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The results of the study reveal that potential maximum daily foraging ranges as well as habitats and habitat zone heterogeneity within these foraging ranges differed greatly across the region. Due to variance in potential plant and animal productivity, settlement patterns undoubtedly differed significantly across the southern Levant particularly with respect to the number of moves per year, the importance of fusion-fission strategies, the seasonality of relocation tactics, and the importance of group territoriality. These variances in annual settlement options and emerging patterns within the southern Levant at the height of the Last Glacial Maximum provide baseline conditions for understanding divergences in adaptive trajectories within the wider region.

Modeling Foraging Ranges and Spatial Organization of Late Pleistocene Hunter-gatherers in the Southern Levant - A Least-Cost GIS Approach

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Abstract

This study takes a regional approach to understanding the nature of Near Eastern hunter-gatherer spatial organization near the height of the Last Glacial Maximum, circa 21,000 calibrated years ago. To do so, we reconstructed the paleogeography and paleovegetation and then employed least-cost GIS analysis to model foraging ranges and potential annual territorial extent associated with a selection of excavated and dated sites throughout the Southern Levant. Settlement trends in the region as a whole are explored first, followed by a case study of annual settlement scenarios in the arid Azraq Basin on the eastern edge of the Levant, focusing on its distinctive large aggregation sites.

The results of the study reveal that potential maximum daily foraging ranges as well as habitats and habitat zone heterogeneity within these foraging ranges differed greatly across the region. Due to variance in potential plant and animal productivity, settlement patterns undoubtedly differed significantly across the southern Levant particularly with respect to the number of moves per year, the importance of fusion-fission strategies, the seasonality of relocation tactics, and the importance of group territoriality. These variances in annual settlement options and emerging patterns within the southern Levant at the height of the Last Glacial Maximum provide baseline conditions for understanding divergences in adaptive trajectories within the wider region.

1. Introduction

This study employs least-cost GIS analysis to model foraging ranges and the potential annual territorial extent of Near Eastern hunter-gatherers around the height of the Last Glacial Maximum, circa 21,000 calibrated years ago (cal BP). After a discussion of how the paleogeography and paleovegetation were reconstructed, this modeling exercise consists of two parts. Initially, we take a regional approach to the nature of spatial organization associated with a selection of excavated sites dating to the Late Glacial Maximum throughout the Southern Levant. In doing so, we subdivide the region into three areas and examine differences in foraging ranges and the nature of associated habitats between them. Predicted settlement pattern implications based on these differences are also highlighted. In the second part of the study, we use these foraging model insights as a starting point to explore in more depth potential annual settlement scenarios in a single locality. This discussion centers on the arid Azraq Basin on the eastern edge of the Levant, and its distinctive large aggregation sites. In doing so, and to gain a nuanced understanding, more archaeological variables are employed including site attributes such as size, thickness, associated material culture, and evidence of regional interaction including trade and exchange. The results of this Azraq Basin case study highlight the potential of least-cost modeling to provide insights into territoriality, travel and trade corridors, and the orientation of annual settlement organization.

Overall, we aim to make three main points. First, potential maximum daily foraging ranges varied significantly within the region. Second, habitats and habitat zone heterogeneity within these foraging ranges also differed greatly across the region. Third, due to variance in potential plant and animal productivity we predict that organizational strategies differed significantly across the southern Levant particularly with respect to the number of moves per year, the importance of fusion-fission strategies, the seasonality of relocation tactics, and the importance of group territoriality. Finally we conclude with a brief consideration of what these spatial patterns within the southern Levant imply for the long-term trajectory of adaptations that led to the emergence of sedentism and food production.

2. Background

This study is focused on the time period from 24,000–18,000 cal BP, which temporally straddles the Last Glacial Maximum of circa 21,000 calibrated years ago. This time span is considered to be culturally transitional in the Levant, as it encompasses the end of the late Upper Paleolithic (circa 30,000–21,300 cal BP) and start of the Epipaleolithic (circa 24,000/21,300 – 11,600 cal BP; Garrard and Byrd, 2013; Goring-Morris and Belfer-Cohen, 2003; Goring-Morris et al., 2009). The Upper Paleolithic and Epipaleolithic are distinguished by a number of attributes; the most fundamental is the emergence and dominance of flaked stone backed bladelets, which were used as small hunting armatures in composite tools. It should be noted that the details of the nature and timing of this transition in technology (and associated settlement and subsistence strategies) is subject to considerable discussion and debate (Goring-Morris and Belfer-Cohen, 2003).

The overall goal of this study is to gain further insight into long-term trends in Epipaleolithic adaptations in order to enhance our understanding of the causal factors leading to the Natufian in the Late Epipaleolthic (circa 14,600–11,600 cal BP). The Natufian is widely recognized as the region's first complex sedentary hunter-gatherers, and the Natufian laid the foundation for the Levantine early Neolithic, the world's earliest farmers near the start of the Holocene circa 11,600 cal BP (Bar-Yosef and Valla, 2013; Belfer-Cohen and Goring-Morris, 2011; Byrd, 2005).

As such, there is considerable interest in the underlying conditions that led to the emergence of the Natufian. For some time consensus was that its Epipaleolithic precursors were uniformly mobile hunter-gatherers living in small groups. With increased fieldwork in the eastern Levant there is much greater appreciation for the complexity of regional variation in artifact assemblages and site characteristics of pre-Natufian Epipaleolithic sites, and research in the Azraq Basin, particularly on the large aggregation sites, has been a seminal aspect of these developments (Garrard and Byrd, 1992, 2013; Maher et al., 2012a; Muheisen, 1988; Richter et al., 2010, 2013). There is also a wide-spread recognition that most traits of the Natufian (architecture, mortars and pestles, on-site burials, grave goods) had their origins earlier in the Epipaleolithic (Maher et al., 2012b).

These insights highlight the need to acquire better understanding of regional patterns in settlement and subsistence strategies prior to the Natufian. In the Levant, such Epipaleolithic studies have been limited, and notably include the early site catchment work of Vita Finzi and Higgs (1970), reconstructing seasonal settlement shifts in the Hisma of southern Jordan (Henry, 1995:426–437), and hypothesizing potential spatial orientation and extent of annual ranges focusing either on the Mediterranean coast (Goring-Morris, 2009:85–86) or the Levant as a whole (Bar-Yosef and Belfer-Cohen, 1989:451; Goring-Morris et al., 2009). As an initial step, this study focusses on rigorously developing background data to facilitate gaining new perspectives into regional variation, trends in background conditions, and potential settlement strategies at the start of the Epipaleolithic in the southern Levant (note that various terms have been applied to this period of time; see Garrard and Byrd, 2013 for a summary).

Modeling environmental conditions at the height of the Last Glacial Maximum is a necessary first step in assessing how these background conditions may have constrained and conditioned hunter-gatherer choices on how to distribute and organize themselves across the landscape. A variety of ethnographic, ethnoarchaeological, and experimental studies have demonstrated that hunter-gatherer settlement and subsistence strategies are patterned in predictable ways with respect to a variety of factors including terrain, environmental productivity, effective temperature, degree of resource homogeneity, and seasonality of resource availability (Binford, 2001; Grove, 2009, 2010; Kelly, 1983, 2013:77–113). For example, Binford (1980) was one of the first to highlight the utility of effective temperature and primary productivity in assessing broad trends in both the relative contribution of plants and animals in the diet and the degree of hunter-gatherer mobility.

Optimal foraging theory has been important in generating foraging efficiency expectations regarding subsistence choices given variation in resource availability and density (Kelly, 2013; Zeenah, 2004). Its application has provided insight into the organization of movement and foraging decisions in relationship to the environment, while taking into account resource variability. Generally, greater annual residential camp movement is anticipated with high resource homogeneity and year-round availability, while fewer residential relocations (and increased use of a collector strategy to acquire resources) are expected when resources are patchy or highly seasonal. Central place foraging models, in particular, have been a useful tool to gain insight into the factors that condition resource acquisition and round-trip transport from base camps (Bettinger et al., 1997; Morgan, 2009; Orians and Pearson, 1979; Zeenah, 2004). The basic premise is that hunter-gatherers aim to maximize their foraging efforts, and such models provide optimal solutions to efforts to look for, acquire, and transport resources. Notably, travel time becomes a key factor in understanding foraging decisions tied to central places, highlighting the need to model the extent and nature of foraging areas around base camps.

These studies provide important insight into how hunter-gatherers respond in predictable ways with respect to various environmental factors affecting resource availability and productivity, and the need to take into account the effects of travel time and transport on central place foraging. Overall, such factors condition the nature and effectiveness of daily foraging (i.e., return rates), the degree of reliance on individual logistical forays and their extent, the role of resource caching and field processing, and provide baseline information to make predictions regarding the nature, frequency, and spatial extent of residential movements within the annual cycle. The approach taken here is to reconstruct the paleogeography and paleovegetation at the height of the Last Glacial Maximum, model the extent and nature of potential foraging territory around key sites, examine patterning within the southern Levant, and then discuss the implications.

3. Approach and Methods

We focused attention on GIS modeling of prehistoric occupation circa 24,000 – 18,000 cal BP. To do so, we plotted in GIS the locations of 25 prominent sites in the southern Levant that date to this time period (Figure 1; Table 1), and then developed GIS data sets to facilitate our analysis. This included sites that have been variously described as having either Upper Paleolithic or Epipaleolithic assemblage traits. Our goal was not to delve into these differences but rather to use these sites as sample data points across the region to explore how potential background conditions may have varied within the southern Levant. In order to have a manageable data set, sites from the Negev and Sinai were not included.

Since the paleogeography was very different than today, we reconstructed and mapped Last Glacial Maximum (circa 21,000 cal BP) sea level and inland lake level shorelines using, as a starting point, the sources shown in Table 2. For comparative purposes we also reconstructed paleoshorelines for the start of the Bolling-Allerod (circa 15,000 years ago) and the start of the Holocene (some 11,600 years ago). We also defined drainage catchments and mapped stream channels within GIS (Greenbaum et al., 2006; Lehner et al., 2008).

For the building of a paleovegetation map we turned to the two earlier reconstructions for the Late Pleistocene in the Levant, which were by van Zeist and Bottema (1991:107–114) and Hillman (1996; and in Moore et al., 2000:73–84). These were based on the interpretation of a number of pollen cores, particularly from the Hula/Huleh Valley in northern Israel (Baruch and Bottema, 1999; Tsudaka in van Zeist and Bottema, 1991:104–105) and the Ghab Valley in western Syria (Niklewski and van Zeist, 1970; Yasuda et al., 2000). In reconstructing the palaeovegetation, the researchers took into account: (1) the distribution and nature of present plant communities in the area; (2) the physiographic features, which include the highland ranges which lie on either side of the Levantine Rift Valley and run parallel to the Mediterranean coast, and the topography of the inland plateau; (3) the impact of the prevailing westerly storm tracks, with possible seasonal monsoonal influences from the south; and (4) the current models of changing temperature and moisture regimes through the Late Pleistocene.

For this publication, we have extrapolated from these earlier reconstructions and taken into consideration more recent palaeoenvironmental research from across the region (for summaries see Enzel et al., 2008; Robinson et al., 2006) and particularly from the results of isotopic analyses of cave speleothems (Bar-Matthews et al., 1999, 2003). We have also drawn on palaeoenvironmental reconstructions from personal field research undertaken in eastern Jordan and northwest Lebanon (Garrard and Yazbeck, 2008; Hunt and Garrard, 2013).

On the basis of the gradient seen in present vegetation communities across the region which relates closely to physiography and rainfall (Hillman in Moore et al., 2000:49–73; Zohary, 1973; see also second column in Table 3), we have suggested a similar gradient in the Last Glacial Maximum, although being very aware that the detailed composition of the plant communities will have changed. The geographical distribution of these vegetation zones will also have altered in response to lower temperatures and lower precipitation levels across the region, although the latter is partly counterbalanced by the impact of reduced evaporation levels on effective moisture regimes. In drawing the speculative boundaries for each vegetation zone, we have made use of the "contour" lines on the current isohyet map, but altered their values to account for the factors outlined above (see third column in Table 3). It is appreciated that there was much climatic variation within the Last Glacial Maximum and what is shown in the map will only represent one part of the spectrum. It is also understood that a number of critical factors beyond physiography and rainfall are significant in the location of plant communities, but it is hoped that this will give an approximation to the palaeovegetation of the time.

Next, we created cost surfaces to model foraging ranges and travel routes. The cost surface is a grid whose values indicate the effort required to traverse each cell which uses terrain to estimate effort. This more accurately reflects ground conditions than the Euclidean distance (Howey, 2007; Morgan, 2009; Surface-Evans and White, 2012; van Leusen, 2002; Wood and Wood, 2006). This cost surface can be subjected to further analysis to, for example, estimate total travel time or optimized travel routes (Kanter, 2012). Initially, this entailed creating a digital elevation model (DEM) of the region's terrain using data from 90-meter grid cells. This DEM served as the basis for generating both a caloric and a time-cost surface. Then we used cumulative time-cost distance to estimate foraging ranges and generated least-cost paths on the caloric surface to estimate travel routes.

For foraging ranges, we modeled two concentric polygons around each site defined using a least-cost GIS analysis that employs travel time as currency. The first represents the distance an individual walks in four hours from the site. We refer to this as the maximum one-day foraging range, since it allows one to turn around and return to the camp by the end of the day. This maximum one-day foraging range is effectively the area within which an individual could access any point from the site as a starting point within four hours of walking (and assuming a four hour return trip). Then we modeled what we refer to as the maximum two-day foraging range—this represents an additional area within which an individual could walk within eight hours from a site. Both values are presented in square kilometers (sq km) and in aggregate represent the maximum two-day foraging catchment of a site. The maximum one-day foraging extent is particularly effective in characterizing the area of daily plant resource procurement, and the area within which most members of the camp conduct daily foraging (Kelly, 2013). Patch searching and intensive foraging efforts, of course, would certainly reduce effective daily foraging. In contrast, the maximum two-day foraging area effectively encompasses nearby settings where an individual would use encounter strategies, such as hunting game, returning to snares, and similar activities that regularly take place (Kelly, 1983). It should also be noted that we have not chosen to present mean foraging radius for each of these foraging area values. This is because least-cost GIS modeling of travel distances and the resulting foraging area are empirically based, the modeling can be altered by changing assumptions, and this is inherently more accurate than general approximations of foraging radii. In fact, the quest for a uniform, broadly applicable mean radius value also requires that one gloss over variations in foraging range based on topography around the starting point and other factors (of course mean radius can be readily calculated for any of these sq km values).

Studies of energetic travel costs, travel times, and travel corridors are based on the assumption that prehistoric site locations were often located in areas with relatively easy access, and that least-cost (in terms of energy) travel routes were preferred (Byrd et al., 2008; Morgan, 2008; van Luesen, 2002; Wood and Wood, 2006). To model energetic travel costs, the calories per second (cost) required to traverse each 295-x-295-foot (90-x-90-meter) elevation grid cell were calculated for the entire study area based on a formula for metabolic rate for walking on a slope (Pandolf et al.1977):

$$M = 1.5 \cdot W + 2 \cdot (W + L)(L / W)^{2} + n \cdot (W + L) \cdot [1.5 \cdot V^{2} + 0.35 \cdot V \cdot G]$$

Where:

M – Metabolic rate
W – Subject weight
L – Load
V – Velocity
G – Slope
n – Terrain coefficient

For this model, we assume a 68-kilogram (150-pound) person carrying no load, and a terrain coefficient of 1. Per van Luesen (2002) we assumed that people move across the landscape most efficiently at -5% slope. Therefore, the slope factor (G) was adjusted by subtracting 5% so estimate downhill metabolic and adding 5% to estimate uphill metabolic rate. The overall caloric cost surface is the sum of the downhill and uphill estimate. Therefore, we are attempting to find the least-cost path that accounts for both directions of travel.

To estimate the velocity we started with the hiker function (Tobler, 1993; Whitley and Hicks, 2003):

$$V = 6 \cdot e^{(-3.5 \cdot |G + 0.05|)}$$

Where:

V – Velocity
G – Slope
e – A real number derived from the exponential function of the slope of the tangent line, commonly defined as the base of the natural logarithm that is a mathematical constant—also called Euler’s number.

However, since the Pandolf et al. (1977) model was designed to describe metabolic rate for a specific range of speeds, we set a lower limit on velocity. The metabolic rate was then converted to kilocalories per meter and multiplied by the velocity to derive the kilocalories per second, which resulted in the estimation of cost-surface with a continuous set of values ranging between about 0.10 kCal/s and 0.24 kCal/s. In general, the metabolic cost functions as a transformation of surface slope, where a linear increase in slope results in a much greater increase in metabolic cost. This cost-surface was used for two calculations:

- Cost distance to sea, or the cumulative metabolic travel cost from each grid cell to the edge of the specific sections of coast (northern Mediterranean, Southern Mediterranean, Red Sea).
- Least-cost path, or the shortest path between a site and the coast using the cost distance surface. This model results in a line or path from the site to the coast which was considered a potential travel corridor.

We recognize that the paleoreconstructions and resulting foraging ranges are estimates; that they represent only one point in time; and that environmental conditions certainly varied during the time frame of discussion (circa 24,000−18,000 cal BP). The least-cost travel routes could be further improved by estimating relative travel rates per vegetation type (allowing *n* to vary in the Pandolf equation). It is also important to keep in mind that empirically we have calculated travel paths, assuming effort was the only factor. Actual travelways, of course, are corridors with breadth, and other factors invariably play a role in determining routes. It is also acknowledged that we have examined only a sample of the sites in the region assigned to this time frame, subjectively selecting those from a variety of settings to provide sufficient geographic coverage. The objective was not to definitively characterize precise moments in time and the full nuanced nature of regional settlement, but rather to identify potential trends and variations that provide a basis for generating hypotheses regarding organizational options to be tested in the future.

4. Regional Last Glacial Maximum Foraging Results

4.1. Foraging Extent

Figure 2 graphically depicts the GIS analysis results of cumulative travel time for one-day and two-day maximum daily foraging ranges from the selected 25 sites in the southern Levant (see Table 1 for data from each site). It should be noted that in locations where several sites are situated, such as in the Eastern Area, there is considerable overlap in foraging ranges. Overall, the mean maximum one-day foraging range is 638 sq km, increasing another 2,054 sq km when the two-day foraging ranges are added for a total 2-day maximum foraging catchment of 2,692 sq km.

If we subdivide the sample by region within the southern Levant – distinguishing sites west of the Levantine Rift/Jordan Valley system from those within it, and from those east of the Levantine Rift – there are substantial differences in foraging ranges (Figure 3; Table 1). These differences are statistically significant at one-day maximum foraging ranges (analysis of variance [ANOVA] $p < 0.000$, $df = 2$, $F = 19.041$) and two-day maximum foraging ranges (ANOVA $p < 0.000$, df = 2, F = 27.145). However, the differences in maximum one-day foraging area between regions have the greatest implication for hunter-gatherer adaptation. Not surprisingly, the Central Area – those sites within the Levantine Rift system – have the smallest foraging range (with a one-day mean foraging area of 310 sq km, and a total two-day mean foraging area of 1,583 sq km), while those in the Eastern Area have the largest foraging ranges (with a one-day mean foraging area of 884 sq km, and a total two-day mean foraging area of 3,843 sq km). West of the Levantine Rift, intermediate values exist (with a one-day mean foraging area of 625 sq km, and a total two-day mean foraging area of 2,063 sq km); moreover, this sample also has the greatest variance in results (see Table 1). These differences between regions are tied to topography especially where sites are positioned in relationship to bodies of water. Notably, the much smaller foraging areas in the Central Area are due to their being bounded by the Jordan Valley freshwater paleolakes (notably Lake Lisan, but also Lake Kinneret) and the Levantine Rift Valley's rugged and steeply sloping topography.

4.2. Foraging Habitat

Glacial maximum vegetation associations and particularly the distribution of forested and woodland areas were much more restricted than today, with forested areas concentrated in the western portion of the region, and distinctive park woodlands present and pervasive in the Central Area (Figure 4). Therefore it's not surprising that the range of paleovegetation habitats available within a foraging area differs by region in the southern Levant.

The extent of paleohabitats within the total two-day maximum foraging range for the study sites is depicted in Figure 5. Clear differences can be discerned between regions. Foraging catchment habitat heterogeneity (measured by taking the mean of all values) is also significantly different by region – greatest in the Central Area, and least in the Western Area (Figure 6). Moreover, this relationship remains the same when either one or two-day catchments are considered.

Figure 7 summarizes these differences by presenting mean paleohabitat representation by region within the maximum one-day foraging range. The types of habitats and the relative dominance of the two most common habitats vary considerably by region. Notably, the Western Area is dominated by dense deciduous Oak-Rosaceae Woodland and Montane and Eu-Mediterranean forest, and together they represent 91% of the one-day foraging range (with sand dunes comprising the only other habitat zone). In contrast, the Central Area has the most diverse and more evenly distributed range of habitats including woodlands, parklands, and steppic areas. The two most common habitats are Oak-Rosaceae park woodland steppe and Terebinth-almond woodland and together they comprise 78% of the one-day foraging range. The Eastern Area has intermediate values with respect to range of habitats and the lowest percentage of the two most common paleovegetation zones – Moist and Dry steppe (71%). However, the next most common habitat is the Desert zone.

4.3. Regional Summary and Implications

In summarizing regional patterns within the southern Levant, clear differences are evident in the size of daily foraging areas (see Table 1). If one were to assume habitat productivity was the same across the region, then larger daily foraging ranges means greater daily access to resources, and fewer residential relocations throughout the year as a result of declining return rates. However, paleohabitat modeling reveals that both habitat heterogeneity and potential productivity also vary greatly across the southern Levant (see Figure 6). Given the strong differences in the size of daily foraging ranges and potential plant and animal productivity within these areas shown in this analysis, we predict that Last Glacial Maximum adaptive patterns should have been significantly different across the southern Levant. Such variation could have included the relative reliance on fusion-fission strategies, the seasonality of relocation tactics, the number of moves per year, and the importance of group territoriality.

The Central Area (falling within the Levantine Rift Valley) has the smallest one-day foraging ranges, yet the greatest habitat heterogeneity and undoubtedly the greatest potential productivity. Hunter-gatherer theoretical research would predict that owing to the patchiness of resources, the inhabitants of this setting would have been more likely to follow the dictums of central place theory (Morgan, 2009; Orians and Person, 1979; Zeenah, 2004). This would entail placing considerable reliance on logistical forays (particularly to acquire resources within nearby productive habitats) and/or employing seasonally based tactics to move residences from one nearby habitat to another during an annual round (Kelly, 2013).

In contrast, the Western Area is characterized by larger one-day foraging ranges (on average two times that of the Central Area) but also by having the lowest habitat heterogeneity. In addition, the densely forested vegetation zones that dominate these settings are likely to have had much lower potential productivity for hunter-gatherers since such habitats typically have lower densities of seeds, nuts, and larger game. Therefore, it is most likely that residential mobility within the Western Area was higher than within the Central Area, and that moves were typically short in distance and within the same habitat. Seasonal relocations into different habitats would have been more costly and less likely as they would have required much longer moves.

Finally, the Eastern Area has much larger daily foraging ranges (the one-day extent almost three times that of the Central Area, and the two-day maximum extent almost two times that of the Western Area). These open spaces had intermediate values for habitat heterogeneity, but desert and dry steppe were most frequent, both of which had lower hunter-gatherer productivity than Central Area settings. It is also likely that water sources played an important role in tethering residents. This may have reduced the number of residential moves per year – as groups were willing to tolerate declining daily return rates for foraging – and increased the incentive for logistical forays. At the same time, the larger area that could be covered within the two-day maximum foraging range benefited logistical forays and increased the probability of encountering large game, which more often was present in groups/herds than in the Central and Western Areas.

5. The Azraq Basin – A Southeastern Levantine Example

5.1. Context and Broader Interaction

The Azraq Basin in the eastern portion of the southern Levant is an ideal setting to explore the potential complexity of factors (adding in archaeological details tied to settlements and regional interaction) at play in Late Glacial Maximum adaptations (see Figure 4). This internal drainage basin is noteworthy in that it has the two largest and most impressive early Epipaleolithic sites in the southern Levant – Kharaneh IV and Jilat 6 – and they greatly contrast from the typical small size of all other sites of this time period (Byrd and Garrard, 1990; Garrard and Byrd, 1992). They are also characterized by thick middens, features, and structures – all indicative of substantial and sustained occupation – and are often referred to as aggregation sites focused on the exploitation of gazelle herds (Garrard and Byrd, 2013; Maher et al., 2012a; Martin et al., 2010; Muheisen, 1988; Richter et al., 2013).

Moreover, these two sites (and the basin as a whole) have quite different early Epipaleolithic microlithic flaked stone tool manufacturing traditions. At Kharaneh IV these microliths have been classified as Kebaran (Maher et al., 2012a; Muheisen, 1988; Richter et al., 2013), while at Jilat 6 they are considered Nebekian and Nizzanan, the latter considered to be closely related but occurring slightly later in time (Garrard and Byrd, 2013). It is widely perceived that these broadly contemporaneous lithic industries (Kebaran vs. Nebekian and Nizzanan), which are mainly defined by backed bladelet manufacturing techniques and the size and shape of the resulting microliths, represent either distinctive ethnic/social groups or tool manufacturing traditions of long-standing duration (Bar-Yosef, 1991b; Goring-Morris et al., 2009; Goring-Morris and Belfer-Cohen, 1997; Henry, 1995; Olszewski, 2011; Stutz and Estabrook, 2004). This perception is reinforced by the fact that Kebaran sites are documented mainly in the more mesic Western and Central Areas of the Southern Levant, while Nebekian sites appear to be primarily if not exclusively concentrated in the more arid Eastern Area (see Figure 4). In fact, the Azraq Basin is presently the only place where both traditions are well documented (Garrard and Byrd, 2013; Richter et al., 2010, 2011a).

Given that these two sites may well have had some temporal overlap, the nature of broader regional interaction and territoriality also need to be considered, especially if these sites were inhabited by distinctive hunter-gatherer groups. It should be noted that it is uncertain if specific occupation events at Kharaneh IV and Jilat 6 were absolutely contemporaneous owing to the precision of radiocarbon dating results (Garrard and Byrd, 2013; Richter et al., 2013). Yet it is probable that at some point during the early Epipaleolithic both Kebaran and Nebekian groups occupied the basin at the same time, given that both traditions are also documented at other sites in the Azraq Basin. As such, issues of territoriality and the nature of regional interaction may have also played a role in shaping adaptive patterns.

To understand the nature of broader regional interaction by groups inhabiting the Azraq Basin, one line of evidence that can be examined is the relative degree of reliance on Red Sea versus Mediterranean shells at sites in the region. Trends in the movement of exotic material of this sort (regardless of precisely how such long-distance goods were acquired) provide insight into the nature, extent, and spatial organization of larger regional social networks (Collar et al., 2015; Pearce, 2014; Whallon, 2006). To generate some expectations regarding regional orientation of marine shell bead procurement, we modeled least-cost travel paths and cost trends from Jilat 6 and closely adjacent sites in Wadi Jilat at three points in time during the Terminal Pleistocene (Figure 8). At the Last Glacial Maximum, the shortest and least-expensive path for direct procurement was a northern route to the Mediterranean using the gap between Lake Lisan and Lake Kinneret (near Ohalo II). This route is significantly less costly than direct procurement from the Red Sea or via a southern route to the Mediterranean.

Over time, the two routes to the Mediterranean change, most notably with an even shorter northern path; while the Red Sea route remains effectively the same. Therefore, from a cost perspective, one would predict that in the Azraq Basin during the early Epipaleolithic direct marine shell procurement or down the line trading would have been Mediterranean-oriented rather than Red Sea-oriented. Although suitable marine shell source data from the Basin are limited, they suggest a more complicated scenario. Overall, in the Jilat area, very small samples from Nebekian sites suggest a fairly even representation of Red Sea and Mediterranean Sea species (Garrard et al., 1994; Reese, 1991). This is consistent with results from Nebekian sites further south in the eastern Levant (Reese, 1995, 2014).

In contrast, data from Kharaneh IV presented by Richter et al. (2011b:103–107) indicate that during the initial phase of site occupation, Mediterranean species outnumber Red Sea species 11 to one (see also Allcock, 2009). In the subsequent phase, species from both locations are almost evenly represented. This pattern of Mediterranean species initially dominating the Kebaran occupation of Kharaneh IV lends credence to the expectation of different groups occupying the basin, with at least the initial occupation of Kharaneh IV represented by a group whose regional orientation interaction may have been more east-west focused; over time this orientation shifts to north-south trade and exchange-level interaction more typical for Eastern Area sites. In contrast, hunter-gatherers occupying the Jilat area had interaction consistent with data from other Nebekian sites further to the south. These results are indicative of different regional social networks/interaction spheres and raise the likelihood that some forms of territoriality may have existed (Whallon, 2006).

5.2. Daily Foraging and Annual Settlement Organization

With respect to a consideration of foraging ranges, both Jilat 6 and Kharaneh IV are located not in the center of the Azraq Basin where the most extensive fresh water and riparian settings existed, but rather in the western portion of the basin. With extensive daily foraging ranges, the two sites have considerable one-day maximum foraging overlap (Figure 9). Two-day foraging ranges also encompass almost the entire one-day foraging range of each other. The major distinction is that the two-day maximum foraging range of Kharaneh IV extends to the springs and lake in the center of the basin, while the two-day range for Jilat 6 does not, ending near the lower Wadi Uwaynid (where other Nebekian sites have been documented).

The one-day foraging habitat of each site is very homogenous, consisting almost entirely of dry steppe. The two-day foraging range is slightly more varied, but mostly with the inclusion of the desert zone and only a small amount of the moist steppe. Although the archaeological data from both sites are representative of intensive occupation near local fresh water sources, it is unlikely that either were occupied throughout each year. Instead, occupation undoubtedly took place for only a portion of the year, likely representing an aggregation settlement and with a heavy emphasis on targeting locally available gazelle herds in the dry steppe (Garrard and Byrd, 1992; Martin, et al. 2010).

So what was the nature of the rest of the annual settlement system for the inhabitants of these two large early Epipaleolithic sites? We predict the rest of the annual settlement system took place either near or beyond their maximum two-day foraging range in order to capitalize on other seasonally available resources. It is also probable that other facets of the annual system were represented by dispersal into smaller residential groups, consistent with the small size of sites documented elsewhere in the southern Levant.

The two most likely scenarios involve capitalizing on different resource sets, and entail either repositioning to the east or to the west (Figure 10). Foraging further north or south within the dry steppe is considered unlikely since seasonal constraints remain largely the same, and on the south they would quickly be impinging on the foraging range of early Epipaleolithic sites near Lake Hasa.

Dispersing and relocating eastward to the oasis at the center of the basin in the desert zone is certainly a viable strategy since it positions these foragers adjacent to resources associated with a freshwater riparian habitat including migratory birds, marsh plants, and large game. Although this locality would allow occupation during the drier summer months owing to a perennial water supply, many of the key resources here would have been most plentiful during other seasons. However, this relocation scenario entails only a modest eight to 10 hours of travel time, and is consistent with the presence of a number of small early Epipaleolithic sites along the marsh margins.

In contrast, shifting to the west into the wetter woodland steppe or park woodlands would have afforded Jilat 6 and Kharaneh IV occupants a wider and more varied range of resources, particularly plants. Cereals and legumes would have been available in late-spring and early summer (after any such resources may have been collectable in the dry steppe), while nuts, such as pistachios and almonds, were available in the fall. Minimum travel time estimates to the woodland steppe are around 11–12 hours, and 13–15 hours to reach the park woodland (see Figure 10).

Several relocation options were available to access woodland steppe during the early Epipaleolithic including the uplands in the Wadi el Hidan directly to the west, the Wadi Mujib uplands to the southwest, and the Wadi Zarka uplands to the northwest. Each of these drainage catchments are large and well-watered, and well-suited for varied occupation events. In contrast, park woodland habitat was much more restricted in extent. It was not present directly to the west or to the southwest. Instead, the nearest woodland was to the northwest along the edge of the Wadi Zarka drainage basin or even further to the northwest near the uplands of the Yarmouk River.

Territorial boundary issues may well have played a role in constraining annual settlement at Jilat 6 and Kharaneh IV. If territoriality existed and was defined simply by the midpoint of travel distance, then the inhabitants of Jilat 6 would not have had access to either the central basin or the park woodlands (as shown in Figure 10 by the line marking the midpoint of travel times). With respect to the central basin, this assumption appears unlikely since both Nebekian and Kebaran sites have been documented here indicating at least some use by both groups (Richter, 2011a; Rollefson et al., 2001). A testable prediction of the role of territoriality in such land-use patterns would be to ascertain if Kebaran sites cluster on the north and west sides, closest to Kharaneh IV, and Nebekian sites are more common on the south and east sides, closest to Jilat 6.

Predicting where a western relocation took place is more challenging when considering the role of territorial ranges, in part because there is almost no data on early

Epipaleolithic sites in this area. For a western relocation, the most likely scenario from a least-cost perspective, and assuming some level of territoriality, would entail Jilat 6 inhabitants dispersing northeast to the uplands of the Wadi Hidan, and those from Kharaneh IV dispersing to the Wadi Zarqa uplands. This would have afforded both groups access to steppe-woodland and park-woodland habitats. The presence of a Nizzanan site (closely related to Nebekian but dating later in the early Epipaleolithic) in the lower Wadi Hisban (Edwards et al., 1999), just north of the Wadi Hidan, provides some potential support for such a northwest-to-southeast-oriented annual settlement pattern reconstruction.

Whether the eastern- or western-oriented annual settlement model is most viable hinges in part on the seasonality of these two large aggregation sites. Martin et al. (2010) argue for winter and early spring occupation when local grasslands attracted large gazelle herds, Jones (2012) suggests spring/summer occupation predominated, and Maher (2012b) suggest autumn and winter occupation. It is also possible that exploitation of the center of the basin was often logistical in nature, and characterized by periodic exploitation events staged from Jilat 6 and Kharaneh IV. As such, winter-early spring in the basin and summer-fall in the west is considered the most likely annual settlement structure. This of course would have entailed sustained westward residential relocations to capitalize on productive and seasonally available resources.

Such an east-west settlement orientation is also applicable to other settings along the eastern edge of the southern Levant, such as the Wadi Hasa and Wadi Musa-Petra regions. In each of these drainage catchments, seasonal movement to other habitats would have enabled early Epipaleolithic hunter-gatherers to access a different set of resources, particularly with respect to plants. Such a wide-ranging annual settlement structure also bears some similarity to reconstructions offered by Goring-Morris (2009; Goring-Morris et al., 2009) in the western Levant.

6. Summary and Discussion

The objective of this study has been to use least-cost GIS modeling to provide some hypotheses regarding the potential extent and nature of hunter-gatherer annual settlement organization at the height of the Last Glacial Maximum in the southern Levant. The results highlight three points. First, such modeling must include paleogeographic and paleoenvironmental reconstructions given the very different landscape of 21,000 years ago as opposed to during the Natufian or early Neolithic, let alone today. A notable aspect of the Last Glacial Maximum landscape was how Lake Lisan and Lake Kinneret impeded the east-west movement and interaction within the region. Much more work refining these data sets, and further modeling how they changed across shorter intervals of time is needed to generate more accurate insights into diachronic shifts in background conditions during the Terminal Pleistocene.

Second, hunter-gatherer maximum one- and two-day foraging ranges are quite a bit larger than have been suggested previously for the Levant, and it follows logically that the annual extent of a group’s foraging range potentially could have been considerably larger as well (Bar-Yosef and Belfer-Cohen, 1989:451; Goring Morris, 2009:85–87; Henry, 1989:174; Vita-Finzi and Higgs, 1970). These values are, however, consistent with the larger body of hunter-gatherer ethnographic literature (Kelly, 2013: Figure 4-8).

The implications of these results need to be woven into future considerations of potential territorial ranges, population densities, inter-group interaction, and trade and exchange within the Levant. It is also important to keep in mind that these are maximum foraging areas and that the distances are modeled based on how long one walks (and still get back to camp at the end of one or two days assuming a maximum of eight hours of walking per day). They provide a useful tool especially for understanding travel distance if going after targeted resources that require little search time (such as places where game congregate, tree-based resources such as nuts and fruits, food caches, or non-food resources). They are also helpful for perceiving where settlement relocations are most likely to occur (i.e., beyond the maximum foraging range) when central place collector strategies are employed. Average daily foraging ranges, of course, will always be smaller, especially if foraging has considerable search, collection, or field processing time.

Third, daily foraging extent, vegetation zones, and habitat heterogeneity differed significantly within the southern Levant during the Last Glacial Maximum. As a result, it is to be expected that adaptive patterns varied as well, and may have included a number of facets as highlighted below. Residential mobility (as measured by the number of moves per year) and the distance per move is predicted to be the greatest in the Western Area owing to pervasive habitat homogeneity and least in the Central Area (falling within the Levantine Rift Valley) given the heterogeneity/patchiness of resource distribution. Similarly, the use of logistical forays to acquire resources is likely to have been most pervasive in the Central Area, and also a commonly employed strategy in the Eastern Area. It is likely that in the open spaces of the Eastern Area, such logistical forays covered greater distances to ensure encounter strategies with large game. It is further predicted that the relative reliance on animal resources was greatest in the Eastern Area versus the other two areas. It also follows logically, that annual territory was greatest in the Eastern Area (owing to lower overall productivity and the greater reliance on game) and the smallest in the Central Area (given the terrain and the diversity of productive habitats available within a relatively restricted area).

The relative importance of a fission-fusion adaptive strategy also undoubtedly varied spatially, and was most commonly employed within the Eastern Area. In the Azraq Basin this appears to have been driven by seasonal availability of large gazelle herds and by tethering major settlement to infrequent well-watered localities. It also appears that territoriality may have been greatest in the Eastern Area, consistent with the importance of logistical hunting and aggregation events (Whallon, 2006). Such activities may also reflect the need for additional mechanisms to enhance social interaction within the mating groups of the southern Levant that were the most spatially dispersed (Pearce, 2014). These attributes of open space adaptation in the southeastern Levant suggest that social complexity - distinguished by coalescing in larger groups (presumably multiple bands) and employing cooperative hunting procurement tactics – was most evident within the eastern Azraq Basin of the southern Levant. Moreover, the presence of two large aggregation sites (each potentially occupied by distinctive groups within the southern Levant) reveals the presence and maintenance of larger social interaction spheres and regional territoriality. The significant differences in daily foraging range within the southern Levant also highlight the unsuitability of uniformly applying a standard foraging radius (such as 5 km, 6 km, or even 10 km) to assess potential productivity or other factors.

These variances in adaptive options and emerging patterns within the southern Levant at the height of the Last Glacial Maximum provide baseline conditions for divergences in adaptive trajectories within the region. For example, Epipaleolithic groups inhabiting the western Levantine woodlands may have been more likely to shift to more costly resources over time owing to the homogeneous nature of the setting and declining foraging ranges, owing in part to sea level rise. Similarly, if inhabitants in the Central Area followed the dictums of central place theory – increasingly relying on logistical procurement tactics rather than seasonal relocations within different habitats – then they may have been preadapted to more sedentary conditions. In the long run, taking a broader perspective on how these baseline conditions and corresponding adaptations differed within the early Epipaleolithic should enhance our understanding of the causal factors that underlie subsequent shifts to sedentism and early food production.

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Figure List

Table List

Acknowledgements

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Table 1. Archaeological sites used in study, associated Epipaleolithic industry, and maximum foraging ranges.

	Sites	**Reference**	**Epipaleolithic Industry**	**Maximum foraging range (sq km) in One Day**	**Maximum (additional) foraging range (sq km) in Two Days**	**Total Maximum Foraging Range (sq km)**
Eastern Area (n=11)						
	Ain al-Buhira (WHS 618)	Coinman, 1993	not applicable	787	2,795	3,582
	Ayn Qasiyya	Richter et al., 2011a	Kebaran and Nebekian	973	3,376	4,348
	Azraq 17	Garrard and Byrd, 2013	not applicable	920	3,324	4,244
	Jilat 6	Garrard and Byrd, 2013	Nebekian/Nizzanan*	1,115	3,429	4,544
	Kharaneh IV	Maher et al., 2012a	Kebaran	1,147	3,413	4,560
	Tor al-Tareek (WHS-1065)	Neeley et al., 1998	Nebekian	808	2,818	3,626
	Tor Hemar	Henry, 1995	Nebekian	588	1,946	2,534
	Tor Sageer (WHNBS 242)	Olszewski, 2011	Nebekian	832	2,872	3,704
	Uwaynid 14 & 18	Garrard and Byrd, 2013	Nebekian	1,074	3,465	4,539
	Yabrud	Rust, 1950	Nebekian	773	2,415	3,188
	Yutil al-Hasa (WHS 784)	Olszewski et al., 1994	Nebekian	708	2,699	3,407
	Mean (std dev)			**884 +/-178**	**2959 +/- 493**	**3843 +/- 661**
Central Area						

(n=8)						
	Ein Gev I, IV	Bay Yosef, 1970, 1991a	Kebaran	269	1,659	1,928
	Madamagh	Byrd, 2014	Nebekian	353	2,046	2,398
	Ohalo II	Nadel, 2003	not applicable	394	1,735	2,129
	Tabaqat al Buma	Banning et al., 1992	Kebaran	432	1,203	1,635
	Urqan e-Rub	Hovers and Marder, 1991	Kebaran	210	889	1,100
	Wadi Hammeh 26	Edwards et al., 1988	Kebaran	241	720	961
	Wadi Hammeh 51 & 52	Edwards et al., 1996	Kebaran	231	701	931
	Wadi Hisban 2	Edwards et al., 1999	Nizzanan*	351	1,231	1,581
	Mean (std dev)			**310 +/- 83**	**1273 +/- 499**	**1583 +/- 552**
Western Area (n=6)						
	Hayonim	Bar Yosef, 1970	Kebaran	759	1,975	2,734
	Jiita II	Hours, 1992	Kebaran	290	827	1,117
	Kebarah Cave	Bar Yosef, 1970	Kebaran	939	1,985	2,924
	Ksar Akil	Hours, 1992	Kebaran	372	762	1,135
	Moghr el Ahwal	Garrard and Yazbeck, 2008	Kebaran	360	1,054	1,414
	Nahel Hadera V	Saxon et al., 1978	Kebaran	1,034	2,019	3,053
	Mean (std dev)			**625 +/- 326**	**1437 +/- 617**	**2063 +/- 933**

* Nizzanan, closely related to Nebekian but dating later in the early Epipaleolithic

Table 2. Ancient shoreline elevations (meters above/below modern mean sea level) used for paleoenvironmental modeling

Setting	**21,000 cal BP**	**15,000 cal BP**	**11,500 cal BP**	**Reference**
Mediterranean and Red Sea	-120	-88	-50	Fleming et al., 1998
Lake Lisan (Dead Sea), Jordan Valley	-200	-285	-400	Bartov et al., 2002, 2003; Hazan et al., 2005; Robinson et al., 2006
Lake Beit Shean, Jordan Valley	na	-250	None	Bartov et al., 2002; Hazan et al., 2005 (figure 1)
Lake Kinneret (Tiberias/Galilee), Jordan Valley	-200	-210	-210	Belitzky, 2002; Hazan et al., 2005
Lake Huleh (Hula), Upper Jordan Valley	73	uncertain; not depicted	uncertain; not depicted	Ashkenazi, 2004; Feibel et al., 2009; Weinstein-Evron, 1983
Lake Hasa, west-central Jordan	810	uncertain; not depicted	uncertain; not depicted	Schuldenrein, 1998; Schuldenrein and Clark, 1994
Lake Azraq, northeastern Jordan	505	505	505	Garrard and Byrd, 2013; Jones and Richter, 2011

na: not applicable, as subsumed by Lake Lisan

Table 3. Last Glacial Maximum (circa 21,000 cal BP) paleo-vegetation reconstruction in relationship to modern rainfall isohyets

Vegetation Zone	**Modern Isohyet range for each vegetation zone ***	**Modern Isohyte "contour" lines used to model boundaries of 21,000 cal BP vegetation zones ****
Desert	<100	0-75
Dry steppe	100-150	75-175
Moist steppe	150-200	175-300
Terebinth-almond woodland steppe	200-300	300-400
Oak-Rosaceae park woodland steppe	300-400	400-500
Dense deciduous Oak-Rosaceae woodland	400-600	500-700
Montane and Eu-Mediterranean forest	>600	>700
Coastal sand dunes		na

* Based on Hillman in Moore (2000:49-73)

** Using data derived from Bar-Matthews et al. (1999, 2003); Hillman (1996); Hillman in Moore (2000:73-84); Hunt and Garrard (2013:114-116); van Zeist and Bottema (1991)

Figure 1

Study Sites	
1	Moghr el Ahwal
2	Yabrud
3	Jiita II
4	Ksar Akil
5	Hayonim
6	Ein Gev I/IV
7	Ohalo II
8	Kebarah
9	Tabaqat al Buma
10	Wadi Hammeh 51/52
11	Wadi Hammeh 26
12	Nahal Hadera V
13	Urkan e-Rub
14	Ayn Qasiyya
15	Azraq 17
16	Wadi Hisban 2
17	Uwaynid 14/18
18	Kharaneh IV
19	Jilat 6
20	Tor Sageer
21	Yutil al-Hasa
22	Ain al-Buhira
23	Tor al-Tareek
24	Madamagh
25	Tor Hamar

Figure 2

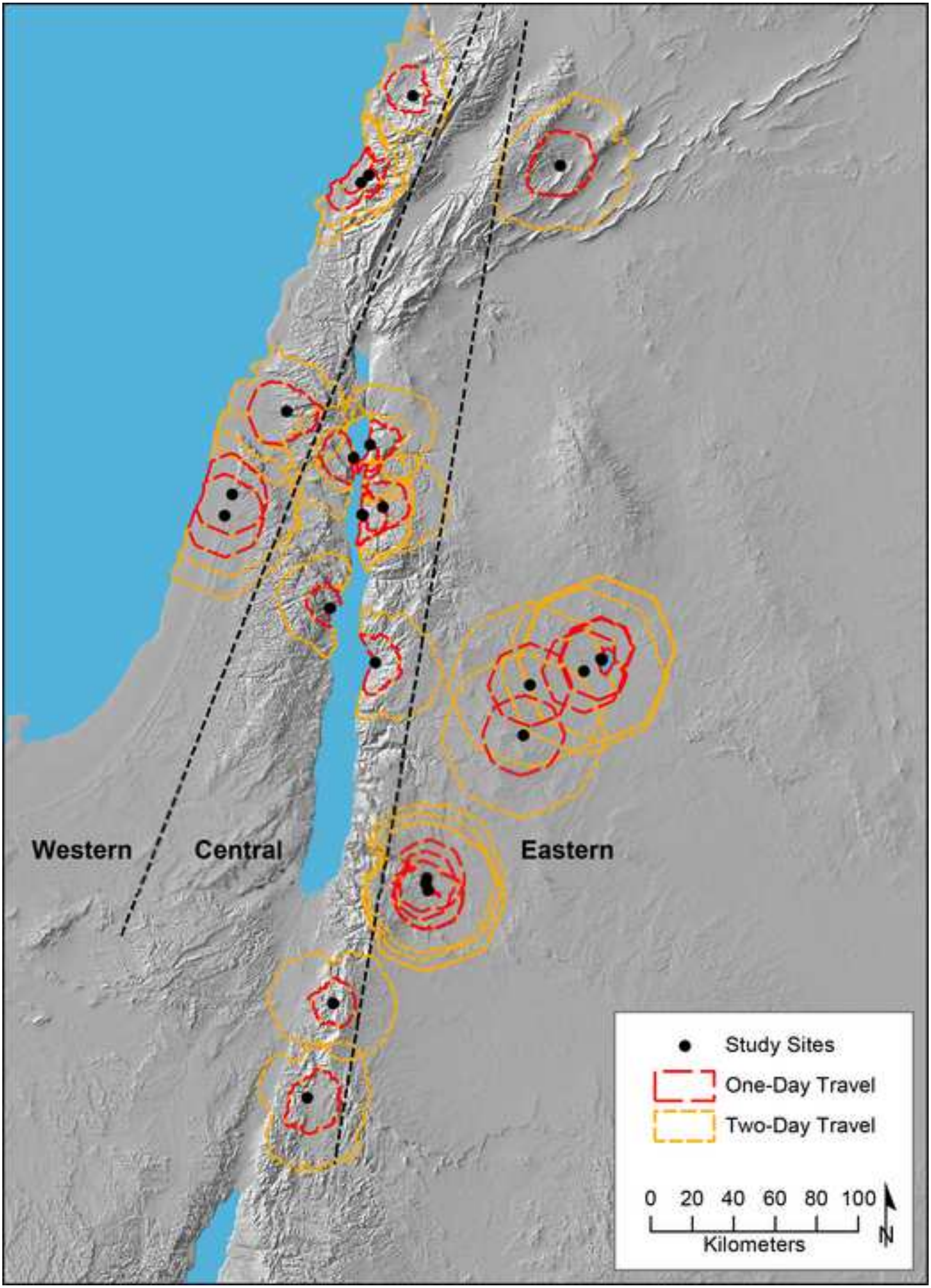

Western
Central
Eastern
● Study Sites
One-Day Travel
Two-Day Travel
0 20 40 60 80 100
Kilometers
N

Figure 3

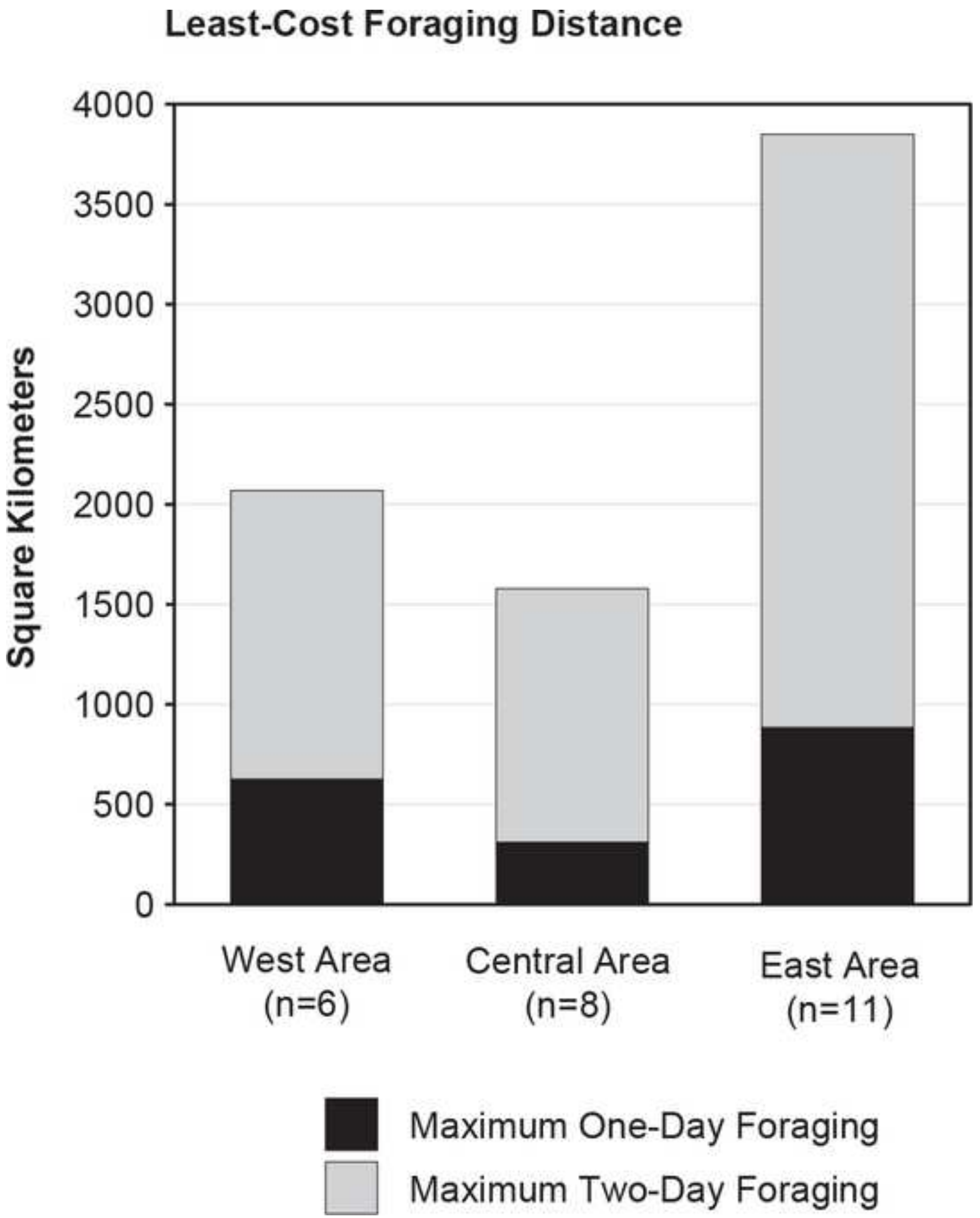

Least-Cost Foraging Distance
Square Kilometers
4000
3500
3000
2500
2000
1500
1000
500
0
West Area (n=6)
Central Area (n=8)
East Area (n=11)
■ Maximum One-Day Foraging
□ Maximum Two-Day Foraging

Figure 4

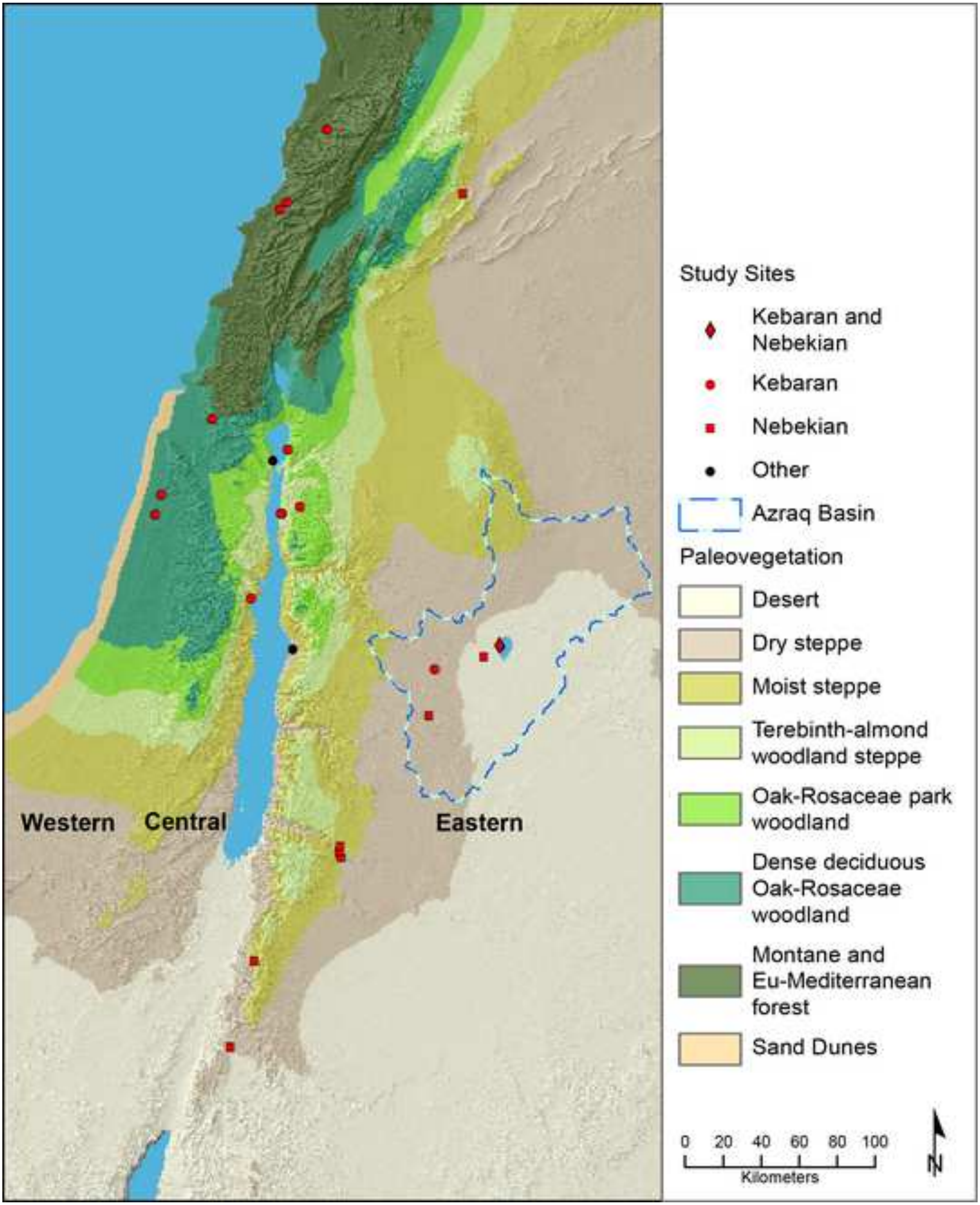

Western
Central
Eastern
Study Sites
Kebaran and Nebekian
Kebaran
Nebekian
Other
Azraq Basin
Paleovegetation
Desert
Dry steppe
Moist steppe
Terebinth-almond woodland steppe
Oak-Rosaceae park woodland
Dense deciduous Oak-Rosaceae woodland
Montane and Eu-Mediterranean forest
Sand Dunes
0
20
40
60
80
100
Kilometers
N

Figure 5

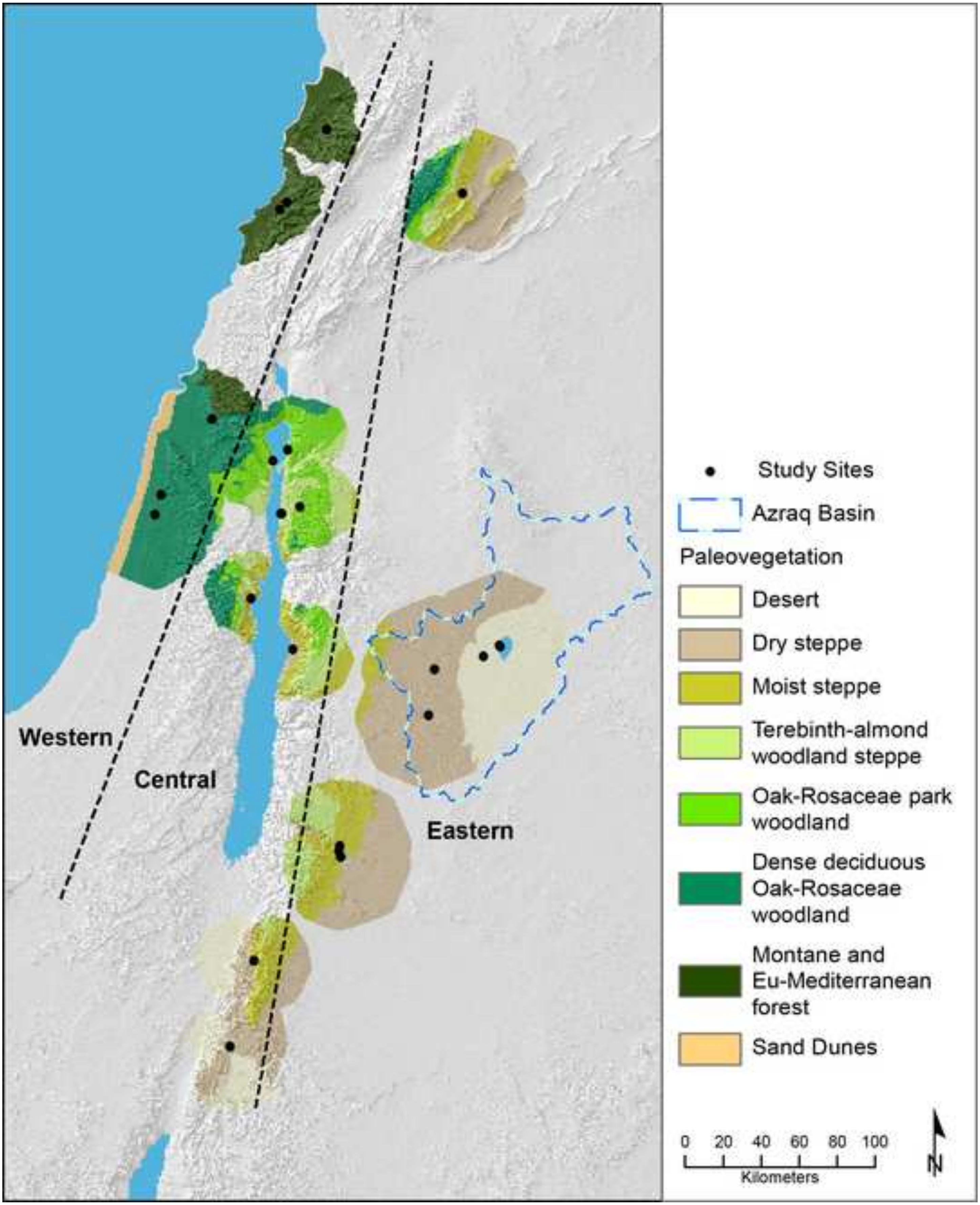

Western
Central
Eastern
Study Sites
Azraq Basin
Paleovegetation
Desert
Dry steppe
Moist steppe
Terebinth-almond woodland steppe
Oak-Rosaceae park woodland
Dense deciduous Oak-Rosaceae woodland
Montane and Eu-Mediterranean forest
Sand Dunes
0
20
40
60
80
100
Kilometers
N

Figure 6

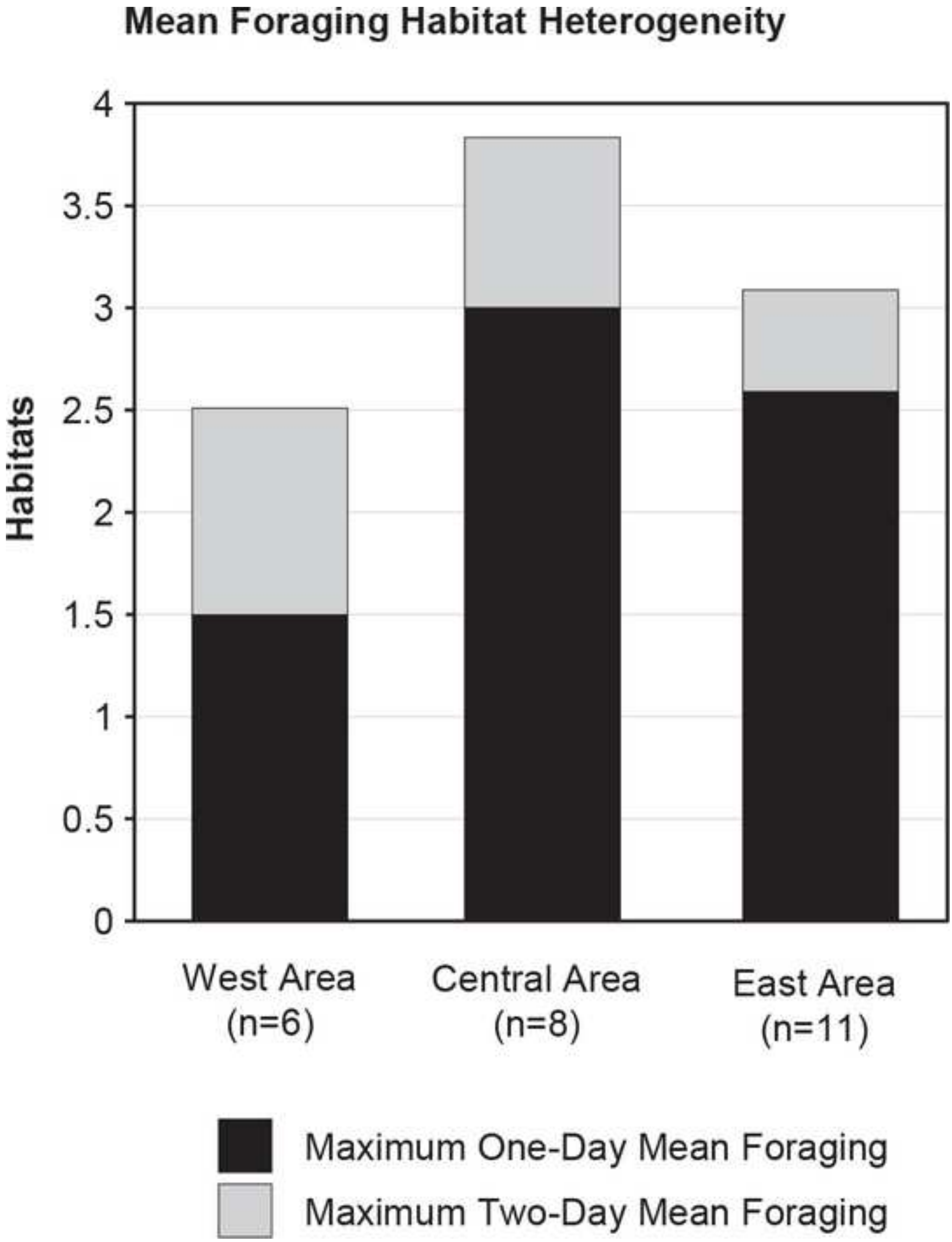

Mean Foraging Habitat Heterogeneity
Habitats
4
3.5
3
2.5
2
1.5
1
0.5
0
West Area (n=6)
Central Area (n=8)
East Area (n=11)
Maximum One-Day Mean Foraging
Maximum Two-Day Mean Foraging

Figure 7

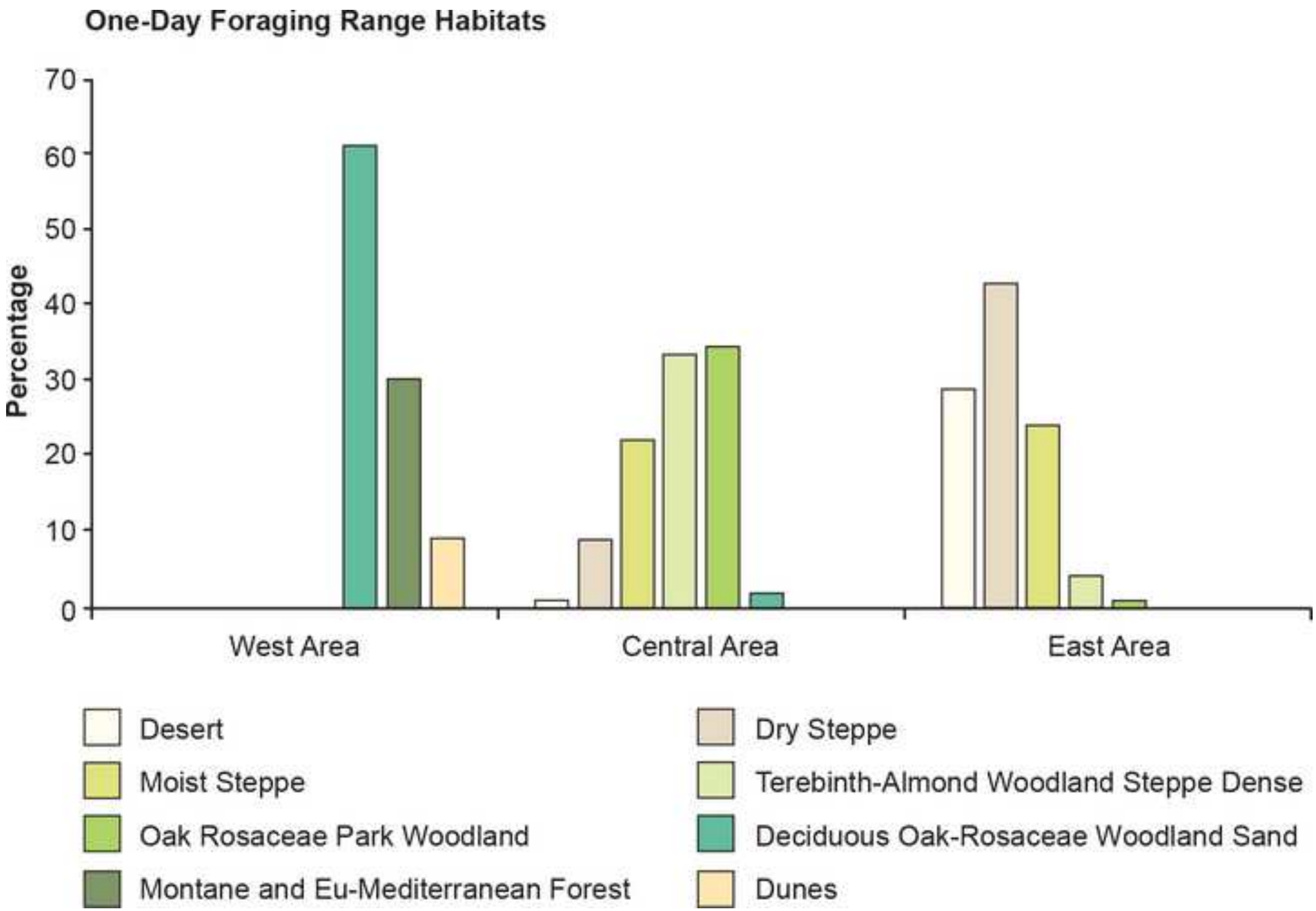
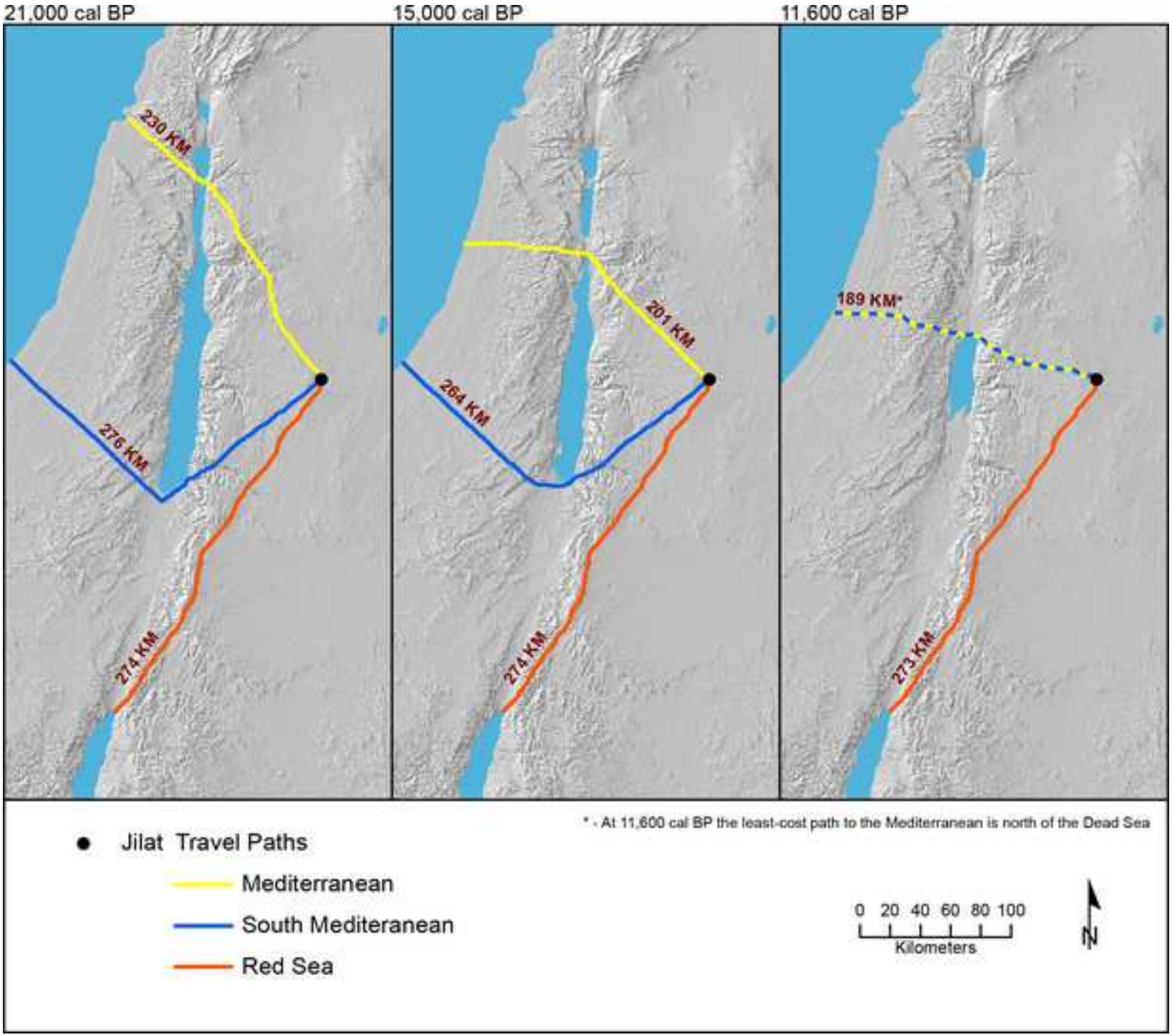

One-Day Foraging Range Habitats
Percentage
70
60
50
40
30
20
10
0
West Area
Central Area
East Area
Desert
Dry Steppe
Moist Steppe
Terebinth-Almond Woodland Steppe Dense
Oak Rosaceae Park Woodland
Deciduous Oak-Rosaceae Woodland Sand
Montane and Eu-Mediterranean Forest
Dunes

Figure 8



* - At 11,600 cal BP the least-cost path to the Mediterranean is north of the Dead Sea

Figure 9

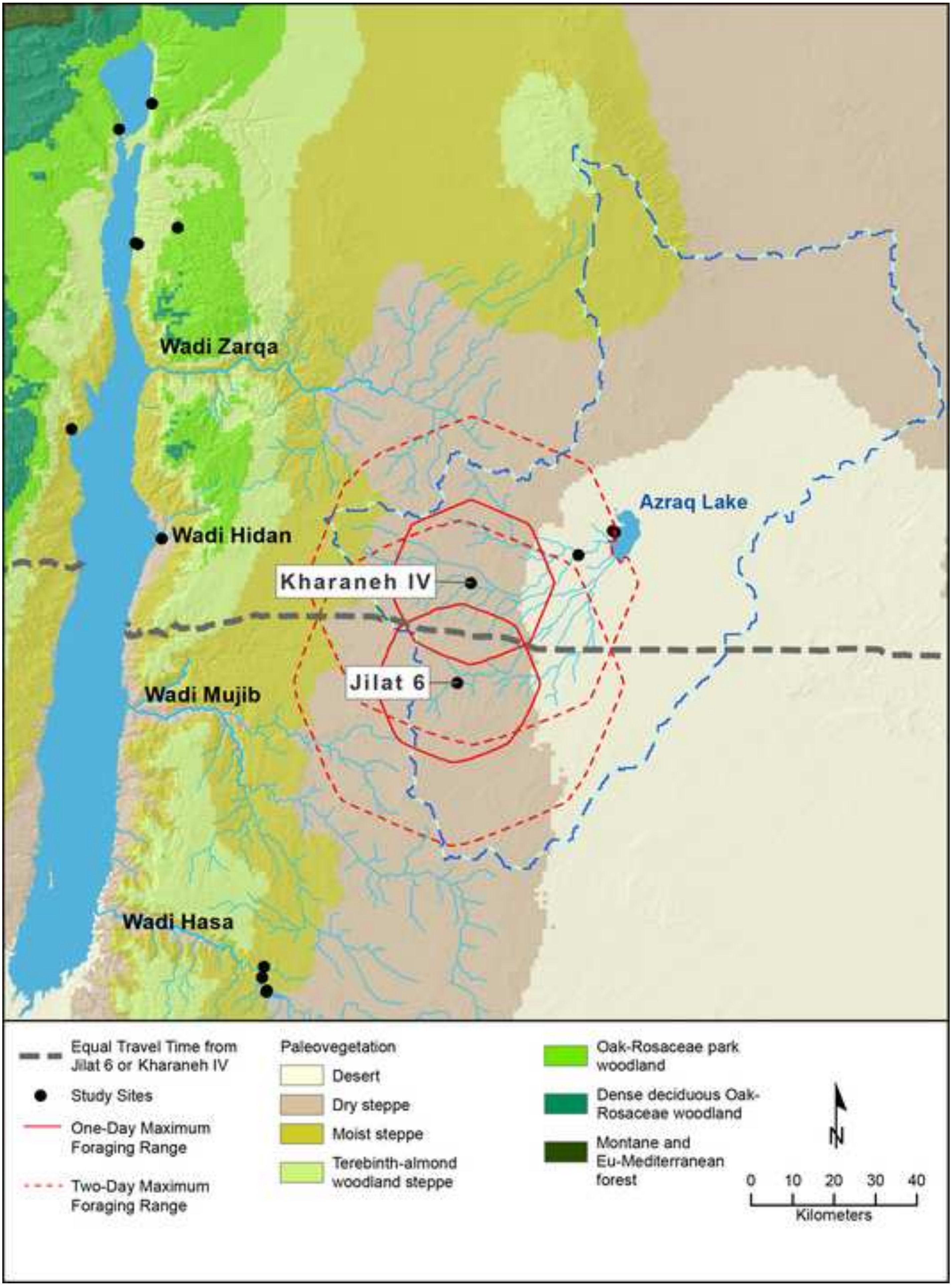
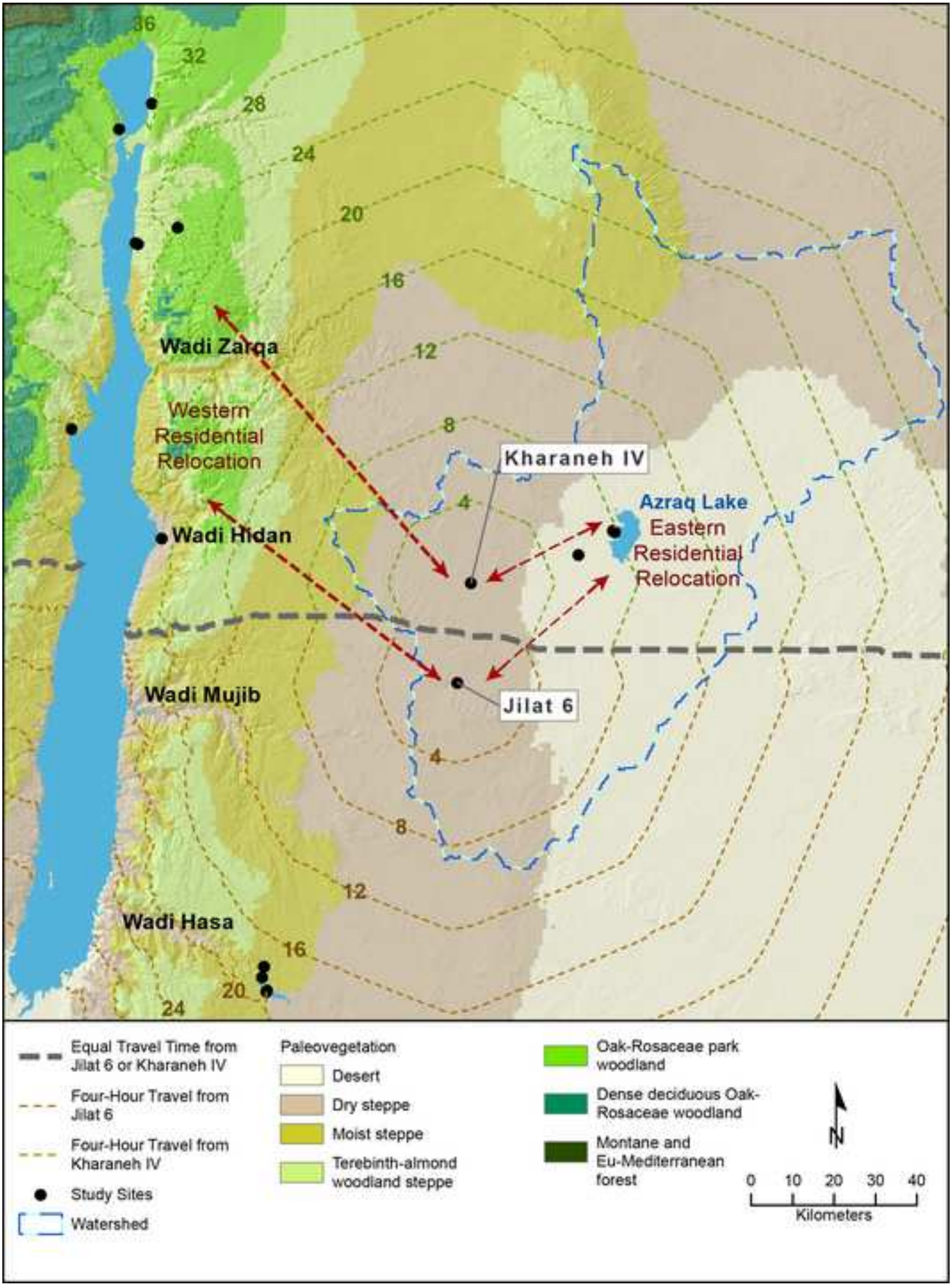

Wadi Zarqa
Azraq Lake
Wadi Hidan
Kharaneh IV
Jilat 6
Wadi Mujib
Wadi Hasa
Equal Travel Time from Jilat 6 or Kharaneh IV
Study Sites
One-Day Maximum Foraging Range
Two-Day Maximum Foraging Range
Paleovegetation
Desert
Dry steppe
Moist steppe
Terebinth-almond woodland steppe
Oak-Rosaceae park woodland
Dense deciduous Oak-Rosaceae woodland
Montane and Eu-Mediterranean forest
N
0
10
20
30
40
Kilometers

Figure 10


36
32
28
24
20
16
12
8
4
Wadi Zarqa
Western Residential Relocation
Wadi Hidan
Kharaneh IV
Azraq Lake
Eastern Residential Relocation
Wadi Mujib
Jilat 6
4
8
12
Wadi Hasa
16
20
24
Equal Travel Time from Jilat 6 or Kharaneh IV
Four-Hour Travel from Jilat 6
Four-Hour Travel from Kharaneh IV
Study Sites
Watershed
Paleovegetation
Desert
Dry steppe
Moist steppe
Terebinth-almond woodland steppe
Oak-Rosaceae park woodland
Dense deciduous Oak-Rosaceae woodland
Montane and Eu-Mediterranean forest
N
0
10
20
30
40
Kilometers