | 3.00  | 3.30  | 3.15  | (29)  | (25,28) |
Data S1. (separate file)
Compiled zooarchaeological levels from eastern Africa examined in this study, including the count of lithics from the associated stone tool assemblages in each.

Data S2. (separate file)
Species by time presence-absence matrix for 100 ka bins in eastern Africa.