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Density, Spatial Pattern and Relief Features of Sacred Sites in Northern Morocco

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Abstract

Sacred sites are of conservation value because of their spiritual meaning, as cultural heritage and as remnants of near-natural biotopes in landscapes strongly transformed by man. The vegetation of sacred sites in Morocco was studied recently. Information about their number, spatial pattern or relief position is fragmentary. However, these parameters are important to evaluate their role as refuge for organisms and their representativeness of potential natural vegetation.

Therefore, density and spatial pattern of sacred sites on the Tangier Peninsula in NW Morocco were studied based on records on topographic maps and by ground check. Their relief position was examined calculating a logistic regression model based on site-presences and random pseudo-absences.

A ground check showed that around 67% of the existing sacred sites are documented in the topographic maps. They occur in the whole study area but are agglomerated around settlements. Although sacred sites occur with preference at elevated sites they can be found in almost all relief positions, thus offering the potential of supporting different types of climax vegetation (climatic climax and pedoclimax). Because of their abundance (around 29 sacred sites / 100 km²) and their distribution pattern they could serve as elements of a biotope network in degraded landscapes.

Keywords:

Marabout, sacred natural site, sacred grove, logistic regression, spatial point pattern, potential natural vegetation, Tangier Peninsula

1 Introduction

The cultural and biological value of sacred sites (= SaS) and their ecosystems came into the focus of cultural ecologist and conservationists in recent years. In many societies and religions all over the world the surroundings of such sites are considered as "sacred" and are therefore protected from logging and deforestation (Sacred natural Sites = SnS). A series of symposia and proceedings, organized by UNESCO, IUCN, and other international organisations was dedicated to this topic (Schaaf & Lee 2006, Persic & Martin 2008, Papayannis & Mallarch 2009, Verschuuren et al. 2010), and resulted in the Yamato-declaration, formulating guidelines on the conservation management of SnS (Schaaf & Lee 2006, Wild & McLeod 2008). Studies about the density, size, relief features, ecology, biodiversity and conservation status of such sites however are unevenly distributed around the world (see Dudley et al. 2010 for a literature review for Asia and Africa).

In Africa most studies are dedicated to the sub-Saharan parts of the continent and concentrate on West and East Africa (Sheridan & Nyamweru 2008, Juhé-Beaulaton 2010). Investigations about SaS in Muslim societies in general and in Africa in particular are rare. One might think the reason for the rarity of such studies is that orthodox Islam does not allow any veneration of saints and that consequently SaS do not exist there. However, the religious practises are different. In the Maghreb countries in Northwest Africa for example, the tombs of Muslim saints and their surroundings as well as cemeteries of local Muslim communities are considered to be holy ("bois sacrés", "forêts maraboutiques" in French literature).

Especially in Morocco, the appreciation of the spiritual authority of patron saints (sing. 'marabout'), religious brotherhoods ('zawias'), and collective pilgrimages ('moussem') to the saints' tombs are common and vivid phenomena (Dermenghem 1954, Lang 1992). A first, but very incomplete impression about the enormous number of SaS in Morocco can be gained from studies about the inner Moroccan tourism. Berriane (1989) estimates that about 750 to 1,000 pilgrimages to Marabouts are carried out every year all over Morocco, most of them in rural areas. SaS are extremely numerous in Morocco (Lang 1992, Demdam et al. 2008, Deil et al. 2009) because almost every rural settlement has its cemetery and local saint. Beside their spiritual values such sites are also relevant for the identity of tribal groups, for genealogy and myths (Bourquia 1990). Furthermore SaS had a peace-making function until the beginning of the 20th century since they were meeting places to discuss and solve tribal conflicts (Mikesell 1958). In a holistic approach of landscape ecology sensu Naveh (1998), SaS link the biosphere with the noosphere and are part of the individuality and uniqueness of cultural landscapes.

But also from a pure biological point of view Moroccan sacred sites are very interesting. Because the tombs of Muslim saints and their surroundings as well as cemeteries of local Muslim communities are considered to be holy, the vegetation surrounding them is often protected for religious reasons (Fig. 1).

Figure 1: Two isolated sacred groves with closed tree canopy on small ridges in mid-slope position within short to medium distance to scattered settlements (Area of the Beni Ider tribe, landscape section D1, NW Morocco).

Thus, SaS can shelter remnants of forests in cultural landscapes which are intensely used for agricultural or pastoral purposes (Frosch & Deil 2011) and they can be resistant to the general tendency of deforestation and degradation of forests in this country (Quézel & Barbéro 1990, Bijaber & Ahlafi 2005, Ajbilou et al. 2006, Hammi et al. 2010). Exemplary and pilot studies about the flora and vegetation of SnS in Morocco have been carried out in the Anti-Atlas and his foreland (Petersen 2007), on the southern slopes of the High Atlas (El Hassani 2003) and on the Tangier Peninsula in NW

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Morocco (Deil 2003, Deil et al. 2005, 2008, 2009, Taïqui et al. 2005, Jäckle & Frosch 2008, Fateh 2008, Tataru 2010). More detailed vegetation studies were realized by Frosch (2010) and Frosch & Deil (2011). Frosch & Deil (2011) could prove a long existing hypothesis (Emberger 1939, Mikesell 1960, Sauvage 1961, Barbéro et al. 1981, Benabid 1984, 1991, Quézel & Barbéro 1990. a. o.) that some of these forests (Fig. 2) represent remnants of former widespread plant communities in a near-natural stage, thus documenting the potential natural vegetation (= PNV) of an ecoregion (climatic climax). Loidi & Fernández-González (2012) underlined the importance of such remnants for modelling PNV and stressed the necessity of a better analysis of their spatial distribution.

Figure 2: Sacred grove with over aged Cork Oak (Quercus suber) (near landscape section C2, NW Morocco).

A study of the physiotope spectrum of SnS and an eventual preference of certain relief positions is a precondition to model and construct the PNV from such locations. It has to be proofed whether SnS are situated on sites submitted to the widespread abiotic conditions of an ecoregion and can represent the climatic climax or whether they occur under special edaphic and microclimatic conditions and represent a pedoclimax (Fig. 3). In Morocco and in other countries of the world, a systematic analysis of the relief position of SaS or SnS was not available. To estimate the relevance of SnS for providing ecosystem services such as maintenance of ecological balance, conservation of biodiversity and supply of resources (Khan et al. 2008) or for serving as stepping stones in

Figure 3: Degraded sacred site with arborescent form of the Dwarf Palm (Chamaerops humilis) on a dry gravel ridge (landscape section A2, NW Morocco).

a biotope network, number, size and distribution have to be known. Based on topographic maps of different scales, Lang (1992) investigated the number of SaS in central Morocco, Demdam et al. (2008) and Taïqui et al. (2009) in NW Morocco. Additionally, Demdam et al. (2008) and Taïqui et al. (2009) tried to explain the distribution pattern of SaS with socio-economic variables using univariate linear regression. However, these studies did not validate the quality of topographic maps with a ground check.

The aim of this study is to analyse the spatial distribution and the relief position of SaS in a landscape dimension. Since about 84 % of the SaS in the study area are SnS (Deil et al. 2009), the geographic features of SaS analysed here are considered to be representative for the geographic features of the SnS. The study was carried out on the Tangier Peninsula in NW Morocco, an area known for its Marabutism (Berriane 1989). The following questions should be answered:

I. Are topographic maps a probable data source for studying abundance and spatial pattern of SaS at different scales?

II. How many SaS exist in the study area and how are they distributed? Is the spatial pattern random or triggered by the settlement structure?

III. Is the number and density of SaS different according to ecoregion or land use intensities surrounding them?

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IV. Are SaS restricted to certain relief features or do the variety of relief positions and the dispersion in the landscape offer the potential of supporting a broad spectrum of vegetation types and all the climax communities?

2 Study area

The study area is situated on the Tangier Peninsula in Northern Morocco. It stretches from the Atlantic coast between Asilah and Moulay Bouselham up to the Outer Rif Ranges (= Prérif) with Numidian Sandstone ridges (Fig. 4). The western limit is the coastline, the northern limit 35° 30’ N, the southern limit 34° 45’ N, the eastern delimitation is the line between 35° 30’ N / 5° 24’ 40” W and 34° 45’ N / 5° 4’ 14” W. The total study area is around 7,253 km² large.

The calcareous mountain ridge of the Western Rif Mountains, the “Dorsale Calcaire” SSE of Tetouan was excluded from the study area, because this completely different ecoregion with limestone, Karst hydrology (see for example Map 4 in Gómez Zotano & Martín-Vivaldi Caballero 2010) and, in consequence, a different pattern of settlements would have introduced further environmental (substrate) and cultural (other tribes) variables. Furthermore, the quality of the topographic maps differs from those of the Central and Western parts of the Tangier Peninsula (see Results).

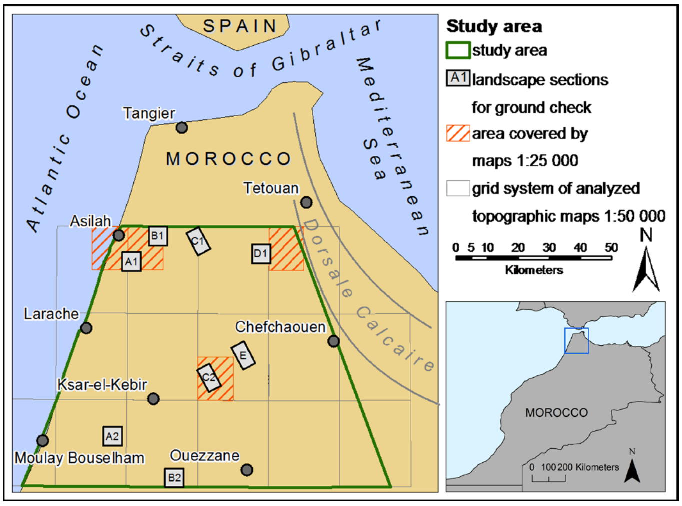

Figure 4: The study area: delimitation, grid system of analysed topographic maps and locations of landscape sections for ground check.

The elevation increases from sea-level at the Atlantic coast to 1,705 m on Jbel el Khizana in the eastern part of the study area. The geology is very diverse with predominating Pliocene and Quaternary sands along the western littoral parts, Flysch and Oligocene sandstone ridges in the centre and East, and a hilly area in between, dominated by marls (Fig. 5).

3 Methods

Sacred Site dataset, topographic maps and ground check

In a first step, the number and the topographical position of SaS in the study area were extracted from the topographic maps 1:50 000 (TM50) (Ministère de l´Agriculture 1965-2002). Symbols used in topographic maps are “Marabout” (the burial ground of a saint and/or the tomb), “Koubba” (the building, when the tomb is conspicuous) and “Cimetière” (cemetery). From 61 SaS, studied by Deil et al. (2009) on the Tangier Peninsula, 75 % of the sacred tombs were surrounded by a cemetery. People want to be buried near a sacred tomb to profit from the “baraka”, the spiritual blessing of all objects in spatial context to the Marabout (Lang 1992). Because SaS have often this double function (saint´s tomb and cemetery), the term SaS used in this study includes all the three types of objects. Mosques have been excluded.

The following maps 1:50 000 were analysed (name and year of publication; pp = only those parts belonging to the study area): Arbaa Ayacha/1965, Arbaoua/2002, Asilah/1965, Bab Taza/1970pp, Beni Ahmed/1974pp, Chaouene/1970pp, El Ksar el Kebir/1965, Lalla Mimouna/2000, Larache/~1965, Moulay bou Salham/1974, Ouezzane/1974, Souk el Kolla/1972, Souk Khemis des Beni Arouss/1966, Souk Larbaa Beni Hessane/1970pp and Zoumi/1970.

To compare the representation of the SaS in maps of different scales the SaS were also extracted for the entire study area from the topographic maps of the following scales:

- 1:500 000 (TM500, map sheet Rabat) (Ministère de l’Agriculture et de la Reforme Agraire 1989)

- 1:250 000 (TM250, map sheets Tanger, Fes, Rabat) (Ministère de l'Agriculture et de la Reforme Agraire 1983-1987)
- 1:100 000 (TM100, map sheets Souk el Arbaa du Rharb, El Ksar el Kebir, Chefchaouene, Larache, Ouazzane, Zoumi) (Ministère de l'Agriculture et de la Reforme Agraire 1942-1974)

Additionally, in a sample of four maps of the scale 1:25 000 (TM25, map sheets Arbaa Ayacha, Assilah, Teffer, Zinat) (Agence Nationale de la Conservation Foncière, du Cadastre et de la Cartographie 2006-2007) the SaS were recorded. The grid system of the analysed TM50 and the area covered by the analysed TM25 are shown in Fig. 4.

To verify the information about SaS in the topographic maps a ground check was carried out within eight landscape sections of 36 km² each. These landscape sections were chosen following a pre-stratified random sampling procedure based mainly on the dominant substrate simplified from the geological map 1:500 000 of Northern Morocco (Ministère de l'Énergie et des Mînes 1980). Only landscape sections with at least four mapped SaS were chosen. The locations of the studied landscape sections are given in Fig. 4. Within these landscape sections the total number of all existing SaS was identified through field surveys. The area covered through the ground check corresponds to around 4.5 % of the surface of the study area.

To estimate the total number of SaS in the study area, a 3-step procedure had to be applied because TM50 do not document all the existing SaS (Demdam et al. 2008, Deil et al. 2009): First, a linear regression was calculated, regressing the number of SaS proved by ground check against the number of SaS mapped in the TM50. Both numbers were derived from the eight landscape sections. Assuming that zero SaS mapped in the TM50 correspond to zero SaS in reality (that means forcing the model through the origin) improved the model fit significantly. In a second step, the total number of all existing SaS was predicted using the linear regression model and the total number of all mapped SaS. However, since some TM50 in the eastern part of the study area document lower SaS densities due to poor mapping (Demdam et al. 2008), these maps were identified calculating a logistic regression model with the topographic maps as the only predictive variable of the probability of occurrence of SaS (for methodology of the logistic regression see below) and then excluded from the prediction. To visualize the uncertainty of the model, 95% confidence intervals were calculated. In a third step, the resulting average SaS density on the TM50 with normal mapping quality was multiplied with the total surface of the study area resulting in a total number of SaS in the study area.

Spatial pattern of Sacred Sites

To analyze the spatial pattern of SaS, the set of all SaS mapped on TM50 was used. To find out if the spatial pattern of SaS is random or if the pattern deviates significantly from complete spatial randomness (CSR), the first-order-functions Diggle's F & G (Diggle 2003) were calculated.

The second-order-function Ripley's K was calculated to identify interactions between the SaS over larger distances than covered by first-order-statistics (Diggle 2003). Since the first-order-measures indicated that the SaS distribution is not stationary, the inhomogeneous K-Function (Baddeley & Turner 2005) was applied to correct for first-order inhomogeneity. The bandwidth used to calculate the intensity-raster needed to calculate the inhomogeneous K-function was chosen according to Berman & Diggle (1989). Deviation from CSR was tested calculating critical envelopes based on the maximum/minimum deviation obtained from 99 Monte-Carlo-Simulations of CSR resulting in a significance level of 1 %.

For each function an edge correction chosen by a selection routine implemented in "spatstat" (Baddeley & Turner 2005) was applied.

Factors influencing the occurrence of Sacred Sites in the landscape

A logistic regression was calculated to identify factors for the deviation from CSR and to describe the position of the SaS in the landscape. Since the dataset contained only presences of SaS it was necessary to create pseudo-absences of SaS (Engler et al. 2004). Those were created randomly corresponding to the number of presences. Only presences and pseudo-absences outside an inner guard area of 2 km from the border of the study area were used to avoid edge effects due to missing data

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outside the study area. Between presences and pseudo-absences and between the pseudo-absences itself a minimum distance of 100 m had to be kept. The resulting dataset comprised 1,303 presences and 1,303 pseudo-absences. So the model outcome corresponds to the probability of occurrence of a SaS.

The variables used in the regression model are shown in Table 1.

Each agglomeration of at least three houses in the TM50 was regarded as settlement. From each SaS and from each pseudo-absence the Euclidean distance to the nearest settlement was calculated (SETTLEMENT).

Table 1: Explanatory variables tested for their relevance for the occurrence of SaS.

Variable	Variable description	Unit
SETTLEMENT	Distance to nearest settlement	Meter
ELEVATION	Elevation	Meter
SLOPE	Slope	Degree
CURVATURE	Plan Curvature	1 / 100 m
VEG	Vegetation	21 classes in 6 groups
TPI250	Topographic position, radius 250m	Meter
TPI4000	Topographic position, radius 4000m	Meter
REGION	Physical region	16 classes
TM	15 Topographic maps 1:50000	0/1

ELEVATION was taken from an elevation model with approximate cell-sizes of 90 m x 90 m (Jarvis et al. 2008). From this elevation model SLOPE, CURVATURE and TPI were derived.

SLOPE shows the rate of maximum change in elevation from each cell.

For CURVATURE the planform or plan curvature was calculated describing the curvature of the surface perpendicular to the slope direction.

TPI is an index used to describe the relative position of a raster cell in relation to its surroundings, calculated as the difference between the elevation of each cell and the mean elevation of its neighbouring cells. The value of the TPI depends strongly on the number of adjacent cells used to calculate the mean elevation of the neighbourhood. Therefore several different neighbourhood sizes were tested and the most significant were put into the starting model. These were the TPI calculated with circular neighbourhood of 250 m (TPI250) and 4000 m (TPI4000) radius. The TPI250 represents medium sized relief forms with diameters between around 100 m and 500 m, whereas the TPI4000 represents larger relief forms with diameters between around 250 m and 8000 m. Relief forms smaller than 100 m are not represented reliably. Both, TPI250 and TPI4000 were calculated using Topography Tools for ArcGIS (Dilts 2010).

REGION was taken from a map of André (1971) showing the physical regions of the study area (“Basse montagne”, “Piedmont et Haut-Rharb”, “Sillon interne”: each with subdivisions).

For VEG the Corine land cover (CLC1990) dataset (European Environment Agency 2003) was used to identify the vegetation in the surroundings of each SaS and each pseudo-absence. Due to the scale of the land cover map and the minimum size of mapped units of 25 ha, the variable VEG shows the dominant vegetation within a radius of around 250 m. The 21 original land cover classes occurring in the dataset were grouped into the following six classes (arranged according to increasing land use intensity):

- beaches/water (Beaches, dunes, sands / Coastal lagoons / Inland marshes / Water bodies),
- forest/shrubland (Broad-leaved forest / Coniferous forest / Mixed forest / Sclerophyllous vegetation / Transitional woodland-shrub),
- pasture (Land principally occupied by agriculture, with significant areas of natural vegetation / Moors and heathland / Natural grasslands),
- agriculture (Non-irrigated arable land / Agro-forestry areas / Annual crops associated with permanent crops / Complex cultivation patterns / Fruit trees and berry plantations / Olive groves),
- intensive agriculture (Permanently irrigated land),
- settlements (Continuous and discontinuous urban fabric).

Agricultural land covered most of the surface and was thus treated as reference in the regression model.

To reduce the influence of the mapping quality the binary variable TM was established. All map sheets with a negative significant influence on the presence of SaS were recoded with “1”, all the other map sheets were recoded with “0” and hence treated as reference in the regression model.

Additionally, all possible two way interaction terms (IAT) between the metric variables were tested for significance.

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The test for correlation between these variables did not show any correlations higher than 0.6. Thus all variables shown in Table 1 and the interaction terms were used for the starting model. The variables of the final model were chosen through backward selection.

The model quality was assessed using the goodness of fit parameters AUC (Area under the ROC-Curve, Mason & Graham 2002) and r^2Nagelkerke (Nagelkerke 1991), which was designed especially for logistic regression models.

Statistical analyses were carried out using the statistical environment R (R Development Core Team 2009, package "Spatstat" for Point Pattern Analysis, "splancs" for choosing the bandwidth of the intensity-raster, "stats" for test of significance, "lattice" for 3D-graphics, "verification" for the calculation of AUC, "descr" for $r^2_{Nagelkerke}$). For raster calculation ArcGIS 9.3 was applied.

4 Results

Number of Sacred Sites and their documentation in the topographic maps

1,420 SaS are documented on the topographic maps 1:50 000 within the study area (Fig. 5).

Five cards with lower densities of SaS were identified (the maps indicated by the hatching in Fig. 5: Chaouene, Zoumi, Souk el Arba de Beni Ahmed, Bab Taza and Souk Larbaa Beni Hessane. Their mean density of 9.2 mapped SaS/100 km² is significantly lower than the mean density of 22.2 mapped SaS/100km² on

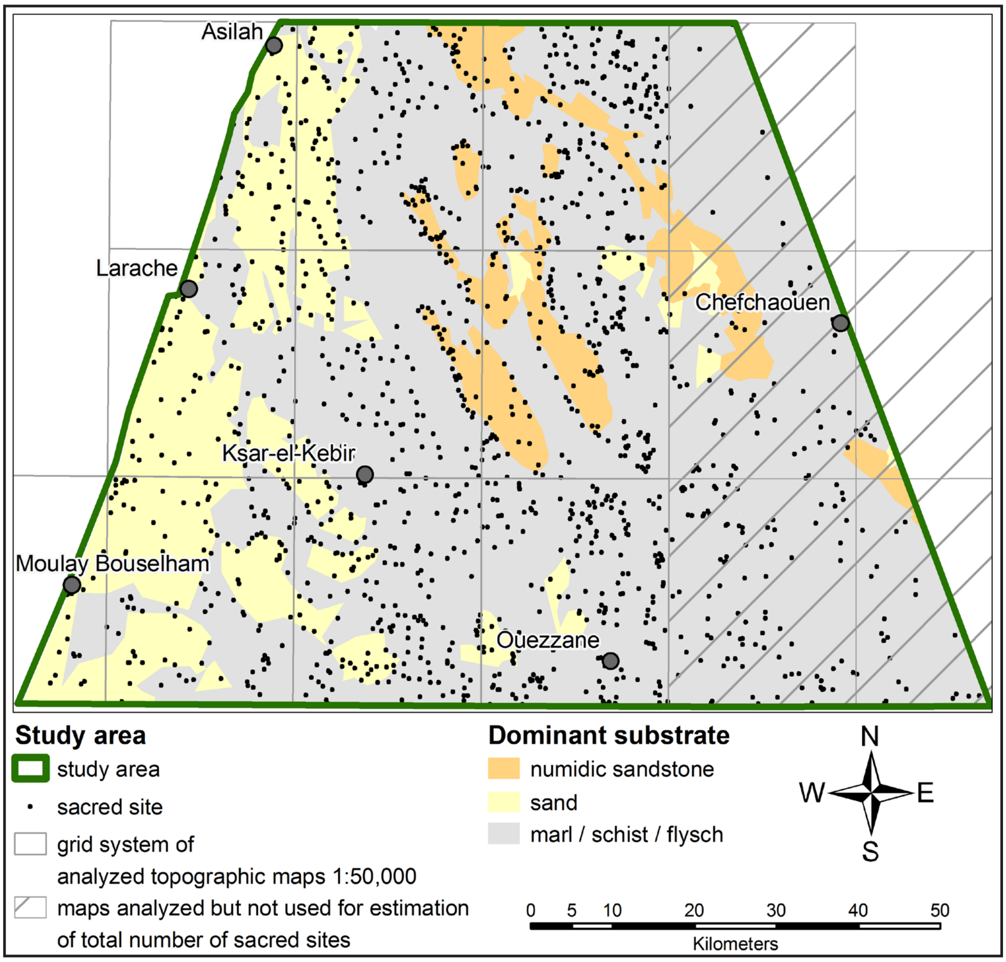

Figure 5: Distribution of SaS in the study area (dominant substrate as background information taken from Ministère de l´Energie et des Mînes 1980).

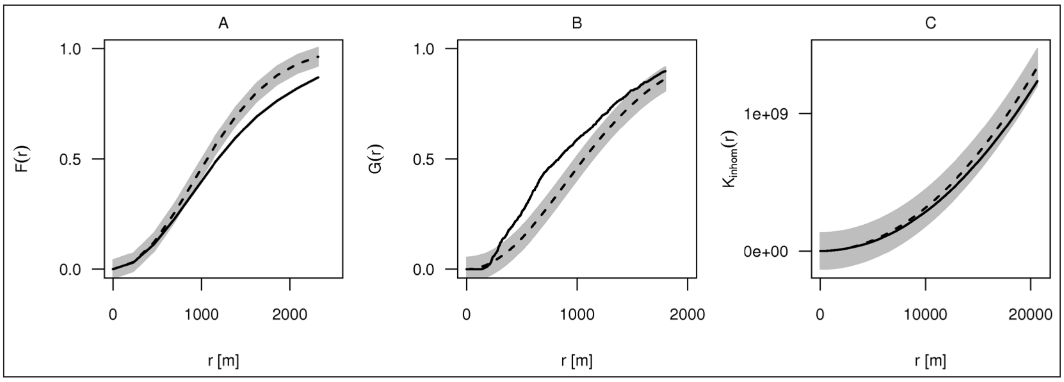

Figure 6: Diggle's F (A), Diggle's G (B) and the inhomogeneous K-function (C) (continuous line) with CSR (dashed line) and simultaneous critical envelopes (grey bands).

the other ten cards (t-test, t=4.43, df=10, p= 0.001). Consequently, the five cards were excluded from the prediction of the total number of SaS.

The ground check within the eight landscape sections shows that out of 120 existing SaS only 90 are mapped on TM50. The number of existing SaS varies from four to 25 SaS between the landscape sections.

The estimation of the total number of SaS using the calculated linear regression model resulted in a total number of 1548 existing SaS and a density of 29.4 ± 6.9 SaS/100km² in the part of the study area covered by the ten "normal" map sheets. Projecting this average density on the whole study area results in a total number of 2127 SaS. Thus, the 1420 SaS mapped on the TM50 represent around 67 % of the real existing SaS.

The exemplary analysis of four TM25 shows that on the TM25 more SaS per area are mapped than on the corresponding TM50 (TM25 Assilah 31 % more than on TM50 Asilah, TM25 Arbaa Ayacha 5 % more than on TM50 Arba Ayacha, TM25 Teffer 26 % more than on TM50 Souk-el-Kolla, TM25 Zinat even 950 % more than on TM50 Souk Larbaa Beni Hessane).

This generalization effect continues with decreasing map scale (20 % of the total of 2127 SaS in the study area shown on TM100; 2 % on TM250; 0 % on TM500).

Spatial distribution of Sacred Sites

SaS density varies also independently from certain cards. Regions with a high SaS density alternate with regions with almost no SaS (see Fig. 5). The point pattern analysis showed that this distribution pattern is not random:

Both, Diggle's F & G show a significant aggregation of SaS at short distances (Fig. 6 A and B). The solid line outside the critical band indicates a significant deviation from CSR (Diggle's F: above regularity, below aggregation; Diggle's G: above aggregation, below regularity).

For the point-event distance Diggle's F the function is significant at distances > 900 m. This means that, starting from a random point in the study area, the probability to find a SaS within a radius > 900 m is less than by random. The event-event distance Diggle's G is significant at distances between 300 and 1500 m. Consequently, starting from a random SaS in the study area, the probability to find another SaS within 300 to 1500 m is larger than at random. This illustrates that within the study area there are regions where less SaS occur than expected at random (Diggle's F) as well as regions where SaS are aggregated (Diggle's G).

The distribution function of the inhomogeneous K-function never leaves the significance envelopes, indicating that beyond the first-order inhomogeneity there is no significant aggregation or repulsion of SaS (Fig. 6 C).

Quantitative description of the spatial distribution of Sacred Sites

Using a logistic regression model several factors influencing the spatial distribution of SaS were identified. The significant variables of the final model are shown in Table 2. The model attained an r^2 of 0.49, an AUC of 0.86 and an AIC of 2453.8.

Table 2: Variables of the final model.

Variable	Deviance	p-value		Coefficient	Standard error	p-value
Null Deviance	3612.7	(2605 degrees of freedom)				
			Intercept	6.899e-01	1.729e-01	<0.001
SETTLEMENT	691.4	<0.001		-3.123e-03	2.616e-04	<0.001
SETTLEMENT ²	56.7	<0.001		7.746e-07	9.378e-08	<0.001
ELEVATION	1.7	0.189		2.373e-03	8.754e-04	0.007
ELEVATION ²	20.5	<0.001		-1.890e-06	8.572e-07	0.027
TPI250	231.1	<0.001		2.100e-01	2.274e-02	<0.001
TPI4000	21.1	<0.001		2.820e-03	8.155e-04	<0.001
SLOPE	12.5	<0.001		1.147e-01	3.406e-02	<0.001
SLOPE²	43.2	<0.001		-6.129e-03	1.513e-03	<0.001
CURVATURE	10.4	0.001		1.302e+00	5.160e-01	0.012
VEG	23.7	<0.001	beaches/water	-5.092e-03	5.406e-01	0.992
			forest/shrubland	-3.658e-01	1.561e-01	0.019
			settlements	4.884e-01	4.750e-01	0.304
			pasture	3.520e-01	1.279e-01	0.006
			intensive agriculture	-2.494e-01	3.083e-01	0.419
TM	40.8	<0.001		-1.009e+00	1.676e-01	<0.001
IAT TPI250, ELEVATION	19.2	<0.001		-1.060e-04	3.677e-05	0.004
IAT TPI250, SLOPE	17.7	<0.001		-6.740e-03	1.548e-03	<0.001
IAT SETTLEMENT, ELEVATION	6.8	0.009		-1.053e-06	4.668e-07	0.024
Residual Deviance	2415.9	(2587 degrees of freedom)				

The variable SETTLEMENT explains most of the deviance. The probability of occurrence of SaS is high close to settlements and decreases rapidly with increasing distance. Far from settlements (> 2000 m) a slight increase of the probability of occurrence is found, indicated by the squared term SETTLEMENT². The interaction term of SETTLEMENT and ELEVATION slightly reduces the probability of occurrence of SaS far from the next settlement at elevations over 500 m (Fig. 7 A). TPI250 was the second most important variable. Response surfaces of the interaction terms of TPI250 with ELEVATION and SLOPE are shown in Fig. 7 B and C. Probability of occurrence of SaS is high at elevated relief positions, illustrated by positive values of TPI250, but decreases rapidly at high values of ELEVATION and SLOPE (see Fig. 7 B and C). At relief positions with negative TPI250 (Depressions, river channels) the occurrence of SaS is unlikely. The significant interaction term of TPI250 and ELEVATION reduced the probability of occurrence of SaS on elevated relief positions at high elevations and increased the probability of SaS at depressions at high elevations. ELEVATION shows a negative unimodal response curve described by the squared term ELEVATION².

In combination with SLOPE the TPI250 can be used to illustrate the relief position of SaS presences in a scatter plot (Fig. 8). In combination with flat slopes

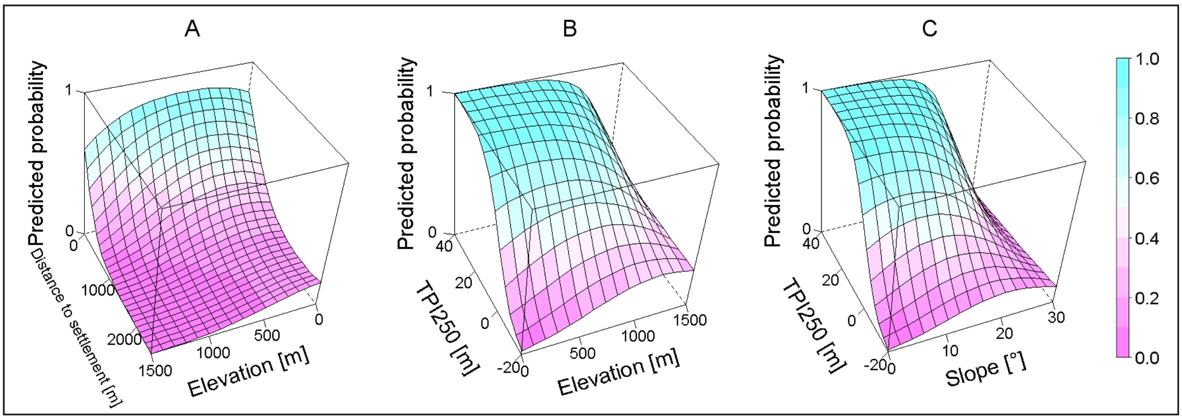

Figure 7: Response surfaces of the variables with significant interaction terms illustrating the predicted probability of occurrence of a SaS dependent on (A) Elevation / Distance to settlement, (B) TPI250 / Elevation and (C) TPI250 / Slope (with the other explanatory variables set to median or reference).

positive values of TPI250 represent summits or ridges; in combination with steep slopes they indicate upper slope positions. SaS occur often on summits and ridges but the probability of occurrence decreases sharply at upper slope positions steeper than 15° to 20°. A TPI250 around 0 indicates in combination with low slope values flat areas but together with higher slope values it indicates a middle slope position. The probability of occurrence is moderate on flats and in mid slope positions with moderate inclination. SaS are almost absent on steep slopes. Negative values of TPI250 indicate in combination with low slope values small valleys and terraces, at steeper slopes they indicate gullies and lower slope positions. In such relief positions SaS are rare. The interaction term of TPI250 and SLOPE increased the probability of occurrence of SaS in valleys and on terraces and reduced the probability in upslope positions. SLOPE itself explains a small but significant portion of the deviance showing a negative unimodal response indicated by the squared term SLOPE².

Regarding the larger relief forms represented by TPI4000, the response curves showed an increase of the probability of occurrence with increasing TPI4000 values (Fig. 9A).

For maximum TPI250 the probability of occurrence is high for all values of TPI4000 (dashed line). For minimum TPI250 the probability is low at negative TPI4000 but increases with increasing TPI4000 (dotted line). Thus SaS occur very often on elevated

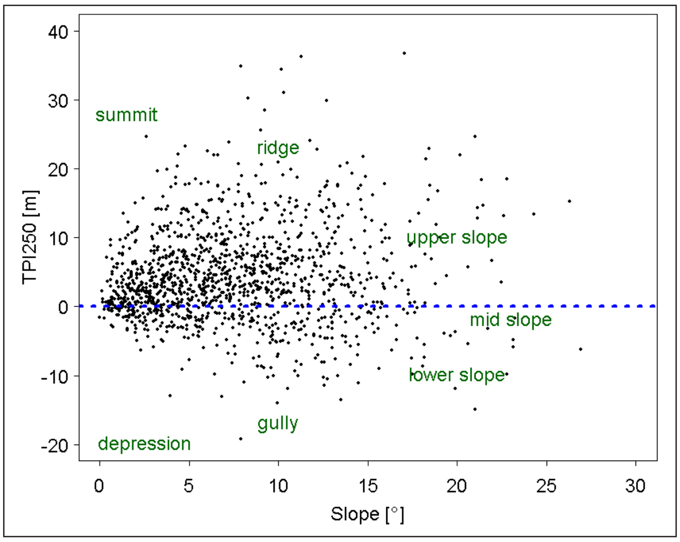

Figure 8: Scatter plot of the mapped SaS illustrating their relief position using SLOPE and TPI250.

relief positions regardless of the TPI4000. SaS in small depressions occur more often if the TPI4000 is positive and are extremely rare in large plains and valleys with TPI4000 negative or around zero.

The variable CURVATURE shows that SaS occur more often at sites with positive plan curvature (Fig. 9B solid line)

The categorical variable VEG had a significant influence on the occurrence of SaS. Compared to the reference agricultural land SaS occur significantly less frequent within forests/shrubland and more frequent within pastures. The other categories were not significantly different from agricultural land.

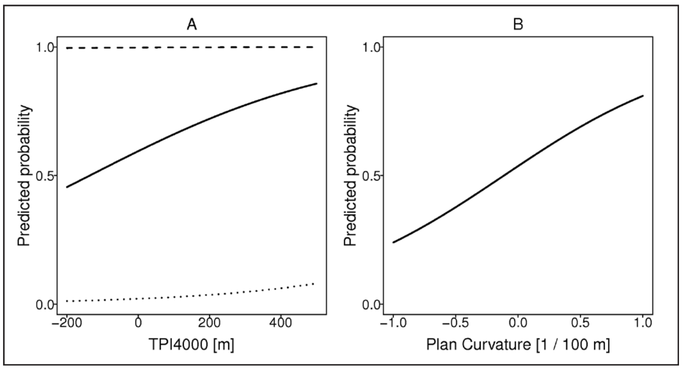

Figure 9: Response curves illustrating the predicted probability of occurrence of a SaS dependent on (A) TPI4000 (solid line: TPI250 = median, dashed line: TPI250 = max, dotted line: TPI250 = min) and (B) CURVATURE (with the other explanatory variables set to median or reference).

TM had a significant influence. The topographic maps with poor mapping quality reduced the probability of occurrence of SaS significantly.

The physical region (REGION) had no significant influence on the presence or absence of SaS.

Geographic and topographic situation of Sacred Sites

The geographic and topographic situation of the 1303 SaS and the 1303 pseudo-absences along the significant metric variables of the logistic regression model is shown in Fig. 10.

The box-whisker-plots show that for all variables the range of the presences is narrower than the range of the pseudo-absences: SaS are missing in extreme relief positions. However, box-whisker-plots A and B show that, although most of the SaS are situated close to

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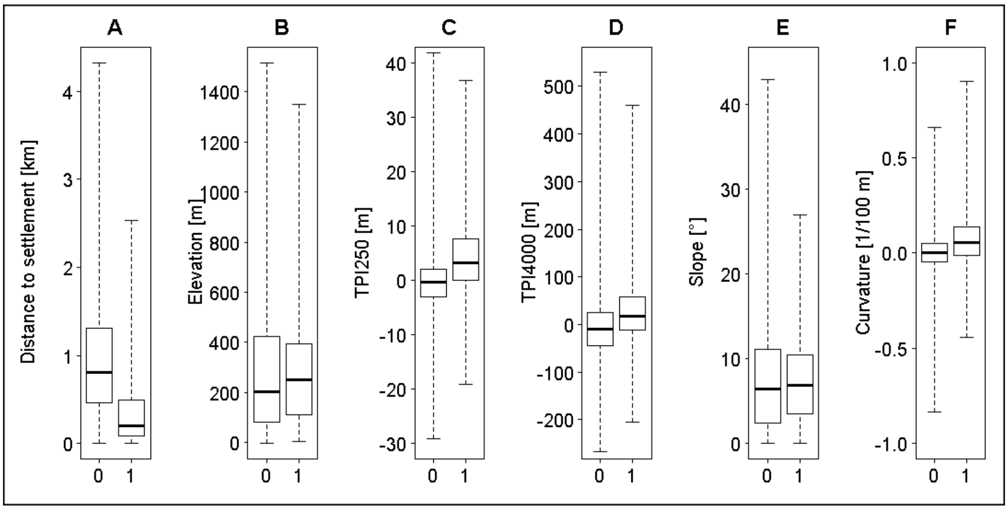

Figure 10: Box-whisker-plots showing median (solid lines), quartiles (boxes) and data extremes (dashed lines) of SaS (1) and pseudo-absences (0) along the significant metric variables of the logistic regression model.

a settlement (median at 300 m) and at low altitudes (median at 250 m), there are also some SaS far away from any settlement and on the highest peaks of the study area. Box-whisker-plots C and D show that SaS occur even in depressions, E and F show that SaS are rare on steep slopes and at slopes with negative curvature.

5 Discussion

Suitability of topographic maps for studying abundance and distribution of Sacred Sites

The documentation of SaS on topographic maps varies between single cards and between maps of different scales. Therefore, an extensive ground check was carried out to estimate the suitability of the topographic maps for the chosen approach. It could be demonstrated that the representation of SaS is best on TM25 but data from the ground check showed that even in this scale not all SaS are mapped. However, of the estimated 2127 SaS in the study area around 67% are mapped on TM50. This was regarded as sufficient for the statistical analyses applied.

Density and spatial distribution of Sacred Sites

The calculated mean density within the study area is around 29 SaS / 100km². Similar densities are recorded by Demdan et al. (2008) and Taïqui et al. (2009) in other parts of NW Morocco. Lang (1992) analyzed two TM100 (covering an area of around 6,000 km²) near Khemisset in central Morocco. He estimated a minimum number of 682 SaS and thus a density of about 11 SaS/100 km². Assuming a similar generalization rate of the analyzed TM100 as in northern Morocco (22 %), the real density around Khemisset could be ca. 50 SaS/100km² and thus almost double the density on the Tangier Peninsula. These numbers underline that SaS are a very important feature of the Moroccan cultural landscape. Studies in other parts of Morocco (e.g. Petersen 2007) document that SaS are not a regional but rather a nationwide phenomenon.

The inhomogeneous K-function shows no significant pattern. On a large scale SaS occur almost homogeneously in the study area. This fact is confirmed by the lacking significance of the physical region in the logistic regression model. Taïqui et al. (2009) found that in the province of Larache, SnS surrounded by vegetation patch of mappable size, are less abundant in the lowlands, supposing that agricultural intensification and urbanisation are reasons for this trend. However, the authors concluded the size of the SnS from the topographic maps. According to our observations in the field, the vegetation signature around SaS is not very reliable.

Concerning the number of SaS it could be shown that land use intensity weakly affects the probability of occurrence of SaS. These objects are more abundant in the land use category pasture in comparison to agricultural land. On the other hand, SaS are quite rare in forests and scrublands. This pattern reflects the spatial relation of SaS to settlements: In most situations, settlements are embedded into arable land or pasture ground, whereas forests and scrublands were cleared close to settlements.

TPI4000 had only a weak influence. But on a smaller scale SaS are significantly clustered at short distances as shown by Diggle's F & G. This clustering is caused by the settlement structure since distance to the next settlement was the most explaining variable in the logistic regression model. 75 % of the SaS were found within a distance of 500 m to a settlement. The multi-functional role of most SaS as saints tomb, pilgrimage destiny and burial ground (75% of the SaS in the study area are used as local cemeteries; Deil et al. 2009)) favours short distances to the next settlement (see also Taïqui et al. 2009, Demdam et al. 2008).

The spatial pattern of the settlements itself in northern Morocco strongly depends on the occurrence of springs and surface water (Mikesell 1958). Fountains are often linked to geological conditions. Especially the borderline between sandstone and underlying marls and Flysch (see Fig. 5) is a spring horizon and thus a preferred location for settlements (El Gharbaoui 1981). Such locations offer also different land use options close to the village (arable land on marl in downslope position, pasture ground and wood resources in uphill position on less fertile sandy soils). In the lowlands near the Atlantic coast the villages are often located at the rim of sand plateaus in transition to marl formations (André 1971) and at the edge of alluvial plains. Within landscapes dominated by marl, the villages and their SaS are often located on small hills with calcareous bedrock (André 1971). It can be concluded that the pattern of the SaS is related to the pattern of the settlements, which itself is triggered by substrate, productivity and land use options. The question whether the vicinity of SaS to villages is a benefit (villagers can easily protect SaS nearby, e.g. from illegal logging) or a threat for SaS (because of higher land use pressure in the surroundings of the villages) must remain an open question at the moment.

Relief situation of Sacred Sites

The second most explaining variable in the regression model is TPI250, most SaS are situated on elevated relief positions, on hills and ridges. On slopes, SaS occur most often on noses or terraces. However, very small scale relief position of SaS could not be analysed with the chosen approach due to the resolution of the digital elevation model. But although SaS occur with preference on prominent locations (summits and ridges), they can be found over a great variety of relief situations except steep slopes. Singular and extreme topographic positions like the one of the nation-wide known pilgrimage site Moulay Abd Sellam (Zouanat 2007) on the top of the Western Rif Ranges cannot be described by any statistical analysis but their occurrence is included and reflected in the box-whisker-plots. Probably, the relief position differs between SaS used as cemeteries and SaS without this function. It might be that cemeteries are situated in moderate relief situations whereas SaS without burial ground can occur also in more accentuated relief conditions. They should not occur in depressions with groundwater close to surface and on steep slopes with shallow soil. Both physiotopes are unsuitable as burial ground.

6 Conclusions

Khan et al. (2008) list maintenance of ecological balance, conservation of biodiversity and supply of resources as important ecological features of SaS in India. In Northern Morocco however, SnS are threatened by degradation (Zouanat 2007, Deil et al. 2009, Frosch 2010, Frosch & Deil 2011), despite of their high cultural (Lang 1992, Verdugo & Kadiri Fakir 1995) and ecological value (Quézel & Barbéro 1990, Deil et al. 2005). Population growth, land use pressure and decreasing spiritual value of SaS are the main reasons for size reduction or total destruction of SnS in Morocco. In other parts of the world, the reasons for the degradation of SnS are the same (e.g. Wild & McLeod 2008, Schaaf & Lee 2006, Pungetti et al. 2012). Consequently, national inventories of SaS are needed (Wild & McLeod 2008): Only known and documented SaS can be protected and monitored.

Deil et al. (2009), Taiqui et al. (2005) and Frosch (2010) showed that near-natural vegetation can still be found at SnS on the Tangier Peninsula in NW Morocco. Some forest types even exist almost exclusively on such sites (Frosch & Deil 2011). These remnants of the climatic climax are important for modelling and reconstructing the potential natural vegetation (= PNV) (Loidi & Fernández-González 2012). Because of their broad spectrum of relief situations and their numerous

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occurrence in all ecoregions of the study area, SnS document and testify the whole spectrum of climatic climax vegetation, in particular edaphic situations even pedoclimax communities.

Preliminary results of Deil et al. (2009) and Frosch et al. (in prep.) show that, although SaS in the study area are small in size (on average around 0.7 ha), most of them (64 %) are covered by a forest patch of at least 500 m². Summarizing these features (often good conservation status, high density, wide spatial distribution) it can be stated that SaS have the potential to serve as a valuable network of near natural biotopes respectively as stepping stones between patches of non-sacred natural vegetation. Their clustering at short distances probably lowers the negative effects of forest fragmentation. But it has still to be studied whether these vegetation patches are functionally connected or shelter isolated populations of plants and animals.

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