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Tracking Mobility in the Syrian Desert. Potential of Simple Features for Mapping Landscapes of Mobile Pastoralists

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Abstract

This paper presents a brief overview of an archaeological prospection in the steppe of eastern Syria based on high-resolution satellite images. While earlier research often stressed the extremely limited visibility of nomadic pastoralists in the archaeological record this study illustrates the high density of nomadic traits in arid areas which can be traced in satellite imagery. Using Ikonos (1m) imagery, a 200 km2 study area 125 km southeast of Palmyra, Syria, was visually searched for evidence for nomadic use of the steppe. Features such as abandoned tent sites, animal feeding sites, stone corrals, cross-wall fields and animal trail networks centered on wells (piospheres) could be readily identified due to their simple characteristic signatures:

- Abandoned tent sites appear as small, regular white (high-reflectance) or sub-white colored rectangles. In just the small study area over 2300 tent sites were visually plotted.
- Sheep are herded together by pastoralists for feeding and drinking where thick layers of dung accumulate. The resulting features are typically dark brown and have a diameter of about 35m.
- Given sufficient rainfall the pastoralists engage in rainwater-harvesting—parallel alignments of low retaining walls in the flat beds of wadis disclose this mode of farming.
- Vast radial networks of narrow animal trails centering on wells, form dramatic patterns over several kilometers. However, as a single piosphere with a radius of six kilometers is composed of around five thousand linear elements it is not efficient to manually map these features in detail.

The tent site rectangles, the circular brown dung patches, the parallel lines of wadi walls and the radial linear piospheres are highly suitable for semi-automated detection due to their simple form, the repetition and configuration of the form and their sheer abundance against the background of a largely uniform barren steppe landscape. This range of features will be of particular interest to scholars looking for a body of data with which to test algorithms in semi-automated archaeological prospection with good chances of achieving high levels of detection. Semi-automated pattern recognition would thus be an efficient method to map the extensive patterns of nomadic activity known to exist and assist in documenting range degradation in arid landscapes across the Near East.

Key words: *satellite imagery, prospection, pastoral nomads, pattern recognition, arid landscapes*

1 Introduction

The research program "Difference and Integration" deals with the interrelation between nomadic and sedentary peoples in the past and present.[1] This paper concerns the results of a systematic visual scan of Ikonos-2 satellite imagery in the search for

[1] Collaborative Research Center (SFB 586) conducted by the universities of Halle-Wittenberg and Leipzig, Germany, www.nomadsed.de.

traces of interaction between nomads and sedentary peoples in the arid hinterland of the ancient Roman oasis city of Palmyra in central Syria.[2] This search has been very fruitful but at the same time it has become apparent that more efficient recording systems are required in order to handle the vast quantity of visible traces which have accumulated up to modern times. [3]

Sites of abandoned camps, stone enclosures, linear cross-wadi field walls and animal trails are basically simple features which are complex only in their repetition and possible subsequent superposition. The application of image algorithms enabling computers to perform automated detection of these frequently recurring features could provide the way forward not only for this research — but also provide a good testing ground for the advancement of semi-automated detection in archaeology in general.

Algorithms have, for instance, been developed to filter out shapes using shape and edge detection to identify feature outlines and the edges of walls.[4] Contour-tracing algorithms have been developed and used for boundary based shape matching.[5] Some research has been made on parallel line extraction, especially extracting roads from maps.[6] Blob or spot detection compares the feature's color to its background[7] and template matching involves comparing the image with images of archive examples or simplified schematic diagrams.[8]

2 Wadi al-Miyah Study Area

The tiny 210 square km study area is located 130 km southeast of the Roman oasis city of Palmyra amid the vast yellow-brown expanse of the Syrian steppe. As this border area is at the moment inaccessible for fieldwork no direct ground-truthing is possible. Proxy data acquired by field checking feature anomalies in a neighboring highland area (Norwegian concession) 12-97 km northwest of Palmyra go some way to mitigating this deficit.

The study area is deliberately positioned on the Wadi al-Miyah as it is here where Antoine Poidebard in the 1920s documented a remote 20 km line of closely set towers and forts deep in the steppe which he ascribed to the Roman period and specifically part of the Eastern Limes of the

[2] This survey (sub-project D7) is directed by Prof. Stefan R. Hauser.

[3] See Roger Cribb, *Nomads in Archaeology* (Cambridge: Cambridge University Press, 1991), for the occurrence of nomads in the archaeological record, and Tony J. Wilkinson, *Archaeological Landscapes of the Near East*. (Tucson: University of Arizona Press, 2003), for a thorough survey of landscapes, and landscape survey in the Near East.

[4] Rosa Lasaponara and Nicola Masini, "On the Potential of QuickBird Data for Archaeological Prospection," *International Journal of Remote Sensing* 27, no. 16 (2006): 3607; Rosa Lasaponara and Nicola Masini, "Detection of archaeological crop marks by using satellite QuickBird multispectral imagery," *Journal of Archaeological Science* 34, no. 2, (2007): 214.

[5] S. Redfern and G. Lyons, "The Application of Digital Techniques to the Detection and Extraction of Archaeological Earthwork Monuments from Aerial Photographs," (2000), http://www.it.nuigalway.ie/TR/abstracts/./papers/sr1.ps.gz.

[6] Takafumi Miyatake, "Extraction of Roads from Topological Maps Using a Parallel Extraction Algorithm," *Systems and Computers in Japan* 16, no. 6 (1985): 77; William Tompkinson et al. "A 'primitive' view of image interpretation for automated mapping," (2005), http://www.ordnancesurvey.co.uk/ oswebsite/partnerships/research/publications/docs/2005/wtompkinson_GISRUK018_rs.pdf.

[7] Bjoern Menze, B. Michael Kelm and Fred A. Hamprecht, "From Eigenspots to Fisherspots - Latent Spaces in the Nonlinear Detection of Spot Patterns in a Highly Varying Background," in *Advances in Data Analysis. Proc. of the 30th Annual Conference of the German Classification Society (GfKl), Free University of Berlin, March 8-10, 2006*, eds. Reinhold Decker and Hans-Joachim Lenz (Heidelberg-Berlin: Springer-Verlag 2007), 255-262.

[8] Siri Ø. Larsen, et al., "Detection of Ring Shaped Structures in Agricultural Land Using High Resolution Satellite Images," in *GEOBIA 2008 — Pixels, Objects, Intelligence. GEOgraphic Object Based Image Analysis for the 21st Century. University of Calgary, Calgary Alberta, Canada, August 05-08*, eds. Geoffrey J. Hay, Thomas Blaschke and Danielle Marceau, ISPRS XXXVIII-4/C1 (2008), http://www.isprs.org/commission4/ geobia2008/Sessions/Session9/6654_Larsen_Proc_pap.pdf.

Roman Empire.[9] At Oumm as-Selabih the line of the main Roman road crosses the Wadi al-Miyah on the Palmyra-Hit-Baghdad route. It is here that the nomadic world encounters the domain of the sedentary Palmyrena.

3 Distribution of Features

2.1 Tent sites

The reverse L-shaped Ikonos-2 image[10] forms the basis of the survey area and is made up of two tiles. The lower horizontal block was recorded in summer 2003 (July 15th 2003 08:27 GMT) and the vertical block in the autumn of the same year (October 19th 2003, 08:23 GMT).[11]

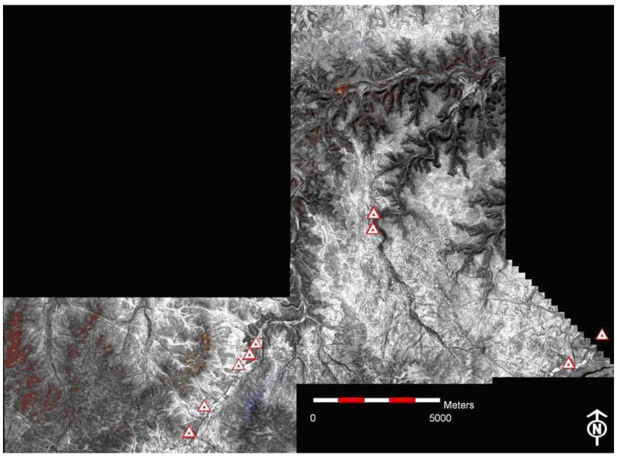

Figure 1: Distribution of tents (triangle symbol), Wadi al-Miyah, Syria.[12]

The darker areas are a dendritic network of wadis of the Wadi al-Miyah system which are cutting down through the gently undulating lighter terrain of the plateau before draining towards the northeast into the 130 km distant Euphrates.

Although sites of singular tents are common the typical contemporary Bedouin tent unit consists of a pair of tents: a long rectangular tent for living and sleeping, and a smaller squarer tent sited some meters away for food preparation. Tent sizes vary considerably, the larger rectangular tents have average dimensions of 25 x 7 m (n. 8) and the smaller squarer tents, on average sited 13 m distant, measure 11 x 5 m (n. 6). In contrast to the visible pitched tents (fig. 1) the sites of abandoned tents number over 2,300 — which, even allowing for tent pairs being counted as two single tent units, reveals a remarkably broad and dense distribution (fig. 2).

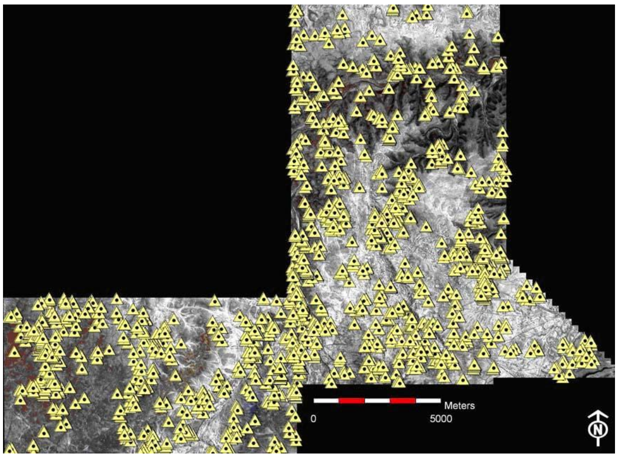

Figure 2: Distribution of tent sites (triangle symbol), Wadi al-Miyah, Syria.

Normally the tent site signature is easily located; however, some areas of the raised plateau are equally reflective which effectively mask the reflectance from the tent floors — thus, this count must be regarded as approximate. Abandoned sites of tent pairs typically appear as two white rectangles.

Compacted by trampling these shapes are often extended by activities in front of the tent so that the

[9] Antoine Poidebard, *La Trace de Rome dans le désert de Syrie. Le Limes de Trajan a la Conquête Arabe, Recherches Aériennes 1925-1932.* (Paris: Paul Geuthner, 1934).

[10] Illustration credits: Figs. 1-7, 9-10 Ikonos2, includes material ©2003, European Space Imaging GmbH. All rights reserved; Fig. 8 (left) QuickBird satellite image, ©2004 DigitalGlobe, Inc., distributed by Eurimage; Fig. 8 (right) Courtesy of the UCL Institute of Archaeology.

[11] The coordinates of the rectangular scene are: south-west corner: 529440,99 / 3757500,52 m, north-east corner 553352,00 / 3775065,50 m (WGS84 UTM, 37N).

[12] Except Fig. 8, all images include material © European Space Imaging GmbH, all rights reserved.

characteristic footprint is often significantly larger in the imagery than the area which would have been enclosed by the tent. Sometimes a narrow footpath can be discerned on the eastern, leeward side — facing towards an adjacent wadi. Sites of pairs of tents typically measure between 20-25 m and 12-14 m in length, respectively (fig. 3).

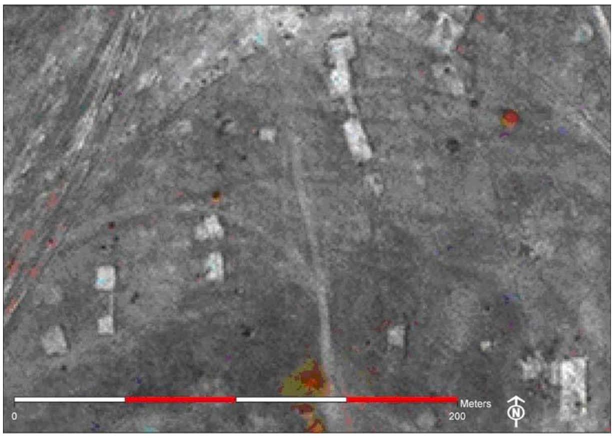

Figure 3: Pairs of abandoned tent sites, Wadi al-Miyah, Syria.

2.2 Dung patches of herding sites

A typical feature associated with abandoned tent site clusters is a large dark oval spread of dung and other organic debris typical of a herding site where animals might be kept safely overnight (fig. 4). Comparison with Google Earth ™ imagery recorded five years after our Ikonos imagery has shown that these trace signatures of tent sites and dung patches persist.

The algorithmic potential of the tent sites lies in their typical shape, proportions, orientation and tendency to spatial concentration.

Dung patches of 30-40 m diameter are frequently found on the edge of the plateau/crest of a slope overlooking a wadi sometimes with and sometimes without adjacent tent sites. The brown patches are persistent and easy to recognize where they contrast with background colors and are less susceptible to be masked by reflected light. Their algorithmic potential lies in their typical shape and dimensions and spatial context in camps and/or in respect to topography.

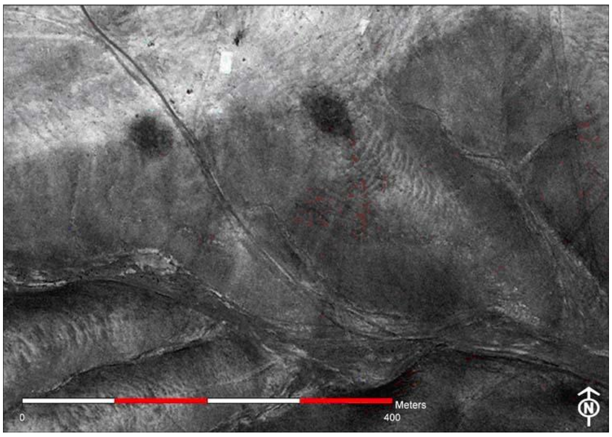

Figure 4: Tent sites near dark dung patches, Wadi al-Miyah, Syria.

2.3 Stone enclosures

Whereas the dung patches simply show a general tendency to be sited close to wadis, stone enclosures, which were probably used as corrals for penning animals, are almost exclusively found at well-drained, south facing, mid-slope locations where outcrops of surface rubble would be easily accessible for building. In the imagery the enclosures are characterized by a dark sub-circular linear feature (fig. 5). When abandoned, the interior is normally the same color as the exterior. Different colors of interior and exterior may indicate recent use. Stone robbing of minor rubble structures is inconsequential in the remote steppe so that monuments may survive for hundreds of years.

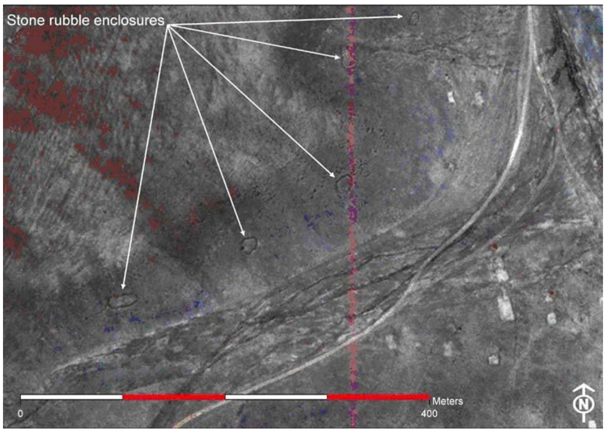

Figure 5: Row of stone enclosures situated on south facing slopes, Wadi al-Miyah, Syria.

Nevertheless, as rubble enclosures are still built even today there remains no sure way to date sub-oval enclosures on morphological characteristics alone. Their algorithmic potential lies in their typical shape and dimensions and to some extent their spatial context.

2.4 Cross-wall fields

To facilitate water harvesting low, narrow walls have been built perpendicular to the wadi flow to slow flash floods and hinder the erosion of sediments. In a good year sufficient water is retained in the saturated sediments (which minimize evaporation) for a modest crop.[13] Tent sites generally are found to cluster in the vicinity of cross-wadi walled fields which are commonly found in the broader middle reaches of wadis, below the lower catchment of the source areas and above the incised channels where raging torrents would demand too high maintenance as a return on invested labor.

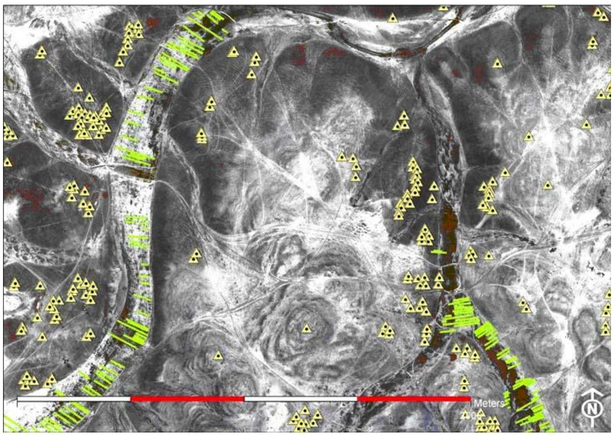

Figure 6: Tent sites (triangle symbol) near cross-wall fields (line symbol) in Wadi al-Butmiyah, Wadi al-Miyah system, Syria.

Viewed in the context of the location of the fields the siting of the eight erected tents takes on a new significance (fig. 6) — it appears that the nomads have deliberately pitched all their erected tents at locations close to cross-wall fields, perhaps in order to exploit the potential gain from grazing remnant stubble. The cross-wall barrier itself, or the vegetation supported by the higher moisture retained, produce distinctive ladder-like patterns of semi-buried narrow lines which structure the wadi bed. The algorithmic potential of cross-walls lies in their linearity, parallel orientation, typical shape and dimensions, and the wadi floor spatial context.

2.5 Animal trails

Tracks and trails of motorized vehicles have in their short space of time left extensive scars in the Earth's surface. If one looks closer between the vehicular tracks other straight and narrow trails come into view which have been formed by herded animals, notably sheep, trampling straight trails as they are driven between resources such as good pasture, wells, or simply the nightly shelter of the campsite. The regular patterning of drove trails is markedly distinct from the often singular, curvilinear and cautious path taken by vehicles (fig. 7). When viewed at a large scale drove trails appear characteristically as bands of parallel lines which are directly aligned towards known destinations with little regard to topography.

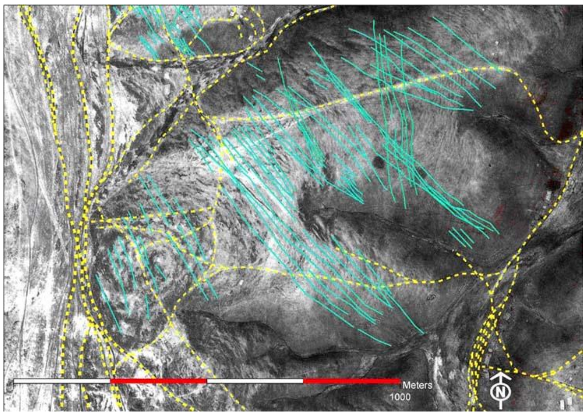

Figure 7: Comparison between vehicular tracks (broken line) and parallel animal trails, Wadi al-Miyah, Syria.

However, when viewed at a smaller scale some of the trail segments are found to group together and

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[13] David Gilbertson and Chris Hunt, "Romano-Libyan agriculture: walls and floodwater farming," in *Farming the Desert: The UNESCO Libyan Valleys Archaeological Survey, Vol. 1, Synthesis*, eds. Graeme Barker, David Gilbertson, Barri Jones and David Mattingly (London: Society for Libyan Studies; Paris: UNESCO, 1996) 191–225.

converge to form vast radial networks. As the networks typically form around wells they have acquired the name piospheres.[14] In more recent studies the term piosphere is applied to any concentrator.[15]

Trails are an abundant resource which can articulate the solitary tent sites, corrals, stone structures and fields they connect and at the same time draw attention to those they ignore. Due to their sheer size and abundance piospheres bring with them problems for efficient documentation and recording over time.

Progressively better resolution in available imagery brings with it progressively more data which, as even this minute study area has shown, is too abundant to efficiently gather visually — semi-automated detection could be a way forward.

Although there has already been some work on developing algorithms to model the general formation of piospheres in modern rangeland management[16] they have been rather neglected in archaeological landscape survey even though they must have also existed in the past to some extent and played a significant role in the structuring and use of space.

At a large scale the algorithmic potential of trails lies in their linearity, parallel orientation, typical shape and relative dimensions. Following initial feature extraction piospheres and regional communication and transit routes could be identified by applying detection tools at smaller scales of regional analysis.

Trails revealed on a modern QuickBird satellite image and overlapping trails traced from a Royal Air Force aerial photograph taken close to the Arsacid city of Hatra (Iraq) shed some light on their persistence that has been enabled by repeated usage over a span of at least seventy years (fig. 8).

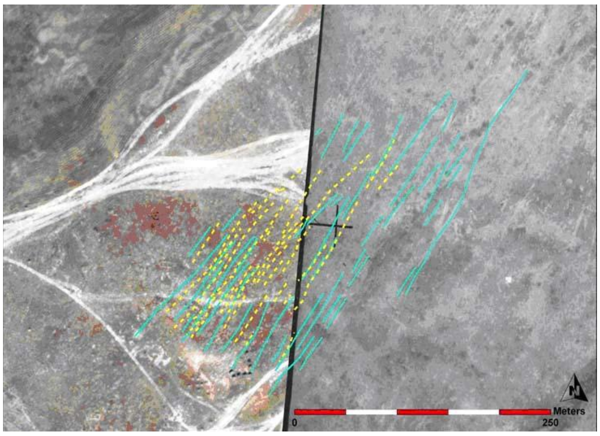

Figure 8: Trailed route (left: QuickBird 2004, light-colored lines; right: Royal Air Force 1938 Hatra, Iraq, dark lines).

However, only in hyper-arid environments, like Namibia, can trails survive over extended periods of time.[17] Even the meager 100 mm of rainfall in the Wadi al-Miyah in a good year is still too much to allow for their long-term survival. Trails survive by being reinforced. Through their successive reuse the cognitive information is relayed that a route holds promise and, as the Hatra image indicates, this may persist over significant time spans. Thus recent trails should not be neglected but also incorporated into archaeological landscape analysis.

Around Hatra ancient hollow-way routes radiate out from the major gateways which in turn serve, by accident or design, to structure the landscape. Similarly the Roman roads in the hinterland of Palmyra structure the steppe — which is now further complicated by a lattice of additional off-road trail-route conduits. Trails of transit as the nomads engage in their annual migratory cycle, everyday trails between pasture and water and the security of the camp, and short trails of

[14] Robert T. Lange, "The Piosphere: Sheep Track and Dung Patterns," *Journal of Range Management* 22 (1969): 396.

[15] Robert A. Washington-Allen et al. "Remote Sensing–Based Piosphere Analysis," *GIScience and Remote Sensing* 41 (2004): 136.

[16] Robert A. Washington-Allen et al. "Remote Sensing–Based Piosphere Analysis," *GIScience and Remote Sensing* 41 (2004): 136.

[17] Jan Boelhouwers and Theo Scheepers, "The role of antelope trampling on scarp erosion in a hyper-arid environment, Skeleton Coast, Namibia," *Journal of Arid Environments* 58 (2004): 545.

convenience between two valleys or across uneven terrain.

Then as now there would have been good reasons to use the highways of the desert (speed) and there would have been good reasons to avoid them (banditry, taxation, administrative control, unreliable/exhausted pastures/ wells). In taking a multi-scaled perspective it is possible at a large scale to integrate nomadic structures in the landscape of the Roman state, which in turn shed light on their *raison d'être* situated on the Wadi al-Miyah.

4 Pattern Recognition

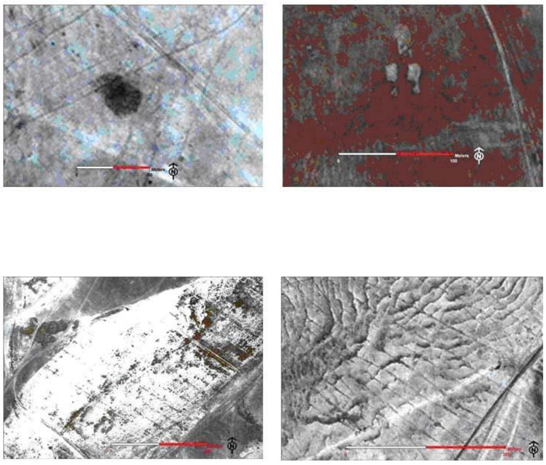

Figure 9: Recurring patterns — standard images, (top left: herding site; top right: tent sites; lower left: cross-wadi walls; lower right: parallel trails), Wadi al-Miyah, Syria.

We have seen how complex patterns are based on simple recurring shapes (fig. 9). Which algorithms will bring the best results will be a matter of trial and error — here are a few suggestions: For tent sites shape and specifically edge detection might be suited to pick up the regular rectangular form and consistent north-south orientation. Circular herding sites could be identified using a shape and color based blob detection. Due to their small size and narrow perimeter stone enclosures present a more challenging target — template matching or contour tracing of object boundaries might be more useful here. To locate linear cross-wadi field boundaries and parallel trails — edge, line or parallel line algorithms could potentially recognize not only the linearity, parallel orientation, typical shape and dimensions but the expected spatial context on the wadi floor could be used to narrow the search domain. Following manual cleaning, the trail data could be automatically scanned for regional scale patterns such as piospheres and routes.

5 Conclusions

The use of semi-automated pattern recognition holds great potential for efficiently dealing with the increasingly detailed imagery we have at our disposal and for extracting the information the imagery contains. The Syrian steppe would make a good test-bed for semi-automated detection as here are features which can be well defined in terms of their shape, size and orientation, and to some extent their restricted spatial context (cross-wadi walls).

In contrast to intensively used agricultural areas the steppe provides an extensive, largely uniform background against which our readings of signatures of the sites of tents, herding places, fields, and tracks of mobile pastoralists could be assisted by computerized pattern recognition.

Visual landscape mapping transforms our perception of the steppe from an empty arid desert to a peopled landscape in flux (fig. 10).

Semi-automated mapping of recurring patterns over extensive areas of steppe would enable new insights into how arid landscapes are used and structured in recent times as well as in the remote past.

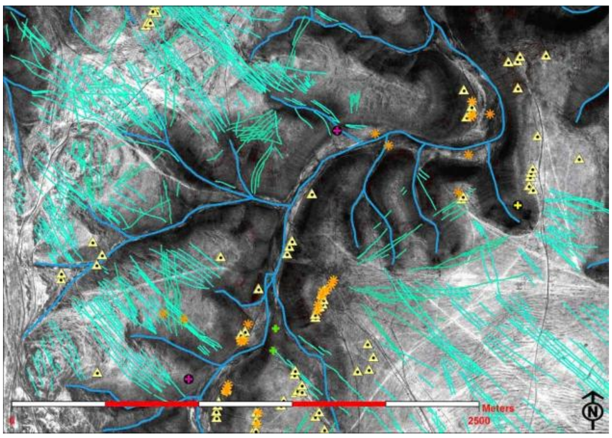

Figure 10: Fluxscape, Wadi al-Miyah, Syria (Legend: stone structure — cross symbol, dung concentration — radial symbol, tent site — triangular symbol, animal trails — straight parallel lines).

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