Fire and "Noise" in Late Paleolithic Camps: an Investigation of Issues in Locating Hearths

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Abstract

The acidic sandy environment of the Late Paleolithic sites on the North European Plain usually prevents preservation of not only organic debris such as burnt bones or charcoal but also heat-altered sediments or ash. Therefore, chemical analyses cannot be applied to identify traces of open fires. Instead, the detection of the location of hearths is approached through spatial statistics. This paper tests the utility of the methods which are most widely applied to solve the related research questions. Our analysis is accompanied by case studies on hearths at Late Paleolithic sites in Western Poland related to the Federmesser and Swiderian cultures. The discussion of the quadrant count method and kernel density analysis, ring and sector model, and nearest neighbor statistics show that the last named model is the most appropriate for locating Paleolithic hearths. A number of issues in the application of nearest neighbor statistics may be improved by the additional analysis of the vertical distribution of fire-affected artifacts and development of new approaches for identifying the areas affected by natural or human-made fires in the future.

Keywords Hearths · Nearest neighbor statistics · Quadrant count method · Ring and sector model · Federmesser culture · Swiderian culture

> This discovery of fire, probably the greatest ever made by man, excepting language, dates from before the dawn of history.
> Ch. Darwin, 1875

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Introduction

The beginning of human use of fire is still a central topic of a very long and lively discussion (i.e., Clark and Harris 1985; Karkanas et al. 2007; Scott 2018). Without any doubt, the discovery of fire was a turning point in human evolution. This crucial technological and cultural revolution not only helped in the geographic dispersal of people, making changes of diet and behavior possible, but was also a crucial factor in the development of bigger brains and the rise of brilliant minds (Wrangham 2009). Both archeological and ethno-archeological records clearly indicate that the fireplace is an essential feature of hunter-gatherers' camps. Activities related to domestic (e.g., cooking, smudging, curing meat, protection from predators and blood-sucking insects, heating of adhesives, retooling, repairing clothes, and generating of warmth and light in the evenings), social, and ceremonial spheres took place in the vicinity of hearths (i.e., Alperson-Afil 2017; Anderson 2006; Binford 1978; Dunbar and Gowlett 2014; Petraglia 2002; Sirina 2006).

Studies of fire use at Paleolithic sites, which significantly increased in number over the last few years, mostly concern the location of areas related to the deliberate use of fire within sites, the identification of hearths, and the analysis of the activities which took place in close vicinity to fire. However, identifying Paleolithic fireplaces is heavily hampered due to their short utilization, the natural altering of charcoals, and their perishable constructions.

Usually hearths were formed on the surface, without any encircling stones, or sporadically in shallow pits (Goldberg et al. 2017). One exception is stone-covered combustion areas, the most appropriate constructions to exploit brushwood as fuel, known mainly from Magdalenian sites (e.g., Coudret et al. 1989; Leesch and Bullinger 2012). Thus, in the majority of cases, these features without any discernable constructions may be very easily destroyed by wind, rain, or trampling by people and animals; they are thus often found in a poor state of preservation (e.g., Camarós et al. 2013). Moreover, materials such as charcoal, ash, burnt bones, and stones may be produced both by human activities and natural processes (e.g., Goldberg 2017; Lyman 1994; Mentzer 2012).

When considering other factors influencing the preservation of the remains of hearths, one must include the type of soil on which such features were set. One of the most unfavorable conditions occurs on the North European Plain, where the dry, acidic, and low-iron sandy soils strongly affect preservation of organic debris such as charcoal and burnt bones in addition to heat-altered sediments or ash (e.g., Kasse 2002; Sergant et al. 2006). In the majority of cases, this does not allow the application of chemical, anthracological, micromorphological, and microcharcoal analyses to identify hearths (e.g., Henry and Théry-Parisot 2014; Mallol and Henry 2017; Marquer et al. 2010; Villa et al. 2002; Wadley 2009), which turns the related research tasks to traditional intra-site analysis of the spatial distribution of the fire-affected artifacts.

This paper aims to analyze the utility of the most widely applied approaches of spatial statistics to the identification of fireplaces and mainly focuses on the following questions: (1) which methods overcome the impact of post-depositional processes, i.e., vegetation cover, difference in landscape elevation leading to the redeposition of artifacts, natural fire events etc.? (2) Which models overcome the issue of fuzziness in the positioning of fire-affected artifacts which result from depositional (human

activities) and post-depositional processes? These research questions highlight the importance of separating patterns (hearths and cleaning zones) and "noises" in the spatial distribution of artifacts affected by fire. The Late Paleolithic camps of Ośno Lubuskie 7 and Lubrza 10, both located in the eastern part of the North European Plain, are used as examples to illustrate advantages and disadvantages of the related methods. Thus, before discussing the different methods of spatial analysis, the following section briefly introduces these two sites.

Case Studies: Late Paleolithic Campsites at Lubrza 10 and Ośno Lubuskie 7, Western Poland

Site no. 10 in *Lubrza* belongs to a complex of Late Paleolithic sites located within an area of 1 km² where hunter-gatherer camps of various chronology, function, and size have been uncovered. The complex of sites is located in the Łagów Lake District, in the northern part of the Lubuskie Lake District (Fig. 1). The very diverse geomorphology of this area created during the Poznań phase of Vistulian Glaciation offered hunter-gatherer groups favorable conditions for settlement and hunting (Sobkowiak-Tabaka et al. 2018).

During five seasons of excavations, 12 flint concentrations related to Federmesser (concentrations 1, 2, 3–3a, and 11) and Swiderian settlement (concentrations 4–10 and 12) were recorded. The site produced a little over 5000 flint items (registered within the concentrations and beyond) and 14 tiny, burnt animal bones. Synchronicity of concentrations belonging to Swiderian occupation is confirmed by refittings. Various off-site analyses enabled the recognition of the function of distinct concentrations. The structure of the Federmesser camp consisted of domestic spaces (concentration 1 and 11) and combined domestic spaces and workshops (2 and 3–3a), while the Swiderian camp included two domestic spaces (concentrations 10 and 12) and two multifunctional activity areas (concentrations 4–9 aggregated into two distinct units) (Fig. 2).
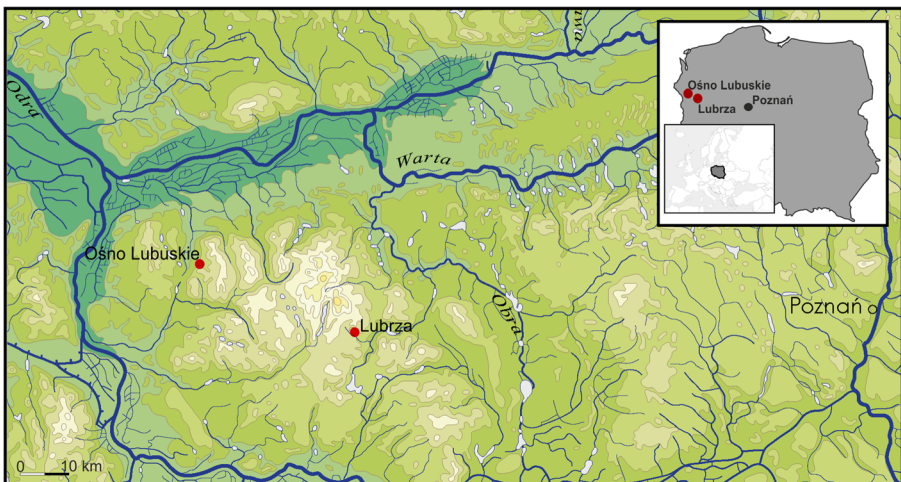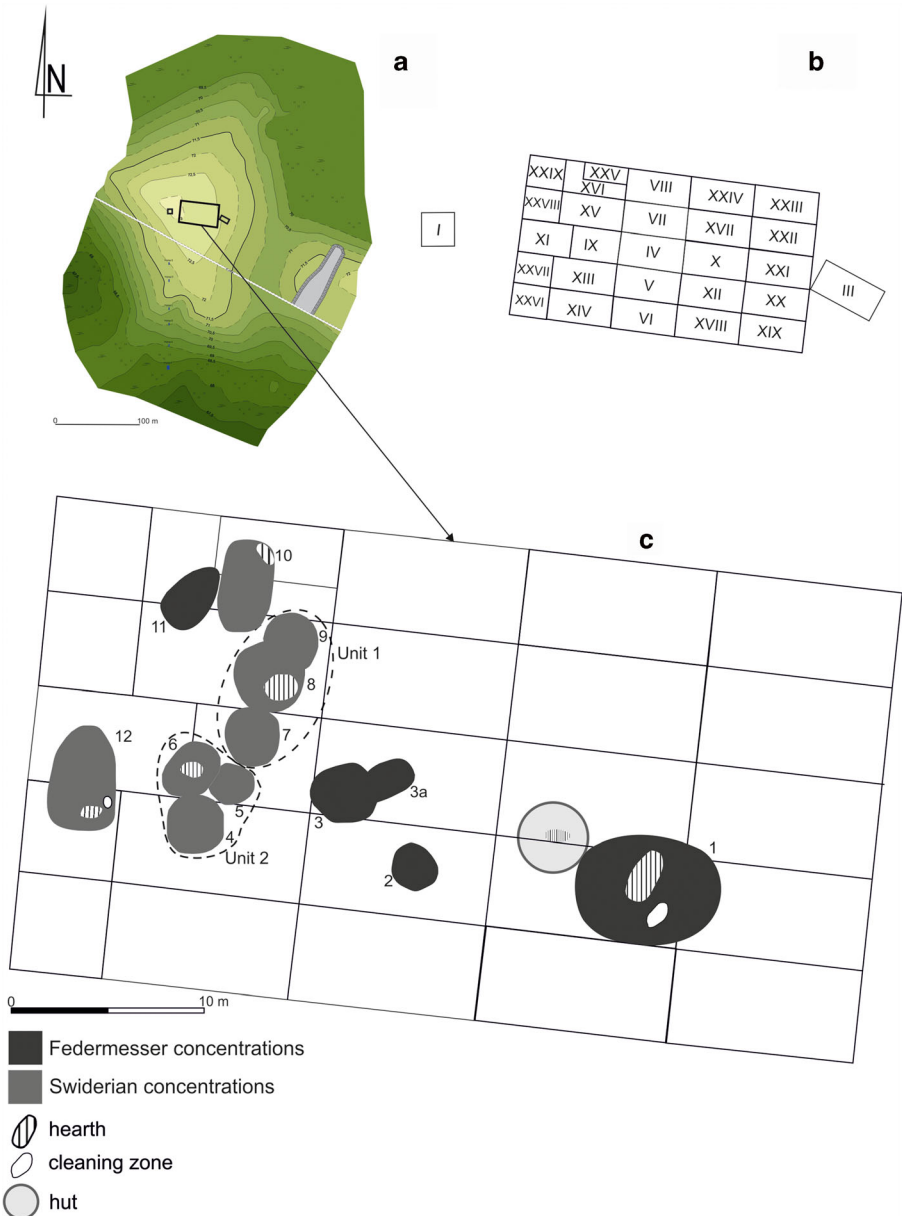

Fig. 1 Location of the sites

Fig. 2 Lubrza, site 10. **a** Range of investigated area; **b** plan of trenches; **c** flint concentrations (hearths and cleaning zones were identified through the application of nearest neighbor statistics)

The second campsite, *Ośno Lubuskie 7*, is located in Western Poland in the landscape of the frontal moraines of the Poznań phase of Vistulian glaciation which are cut by glacial troughs with glacial lakes or plains of biogenic accumulation. The site is set on a river terrace of sands and gravels (Fig. 1). During fieldwork, flint artifacts related to different epochs and cultural units–Late Paleolithic: Hamburgian (4 items) and Swiderian (1129 items), and Mesolithic (several dozen items)–were recorded. The

matter of our interest is the Swiderian occupation of the site, manifested in the remains of 8 flint concentrations and flints scattered beyond them. We would like to focus on the flints occurring within concentrations which are distributed over a relatively small area with two aggregations of concentrations–concentrations 1–5 in the south and concentrations 6 and 8 in the north–separated north-south by 70 m with a third small cluster (7) between (Fig. 3). The concentrations are comprised of 18 to 324 items made
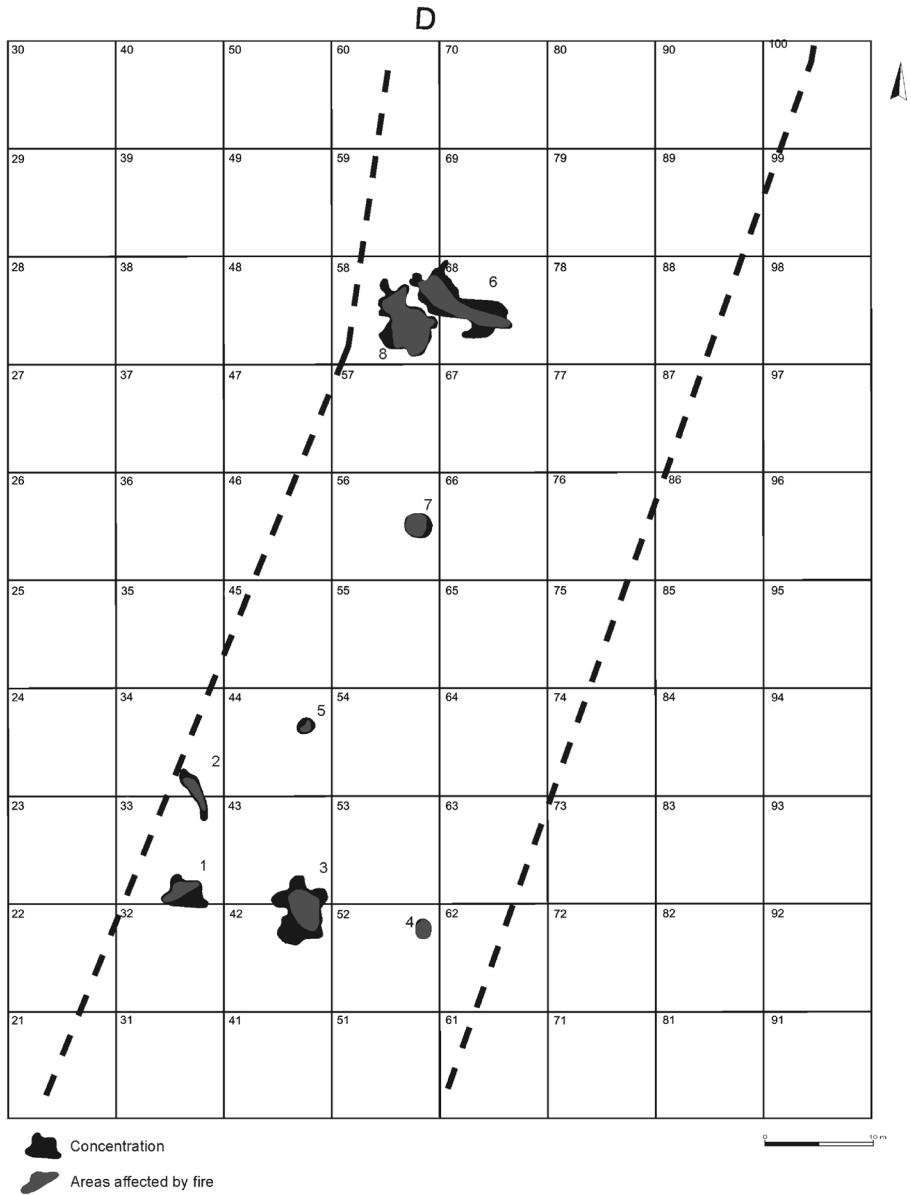

Fig. 3 Ośno Lubuskie, site 7 (areas affected by fire are identified through the application of nearest neighbor statistics)

of local, erratic flint. A little over 45% of the flint artifacts were heated (Kabaciński and Sobkowiak-Tabaka 2010).

Detailed planigraphy of the assemblages enabled the analyses of internal differentiation of the concentrations and determination of their character and presumed function. The first five clusters (1–5), low in number of flints, are located very close to one another and appear to build a functionally interconnected aggregation where domestic activities were carried out. It is important to note that within concentration 4, two tools used as strike-a-lights were recorded (Winiarska-Kabacińska 2010).

The next two flint aggregations, 6 and 8, contained a larger amount of items which reflect the full processing cycle of raw materials, starting from the preparation of cores, through the production of blanks, to the manufacturing of tools. These actions were accompanied by domestic activities such as processing of hunted game (related tools: broken tanged point, end-scrapers, and burins).

Fires and "Noises": the Issue of Distinction

In the frame of intra-site analysis, the identification of hearths is a question of clustering finds affected by open fire. The temperature affecting flint ranges from c. 300 to 800 °C (e.g., Bobak et al. 2010; Sergant et al. 2006; Stahlschmidt et al. 2015). The effect of fire on flints varies with the increase of temperature from changing the raw material in color, to changing its structure, and eventually destruction (e.g., Nieto-Márquez and Preysler 2015; Sergant et al. 2006). The clustering of fire-affected artifacts may be approached through the application of parametric or non-parametric density functions (e.g., Hodder and Orton 1976; Nakoinz and Knitter 2016). The most widely used of these approaches are briefly considered below.

Kernel-density analysis and the *quadrant count method* in its different variations have good utility for spatial analysis of activity areas associated with the deliberate use of fire (e.g., Alperson-Afil 2012, 2017; Pop et al. 2016; Shimelmitz et al. 2014). Figures 4 and 5 present an example of the simple variation of the quadrant count method applied to the flint concentrations of Ośno Lubuskie 7 and the campsite of Lubrza 10.

In the case of Ośno Lubuskie 7, the quadrant count method was applied in the following way. The expected value of fire-affected artifacts per 1 m² was estimated as the number of all fire-affected artifacts (258) divided by the number of 1×1 m units (10) which include concentrations. If the artifact density (items per m²) exceeds the expected value (26), the related quadrant is identified as being affected by fire. If the artifact density exceeds the expected value multiplied by 2, then the related quadrant is considered strongly affected by fire. An artifact density below the expected value reflects weak or zero impact of heat, often representing post-depositional processes (for the more general characteristics of the model see: Nakoinz and Knitter 2016). The model outcomes may be interpreted as identifying the presence of hearths in concentrations 4, 8 and, most probably, 6. The remaining flint aggregations do not show a significant impact of fire (Fig. 4). Comparing these outcomes with the portion of fire-affected artifacts in each assemblage, one may note that the "strong impact of fire" corresponds to 98% (concentration 4) or 40% (concentration 8) of flints being fire-affected, while the "impact of fire" corresponds to 24% of the artifacts being fire-
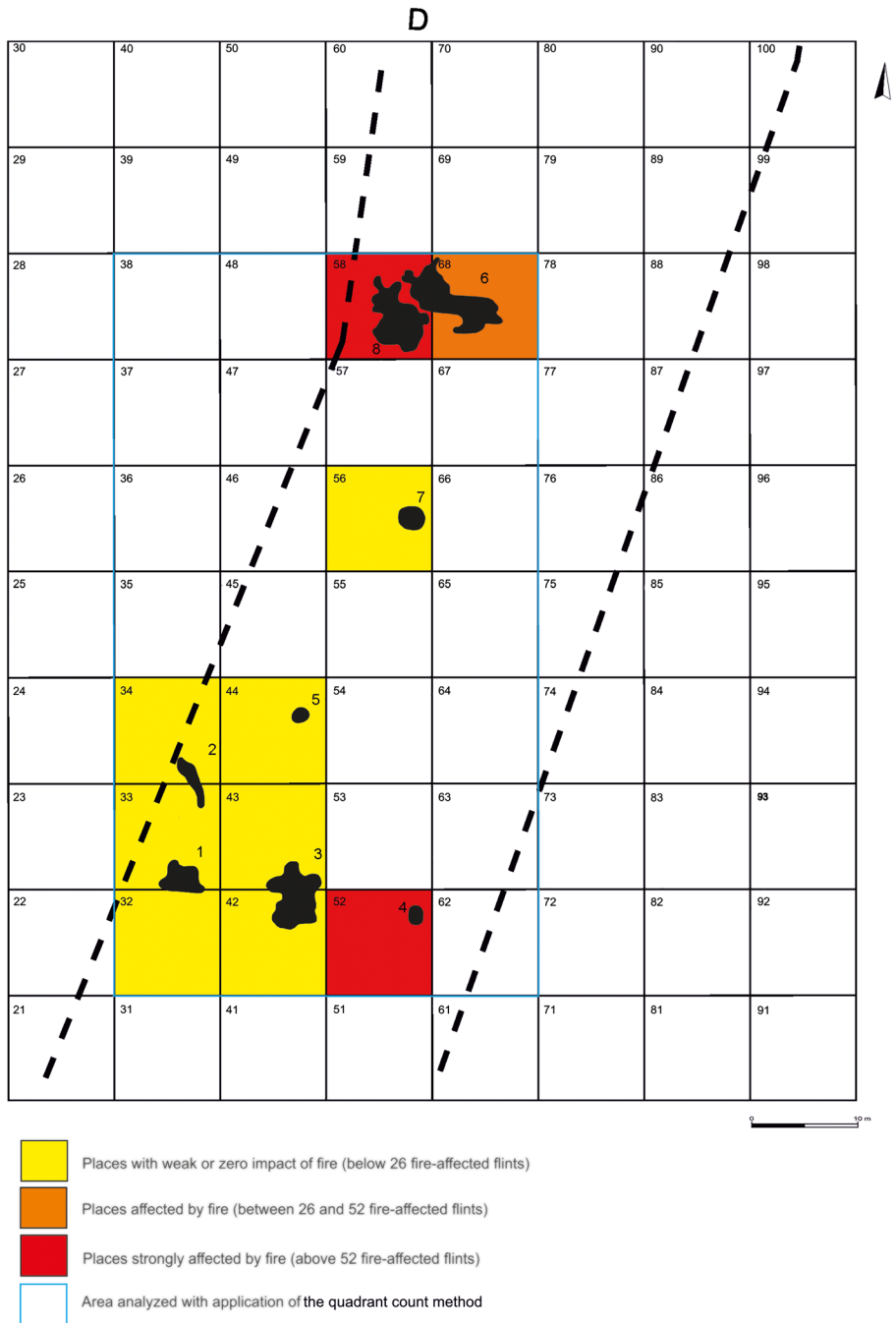
Fig. 4 Ośno Lubuskie, site 7. Application of the quadrant count method

affected (concentration 6). Notably, similar proportions of fire-affected flints were also present in the concentrations identified as having "weak or zero impact of fire"–i.e., 23% (concentration 5) or 39 % (concentration 7) fire-affected.
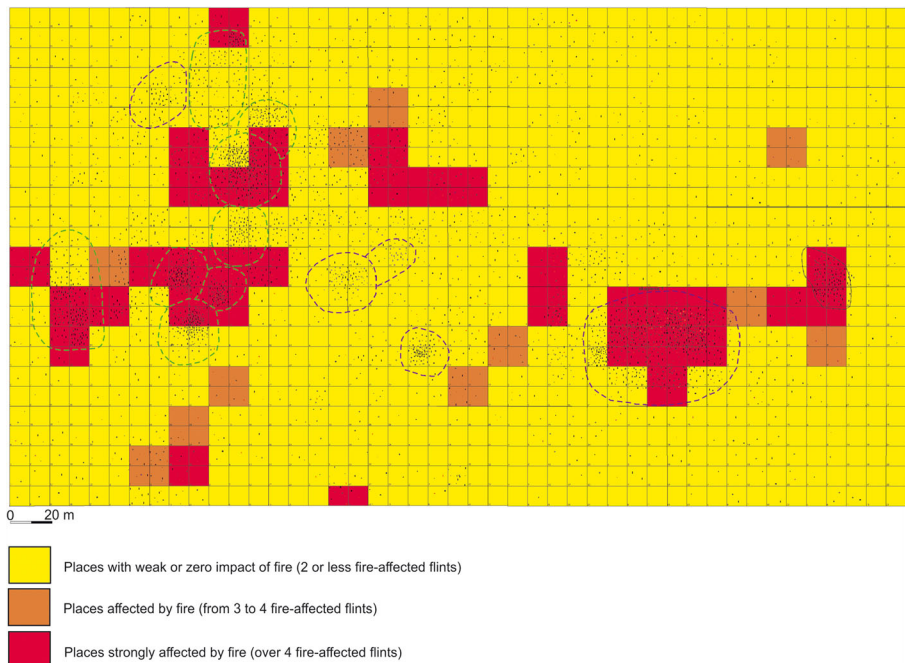
Fig. 5 Lubrza, site 10. Application of the quadrant count method

The quadrant count method was applied to the Lubrza 10 campsite in a similar way. The total number of fire-affected artifacts found in the 300 2 × 2 units is equal to 605, making the expected density value 2 fire-affected artifacts per 1 m². The model highlighted numerous places affected by fire both inside and outside of the concentrations (Fig. 5). The latter case raises doubts considering the obtained results due to the difficulty of identifying a necessity for organizing the hearths outside of living or domestic spaces.

To summarize, the outcomes of the case studies point to several main issues of the quadrant count method which result from the general properties of this model. First, when there is a low total number of flints per concentration, the impact of fire on them may be underestimated. Second, the obtained results are significantly dependent on the size of units in a grid, which is chosen arbitrarily. Third, the model outcomes could be essentially different depending on the total size of the analyzed area (Nakoinz and Knitter 2016).

One may overcome these issues by applying kernel-density analysis (a non-parametric function) which separates areas for calculation and areas for visualization. However, both the quadrant count method in its different variations and kernel-density analysis produce smoothed density models (Nakoinz and Knitter 2016). In other words, both approaches mirror the fuzziness of the location of fire-affected artifacts instead of converting their spatial distribution into patterns and "noises", making these methods relatively weak for locating actual hearths.

The *ring and sector method* includes different assumptions considering the distribution of artifacts of particular types closely to, or at a certain distance from, the fire; as a rule, Binford's (1978, 1983) model of drop and toss zones are adopted. This method

is also applicable for the analysis of the function of an activity area (Boekschoten and Stapert 1995; Leesch et al. 2010; Osipowicz 2017; Stapert 1989; Stapert and Street 1997; Stapert and Terberger 1989). Presumably, one may reverse the ring and sector model to obtain the location of a hearth from the spatial distribution of artifacts within assumed drop and toss zones. Small debris such as chips are usually found close to the hearth, falling there during all sorts of activities, while particular types of tools may have been distributed in various ways–close to the fireplace or far away from it. This distribution depends on which types of activities could have taken place around an outdoor hearth. However, some technical and domestic activities requiring a heat source were executed at the very edge of the hearth, e.g., manufacturing and reparation of the tools. Therefore, in some cases, characteristic debitage resulting from the production of blanks necessary to make a new tool is found in this area (Leesch et al. 2010; Stapert 1989).

Here, the oval-shaped concentration 11, located in the north-western part of the 100-m^2 excavation trench at Lubrza 10, is used as an example (Fig. 6). Within an area of a little over 7 m^2, 62 artifacts belonging to the Federmesser culture were recorded. The flint assemblage consisted of 14 items from core preparation for processing (cortex flakes and blades, preparation flakes), 6 flakes, 23 blades, an opposite platform core, 17 undefined specimens (fragment of a core, undefined flakes and blades, chips and chunks), a retouched flake, and a backed point (Fig. 6). The last piece was used for drilling or piercing (Sobkowiak-Tabaka and Kufel-Diakowska 2019).
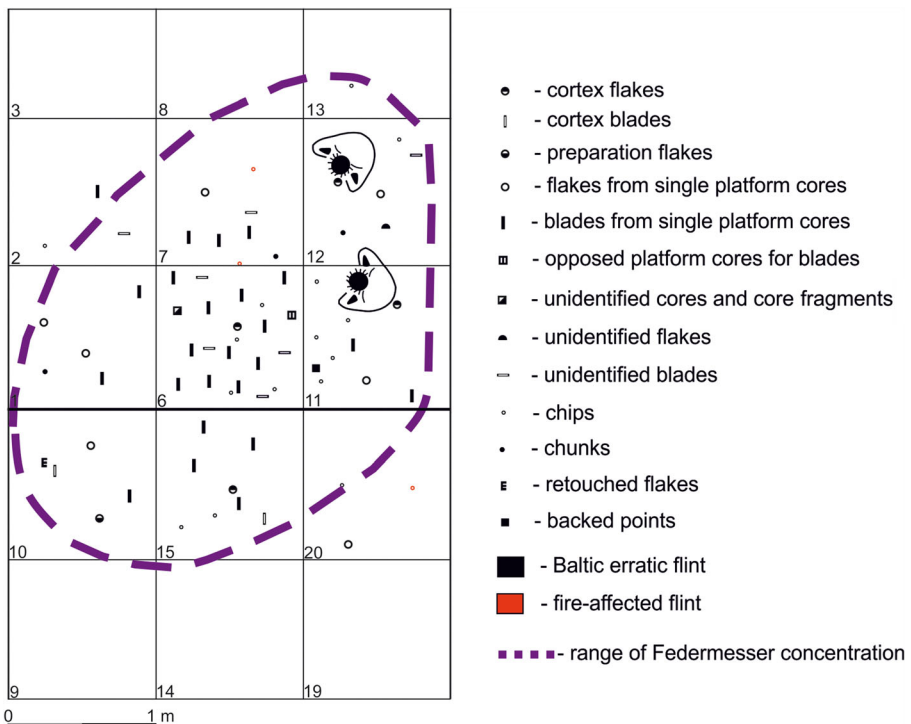

Fig. 6 The Federmesser concentration 11 at Lubrza, site 10

Following the logic of the "reversed" ring and sector method, the core, most of blanks (blades) and the backed point from concentration 11 presumably would occur in the closest vicinity to a hearth while flakes detached in the early stage of core processing and rather small in size (from 22 up to 31 mm in length and therefore light) would gather mostly farthest away from the hearth. This would indicate the location of a hearth in quadrant 6 or 7 and a position of the flint knapper at the border of quadrants 1, 6, 10, and 15 or in the north-western corner of quadrant 11 or 12. In quadrant 11, no fire-affected artifacts were found, while in quadrants 6 and 7, the presence of a hearth might be confirmed by the two fire-affected artifacts found in the northern part of the concentration (Fig. 6). Notably, these observations do not correspond to the results of the quadrant count method, which showed weak or zero impact of fire at this place (Fig. 5).

To summarize, the aim of detecting the precise location of a hearth cannot be reached with the application of the ring and sector model. Moreover, in contrast with the notion of drawing on Binford's more general ethnographic observations for the purpose of fire location, we note that the center of a ring drawn on the basis of spatial distribution of different artifacts does not necessarily represent a hearth. We will thus return to parametric density functions.

Nearest neighbor statistics (hereinafter—NNS) makes possible the distinction between spatial patterns and randomness in the spatial location of objects (e.g., Hodder and Orton 1976; Nakoinz and Knitter 2016; Whallon 1974). The mathematical background of this method was initially proposed by Clark and Evans (1954). The model concerns the distribution of distance (r) between N points in a grid consisting of A units. The mean nearest neighbor distance (r_0) is given by:

$$r_0 = \sum r / N. \tag{1}$$

The expected mean nearest neighbor distance (r_e) is estimated as follows.

$$r_e = 1/2 \sqrt{(N-1)/A}. \tag{2}$$

The ratio R ($R = r_0/r_e$) characterizes the outcome of the point process. For a clustered distribution ($r_0 < r_e$), R is less than 1, for a random ($r_0 \approx r_e$) distribution, R is equal to 1, and for a regular distribution ($r_0 > r_e$), R is greater than 1 (Hodder and Orton 1976).

NNS can be used as a "filter" which removes "noise", forming clusters out of the groups of points that are characterized by nearest neighbor distances significantly less than the value of r_e. Except for the one notable pattern discovered in "noise", which is presented below, individual fire-affected finds and groups composed of 2–4 fire-affected flints are classified as "noise" and thus ignored. Such noise is caused by post-depositional processes, including vegetation, forest fires, and the redeposition of materials caused by differences in landscape elevations.

Similar to the quadrant count method, NNS faces an issue of arbitrary selection of a unit size in the grid and the size of the analyzed area. The expected mean nearest neighbor distance and the cluster area increase in size with the decrease of a unit size. Therefore, we decided to apply a grid consisting of 2 × 2 m units in the case of Lubrza 10 (the whole excavated area was considered) and 0.5 × 0.5 m in the case of Ośno Lubuskie 7 (an area of 8 × 5 m including flint concentrations was analyzed) in order to

obtain the values of r_e appropriate for the analysis of hearth location. Given the expected mean nearest neighbor distance (r_e) of 0.35 m at Lubrza 10 ($N = 605$, $A = 300$) and 0.45 m at Ośno Lubuskie 7 ($N = 258$, $A = 128$), all artifacts with mean nearest neighbor distances (r_0) smaller than these values or equal to them could be placed in clusters.

Figure 3 presents the outcomes of the application of NNS to the concentrations at Ośno Lubuskie 7. Each concentration appeared to be associated with a hearth of a large size. It should be noted that in the case of this campsite, we can determine the chronology of Late Paleolithic settlement only roughly—from the second half of Younger Dryas till the beginning of the early Holocene, namely, the timespan when Swiderian populations were present in the Polish Plain (Sobkowiak-Tabaka 2016). Various proxies obtained from terrestrial sites and marine and lake cores from four continents suggest increasing instances of intensive, widespread, coeval natural wildfires across North America and Europe during the Younger Dryas and Holocene, especially in the early stage of the latter period (Daniau et al. 2010; Dietze et al. 2018; Wolbach et al. 2018). The outcomes of the application of NNS in this case study may thus merely represent post-depositional processes.

The application of NNS to Lubrza 10 prepared as part of a separate study (Sobkowiak-Tabaka and Diachenko, in preparation) allowed the precise identification of the hearth and cleaning zone (a place containing the rubbish which resulted from cleaning of the hearth) in Federmesser concentration 1; hearths in Swiderian concentrations 6, 8, and 10; and the hearth and cleaning zone in Swiderian concentration 12. However, it should be noted that precisely locating the hearth in concentration 1 also required the analysis of the distribution of depths of the artifacts due to the effects of modern vegetation. The majority of "noisy" arrangements consisting of 2–4 fire-affected artifacts at these campsites are most probably the result of the difference in landscape elevations in the west-east and north-south direction, which caused the related redeposition of fire-affected artifacts (Sobkowiak-Tabaka and Diachenko, in preparation; Fig. 2). As this redeposition likely interfered with previously existing patterns, the question arose: is it possible to find something "noisy" in "noise"?

A notable spatial pattern in Lubrza 10 was registered for several arrangements to the west and north-west of concentration 1 characterized as "noise". More specifically, to the west of this flint aggregation, the only hearth outside of the flint concentrations themselves was detected. Three arrangements registered as "noise" to the north of this hearth form a spatial pattern close to linear. The observed trends in the location of fire-affected and non-heated artifacts to the west of concentration 1 delineate a Federmesser hut with a hearth in its center, while the fire-affected flints to the north likely represent rubbish thrown out of an entrance located in the northern or north-eastern part of the hut (Sobkowiak-Tabaka and Diachenko, in preparation; Fig. 7).

To summarize the outcomes obtained for Lubrza 10, the application of NNS to this site proved the utility of this model for locational analysis of hearths in poorly preserved contexts embedded in sandy sediments. The model made possible the distinction of patterns and "noisiness within the noise," allowing the precise location of hearths and cleaning zones as well as the detection of a Federmesser hut. The issues of fuzziness and artifact redeposition were successfully resolved.
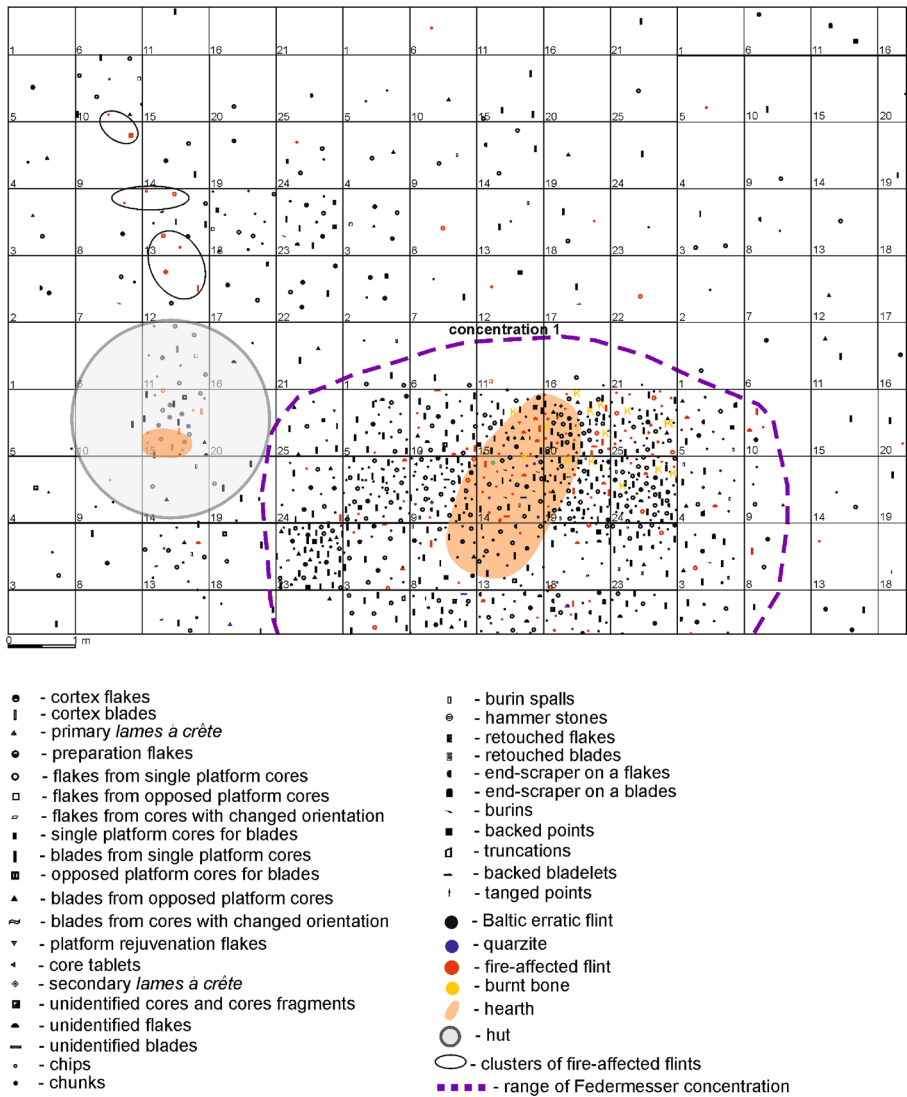
Fig. 7 The Federmesser concentration 1 and hut at Lubrza, site 10

Discussion

In several cases, the application of the different models of analysis to the same datasets produced contradictory results. These contradictions are worth a more in-depth discussion.

Although the ring and sector model indicated the presence of a hearth in Federmesser concentration 11 at Lubrza 10, the NNS and quadrant count method did not detect any impact of fire at this location. While the quadrant count method could underestimate the effect of fire due to its properties and related issues in application (see above), the results obtained with the NNS and quadrant count method are considered

more reliable due to the intensive redeposition of artifacts at the site caused by differences in landscape elevation. This leads to a broader discussion of the utility of the "reversed" ring and sector model for the identification of fireplaces. Although the solution of "placing" a hearth into the center of an analyzed activity area is elegant, the initial assumptions behind such application of the model raise reasonable doubts. For instance, activities organized at summer camps should not necessarily include a fireplace as an integrative element (e.g., Chabai 2006). The same may be true for activities with a short duration in winter camps. Even concentrations visually including numerous artifacts can in fact require a surprisingly short time to be produced (e.g., Olausson 1986).

As exemplified by the application of the models to the data from Late Paleolithic camps on the North European Plain, in different cases, the quadrant count method "produces" many more (Lubrza 10) or far fewer (Ośno Lubuskie 7) places affected by fire than NNS. This indicates the issue of application of models based on simple density functions. Taking into account the utility of NNS to resolve the issue of "noises" caused by depositional and post-depositional processes, we consider its application to precisely determine the location of fireplaces as more justifiable than the usage of the quadrant count method. Meanwhile, case studies have shown several issues in the application of NNS which should be considered in further research and in the development of analytical approaches to the spatial distribution of fire. These are as follows.

First, NNS is used to analyze data in two-dimensional space. As represented by the identification of the hearth in Federmesser concentration 1 at Lubrza 10, the analysis of the vertical distribution of artifacts in addition to the NNS produced much more reliable results than NNS would have alone. Consideration of vertical and horizontal distribution of artifacts makes possible the specification of post-depositional processes, identification of a hearth type (i.e., sunken hearth), etc. We suggest consideration of such combined analyses for future applications of the model (Aldeias et al. 2016; Alperson-Afil 2012; Lawrence and Mudd 2015). This is also important in distinguishing scatters and hearths of different chronological horizons (e.g., Sorensen and Scherjon 2018).

Second, as exemplified by the case study of Ośno Lubuskie 7, NNS is not necessarily always able to distinguish post-depositional processes, such as natural fire events, from the deliberate uses of fire at hunter-gatherers campsites. The interpretation of the results of NNS may therefore be inappropriate if the particular environmental conditions in which a Paleolithic camp was functioning are not also taken into account. This requires the development of additional methods and analytical procedures capable of overcoming this issue.

Conclusion

The identification of the location of a hearth through chemical analyses is seldom possible in the natural environments of certain regions that are not conducive to the preservation of organic remains, such as the acid sandy soils of the North European Plain. This limits the methods applicable to related research tasks to spatial statistics, in which, however, there remains a certain level of uncertainty regarding the obtained results. An analysis of the most widely used methods—quadrant count method and kernel density analysis, ring and sector model, and nearest neighbor statistics—and

their application to the Late Paleolithic sites of Lubrza 10 and Ośno Lubuskie 7 in Western Poland showed that the nearest neighbor statistics is the most appropriate approach to identify the spatial location of hearths. The suggestion was furthermore made that future applications of this method should be complemented by the analysis of the vertical distribution of artifacts. Limitations of NNS revealed through the case study of Ośno Lubuskie 7 also underline the necessity of developing new approaches which could be used to determine the location of Paleolithic fireplaces even in areas affected by later wildfires or deliberate anthropogenic uses of fire.

Compliance with Ethical Standards

Conflict of Interest   The authors declare that they have no conflict of interest.

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