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Experimental lithic tool displacement due to long-term animal disturbance

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Abstract

Controlled experiments in lithic technology tend to focus on controlling the human component of lithic tool manufacturing and use; however, animal disturbance can move and alter artifacts in non-random ways, thus altering the behavioral meaning assigned to artifacts and their contexts. The patterning visible in archeological debris on a horizontal plane can provide evidence for activity zones, pathways, and site formation processes. While the effects of trampling actors on the vertical displacement of artifacts have shown that artifacts can be dramatically displaced, the horizontal movement due to trampling is relatively less studied, particularly the effect over extended time periods. Here, an experimental investigation of experimentally produced lithic tools in three contexts with varying degrees of animal trampling intensity is described, and the resulting patterns of artifact displacement are presented. Animal trampling can produce directed, non-random patterning in how artifacts are moved from their original location. The role that bedding slope plays in transport direction given different degrees of activity is also explored. These results show that trampling can produce patterned artifact scatters similar to activity centers and should be taken into consideration for spatial analyses of archeological formation processes.

Keywords Taphonomy · Spatial analysis · Trampling · Activity areas

Introduction

Behavioral interpretations of prehistoric patterning are complicated by the effects of post-depositional processes. Natural processes influence the burial, modification, and patterning observed on all archeological materials at multiple scales (Flenniken and Haggarty 1979; Villa and Courtin 1983; Gifford-Gonzalez et al. 1985; Behrensmeyer et al. 1986; Olsen and Shipman 1988; Nielsen 1991; Shea and Klenck 1993; McBrearty et al. 1998; Barton et al. 2002; Schoville et al. 2009; Eren et al. 2010; Pargeter 2011). Although stone tools are the most common surviving artifact from most Pleistocene archeological contexts, they are subject to the same trampling, bioturbation, and displacement processes that impact the archeological visibility of other artifact classes (Lyman 1994; Dibble et al. 2006). The cumulative effect of these processes influences the preservation of stone tools and their spatial distribution and may modify tool edges in ways that mimic retouch (Dibble et al. 2006) and use-wear (Shea and Klenck 1993).

Patterns of artifact distribution that relate to the behavioral component of an assemblage's formational history are of interest for addressing questions about human behavior. Therefore, identifying and accounting for the post-depositional component of site formation which may lead to similar patterns are critical (Marean and Bertino 1994). The spatial arrangement of lithic artifacts provides clues to site occupation behavior such as activity zones, dumping, and site maintenance activities (Binford 1978, 1980; Carr 1991; Wandsnider 1996). These have been incorporated into archeological interpretations of past behaviors through lithic refitting and conjoining studies (Sisk and Shea 2008) and analysis of spatial cluster analysis (Koetje 1994), as well as the spatial distribution in artifact sizes (Wandsnider 1996). However, neither behavioral formation processes nor post-depositional processes are uniform across time or space, and expanding the range of experimental studies across these dimensions provides additional insight into the complex formational histories at archeological localities.

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There have been numerous studies directed at understanding the effects of trampling on stone tools, including raw material differences (Pryor 1988; Driscoll et al. 2016), the duration of trampling (Pryor 1988; Shea and Klenck 1993), the density of artifacts, and sediment compaction (Pryor 1988; Eren et al. 2010). These factors also influence the spatial displacement of artifacts (Villa and Courtin 1983; Gifford-Gonzalez et al. 1985). Previous studies have largely emphasized the importance of human trampling in site formation (Benito-Calvo et al. 2011; McPherron et al. 2014), but the role of animal activity, particularly on Stone Age implements, is underexplored. In this study, the impact of animal disturbance processes over a 5-month period is evaluated by analyzing the initial and final position of lithic pieces placed in three different animal trampling locations. This study provides a framework whereby site formation processes impacting the spatial organization of artifacts can be usefully compared.

Background

The spatial distribution of artifacts is a key line of evidence used to reconstruct past behavior. Hunter-gatherer spatial organization has provided an interpretive middle range linkage within which archeological patterning may be understood. Binford (1978) developed the concepts of drop zones and toss zones from his ethnoarcheological work to infer activity locations from spatial patterns of archeological assemblages. These zones consist of two concentric circles around an activity area such as a hearth. The inner circle is the drop zone and consists of small debris generally discarded randomly around the activity area. Binford estimates this band to be 0–1.2 m from the activity locus or hearth edge (Binford 1983; Carr 1991). The outer circle is the toss zone, where larger waste flakes and debris that would be cumbersome or uncomfortable to work around are tossed either forward or backward a suitable distance to be removed from the activity area. This is argued to be 1.5–2.5 m from the activity locus or hearth edge. Other ethnoarcheological studies have found that cleaning and site maintenance activities can lead to systematic behavioral patterning at the edge of activity areas (Yellen 1977; Brooks and Yellen 1987; O'Connell 1987; Simms 1988). Wandsnider's (1996) overview of site spatial analysis identifies size sorting of artifacts as a key hallmark of site use and maintenance behaviors. Since the distribution of artifact size production, use, and discard relates to the structured occupational input into a site, identifying artifactual gradients can provide insight into site functional histories (Wandsnider 1996). Critical to applying ethnoarcheological models to excavated contexts is incorporating the taphonomic processes that may result in pattern equifinality (Lyman 2004). Among other potential effects, fluvial activity, downslope migration, and trampling activity have been shown to leave patterned traces in cultural debris and will be reviewed here.

Fluvial movement

Moving water has well-understood effects on lithic artifacts, including size winnowing, reorientation, and the formation of lag deposits (Byers et al. 2015; McPherron 2018). In general, the size of artifacts transported by fluvial action is positively correlated with increased water flow. In Schick's (1984) flume studies, fluvial winnowing of lithic artifacts was shown to clearly alter the original distribution of size clasts in experimental assemblages. With low-velocity water, only the smallest size artifacts are reoriented, but with increasing flows, the smallest artifacts enter suspension first, with increasingly larger artifacts reorienting with the direction of flow. With added water volume, increasingly larger artifacts begin to reorient and enter suspension.

The reorientation of artifacts to the direction of water flow provides a critical line of evidence to infer post-depositional processes from artifact spatial fabrics. Using Benn's (1994) eigenvalue method, archeological fabrics can be diagnosed based on how well they conform to horizontal and vertical dimensions of displacement. Using the 3D positioning of clasts excavated with high-precision total station plotting, archeologists have been incorporating this method to understand the effects of water runoff, debris flows, and solifluction in prehistoric cultural contexts (e.g., McPherron 2005; Bernatchez 2010; Oestmo et al. 2014). McPherron (2018) has recently advanced new analytic tools for statistically calculating confidence intervals and permutation tests for the Benn eigenvectors to aid in site formation history interpretations.

Downslope movement

The downslope movement of artifacts is related to slope steepness. Steeper slopes result in greater artifact movement, whereas generally flatter slopes have a more representative sample of the originally deposited artifacts. Rick (1976) found a counter-intuitive pattern where abundance was negatively correlated with slope angle, such that steep slopes have a greater number of lithic, ceramic, and faunal artifacts but that these tend to be smaller in size than those found on less sloping surfaces. That heavier objects move further distances is similar to the results from some human trampling studies (see below). However, the downslope movement Rick (1976) observed was on surface exposures on fairly steep slopes (> 10°). Fanning and Holdaway (2001) found that downslope artifact migration with shallower slopes is less pronounced and found a slight, but significant, positive correlation between artifact length (on artifacts > 20 mm) and slope in Australian contexts for a very large dataset ($n = 17{,}128$). However, only slopes between 0° and 5.6° were analyzed, which make the results with Rick (1976) difficult to reconcile. Fluvial transport and slope are also related to the amount of precipitation in the environment. Artifacts deposited on a steeper gradient have greater potential energy from fluvial transport; therefore, these processes (water and slope) are not independent factors of horizontal artifact displacement.

Human trampling

Spatial movement of artifacts is also influenced by patterns of human movement within the site which can displace lithic tools. In Nielsen's (1991) experiments, large artifacts tend to be kicked away from traffic zones such as pathways and high activity areas and accumulate in marginal zones at the fringes of activity areas. Small artifacts may be more likely to be integrated into the substrate and are less easily disturbed from site occupation traffic (Stevenson 1985). However, neither Nielsen (1991) nor Villa and Courtin (1983) feel that there is a significant correlation between horizontal displacement and artifact size after human trampling. More recent experiments have suggested that this relationship may be more significant than previously thought with increased trampling intensity. In sandy substrates, Marwick et al. (2017) found that tool elongation was significantly correlated with horizontal displacement distance after 15 min of human trampling. After a 2-week trampling study, Driscoll et al. (2016) found that the heaviest size experimental lithic tools (> 7 g) were moved significantly further, almost five times further than the lightest tools (< 0.4 g).

The influence of slope on artifact displacement patterns has also been explored. In Benito-Calvo et al.'s (2011) experiments, they found that human trampling did not result in a random assortment of artifacts. In the two experimental trampling plots laid out along a trail leading to the sieving area near the site of Cova Gran, Spain, objects that moved the furthest were more in line with the direction of trampling along the pathway rather than the direction of the slope. Overall, Benito-Calvo et al. (2011) found that their human trampling experiments failed to replicate the distribution of artifacts from Cova Gran, Spain, and argue that sediments there did not undergo intense trampling.

Animal trampling experiments

Several studies have used animal trampling to create fractures on stone tool edges that can be used as a reference for understanding and identifying behavioral wear traces (Pargeter and Bradfield 2012; Balirán 2014; Schoville 2014). Cattle, goats, horses, buffalo, and elephants have been considered in this respect (Lopinot and Ray 2007; Eren et al. 2011; Pargeter 2011; Pargeter and Bradfield 2012; Schoville 2014), while the disruptive effects of carnivores on artifacts surrounding hearth structure have also been considered (Camarós et al. 2013). Overall, however, fewer studies have examined the lateral movement of lithic clasts due to animal trampling processes. Eren et al. (2011) found that neither moisture content nor type of animal significantly influenced horizontal movement. Schoville's (2014) fabric analysis of Eren et al.'s clast orientation and dip data indicates that trampling on a dry surface did not significantly reorient artifacts on a linear plane (as fluvial action does), but that heavily trampled clasts in wet sediments are consistent with a debris flow. Eren et al. (2011) also found no relationship between artifact size and horizontal displacement, suggesting that artifacts may have moved with equal likelihood regardless of size. However, in their experiments, animals made a single pass from each direction; therefore, some artifacts kicked in one direction may have been kicked back on the subsequent transect (~ 3 min and 30 s total trample time), which may limit how far the lateral displacement results can be extrapolated. In Pargeter and Bradfield's (2012) experiments involving goats for 30 min of trampling, stone tools were moved a maximum of 24.1 cm, and they found no relationship between tool size and post-depositional movement after this time period.

Short vs long exposure

One area for additional research is the duration of exposure, which has received limited attention. This is usually due to practical reasons, such as the duration of field seasons, limited animal availability, and cost considerations. Eren et al. 2011 (Table 1) provide a summary of well-published trampling experiments. In terms of trampling days, the longest duration of human trampling is 36 days (Villa and Courtin 1983), while the longest animal trampling experiments lasted 2 weeks (Fiorillo 1989). More recent studies by Pargeter (2011) allowed stone flakes to be trampled by cattle twice a day for 27 days. Although, some researchers have suggested the effects of trampling occur only "within the first few hours of trampling" (Pargeter 2011: 2887), and thus, short-term experiments are sufficient. Others have noted that the rate of burial may be an important factor. This includes artifact size, particularly thickness, since thinner objects may be buried more readily (e.g., Pryor 1988; Nielsen 1991), as well as the overall sediment compaction and sedimentation rate. Driscoll et al. (2016: 142) argue that over a 2-week period, tools undergo multiple burial and uncovering events due to soil compression and the effects of "kicking and dragging" on the tools.

Additionally, multiple experiments have shown that increasing the amount of trampling increases the magnitude of the effect. For example, Shea and Klenck (1993) found increasing amounts of trampling damage occurring on experimentally trampled flakes after 15–30 min of trampling and 45 min of trampling. In Driscoll et al.'s (2016) "high-intensity" trampling zone, the average displacement

Table 1 Experimental stone tool metrics in each location in millimeters (except mass in grams). Measurements are given as mean, (range), standard deviation

Location	Length	Width	Thickness	Weight (g)
Corral (*n* = 100)	63, (26–106), 17	30, (12–63), 10	9.6, (2.6–21.4), 3.4	20.4, (1–96), 17
Trail (*n* = 100)	63, (33–106), 16	29, (13–55), 9	10.4, (3–20.7), 3.9	21.7, (1–96), 18
Field (*n* = 100)	63, (28–120), 16	31, (14–55), 10	10.6, (3.6–22.8), 3.5	21.6, (3–57), 13

distance was greater than in the "low-intensity" trampling zone after 2 weeks of exposure. Given the long duration of potential artifact exposure, the issue of trampling duration deserves additional insight. While some studies such as the edge damage observations by Balirán (2014) after 1 year of trampling are an exception, additional long-duration studies of artifact movement may hold important clues at more archeologically relevant time scales (Burger et al. 2008). The trampling experiments presented here focus on the horizontal movement of artifacts over a long duration from three different contexts in an effort to expand the range of trampling studies that can be meaningfully compared to archeological datasets.

Methods

Previous studies of trampling tend to emphasize short-term, focused, intentional trampling events (Shea and Klenck 1993; Eren et al. 2010; Pargeter 2011; McPherron et al. 2014), where human traffic covers the experimental artifact zone for set periods of time. However, for this experiment, three long-term study sites were used with animal agents allowed to traverse the artifact zones in an undirected fashion. These experiments were initially completed to generate edge damage on the stone tools that was published by Schoville et al. (2016). That study did not describe and present the results of artifact movement patterns due to the trampling, and those results will be presented here.

The trampling experiments were completed on a small vineyard and farm in Trinity County, Northern California (Fig. 1). The owner of the property maintained a small group of cattle during this period that was moved to the corral during the last month of the trampling experiments prior to being removed from the property. There are also two resident unshod horses on the property. This is a rural area with minimal fencing, and a variety of wild animals such as deer, bear, and small mammals were documented passing through the trampling locations by motion cameras (Schoville et al. 2016).

Three contexts were chosen based on the differences in the anticipated amount of animal activity in the area. An enclosed cattle corral was identified as a high-intensity trampling location because the pen is used to feed horses and cattle periodically, and a fresh water drinking trough is located west of the designated trampling area. This area is expected to result in random artifact movement directions because animals will be congregated there for long periods of time rather than moving through following a regular bearing.

A flat, grassy area which connects the corral and a grazing field was chosen as a "medium-intensity" trampling location. There is a clear cattle trail which passes through the center of the trampling plot from west to east (Fig. 1b). It was anticipated that animals would tend to pass through this area on a regular basis, but since it is neither a constrained space nor a large area, animals would be unlikely to congregate there for long periods of time. Following prior studies that suggested tools along a pathway tend to move parallel to the pathway, and given the clear evidence of regular animal movement bearing, it is expected that this area will result in artifacts being moved following the direction of the trail (NW to SE, 122° through the plot). It is also expected that artifacts moving further distances would follow a similar bearing (such as a trail or downslope direction), while those that are recovered not far from their original location would have moved at random shorter distances due to more occasional disturbances.

The low-intensity site is a flat area positioned at the margin of the largest grazing field on the property near a small grove of trees. Animals use the field as a homogenous grazing area, and high levels of congregation at this particular location seem unlikely. However, there is also no evidence for patterned movements through the area such as trails or pathways; therefore, it is expected that trampling in this area will result in random artifact displacement directions due to trampling.

It would be difficult to justify a linkage between trampling processes and the patterns which result from a long-term trampling study such as this that was unmonitored. Ruling out other potential sources of the observed patterning requires direct observations between actor, the effector, and the causal agents of observed patterning (Gifford-Gonzalez 1991). Middle range linkages between actors and trampling patterns are achieved here by monitoring the three trampling locations using motion-sensitive digital camera traps (Fig. 1d). The digital images recorded as animals move within the trampling locations provide a linkage between the actors and the resulting movement and damage exhibited on the stone tools. Motion-sensitive camera traps were placed ~2 m high on a tree that provided a vantage view of the complete trampling zone. Each image is time-stamped when triggered with the

Fig. 1 **a** Trampling grid located in the corral. **b** Trampling grid located along the animal pathway that is visible from upper-left to lower-right across grid. **c** Trampling grid located in the field. **d** Motion-activated camera traps located near each trampling grid

date, time, lunar cycle, and current temperature. Although the type of camera used (Primos Truth Cam 35®) is rated for 6-month battery life, we chose to change batteries after 3 months.

The stone tools were knapped by Kyle Brown to replicate typical flakes, points, and blades found at Middle Stone Age (~ 300,000 to 35,000 BP) archeological assemblages in South Africa. The raw materials were collected from primary and secondary sources in South Africa and knapped using hard hammer percussion. The size and shape ratio distributions are provided in Table 1. As described by Schoville et al. (2016), the stone tools were laid out across a 3 × 3-m grid divided into 100 grid cells measuring 30 × 30 cm. The grids were roughly oriented to magnetic north, but each grid was arbitrarily defined with a SW datum of N100 m, E100 m, and Z100 m. The trampling assemblage consisted of approximately 40 quartzite, 40 heat-treated silcrete, and 20 quartz and ironstone detached pieces so that 100 tools were arranged at each trampling location. The corners of the sampling grid were marked with metal stakes that were plotted using a total station, and the initial starting location of each tool was offset relative to the corners of the grid.

All the tools were collected after 5 months of exposure prior to the onset of winter. A Topcon Total Station was used during recovery to piece plot the location of each tool. The angle of artifact movement was calculated using the total station coordinates relative to the starting location using ArcGIS v10.4. The distance was calculated using the calculate geometry function. The distribution of angles was then compared to a uniform distribution with the Rayleigh test using Oriana v4.02 (Kovach 2011). Watson's two-sample test for homogeneity and the correlation coefficient for angular variables were analyzed with R and R studio with the CircStats package (Agostinelli 2012). Rose diagrams were also constructed in Oriana v4.02.

The surface topography of the trampling grids was calculated in ArcGIS v10.4 using the artifact elevation coordinates and empirical Bayesian kriging function in the ESRI Geostatistical Analyst module. The resulting predictive elevation surface was then converted to a map of the downward sloping direction using the aspect calculations in ArcGIS v10.4. The individual starting artifact aspect was then extracted from the raster map, and these are compared to the direction of artifact movement after being exposed to trampling in the three locations.

Results

As reported in Schoville et al. (2016), the stone tools exposed to trampling processes in the three different contexts largely followed expectations in terms of the amount of animal activity documented at each location. Based on the number of motion detection images collected from each trampling site, the corral had the greatest animal activity ($n = 8231$ images) while the field ($n = 2734$ images) had more animal activity than the trail ($n = 2147$ images) location. The animals tended to stay and graze in the open field for longer periods, which caused the camera trap to acquire more images, whereas animals traversing the trail images generally were only captured once as they walked through.

After 5 months of exposure, not every stone tool was able to be recovered. While each location started with 100 individual tools, only 65 tools were recovered from the corral, 87 from the trail, and 95 from the field locations (Schoville et al. 2016). In the corral, fewer tools were visible on the surface than in the other two contexts, and it was necessary to shovel and screen the muddy sediment in order to recover as many tools as possible. Therefore, only 22 of the 65 recovered tools were piece plotted with the total station and are analyzed further below. Stone tools in the field and trail locations were largely still on the surface, and minimal subsurface recovery was required (e.g., Fig. 2). Each artifact fragment was piece plotted after trampling; therefore, some artifacts may contribute more than once to the analysis of post-trampling artifact movement patterning discussed below.

Movement direction

The highest activity area was located within the corral. Here, the average artifact movement bearing is preferentially oriented to the southeast (Fig. 3; mean = 157°) and is significantly different from a uniform distribution (Rayleigh test, $p = 0.004$). In contrast, the corral ground surface slope is random with no significant patterning in the downslope direction (Fig. 3; mean aspect = 173°; Rayleigh test, $p = 0.102$). Since the surface was found to be random, testing the mean artifact movement direction and mean slope aspects with the Watson two-sample test would not be meaningful. However, a Pearson's product-moment correlation for angular variables test between the initial ground surface aspect and the movement direction of the recovered tools is not significant ($r = -0.386$, test stat $= -1.866$, $p = 0.062$). The mean movement direction of the 25 recovered tool pieces is non-random and is not correlated with the initial surface aspect prior to the experiments. The maximum difference in elevation in this area is 12 cm between the highest and lowest elevations. The movement of artifacts due to animal trampling is significantly patterned in this constrained enclosure, opposite of what was expected.

Fig. 2 Stone tool (no. 12-144, silcrete blade) plotted in situ broken during trampling

Average artifact movement bearing within the trail context is significantly different from a uniform distribution, indicating average movement to the southwest (Fig. 4; mean = 202°; Rayleigh test, $p = 0.001$). The ground surface aspect is predominantly south-sloping (Fig. 4; mean aspect = 177°; Rayleigh test, $p < 0.001$), and the maximum difference in elevation in the trampling grid is 8.1 cm between the highest and lowest elevations. Watson's two-sample test of mean vectors indicates the difference in artifact movement direction, and slope aspect is not significant (t stat = 0.0828, $p > 0.10$); however, a Pearson's product-moment correlation for angular variables test between the starting artifact aspect and the movement direction due to trampling is not significant ($r = -0.107$, test stat = 1.0850, $p = 0.278$). In other words, the overall mean movement direction and starting aspect are similar, but there is no significant correlation between individual tool starting aspect and movement direction. The orientation of the pathway (122°) across the trampling grid is predominantly from west to east. A variation of the Rayleigh test of uniformity that assesses an alternative hypothesis that the sample was drawn from a unimodal distribution with specified mean direction (122°) is not significant ($r = 0.047$, $p = 0.253$). These results suggest that the experimental lithic tools are moving obliquely rather than parallel to the trail.

Stone tools trampled within the field context had an average movement bearing due to trampling towards the north that is significantly different from a uniform distribution (Fig. 5; mean = 11°, Rayleigh test, $p < 0.001$). This is in contrast to the ground surface aspect direction which is predominantly to the east (Fig. 5b; mean aspect = 85°, Rayleigh test, $p < 0.001$), and the maximum difference in elevation in the trampling grid is 8.6 cm between the highest and lowest elevations. A Watson's two-sample test of homogeneity that indicates the difference in the artifact movement and slope aspect mean angles is significant (t stat = 1.348, $p < 0.001$), and there is no significant correlation between the starting artifact aspect and the movement direction due to trampling ($r = 0.186$, test stat = 1.912, $p = 0.056$). The low-intensity traversing of lithic flakes in the field did not follow the downward trend of the area but rather were moved towards the north, perpendicular to the ground surface slope.

Movement distance

The average distance artifacts moved from each of the trampling locations is provided in Table 2. The average artifact movement distance was much greater in the corral (Wilcoxon pairwise; corral vs field, $Z = -6.506$; $p < 0.0001$; corral vs trail, $Z = -5.969$; $p < 0.0001$), reflecting the greater

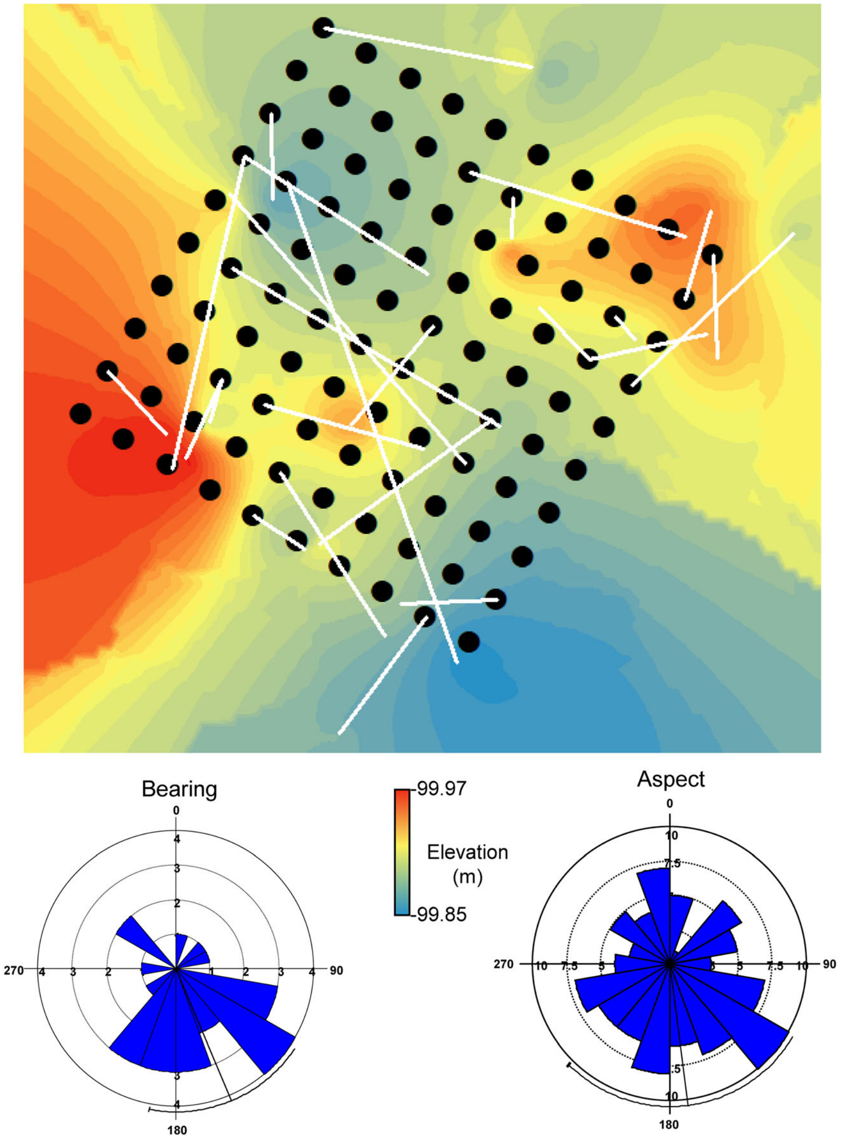


Fig. 3 Corral trampling grid location showing stone tool starting positions (black dots) and bearing vectors (white lines) on top of the interpolated elevation map. Rose diagrams show patterned stone tool displacement bearing due to trampling and non-patterned aspect

intensity of animal activity in this area overall. Conversely, artifacts in the field were moved the least on average, although no significant differences are evident between the trail and field (Wilcoxon pairwise; trail vs field, $Z = 1.437$; $p < 0.1508$).

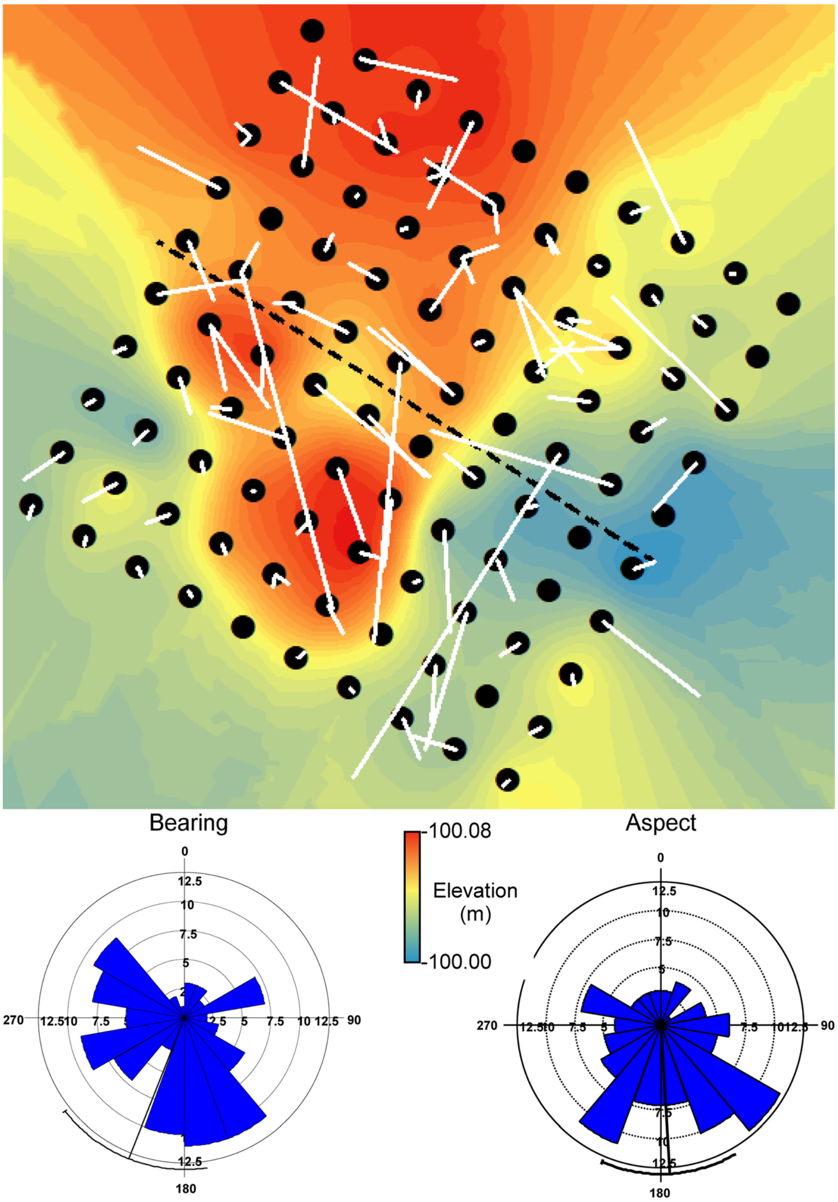
Distance and direction

Although it could be anticipated that artifacts moving further distances may follow a different, potentially more patterned trajectory than those only moving short, more randomly oriented distances, there is no evidence for this. Within the corral, tools recovered less than 60 cm ($n = 10$; mean = 179°) from their starting location did not follow a significantly different bearing from those traveling further than 60 cm ($n = 15$; mean = 145°; test stat = 0.086, $p > 0.10$). Within the trail, tools that moved less than 20 cm ($n = 59$, mean = 209°) were not following a significantly different trajectory than those that moved more than 20 cm ($n = 43$, mean = 192°; test stat = 0.068, $p > 0.10$). And the same is true for the field (< 20 cm, $n = 74$, mean = 4°; > 20 cm, $n = 37$, mean = 28°; test stat = 0.043, $p > 0.10$). Whether there is a relationship between trampling distance and direction was also evaluated with circular-linear correlation (Kovach 2011), with no significant patterns between movement distance and bearing observed at any of the locations (corral, $r = 0.111$, $p = 0.761$; trail, $r = 0.108$, $p = 0.316$; field, $r = 0.133$, $p = 0.149$).

Size and distance

The relationship between artifact size and movement distance varies with respect to trampling intensity as summarized in Table 3. In both the field and the corral locations, there is a significant positive relationship between both artifact thickness and artifact mass and the distance moved due to

Fig. 4 Trail trampling grid location showing stone tool starting positions (black dots) and bearing vectors (white lines) on top of the interpolated elevation map. Black dashed line shows the location of the midline of animal trail. Rose diagrams show patterned stone tool displacement bearing due to trampling and patterned aspect



trampling (Fig. 6). This pattern is more consistent with trampling processes akin to downslope artifact movement and unlike disturbance attributable to fluvial action. There is no relationship between artifact size in any dimension and movement distance from trampling at the trail location.

The relationship between artifact size and movement distance at the corral and field was further investigated in two ways. First, because it has been proposed that only the largest artifacts are laterally dispersed, the following analyses are completed with the largest 15% of tools separated to determine whether the strong relationship between tool size and trampling movement is being driven only by these larger tools. For the corral, there is still a significant relationship between mass and displacement distance with the largest 15% of tools removed from the analysis ($n = 21$; F-ratio = 6.1123; $p = 0.0230$). The linear relationship between mass and displacement distance is still significant at the field location with the largest stone tools removed from the analysis ($n = 92$; F-ratio = 7.7186; $p = 0.0067$). While the relationship between mass and displacement distance was shown to be significant even without the largest tools at the corral and field trampling locations, Fig. 6 does indicate the potential presence of heteroscedasticity across the samples. To account for this, the relationship was explored by binning the datasets into four intervals of approximately equal sample sizes based on mass as shown in Fig. 7. For the field location, a Levene's test for unequal variances was significant (F-ratio = 7.533, $p < 0.0001$). A weighted least squares was performed using the reciprocal group variance to minimize the effect of unequal variance; however, there are still significant differences

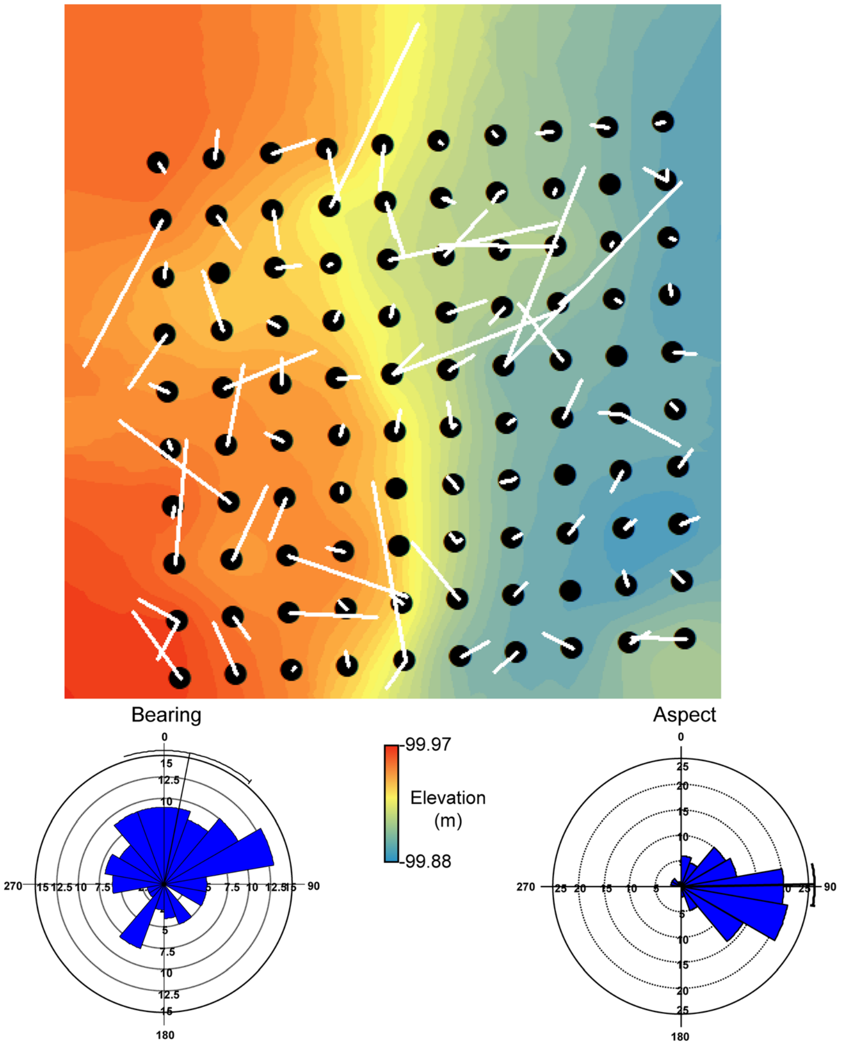


Fig. 5 Field trampling grid location showing stone tool starting positions (black dots) and bearing vectors (white lines) on top of the interpolated elevation map. Rose diagrams show patterned stone tool displacement bearing due to trampling and patterned aspect

in displacement distances across the tool size intervals (ANOVA, *F*-ratio = 8.777, $p < 0.0001$). For the corral, the binned weight intervals are shown in Fig. 7, and a Levene's test suggests that the variances are not significantly different (*F*-ratio = 0.846, $p = 0.484$). A least squares model also found significant differences in displacement distance across the tool size intervals at the corral location (ANOVA, *F*-ratio = 3.098, $p = 0.049$). The magnitude of trampling displacement appears to be related to tool size, and there is a greater tendency for very large tools to move the furthest due to animal trampling.

The relationship between tool elongation (width:length ratio) and movement distance was also evaluated. Marwick et al. (2017) found a relationship between increasing width relative to length and the distance artifacts moved during trampling. In fluvial contexts, flume experiments have shown more elongated clasts reorient in the direction of the water flow (Schick 1984; McPherron 2005). However, there does not appear to be any relationship between elongation and the distance stone tools move during trampling from the three contexts examined here (Table 3).

Table 2 Mean distance tools and tool fragments moved from starting to final provenience after animal trampling in the three locations

Trampling location	Mean distance (m)	Max distance (m)	SD
Corral (*n* = 25)	0.98	3.03	0.69
Trail (*n* = 102)	0.29	2.79	0.40
Field (*n* = 111)	0.22	1.35	0.27

Discussion and conclusion

These data suggest that non-human trampling can produce non-random, directed artifact movement patterns in some contexts. The average tool movement distance showed the clearest difference between the three trampling localities, with stone tools in the corral moving nearly four times further on average than in the trail or field areas. In terms of tool

Table 3 Significant *p* values of linear fit between artifact size and tool movement distance due to trampling

Trampling location	Tool length	Tool width	Tool thickness	Tool mass	Tool elongation
Corral	0.1068 (2.8169)	0.0743 (3.4956)	*0.0295* (5.3889)	*0.0153* (6.862)	0.7633 (0.0929)
Trail	0.9322 (0.0073)	0.4875 (0.486)	0.4686 (0.5296)	0.6686 (0.1844)	0.6397 (0.2205)
Field	0.0667 (3.4311)	*0.0148* (6.135)	*0.0004* (13.636)	*0.0002* (14.6361)	0.3999 (0.7143)

Italic values indicate significant relationship at 0.05 level; *F*-ratio in parentheses

movement direction, the tools were moved with non-random directionality in all three cases. While this was expected at the trail context, it may run counter-intuitive to how animal trampling may be thought of in the corral and field locations.

Other than trampling intensity, there were two main differences between the corral and field contexts—slope and vegetation. At the corral, there was no clear preferential ground surface aspect, while at the field location, stone tools actually were moved perpendicular to the downslope aspect due to trampling. While all three areas were relatively flat, a maximum of 12 cm elevation change across 3 m was observed at the corral equivalent to a 4% slope grade; there was non-random surface aspect observed at both the trail and field locations. Despite the relatively even surface, tools from the trail location generally moved in the down-slope direction following the overall slope aspect, obliquely to the trail, rather than along the trail, and tools in the field moved perpendicular to the slope. Driscoll et al.'s (2016) experiments found that the effect of human trampling after 2 weeks was to move lithic tools parallel to the trampling direction and not with the slope. This pattern may be consistent with the results from the field that demonstrated artifact movement perpendicular to the slope but is inconsistent with the results from the trail context. Whether these results reflect a difference in how animals move artifacts when traversing compared to humans or the effect of trampling duration deserves further exploration.

Differences in surface vegetation may have had an influence on artifact movement as well. At the corral, the high volume of animal traffic had completely removed any surface vegetation in the trampling grid, while the field location was grassy, and the trail was in between (the cattle pathway was visible because of the lack of vegetation; however, the rest of the grid was vegetated). The tool recovery rate at the field (95%) was higher than the trail (87%) and much higher than the corral (65%). While lower levels of activity at the field location compared to the corral may have played a role, the

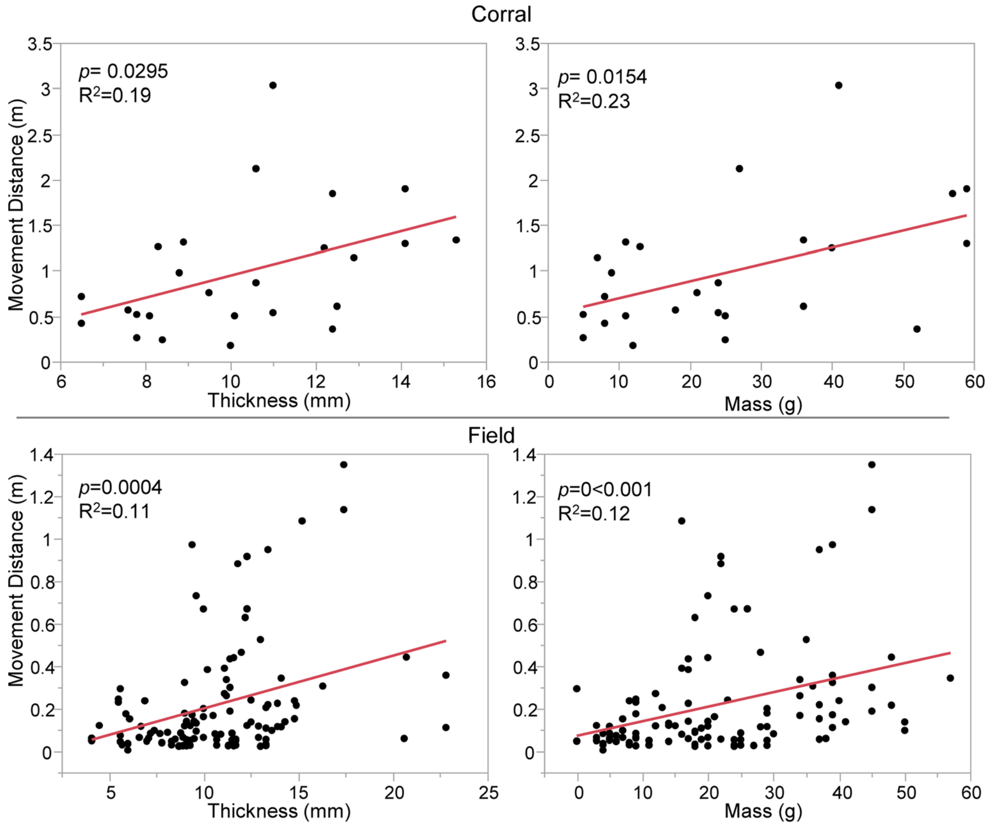
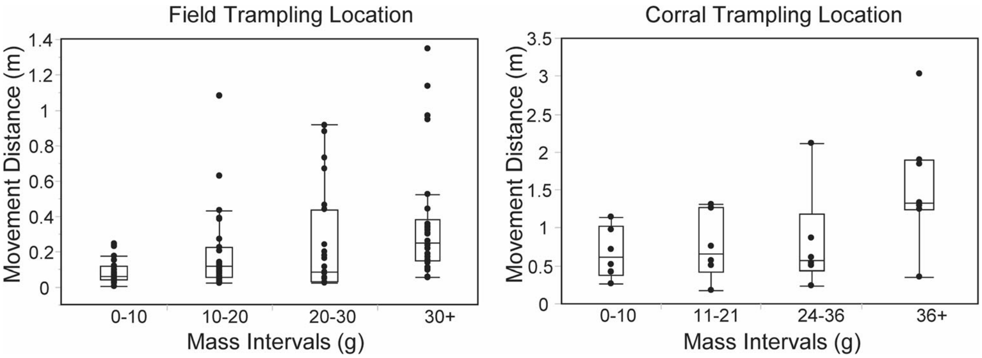


Fig. 6 Linear relationships between trampling tool thickness (left) and mass (right) with the displacement distance artifacts moved due to 5 months of trampling at the corral (top) and the field locations (bottom). *p* values and *R*-squared values provided on individual panels

Fig. 7 Boxplots of trampling movement distance by tool mass size intervals for tools located in the field (left) and corral (right) locations



field actually had more activity than the trail ($n = 2734$ motion triggered images compared to $n = 2147$ at the trail). Given the lower average tool movement of artifacts at the field (22 cm) compared to the trail (29 cm), the increased grassy vegetation may have helped to prevent tools from becoming embedded in the soil while at the same time restricted their lateral movements due to trampling. In terms of archeological implications, surface scatters deposited on vegetated surfaces may be less prone to horizontal artifact movement than scatters deposited on less vegetated surfaces.

One aim of this project was to compare the patterned effects of animal trampling on the archeological record to the effect of fluvial activity, downslope movement, and behavioral expectations. The different expectations based on previous experiments, and generated by this experimental investigation, are summarized in Table 4. Results from this study show that trampling on lithic debris may replicate some of the features associated with knapping activity and activity zones described by Binford (1978) and others (e.g., Brooks and Yellen 1987; Wandsnider 1996). Animal trampling disturbs artifacts on a similar scale as toss zone features, less than 3 m, while downslope artifact movement and fluvial processes may be much more disruptive to lithic clasts. Larger stone debris will tend to be kicked and scuffed further from the starting location when exposed to long-term animal trampling, leading to a positive relationship between artifact size and distance. The two locations with the highest animal activity (corral and field) were also the two locations where a positive relationship between artifact size (mass and thickness) and displacement distance was found. Trampling can move artifacts either with the slope or against the slope, whereas downslope movement and fluvial processes move artifacts downslope.

The final spatial arrangement of artifacts contains useful clues for understanding prehistoric human behaviors such as activity areas, task structuring, settlement patterning, and living space maintenance. Post-depositional processes can alter these patterns in both patterned and non-patterned ways. These experiments provide added insight into the long-term processes that impact archeological assemblages due to the traversing of animals across cultural artifact horizons. Natural processes that may rearrange the horizontal constellation of artifacts can generally be identified; however, the patterned nature of longer-term trampling can influence the resulting size distribution, and the distance and direction of artifact refit and conjoin. Because the resulting patterns mimic another process, they could be misinterpreted within archeological assemblages. Additional work that links experimental patterns of lithic movement can help develop diagnostic tools for identifying equifinality in the archeological record

Table 4 Model of spatial movement processes on lithic tools

Process	Distance	Relationship between distance and size	Bearing with respect to slope	References
Downslope	20–300 m at the slope of 10–44°	Positive	Non-random, with slope	(Rick 1976; Fanning and Holdaway 2001)
Fluvial	Dependent on flow	Generally negative	Non-random, with slope	(Schick 1984; Hosfield and Chambers 2016)
Animal trampling, 5 months, corral	0–3 m	Positive	Non-random (no slope)	This study, highest activity area
Animal trampling, 5 months, trail	0–3 m	None	Non-random, with overall aspect, oblique to trail	This study, lowest activity area
Animal trampling, 5 months, field	0–1.5 m	Positive	Non-random, against the slope	This study, medium activity area
Human toss zones	Small artifacts 0–1.2 m; large 1.5–2.5 m	Positive	Non-random, with or against the slope	(Yellen 1977; Binford 1983; Carr 1991)

that will enable archeologists to more confidently make behavioral interpretations from lithic artifact spatial and refitting data.

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References

Agostinelli C (2012) CircStats: circular statistics, from "Topics in Circular Statistics"(2001) R package version 0.2–4, S-plus original by Ulric Lund and R port by Claudio Agostinelli

Balirán C (2014) Trampling, taphonomy, and experiments with lithic artifacts in the southeastern Baguales Range (Santa Cruz, Argentina). Intersecciones en Antropología 15:85–95

Barton CM, Bernabeu J, Aura JE, Garcia O, La Roca N (2002) Dynamic landscapes, artifact taphonomy, and landuse modeling in the Western Mediterranean. Geoarchaeology 17:155–190

Behrensmeyer AK, Gordon KD, Yanagi GT (1986) Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature 319:768–771

Benito-Calvo A, Martínez-Moreno J, Mora R, Roy M, Roda X (2011) Trampling experiments at Cova Gran de Santa Linya, Pre-Pyrenees, Spain: their relevance for archaeological fabrics of the Upper–Middle Paleolithic assemblages. J Archaeol Sci 38:3652–3661

Benn D (1994) Fabric shape and the interpretation of sedimentary fabric data. J Sediment Res A64:910–915

Bernatchez J (2010) Taphonomic implications of orientation of plotted finds from Pinnacle Point Cave 13B (Mossel Bay, Western Cape Province, South Africa). J Hum Evol 59:274–288

Binford LR (1978) Nunamiut ethnoarchaeology. Academic, New York

Binford LR (1980) Willow smoke and dogs' tails: hunter-gatherer settlement systems and archaeological site formation. Am Antiq 45:4–20

Binford LR (1983) In pursuit of the past. Thames and Hudson, New York

Brooks AS, Yellen JE (1987) The preservation of activity areas in the archaeological record: ethnoarchaeological and archaeological work in northwest Ngamiland, Botswana. In: Kent S (ed) Method and theory for activity area research: an ethnoarchaeological approach. Columbia University Press, New York, pp 63–106

Burger O, Todd LC, Burnett P (2008) The behavior of surface artifacts: building a landscape taphonomy on the High Plains. In: Scheiber LL, Clark B (eds) Archaeological landscapes on the High Plains. University Press of Colorado, Boulder, pp 203–236

Byers DA, Hargiss E, Finley JB (2015) Flake morphology, fluvial dynamics, and debitage transport potential. Geoarchaeology 30:379–392

Camarós E, Cueto M, Teira LC, Tapia J, Cubas M, Blasco R, Rosell J, Rivals F (2013) Large carnivores as taphonomic agents of space modification: an experimental approach with archaeological implications. J Archaeol Sci 40:1361–1368

Carr C (1991) Left in the dust, the interpretation of archaeological spatial patterning. Springer, Berlin, pp 221–256

Dibble H, McPherron SP, Chase P, Farrand WR, Debenath A (2006) Taphonomy and the concept of Paleolithic cultures: the case of the Tayacian from Fontéchevade. PaleoAnthropology:1–21

Driscoll K, Alcaina J, Égüez N, Mangado X, Fullola J-M, Tejero J-M (2016) Trampled under foot: a quartz and chert human trampling experiment at the Cova del Parco rock shelter, Spain. Quat Int 424:130–142

Eren MI, Durant A, Neudorf C, Haslam M, Shipton C, Bora J, Korisettar R, Petraglia M (2010) Experimental examination of animal trampling effects on artifact movement in dry and water saturated substrates: a test case from South India. J Archaeol Sci 37:3010–3021

Eren MI, Boehm AR, Morgan BM, Anderson R, Andrews B (2011) Flaked stone taphonomy: a controlled experimental study of the effects of sediment consolidation on flake edge morphology. J Taphonomy 9:201–217

Fanning P, Holdaway S (2001) Stone artifact scatters in western NSW, Australia: geomorphic controls on artifact size and distribution. Geoarchaeology 16:667–686

Fiorillo AR (1989) An experimental study of trampling: implications for the fossil record. In: Bonnichsen R, Sorg MH (eds) Bone modification. Center for the Study of First Americans, Orono, pp 61–71

Flenniken JJ, Haggarty JC (1979) Trampling as an agency in the formation of edge damage: an experiment in lithic technology. Northwest anthropological. Res Notes 13:208–214

Gifford-Gonzalez D (1991) Bones are not enough: analogues, knowledge, and interpretive strategies in zooarchaeology. J Anthropol Archaeol 10:215–254

Gifford-Gonzalez D, Damrosch DB, Damrosch DR, Pryor J, Thunen RL, Reinhard KJ, Ambler JR, McGuffie M (1985) The third dimension in site structure: an experiment in trampling and vertical dispersal. Am Antiq 50:803–818

Hosfield R, Chambers J (2016) Flake modifications during fluvial transportation: three cautionary tales. Lithics—the journal of the lithic studies. Society 57

Koetje TA (1994) Intrasite spatial structure in the European Upper Paleolithic. J Anthropol Archaeol 13:161–169

Kovach W (2011) Oriana–circular statistics for windows, ver. 4. Kovach Computing Services, Pentraeth

Lopinot NH, Ray JH (2007) Trampling experiments in the search for the earliest Americans. Am Antiq 72:771–782

Lyman RL (1994) Vertebrate Taphonomy. Cambridge University Press, New York

Lyman RL (2004) The concept of equifinality in taphonomy. J Taphonomy 2:15–26

Marwick B, Hayes E, Clarkson C, Fullagar R (2017) Movement of lithics by trampling: an experiment in the Madjedbebe sediments, Northern Australia. J Archaeol Sci 79:73–85

McBrearty S, Bishop L, Plummer T, Dewar R, Conard N (1998) Tools underfoot: human trampling as an agent of lithic artifact edge modification. Am Antiq 63:108–129

McPherron SP (2005) Artifact orientations and site formation processes from total station proveniences. J Archaeol Sci 32:1003–1014

McPherron SP (2018) Additional statistical and graphical methods for analyzing site formation processes using artifact orientations. PLoS One 13:e0190195

McPherron SP, Braun DR, Dogandžić T, Archer W, Desta D, Lin SC (2014) An experimental assessment of the influences on edge damage to lithic artifacts: a consideration of edge angle, substrate grain size, raw material properties, and exposed face. J Archaeol Sci 49:70–82

Marean, C.W., Bertino, L. 1994. Intrasite spatial analysis of bone: subtracting the effect of secondary carnivore consumers, American Antiquity 59(4):748–768. https://doi.org/10.2307/282346

Nielsen AE (1991) Trampling the archaeological record: an experimental study. Am Antiq 56:483–503

O'Connell JF (1987) Alyawara site structure and its archaeological implications. Am Antiq 52:74–108

Oestmo S, Schoville BJ, Wilkins J, Marean CW (2014) A Middle Stone Age Paleoscape near the Pinnacle Point caves, Vleesbaai, South Africa. Quat Int 350:147–168

Olsen SL, Shipman P (1988) Surface modification on bone: trampling versus butchery. J Archaeol Sci 15:535–553

Pargeter J (2011) Assessing the macrofracture method for identifying Stone Age hunting weaponry. J Archaeol Sci 38:2882–2888

Pargeter J, Bradfield J (2012) The effects of class I and II sized bovids on macrofracture formation and tool displacement: results of a trampling experiment in a southern African Stone Age context. J Field Archaeol 37:238–251

Pryor J (1988) The effects of human trample damage on lithics: a consideration of crucial variables. Lithic Technol 17:45–50

Rick JW (1976) Downslope movement and archaeological intrasite spatial analysis. Am Antiq 41:133–144

Schick KD (1984) Processes of Palaeolithic site formation: an experimental study. University of California, Berkeley

Schoville B (2014) Testing a taphonomic predictive model of edge damage formation with Middle Stone Age points from Pinnacle Point Cave 13B and Die Kelders Cave 1, South Africa. J Archaeol Sci 48: 84–95

Schoville B, Burris L, Todd LC (2009) Experimental artifact transport by harvester ants (*Pogonomyrmex* sp.): implications for patterns in the archaeological record. J Taphonomy 7:285–303

Schoville BJ, Brown KS, Harris JA, Wilkins J (2016) New experiments and a model-driven approach for interpreting middle stone age lithic point function using the edge damage distribution method. PLoS One 11:e0164088

Shea JJ, Klenck JD (1993) An experimental investigation of the effects of trampling on the results of lithic microwear analysis. J Archaeol Sci 20:175–194

Simms SR (1988) The archaeological structure of a Bedouin camp. J Archaeol Sci 15:197–211

Sisk ML, Shea JJ (2008) Intrasite spatial variation of the Omo Kibish Middle Stone Age assemblages: artifact refitting and distribution patterns. J Hum Evol 55:486–500

Stevenson MG (1985) The formation of artifact assemblages at workshop/habitation sites: models from peace point in Northern Alberta. Am Antiq 50:63–81

Villa P, Courtin J (1983) The interpretation of stratified sites: a view from underground. J Archaeol Sci 10:267–281

Wandsnider L (1996) Describing and comparing archaeological spatial structures. J Archaeol Method Theory 3:319–384

Yellen J (1977) Archaeological approaches to the present: models for reconstructing the past. Academic, New York