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PREDICTING THE STATUS AND DISTRIBUTION OF THE NUBIAN IBEX (*Capra nubiana*) IN THE HIGH-ALTITUDE MOUNTAINS OF SOUTH SINAI (EGYPT)

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Abstract

Nubian Ibex (*Capra nubiana*) is a one of the few species of large mammal species in the Egyptian fauna. The range inhabited by the species in the mountains of Sinai represents an important bridge between its distribution in Asia and Africa. The impact of various environmental factors shaping its distribution were investigated using distribution modeling methods. Maximum entropy modeling showed that presence of water resources is most influential in the species distribution in south Sinai, followed by slope, habitat, altitude and finally aspect. The current range of the species was estimated as 506 square kilometers in the mountains of south Sinai.

Keywords: Maxent, bedouin settlements, distribution range, nubian ibex, corridors, south Sinai.

Resumen

*Pronóstico del estado y de la distribución del íbice de Nubia (*Capra nubiana*)*
en la alta montaña del Sinaí meridional (Egipto)

El íbice de Nubia (*Capra nubiana*) es una de las pocas especies de mamíferos grandes en la fauna egipcia. El rango que ocupa la especie en las montañas del Sinai, representa un puente entre Africa y Asia, en su área de distribución. El impacto ambiental de varios factores que determinan su distribución se ha investigado modelizando su distribución. El modelo de máxima entropía muestra que la presencia de recursos hídricos es lo que más influye en la distribución de la especie en el sur del Sinai, seguido de la pendiente, hábitat, altitud y por último el aspecto. El área de distribución de la especie se ha estimado en unos 506 Km^2, en las montañas del sur del Sinai.

Palabras clave: asentamientos beduinos, corredores, íbice de Nubia, Maxent, rango de distribución, Sinai meridional.

Introduction

Many large ungulate species have been reported to be part of the Egyptian fauna. Many of them are extinct, threatened or undergoing a decline since the beginning of the 20^{th} century (Osborn 1980, Osborn & Helmy 1980, Saleh

1987, El Alqamy 2006), and the Nubian Ibex (*Capra nubiana*) is no exception. However, there have been no studies specifically of this species for more than 25 years, since Baharav (1981). The Nubian Ibex is a mountain specialist with a highly fragmented distribution around the Red Sea and in southern Oman. About 20-25% of its range is in Egypt, where it still occurs widely in the mountain ranges of the Eastern Desert and South Sinai (Osborn & Helmy 1980, Baharav 1982, El Alqamy *et al.* 2003, Attum *et al.* 2009): it has never been recorded west of the Nile.

Conservation efforts targeting this species have a major obstacle in the lack of current information about its status, population trends and distribution range. South Sinai comprises a significant part of the Ibex's range in Egypt because it contains the most rugged mountain massif and some of the highest peaks in Egypt. This landscape is isolated from similar mountain habitat elsewhere, and the ibex population on these mountains may have evolved to be genetically unique and hence a separate conservation unit. South Sinai has a very comprehensive network of protected areas, and conservation is high on the agenda of the various stakeholders. It is therefore important to define conservation priorities for Ibex in South Sinai. Almost the entire mountain massif is included within the borders of the St Katherine Protectorate, and thus most of the ibex range is within this protectorate. The status of the population is still obscure. However, direct counts by the community guards hired by the St Katherine Protectorate for the period 2005-2009 are reassuring because these counts range from 200 to 250 individuals each year (Rashad 2008).

The Nubian Ibex currently endures several threats in its Sinai range. Poaching is ranked as the highest threat to the population. The combination of the two facts that local Bedouin have access to modern guns and that Ibex have to visit water regularly to drink makes it very easy to affect the population in the short term. Poachers usually ambush thirsty ibex at water sources. The second most important threat comes from competition with local livestock. Bedouin living in these high mountains are gradually shifting from their former nomadic lifestyle to a more settled existence in villages around major cities to benefit from jobs in growing tourism industry. Some Bedouin still keep relatively large herds of goats and sheep, although for many the lack of vegetation caused by the drought has forced them to contract their herds down to just a handful, often kept just for sentimental reasons of tradition because they cost them money to feed. There are still a few herds taken to graze in the same mountain pastures every day. The third important threat is the rising levels of drought, probably caused by global climate change. The area receives less frequent showers and less annual precipitation, although the lack of long-term climate monitoring makes this hard to substantiate quantitatively. It is essential for conservationists and natural resource managers to know more about this species and especially its current distribution range, so as to activate a conservation plan. Another facet of this knowledge should be the anticipated future changes that might impact the species and its range in Sinai under climate change, with the potential for more arid conditions.

The fact that it is a species of rugged inaccessible mountains makes it very hard to accomplish comprehensive surveys that would identify particular areas inhabited by the species and exclude regions where it is not. Most of the available records of the species are opportunistic records obtained either by scientists on short visits, Bedouin or casual trekkers. Conventional methods of wildlife mapping can extract little from this type of data. A recent breakthrough in mathematical modelling enables the utilization of such presence-only records to estimate species distributions with the help of corresponding maps of environmental data.

The availability of detailed comprehensive global environmental datasets along with increasingly powerful and affordable computers has fuelled a rapid increase in the predictive modeling of species geographic distributions. Many methods and software platforms are currently available such as GARP (Stockwell & Peters 1999), Biomapper (Hirzel & Arlettaz 2003), GLM and Maxent (Phillips *et al.* 2006). A wide range of methods has been used for predicting species potential geographic distributions (Wisz *et al.* 2008), but despite their frequent use, the number of records available for individual species from which to generate predictions is often limited. Under a wide range of conditions and data quality, consistently Maxent performs as well or better than other methods (eg Wintle *et al.* 2005).

Methods

The southern part of Sinai extends from 27° 42’ 00” to 29° 30’ 00” N, and from 33° 00’ 00” to E 34° 48’ 00” E (Figure 1). The area is bounded by the Gulf of Suez in the west and the Gulf of Aqaba in the east. The altitude ranges from sea level up to 2,600 m, with a gently sloping coastal plain in the west, and a steep narrow descent to the east, the whole massif dissected by dry valleys, the wadis. There is a rich relict fauna and flora. Precipitation is in the cold season from October to late March, of variable amounts from 0 to about 100 mm, but patchy and very localized. Snow is not uncommon during the winter months above 1,500 m.

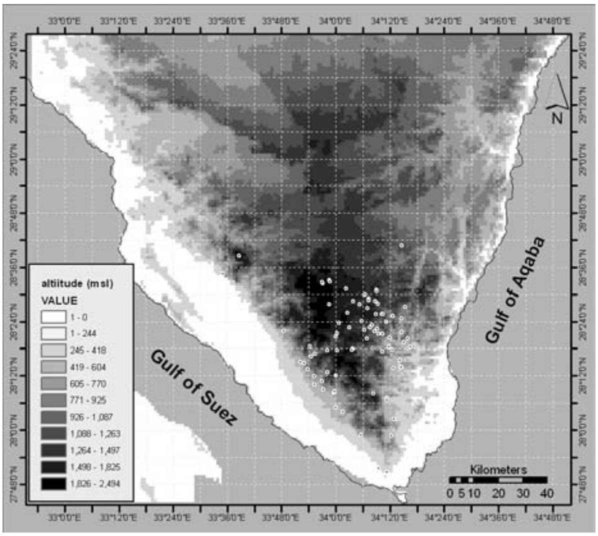

Figure 1. Study region of South Sinai, showing the mountain massif in the middle and Nubian ibex sightings used in the study.

The data set comprises 84 records covering the period from 1999 to 2009, all from within the area of the mountain massif of South Sinai and its wadi system (Figure 1). Observations were obtained by three different methods: camera-traps fixed in several destinations in South Sinai (El Alqamy *et al.* 2003); rangers during their field activities; and local Bedouin hired by the St Katherine Protectorate Management Unit as local community guards (part of whose job is to report wildlife in their area). All observations and records are georeferenced and documented in the Management Unit.

Environmental data were climatic, topographical and anthropogenic. Climate data for 19 variables were obtained from WorldClim (Hijmans *et al.* 2005) at a spatial resolution of 1 km^2 (Table 1). Topographic data consisted of altitude, slope, aspect and terrain. Altitude data was from the Shuttle Radar Topography Mission (Farr 2007), they were clipped and processed into slope and aspect raster grids using ArcGIS 9.3 and Spatial Analyst Extension®. The terrain dataset (Table 1) was developed by the BioMAP project (see Newbold *et al.* 2009). A data layer of human influence was produced from proximity to Bedouin settlements to all locations in the study region. Settlement locations were obtained from the St Katherine Protectorate Management Unit; the distance to the nearest settlement calculated from the center of each raster cell and the Inverse Distance Weighting used to produce the surface. All layers were produced or resampled to a pixel size of one km^2.

Maxent 3.3.1 software was used to model the data using the models described below with 81 presence locations (Maxent reduced the 84 points to 81 as removing replicate records in the same cell). The training data was about 85% (n= 70) of this set, and the test data (n= 11) was used for model validation. The maximum iteration was set to 500, and convergence threshold to 10^{-5}.

Model selection was done using a stepwise approach to detect the most influential variables affecting Ibex distribution to minimise overfitting. The following steps were used: (i) a model including all variables; (ii) omitting all climatic variables that did not explain variation in the data; (iii) topographic and anthropogenic variables only, with no climatic variables; (iv) determining the influence of proximity to Bedouin settlements, by running three models, first all variables except settlement proximity, second all the non-climatic factors except settlement proximity, and third the influential climatic factors with settlement proximity. Table 2 lists all the models used. Rival models were assessed using two criteria standardly used in species distribution modeling: AUC (Deleo 1993) and the Akaike Information Criterion (Akaike 1981). Since Maxent uses a maximum likelihood approach to determine coefficients, we used this to calculate the AIC using a Perl language script developed by Dan Warren (personal communication). The script standardizes Maxent likelihood scores so that they sum to 1 over the geographic space and then treats them as a probability distribution, allowing the calculation of likelihoods: the best-fit model was selected on the basis of the lowest AIC. Model weights were calculated using the Akaikae weights formula (Burnham & Anderson 2002).

TABLE 1
Definitions of the climatic and topographic variables, and habitat categories used in Maxent modeling.

	Climatic		Topographic	Habitat categories
Bio1	Annual Mean Temperature	alt	altitude	Sea
Bio2	Mean Diurnal Range (Mean of monthly (max T-min T))	slope	slope in degrees	Littoral coastal land
Bio3	Isothermality	aspect	aspect in degrees	Cultivated land
Bio4	Temperature Seasonality (standard deviation *100)	terrain	habitat categories	Sand dune
Bio5	Max Temperature of Warmest Month			Wadi
Bio6	Min Temperature of Coldest Month			Metamorphic rock
Bio7	Temperature Annual Range			Igneous rocks
Bio8	Mean Temperature of Wettest Quarter			Gravels
Bio9	Mean Temperature of Driest Quarter			Serir sand sheets
Bio10	Mean Temperature of Warmest Quarter			Sabkhas
Bio11	Mean Temperature of Coldest Quarter			Sedimentary rocks
Bio12	Annual Precipitation			
Bio13	Precipitation of Wettest Month			
Bio14	Precipitation of Driest Month			
Bio15	Precipitation Seasonality (Coefficient of Variation)			
Bio16	Precipitation of Wettest Quarter			
Bio17	Precipitation of Driest Quarter			
Bio18	Precipitation of Warmest Quarter			
Bio19	Precipitation of Coldest Quarter			

TABLE 2
Maxent models used arranged according to AIC scores and Akaikae weights.

Model	Model predictors	AUC	AUC SD	No.of parameters	Log Likelihood	AIC score	w_i	Model rank
Model 3	Altitude, slope, aspect, habitat, settlement proximity	0.9338	0.0181	33	-725.504	1517.0	0.918	1
Model 1	All predictors	0.9459	0.0180	47	-715.460	1524.9	0.019	2
Model 2	All predictors except unimportant climatic variables	0.9464	0.0182	55	-715.697	1541.4	0.000	3
Model 4	All predictors except settlement proximity	0.9419	0.0151	51	-736.873	1575.7	0.000	4
Model 5	All non-climatic predictors except settlement proximity	0.8931	0.0510	49	-739.882	1577.8	0.000	5
Model 6	All important climatic predictors + settlement proximity	0.9393	0.0167	26	-778.519	1609.0	0.000	6

The significance of the predicted geographical range of Nubian ibex was tested against a null model of equivalent data set generated at random as described by Raes & Steege (2007). Randomly selected 81 points in the study area that are equal to the actual number of presence records were generated and fed into Maxent and distribution model was generated (using the chosen model by AUC and AIC). This process was repeated 499 times to generate a frequency histogram of AUC values. AUC of each fit is calculated and all are used to build a normal distribution histogram. The prediction model is considered performing significantly better than expected by chance if its AUC is greater than the upper limit of the 95% C.I. calculated from the frequency histogram of the null-models (that's the AUC of the 474^{th} run 0.95 x 499 = 474). A model with low AIC and high weight was considered as best fit.

Results

The six models tested varied in their performance, as assessed by the AIC and AUC (Table 2). Model 3 was the best, with an AIC score 9 units less than the nearest other model, and with an AUC of 0.9355 with relatively low standard deviation. Model 3 also proved to be highest in its weight (w_3=0.918). This model was adopted as the best fit and used for further. Inclusion of the 'proximity to Bedouin settlements' as a predictor resulted in a discontinuous predicted range, with some of the areas in the east of predicted range lacking connections to those on the west (Figure 2). The most influential variable was proximity to settlements, followed by slope, habitat, altitude and finally aspect.

The contribution of individual variables held some surprising findings. Proximity to Bedouin settlements had a positive relationship with the presence of ibex (Figure 3). The relationship was expected to be one where higher presence values were predicted in more remote areas, but it was the opposite. Ibex predicted presence falls sharply further than about 15 km away from Bedouin settlements, and is effectively zero more than 35 km from settlements (see Figure 3). Altitude showed a very predictable response, with 1000 m a critical threshold for predicted presence, increasing sharply above 1100 m. The effect of aspect showed a sharp increase of Ibex predicted presence at an aspect of 350°, suggesting preference for west-facing slopes. As expected, the results showed also that ibex prefer steepe slopes. Regarding terrain categories, there was considerable preference for metamorphic and igneous rocks, as expected.

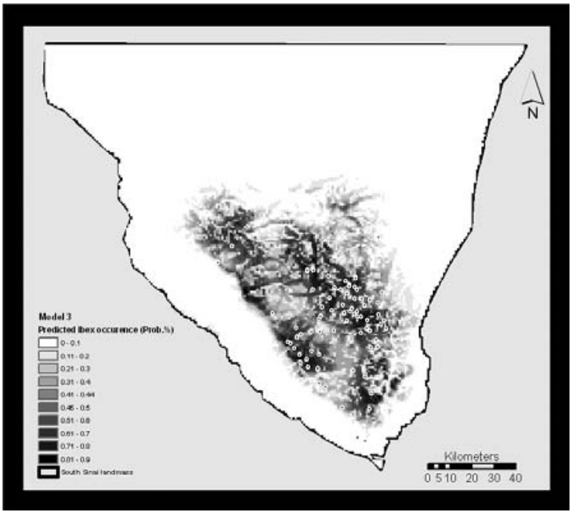

Figure 2. Predicted presence of Ibex in South Sinai, using the best model (model 3), together with the actual data. Note the separate areas of predicted high probability of occurrence.

Two thresholds of presence probability were used to compare ibex ranges as predicted by the different models. All grid units scoring more than 80% and more than 90% probability of presence were considered to indicate the natural range of the Nubian Ibex in south Sinai. Different models predicted different sizes of natural range: the largest was predicted by model 6 (1276 km^2) and the smallest by model 1 (433 km^2); the chosen best-fit model 3 predicts a natural range of 506 km^2 (Figure 4).

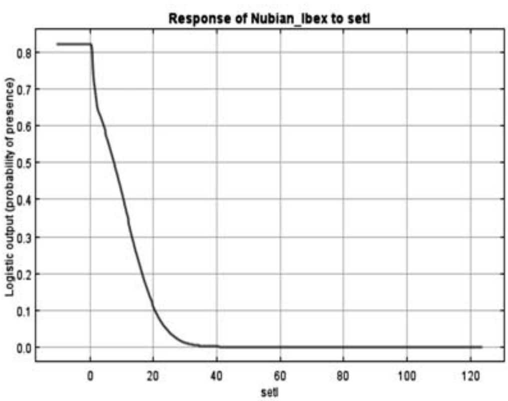

Figure 3. Relationship between the distance to settlements and the probability of presence of Ibex, as modeled by Maxent from presence records.

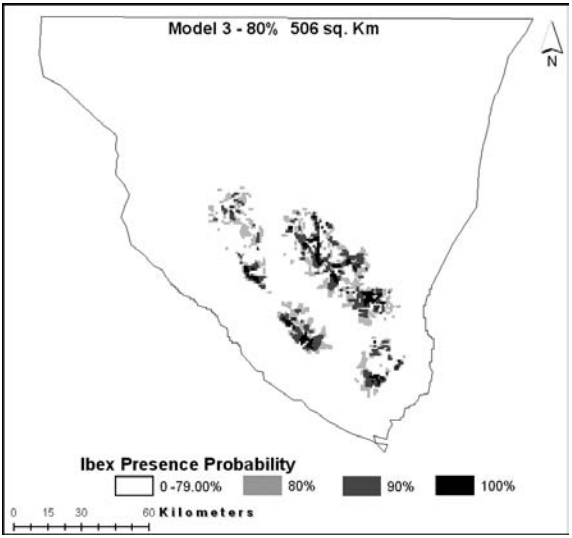

Figure 4. Predicted range size of the Nubian Ibex in South Sinai, as modelled by Maxent from presence records. The colours indicate the predicted probability of occurrence (as a percentage): white= <80%, light gray= 80%, dark gray= 90%, black= 100%.

Prediction from Model 3 shows to be significantly better than expected by chance when tested against a null-model using equal number of records. A histogram of AUC values from 499 runs shows that the 95% CI value is 0.6545 while the calculated AUC value for Model 3 is 0.9338 which obviously much higher (Figure 5).

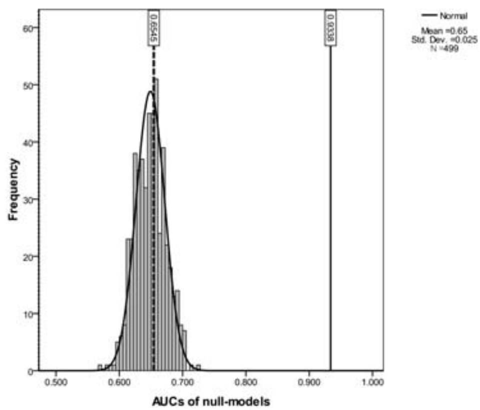

Figure 5. The AUC value of "Model 3" based on the 81 presence records (continuous line, AUC=0.9338) and the average AUC value (dotted line, AUC= 0.6545) of 499 model runs using 81 randomly generated points in each run from the total 49324 cells of the study region, indicating that the range prediction is significantly better than expected by chance of a null-model.

Discussion

The use of the Maxent distribution prediction software to predict the distribution of an elusive species such as the Nubian Ibex was clearly successful, producing a range map that can be used to initiate conservation actions. All tested models had high AUC values (all >0.9) and it would be hard to rank the models on this basis: the use of AIC was decisive, however, in supporting one particular model, which indicated the biophysical factors shaping the distribution. The selected model contained no climate variables. This could be because climate data for South Sinai are scant or non-existent, with only a short run of data from St Katherine in the high mountains: thus the climate data as obtained from WorldClim were probably largely or entirely interpolated from altitude. It is therefore not surprising that the variables altitude and habitat were surrogates for climatic conditions in the model, with the climatic data adding nothing to the efficiency of the prediction.

Nubian Ibex have an essential need for frequent access to free water. This is a possible explanation for the surprising result of the animals being predicted to occur close to human settlements. Bedouin also target areas where they can find water to place their settlements, and in doing so they occupy the core areas of Ibex habitat, hence the predictive value of 'proximity to settlement'. This makes competition between Bedouin livestock and Ibex highly likely. Human use of waterholes is known to affect significantly the utilization of these resources by Ibex (Wakefield & Attum 2006): Ibex visited significantly less often within 6 h after a human visit. The increased level of vigilance and temporary avoidance of water holes will reduce drinking opportunities and increase thermal stress, eventually reducing fitness (Lima & Dill 1990, Burger & Gochfeld 1992, Brown *et al.* 1999). Unfortunately, there is no information about livestock grazing intensity that covers the whole study area, so we were unable to test this obviously potentially useful variable as a predictor in the models. Conservation measures should address the issue of competition between Ibex, livestock grazing and waterhole use by humans, and try to quantify the magnitude of this competition.

The predicted range of the Ibex in South Sinai was quantified as 506 km². This range should be quantified frequently with new data to elucidate whether it is stable, increasing or declining. The predicted range showed some core areas, marginal regions and connecting corridors. Observations suggest that animals do move between west and east through corridors, and it is a priority for the managing authority to test whether the predicted corridors are actually used by Ibex, and if so, to initiate measures for their maintenance and incorporate their conservation into the St Katherine Protected Area management plan.

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