Settlement patterns of the Middle Palaeolithic in Southern Germany. A GIS-supported predictive model for sites in Bavaria and Baden-Wurttemberg

Das Siedlungsmuster des Mittelpaläolithikums in Süddeutschland. Eine GIS-gestützte Archäoprognose für Fundstellen in Bayern und Baden-Württemberg

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Abstract - As a largely glacier-free zone throughout the entire Middle Palaeolithic, Southern Germany has often been discussed as a key area for Neanderthal migration. In this study, the settlement patterns of the Southern German Middle Palaeolithic were investigated via Weighted Layer Analysis, resulting in key insights about the prognostic qualities of topographic variables like elevation, slope, aspect, distance to river and outgoing visibility, as well as two predictive maps for cave and open-air sites. Comparing the high probability zones for both site types, their possible interplay in Southern Germany and the special role of the infrastructure of the Franconian Swabian Jura for Neanderthal migration in Europe are discussed.

***Zusammenfassung** - Als überwiegend gletscherfreies Areal während des gesamten Mittelpaläolithikums wurde Süddeutschland häufig als Schlüsselgebiet für die Ausbreitung des Neandertalers diskutiert. In dieser Studie wurde das Siedlungsmuster des süddeutschen Mittelpaläolithikums via Überlagerungsanalyse untersucht. Hierdurch konnten nicht nur Erkenntnisse über die Prognosefähigkeit der topographischen Variablen Höhe, Hangneigung, Hangausrichtung, Distanz zum Fluss und ausgehendes Sichtfeld gewonnen, sondern auch zwei Prognosekarten für Höhlen und Freilandfundstellen generiert werden. Auf der Grundlage des Vergleichs der Verdachtsflächenverteilung beider Fundstellentypen wird ihr mögliches Zusammenspiel innerhalb Süddeutschlands diskutiert, ebenso wie die besondere Bedeutung der „Infrastruktur" der Fränkisch-Schwäbischen Alb für die Migration der Neandertaler innerhalb Europas.*

Keywords - **weighted layer analysis, predictive modelling, Middle Palaeolithic, Southern Germany, settlement patterns, Franconian-Swabian Jura**
Überlagerungsanalyse, Archäoprognose, Mittelpaläolithikum, Süddeutschland, Siedlungsmuster, Fränkisch-Schwäbische Alb

Introduction

Southern Germany harbours some of the most well-known Middle Palaeolithic sites in Central Europe, among them the Sesselfelsgrotte (Weißmüller 1995; Richter 1997; Freund 1998), Klausenhöhlen-complex (Freund 1963; Rind 2008), Bocksteinschmiede (Wetzel 1958; Krönneck 2008), Speckberg (Müller-Beck 1992; Çep 2000; Rieder 2011), Hohler Stein (Rieder 2016) and Großes Schulerloch (Birkner 1916; Beck 2006). Offering a variety of landscapes and altitudes in a fairly wind protected and continuously glacier-free zone, this area has often been discussed as a central hub for Middle Palaeolithic migration during the colder periods from MIS 5 through to MIS 3, when human groups had to repeatedly retreat to milder refuge areas in the southern part of East- and Western Europe (Jöris 2004; Richter 2016). The extent of this potential migration was poignantly demonstrated by recent analysis of Neanderthal assemblages from the Altai Mountains in Southern Russia that show techno-morphological similarities to Middle Palaeolithic industries from Central and Eastern Europe – particularly to those of the Sesselfelsgrotte in Bavaria (Kolobova et al. 2020).

To contribute to the understanding of the Middle Palaeolithic settlement patterns in this 'junction' between West and East and to facilitate future research and heritage management, a GIS-supported predictive model for sites in Bavaria and Baden-Wurttemberg based on pre-existing site data was conducted. The assessment of predictive location

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This article contains supporting information online at: https://journals.ub.uni-heidelberg.de/index.php/qu/issue/archive parameters for cave and open-air-sites constitutes the basis of this predictive model. Therefore, the factors elevation, slope, aspect, distance to rivers and outgoing visibility were evaluated for their significance as prognostic variables for both site types in order to understand their possible interplay. Following this, two separate predictive maps for cave sites and open-air sites were generated in the open-source software QGIS (QGIS Development Team 2020) by Weighted Layer Analysis (Warren 1990). The results show that especially along the Franconian-Swabian Jura and its outskirts, areas with simultaneously high potential for cave and open-air sites were plenty, offering optimal conditions for fast and efficient migration along the west-east-axis of the karst landscape. Herein lies one possible reason for this area's key role in facilitating Neanderthal migration that can be traced from Central Europe to the Siberian Altai.

Materials and Methods

Geographical and climatic characteristics

The study area is described by the territory of the modern-day federal states of Bavaria and Baden-Wurttemberg, Germany (Fig. 1). These two states share major natural and geomorphological landscape units, among them Germanys largest connected karst region, the Franconian-Swabian Jura, the South German Scarplands and the Alpine Foreland (Meynen et al. 1962; Kappas et al. 2003; Kempe 2005). Whereas the latter had been covered by the Alpine glaciers to a varying extend during the Middle Palaeolithic, the larger part of Southern Germany stayed permanently ice-free except for smaller cirque glaciers in the high mountains (Fiebig et al. 2011).

The Franconian-Swabian Jura is characterised by medium mountain ranges intersected by steep valleys which are a product of meandering rivers carving through the karst landscape, leaving a large number of natural rock shelters and cavities along the valley borders. Within these shelters and caves most of the Middle Palaeolithic remains and artefacts have been found, indicating that Neanderthal groups used these weather-protected spaces as camps and hideouts (Conard et al. 2012; Rieder 2016).

The Southwestern German Scarplands with the Main Franconian Plateau, Gäu Plateaus and Swabian-Franconian Keuper-Lias Land is in large part comprised of wide plains and hills (Meynen et al. 1962). The flat relief of this landscape in combination with its keuper and loess soils does not only set favourable conditions for open-air site preservation, but it also makes

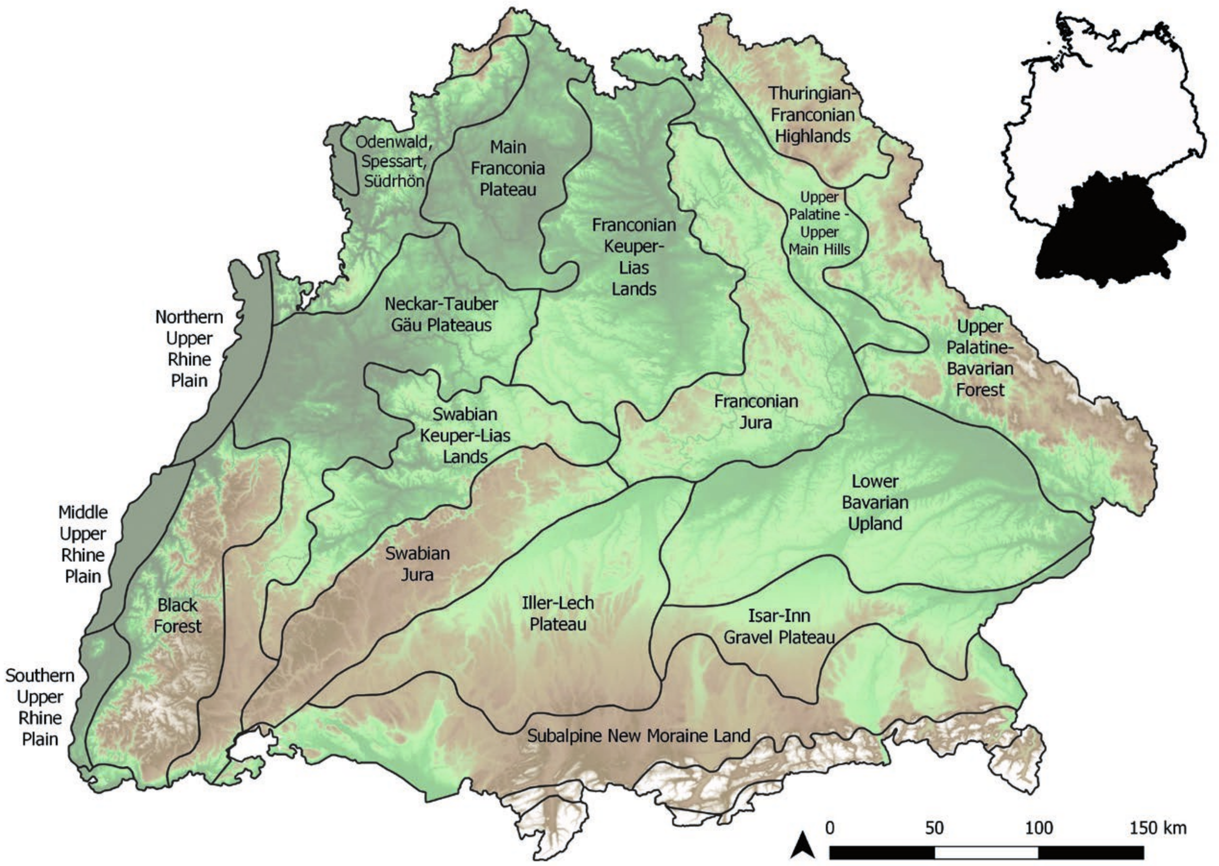

Fig. 1. Location of the study area within Germany (right upper corner) and main natural landscape units according to Meynen et al. 1962; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 1. *Lage des Arbeitsgebietes innerhalb Deutschlands (rechte obere Ecke) und naturräumliche Gliederung nach Meynen et al. 1962; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

it an attractive area for agriculture (Völkel 2006). Also, in the Swabian Keuper-Lias Land along the Neckar, travertine terraces with exceptional site preservation qualities occur (Wenzel 1998).

The previously described landscape units that expand over both federal states make up more than two thirds of the entire study area. This includes the majority of the Southern German river system, in particular the Main and Danube rivers and their confluent stream network. Together, the Main and Danube river system comprise an extended part of the main European watershed between the Atlantic Ocean and the Black Sea (Völkel 2006).

Although the choice of the study area within the borders of two modern federal states is an arbitrary one in regards to the Middle Palaeolithic and does not completely follow the natural landscape units proposed by Meynen et al. (1962), the application of a joint dataset from Bavaria and Baden-Wurttemberg presents an effort to reverse the previous trend of analysing data solely on a smaller scale within individual federal states for administrative reasons (Fig. 2, for complete site list see SI Tab. 1).

Although changes in topography have certainly occurred, the main structures of the Middle Palaeolithic relief and hydrological situation of Southern Germany can be considered roughly comparable to that of today on the larger to medium scale - obvious exceptions being formerly glaciated regions (Völkel 2006; Krönneck 2008). This however does not hold true for the climatic conditions of the study area. Central Europe saw a series of radical changes in mean temperatures during the Late Pleistocene, whose impact on the South of Germany can only be partly reconstructed by the analysis of ice core samples and stratigraphical sequences (Eitel & Felix-Henningsen 2003; Jöris 2004; Banak et al. 2020). On the larger scale, these were caused by the sequence of the Riß-glacial (300,000 BP to 125,000 BP), the interglacial warm period Eem (125,000 to 115,000 BP), followed by the Würm-glacial (115,000 to 11,500 BP) (Fiebig et al. 2011). But as faunal remains and pollen profiles from the site Hunas and the lake deposits of Samer Berg witness, the actual climatic conditions saw far more frequent changes from milder to colder mean temperatures within one and the same isotope stage (Groiß 1983; Grüger 1979; Rosendahl et al. 2011). Some of the sediments from Saalian and Weichselian interstadials are rich in faunal remains of thermophile species, although their percentage seems to diminish closer

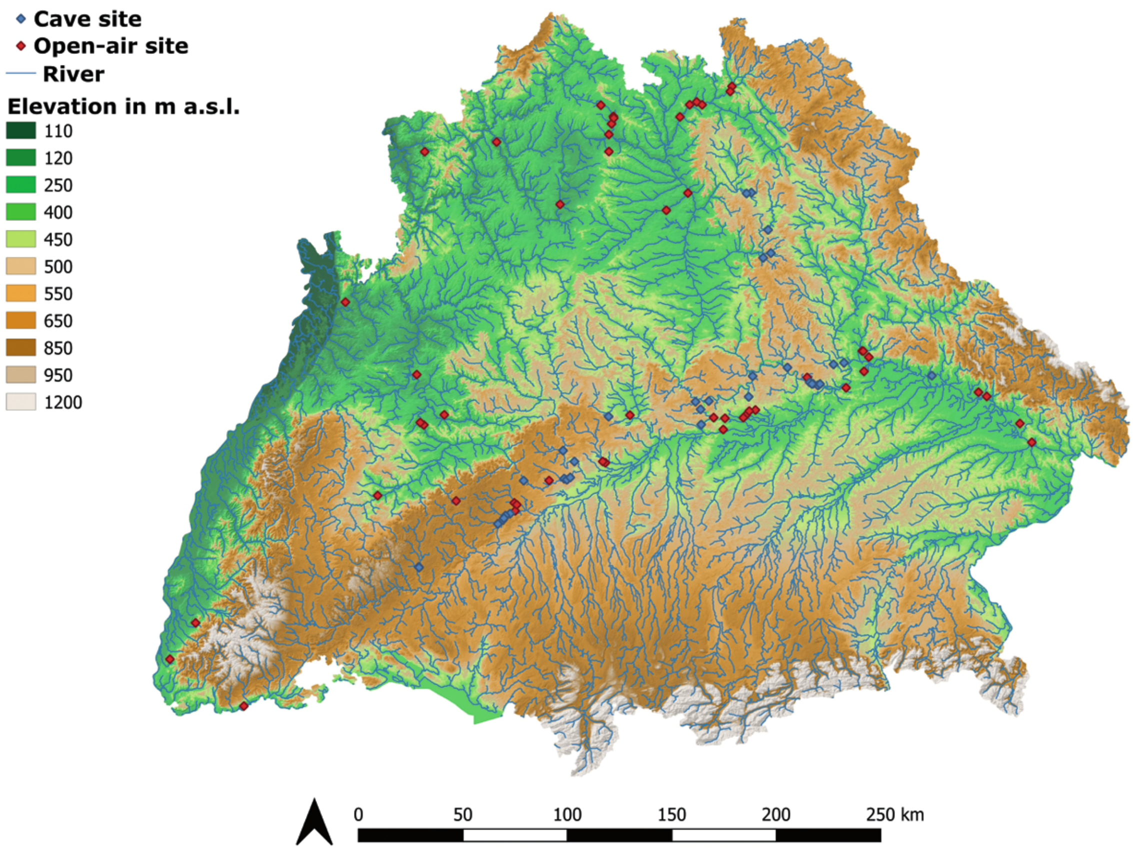

Fig. 2. Overview of Middle Palaeolithic sites included in the study sample; CRS: EPSG 25832. Geodata: DEM and water mask © EEA 2020; Site data © Bayerisches Landesamt für Denkmalpflege 2020, Landesamt für Denkmalpflege Baden-Württemberg 2020, Höhlenkataster Fränkische Alb 2020.

Abb. 2. *Übersicht der mittelpaläolithischen Fundstellen des Studiensamples; KBS: EPSG 25832. Geodaten: DEM und Wassermaske © EEA 2020; Fundstellendaten © Bayerisches Landesamt für Denkmalpflege 2020, Landesamt für Denkmalpflege Baden-Württemberg 2020, Höhlenkataster Fränkische Alb 2020.*

to the first glacial maximum around 64,000 BP (Groiß 1983; Uthmeier 2004). Even at this point of maximum glacier extent, Southern Germany remained ice-free, leaving human groups the possibility to either stay within the area or migrate to warmer refuges (Jöris 2004).

The latter possibility is suggested by the important reference stratigraphy of the Sesselfelsgrotte in the Altmühl Valley, Bavaria. Here, we find several Neanderthal occupations dating to the MIS 5c and 5a, followed by the culturally sterile layers attributed to the maximum glaciation of the Interstadial MIS 4, not least due to a rich assemblage of rodent remains, indicating climatic cooling. In the following moderate phases of the MIS 3, the Sesselfelsgrotte then was once again used repeatedly by Neanderthal groups (Freund 1998; Richter 2002, 2016). This hiatus might not be exclusive to the Sesselfelsgrotte since in fact, no Middle Palaeolithic site in Bavaria or Baden-Württemberg contains cultural layers safely correlated to the MIS 4 (Jöris 2004; Richter 2016; SI Tab. 1) This does not proof the absence of humans, it does insinuate however that a lot of former frequented sites seem to have been abandoned around the same extended cold period of MIS 4. So, although the study area cannot be considered a climatic refuge itself, its wind protected topographic situation surrounded by four medium mountain ranges (Bürger 2003) may have made it a suitable habitat during the less extreme cold periods of the Middle Palaeolithic and traversable throughout the entire Pleistocene.

Between the first glacial maximum around 64,000 BP and the second around 20,000 BP lies the climatic period of the Interpleniglacial (MIS 3) which most Neanderthal sites in Germany are associated with (Uthmeier 2004; Richter 2016). Despite moderately varying mean temperatures, the landscape of this stage was continuously characterised by a mostly treeless grass tundra occupied by migrating herds of large herbivores like bison, wild horses and mammoths, the so called *Mammutsteppe* (Eitel & Felix-Henningsen 2003; Beck et al. 2006). The latest evidence of Neanderthal occupation in the study area dates around 43,000 BP. After this, all cave sites of the Franconian-Swabian Jura exhibit a stratigraphic hiatus, until a few thousand years later modern humans leave traces in the karst cavities (Conard&Bolus 2008).

Archaeological predictive modelling and Weighted Layer Analysis

The term predictive modelling is generally used to describe

"[…] a technique to predict, at a minimum, the location of archaeological sites or materials in a region, based either on the observed pattern in a sample or assumptions about human behaviour (Kohler & Parker 1986: 400).

Put into practice, it is a statistical procedure to evaluate the archaeological potential of an area using existing site data or pre-existing knowledge, usually resulting in a georeferenced map indicating areas of interest (Münch 2006). Developed in the late 1970s in the United States, predictive modelling has been successfully applied in American archaeological research and heritage management for around 40 years (van Leusen 2002).

Among the numerous possible statistical methods and general approaches (Rose & Altschul 1988; Verhagen et al. 2011; Yaworsky et al. 2020), the predictive model for this study was generated via Weighted Layer Analysis (WLA), which is a form of multiple linear regression. This statistical method assumes that an unknown, dependable variable (e.g., site probability) can be expressed through a linear function that contains several known, dependent variables (e.g., predictive factors) (Rose & Altschul 1988). In case of archaeological predictive modelling, the site probability is calculated for every cell of a georeferenced raster map that indicates high probability for cells that reach high values (Brandt et al. 1992).

As predictive variables *elevation*, *slope*, *aspect*, *distance* to *nearest river* and *outgoing visibility* were chosen, which are known to have delivered reliable results for previous models in the past (Brandt et al. 1992; van Leusen 2002; Sauer 2017). Every variable is represented as a separate raster layer in the GIS-software containing the variables values for each cell. In preparation for the final overlay and calculation of the probability map, these continuous values have to be classified, tested for statistical significance and weighted (Brandt et al. 1992; Verhagen 2007). In order to assess which variable classes are overrepresented and are therefore assumed to be related to site choice, they are tested for statistically significant distribution. In the case of this study, this was performed via Chi-Square-Test (Rose & Altschul 1988; Barceló 2018). Only if significance of distribution is established, its classes are weighted according to their actual occurrence rate in the sample and the raster layer can be incorporated into the predictive model.

Challenges and chances of predictive modelling via WLA

A major point of critique is the tendency of predictive models to approach human settlement behaviour from a strongly environmentally deterministic perspective (Gaffney & van Leusen 1995). Predominantly topographic parameters are tested as predictive variables even though ethnographic studies clearly suggest that other influences are sure to have played a role in picking a specific location for a camp site (Venkataraman et al. 2017). Cultural norms, spiritual concepts about the landscape, aesthetic preferences, relationships to other groups and territoriality are only a couple of factors that cannot be properly factored into the model's algorithm – they only play an indirect role in predictive modelling when they are discussed as reasons for unexpected results and outliers (Verhagen et al. 2011). Notwithstanding that these topographic parameters have been shown to play a significant role in the site choices of modern hunter-gatherers in ethnographically documented and archaeological contexts (Jochim 1976; Kvamme & Jochim 1989; Binford 2012). In the case of cave sites, the preposition of 'intentional choice', directed by environmental or cultural factors, is even more problematic, since the occurrence of natural caves is strongly limited by the topography and geology of the landscape. This goes to say that true options between caves with different features or as an alternative to open-air sites were only available in regions with a high occurrence of natural caves, which is not the case for most of the study area.

Another problem is the available data and its suitability for predictive purposes. Depending on the study area and period of interest, pre-existing site data is often sparse, incoherent, and highly selective, resulting in small samples that are not sufficiently representative (van Leusen 2002; Kamermans 2007; Verhagen & Whitley 2012). This is caused by several factors that fall into one of two categories: probability of preservation and find probability.

The first is heavily influenced by the geology and topography of the landscape, leading to varying degrees of natural or man-made erosion and solifluction. Obviously, only where deposits of Pleistocene soil remain in situ, respective archaeological layers can be found. As cave deposits are in general more protected from these effects, it is clear why most stratified Middle Palaeolithic sites belong to this site type (Conard et al. 2012; Eitel & Felix-Henningsen 2003). The second category concerns the visibility of sites, which is determined among other factors by modern vegetation and land use. In agricultural areas with uncovered, ploughed soil, it is considerably easier to spot artefacts leading to the discovery of sites. This is also true for areas with very active and knowledgeable collector communities (Sauer 2017). The algorithm of predictive models will always reproduce data biases to a certain extent (Verhagen 2007), yet it also offers the chance to partly counterweigh it through exposing former unexplored areas as zones of interest, contributing to a more complete picture of prehistoric settlement patterns.

The transparency of predictive models poses a third challenge. Considering that the amount and quality of data, the modelling approach and even the specifics of hard- and software contribute highly to the final result, it becomes evident that it is quite difficult to assess model performance from the outside without a lot of additional information. To complicate matters further, GIS-programs and their design functions tend to make results look less ambiguous than they actually are. It is no wonder then, that researchers like P. Verhagen (2007; Verhagen et al. 2011) have objected to uncritically using predictive maps as main decision factors for heritage management development

The profound benefit of predictive modelling for archaeology is evident: not only does this method offer insights into settlement patterns, but at the same time delivers possible access to new sites. This is particularly intriguing for Middle Palaeolithic research, since sites of this period are usually not easily detectable through non-invasive, comparatively low-cost prospection methods like aerial photography or geomagnetic resonance measuring. Lacking the extensive amount of funding and workforce necessary to systematically search larger areas for Middle Palaeolithic sites, discoveries are often left to chance. For this very reason, predictive modelling has become a staple tool to make heritage management und field research more efficient and feasible (Brandt et al. 1992; van Leusen 2002; Münch 2006; Verhagen et al. 2011).

Besides the prospect of adding to the number of known sites, most of the scientific value is already generated in the process of collecting, preparing, and operationalizing the archaeological data. Caution is advised though, since patterns emerging during model generation have to be understood as primarily quantitative phaenomena. So, whereas correlation between predictive factors and site occurrence for example can be pointed out by predictive modelling, causality can only be suggested and should become the starting point for further testing (Shmueli 2010; Barceló 2018).

Base data, software and critical source review

The analysis was performed on three samples, one consisting of 41 cave sites, another of 51 open-air sites and one that combined all 92 sites regardless of site type. The sample data was acquired through an extensive and systematic literature research and consultation of the federal heritage management data banks. By creating a task-specific evaluation system considering inventory size, stratigraphical context and typo-chronological pronunciation of the lithic inventories, only 92 sites were chosen from a considerable larger amount of available database entries – most of them too unspecific in typological association or location to use for predictive modelling (see SI Tab. 2). Data management was done in MS Excel.

All steps of model creation were executed with the freeware program Quantum GIS (QGIS) Version 3.12.3 and the available Plug-Ins and Tools of GRASS 7.8.3 and SAGA (QGIS Development Team 2020).

The topographic base data was provided by the European Digital Elevation Model (EU-DEM V. 1.1), a georeferenced topographic map available as a free geotiff-file of 25 x 25 meter grid size. The elevation values of the EU-DEM are derived from a combination of satellite data from the *Shuttle Radar Topography Mission (SRTM) and the Advanced Spaceborne*

Thermal Emission and Reflection Radiometer (ASTER), collected from 2003 to 2009. The overall root mean square error of this model lies at 2.9 m vertical deviation, which was evaluated through independent satellite data from the *Ice, Cloud and Land Elevation Satellite* (ICESat). Version 1.1 was published in 2017 by the European Environmental Agency (EEA 2014; 2020a).

In addition to the topographical map, the EEA also released a hydrological vector map that was used for the model (EEA 2020b). It is important to notice that this map does not include lakes and small streams, which could therefore not be considered for the predictive variable *distance to river*. Since lakes and small rivers already constitute a problematic factor in palaeolithic site modelling to begin with, mainly due to their seasonal fluctuation and general impermanence (Kvamme & Jochim 1989), this inaccuracy was accepted.

The digital elevation model and water mask were cropped down to the modern borders of Bavaria and Baden-Wurttemberg. For several calculations, the area was buffered with 5 to 30 km to ensure correct calculations for the cells along the edge of the raster map.

Using modern day satellite data to model a prehistoric environment is a delicate undertaking, for it can be argued that the landscape might have changed to a degree that does not allow comparison. In an ideal world, predictive models would work with data sets specifically reconstructing the topographical conditions of the study period, but unfortunately, such data is not available in most cases. Whereas it might be critical to work with reconstructed data on a regional level for a very accurate predictive performance, on a larger scale like the area of Southern Germany on a 25 x 25 m grid, most minor changes in relief do not fall into account whereas larger topographic features can be considered stable enough to be comparable (Kvamme 1992).

Results and preliminary discussion

Elevation

The elevation values were directly taken from the Digital Elevation Model EU-DEM V. 1.1 (EEA 2020a). An above average number of cave sites fall into the classes 8 and 9, between 400 m and 500 m above sea level (Fig. 3). This is explained by the topographic conditions in which natural cavities in Southern Germany occur, mostly along the medium and low mountain ranges of karst regions (Kempe 2005). Open-air sites tend to be found in lower elevation classes 5 to 7, with 250 m to 400 m altitude. Obviously, this is due to the fact that open-air sites are the only available site type in plains below the mountainous karst regions and at the same time, it is not likely for open-air sites to be preserved in higher elevation classes due to erosion. Both site types show a statistically significant deviation from the expected distribution (caves: $p = 0.0001 < 0.05$; open-air: $p = 0.0013*10-2 < 0.05$), which renders elevation a valid predictive factor for Middle Palaeolithic sites in the study area.

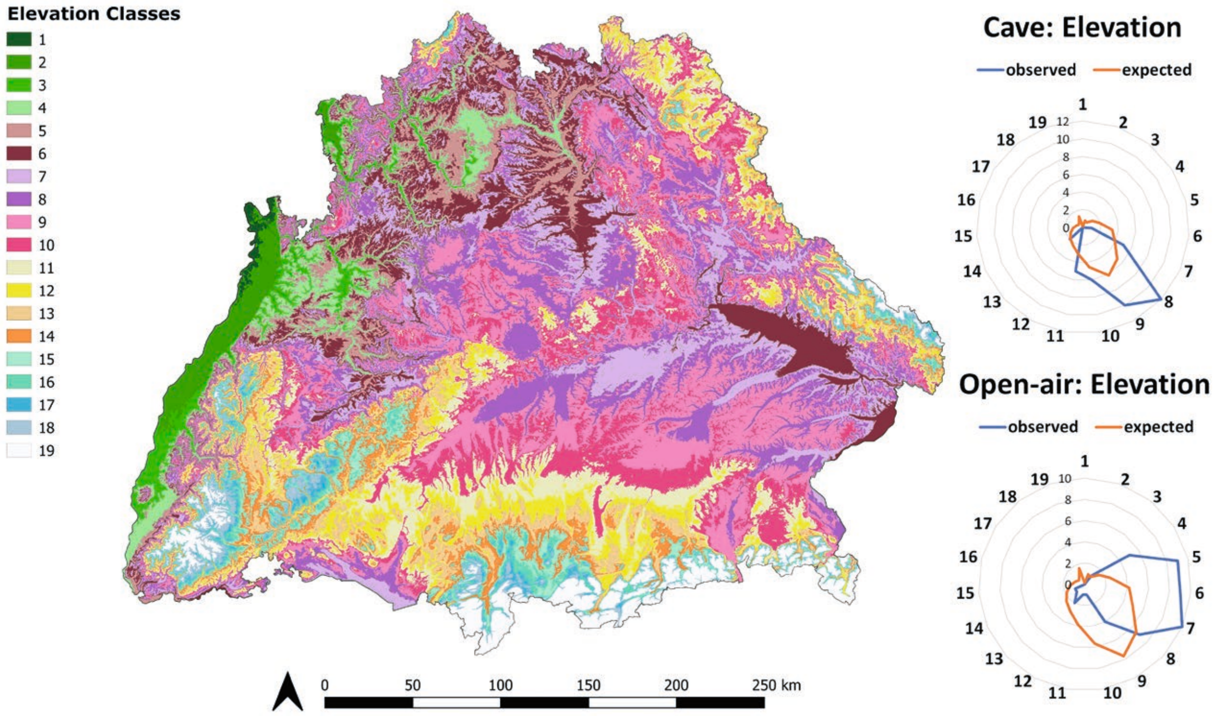

Fig. 3. Distribution of elevation classes in the study area; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 3. *Verteilung der Höhenklassen im Arbeitsgebiet; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

Slope

Slope (Fig. 4) is defined as the mean inclination of a surface in the Digital Elevation Model, calculated from the difference in height of each cell and its eight neighbouring cells in the raster map. Cave sites in Southern Germany can be found in slope classes 3 to 5, most often in class 4 between 16 and 25 degree mean inclination. Since caves are normally situated along the steep borders of mountain valleys, this does not surprise. Open-air sites however are positioned on even plains, mainly within slope class 1 of 0° to 3° degrees. The preference of plain areas for this site type has also been shown for Mesolithic and Late Palaeolithic hunter-and gatherers (Jochim 1976; Sauer 2017). This can possibly be attributed to the fact that flat areas are favourable for everyday camp and hunting-related activities (Kvamme & Jochim 1989; Kvamme 1992). Both site types are distributed in a statistically significant manner (caves: $p = 0.0081*10^{-21} < 0.05$; open-air: $p = 0.0276 < 0.05$).

Aspect

Aspect (Fig. 5) describes the direction toward which a raster cell is angled, measured in 45° sections of the 360° cardinal directions. Both site types are not significantly distributed in terms of aspect classes (caves: $p = 0.6077 > 0.05$; open-air: $p = 0.8963 > 0.05$). As a result, the aspect layer could not be used as a predictive layer in the Weighted Overlay. This result was considerably surprising, since there has been a documented tendency for Late Palaeolithic, Mesolithic and modern hunter-gatherers to settle on southern slopes for open-air sites, possibly to profit from extra sun exposure and plant resources (Kvamme & Jochim 1989; Kvamme 1992; Sauer 2017). This trend does not show in the Middle Palaeolithic sample data. One possible explanation might be that southern slopes probably did not offer the same degree of additional value for Neanderthals in the climatic conditions of the Upper Pleistocene that it did for modern humans closer to the Holocene. There is for example no evidence that Neanderthals exploited plant resources for sustenance in a structural manner (Power 2019; Wißing et al. 2019). When it comes to cave sites, their aspect is predetermined by the mountain range and in most areas not a matter of choice.

Distance

The variable distance to river (Fig. 6) was measured as the Euclidean distance of each cell to the nearest river cell of the water mask. The sites of the sample are significantly distributed over the distance classes in both cases (caves: $p = 0.0056*10^{-11} < 0.05$; open-air: $p = 0.0004 < 0.05$). Both cave sites and open-air sites are located close to rivers, caves mainly up to 200 m and open-air sites between 200 m and 800 m from the nearest larger stream. This preferred proximity is no surprise considering that human groups and their prey both need access to fresh water and probably used streams as guide rails for their seasonal movement (Jochim 1976). Cave sites are on average closer to streams than open-air sites, since they are usually situated

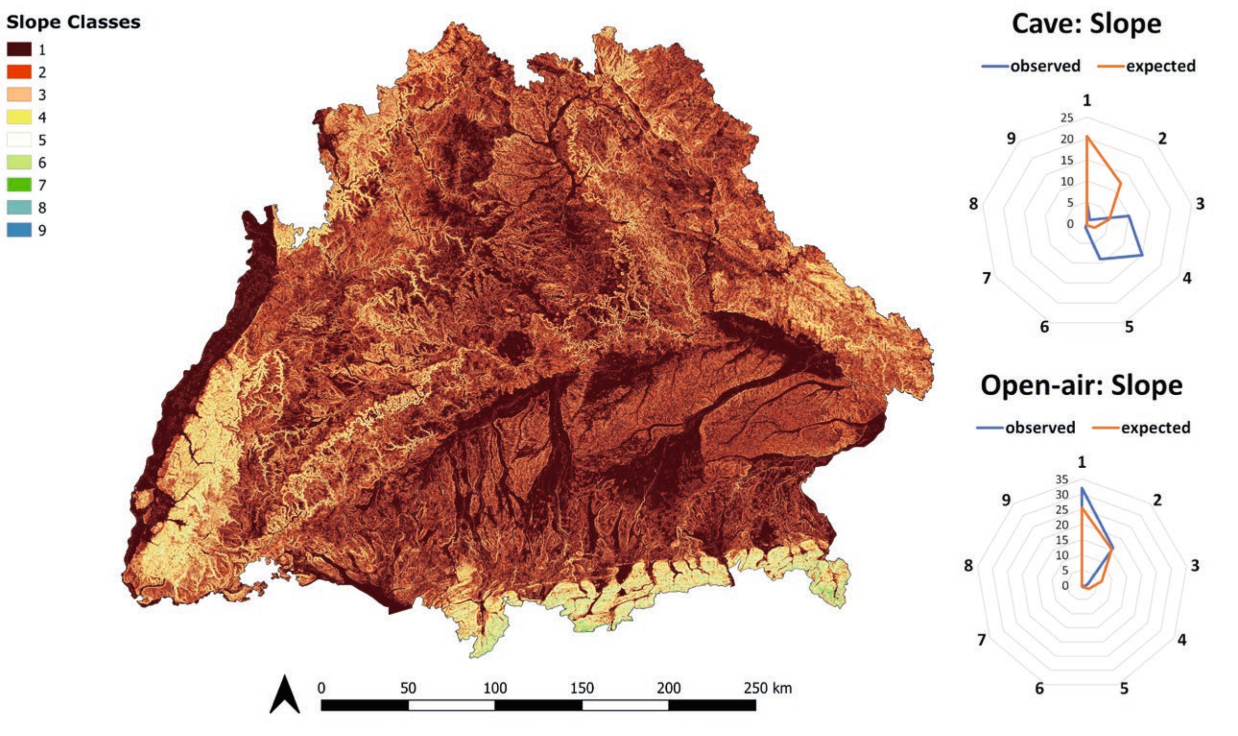

Fig. 4. Distribution of slope classes in the study area; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 4. *Verteilung der Hangneigungsklassen im Arbeitsgebiet; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

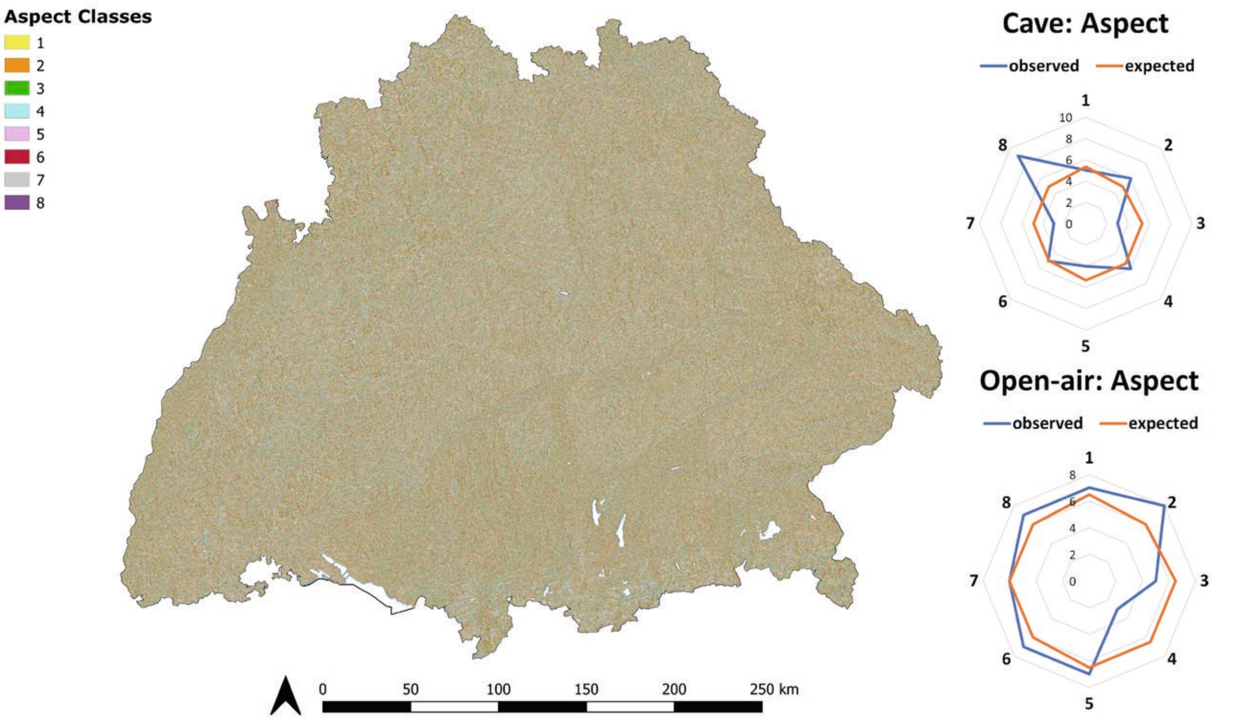

Fig. 5. Distribution of aspect classes in the study area; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 5. *Verteilung der Hangausrichtungsklassen im Arbeitsgebiet; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

within slopes carved out by rivers, where drainage is mostly not an issue. For open-air sites however, locations too close to the river can be affected by flooding and waterlogging (Kvamme & Jochim 1989; Sauer 2017).

Outgoing Visibility

Outgoing visibility (Fig. 7) turned out to be an interesting factor for site prediction. For both site types, the distribution is statistically significant (caves: $p = 0.0026*10^{-10} < 0.05$; open-air: $p = 0.0231 < 0.05$).

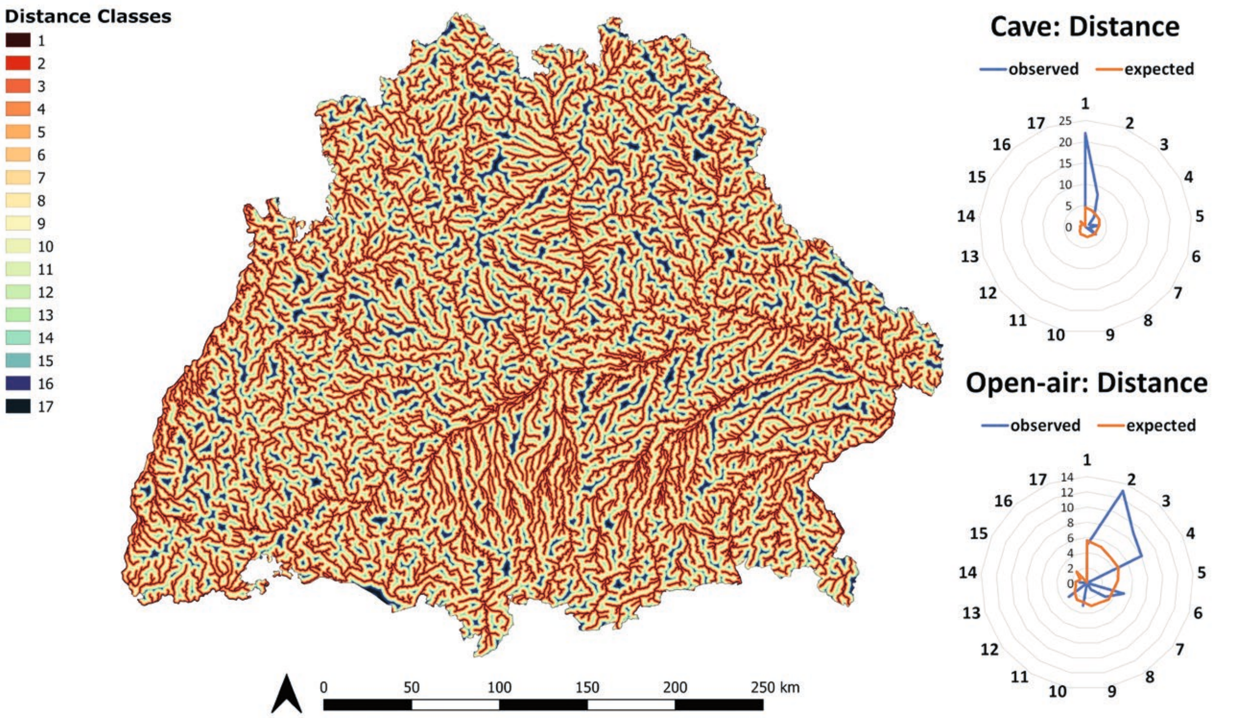

Fig. 6. Distribution of distance classes in the study area; CRS: EPSG 25832. Geodata: DEM and water mask © EEA 2020.

Abb. 6. *Verteilung der Distanzklassen im Arbeitsgebiet; KBS: EPSG 25832. Geodaten: DEM und Wassermaske @ EEA 2020.*

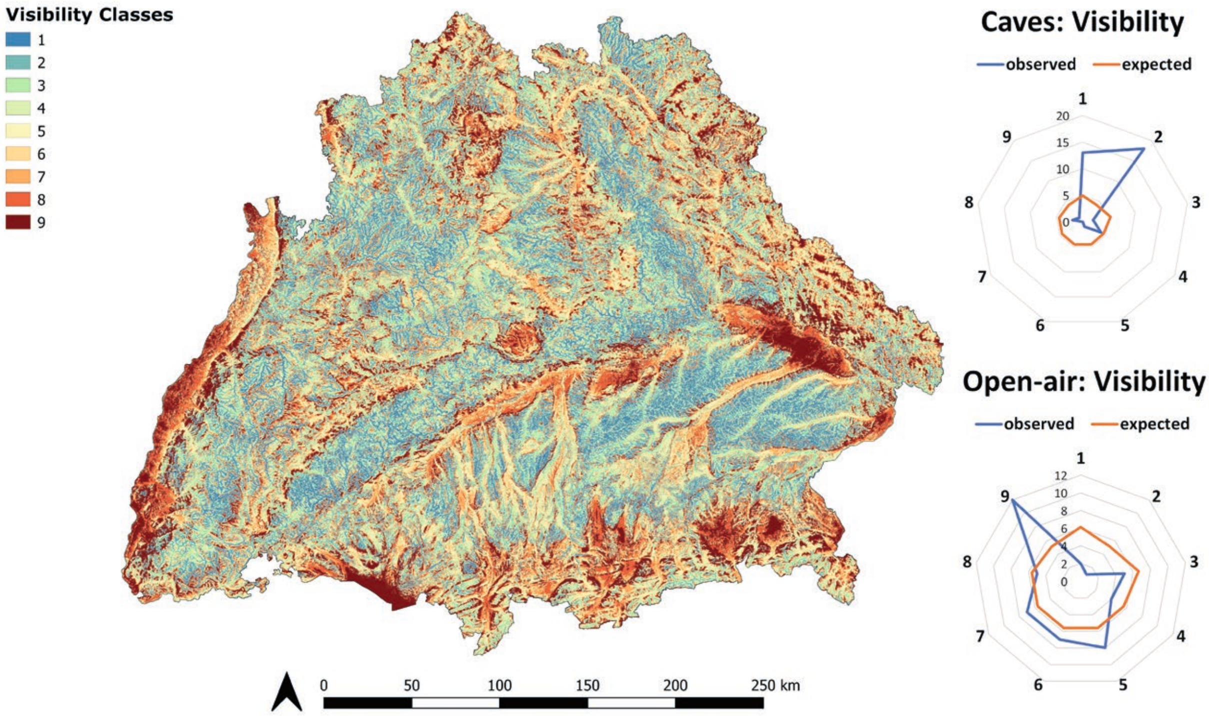

Fig. 7. Distribution of visibility classes in the study area; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 7. *Verteilung der Sichtfeldklassen im Arbeitsgebiet; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

Interestingly enough though, cave sites tend to occur in places with low outgoing visibility, class one and two, whereas open-air sites in places with high visibility, class 9. This might seem counter-intuitive, as caves and shelters along the mountain slopes are often pictured as perfect viewpoints to overlook the valley (Jochim 1976; Binford 1982). To interpret this result, it is crucial to understand how outgoing visibility was measured for the analysis.

To generate the visibility index value for a cell, the number of surrounding cells in 16 directions that lie within the cell's lines of sight are calculated. The more surrounding cells are hit, the higher the outgoing visibility value (1 = 100 % of cells in 16 directions hit) (Čučković 2020). In case of cave sites, usually only a couple of sight lines along the valley channel run uninterrupted, whereas the sight lines leading to the opposite valley slope or behind the back of the cave are extremely short. On the other hand, open-air sites in plain areas often have views of 360 degrees and therefor reach higher values more easily. This does not infer that the view from cave sites was worse, but of a different quality: from higher above and far along the valley channels yet limited in its range.

Assessment of high probability zones for cave and open-air sites

By layering the raster maps, their weighted values are added up to create a predictive map whose values were normalized to 100 %. The cells reaching the top 25 % of all overlay values are the high probability zones or zones of interest. It is important to keep in mind that 100 % on the predictive map does not equal 100 % site probability, but 100 % fulfilment of requirements for a site in the context of this specific model.

High probability zones of cave sites

The high probability zone for cave sites is considerably small, constituting only 1.4 % of the area. These zones run mainly along the rivers of the medium mountain ranges of the Alps, the Franconian-Swabian Jura and its foothills as well as the Black and Bavarian Forest. The Alps and the two latter mountain regions can be disregarded since they do not consist of soluble rock and do not tend to form natural cavities (Kempe 2005). In the karst area of the Franconian-Swabian Jura and its foothills to the north and south however, the chances to find cave sites are actually high (Fig. 8).

High probability zones of open-air site

Considering open-air sites, the high probability area constitutes 14.7 % of the map, which is ten times the extend of those for cave sites. The zones of interest also stick close to the rivers, but not as close, expanding over large areas of the Northern Alpine Foreland, the South German Scarplands, and the Lowlands of the Upper Rhine Region. A huge part of the Alpine Foreland can be excluded due to glacial erosion (Fiebig et al. 2011). Regions with extended high probability zones are definitively the Alpine Foreland directly south of the Danube river (Fig. 9: 1), the Franconian Keuper-Lias Lands, the Upper Palatine-Upper Main Hills and the Nördlinger Ries (Fig. 9: 2) as well as parts of the Swabian Keuper-Lias-Lands and Tauber-Neckar

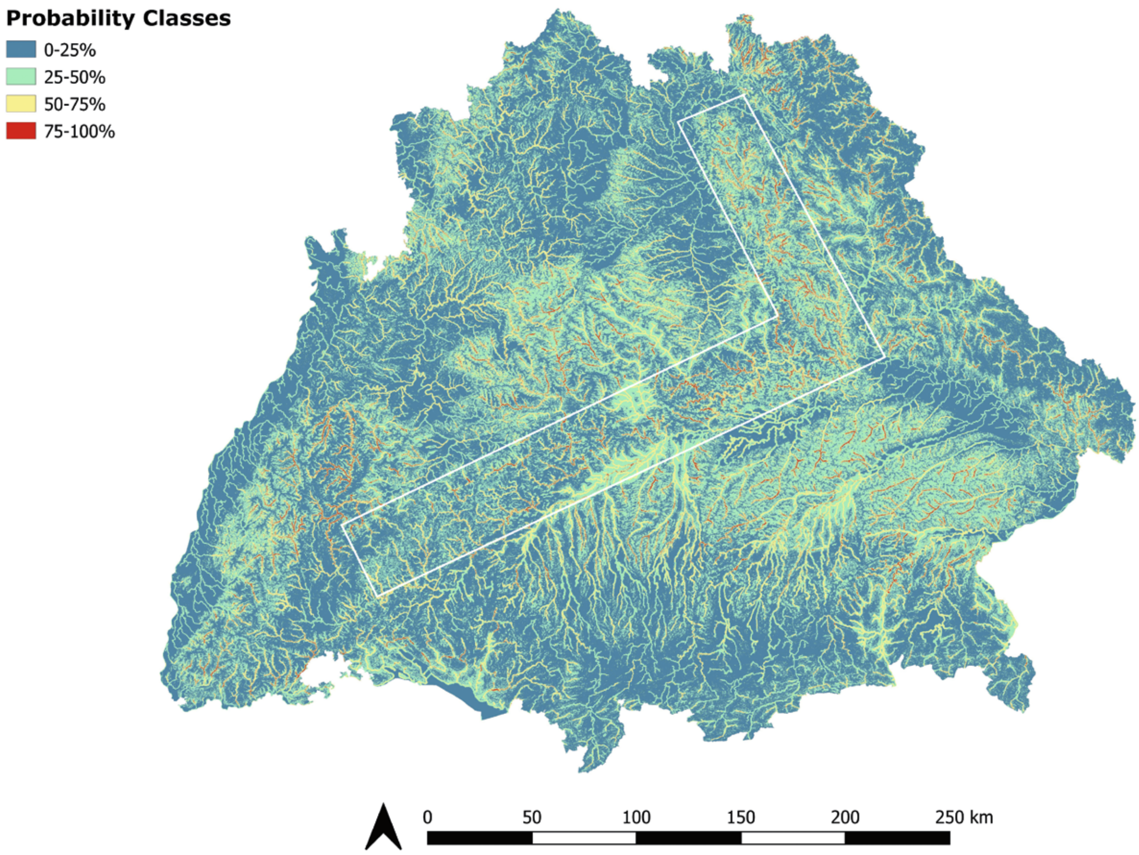

Fig. 8. Distribution of probability classes for cave sites; CRS: EPSG 25832. Geodata: DEM © EEA 2020.
Abb. 8. *Verteilung der Verdachtsflächen für Höhlenfundstellen; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

Gäue Plateau (Fig.9: 3) and parts of the Upper Rhine Valley (Fig. 9: 4).

About "bad" cave choices: Predictive probability vs. human decision making

Since the cave map performed well on the larger scale with a Kvamme's gain value of 0.9 out of 1 (Kvamme 1988), it was tested against a sample of non-sites on a regional level for experimental purposes.

Therefore, the overlay values of cave sites and of unoccupied caves in close proximity were compared in order to assess whether high overlay values are an appropriate indicator of cave choice. The result is demonstrated by boxplots for the overlay values of caves within the different catchment areas of cave sites (Fig. 10). It is indeed the case that actual sites often reach very high or above average values among the other available caves, like the Hohler Stein cave site, who reaches the top value in its catchment area (Fig. 10: left orange boxplot). The boxplots reveal a few examples however where the actual sites were not the best possible option according to the algorithm of the predictive model. The Fuchsenloch for example (Fig. 10: central green boxplot) is an outlier below the first quartile, suggesting that the Fuchsenloch cave is among the worst choices of the area.

Outliers like the Fuchsenloch can be inconvenient to explain, yet they constitute a good starting point for further hypothesis. Why was the Fuchsenloch chosen among other caves in the area? Maybe, there was a small water stream nearby that the model did not factor in, giving it an unreasonably low overlay value. Maybe the other caves in the area were not accessible due to animal occupation (Çep 2013), rock collapse, water leaking or overgrowth. Maybe territorial (Guenther 1981) religious or other social concepts (Venkataraman et al. 2017), or even aesthetic preferences of Neanderthals made the other options less preferable. Or maybe the Fuchsenloch was the nearest shelter after a successful kill and had to suffice for that reason only. These are all factors predictive modelling cannot account for and it becomes evident that it can only touch on a fraction of the complex process that is prehistoric life and human decision making (Mithen 1989; Jochim 1991; Kvamme 1992).

Discussion

The possible interplay of cave and open-air sites

The evaluation of predictive variables and comparison of high probability zones for cave and open-air sites points towards an interesting possible interplay between both site types. As demonstrated earlier, the two types are associated with different topographic positions concerning elevation, slope, distance to the next larger stream and outgoing visibility.

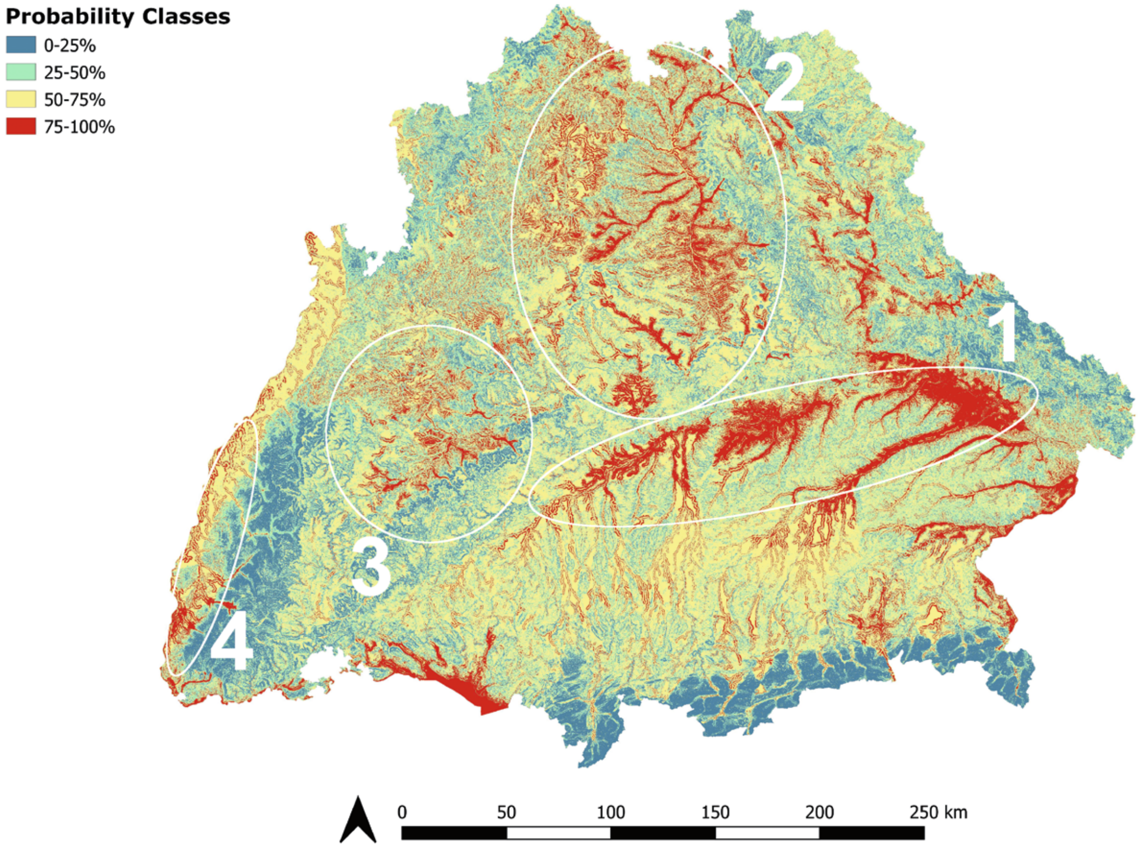

Fig. 9. Distribution of probability classes for open-air sites; CRS: EPSG 25832. Geodata: DEM © EEA 2020 (for further information see text).
Abb. 9. *Verteilung der Verdachtsflächen für Freilandfundstellen; KBS: EPSG 25832. Geodaten: DEM © EEA 2020 (weitere Informationen im Text).*

These characteristics are not only abstract statistical variables for predictive purposes, but they also describe the general qualities of these site locations e.g., view, accessibility, suitability for everyday activity and access to close-by resources.

In general, caves and shelters were probably chosen primarily for their protective qualities against weather conditions. Although it is safe to assume that Neanderthal groups knew how to protect themselves from the elements in an open-air situation through tents and windshields (White 2006; Demay et al. 2012), using naturally roofed cave and shelter rooms is in most cases the far more effective and economical option. This concerns not only seasonally frequented base camps and hunting stations, but especially temporary hideouts and caches during short resource acquisition or scouting trips that have to be set up on the spot in varying contexts (Binford 1980; Krönneck et al. 2004; Conard et al. 2012; Çep 2013).

On the downside, the activity space of caves and shelters is often limited in diameter and height, which can obviously limit the range of activity, comfort and not the least the number of people who can inhabit the cave at the same time. Further, the analysis of topographic variables shows that caves in Southern Germany are usually very close to large streams within steep river valley slopes. This can be considered a further protective factor from flooding and animal predators, yet a steep incline also goes along with an energy consuming and potentially dangerous trail from the cave site to the resources in the valley.

Concerning the outgoing visibility, cave sites are able to offer a wide distance view along the valley channel they are positioned in, which can be a more or less large area depending on the individual valley. It is however difficult to observe game movement in a larger area from one elevated viewpoint only, especially considering that migrating animal herds do not necessarily stick to one stream, but will also frequent side valleys as long as they provide enough fresh water and plant biomass. Therefore the additional set-up of open-air observation stations with a higher outgoing visibility in the area is a plausible suggestion, as it was documented by Krist and Brown (1994) for Paleo-Indian caribou hunting in the canyons of Lower Michigan.

Indeed, the majority of Middle Palaeolithic open-air sites in Southern Germany have been interpreted as seasonal hunting stations (Uthmeier 2004) and the topographical variables they correspond with further support this functional attribution. Open-air sites do not offer the same extend of protection as cave sites, however, cover from rain and wind can be accomplished by setting up temporary structures made from plant and animal resources (White 2006).

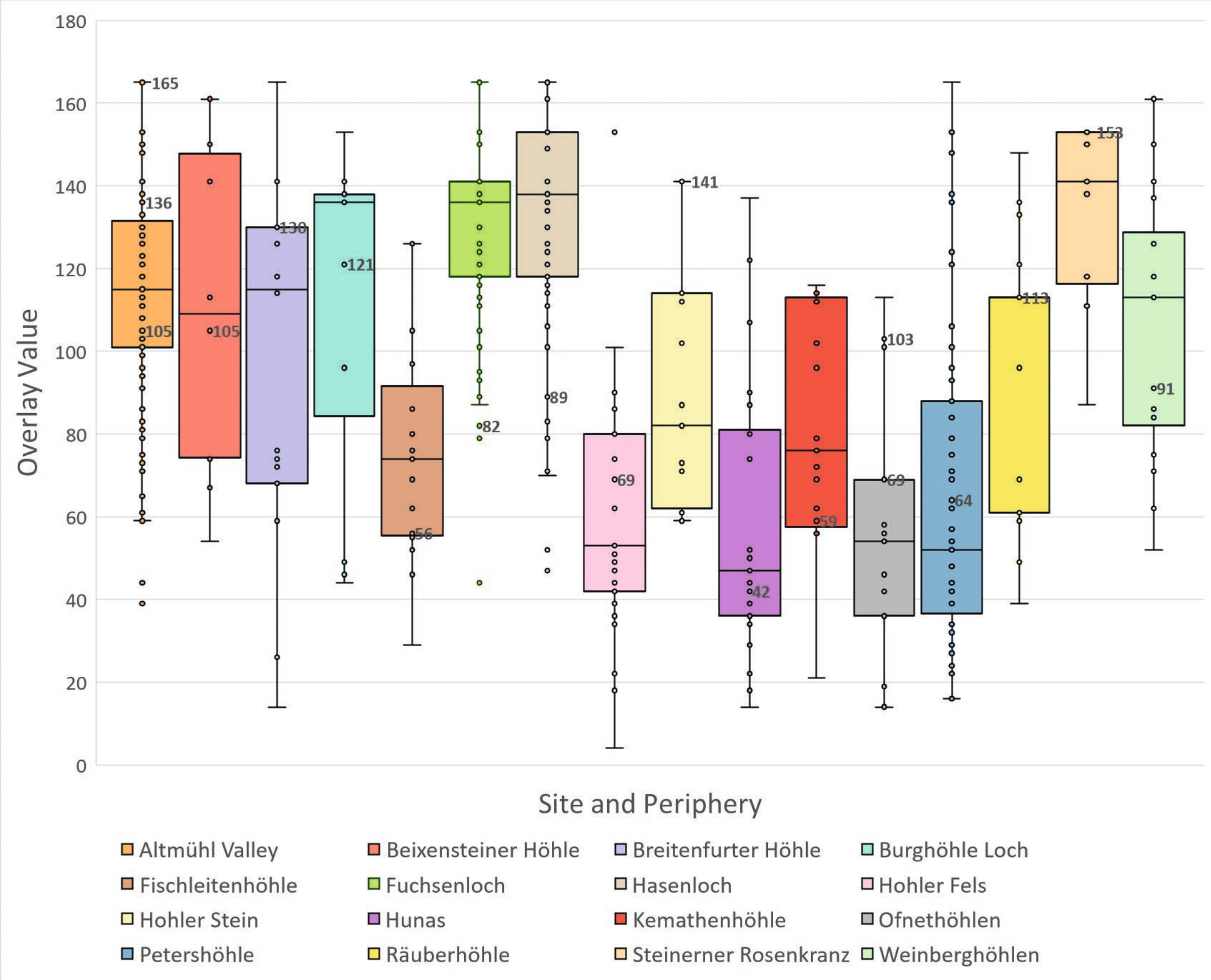

Fig. 10. Boxplots of overlay values for Middle Palaeolithic cave sites and unoccupied caves in the periphery along the Franconian Jura; Overlay values of sites are represented by a small number, those of unoccupied caves as dots. X-axis: Catchment area of cave site; Y-axis: Overlay value.

Abb. 10. *Boxplots der WLA-Werte für mittelpaläolithische Höhlenfundstellen und unbesiedelte Höhlen im Umkreis entlang der Fränkischen Alb. WLA-Werte von Fundstellen sind als kleine Nummern am Boxplot angetragen, die der unbesiedelten Höhlen als Punkte. X-Achse: Einzugsgebiet einer Fundstelle; Y-Achse: WLA-Wert.*

It becomes evident from the distribution of high probability zones that open-air sites are less restricted to specific, less frequently available topographic structures and variables, which is the reason 14.7 % of the surface of Southern Germany hit the requirements for open-air high probability zones in contrast to only 1.4 % for cave sites. This means that open-air sites can be set up in a variety of settings and are the only available option in areas where natural cavities do not occur, which is the majority of space in the study area. Open-air sites are mostly found in fairly plain areas along the rivers, in safe distance to the streams to avoid flooding and water logging. Whereas the direct distance to fresh water may be greater than for cave sites, the actual walking distance and energy expense on a low-incline surface might be equal or even lower in many cases. Since they are theoretically not restricted in diameter like caves, they can be extended if group size or site activity prescribes it.

Furthermore, if they are positioned on even a small elevation within a levelled area, they can reach high outgoing visibility with an up to 360 degrees view range, which makes them ideal observation points and allow for fast access to animal herds during hunting events (Binford 1982; Kvamme 1988; Krist & Brown 1994). Due to their flexible set up, they can be positioned at strategically advantageous points in the landscape according to site function, resource distribution and connection to other sites in the area.

Even if it is impossible to proof site synchronicity with the chronological resolution as well as the erosional and depositional conditions given for the Middle Palaeolithic, taking into account the different qualities of both site types as they are determined by their topographic variables, it makes sense that at least in areas where it is possible, both site types were probably used simultaneously in order to make optimal use of their complimenting characteristics (Binford 1982; Richter 2006). Specifically, the combination of well protected cave sites that are restricted to a specific, difficult to access position with topographically more versatile open-air stations that can be moved close to practically any exploitable resource. Furthermore, it seems that in these areas where both site types are available, human groups used cave and open-air locations according to their needs, in relationship to other sites in the area (Uthmeier 2004) and probably factoring in more than just topographic characteristics when choosing a camp. However, it has to be stressed again that only certain regions, such as the Franconian Jura, allowed for a complementary setup of cave and open-air sites, whereas in most parts of the study area, open-air sites remained the only available option.

The infrastructure of the Franconian-Swabian Jura

The second takeaway from the analysis is the special role of the Franconian-Swabian Jura for the general settlement pattern of the study area. Today we can trace two dispersals of Neanderthal migration during the MIS 5 and the MIS 3 through DNA- and techno-typological lithic analysis from Central Europe as far as to the foothills of the Russian Altai (Krause et al. 2007; Kolobova et al. 2020; Mafessoni et al. 2020). Recent multivariate analysis and comparison of lithic artefacts from Sesselfelsgrotte in Bavaria and Chagyrskaya Cave in the Altai specifically brought to light similarities in typological composition and technological features of the assemblages attributed to the Central European and Siberian Keilmessergruppen of the Interpleniglacial period of MIS 3 (Kolobova et al. 2020). These results underline once more what several other researchers have been pointing out over the last decades of Neanderthal research: Firstly, that Neanderthals were a highly mobile species and adapted perfectly to the environment of the extended *Mammutsteppe*, which they were obviously able to traverse along an approximately 4,000 km long West-East-Axis. And secondly, that Southern Germany is one of the key regions we could pin down possible migration routes – if only for the fact that it has been one of few permanently glacier-free areas for the entire time period of the Middle Palaeolithic.

As this study has shown, the importance of the area might not only be due to Southern Germanys convenient position between the Alpine and Fennoscandian ice sheet. Far more, the topographic "infrastructure" of Germanys largest continuous karst region and its foothills probably played an important role in catalysing Neanderthal migration in Central Europe. This is not only suggested by the number of documented sites, but also by the distribution of high probability zones for open-air and cave sites (Fig. 11). No other area in Southern Germany offers more

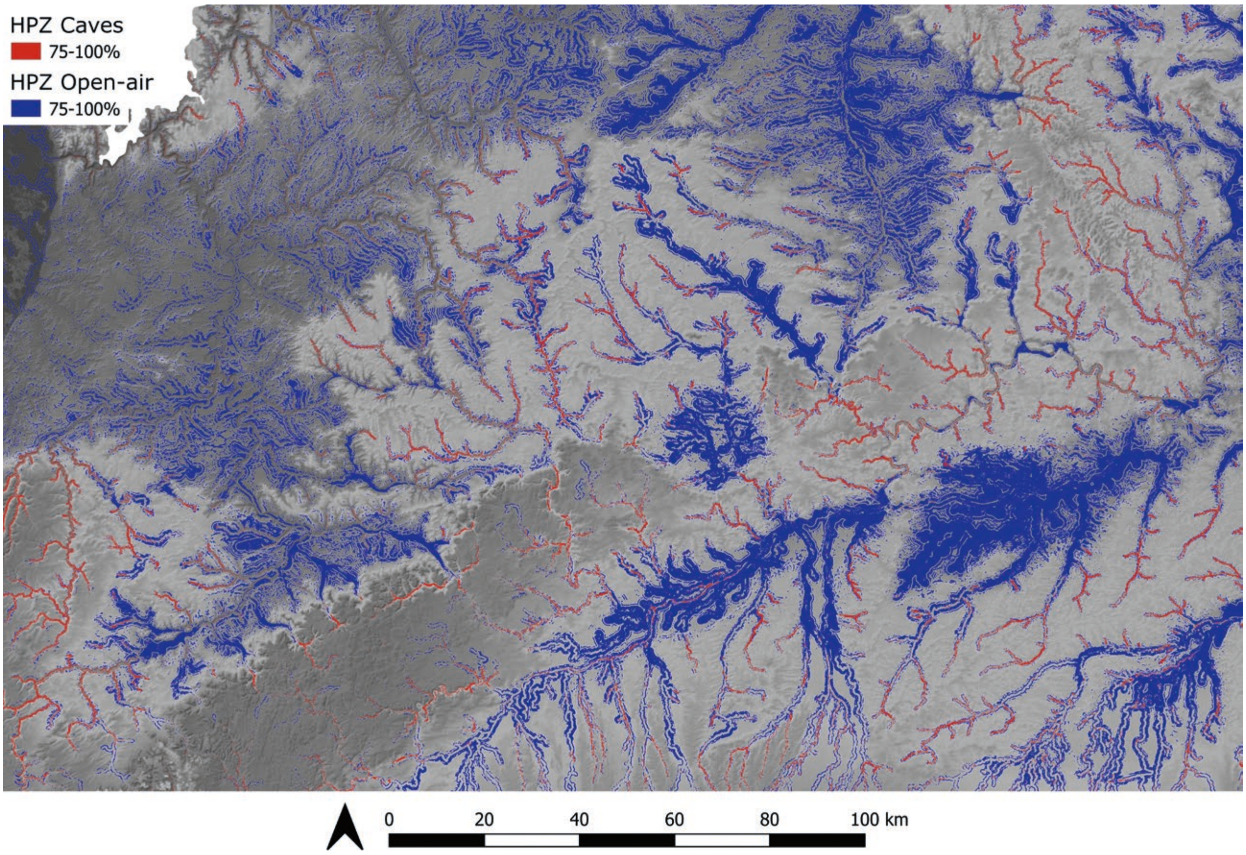

Fig. 11. Distribution of high probability zones (HPZ) for cave and open-air sites along the Franconian and Swabian Jura; CRS: EPSG 25832. Geodata: DEM © EEA 2020.

Abb. 11. *Verteilung der Verdachtsflächen (HPZ) für Höhlen- und Freilandfundstellen entlang der Fränkisch-Schwäbischen Alb; KBS: EPSG 25832. Geodaten: DEM © EEA 2020.*

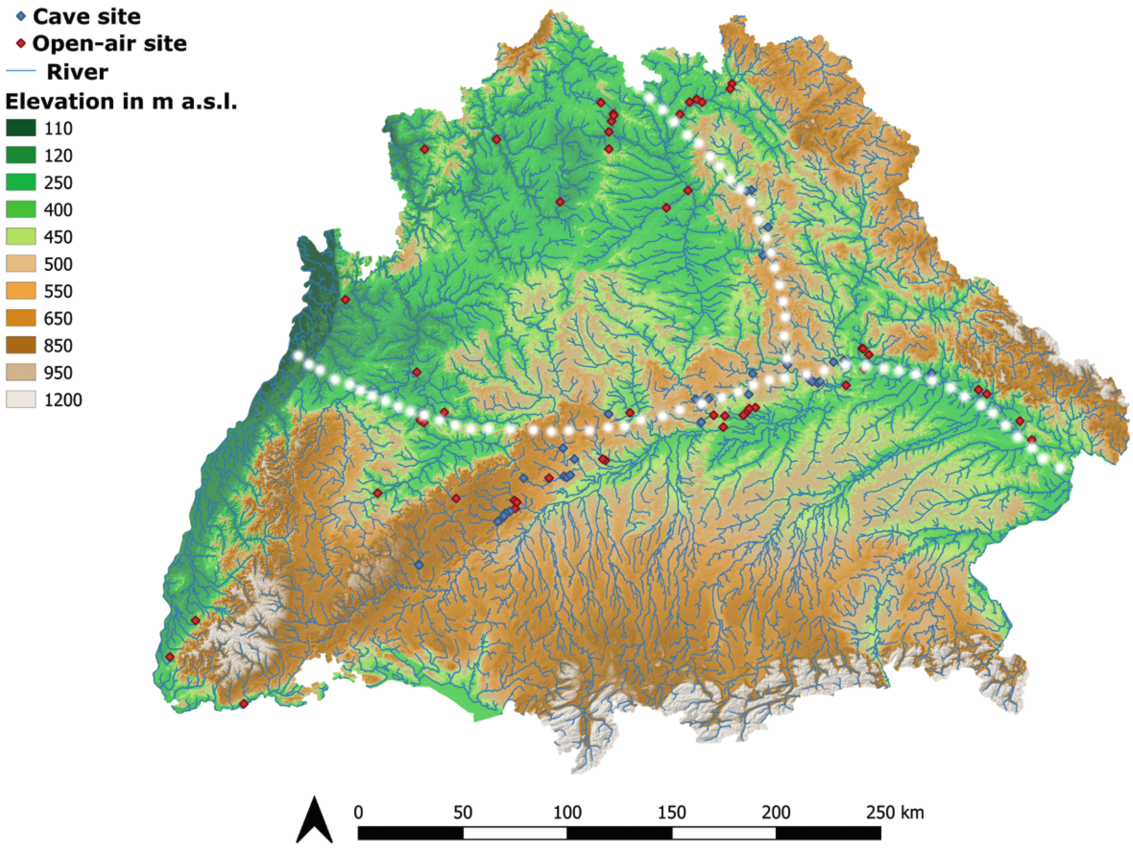

Fig. 12. Proposed main migration axis along the karst region of the Franconian and Swabian Jura (dotted line); CRS: EPSG 25832. Geodata: DEM © EEA 2020; Site data © Bayerisches Landesamt für Denkmalpflege 2020, Landesamt für Denkmalpflege Baden-Württemberg 2020, Höhlenkataster Fränkische Alb 2020.

Abb. 12. *Mögliche Hauptmigrationsachsen entlang des Karstgebietes der Fränkisch-Schwäbischen Alb (gepunktete Linie); KBS: EPSG 25832. Geodaten: DEM © EEA 2020; Fundstellendaten © Bayerisches Landesamt für Denkmalpflege 2020, Landesamt für Denkmalpflege Baden-Württemberg 2020, Höhlenkataster Fränkische Alb 2020.*

extended overlapping zones of interest for both site types then the Franconian-Swabian Jura and its foothills, potentially allowing Neanderthal groups to make best use of their combined qualities: protection (caves) and versatility (open-air). This circumstance could facilitate optimal land use in the already favourable landscape along the mountain ranges, that guaranteed available shelter in steep slopes, fresh water from a dense network of danube confluents and animal herds crossing the narrow river valleys or collecting in the adjacent plains depending on the season (Krönneck et al. 2004; Çep 2013). This is not to say that the karst regions were the most populated areas during the Middle Palaeolithic, for it is safe to assume that its large cluster of documented sites is partly a result of data bias (van Leusen 2002). Yet the findings of this study indicate that the topographic characteristics of the Franconian-Swabian Jura probably promoted settlement and movement along these regions (Fig. 12).

Even more so, it could be argued that a landscape with considerably stable resources and protective shelters encourages exploration and long-distance movement, specifically along the West-East-axis of the Jura massive. To use an unconventional comparison: The Franconian-Swabian Jura functioned similar to a modern highway with plenty of affordable hotels and restaurants on the roadside that most travellers will stick to out of convenience. In case of climatic cooling and rising environmental pressure, as we assume for the glacial maximum of the MIS 4, this comfortable main road might easily have turned into an essential exit route. Since the archaeological evidence so far suggests an occupation hiatus between 70,000 and 60,000 BP, when Central Europe seems to have been void of human populations (Jöris 2004; Richter 2016), the topographically favourable infrastructure of the Franconian-Swabian Jura and the Donau valley might have been the glacier-free hub Neanderthals relied on to reach climatic refuges in Southern and Eastern Europe. This could at least partly explain why we see similarities between Southern German, Eastern European and even Siberian Keilmesser assemblages attributed to the MIS 3 (Kolobova et al. 2020).

Conclusion

Within this study, the author conducted a predictive model for Middle Palaeolithic sites for the area within the modern borders of Bavaria and Baden-Wurttemberg. Through the assessment of predictive variables for Middle Palaeolithic cave and open-air sites, it was demonstrated that both site types are associated with different topographic characteristics and therefrom resulting qualities. The weighted overlay analysis did not only bring to light possible zones of interest for each site type, but also pointed out the region of the Franconian-Swabian Jura as favourable area for their combined high probability zones. It is argued that through this specific topography that allows for the combination of the complimenting qualities of shelter and open-air sites, land use and specifically migration along the axis of the Jura massive was promoted, explaining the key role of Southern Germany for inter-European Neanderthal migration. As it is the advantage of predictive modelling, this study does not only highlight the significance of this region for Middle Palaeolithic research, but also delivers two predictive maps as tools to be used in further research or heritage management.

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