SITE CATCHMENT ANALYSIS APPLIED TO THE PASTORAL LANDSCAPE OF JEBEL BISHRI IN SYRIA BY USING QUICKBIRD SATELLITE IMAGERY AND ASTER-DEM DATA

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ABSTRACT:

Site catchment analysis has usually been executed in archaeological studies pertaining to hunter-gatherer economies and site resource basis within a certain radius of a distance. It was initially introduced to archaeology by C. Vita-Finzi and E. Higgs. The Finnish project SYGIS carrying out archaeological prospecting, surveying and mapping on the mountainous region called Jebel Bishri in Central Syria, decided to apply the analysis to ancient curvilinear stone enclosures known as pastoral corrals or pens and environmental areas surrounding them. Our aim is here to identify the pens, study their distribution and the potentials of the surrounding grazing grounds by using remote sensing and GIS (Geographic Information Systems). A general overview of the present land cover was produced from Landsat images using cluster analysis. Because of its high spatial resolution a QuickBird satellite image covering 8 km x 8 km of the mountain was utilized in prospecting the corral sites, capturing their location information and studying their distribution in the landscape. ASTER-DEM was used in analysing the topography and a one to two hour's walking radius surrounding each corral site. The analyses elucidate the preferred locations of the corrals in respect to grazing potential. Most of the sites are situated more or less within one kilometre's radius from a *wadi,* a seasonal water way. Areas furthest to the East offered the largest concentration (ca. 50 %) of the corrals, apparently because of a proximity to large *wadis* and the longest distance to a desert line and spreading sands coming from the West and the Southwest.

1. INTRODUCTION

Like hunter-gatherers, pastoral nomads are mobile in their life style and are dependent on natural resources available, but they are more flexible than sedentary agriculturalists for seasonal and even long-term changes in the environment. The mobility of pastoral nomads depends on the subsistence economy based on flock rearing, which in turn needs sufficient space for grazing. Environment dictates the available plants and animals for hunter-gatherers to use. For pastoralists the subsistence economy is directly based on animals, but the type of animals used has been chosen also with respect to the environment. The cow and sheep/goat pastoralists tend to live in association with agricultural areas and often have mixed type of economies in which cultivation plays a smaller or larger role depending on the availability of arable land and water. Cows and sheep are animals suitable for short distance grazing compared to camel that can travel long distances across deserts. The maximum period for which livestock can be without water in the summer season is approximately three days for goats/sheep, four days for donkeys and twelve days for camels (Heathcote, 1983: 93-94).

The mountainous region of Jebel Bishri in Central Syria has been the focus of the Finnish project SYGIS (the Syrian Geographic Information Systems) since 1999/2000. The project has used satellite images in archaeological prospecting, surveying and mapping the mountain region covering ca. 1 million ha between the Euphrates river and the Syrian Desert. (see Lönnqvist and Törmä, 2003, see also: www.helsinki.fi/hum/arla/sygis) The area consists of desert-steppe falling under the 200 and 250 mm isohyets and has been occupied by the mobile people, such as hunter-gatherers and pastoral nomads, for millennia.

Figure 1. Ancient stone enclosures (Site **F 22**) identified as animal pens also known as pastoral corrals in the study area of Jebel Bishri. Photo: Minna Lönnqvist 2008

"The site catchment analysis" was initially developed by C. Vita-Finzi and E. Higgs (1970) to study ancient hunter-gatherer mobility and subsistence in order to see the radius of movement from camps, taking the topography of the area into account. The method explores human – environment relationship. Apart from studying the hunter-gatherer economy the site catchment analysis has been earlier applied to the studies of site locality in relation to ancient agricultural potential and use of animals (Barker 1985). In our project we decided to apply the analysis to ancient curvilinear stone enclosure sites known as animal pens, pastoral corrals (see Fig. 1.), and environments surrounding them. Stone-built enclosures like corrals are common nomadic structures in the Near East, but some corrals in Iran and Afghanistan have been made of mud (Cribb, 1991: 96). In his aerial images Yann Arthus Bertrand also offers a vivid example of corrals of the present-day Peul nomads and their huts at Timbuktu in Mali (see: http://www.yannarthusbertrand2.org.). The layouts of these corrals and huts find parallels with the ancient sites of Jebel Bishri.

The aim of the present paper is to identify the corrals, study their position and distribution as well as the potential of the surrounding grazing grounds in the pastoral landscape of Jebel Bishri. GIS (Geographic Information Systems) has become an efficient tool to execute predictive models and simulations in archaeology including the site catchment analysis (Savage, 1990). Availability of space-born data offers excellent possibilities to study the environment and execute GIS analyses. First we decided to use cluster analysis with Landsat images to provide a clearer evidence of the present potential of the environmental areas of the mountain taking into account differences in seasons. Because of the high spatial resolution of the QuickBird images (0.6 m), they offer possibilities to trace, locate and record even flimsy structures left by mobile societies. DEM tiles from ASTER-DEM (ASTER Digital Elevation Model data) provides topographical data needed for the site catchment analysis. A satellite map with a scale of 1: 100 000 constructed by the Technische Fachhochschule, Berlin (Meissner and Ripke, ed. 1995) is used in locating elevation contour lines and seasonal water courses, such as *wadis*, on Jebel Bishri.

In its central regions Jebel Bishri had largely archaeologically remained a kind of *terra incognita* before the Finnish studies. Moreover, the existence of stone enclosures in the neighbourhood (Dussaud, 1929; Buccellati and Kelly-Buccellati, 1967; Zarins, 1992) has been known for decades, but exact location information has not been published before our project. On Jebel Bishri the size of the enclosures surveyed and recorded on the ground are ranging from 5 to 20 m in diameter, and according to our studies they form the second commonest archaeological structure type on the mountain proper, the cairn/*tumulus* tombs being the most common category of the structural remains. Most of the stone circle sites can be classified as corrals, but some of them may have served as bases of prehistoric huts of hunter-gatherers. These may later have been reused as corrals thus serving as multi-period sites. Some stone enclosures form megalithic rings that may be associated with ancient ritual worlds. (See Lönnqvist *et al.*, 2006).

2. CLUSTER ANALYSIS FOR DISPLAYING THE PRESENT ENVIRONMENT AND ITS POTENTIAL

The study of the present environment of Jebel Bishri was carried out with Landsat images taken in different years; the ancient situations were predicted from the availability and nature of the archaeological structures as it was not permitted during our surface survey to excavate and to acquire soil samples for archaeobotanical studies and thus collect proxy data for palaeoenvironmental reconstructions. Taking into account some short periods of climatic fluctuations, our studies indicate that generally the area of Jebel Bishri has been steppe and desert-steppe throughout the Holocene – the area has potentially been woodland steppe at some point (Lönnqvist *et al.*, 2006).

A general overview of the present land cover was acquired using cluster analysis (Figs. 2. - 5.). In the cluster analysis, or unsupervised classification, the image pixels have been divided into categories or clusters according to their spectral similarities. The principle used is that the spectrally similar pixels belong to the same cluster, whereas different pixels belong to different clusters. When clusters had been formed, they were interpreted by comparing them to their satellite images, or to reference images such as those presented in aerial images or maps, or ground survey data. The Landsat TM and ETM images were clustered into 30 - 60 clusters using k-means algorithm (Richards, 1993). The clusters were interpreted by comparing them to satellite images and then determining the most likely land cover type.

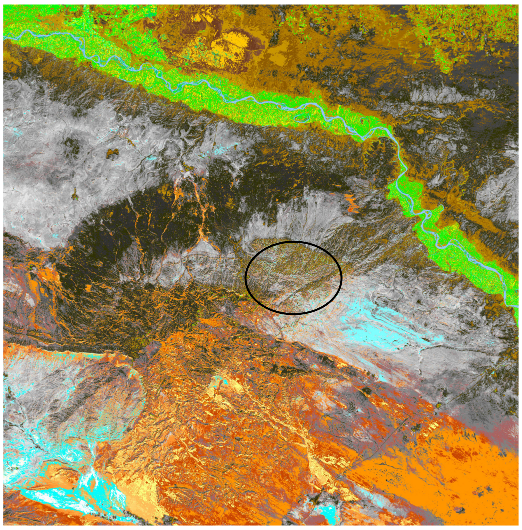

Figure 2. The cluster analysis of the vegetation cover of Jebel Bishri area carried out by using a Landsat-7 ETM image, taken in January 1999. The target area of the study in this paper is circled in the centre. Note the large area under desertification covering the Southwestern part of the mountain. Data© Eurimage.

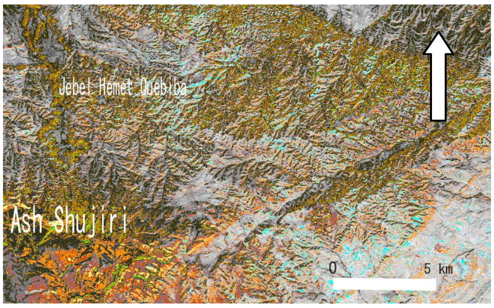

Figure 3. Zooming in on the study area interpreted with the cluster analysis on the Landsat-7 ETM. Grazing potential in this area is clearly visible as green areas. Some features of the topography are revealed in the image as well. Data© Eurimage

Figures 4. and 5. are presenting a TM image taken on 01.09.1990 and an ETM image taken on 29.1.1999, using 60 clusters. Blue indicates water. Green indicates vegetated areas, mainly agricultural fields, but also steppes depending on the season. Light green indicates areas with lower vegetation. Brown shows non-vegetated areas. Dark blue, yellow, or grey reveals non-vegetated ground; and white or reddish yellow show sandy areas. It was difficult to separate same sets of land features when using the TM and ETM images. The main source of difference between the results in interpreting the TM and ETM images is due to the time lapse between different acquisition dates of the images concerned, causing different phonological states of vegetation. Clearly in the TM image dating to the autumn season dryness is visible compared to the ETM image dating to a rainy season.

We can detect seasonal differences between winter/spring and late summer in the Figures 4. and 5. However, the large veil of sand had expanded significantly between 1990 and 1999 due to increasing desertification (see Lönnqvist and Törmä, 2004).

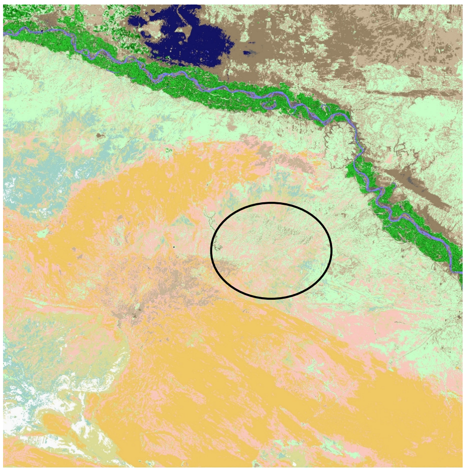

Figure 4. The clustering result of the Landsat TM image, dated 01.09.1990, using 60 clusters. Datasource: NASA.

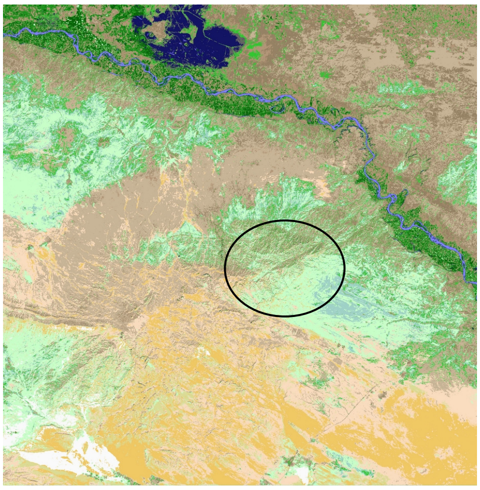

Figure 5. The clustering result of the Landsat ETM image, dated 29.01.1999, using 60 clusters. Data source: NASA.

3. LOCATING PASTORAL CORRALS

QuickBird satellite image data from the central district of Jebel Bishri (centre coordinates lat. 35. 422, long. 39. 4788, taken 15.7.2003, see Fig. 6.) covering 8 km x 8 km served as a basis for prospecting for more or less ancient corral sites of pastoral nomads in the target area. The image area includes parts of the highest peak of the mountain, which rises ca. 867 m a.s.l. (Wirth, 1971: 55). The image was further divided into 16 smaller images in order to carry out the prospecting for pastoral corrals by the naked eye. Each of the 16 images covered 4 km², and their order ran from the North to the South in 4 image sets. When a site was identified, the UTM coordinates were collected for the location information (see UTM coordinates for the corral sites identified in the QuickBird image: Tables 1.and 2.).

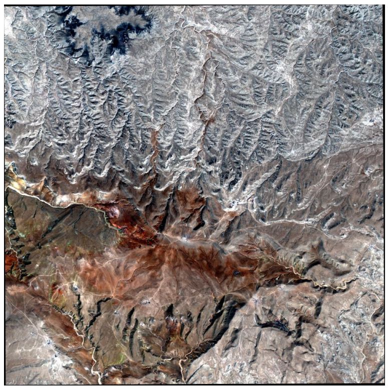

Figure 6. QuickBird pan-sharpened multispectral image, dated 15.07.2003.© DigitalGlobe Inc.

Image 1	Image 2	Image 3	Image 4	Image 5	Image 6	Image 7	Image 8
None	F 1 540300 3922350	F 6 540400 3920300	F 9 539920 3916700	None	F 13 542300 3921800	None	F 16 541650 3917200
	F 2 539800 3922200	F 7 540500 3920120	F 10 540080 3916800		F 14 542500 3921800		
	F 3 539850 3921950	F 8 540700 3920300	F 11 540520 3916850		F 15 543200 3921950		
	F 4 540770 3922400		F 12 540580 3916680				
	F 5 540700 3922200						
None	5 sites	3 sites	4 sites	None	3 sites	None	2 sites

Table 1.

Image 9	Image 10	Image 11	Image 12	Image 13	Image 14	Image 15	Image 16
None	F 17 543800 3921700	F 19 544000 3919900	F 20 544100 3916900	F 22 547080 3924300	F 24 547530 3922400	F 28 547200 3920220	F 32 547600 3918520
	F 18 545420 3921200		F 21 544500 3916700	F 23 546650 3924350	F 25 546500 3921180	F 29 547230 3920250	F 33 547400 3918450
					F 26 546700 3920900	F 30 546800 3919930	F 34 547450 3918600
					F 27 546500 3921220	F 31 546700 3919780	F 35 547280 3918480
							F 36 546400 3918350
							F 37 546400 3918300
							F 38 54 6600 39 17200
							F 39 54 6600 39 17300
							F 40 54 6600 39 17180
							F 41 54 6550 39 17180
None	2 sites	1 site	2 sites	2 sites	4 sites	4 sites	10 sites

Table 2.

It needs to be emphasized that all the traced and identified corrals are not necessarily contemporary structures, but despite of that their location and frequency in the landscape can provide information of the preferred areas and thus the ancient grazing potential.

Only random experimental visits have been made on the ground to the QuickBird image area to check the nature of some structures analysed in this study, because this area in specific was outside our ground survey permission of the years 2004-2008. Therefore, no associated small finds were allowed to be collected to infer any dating of the structures. Based on the comparable sites found during the previous ground surveys on the mountain providing associated finds (see Lönnqvist *et al*., 2006), we know that the use of corrals may vary from the Neolithic to the Medieval times, or they may even have been reused by the very recent Bedouins.

Altogether 41 sites were identified in the area covering 64 km², and they range from a single stone circle to multiple agglutinated enclosure constructions. The reasons for the number and size of the enclosures have been ethnoarchaeologically lucidly explained, for example, by M. Haiman (2002) in his studies of the pastoral sites in the Negev. According to his observations, the sheep were allocated to different enclosures according to age and their function in the pastoralists' subsistence system. The enclosures varied from 5 to 20 m in diameter. An example site with six enclosures was divided so that one enclosure was for 30 lambs, one for 150 ewes that had not given birth yet, one was a sleeping area, one was allocated to 80 ewes already having lambs, one was for 40 up to 3 month old lambs that were not yet pastured and one for 16 sheep that were not pastured yet.

Four images out of the 16 image set of the QuickBird area did not provide any traces of corrals. So 16 km² remained empty from the structures corresponding to 25 % of the total area. The number of sites indicates that 3/4 of the area covering 64 km² provides one site for every 1 km² on average.

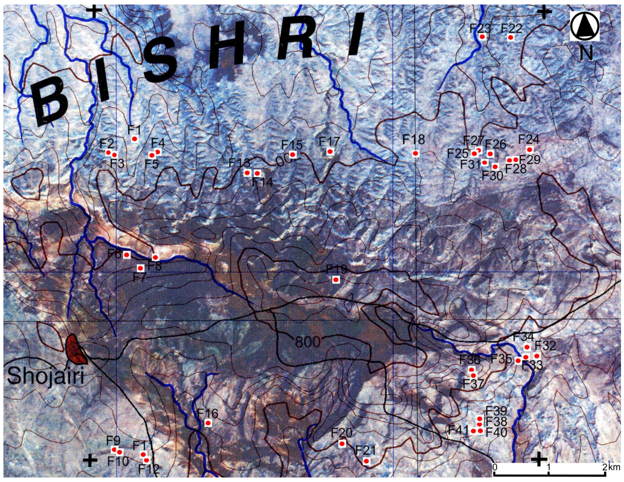

Figure 7. Distribution of the identified corrals displayed on a plot of the satellite map with the scale of 1:100 000 (ed. by Meissner & Ripke 1995). The corners of the QuickBird image are marked with black crosses.

4. SITE CATCHMENT ANALYSIS

Site catchment analysis is based on the least-cost movement and thus on the preference that the resources from the base (here the stone enclosures) should be within one hour's or two hour's walking distance. Nowadays GIS provides a convenient tool to calculate distances taking the topography into account. (See, e.g., Savage, 1990). In our study ASTER-DEM data covering the target area of the QuickBird image (see Fig. 8; the central coordinates for the corner pixels of the ASTER-DEM: UTM 539510, 3924752 and UTM 547700, 3916562) was acquired by downloading it from EOS data archive provided by NASA (http://asterweb.jpl.nasa.gov/gdem.aspwas). It was utilized in analysing the topography and amount of time needed to traverse a certain radius surrounding some of the pens.

Figure 8. The ASTER-DEM image covering the study area. Data source: NASA.

The ASTER-DEM was reprojected into the same coordinate system as the QuickBird image (UTM zone 37, > WGS84) using 30 m pixel size. The accuracy of ASTER-DEM should be 20 m in height and 50 m in location (Fujisada *et al*., 2005). Travel time was estimated using Tobler's hiking distance (Tobler, 1993). The walking velocity in a hilly terrain can be estimated as W = 6 x exp { -3.5 x ABS (S + 0.05) }, in which W corresponds to the walking velocity in km/h whereas S denotes to a slope. The slope is estimated as dh/dx, in which dh corresponds to difference in height, if two places (e.g. neighbouring pixels of DEM) and dx correspond to their horizontal distance in the same units as the height. On a flat terrain the walking velocity is ca. 5 km/h. The travel time is computed as distance / velocity. The results are presented in Table 3., in which each zone of colour is equivalent to 20 minutes of walk, and the maximum measured time estimated for the effort used to attain grass for flocks varies from ca. 1 hour to 2 hours according to the site catchment theory.

	F		F		F		F		F		F		F		F
	1		2		3		4		5		6	7	8		9
	F		F		F		F		F		F		F		F
1	0	1	1	1	2	1	3	1	4	1	5	1	6	1	7
	F		F		F		F		F		F		F		F
1	8	1	9	2	0	2	1	2	2	2	3	2	4	2	5
	F		F		F		F		F		F		F		F
2	6	2	7	2	8	2	9	3	0	3	1	3	2	3	3
	F		F		F		F		F		F		F		F
3	4	3	5	3	6	3	7	3	8	3	9	4	0	4	1

Table 3.

The eight Sites **F 1 - F 8** analysed showed that topographical constraints for each site appeared generally to be located to the West and the Northwest, evidently meaning steep slopes, ridges, ravines or escarpments hindering easy access. The direction towards the East and Southeast seems to be easiest for moving even longer than two hours = over 10 km. However, with the flocks of sheep the pace could be considerably slower compared to a person that is hiking alone. However, the nearest *wadis* are to be found to the West, so constraints in topography do not necessarily completely hinder the progress in this case. Access to Sites **F 9 – F 12** is most favourable in the Northeast the topographical constraints being in the Southwest. However, at Sites **F 13 – F 15** there is a fairly free access in short distance to all directions, and the terrain there seems to be easiest as only an hour is needed for walking the same distance compared to the two hours' walk to other sites. The favourable part for movement from Site **F 16** seems to be in the Northeast. The best access to move from Sites **F 17** is in the South, whereas **F 18** also is due to the South, but has the best access to the West. Site **F 19** has free access to all directions, and the topography is easier than in the previous ones. Here the altitudes are some of the highest on the mountain. Sites **F 20** and **F 21** are due to the North, and somewhat to the Northwest and Northeast. Sites **F 22** and **F 23** offer the best access to the Southwest. The most favourable direction from Sites **F 24 – F 27** is in the West, and the same applies to Sites **F 28 - F 31**. The highest number of sites, altogether 10 sites, is situated on the Southeastern corner of the QuickBird image. Some bush vegetation is visible there unlike in other areas. Of them **F 32 – F 37** had topographical constraints to the East but have the best access for moving to the West and Northwest while Sites **F 38 – F 41** opened slightly more to the Northwest than to West. Our experience concerning the Site **F 37** on the ground confirmed the topographical analysis and restrictions of a huge ridge to the South.

The sites in general are clearly concentrating in particular areas. As we see, for example, the East offers the densest area of corrals: altogether 20 out of 41. This may be due to the direction of water currents and their catchment areas as visible in Fig. 7. There also the grazing potential seems to be greatest. Furthermore, the distance to the desertification line and spreading sands coming from the West and Southwest was the longest.

5. GENERAL OBSERVATIONS ON THE SITE LOCATIONS AND SITE DISTRIBUTION

General topographical and topological observations of the sites can also be carried out by the naked eye on the satellite images and maps. We used the topographical map with the scale of 1: 100.000 (edited by B. Meissner and U. Ripke, Technische Fachhochschule, Berlin, 1995). The five Sites **F 1** - **F 5** are located between the 600 and 700 m elevation contour lines, three of them being very close to a large *wadi*, a seasonal water course, leading from the village of Ash-Shujiri (Shojairi) northwards. We know that on the summit area there has been a well called `As Siqri (Poidebard, 1934), close to Ash-Shujiri.

Sites **F 6 – F 8** are in the vicinity of the 700 elevation contour line and here again they all are situated near a *wadi*. Sites **F 9** – **F 12** are located even higher, between the 700 and 800 m elevation contour lines, Southeast from the village of Ash-Shujiri, situating over one km's radius from a large *wadi*. Sites **F 13** – **F 15** are again close to the 700 m elevation contour line but there are no visible large *wadis* nearby; only within one-two kilometre's radius there is a large water course. Site **F 16** is situating above the 700 m elevation contour line, near a Roman military camp that we have discovered, and it is also associated with a large water course. Site **F 17** is lower than the 700 m elevation contour line whereas **F 18** is located above it; both of the sites are within one kilometre's radius of a large *wadi*. Site **F 19** instead is above the 800 m elevation contour line and has over a kilometre to a large *wadi*. The two Sites **F 20** and **F 21** are located along the alignment of a Roman road leading Southeast from the Roman camp and within one kilometre's radius from a large *wadi*. Sites **F 22** and **F 23** are located between the 600 and 700 elevation contour lines and are also within one kilometre's radius of a *wadi*. Sites **F 24** – **F 27** are located above the 700 m contour line three of them being slightly over a distance of one kilometre to the nearest large *wadi* and one lies on its bank. Sites **F 28** – **F 31** are situated above the 700 m contour line and have slightly over one kilometre to a large *wadi*. As previously mentioned, the largest amount of sites, namely Sites **F 32** – **F 39**, altogether 10 sites, is situated on the Southeastern corner of the QuickBird image. They are all surrounding a large *wadi* and a water catchment area situating between the 600 m and 800 m elevation contour lines.

More or less one kilometre seems to be the maximum distance to a nearest seasonal water course in general. As previously mentioned, the grazing potential seems to be the best in the East as there appears to be the densest occurrence of sites. This is in accordance with the existence of large seasonal currents and the present desertification line coming from the West and Southwest (cf. Figs 3.-6.). The major water course is associated with the Nadra plain that used to form a palaeolake. There also exist a number of natural springs, water harvesting sites and a well (see Lönnqvist *et al.*, 2006). Three of the corral sites studied on the Quick Bird image have been visited on the ground. Site **F 12** is one of the corral sites defined with UTM 540580, 3916680 corresponding to UTM 0540576, 3916775 on the ground and situating ca. 756 m a.s.l. The site consisted of five stone rings forming corrals. Their diameter varied from 4.5 m to 17 m. The corral Site **F 37** was also visited on the ground in 2003 and corresponds to GPS recordings (UTM 0546264, 3918376 being 764 m a.s.l.). The site consists of 5-6 stone circles of corrals varying from 7 m to 17 m in diameter. The site was very close to a steep slope that opened on the southern side of the site which was an intriguing phenomenon. Site **F 22** is situated near to a large water-harvesting area.

6. CONCLUSIONS

The Finnish archaeological survey and mapping project SYGIS has chosen to use remote sensing methods based on satellite image data sources for archaeologically prospecting the mountainous area of Jebel Bishri in Central Syria. In remote sensing high spatial resolution is needed for studying remains of mobile cultures, such as pastoral nomads, who often leave flimsy structures or ephemeral remains behind. A QuickBird image offering the spatial resolution of 0.6 m and covering 64 km² in the central area of the mountain was used for identifying stone enclosures such as animal pens and for capturing coordinate information of these sites. The area lies outside our intensive ground surveys. Only random experimental visits have been made on the ground to check and confirm the nature of the structures analysed in this study.

GIS was used in analysing the satellite image and radar data in this stud: the cluster analysis was used for visualising the grazing potential in the studied area, and the site catchment analysis was carried out to study more closely the grazing potential surrounding each identified ancient pastoral corral. The cluster analysis which was carried out with Landsat images taken in the 1990s reveals the present land cover of the target area in different years and seasons. Spring shows the best greenness in the chosen area, while in the autumn the area is clearly affected by dryness and the expanding desert line. UTM coordinates provided the location information of the corrals for the site catchment analysis. Altogether 41 stone enclosures were identified in the area of the QuickBird image covering 64 km², and in them some enclosures had multiple cells. 25 % of the image area did not offer any sites. However, in 3/4 of the image area there existed one site for every 1 km² area on average. Time and effort were calculated for attaining grazing areas from individual sites. That was carried out with an ASTER-DEM image. Travel time was estimated applying Tobler's hiking distance to the ASTER-DEM data, the preferred time to reach the resources being 1-2 hours. According to the analysis carried out here the uneven topography caused constraints in several areas. The best directions to movement were analysed. Most of the sites appeared to be located more or less within 1 km's hiking distance from seasonal water courses, which apparently provided water in the spring and early summer seasons. The densest areas of the sites were located at the water catchments. In the site catchment analysis topographically the free choice of access to different areas were in Sites **F 13** - **F 15** and **F 17** as well as **F 19,** situating in the central part of the image and some of them having the longest distance to the nearest water courses.

The most visible site concentrations were on the eastern side of the QuickBird image area offering 20 pastoral corrals out of the 41 sites, which may be due to the existence of large water courses. Moreover, the desertification line is situating to the West and the Southwest, whence sands spread first affecting the western areas. However, the distribution of the corral sites itself, reveals that grazing potential existed in the target area in ancient times like today being visible in the cluster analysis of the Landsat images. We know that on the summit area there has also been a well site called `As Siqri near the village of Ash-Shujiri, and natural springs, water harvesting sites and a well are located in the plain of Nadra in the lower area of the image. It is possible that the distribution of the corrals in the landscape denote some pastoral territorialism, but this cannot be conclusively demonstrated in the present study because we lack evidence of the cultural reference matrix based on small finds from the pens.

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