Using GIS and ecological variables to identify high potential areas for paleoanthropological survey: an example from northern Armenia

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Abstract:

The timing and nature of the initial hominid dispersals from Africa during the Plio-Pleistocene (here 2.0-1.5 million years ago [MYR]) is an issue of great interest for paleoanthropology. However, the biological, technological, and ecological context of these dispersals remains cloudy due largely to a paucity of Eurasian paleoanthropological sites dating to this time period. Indeed, there are only a handful of well-accepted Plio-Pleistocene sites from Eurasia: Dmanisi in the Republic of Georgia at 1.77-1.81 MYR (de Lumley et al. 2002), the Nihewan and Yuanmou basins of China at 1.66-1.70 MYR (Zhu et al. 2008), and the Indonesian island of Java at least 1.66 MYR (Sangiran) but perhaps as early as 1.81 MYR (Mojokerto) (Larick et al. 2001; Swisher et al. 1994). Although the Levant, given its geographic location, is the most logical extra- African source of dispersing hominid populations, the earliest well-accepted occupations there ('Ubeidiya in Israel) date to somewhat later in time at 1.4 MYR (Belmaker et al. 2002).

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Field Note

Using GIS and Ecological Variables to Identify High Potential Areas for Paleoanthropological Survey: An Example from Northern Armenia



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INTRODUCTION

The timing and nature of the initial hominid dispersals from Africa during the Plio-Pleistocene (here 2.0-1.5 million years ago [MYR]) is an issue of great interest for paleoanthropology. However, the biological, technological, and ecological context of these dispersals remains cloudy due largely to a paucity of Eurasian paleoanthropological sites dating to this time period. Indeed, there are only a handful of well-accepted Plio-Pleistocene sites from Eurasia: Dmanisi in the Republic of Georgia at 1.77-1.81 MYR (de Lumley et al. 2002), the Nihewan and Yuanmou basins of China at 1.66-1.70 MYR (Zhu et al. 2008), and the Indonesian island of Java at least 1.66 MYR (Sangiran) but perhaps as early as 1.81 MYR (Mojokerto) (Larick et al. 2001; Swisher et al. 1994). Although the Levant, given its geographic location, is the most logical extra-African source of dispersing hominid populations, the earliest well-accepted occupations there ('Ubeidiya in Israel) date to somewhat later in time at 1.4 MYR (Belmaker et al. 2002).

Plio-Pleistocene sites are extremely rare, and sites preserved in high-integrity depositional contexts are even more so. In fact, the rich early Pleistocene component at Dmanisi was itself unearthed more-or-less accidentally during the excavation of a medieval fortress (Djaparidze et al. 1989). As fortunate as this discovery was, survey efforts informed by ecologically relevant variables such as vegetation, geography, topography, and geology may not only increase the chances of finding paleoanthropological sites, but will also help place hominid occupations into a broader environmental context. Here we describe an approach to identify target areas for paleoanthropological survey. This method uses GIS to integrate data from archaeology and ecology to identify high potential areas for intensive ground survey. As an example, we present pre- and post-survey data from a new paleoanthropological research project in northern Armenia.

PREDICTIVE MODELING USING GIS DATA

Predictive models assume that the locations of sites are at least partially influenced by modern or prehistoric environmental factors such as vegetation, distance to water, or topographic setting (e.g., Mehrer and Wescott 2006). For example, remote sensing data have been successfully used to identify high potential geological strata for paleoanthropological survey in East Africa (Asfaw et al. 1990; Harmand et al. 2009). The greater affordability of digital data and the ability of GIS to integrate and manipulate numerous datasets now permit relatively sophisticated remote predictive modeling. As described below, the isolation of possible hominid dispersal routes and—within these dispersal corridors—areas that are likely to contain evidence of early hominid activity, allows for more focused pedestrian survey.

NORTHERN ARMENIA AS A HIGH POTENTIAL SURVEY REGION

Current evidence indicates that by the early Pleistocene, hominids had traveled between 1,000 and 5,400 miles from their African homeland (Carbonell et al. 2008). However, this seemingly widespread occurrence does not necessarily mean that hominid populations were distributed evenly across Eurasian landscapes, especially during the initial stages of dispersal. It is therefore possible that hominids used particular corridors that contained favorable ecological conditions for their expansion. Therefore, the first step is the identification, in a very broad sense, of potential survey regions.

A theoretical dispersal path was constructed between the Levant and the earliest well-accepted evidence for hominid occupation outside of Africa—Dmanisi. Any origin point in the area provides the same results;

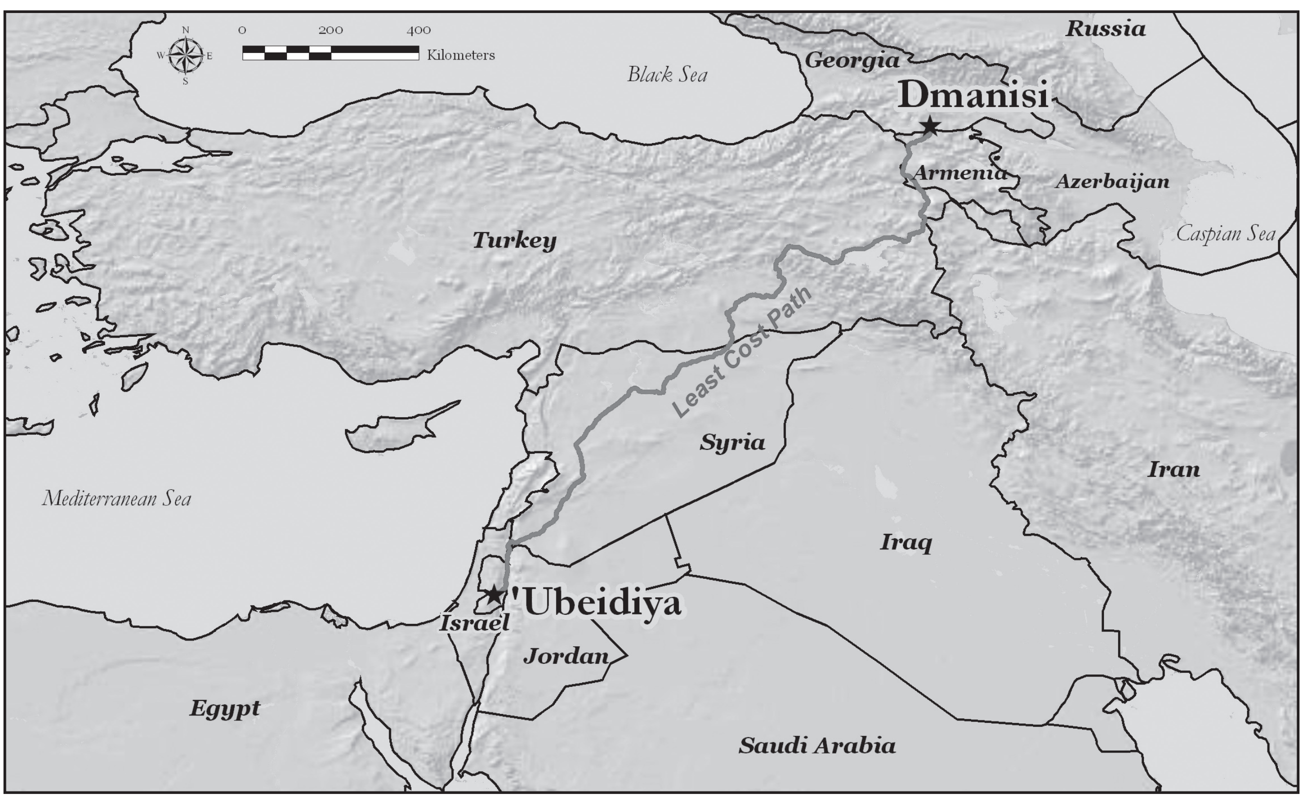

FIGURE 1: Regional map showing origin ('Ubeidiya, Israel) and destination (Dmanisi, Georgia) points for the Cost Path Analysis.

in the analysis presented here, the site of 'Ubeidiya in Israel was used. A simple cost path analysis (CPA) model was employed, which determines the path from a source to a destination using a series of algorithms that take into account impediments to travel (e.g., Hare 2004). Assuming that populations will select a path that minimizes the cost (energy) of travel, the goal of the application was to identify a least cost path (LCP). This function was performed in ArcMap 9.3 using the Spatial Analyst with two input raster layers: the cost raster and the back link raster. The cost raster was represented by modern terrain (derived using digital elevation models [DEM]), while the back link raster retraced the least-costly route from the destination to the source over the cost distance surface. Using these two raster layers, an algorithm calculated a single path of raster cells that is the "cheapest" cumulative route relative to cost (i.e., slope). Once the slope and back link rasters were created, ArcMap performed the cost path analysis to create a raster layer of the least cost path, which was then converted to a vector file for display.

Based on modern terrain, the cheapest route between 'Ubeidiya and Dmanisi runs northeast across Syria, into eastern Turkey and skirts along the northwestern border of Armenia (Figure 1). Once in the Lesser Caucasus of northern Armenia, the least cost path passes north across the Tashir Plateau before terminating at Dmanisi. Because regional topography has changed somewhat over the past two million years (see below), this cost path analysis was not meant to predict the precise location of paleoanthropological sites; rather, as mentioned above, it served to isolate potential survey regions. That the cost path analysis matched well with the distribution of known Lower Paleolithic occurrences in northern Armenia supports the presumption that the region was an important corridor for the movement of early hominid populations (Figure 2).

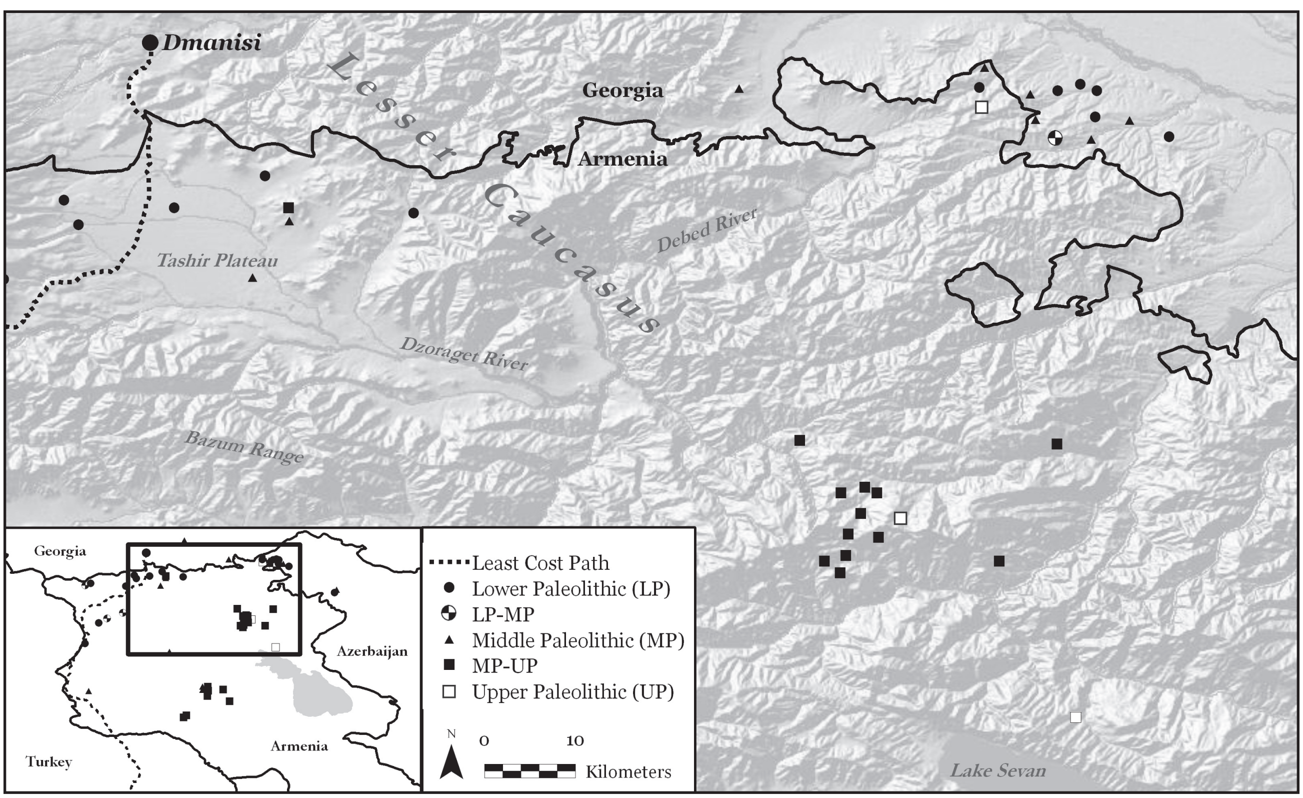

FIGURE 2: Map of northern Armenia (inset) and northeastern Armenia with the location of geographic features, previously identified Paleolithic sites, and the Least Cost Path.

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Although systematic data for the Plio-Pleistocene of the Lesser Caucasus is only beginning to emerge (e.g., Roiron et al. 2007), paleoenvironmental considerations further buttress this assertion. Perhaps most importantly, the site of Dmanisi clearly indicates that the Lesser Caucasus could accommodate hominid habitats during the Plio-Pleistocene. It has even been suggested that the region served as a refugium during colder time periods (Gabunia et al. 2000). In addition, many of the intermontane depressions of the Lesser Caucasus were filled by large freshwater lakes during the late Pliocene. Pleistocene volcanism eventually fragmented these lakes into smaller lacustrine basins (Lededev et al. 2008a, 2008b; Sayadyan 2006a, 2006b). The potential presence of lake-margin and alluvial environments of Plio-Pleistocene age in the region is especially significant given that Dmanisi itself is thought to have been in close proximity to a lake (Gabunia et al. 2000), and early hominid occupation of well-watered habitats such as riparian woodlands and lake-margins is well-documented in East Africa at both Olduvai Gorge and sites in the Turkana Basin (Hay 1976; Rogers et al. 1994).

The next step was to identify specific areas in the Lesser Caucasus for focused pedestrian survey. As Figure 2 shows, there are several paleoanthropological sites documented on the Tashir Plateau that lie along the dispersal path calculated by the cost path analysis. However, many of these and other known sites in the region document hominid occupation only back to the early middle Pleistocene—which post-dates the earliest dispersals from Africa—and tend to lack materials that provide reliable dates (e.g., volcanic material and/or well-preserved fauna) (Doronichev 2008). The closest area within the high potential dispersal region (as determined by the cost path analysis) that preserves alluvial, lacustrine, and, most importantly, datable volcanic deposits spanning much of the Plio-Pleistocene, is the Debed River Valley of northeastern Armenia. The Debed was therefore considered to be an attractive area for identifying new paleoanthropological sites. Particularly striking was the lack of paleoanthropological sites in and along the valley (Figure 2), which is related directly to a lack of prior paleoanthropological research in the area. GIS was therefore used to conduct a site suitability analysis for the Debed River Valley.

TABLE 1: Land cover categories used in the site suitability analysis. All LST scores were scaled to the maximum value (23) to derive suitability scores. See text for full explanation.

Land Cover Type	No. of Occurrences	LST Score[1]
14 - Rain-fed croplands	11	48
20 - Mosaic croplands/vegetation	23	100
30 - Mosaic vegetation/croplands	22	96
50 - Closed broadleaved deciduous forest	15	65
110 - Mosaic forest/shrubland/grassland	1	4

[1]LST = Linear Scale Transformation

TABLE 2: Aspect categories used in the site suitability analysis. All LST scores were scaled to the maximum value (13) to derive suitability scores. See text for full explanation.

Aspect (Degrees)	No. of Occurrences	LST Score[1]
23-67	5	38
68-112	8	62
113-157	11	85
158-202	11	85
203-247	4	31
248-292	13	100
293-337	12	92
338-360	6	46

TABLE 3: Slope categories used in the site suitability analysis. All LST scores were scaled to the maximum value (29) to derive suitability scores. See text for full explanation.

Slope (Degrees)	No. of Occurrences	LST Score[1]
0.0-0.5	29	100
0.6-1.0	17	59
1.1-1.5	11	38
1.6-2.0	12	41
2.1-2.5	1	3
2.6-3.0	2	7

TABLE 4: Elevation categories used in the site suitability analysis. All LST scores were scaled to the maximum value (31) to derive suitability scores. See text for full explanation.

Elevation (Meters)	No. of Occurrences	LST Score[1]
0-1000	19	61
1000-2000	31	100
2000-3000	16	52
3000+	6	19

[1]*LST = Linear Scale Transformation*

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SITE SUITABILITY ANALYSIS

Site suitability analysis enters variables into a computer model that geographically displays areas that are most (and least) likely to preserve sites based on numerical suitability scores (the higher the score, the more conducive an area is for site identification). The location of previously identified Paleolithic sites in northern Armenia (n = 72; see Figure 2) was used to identify predictive variables for site location. The variables most closely associated with site location were slope, aspect, elevation, land cover, and proximity to rivers. For the GIS analysis, polygon data for each variable were converted from shapefiles to raster files. As an example, consider land cover: five categories coincided with previously identified Paleolithic sites (Table 1). Using a linear scale transformation (LST; Malczewski 1999), numerical values for each land cover category were assigned based on the number of sites that occurred in a particular category. For land cover, known Paleolithic sites were most often associated with mosaic croplands/vegetation (a total of 23 times). Because this represented the highest frequency of associations, croplands/vegetation received a suitability score of 1 and all subsequent scores were scaled to this value. The linear scale transformation values for each variable were summed using the raster calculator, averaged to remove potential outliers, and multiplied by 100. This resulted in a composite suitability score that ranged from 0 (lowest suitability) to 100 (highest suitability). In general, the highest suitability scores were associated with areas located near rivers with low slope and relatively open vegetation (i.e., cropland). Tables 2-4 summarize the LST scores for aspect, slope, and elevation. A 2 km buffer was constructed along major rivers to assign distance-to-water scores.

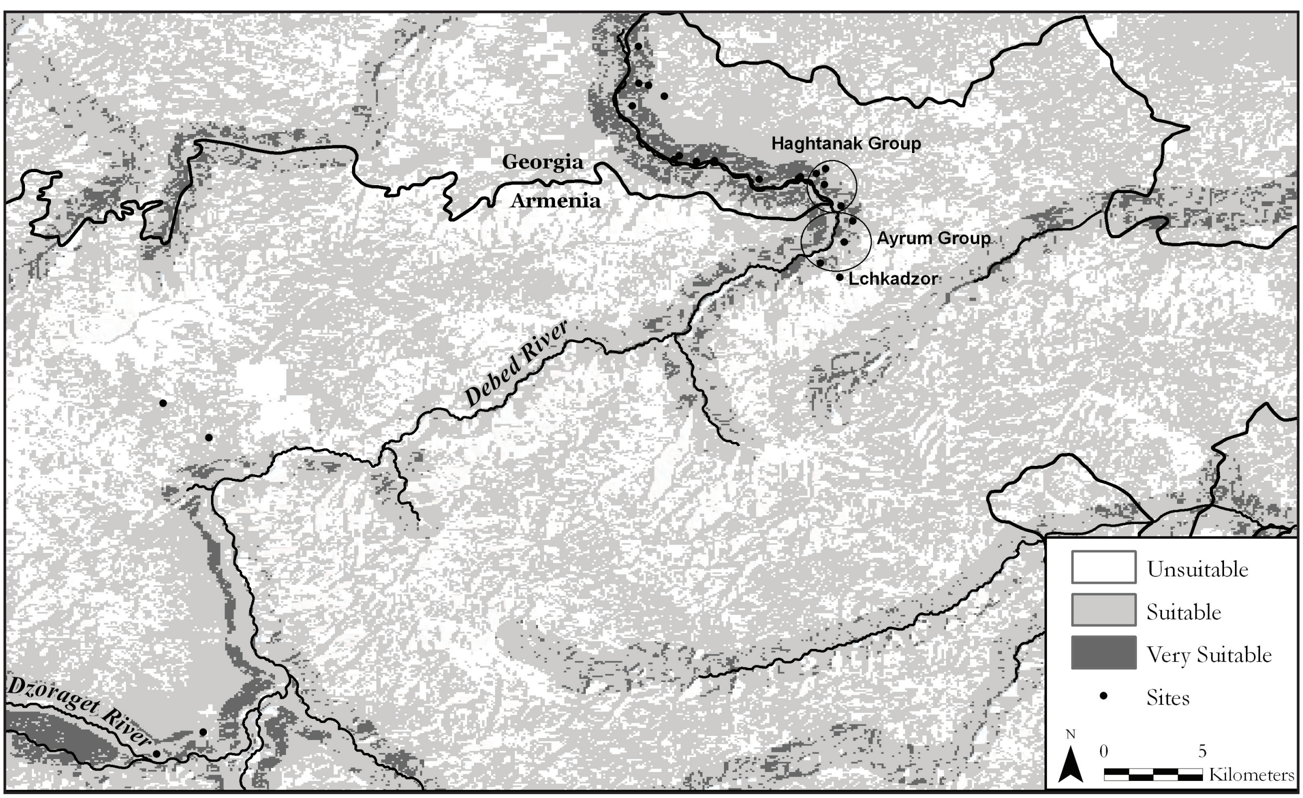

FIGURE 3: Raster map of site suitability scores for the Debed River Valley and the location of identified paleoanthropological sites.

The calculated raster values were reclassified into three suitability categories: Unsuitable, Suitable, and Very Suitable. Suitable was defined as the mean suitability score of the previously identified sites (= 65) with a range equal to the standard deviation of the previously identified sites (SD = 15.4). This provided a range of 50-81 for the Suitable category. Scores below 50 were then defined as Unsuitable and scores above 81 as Very Suitable. These values were then used to produce a raster map to visualize the potential location of paleoanthropological sites in the Debed River Valley (Figure 3), which in turn served to focus survey efforts. It quickly became clear that, based on the site suitability analysis, the northernmost stretch of the Debed near the Georgian border had the highest potential to preserve paleoanthropological sites.

POST-SURVEY RESULTS

During the summer of 2009, preliminary survey was conducted along the Debed River Valley between its confluence with the Dzoraget River in the south to the Georgian border in the north, a distance of approximately 60 km. Limited field time precluded a complete and systematic survey of the entire 60 km stretch, so, guided by the suitability analysis, the survey team was transported to high potential localities by vehicle after which pedestrian survey was carried out. A total of 25 new sites spanning the Lower Paleolithic through the Upper Paleolithic were identified (Table 5). As can be seen in Table 5, a majority of the sites were discovered—as predicted by the suitability analysis—along the lower Debed near the border with Georgia (Figure 3). Two of these sites (Haghtanak 3 and Ayrum 2) preserved Oldowan-type chopper forms that may be associated with a Plio-Pleistocene hominid occupation (Egeland et al. 2010).

The concentration on Suitable and Very Suitable areas in the Debed River Valley was an effective survey strategy, and the remote GIS analysis certainly maximized field time. However, there are some limitations to the study as currently conceived. First, the goal of this initial round of research was simply to identify the presence of paleoanthropological material. Survey of the valley in general and at each site in particular was by no means systematic

TABLE 5: List of Paleolithic sites identified in the Debed River Valley during the summer of 2009 and associated site suitability scores. Suitability scores below 50 are considered Unsuitable scores between 50-81 are considered Suitable, and scores above 81 are considered Very Suitable.

Site	Site Suitability Score
Lchkadzor	49
Akori 1	59
Haghtanak 3	59
Arevatsag 2	60
Vahagni 1	60
Bagratashen 5	61
Akori 2	64
Arevatsag 1	66
Debedavan 3	67
Haghtanak 2	68
Ptghavan 3	69
Haghtanak 1	71
Bagratashen 4	71
Ptghavan 4	77
Ayrum 1	78
Debedavan 1	78
Debedavan 2	78
Haghtanak 4	81
Ayrum 3	82
Ayrum 2	84
Bagratashen 1	88
Bagratashen 3	88
Bagratashen 2	89
Ptghavan 1	91
Ptghavan 2	92

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and it therefore cannot be determined at this point what percentage of each suitability category was surveyed. It can be said, however, that several areas with high suitability scores have yet to be surveyed. Second, the data on modern landscape variables were relatively coarse-grained and, importantly, lacked a temporal dimension. Environmental reconstructions are available for the middle Pliocene in formats easily incorporated into a GIS (Salzmann et al. 2008). Unfortunately, these data are simply too coarse to be of much use for an analysis at the scale presented here. More detailed data on a number of paleogeographic and paleoecological variables and how they would affect the predictive modeling are needed. The spatial extent of Pleistocene lakes throughout the Lesser Caucasus would be particularly useful in this context. Finally, it must be realized that remote GIS predictive modeling, while providing a useful guide for site identification, is no substitute for (and can be modified by) on-the-ground experience. Consider the site of Lchkadzor, which is the one locality that scored in the Unsuitable category (though only by a single point). The site is a diffuse lithic scatter located on the relatively steep slopes of a small foothill overlooking the Debed. The sedimentary outcrops that prompted further investigation at Lchkadzor were only identified when the survey team was on the ground investigating a high potential area nearby. Future work will aim to address these issues more fully. Nevertheless, the results of this study indicate that paleoanthropological survey can benefit from predictive modeling using the integration of environmental variables and GIS.

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