A GIS method for assessing the zone of human-environmental impact around archaeological sites: a test case from the Late Neolithic of *Wadi Ziqlâb*, Jordan.

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Abstract

Assessing the impact of prehistoric sites on their local environment is difficult to accomplish with standard archaeological methods. Simulation modeling offers a solution to this issue, but it is first necessary to delimit a site catchment, or "zone of impact", around archaeological sites in which to carry out human-environment interaction modeling. To that end, I have distilled a new method for GIS-based catchment reconstruction into a custom module (*r.catchment*) for GRASS GIS, which calculates catchments of a given area based on anisotropic travel costs from a point of origin. One method of applying this new module in exploratory catchment modeling is discussed using the pastoral economy of the Late Neolithic period in Wadi Ziqlâb, Northern Jordan as a test case. A model of Late Neolithic herding economy and ecology is constructed, which combines data from archaeology, phytogeography, range science, agronomy, and ethnohistory. Four sizes of pastoral catchments are then derived using *r.catchment*, and the herd ecology model is used to estimate the stocking-rate (carrying capacity) of mixed goat and sheep herds for each catchment. The human populations these herd numbers could support are then compared with human population estimates derived from household architectural analyses to determine the most probable catchment configuration. The results indicate that the most probable zone of impact around the known Late Neolithic sites in Wadi Ziqlâb was somewhere between 9 and 20 square kilometers, delineated by 3 and 4.5 kilometer pasture radii respectively.

1 Introduction

The Mediterranean Landscape Dynamics (MEDLAND) project is attempting to better understand the long-term effects of human agropastoral land-use on environmental degradation (Barton et al. 2010). A major component of this type of research involves modeling the zone of environmental impact surrounding archaeological sites. In an especially broad-reaching analysis, Danti (2000) models the entire agropastoral system at Early Bronze Age Tell Sweyhat in northern Syria. Danti makes it clear that—from a landscape perspective—the true zone of impact around a site is the sum of both the agricultural and pastoral catchments. There is abundant ethnographic and archaeological information regarding location of agricultural impacts (e.g., Kramer 1982, Watson 1979, Wilkinson 2003), but much less information regarding the location of the impacts of pastoralism. Because the long term signatures of pastoral land-use are fairly ephemeral even in comparison to those few that are left by agriculture, traditional archaeological methods provide only indirect evidence for the extent and nature of pastoral exploitation around sites. This paper examines the available data on pastoral economies, and provides a method for modeling pastoral catchments from archaeological data. I define the pastoral catchment as the area around a site commonly used by animals associated with that site; especially the area within which those animals are pastured on a regular basis. This definition is comparable to the idea of a "herding radius" as proposed by Coppolillo (2000).

This paper uses spatially explicit computer simulation as an experimental laboratory to better understand the ecological footprint of pastoralism during the Late Neolithic (5706-5542 to 5276-5072 cal BC [Banning 2007]) of *Wadi Ziqlâb* in Northern Jordan. I use Geographical Information Systems (GIS) to model a series of differently-sized pastoral catchments using an explicit catchment growth algorithm based on the cost of walking across the landscape from a point of origin. I use a model of ancient landcover produced from a Maximum Entropy paleovegetation model as input into herd animal stocking-rate equations (borrowed from rangeland science) for each modeled catchment. These herd estimates are translated into human population with the aid of ethnoarchaeological data from modern pastoral groups. I argue that a reasonable pastoral catchment can be defined by comparing the simulated Late Neolithic human populations associated with different pastoral catchment sizes with human population estimates derived from architectural analysis at the Late Neolithic sites themselves. A robust, open source Geographical Information System (GIS), GRASS, serves as the modeling environment (GRASS Development Team 2010).

2 Background

2.1 Site Catchment Analysis

Site Catchment Analysis (SCA) was developed as way to understand the relationship between human settlements and their local environments (Higgs and C. Vita-Finzi 1970). In SCA, a "catchment" is commonly defined as the area regularly exploited by the people of a particular site (Higgs and C. Vita-Finzi 1970). Early SCA studies were held back by the available suite of analysis techniques, which were mainly limited to field-walking along transects outwards from the site for a given amount of time (e.g, 1 hour) to determine a series of catchment radii in the four cardinal directions (Higgs 1975). The termini of these radii were then connected together "by eye" to define the actual shape of the catchment. An easier, and thus more popular method is to determine a single time-distance radius, and then to approximate the site catchment boundary by using that radius to calculate a circular "buffer" around the site (e.g., Jarman and Webley 1975). The computational power of modern computers and GIS software has coupled with the unprecedented availability of high quality topographic and spatially-explicit environmental data to enhance the accuracy of site catchment modeling, while concurrently simplifying the process of actually doing the modeling; but unfortunately, the legacy of the circular “buffer” catchments remains to this day (e.g., Hunt 1992, Ayala and French 2005, Nyerges and Green 2000). However, a few recent SCA studies have begun to use GIS-based models of walking costs to more accurately delineate site catchment boundaries (e.g., Arroyo 2009, Christopherson et al. 1999, Hill 2006). This technique allows the operationalization of Higgs and Vita-Finzi's (1970) original concept of how site catchments should be defined, but there is still no standardized method for integrating GIS-based models of walking costs in SCA. This is mainly because there exists no specific software tools built for SCA that incorporate such costs. To that end, I have developed an addon module (*r.catchment*) for the free and open-source GRASS GIS suite (GRASS Development Team 2010).

SCA is not an end goal in its own right; rather, it is one tool in an suite of many that archaeologists use to understand the relationship between people and environments. For example, a growing number of archaeologist are investigating the environmental impacts of ancient human land-use practices (e.g., Ayala and French 2005, Barker et al. 1999, Barker et al. 2000, Barton et al. 2004, Barton et al. 2010, Comer 2003, Hill 2006, Menze, et al. 2006, Philip 2002, Wainwright 2008, Wilkinson 2003). SCA is an important first step that must be completed before such studies can be undertaken, as researchers must be able to delineate the areas of the landscape that were utilized by ancient peoples, and thus the location of potential human-caused environmental degradation. However, these types of studies often only implicitly incorporate SCA (e.g., Fisher et al. 2003; Woods 2004), and even when SCA is explicitly incorporated into these types of studies, it is often done deterministically (e.g., Ayala and French 2005, Nyerges and Green 2000). I suggest that SCA should be viewed as an experimental procedure, and thus not producing “the site's catchment”, but rather returning a range site catchment scenarios that are plausible in the light of the available contextual data, and that can serve as input into further analyses. This paper espouses this experimental approach, and catchments derived using the method outlined in this study have already served as input for a larger experimental modeling study of how these Neolithic farmer/herders impacted their local environment over long time-spans (Barton et al. 2010).

2.2 The Ecology of Herding Societies

There exists a large body of research largely untapped by archaeologists that can act as input for models of ancient pastoral behavior (but for a good archaeological implementation of these data see Danti [2000]). This corpus, developed by modern agronomists and rangeland scientists interested in the sustainability of pastoral land-use, herd ecology, and range productivity, provides many methods that are directly applicable to the archaeological study of ancient rangelands. The literature regarding rangeland carrying capacity and the stocking-rate of herd animals (Hocking and Mattick 1993, Lubbering et al. 1991, Monte-Luna et al. 2004, Nyerges 1980, Stuth et al. 1990, Stuth and Kamau 1989, Stuth and Sheffield 1991) is especially important. The concept of carrying capacity (the ecological maximum population a given set of resources can support) is somewhat problematic as a hard-line, deterministic measure because these estimates must be calculated from short-term “snapshots” of the environment and therefore yield higher populations than would be sustainable over the long-term (Monte-Luna et al. 2004). Environments are dynamic, and the number of animals they can support varies both seasonally and over longer periods of time. None-the-less, stocking-rate (carrying capacity) estimates are both quantitative and ecologically-based and therefore are still good starting points for use in models of ancient pastoral land-use. They offer theoretical herd size maxima under ideal environmental conditions, and provide thresholds that separate the possible from the impossible.

3 Study Area

Wadi Ziqlâb, located on the eastern flank of the Jordan River valley in Northern Jordan, is an incised valley with a perennially flowing tributary stream (*'Ayûn Ziqlâb*) which eventually drains into the Jordan River (Figure 1). Much of the modern landscape surrounding the *Wadi* is given over to wheat and legume agriculture, but olives, pomegranates, citrus, and bananas are grown on the terraces in the *Wadi* itself. The current natural vegetation of the *Wadi* can be categorized into three of the phytogeographic zones described by Al-Jaloudy (2006). The lower reaches of the *Wadi* exhibits a Saharo-Arabian vegetation, which includes annual grasses and various hardy forbs (mainly *Artemisia herba- alba, Retama raetam, Achillea fragrantissima, Salsola vermiculata, Atriplex* sp*., Poa* sp*., Carex* sp*, Stipa* sp.). The mid-reaches of the *Wadi* exhibit an Irano-Turanian vegetation (all the former species plus *Acacia* sp., *Ziziphus* sp*., Prospis* sp., and *Ceritonia* sp.), while the higher elevations of the watershed are characterized by a Mediterranean open woodland (*Quercus calliprinos*, *Quercus ithaburensis, Pinus* sp., *Pistachia,* and *Juniper*) interspersed with annual grasses.

The geological, environmental, and archaeological history and the ethnographic present of *Wadi Ziqlâb* is well documented. *Wadi Ziqlâb* is therefore an ideal natural laboratory for the type of modeling that I advocate here. It has been the focus of research for the *Wadi Ziqlâb* Project of the University of Toronto for more than twenty years, and an abundance of data is available (Banning 1982, 1985, 1995, 1996, 1999, 2001, Banning et al. 2004, Field and Banning 1998, Gibbs et al. 2006, Maher and Banning 2001). The Late Neolithic period in the region is typified by dispersed small farmsteads of only one or two households at any one time, and proxy data recovered from excavations in the *Wadi* indicate that the slopes were likely forested by *Pinus* during the Late Neolithic period (Banning 1992, 1995, 2001). The small size and number of these sites means that relatively small pastoral catchments would have been used, thus simplifying the calculations for experimental pastoral catchment analysis. Figure 1 shows the locations of the 3 sites in *Wadi Ziqlâb* with well known Late Neolithic components.

4 Methods and Results

Defining ancient pastoral catchments requires connecting models of ancient pastoral economy with a model of herd animal ecology and a model of paleovegetation. The output catchments must then be independently evaluated by comparing human population estimated based on the resultant profile of herd economy with population estimates derived from other sources. In this study, these outside population estimates will be based on site architecture.

4.1 Paleoenvironmental Reconstruction

A team of plant geographers, archaeologists, and paleoclimatologists associated with the MEDLAND project at Arizona State University have developed a method to retrodict climate patterns, and thus extent of certain vegetation regimes through the Holocene (Hill et al. 2008; Soto et al. 2007). Holocene climate reconstructions are created using the Archaeoclimatology Macrophysical Climate Model (AMCM [Bryson and McEnaney-DeWall 2007]). The output of the climate modeling are used as input in to the Maximum Entropy Model (MAXENT [Poveda et al. 2006]), which combines climatological and topographic data with information about plant phytogeography to predict the location of particular plant communities on a landscape under a given climatic regime. The MAXENT model output for the early Holocene *Wadi Ziqlâb* predicts the extent of Mediterranean, Irano-Turanian, and Saharo Arabian vegetation macro-communities at a one kilometer resolution (Figure 2).

In order to calculate the stocking-rates of prehistoric herds, we must calculate the amount of edible biomass produced by the three different vegetation classes represented on the paleovegetation map created by the MAXENT model. This data is available from the Food and Agriculture Organization (FAO) of the United Nations who report the edible biomass productivity (total kilograms of dry fodder produced per hectare in one year) of different vegetative communities in Jordan (Al-Jaloudy 2006). The FAO data closely matches data from similar vegetation regimes in other parts of the Near East and Africa (e.g., Hocking and Mattick 1993). The average modern productivity values of Jordan's common-use rangelands are arguably lower than those of ancient Near Eastern environments because these rangelands have experienced millennia of grazing pressure and human-caused suppression of vegetation regrowth. Fortunate, Al-Jaloudy also provides data for regions, such as nature reserves, that have been protected from the overgrazing of the last several decades, and thus may more closely represent the productivity of ancient vegetative communities. In these protected areas Saharo-Arabian vegetation produces roughly 150kg/Ha of fodder, Mediterranean vegetation produces 300kg/Ha of fodder, and Irano-Turanian vegetation produces 450kg/Ha of fodder (Al-Jaloudy 2006), and these are the data used in this study.

4.2 Modeling Herd Ecology

Archeology, ethnoarchaeology, and range science inform the model of Late Neolithic herd composition, ecology, and pastoral economy. Although there is some evidence for a sheep dominated herd composition in Eastern Jordan during the Late Neolithic (Garrard, et al. 1996), the evidence from Late Neolithic *Wadi Ziqlâb* as yet precludes a detailed study of the proportions of *Ovis* to *Capra*. The evidence from *Wadi Ziqlâb* and nearby *'Ain Ghâzal* do indicate, however, that by the Late Neolithic domesticated sheep and goats contributed more dietary meat than wild ungulates, that goats were domesticated in the area before the introduction of sheep, and that goats may also have been more numerous than domesticated sheep at the beginning of the Late Neolithic (Banning et al. 2004, Banning 1996, Kohler-Rollefson 1989, Simmons et al. 2001, Rollefson 1992). Ethnohistorical records and ethnoarchaeological research indicates that herd composition varies in modern pastoral groups, being more sheep dominated when pastures are better and wool and market sales of animals is important, and more goat dominated when pasture resources are poorer and the need to draw subsistence from dairy products is important (Khazanov 1994). A modern ethnography of Jordanian Bedu indicate that although flocks are predominantly sheep-based, the ratio of goats to sheep increases along a north to south cline (Blench 1998). Wilson (1982) reports that in Africa, goat to sheep ratio's range from 1.58 in the more humid areas to 0.36 in the Mediterranean zone. Without direct evidence for the Late Neolithic herd compositions of *Wadi Ziqlâb*, it is necessary to model a variety of potential herd ratios. In the light of the ethnographic and archaeological data, I decided to model stocking rates for goat dominated (goat:sheep ratio of 2.0), sheep dominated (goat:sheep ratio of 0.5), and equally mixed (goat:sheep ratio of 1.0) herd compositions for all modeled catchments.

Because range scientists are interested in fodder productivity of specific plots of pasture rather than complete landscapes, the annual fodder requirements of herd animals are calculated differently for graze- versus browse-dominated pastures. This is important because grazeable (grassy and soft-stemmed) plants differ from browseable (herbaceous and woody) plants in both general ecological characteristics and productivity. Also, all else being equal, goats and sheep differ in their preferences for browse and graze. In general, goats prefer browse to graze, while sheep prefer graze to browse. Because the MAXENT model only provides output at the level of large scale vegetation communities, I use an intermediate measure that is effectively the feeding preference of the herd animal in a pasture of equal browse and graze quantities.

Data are available for the ecological characteristics of the most common modern breed of goats (*baladi*) and sheep (*awassi*) in Jordan. These animals are specifically adapted to the Levantine climate and landscape, and differ substantially from other goat and sheep breeds in body size, fodder consumption, and hardiness (Al-Jaloudy 2006, Naga and Abd El-Salam 1988, Nyerges 1980, Stuth and Kamau 1989, Stuth and Sheffield 1991, Wilson 1982). Table 1 summarizes the ecological characteristics of *baladi* goats and *awassi* sheep as well as their fodder intake preferences in browse and graze dominated pastures as reported by Lubbering et al. (1991). It is important to note that the yearly fodder requirements reported in Table 1 are somewhat higher than estimates from data reported by Naga and Abd El-Salam (1988), which yield a yearly fodder intake of 379 kg for goats and 475 kg for sheep, and estimates from data reported by Wainwright (2008), which yield a yearly fodder intake of 370 kg for goats and 507 for sheep. Both Wainwright and Naga and And El-Salam use average sheep and goat body weights that are lower than those reported for *baladi* and *awassi*, and they also report lower daily fodder intake needs. The poor preservation of faunal remains in *Wadi Ziqlâb* precludes an estimate of the body size of Late Neolithic ovicaprids herded in the region. Data from elsewhere in the region suggest that ovcaprids had not yet undergone drastic body size reductions by the Late Neolithic (Haber and Dayan 2004; Kohler-Rollefson 1989; Zeder and Hesse 2000; Zeder 2001), thus I feel that the use of the larger *baladi* and *awassi* breeds are better analogs for Late Neolithic goats and sheep. In any case, it is better to slightly underestimate Neolithic ovicaprid stocking-rates than to grossly overestimate them.

The total scaled amount of graze and browse available for pasture available in a given catchment is derived by multiplying the area of each vegetation community present in the catchment by the scaled fodder productivity for that type of vegetation (Table 2). Like fodder intake, stocking-rate is calculated differently for browse- versus graze-dominated pasture plots. Essentially, stocking-rate equations scale the total annual edible biomass of a given pastoral catchment by the annual fodder requirement of a given herd structure (in ratios of herd animal species). One equation gives preferential weight to available browse, while the other gives preference to graze. Again, because the MAXENT model provides information on large vegetation communities rather than specific species, I calculated stocking-rates using both equations, and took the mean of the two estimates as the general stocking-rate of a particular pastoral catchment (Table 3).

4.3 Modeling Pastoral Catchments

I developed the *r.catchment* module as an addon for GRASS to define realistic agricultural or pastoral catchments of given area around known site locations. This script, written in the cross-platform Python scripting language, uses the GRASS module *r.walk* to calculate a map of walking costs (cost surface) along least-cost routes (least-cost map). These are anisotropic costs (ie., it takes more effort to walk up a slope than it does to walk down that same slope) that are calculated using the variation of Naismith's rules for walking proposed by Langmuir (1984). The walking paths are routed according to Dijkstra's algorithm (Dijkstra 1959) for determining the lowest accumulated cost from the origin to all other cells of the map. More detail about *r.walk* and cost-distance modeling in GRASS can be found in Neteler and Mitasova (2007). The resultant cost surface map is in units of walking time for the average human traveling at an average stride to reach a given spot on the landscape from the point of origin (Figure 3). A catchment is defined from the cost surface map by a time-cost distance isohyet, which delimits all areas of the map that are within a given walking time from the point of origin. The intricate geometry of a catchment boundary defined by a time-cost isohyet prohibits the *a priori* definition of a catchment of a given size, thus *r.catchment* utilizes an iterative cost isoheyt search routine until a catchment of user-defined size is achieved. The search routine is “smart”, in that if the catchment defined by the time-cost isohyet in the current iteration is too large or too small, it will adjust accordingly, testing a catchment defined by a smaller or larger cost isohyet (respectively) in the next iteration. Thus, the routine quickly hones in on the time-cost isohyet that produces a catchment whose area matches the requested area as closely as possible. The module also accepts a slope threshold, and will ignore areas with slopes higher than this threshold when calculating catchments. This function is especially useful for modeling agricultural catchments, as farming is generally done in low slope areas, but this option may be bypassed for pastoral catchment modeling, where slope is irrelevant. I have made the *r.catchment* module available for free download and installation from the official GRASS addon repository (http://svn.osgeo.org/grass/grass-addons/LandDyn/r.catchment.py).

Although other factors, such as cultural preferences and/or constraints about traveling through specific locations or perceived "goodness" of specific areas for grazing are not included, the shape of the resulting catchments are more realistic than simple circular buffer of a given herding radius (Higgs and Claudio Vita-Finzi 1972). Four sizes of pastoral catchments were modeled around the three known Late Neolithic sites at 3, 9, 20.25, and 113 square kilometer—the areas a 1.5, 3, 4.5, and 6 kilometer herding radius (*sensu* Coppolillo 2000) would cover respectively (Figures 4-7 and Table 2).

Table 3 summarizes the carrying capacity herd animal maxima for each catchment size for the three different herd compositions. In a summary of modern nomadic pastoralists, Khazanov (1994) reports that the ratio of caprines to people in pastoral societies relying on their herd animals for a large proportion of their dietary needs is between 20 and 40 animals per capita. Indeed, a recent pan-Jordanian study of household and herd composition among nomadic pastoral *Bedu* reports a mean of 296.7 sheep and 38.6 goats per household (Blench 1998). Blench also reports an average household size of 11.5, which yields a ratio of 29 small ruminants per person. In a more sedentary agropastoral economy, like that of Late Neolithic *Wadi Ziqlâb* (Banning 2001, Banning, et al. 1996), herding may have contributed less to the overall subsistence economy than it does in the case of modern *Bedu*, and thus the ovicaprid to human ratio could have been somewhat lower. To account for any such variation in the importance of herding in the Late Neolithic subsistence economy, I calculated maximum and minimum human populations using ratios of 10 and 30 animals per capita, respectively. Table 4 summarizes the human population estimates for all combinations of herd compositions and pastoral catchment sizes.

5 Discussion

An external population estimate is needed to asses the validity of the modeled population estimates for the different catchment sizes. Such an estimate is provided by Banning (1998, 2003), who's architectural analysis of Late Neolithic houses in the region suggests that 1-3 families lived at each farmstead. The size of the Late Neolithic population in *Wadi Ziqlâb* can then be estimated using the well accepted household size of 6 persons for ethnographic village-based subsistence agropastoralism (Kramer 1980). This means that there were between 6 and 18 people living at each Late Neolithic site at any one time. When comparing Banning's population estimates with those in Table 3, it is clear that the 1.5 km herding radius pastoral catchment would have been too small to support even the most modest-sized Late Neolithic herds, regardless of herd composition. The human population estimates for all three herd compositions from the 3 km and the 4.5 km herding radii overlap well with those derived from architectural data. It is important to note, however, that the population estimates produced by the herd ecology model are *maxima* representing population sizes based on a herding strategy *operating at carrying capacity at a snapshot in time*. The actual sustainable long-term herd sizes would almost certainly have been somewhat less than the estimates returned by this model. That being said, the population estimates returned for the 6 km radius catchment area greatly exceed Banning's estimates, indicating that a catchment of that size was likely bigger than necessarily needed by Neolithic pastoralists. On the other hand, the 3 and 4.5 kilometer radius pastoral catchments leave enough leeway at either end of Banning's population estimates—irrespective of the species composition of the ancient herds—to allow for more sustainable, sub-carrying capacity stocking rates. As human populations in the valley fluctuated, and as the changing economics of agropastoral subsistence influenced herd composition, it is likely that the size of the actual Late Neolithic pastoral catchments fluctuated in response―most probably never getting much smaller than the 3 km nor much larger than the 4.5 km catchments defined here.

6 Conclusion

The lasting effects of pastoral land-use, such as increased erosion, environmental degradation, and large scale environmental change, obscure much of the direct evidence archaeologists typically look for when characterizing prehistoric economies. Models of prehistoric behavior allow the archaeologist to address social and economic phenomena of ancient peoples that are not directly accessible from the archaeological record. These models take the fragments of data provided by standard archaeological work, and seek to fill in the greater story, which is typically missing in the physical record. The model presented in this paper combines data and methods from phytogeography, GIS, computer science, range science, archaeology and ethnography to address a problem that would be impossible to solve with standard archaeological methods alone. The pastoral footprints defined by this study bring us one step closer to assessing the real ecological impact of human land-use of Late Neolithic *Wadi Ziqlâb*. This study has also provided a better understanding of how changes in herd composition and human population affect catchment size, and thus change the scale of any potential pastoral impacts on the local environment. In the future, the methodology presented in this paper can be used to asses hypotheses of prehistoric pastoral economies from different sites and temporal periods. Beyond simpling improving our ability to identify diachronic and interregional variations in pastoral economy, the procedure also provides a framework for testing hypotheses about the cause and character of these variations.

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Tables

Table 1: Ecological characteristics of *Baladi* goats and *Awassi* sheep.

			Browse:Graze Ratio		**Total Fodder kg/year**			
Animal	**Body weight (kg)**	**Daily fodder (kg)**	**Browse Dominated Landscape**	**Graze Dominated Landscape**		**Browse Dominated Landscape**	**Graze Dominated Landscape**	**Equally Mixed Landscape**
Baladi goat	40	2.45	3:2	3:7	Browse	350.4	175.2	*262.8*
					Graze	233.6	408.8	*321.2*
					Total			*584.0*
Awassi sheep	70	1.6	1:1	2:8	Browse	447.1	178.9	*313.0*
					Graze	447.1	715.4	*581.3*
					Total			*894.3*

Table 2: Vegetation extents and fodder amounts within each modeled catchment.

	1.5 km range	**3 km range**	**4.5 km range**	**6 km range**
Area (Ha)				
Irano-Turanian	893	2634	5842	24217
Mediterranean	6	143	512	8277
Saharo-Arabian	*0*	*0*	*0*	*1978*
Total	*898*	*2776*	*6354*	*34473*
Raw Fodder (kg Dry Matter)				
Irano-Turanian	401742	1185176	2628824	10897717
Mediterranean	1701	42775	153600	2483123
Saharo-Arabian	0	0	0	296750
Total	403444	1227951	2782424	13677590
Scaled Fodder (kg Digestable Matter)				
Irano-Turanian	136592	402960	893800	3705224
Mediterranean	578	14543	52224	844262
Saharo-Arabian	0	0	0	100895
Total	137171	417503	946024	4650381

Table 3: Total livestock (stocking-rates) for each catchment size, and herd sizes per site.

Total livestock for all sites combined

Goat:Sheep Ratio	Animal	1.5 km range	3 km range	4.5 km range	6 km range
2:1	Goats	88	267	606	2977
	Sheep	44	134	303	1488
	Total	*133*	*405*	*917*	*4510*
1:1	Goats	93	282	640	3146
	Sheep	93	282	640	3146
	Total	*186*	*565*	*1280*	*6292*
1:2	Goats	38	116	263	1294
	Sheep	76	232	526	2587
	Total	*116*	*352*	*797*	*3920*

Average herd size per site

Goat:Sheep Ratio	Animal	1.5 km range	3 km range	4.5 km range	6 km range
2:1	Goats	13	38	87	425
	Sheep	6	19	43	213
	Total	*44*	*135*	*306*	*1503*
1:1	Goats	13	40	91	449
	Sheep	13	40	91	449
	Total	*62*	*188*	*427*	*2097*
1:2	Goats	5	17	38	185
	Sheep	11	33	75	370
	Total	*39*	*117*	*266*	*1307*

Table 4: Population estimates for each modeled catchment based on animal to human ratios derived from ethnoarchaeological study of pastoral economies.

Goat:Sheep Ratio	1.5 km range	3 km range	4.5 km range	6 km range
2:1	1 – 4 people	4 – 13 people	10 – 31 people	50 – 150 people
1:1	2 – 6 people	6 – 19 people	14 – 43 people	70 – 210 people
1:2	1 – 4 people	4 – 12 people	9 – 27 people	44 – 131 people

Figures

Figure 1: The location of the *Wadi Ziqlab* study area in northern Jordan, and the location of the three known Late Neolithic sites within the *Wadi*.

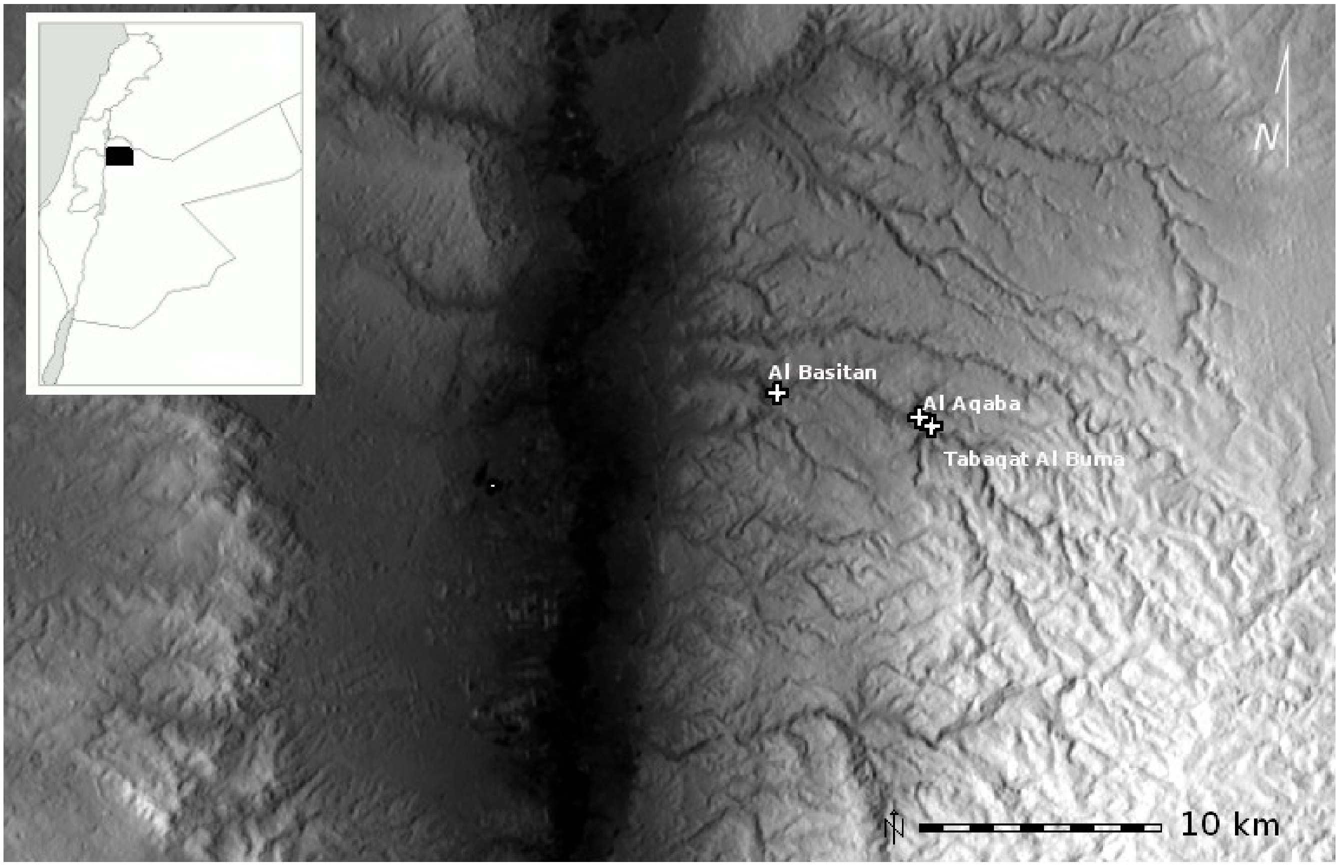

Figure 2: Early Holocene MAXENT model of the three major vegetation communities included in this study.

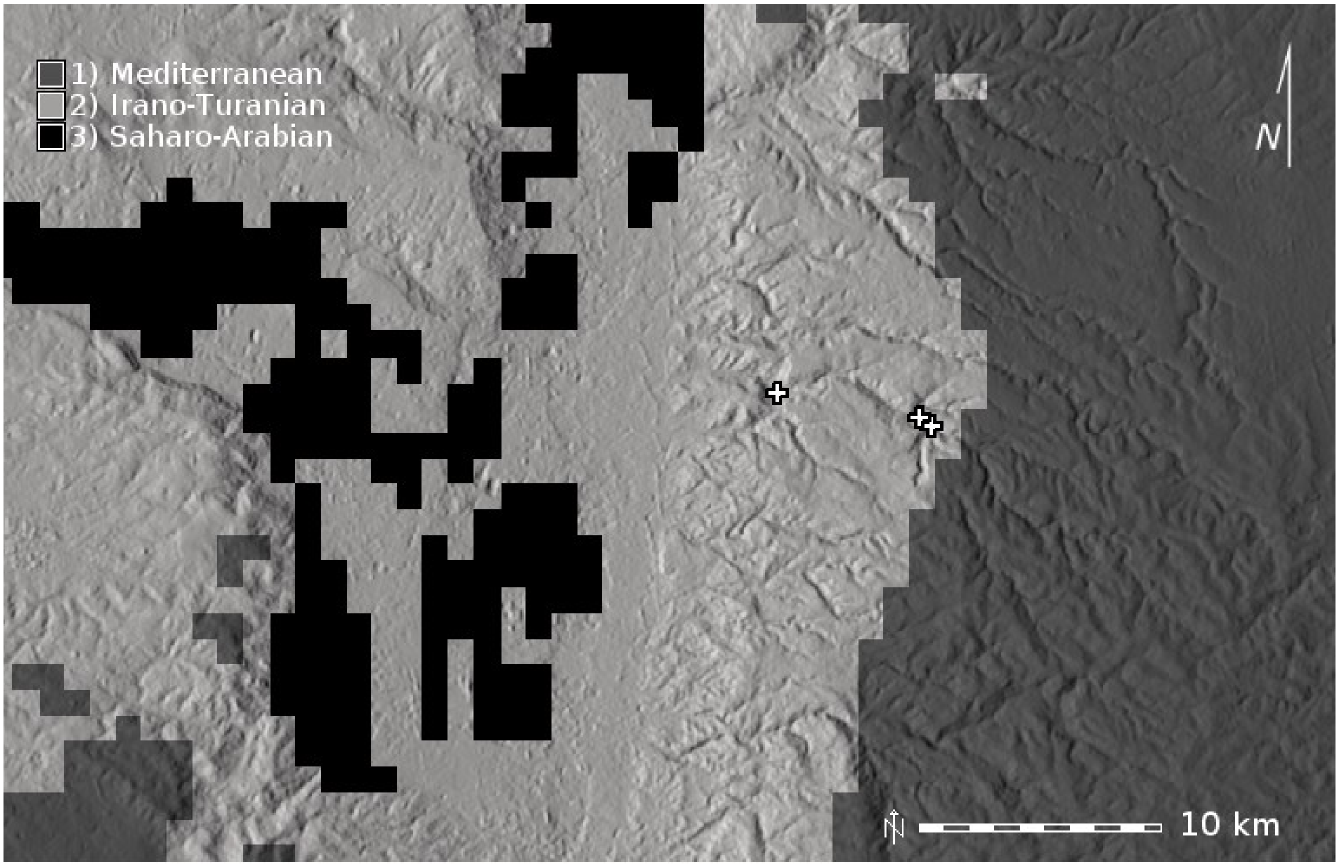

Figure 3: Map of anisotropic walking costs (in hours) used as the basis for delimiting the catchments used in this study.

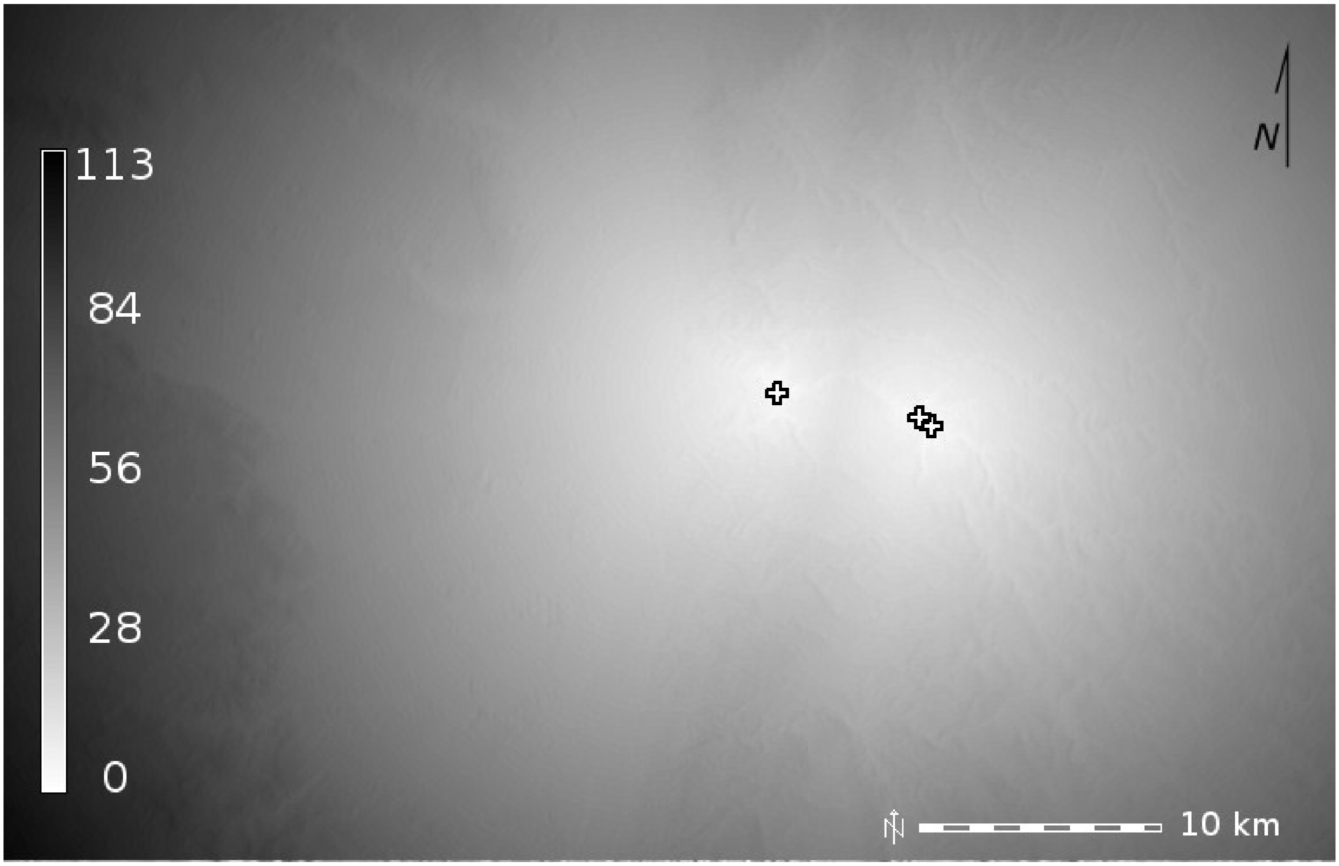

Figure 4: 1.5km herding radius catchment.

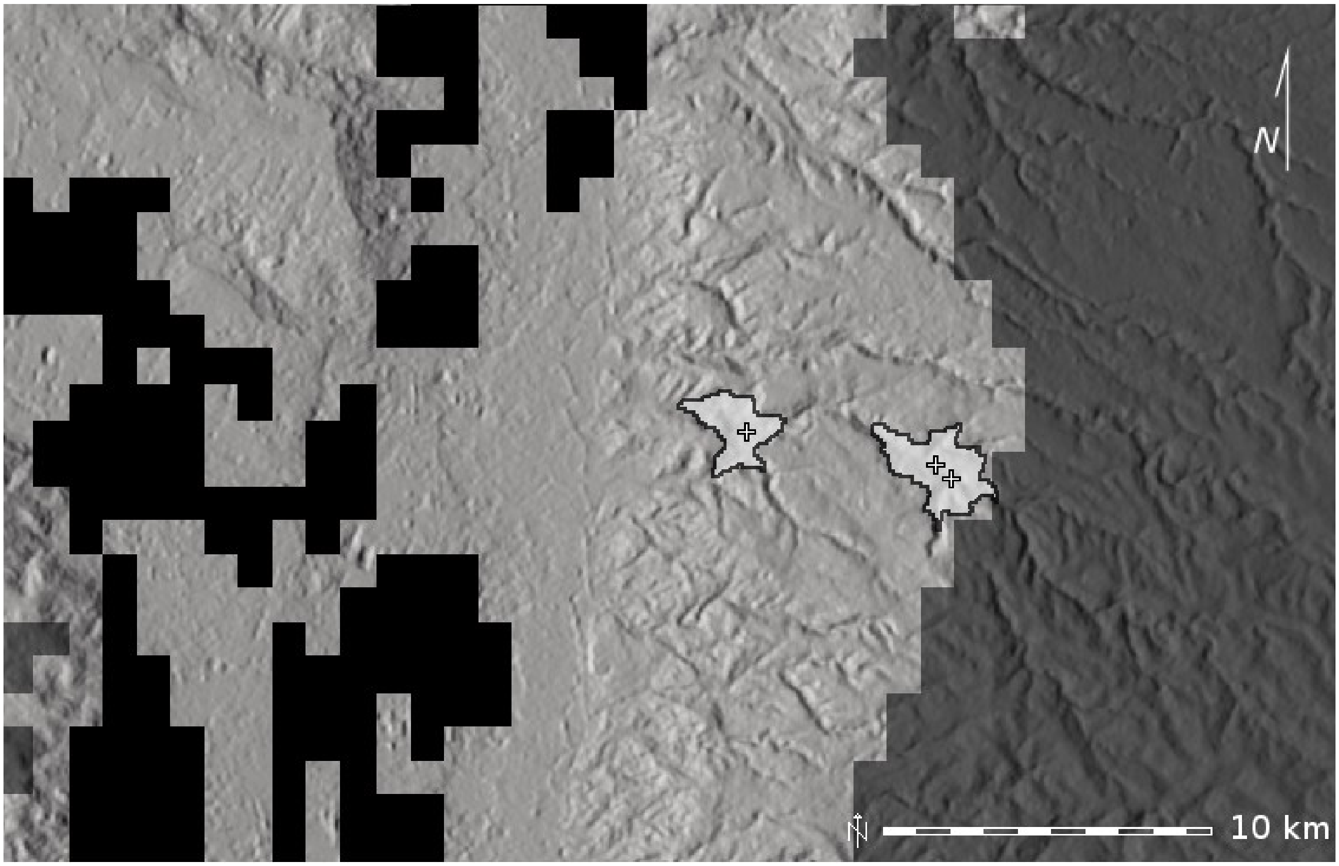

Figure 5: 3 km herding radius catchment.

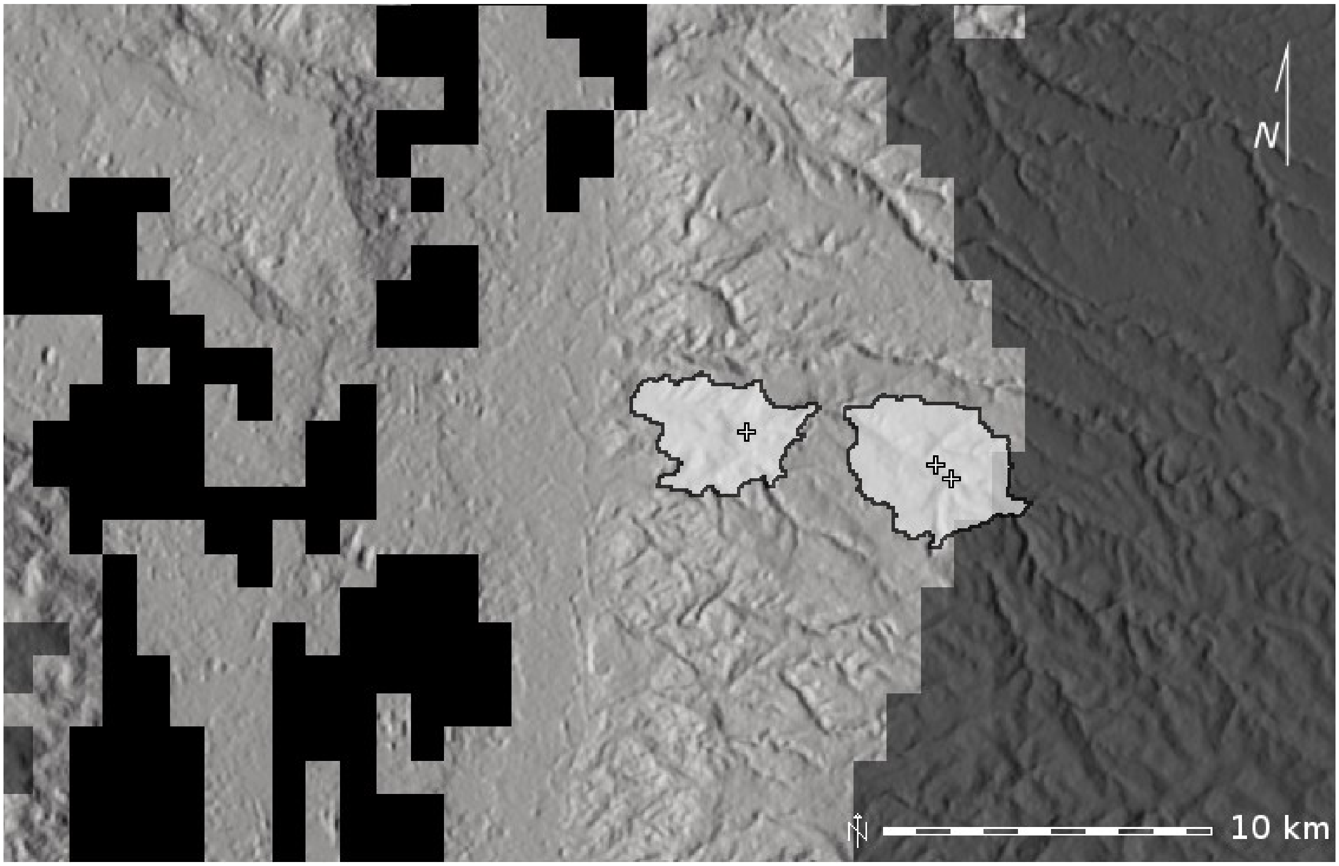

Figure 6: 4.5 km herding radius catchment.

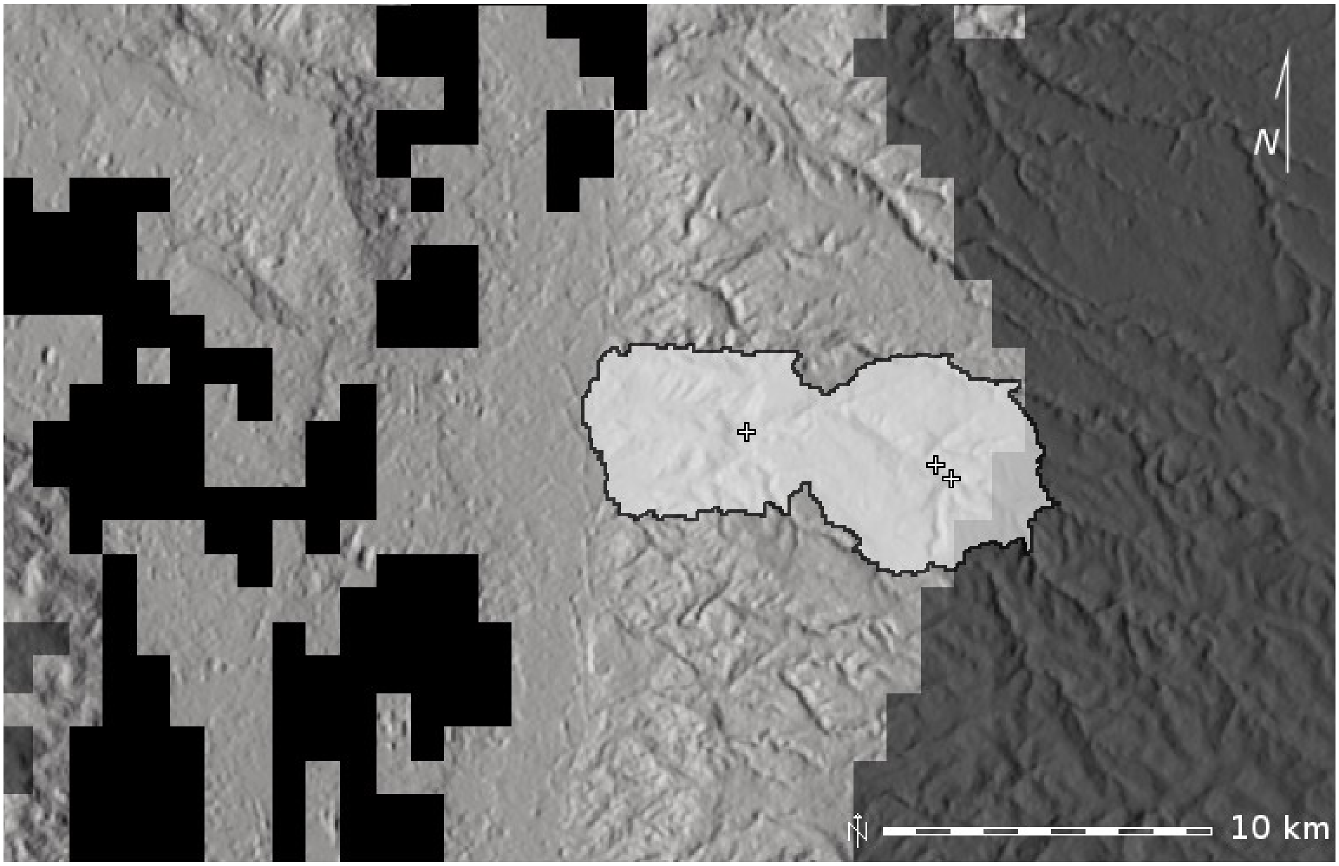

Figure 7: 6 km herding radius catchment.