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Towards an artefact's-eye view: Non-site analysis of discard patterns and lithic technology in Neotropical settings with a case from Misiones province, Argentina.

Philip Riris*

*Institute of Archaeology, University College London, 31-34 Gordon Square, London WC1H 0PY, United Kingdom
E-mail address: P.Riris@ucl.ac.uk.

Abstract

Surface scatters are an important source of archaeological data in the Neotropics, yet despite their role in exploring regional land use, existing frameworks have serious methodological and theoretical drawbacks. This study proposes a robust alternative to site-centric approaches, by examining spatial and technological variability in time-averaged deposits of artefacts collected from the modern surface of Misiones province, north-eastern Argentina. A family of spatial statistical techniques supported by Monte Carlo simulation identify statistically significant inhomogeneity and clustering in lithic point pattern data. This highlights interaction between technologically meaningful sub-samples of four assemblages, which is interpreted as reflecting long-term discard and association of distinctive reduction sequences. These are irreducible to individual episodes, demonstrating that partitioning palimpsests into sites poorly reflects record formation on a landscape level. This illustrates how explicit models of depositional trends can provide information on indigenous land use, and underlines the rich informative potential of surface archaeology in tropical settings.

Keywords: Surface archaeology, Spatial analysis, Survey, Argentina, Lithic technology

1. Introduction

Over the past two decades, the ubiquitous adoption of spatial technologies in the discipline has precipitated a geospatial revolution, as large spatial databases can be collected and manipulated with relative ease (Conolly and Lake, 2006; Bevan et al., 2013). This new reality for archaeological fieldwork introduces both possibilities and challenges, as the increasing volume and accuracy of spatial data precludes the interpretative value of density-based visualizations (Bevan et al., 2013). This paper proposes a new approach to spatial point pattern data in Neotropical environments, with the aim of characterizing discard patterns over the long term in Misiones province. Formal tests are increasingly deployed to test hypotheses on the formation and configuration of archaeological deposits, drawing in large part on methods developed in landscape ecology and spatial epidemiology (see Pélissier and Goreaud, 2001; Diggle, 2003; Wiegand and Moloney, 2004; Baddeley and Turner, 2005; Jacquemyn et al., 2007; Shekhar et al., 2011). In parallel, research on pre-Columbian cultural landscapes has proven to be extremely fertile ground in recent years (Zeidler, 1995; Walker, 2012). It is argued here that the potential contribution of intensive survey to this strand of investigation has yet to be fully realized, in part due to a lack of rigorous spatial analytical frameworks (see Bevan et al., 2013; Crema and Bianchi, 2013). As a tentative first step, this article reports on the implementation of a "non-site" archaeological survey in Misiones province, Argentina (Fig. 1), whose landscape dimension has hereto been defined largely by unknowns (Iriarte et al., 2008; Iriarte et al., 2010; Loponte, 2012; Riris, 2014).

Against this backdrop, this study will adapt a set of methods for exploring spatial point patterns, in order explore indigenous discard practices and, ultimately, land use in a Neotropical setting. This will seek to (a) identify the existence and nature of spatial relationships between three technologically-defined subsets of surface collected lithic data, and (b) characterize the significance and variability in these relationships across space in Misiones province.

Despite the pretensions of nomenclature such as "workshop", "encampment" or "village" commonly applied to surface scatters, these data rarely translate directly to processes which unfolded on a phenomenological scale (Holdaway and Wandsnider, 2006; Lucas, 2008). Similarly, the assignation of cultural provenance to palimpsest datasets simply on the basis of presence or absence of diagnostic artefacts, often with temporal implications, is equally problematic (Bailey, 2007, cf. De Souza and Merencio, 2013). Together, these sources of bias risk framing archaeological evidence in terms that embody behavioural or social significance, by over-emphasizing high-density clusters of material (Nance, 1983; Ebert, 1992) to the detriment of the majority of the material record that occurs in vast, weakly-patterned distributions (Sullivan, 1995). One potential solution is to treat archaeological data as stemming from a continuum of context types rather than a strict dichotomy of open-air (weakly patterned or unstructured) and excavated (controlled, structured) sites (Ebert, 1992; Lucas, 2002). The body of theory called non-site archaeology eschews the use of sites as analytical or interpretative units (see Foley, 1981; Dunnell, 1992; Ebert, 1992), arguing that its inherent bias inadequately describes the full range of human activity that occurred on a landscape scale.

In a bid to surmount the above challenges, this study treats the individual artefact as the unit of discovery, focusing on lithic technological variability in surface archaeology from Misiones province. The following case study will develop this strategy by (1) defining how surface data can be used to characterize spatial trends in deposition and discard across a range of settings, (2) exploring how the distribution of lithic technology varies within and between a sample of locations and (3) suggesting how indigenous land-use patterns might manifest at multiple spatial scales on millennial timescales. Ultimately, this is precipitated on a group of spatial statistical techniques supported by Monte Carlo simulation, which are leveraged towards building an “artefact's-eye view” (Purves and Law, 2002) of indigenous cultural landscapes in the study area.

1.1. Background to study area

Misiones province is located in the far north-east of Argentina, bordered on three sides by the Paraná, Uruguay and Iguazú rivers. Their courses circumscribe its boundaries with Paraguay and Brazil (Fig. 1). The study area encompasses Eldorado Department in the north-central sector of the province, whose topography is strongly influenced by a perennially wet climate, with fast-flowing rivers cutting steep valleys into the otherwise gently undulating plateaux and floodplains between the major rivers. The native vegetation is composed principally of semi-deciduous subtropical Paraná Interior Atlantic forests, with a dense evergreen canopy. In the south-west these forests transition to open grasslands, while in the uplands near the Brazilian border the western-most extent of Mixed Highland Paraná Pine (*Araucaria angustifolia*, Bertol. Kuntze) forest is found. In the modern day, the native biomes are heavily fragmented by industrial and agricultural activity around modern settlements and highways. The highly weathered red soils are acidic, which prevents the archaeological preservation of bone.

Sustained archaeological fieldwork began in earnest only recently in Misiones province (Iriarte et al., 2008, 2010). From the middle of the twentieth century the majority of investigations have taken the form of sporadic surveys, rescue projects, and trial excavations (Schimmel, 1967; Madrazo and Laguzzi Rueda, 1967; Rizzo, 1968; Giesso and Rizzo, 1985; Giesso and Poujade, 1986). The results of these surveys indicate that, in terms of information yield, intensive systematic is ideal for generating large quantities of archaeological data when deployed in open areas. This is valuable especially where virtually no preceding fieldwork has taken place, as in Misiones; every zone targeted in the highlands by a previous survey yielded evidence of discard (see Iriarte et al., 2010). This underlines how targeting the surface record can expand the body of available data significantly and cost-effectively (Riris, 2010). Furthermore, it hints at the presence and potential of extensive, multi-period datasets for investigating cultural variability in land use patterns on a broader spatial scale, in ways which bounded interpretative units cannot. Preceding research has of course been limited by the difficulty of detecting a record dominated by the unobtrusive remains of hunter-gatherers and horticulturalists in dense subtropical forests. Further to this, surveys in southern Brazil suggest major variability in the content and distribution of materials in surface sites (Araujo, 2001; Saldanha, 2005; De Souza and Merencio, 2013).

Unlike neighbouring southern Brazil, a Late Pleistocene occupation is unknown to date in Misiones. Current consensus identifies a long pre-ceramic period began with the initial appearance of the Altoparanaense (Humaitá in Brazil) and Umbu industries around approximately 8000 BP (Hoeltz, 2007; Dias and Hoeltz, 2010; Dias, 2012; Loponte, 2012). These are differentiated on the basis of lithic tool morphology. The toolkit of the former consists of large bifacial tools while the latter is mainly small cruciform and lanceolate projectile points (see Schmitz, 1987; Dias, 2007; Dias, 2012). Both are documented in Misiones through informal collections, rescue projects, and excavations in rockshelters. Recent work has highlighted the long term persistence and conservatism in these industries, which overlap to a certain extent with a comparatively short ceramic period that started after c. 2000 BP (Araujo, 2007; Dias and Hoeltz, 2010; Loponte, 2012; Okumura and Araujo, 2014).

One of the largest documented funerary monuments of the southern proto-Jê culture (180 m diameter) is located in Eldorado Department, Misiones, among a group of seven other mound and enclosure complexes (Menghin, 1957; Wachnitz, 1984; Iriarte et al., 2008). A range of absolute dates span the twelfth and fourteenth centuries AD, which are among the few reliable age determinations for the entire province (Iriarte et al., 2008). Somewhat after the arrival of the southern proto-Jê in Misiones, the Tupiguarani culture spread via the Paraná and Uruguay valleys from an Amazonian origin (Brochado, 1984; Bonomo et al., 2015). While Tupiguarani sites are relatively abundant, sites few unambiguously pertain to the southern proto-Jê archaeological culture, excepting the aforementioned funerary complex (Iriarte et al., 2008) and a handful of surface finds (Iriarte et al., 2010). The exact nature of the scale and extent of interactions between these two cultures in Misiones province is currently an open question (Iriarte et al., 2008; Loponte, 2012).

1.2. The structure of surface archaeology

The peculiar nature of surface collected data affects the types of interpretations that may be drawn from them (Ebert, 1992). Complex sequences of depositional and post-depositional processes, such as superimposed discard patterns, partial destruction, artefact recycling, and active surface geomorphologies modify the relative quantity of visible surface archaeology at any given moment in time (Foley, 1981; Dunnell and Dancey, 1983; Holdaway et al., 2010). Depositional events separated by centuries can be located in relatively close spatial proximity (Holdaway and Wandsnider, 2006), meaning that intensive short-term discard activity in a given location may theoretically be equifinal to long-term deposition of a very low intensity (Bintliff and Snodgrass, 1988). Consequently, any attempt to translate a surface scatter into initial conditions that correlate to events on a phenomenological scale or cultural historical constructs will presume a degree of temporal control over surface data that is challenging to achieve in the vast majority of cases (Ebert, 1992; Dunnell, 1992). For this reason, although indigenous occupations in Misiones have a time-depth spanning the majority of the Holocene, it is at present impossible to conclusively correlate surface archaeology in this setting with the archaeological cultures outlined briefly above. Although it is standard in the regional literature to "date" scatters by the presence or absence of diagnostic artefacts (Saldanha, 2005; De Souza and Merencio, 2013), this study proceeds on the assumption that artefacts scattered over multiple hectares, only a very limited number of which are temporally sensitive, cannot be confidently assigned to a single cultural entity existing at a single point in time, as is often assumed.

A distributional approach requires an alternative set of expectations for surface collected data, focusing on spatial scale and technological variability in a flattened temporal framework (Ebert, 1992; Holdaway and Wandsnider, 2006; Holdaway et al., 2010). Worked stone is the only multi-period time-transgressive class of artefact that can currently be encountered in Misiones, and is the most reliable basis for approaching variability in land use in multi-period datasets (Sullivan, 1995; Jones and Beck, 1992). Analysing the spatial patterning in lithic scatters can provide insight into the relationship between depositional trends, land use and technological strategies. For this reason, lithic data form the basis of the majority surface archaeological investigations (Holdaway and Wandsnider, 2006; Holdaway et al., 2010). They can be compared metaphorically to a long-exposure photograph, providing a snapshot of the totality of discard and preceding activities in a location, mediated through formation processes (Carr, 1984; Sullivan, 1995; Wandsnider, 1998). This spectrum of patterned deposition can be used to define and explore persistent places (or lack thereof) in a landscape (Schlanger, 1992; Fanning and Holdaway, 2001). This is interpretatively attractive to identify concurrent trends in multivariate data, employing methods that are more robust than simple density-based metrics.

2. Data collection

Due to the ubiquity of dense vegetation in the Neotropics, fieldwork, and survey specifically, has tended to rely on “methodologically unlovely techniques” (Schiffer, 1987 in: Zeidler, 1995). Adequate sampling is difficult to achieve over large, continuous parcels of space under logistically challenging conditions, limiting the degree to which data can be treated as representative. Some factors to highlight include reduced site accessibility, low visibility of the surface, and diminished ability to maintain a consistent sampling strategy (Zeidler, 1995). Misiones province is no exception. The majority of its land cover was semi-deciduous subtropical forest until the latter half of the twentieth century. The introduction of mechanized tools, however, led to vast tracts of the Interior Atlantic Forest being cleared. Although the impact on native ecologies is severe, the process of clearance, burning, and replanting also creates ideal conditions for pedestrian field survey in well-spaced and manageable parcels of land (Fig. 2). Previous surveys in the region (Iriarte et al., 2010; Riris, 2010) have illustrated the difficulties involved in imposing strict separations between site and non-site space, but also provide a template for a data collection strategy.

To this end, a systematic survey was executed by a team of five targeting plantations and areas of mixed cultivation in Eldorado Department. Quadrats were primarily planted with juvenile pine (*Pinus* sp.) and varied in area from 0.92 to 19.2 ha. Pine is planted in straight rows spaced 5 m apart, which served as guides during transects and ensured that at least 2.5 m to either side were consistently scanned by surveyors. In quadrats lacking pine (for example cleared plots and cultivated fields), this spacing was manually measured out, maintained and corrected where necessary after each transect. The broad class of land use was also noted (Table 1). All artefacts were collected and the coordinates noted with a handheld Garmin GPS with a random horizontal error of up to ± 4 m. As the areas targeted by the survey were all open and with uniformly excellent satellite signal, the recorded error was never above this figure even on overcast days. The recorded boundaries of quadrats were cross-referenced with remotely sensed imagery. In the highland zone, clearings are generally larger, yet restricted by steeper hillsides, meaning that only relatively fiat and well-drained inter-valley plateaux can be surveyed, excluding valley bottoms (see Riris, 2010). As the study area is essentially a gently undulating flood-plain of the Paraná, some of the biases inherent to the highland topography are mitigated in this survey. This resulted in a sample of 18 quadrats across the study area (see Fig. 1) totalling 136.02 ha, in which 736 artefacts were recorded. The vast majority of these finds were flaked basalt artefacts; ceramics only constitute 11.1% of the final assemblage and were all highly fragmented.

3. Methods

3.1. Flaked stone

The lithic analysis focused on identifying and comparing patterns of reduction and retouch across multiple assemblages, enabling assessments of their technological organization to be made in terms of raw material management and discard. While there are existing typologies based on diagnostic forms of the aforementioned Umbu and Humaitá industries (side-scrapers/projectile points and large bifaces, respectively), the vast majority of the surface lithics of Misiones consists of morphologically indistinct pieces with a low investment of energy in their production, typically termed "expedient" technology (Bamforth, 1986; Parry and Kelly, 1987). The same criteria were applied to the whole assemblage. Artefact dimensions (cm) and mass (g), as well as 1) scar counts, 2) the degree and extent of retouch, and 3) cortical cover percentage (the latter three on four point ordinal scales) were recorded. For technical details of the analysis, refer to Riris (2014) and Riris and Romanowska (2014). The classification below is primarily a heuristic for presenting the relatively homogeneous lithic technology present in the study area (Fig. 3), which lacks chronological control and thus justifies the overall non-site approach employed. Three distinct reduction sequences were defined in the assemblages:

- Core and flake technology dominates the assemblages. This system of reduction involved detaching large quantities of flakes from river cobbles, which received little preparation. Abundant basaltic raw material allows for nodules to be converted as required into a dependable source of flakes in the 25–50 mm size range, although larger flakes were produced in certain cases. Retouch is uncommon and informal, with no dominant morphological pattern. It can be inferred that without a shortage of cores from which to detach flakes, there is little reason to either a) exert a lot of control over morphology or b) produce and select flakes conservatively (Parry and Kelly, 1987). Cores were flaked using a variety of techniques (unidirectional, alternating platform, multiplatform), yet reduction intensity is stable across these categories and cores were frequently discarded after a very small number of removals. Since these are universal ways of knapping non-prepared cores, any cultural significance is an open question. Average core volume is consistent across assemblages, which is likely related to the ubiquity of uniform river cobbles. No formally prepared cores (e.g. blade cores) were encountered.
- *Unifacial tool technology* is a subset of the core and flake system, where significant qualitative differences in the formality and intensity of re-touch were detected. Typologically, these tools would be considered end- and side-scrapers, showing a more careful selection and preparation of material than the bulk of the informal flakes (Fig. 3). The pattern of intensive retouch along single edges implies that blank selection was for adaptability to comparatively long use-lives. Size and ability to receive shaping likely was a determining aspect and so, unifacial tools may have provisioned relatively mobile people (see Holdaway et al., 2010).
- *Bifacial tool technology* consists of large bifacial tools and their pre-forms (i.e. the long-lived Humaitá-type tools), whose morphology is largely symmetrical until the final stages, when a pronounced left-right asymmetry is imposed ("curved cleavers", see Riris and Romanowska, 2014). Deposition of these tools in either "final stage" or broken forms may provide direct evidence of *in situ* usage in specific places. The discard of preforms could be related to provisioning places with material that could later be shaped into curved

cleavers, or else shows the rejection of unsuitable blanks. No projectile points or clear precursor forms were detected.

3.2. Spatial statistical methods

In point process theory, first order characteristics are global trends in a pattern that directly affect the number of points per unit of area (Diggle, 2003) (its intensity). Conversely, second order characteristics describe the interaction between points, meaning the propensity for the locations of points to be attracted or inhibited by the locations of others (Ripley, 1976; Bevan et al., 2013). In practice, most empirical spatial data exhibits interaction in some way (Shekhar et al., 2011). This is self-evident for flaked stone, since all knapped material ultimately originates from another objective piece of raw material that is manipulated within a specific technological system. Crema and Bianchi (2013), analysing interaction between diagnostic Middle Palaeolithic and Epipalaeolithic stone tools, were able to detect significant spatial clustering between these two classes, possibly reflecting re-occupation of particular locales by people across multiple periods. It therefore makes sense to dissect spatial patterns in lithic data in Misiones further using this approach.

Ripley's *K* statistic (Ripley, 1976) is a robust measure of second order structure described by the function $K(r)$ that is widely applied to point patterns. It measures the observed number of points in a circle of radius r around each point in a pattern divided by the overall intensity of the pattern, in order to test the extent to which point locations are determined by others. The function accumulates at each value of r and is displayed alongside its expected value under conditions of complete spatial randomness (CSR), which function as null hypothesis (Pélissier and Goreaud, 2001; Wiegand and Moloney, 2004). The O-ring statistic $g(r)$ is a modification proposed in (Stoyan and Stoyan, 1994) which replaces the circles of $K(r)$ with annuli, where spatial structure is measured *between* distance bands of r1 and r_n rather than first within r1 and *up* to r_n (Fig. 4) and has seen some use in archaeology (Bevan et al., 2013). This normalised statistic therefore provides a more intuitive output (Wiegand and Moloney, 2004, 225; Jacquemyn et al., 2007). Nonetheless, global measures of autocorrelation only present an average, which can conceal variability in spatially heterogeneous datasets. To mitigate this limitation, a local variant of the statistic is also usually deployed (Crema and Bianchi, 2013) to demonstrate where and at what scale heterogeneity exists within point patterns (Getis and Franklin, 1987). This functions by computing, in effect, an unsummed version of the K function at fixed spatial scales of interest (Pélissier and Goreaud, 2001) to detect the presence and degree of local interactions within complex spatial datasets (Getis and Franklin, 1987; Jacquemyn et al., 2007).

Finally, the analysis makes use of bivariate versions of these statistics to test for spatial association/inhibition between designated groups of points, independent of any patterning within the individual groups or the assemblage as a whole (Wiegand and Moloney, 2004). A rejection of the null hypothesis of CSR is equivalent to the groups of points being independent realizations of different patterns (Crema and Bianchi, 2013), effectively testing whether subsets of the assemblages are part of similar or unrelated discard processes. Tests of significance for each application were carried out via a Monte Carlo procedure. Alongside each application of the bivariate $g(r)$, 99 realizations of CSR were generated from a Poisson process to define critical envelopes, above and below which clustering and inhibition (respectively) are statistically significant at the 0.02 confidence level (Diggle, 2003; Stoyan and Stoyan, 1994; Baddeley and Turner, 2005).

3.3. Landform classification

The key determinant of artefact movement on surfaces is the slope and the relationship of a surface to surrounding topographical units, both of which relate directly to erosion rates (Fanning and Holdaway, 2001). Mechanized cultivation, besides inducing horizontal and vertical artefact movement, also increases the erosion potential of the surface. Experimental research in ploughed contexts indicates that lateral movement of artefacts tends to follow the direction of tillage (Roper, 1976), whose “average cumulative displacement” attains equilibrium around 2 m in any direction (Odell and Cowan, 1987; Navazo and Díez, 2008) irrespective of how “ploughed out” the surface is. More recent work indicates that small artefacts are also more likely to be forced downwards in the soil profile (Navazo and Díez, 2008). Drying out the soil and increasing the susceptibility to erosion may also contribute to altering artefact positioning further. Smaller artefacts are hence less likely to be susceptible to water transportation, while massive artefacts are more resistant to movement. In effect, these factors together increase the likelihood of retrieval of large artefacts by eliminating some smaller artefacts from the sampled population (cf. “size-sorting effect” in: Baker, 1978; Lewarch and O'Brien, 1981).

To explore erosion risk within a dynamic topsoil and its potential impact on the distribution of the assemblages, the topography of the study area was analysed in ArcGIS 10.2 for slope classification and Landserf 2.3 for a geomorphological analysis (Wood, 1996). Furthermore, as noted above, the measurement error may be up to 4 min any horizontal direction, which has introduced a further random displacement to the point patterns.

Slope angle in degrees was calculated from the SRTM digital elevation model (DEM) with 30 m resolution, and reclassified into five classes derived from Jenks breaks in the dataset, rounded to the nearest whole number. The DEM also served as input in the morphometric analysis. Based on the elevation value of a window of cells, a bivariate quadratic function assigns the terrain to one of six predefined feature types (see Wood, 1996) by taking into account a number of first- and second-order DEM derivatives, including six different curvature measures plus slope steepness (Wood, 1996):

$$Z = ax^2 + by^2 + cxy + dx + ey + f$$

Calculations run within a user-defined window, which was iterated from the default (3 × 3 cells) to 5,10,15, and 25 cell neighbourhoods. The 25 × 25 window (750 m^2) was judged sufficient for detecting broad-scale features. The relatively low resolution of the SRTM data partially obscures fine topographical features, such as channels and track-ways, regardless, leading to minimal loss of information overall using these parameters.

4. Results

This section integrates the technological analysis and the formal spatial statistical approach. As noted, three distinct reduction sequences were detected within the study area: core and flake reduction, unifacial tool production, and bifacial tool production (see also Riris, 2014). Visualizing the raw distributional patterns reveals a high degree of short-range clustering (Fig. 5). This obtrusive raw pattern may nonetheless hide unrelated and statistically significant technological variability. Post-depositional patterns of note are also present. For example, Ziegler II possesses a tight linear cluster of cores and flakes in its centre, which eroded out of a trackway along an east-west axis. This dirt track was 10– 15 cm below the surface level of the plantation, and was evidently heavily shaped by recent water flow. The appearance of this cluster is likely almost entirely due to post-depositional alluvial transportation, and is thus definitively (as opposed to potentially) behaviourally unrelated to the remaining clusters. These artefacts have been included in the analysis in order to test the sensitivity of the local spatial statistical functions to taphonomically anomalous patterning which, in purely statistical terms, are likely to be detected as highly significant. This underscores the importance of significance testing the results of spatial analyses with Monte Carlo methods.

4.1. Landform analysis and sample selection

The morphometric analysis (Fig. 6) shows that over half of the surface area of the quadrats (54.4%) is on relatively fiat areas of land with low relief, classified as planes. The next most numerous landform are ridgetops (22.6%), while the low percentage of channels (20.4%) is interesting given the fluvial nature of the study area. This might be explained by the fact that most quadrats were not located very close to rivers or streams. Compared to previous surveys (e.g. Riris, 2010), both high and low points in the landscape were surveyed. Finally, an overall insignificant quantity of passes and peaks make up 2.1% and 0.6% of the cells in field sites, respectively. The slope classification supports the morphometric analysis, with the vast majority of the terrain surveyed being fiat to gently inclined (<7°). None of the terrain surveyed fell in the steepest categories of slope shown (> 7°). Although areas of sheer relief are not included in the surveyed quadrats, intuitively, steep slopes and the difficulty of travel within these areas would limit their archaeological potential even if they were targeted by the survey.

As the areas surveyed are generally on surfaces with no or shallow slopes, erosion and downslope movement of artefacts in the quadrats themselves is likely to be of minimal severity. The impact of post-depositional displacement did not overly affect or restrict the collection of a representative archaeological dataset in the study area, and the recorded data largely can be taken to represent real archaeological phenomena rather than noise. In aggregate, therefore, broad depositional trends are likely preserved in the relative horizontal positioning of ploughed deposits on these surfaces (Bintliff and Snodgrass, 1988; Steinberg, 1996; Taylor et al., 2000), despite the action of both anthropic and natural forces.

It is worth noting that the majority (79.8%) of the lithic component of the survey assemblage was encountered within only four quadrats (Aumer I and Ziegler II-IV), while the remaining quadrats only produced relatively small assemblages of stone artefacts (Table 1). The very small numbers and low density of lithics recorded in these cases places hard limits on the extent to which spatial structure can be investigated quantitatively. The results presented below therefore focus on understanding patterning in four "analytical quadrats" (see Fig. 5) with comparatively large assemblages and an artefact density of >0.1 artefacts/m^2. Although the next two most populous quadrats (MPM016 and MPM024) have a similar raw count of artefacts, the majority are ceramic sherds not amendable to comparative analysis alongside lithics in the manner outlined above.

As noted, site formation processes and the overall sparseness of the surface record also present a challenge to understanding quantitative technological variation in assemblage structure (Holdaway and Wandsnider, 2006). While the cumulative effects of displacement and recording errors in GPS readings can be mitigated by using large number of data points, erroneous interpretations of spatial structure must be avoided, especially at smaller scales. To this end, I impose a lower threshold of 10 m for the spatial analysis as the minimum scale at which meaningful interpretations can be made. This represents a slight limiting factor for fine-scale spatial analysis but does not confound the approach as a whole.

4.2. Global spatial structure

The bivariate g(r) analyses were executed on three subsets representing basic technological elements of the survey assemblages in each of the four quadrats. In order, the subsets used are:

(1) The distribution of all cores and all flakes (including unifacial flake tools) against those of bifacially flaked artefacts. This investigates the presence or absence of relationships between the two principal stoneworking techniques present in the study area.

(2) As proxies for evidence of tool production versus tool discard during use, the distributions of preforms and unutilized flakes were compared to the locations of retouched flakes, unifacial tools and broken/final stage bifacial tools.

(3) Evidence of raw material extraction (cortical flakes and tested cobbles) is compared to worked cores and tool preforms to examine the relationship between material extraction and procurement, and time-extended reduction sequences.

It should be clear from this that in many cases, certain artefacts can appear more than once in the analyses. For example, a tested cobble is technically a core for the purposes of the first test but also serves evidence of raw material procurement in the third.

Comparing core and flake reduction with bifacially-worked tools, the strongest pattern of spatial association between these systems is found above the 10 m threshold in all cases excepting Ziegler II, where a weak significant relationship is found above 20 m. Strong clustering behaviour is the norm in each quadrat (Fig. 7). Assemblages only approximate spatial randomness at distances >60 m in Ziegler IV, <25 m in Ziegler III, between 50 and 60 m in Ziegler II, and never in Aumer I. A dispersed pattern, or spatial inhibition, is not found at any scale. Redundancy in place use and discard patterns (see Binford, 1980) can therefore be inferred between these two significantly different reduction sequences, except at very large and very short scales in three of the four cases. Each area also appears to possess its own particularities at different spatial scales as well.

Clustering is even more pronounced and consistent in the case of tool production and tool usage discard (Fig. 8, left). Only for short intervals near 55 min Ziegler II and Ziegler IV, and 35 min Ziegler III are the point patterns anything other than strongly associated and the empirical functions in all four quadrats are well above their corresponding significance envelopes. The analysis indicates that tools, regardless of the technology or stage of reduction, tend to cluster together at all scales, excepting a few limited cases.

The results of the above are mirrored in the behaviour of material extraction versus reduction, with pervasive clustering at all scales. The only notable exception is Ziegler II, where at approximately 25 m the pattern dips momentarily into randomness, clustering again, and descending to randomness for a final time around 50 m (Fig. 8, right). This indicates that, most often and at multiple spatial scales, raw material tended to be prepared close to where it was found.

Summarizing these results, it is evident that the analysed subsets of the assemblage universally tend towards significant positive autocorrelation at all spatial scales. The total lack of any definitive spatial inhibition is noteworthy, insofar as large parts of the point patterns superficially appear to be diffuse. Nonetheless, the individual empirical curves also reveal variability in the degree of clustering. As the values of the global function at any given distance will reflect the average spatial trend in the data, less obtrusive patterns in the mix will be subsumed by the dominant trend. This is an intentional feature of the function (Diggle, 2003; Crema and Bianchi, 2013), however, summaries cannot directly show which points in an empirical distribution are associated or segregated relative to the null hypothesis of CSR. This invites further investigation of heterogeneity with local statistics in order to disentangle any variability subsumed by the global statistics.

4.3. Local spatial structure

The analysis with local statistics of autocorrelation was iterated in 10 m intervals up to 60 m, using the same artefact groups as the global analysis. Figs. 9–11 present the results for clustering (top row) and dispersal (bottom) at a range of 30 m. Beyond this point, the results had no appreciable change. The magnitude of the spatial relationship is symbolized at three significance levels, where p ≤0.01 (highly significant, black points), b 0.05 (significant, dark grey points) and N 0.05 (insignificant, white).

In Aumer I, all three groups of compared artefacts show significant association at the aforementioned scale (Fig. 9). Besides the two main clusters visible in the raw data, there is a probable secondary cluster of artefacts of moderate size to the south of the northernmost cluster. These relationships appear to hold regardless of the technological features under examination. Owing to the diversity of different sequences of lithic production and use apparent in these areas, they may be areas of long-term place redundancy. At the same time, a broad swathe of terrain between these areas hosts significantly fewer artefacts than expected, attesting to previously undetected spatial inhomogeneity in the point pattern. Finally, a non-trivial quantity of points in both sets do not interact significantly with the pattern as a whole.

The tests for clustering in Ziegler II (Fig. 10) show major groups of artefacts in the western portion of the site. There are up to four distinct clusters of significant size, depending on the technological subset of the assemblage in question. One of these is composed of the abovementioned linear cluster recorded eroding out of a trackway along an east-west axis, whose presence likely biased the global functions somewhat. At the scale investigated with the bivariate local K, however, their influence is minimal in relation to the data as a whole and do not confound the analysis. Few artefacts are significantly dispersed compared to Aumer I, and are actually outnumbered by randomly-distributed artefacts in this quadrat. Tool production and tool use present the most spatially-circumscribed and least significantly dispersed discard activity in the quadrat, as the clusters are discrete. Raw material extraction/preparation appears strongly similar to core and flake versus bifacial reduction, paralleling the relationships in Aumer I.

The local bivariate K in Ziegler III (Fig. 11, top) presents a similar scenario. A single area of significant clustering forms an arc of associated artefacts in the extreme south of the quadrat, near a small tributary to the Arroyo Piray Guazú. None of the compared groups of artefacts appear significantly dispersed at $r = 30$ and a large proportion are clearly randomly distributed and exhibit no detectable spatial structure.

In contrast, point locations in Ziegler IV display more variable relationships depending upon the technological traits under investigation (see Fig. 11, bottom). The core and flake system associates with bifacial reduction in a wide region towards the north-eastern edge of the quadrat. Smaller clusters of tool production/use and material procurement/preparation present themselves in the eastern edge of the quadrat, but with a certain degree of variability in terms of spatial extent and overall significance. In all three cases, a small cluster is located to the far south-west which appears not be associated to any other part of the quadrat. Dispersed artefacts are again in the minority to randomly distributed ones.

5. Discussion

Non-site theory emphasizes that cultural activity rarely unfolds in neatly bounded units, and are still less frequently preserved or recorded in such a manner. This implies that artefact density on its own is not rigorous enough to distinguish what makes a certain threshold more socially or systemically significant in comparison to a second (Ebert, 1992; Holdaway and Wandsnider, 2006). Here, raw patterns in the data can be identified with relative ease using visualization (Fig. 12), or with basic exploratory statistics such as kernel density estimates or k-means clustering. These are trivial, however, and do not on their own shed any new light on indigenous land use in Misiones province, since they do not possess the statistical framework for determining significance nor engage with technological variability. Lacking this, there is no way to discern at which scale a given phenomenon, potentially composed of hundreds of points, is significant in relation to the data as a whole. Against this backdrop, focusing on technological features together with spatial configuration permits the detection of patterns in the surface record that are not necessarily obtrusive or immediately apparent.

Perhaps the most common trend revealed by the global functions is the propensity for artefacts to be most strongly associated over short to medium distances, but closer to the maximum ranges investigated (≥50 m) tend to lose significant association. Short-range clustering is not universal, however. Core and flake reduction versus bifacial production in Ziegler III shows the inverse (random patterning at short distances, clustering at long distances), implying different patterns of discard existed between these classes. Tool production versus tool use in the same quadrat and its neighbour Ziegler IV do not associate below 40 m, yet associate strongly above this point. Although strong clustering is the norm at relatively short ranges, the most significant variation between quadrats is the scale at which this clustering appears. This variability in discard may translate into the existence different cultural practices on a broader spatial scale, perhaps dependent on landscape setting. Due to dominance of this trend, however, spatial segregation was not apparent at any scale in the global analyses, encouraging the use of local statistics to "dig deeper" into the empirical patterns.

The analysis with the local bivariate K served to identify the size and relative configurations of specific areas. A major finding in this regard is the shifting edges of the large clusters in Aumer I mentioned above, showing a range of different associations between different technological groups. The statistically significant spatial heterogeneity in Ziegler II and IV not detected by the global functions, shows how complementary methods are necessary to explore multiple facets of an empirical pattern. Inspecting the analysis of bifacial artefacts versus core and flake systems reveals that the artefacts most often significantly dispersed in this set are flakes with numerous scars and well-reduced cores. The implication, confirmed by inspecting the clustered points, is that bifacial tools associate only with a small sub-component of core and flake systems, producing a misleading global signal yet a highly variable local one, potentially reflecting different place use histories. In turn, exhausted cores may have been discarded relatively far away from where they were extracted or prepared. The constancy of the pattern across the sampled locations raises interesting questions about the role of bifacial tools versus core and flake technology in patterns of long-term land use and mobility (Bamforth, 1986; Parry and Kelly, 1987), as a probable function is of the former tools is foraging and digging (Riris and Romanowska, 2014). Despite the uncertain temporality of this pattern of discard, it paints an altogether different picture to the common-sense interpretation of clusters as single occupational events and ignoring dispersed spatial data wholesale.

The small quantity of artefacts that exhibit no significant spatial structure demonstrates how few data points in a given empirical pattern can realistically be considered "noisy" at the scales investigated. The most notable exception to this is found in Ziegler III, where few clustered points were detected and no dispersed points were found whatsoever. Excepting this case, the limited number of data points displaying CSR are likely in areas where unaccounted-for formation processes or discard trends are present at scales beyond those investigated here, such as infrequent visitation or large-scale spatial inhibition processes (e.g. strongly defined territoriality) were in operation over long time-scales. Artefacts in these locations are problematic to interpret at present without a larger spatial sample to draw upon and a more in-depth geomorphological characterization.

The variability in lithic discard patterns supplies flesh to the bones of the spatial analysis over multiple scales. Despite post-depositional modification of the record, the results clarify the extent to which the surface record in the Eldorado study area represents a complex spectrum of overlaid, mixed, and obscured material remains of different technological strategies over relatively short distances. If future research reveals that these reduction sequences also function as useful cultural markers through time, this study underscores that there is actually relatively little to distinguish them spatially. In other words, despite being occupied by multiple cultures over a long period of time with, presumably, different land use practices, there is significant long-term redundancy in place use in Misiones province. This is interesting in light of technological conservatism documented in neighbouring regions (e.g. Okumura and Araujo, 2014). Grounding the analysis Monte Carlo methods, as well as a cautious approach to small-scale patterning, enabled a deep integration of lithic and spatial information to reveal this pattern. Taken as a whole, the results draw attention to the constant low-level activity that makes up the bulk of the material record (Wandsnider and Camilli, 1992). The results extend traditional methods of analyses in the wider study region, such as the Middle Paraná and southern Brazilian Highlands, by adding a rigorous statistical control on systematically collected archaeological data.

Individual discard events may be widely separated in space and time, yet habitual repetition of practices in specific spatial contexts produce palimpsests, such as the data presented here (Tainter, 1998 Holdaway and Wandsnider, 2006). Over time, the occupation of an environment creates affinities for particular places, and are appropriated into a cognized landscape of material and social relationships as a result (Binford, 1980; Schlanger, 1992; Wandsnider, 1998). As has been demonstrated, these are far from homogenous phenomena, and require dissection with appropriate analytical techniques. Non-site analysis thus creates the impetus to understand the nested, scalar nature of the surface record. Through complementary data in the form of excavations, palaeoenvironmental reconstruction, and geoarchaeological studies, these patterns can in the future usefully inform traditional archaeological explanatory frameworks. Building on the results presented here, investigations in Neotropical settings more broadly are afforded an empirical baseline for the appearance, behaviour and structure of surface archaeology within a defined context. Ultimately, cross-contextual comparisons with chronological controls may be carried out to examine the range and variability in discard patterns on a broader scale, including information that is presently absent. An obvious hole in the data at the present time is the lack of Tupiguarani artefacts, notably highly distinctive polished stone axes.

6. Conclusions.

Exploring landscape-level patterning in lowland South America is of tremendous importance for characterizing the diversity of indigenous land use practices and settlement patterns. This includes long-term demographic trends and major socio-political transitions seen in later periods, such as the development of sedentism and circumscribed territoriality (Heckenberger, 2005; Balée and Erickson, 2006; Walker, 2012; Goldberg et al., 2016). Despite an awareness of the potential of surface collected data among archaeologists in the tropical lowlands of South America (Araujo, 2001; Schaan, 2012), this is the first formal study demonstrating the efficacy of spatial statistics to this end. The informative potential of surface data for landscape archaeology is great strongly suggests that the surface record of Misiones province is not an empty canvass dotted with pin-points of isolated "sites". Rather, the analysis supports a characterization of the landscape as a palimpsest composed of a broad spectrum of material patterning over multiple spatial scales, which are linked to a range of different discard processes reflected in the lithic technology. An important implication in this regard for the cultures in question (see Section 1.1) is that major spatial co-occurrence is evident throughout the sample between highly divergent technological systems. Thinking through this finding in economic terms, additional confirmatory research could support the notion that cultigens were an additive rather than a revolutionary component of indigenous land use and subsistence practices despite the millennial timeframes implied in the culture history of the province (Gessert et al., 2011). Alternatively, but unlikely, a pre-horticultural signal might hereto be missing from the record, necessitating an extensive re-evaluation of the received chronology. Both these eventualities rest on access to complementary diachronic evidence to this effect.

I reiterate the metaphor of the material record as a time-averaged view of the accumulated discard processes which took place, comparable to extremely long-exposure photograph of all the individual events that contributed to its formation (see Ebert, 1992). Discard patterns were identified through comparisons between the components of three systems of reduction, highlighting landscape-level variability in material acquisition and management. The examples highlighted here show how even unambiguous clusters of material, which might fit the common-sense definition of “sites”, are actually fuzzier than first apparent when placed under appropriate scrutiny. The methods employed enabled analyses to be made in both geographical and technological space, extending the boundaries of knowledge to the “blank spaces on the map” (Walker, 2012) in new ways. Prioritizing individual artefacts is a flexible and interpretatively powerful analytical strategy, as well as extendable to any number of new contexts. In this case, this characterizing the spatial distribution of the surface record helped to narrow several long-standing gaps in the scale and extent of archaeological knowledge in Misiones province.

Discard processes reflect part of the appropriation of the environment into a cultural landscape (Schlanger, 1992; Wandsnider, 1998; Ingold, 2000), recovered archaeologically as a palimpsest. The treatment of such persistent places as the result of particular regimes of human-environmental interaction is crucial to characterizing the range of human behaviour in a given setting (Wandsnider, 1992; Ebert, 1992; Holdaway and Wandsnider, 2006). In contrast to previous studies employing comparable data in the wider regional context (e.g. Araujo, 2001), the methods used here support to the notion that treating surface scatters only as functional entities is a poor representation of how the material record in surface contexts actually forms (Foley, 1981; Dunnell, 1992; Ebert, 1992; Tainter, 1998). These aspects of the material record are largely unexplored in tropical and sub-tropical settings, and the approaches presented here aim to serve as a template for future research. The findings of this study are commensurate with a pluralistic and multivocal archaeology of landscape (Harrison, 2011; Llobera, 2012; Bevan et al., 2013), to which Misiones province now contributes.

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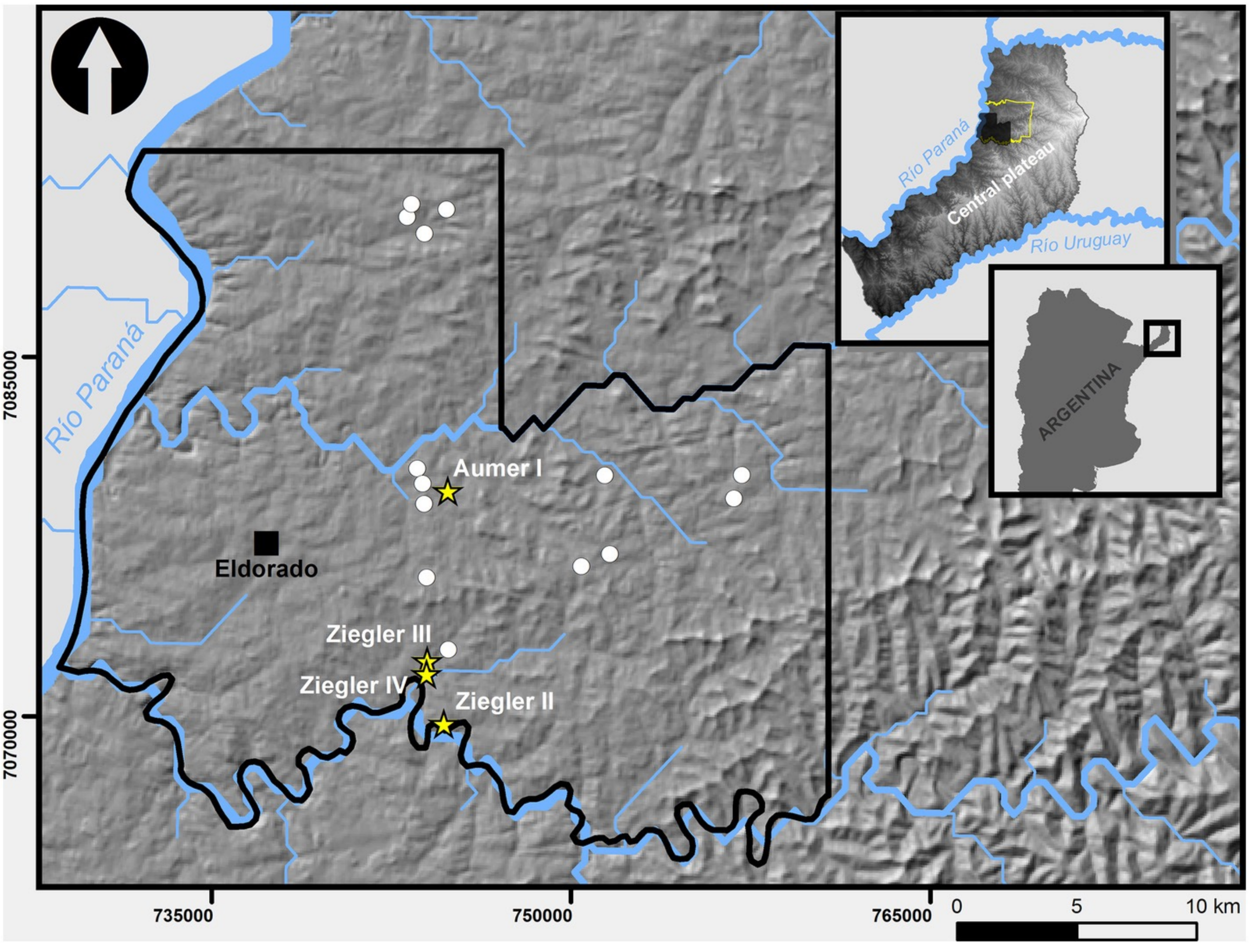

Fig. 1. Location of study area in the hinterland of Eldorado city, with sites surveyed. Sites discussed in text shown as stars. Insets: Study area within Misiones province and Argentina.

Fig. 2. Quadrat types surveyed (clockwise from top-left): pine plantations, mixed pine-agricultural fields, cleared plots, and agricultural plots.

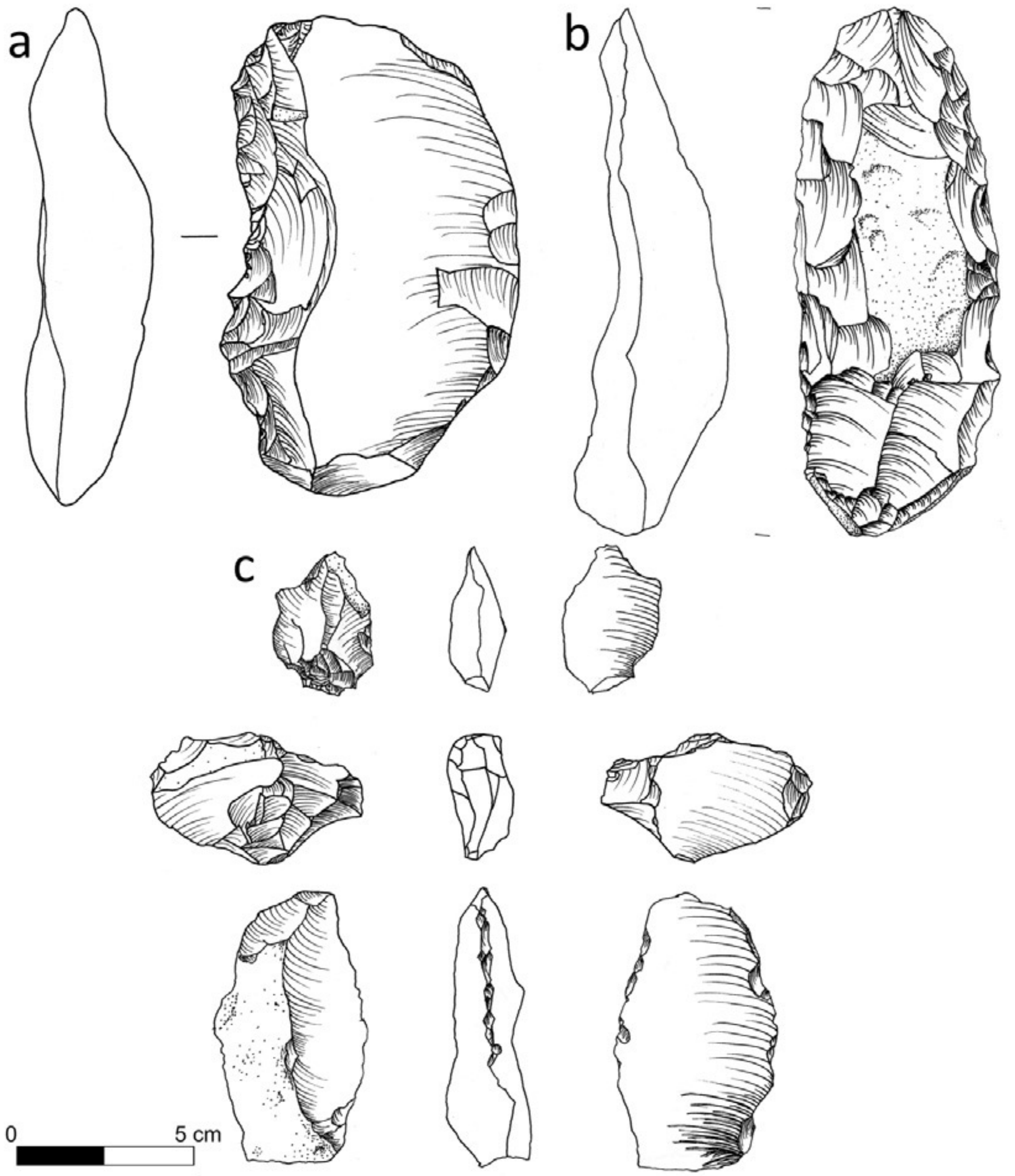

Fig. 3. Specimens from quadrat Aumer I of a) unifacial and b) bifacial tool technology, as well as c) three examples of simple flakes that form the majority of the assemblages. These artefacts were all recorded in close spatial proximity. Drawing by I. Romanowska.

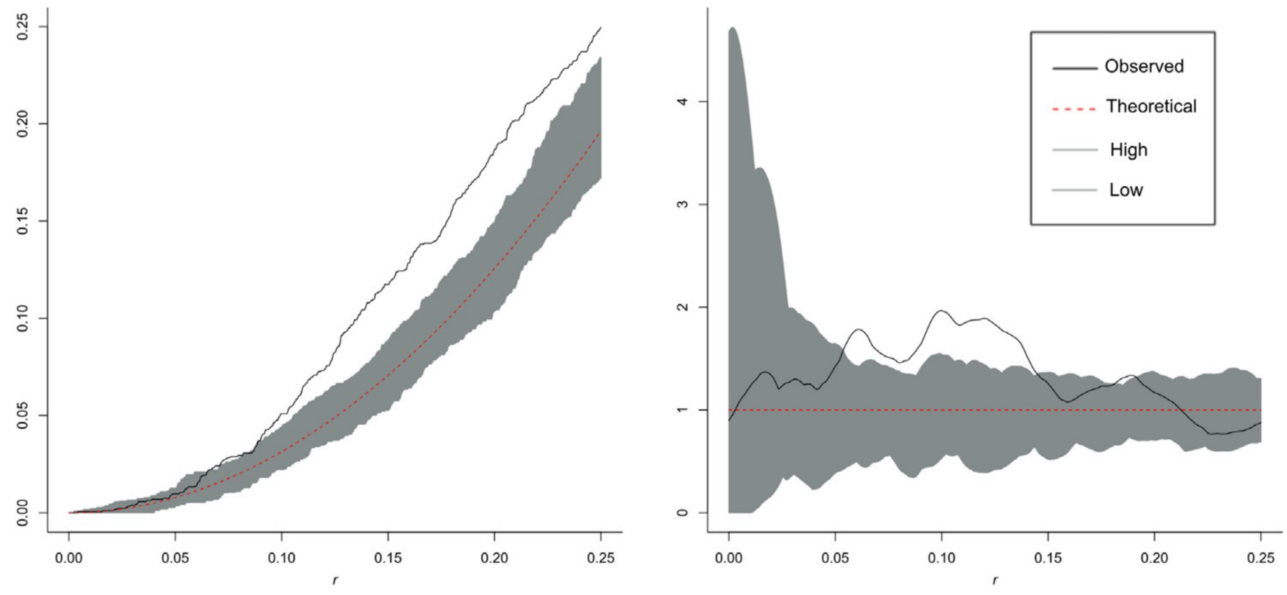

Fig. 4. Output of the K(r) and g(r) functions (left and right, respectively) on a simulated point pattern dataset, showing that under CSR g(r) = 1, while K(r) accumulates. The pair correlation function provides a visually more intuitive output.

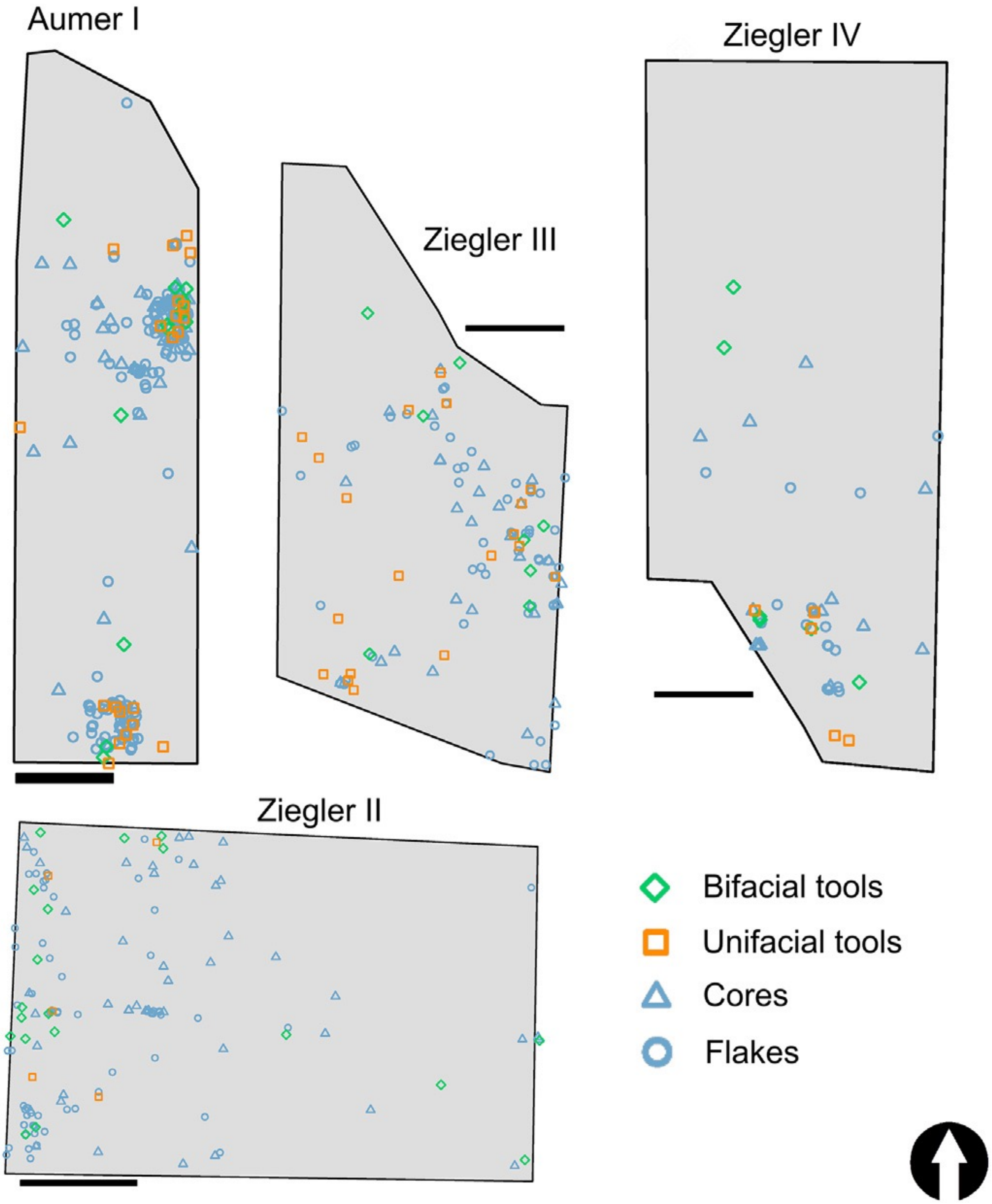

Fig. 5. Distribution of flakes, cores, and tool types in the four analytical quadrats. Knapping debris form the majority of the assemblages, although cores are also relatively abundant.

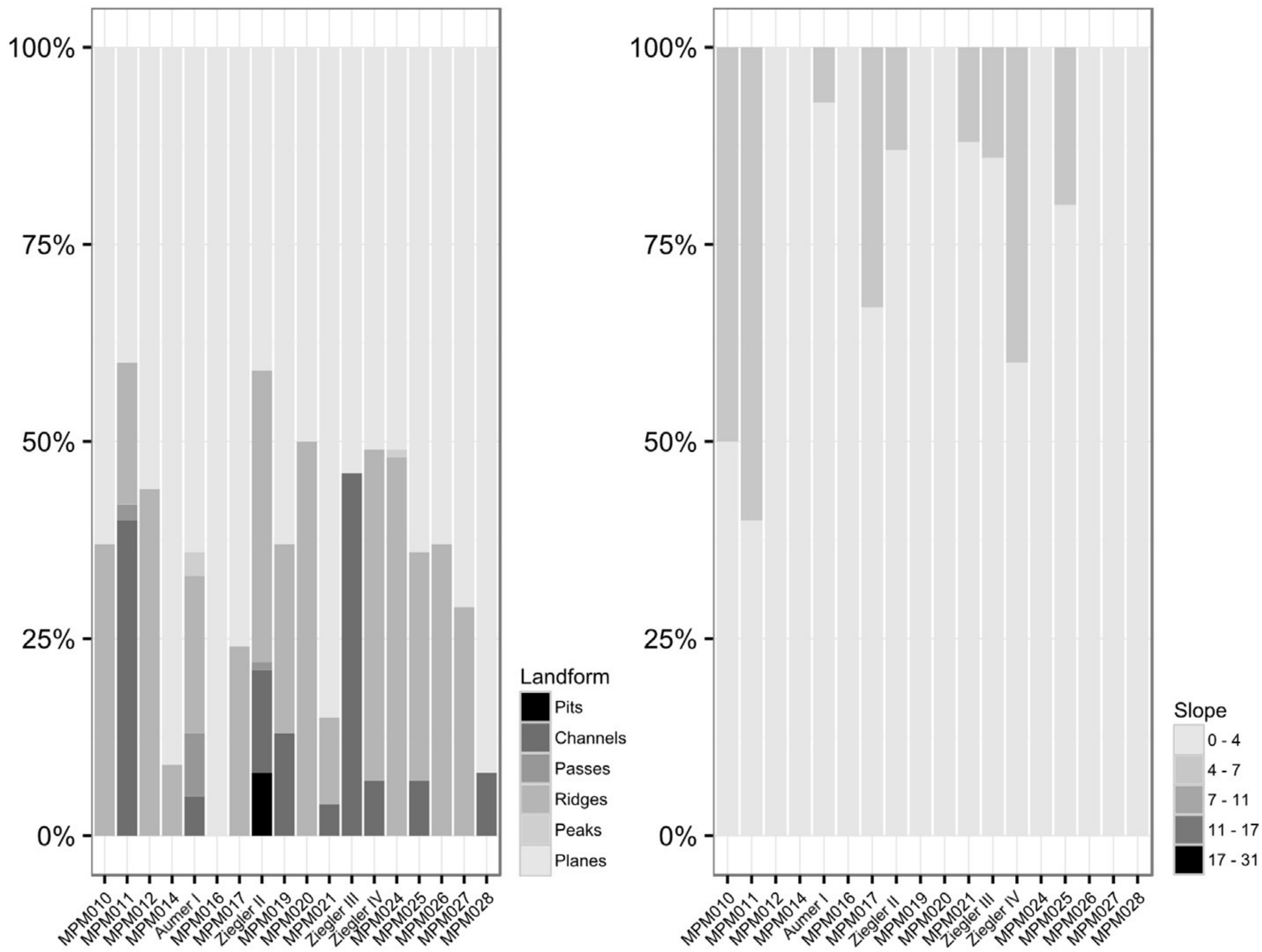

Fig. 6. Geomorphometric analysis and slope classification of the area contained by the quadrats. The results confirm that erosional potential is comparatively low and less likely to impact the distribution of archaeological material than in upland environments.

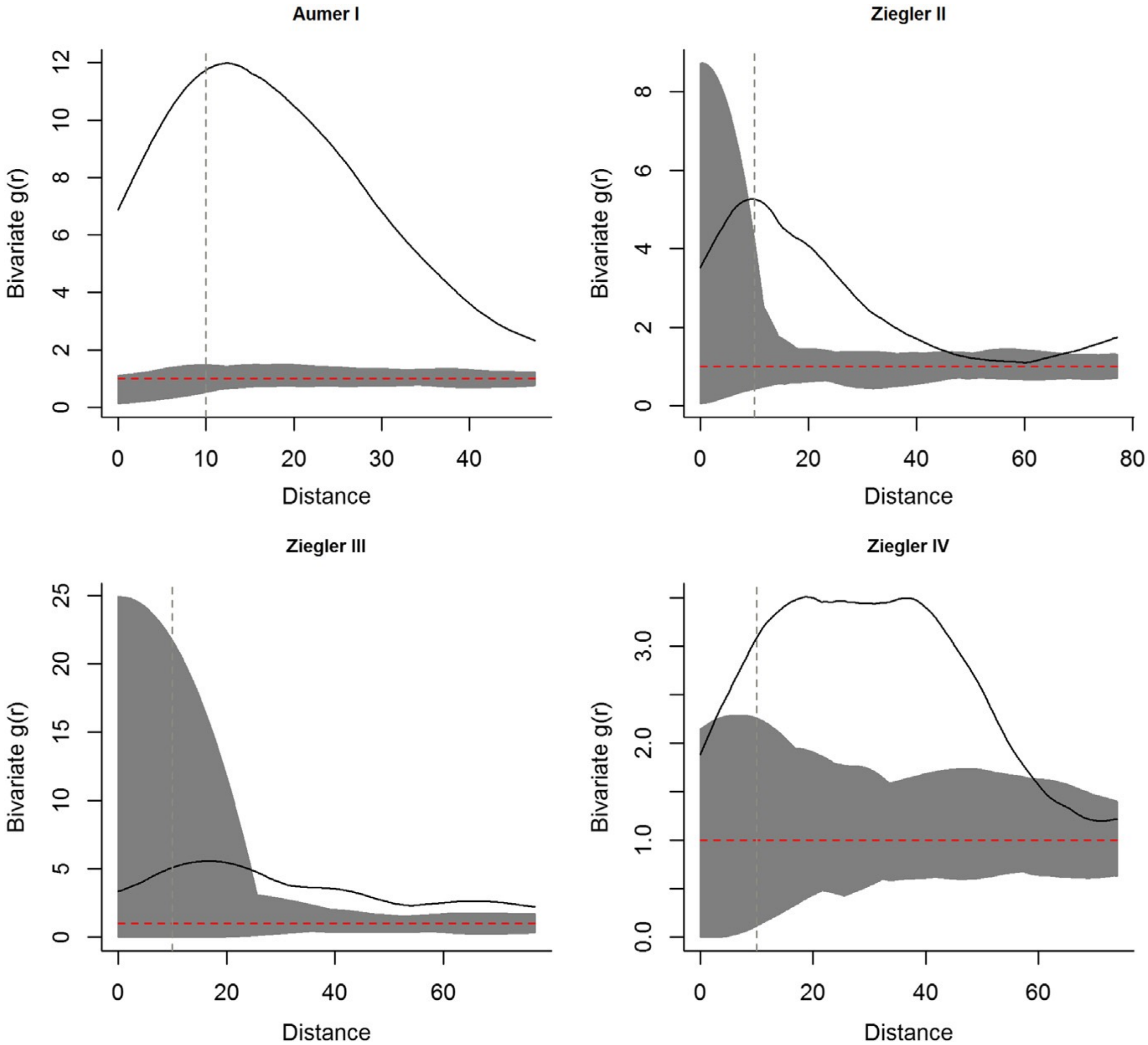

Fig. 7. Global bivariate O-ring statistic for core and flake reduction versus bifacial tool production in the four analyzed quadrats. The value of g(r) is displayed as a black line, the simulation envelope based on 99 realizations of CSR is shown in dark grey, and the expected value of the statistic under CSR is represented by the red line.

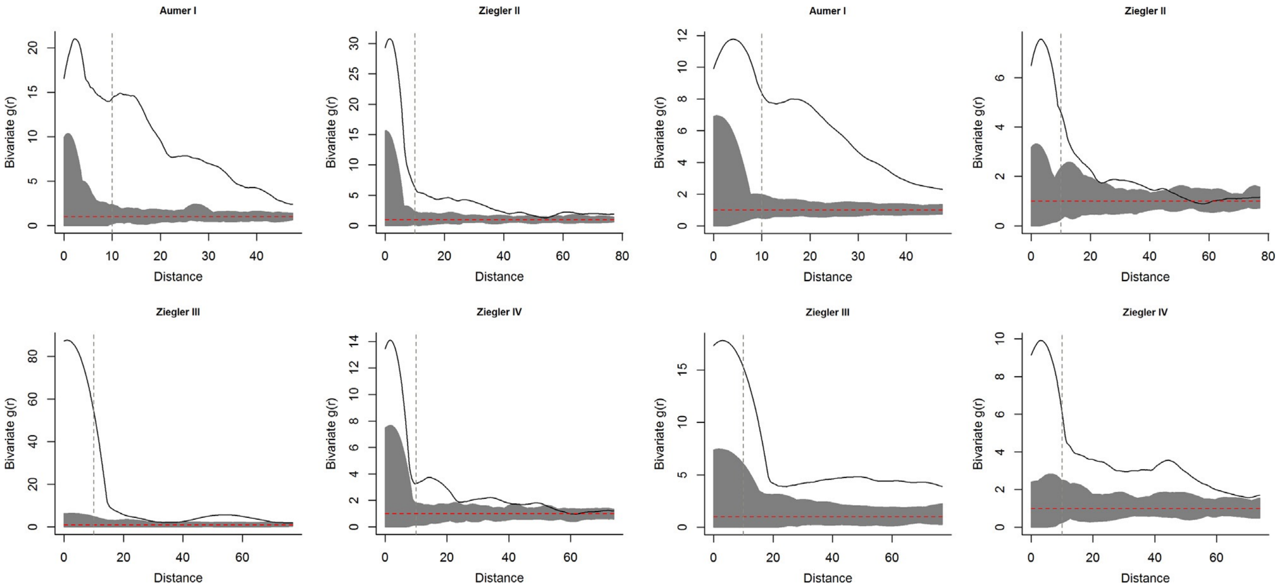

Fig. 8. Bivariate O-ring statistic for tool production versus tool use (left) and raw material procurement versus raw material reduction (right) in four quadrats.

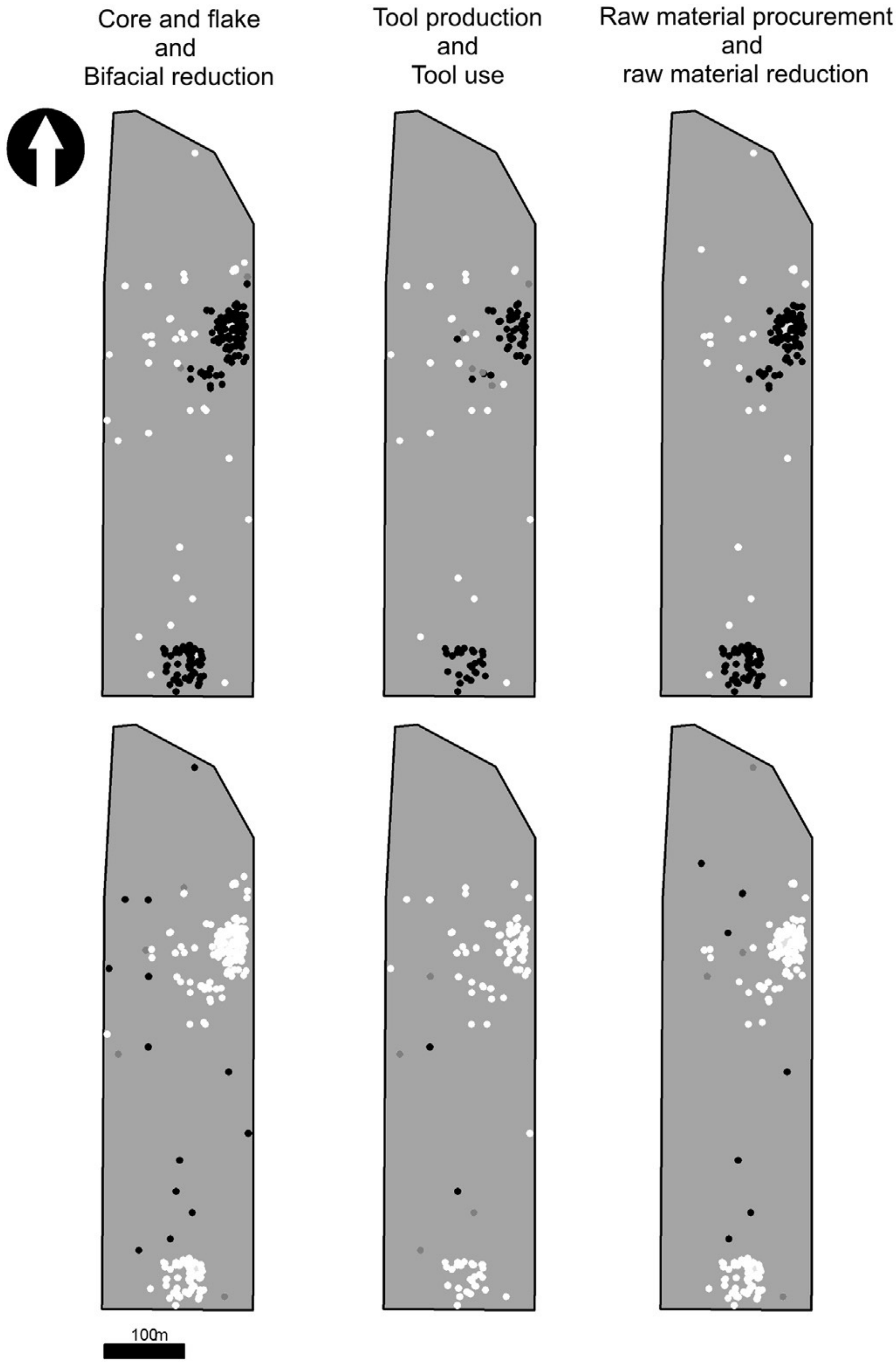

Fig. 9. Local bivariate K in Aumer I at r = 30 for three comparisons. Top row: clustering, bottom row: dispersal.

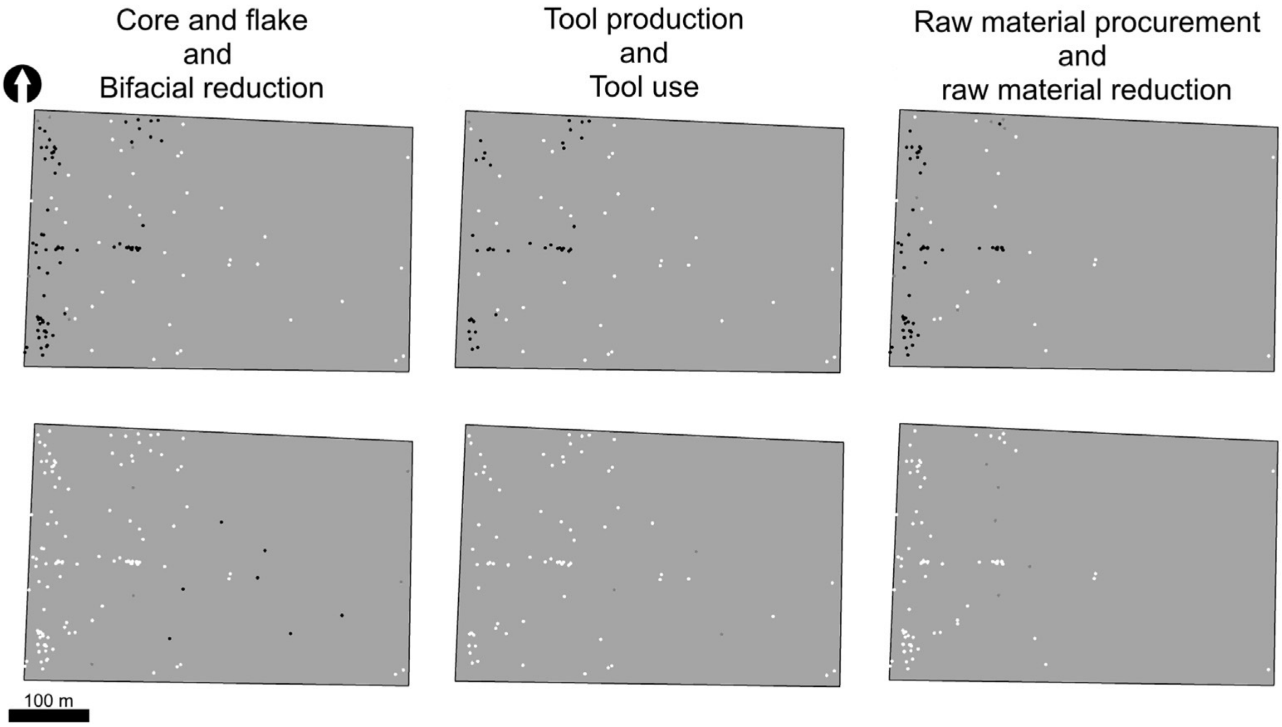

Fig. 10. Clustered (top row) and dispersed (bottom) artefacts in Ziegler II at r = 30 for three technological systems.

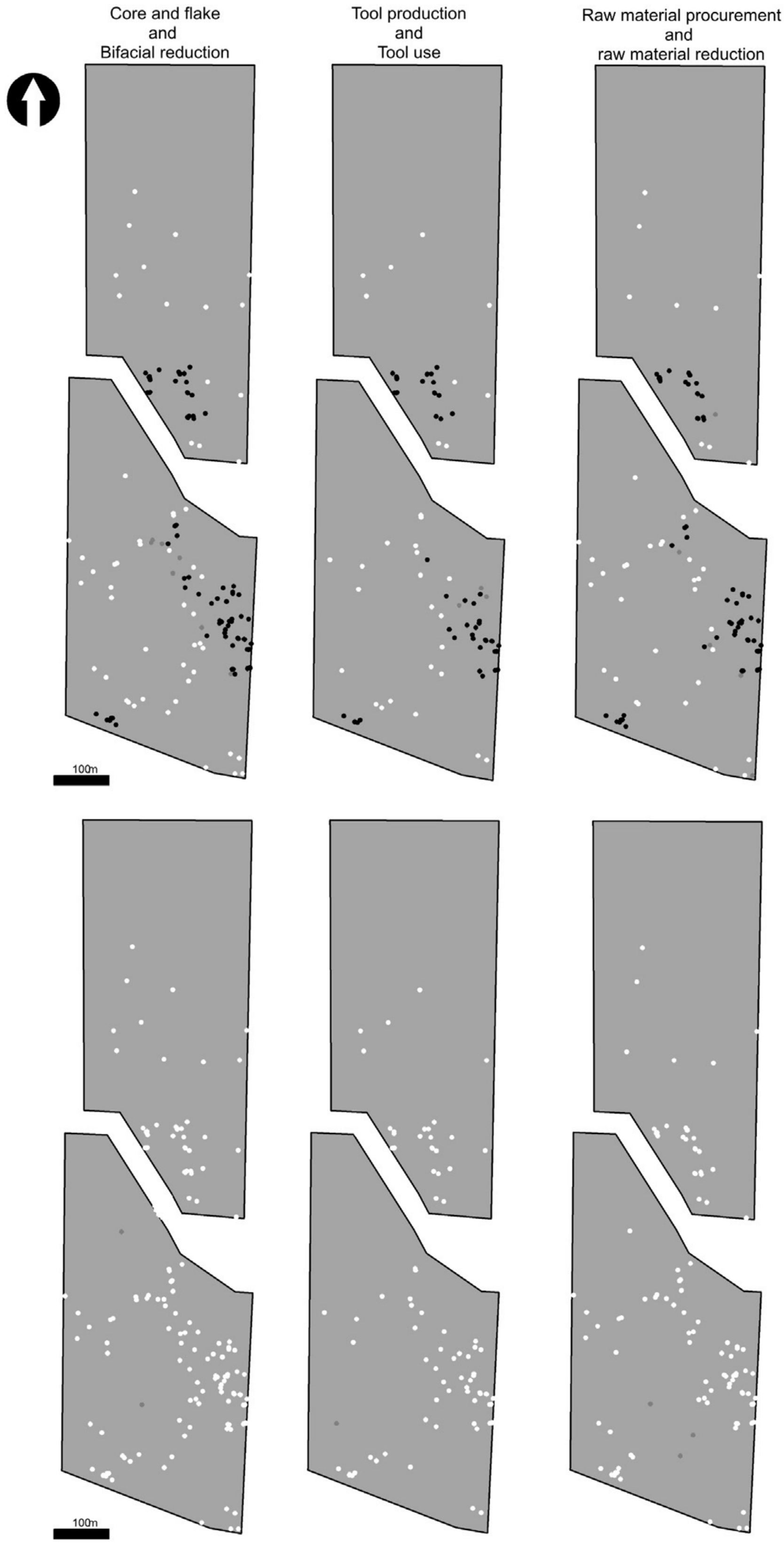

Fig. 11. Clustering and dispersal in Ziegler III (top) and Ziegler IV (bottom) at r = 30 for core and flake reduction versus bifacial production, tool production versus tool use, and raw material procurement versus reduction.

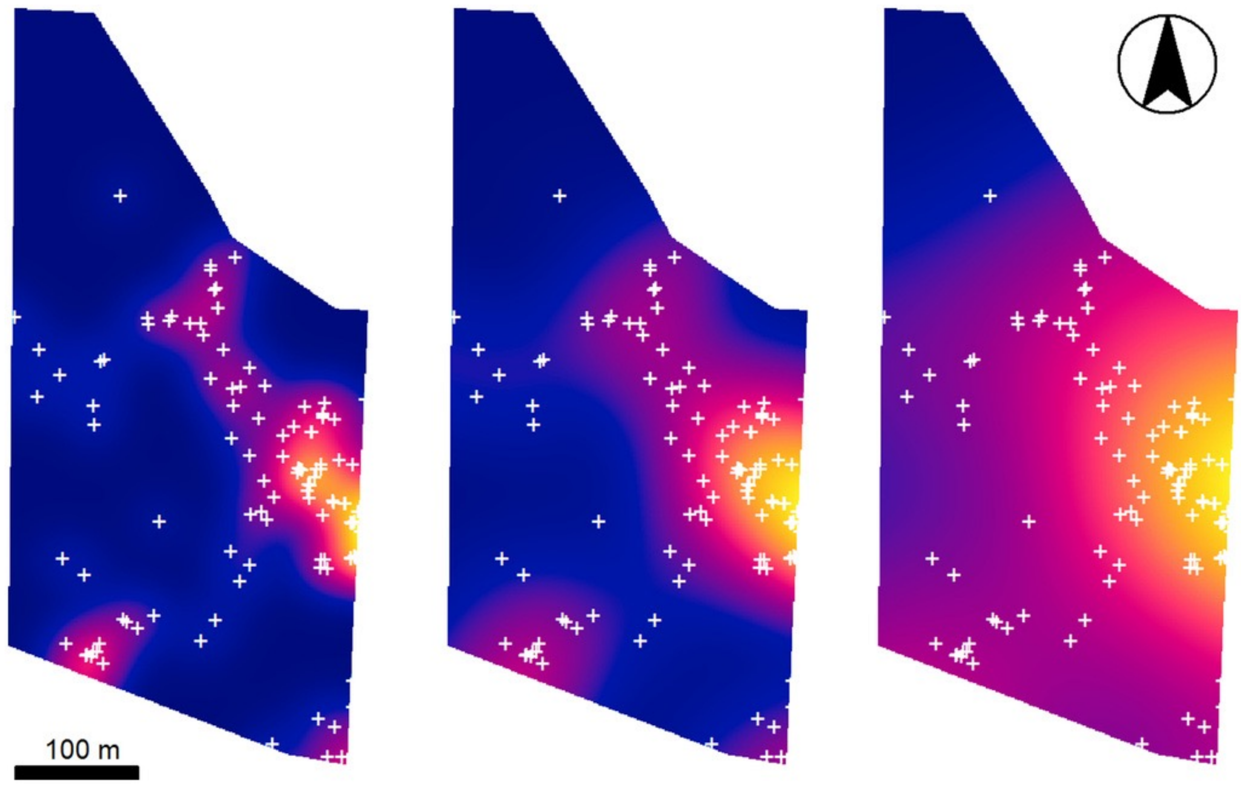

Fig. 12. Smoothed kernel density estimates in Ziegler IV, an example of a traditional density-based measure of spatial structure at three arbitrary scales. Overall, the interpretative power of such approaches is minimal.

Table 1. Summary of field site and artefact data. An ANOVA reveals that the variance between type of modern land use and artefacts encountered is statistically significant ($F_{1,3} = 4.003$, p b 0.05), suggesting that this might be a factor in recovery rates of artefacts. A post hoc Tukey's test (p b 0.05) reveals that this only applies between Mixed and Plantation classes, which are identical in terms of tillage depth and intensity. The observed archaeological distribution is therefore more likely due to the underlying population rather than modern land use. In the spatial analysis, proxies for tool use include utilized flakes.

Quadrat	Area (ha)	# artefacts	Flakes	Tools: Unifacial	Tools: Bifacial	Cores	Ceramics	
MPM010	2.26	0	0	0	0	0	0	Plantation
MPM011	4.41	35	23	1	1	10	0	Mixed
MPM012	4.02	4	3	0	1	0	0	Plantation
MPM014	9.38	2	1	0	0	1	0	Agriculture
Aumer I	12.9	231	180	3	13	34	3	Mixed
MPM016	6.16	39	7	0	3	1	28	Plantation
MPM017	5.73	6	4	0	1	1	0	Agriculture
Ziegler II	13.2	137	71	3	18	46	0	Plantation
MPM019	6.28	0	0	0	0	0	0	Barren
MPM020	8.21	4	0	0	0	4	0	Plantation
MPM021	4.71	4	2	0	2	0	0	Agriculture
Ziegler III	19.2	61	24	2	7	14	14	Plantation
Ziegler IV	13.1	112	71	1	8	28	2	Mixed
MPM024	8.17	44	11	0	0	0	33	Barren
MPM025	4.17	4	2	0	1	1	0	Barren
MPM026	4.54	3	0	0	1	2	0	Agriculture
MPM027	8.66	18	8	5	0	5	0	Plantation
MPM028	0.92	32	20	0	1	9	2	Plantation
Total	136.02	736	426	15	57	156	82	