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# Predicting habitat suitability of the goitered gazelle (*Gazella subgutturosa subgutturosa)* using presence-only data in Golestan National Park, Iran

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## Abstract
The goitered gazelle (*G. s. subgutturosa*) facing the highest rate of illegal hunting and habitat destruction has been classified as threatened in the IUCN Red List. Thus, knowing the distribution of this species and its habitat requirements is important in designing efficient conservation measures for its rehabilitation. An ecological-niche factor analysis (ENFA) using presence only data was carried out using the Biomapper 4.0 software to assess the environmental and human-related factors that affect the *G. s. subgutturosa* presence, as well as identified areas with high habitat suitability in Golestan National Park (GNP) and nearby areas. ENFA indicated a high marginality (1.40) and low tolerance (0.46) scores, suggesting a strong tendency for the species to live in a particular habitat throughout the study area. Although environmental factors limited the presence of the *G. s. subgutturosa,* human activities causing habitat loss/fragmentation plus irregular hunting were the major barriers to the distribution and survival of these gazelles. The model also showed that overall, 50% (313km$^2$) of the study area was suitable, of which approximately 3.66% (23 km$^2$) had high suitability. The ENFA updated our information on *G. s. subgutturosa* habitat status and showed us the need to revise the boundary of the GNP for efficient conservation of this species. However, a considerable portion of the suitable area was located outside the park, which is under weak protection rules. Therefore, to protect the remaining population of the gazelles in the GNP, it is necessary to focus management efforts on specific areas outside the park.

## 1. Introduction

Certain biological characteristics expose species to greater risk of extinction. For instance, the risk of extinction could be higher in species that are characterized by a small population size (40), small geographical range sizes (42), and in those species that are also categorized as trade species, which inhabit an area with a high human activity rate (24). Therefore, any species that display these characteristics should be more sensitive to habitat change and more vulnerable to extinction.

Based on several previous studies, the goitered gazelle (*Gazella subgutturosa*) could be considered to be at risk of extinction since it possesses most of the high risk factors in its list of biological attributes. Gazelles, being small ungulates, are selective in their food habits (15, 58, 11). The earlier dispersal rate of the goitered gazelle was about 450-700 km, and gazelles migrated over long distances to find pastures and water, especially during the summer time (14, 18). However, to date, this distance has decreased to 50-60 km because of the low population size of the gazelle herds (63 cited in 14), habitat changes, and fragmentation (38). Most people are interested to live catch new born gazelles and local people often keep them as pets. Moreover, the goitered gazelle is most threatened by habitat loss and fragmentation (41, 18).

One of the important topics in conservation biology is information about the distribution of endangered and threatened animal species and their habitat requirements (59, 55). Habitat suitability modelling is required for management of the endangered species (50), re-introduction of species to their historical or other habitats, population viability analysis (5), understanding of human-wildlife interaction (51), and restoration of the ecosystem (44). Habitat fragmentation resulting from land use has long been recognized as a major threat to the preservation of the biodiversity and to the viability of a species (39). Conservation strategies have focused on both the preservation of adequate habitat areas and the spatial distribution of these areas throughout the landscape. To attain these goals, the use of spatial models (53, 48, 1) has become a common ecological practice. A wide variety of predictive models have been used to simulate the spatial distribution of plant and animal species (55, 34). Most of these models identify a quantitative or qualitative relationship between the presence of a species and a number of climatic and geomorphologic variables as well as information on vegetation cover, land use and anthropogenic disturbances (30)

Although models can easily be made from presence/absence data of a species (27), however, the modeller should distinguish between true absence data and a lack of information (56, 8), as absence data could be due to an insufficient sampling effort (31), lack of detection even though it was present (54), extirpation of the species in the past even though the habitat is suitable, or a truly unsuitable habitat for the species. Only the last clause is relevant for predictions, but the occurrence of “false absences” may considerably bias analyses. Hence, when absence data is not available or is unreliable, most of the modelling methods are of limited use because certain sites may be suitable but may not have been reached yet by the specie (27).

Accordingly, logistic regression/classification, generalized linear model (GLM) and regression trees; as common ecological modelling methods relying on both presence and absence data become useless in these instances (52, 34). An alternative method is modelling based on presence-only data (27, 26, 31, 51, 1). One of these alternative techniques is the Ecological Niche Factor Analysis (ENFA) (26). The ENFA is performed through Biomapper software (28, URL: http://www.unil.ch/biomapper). Originally, the ENFA was set to predict fauna distributions, which are sensitive to “false” absence data (55). Also, the ENFA modelling is able to predict the potential distribution of rare species, as well as plant or native species from presence-only data, but it might not be the best model for invasive species (55). The data used in the ENFA fall into two categories: independent environmental variables and dependent species distribution data.

In Iran, the goitered gazelle is distributed widely throughout the steppe or semi-desert habitats and in the far south of the country with the exception of the mountain ranges (36). Today, only about 20% of the former population of the gazelles remains (23), mostly in protected areas, while poaching is still a serious problem. In Iran, like other places, poaching, habitat degradation due to overgrazing and removal of shrubs and bushes, conversion of land to agriculture, construction, mining, and military activities (35) are acting as threatening factors for these gazelles. Therefore, if conservation efforts are not immediately implemented for this species, its status can soon change to the Extinct (EX) category (33).

In this study, a habitat suitability model was developed for a subspecies of the goitered gazelle named the *Gazella subgutturosa subgutturosa*. The output of this study will be to identify the environmental factors that explain the distribution of the *G.s. subgutturosa* and to predict the highly suitable areas for the conservation and management of the endangered gazelle inside and outside of the GNP. The *G. s. subgutturosa* is the only subspecies of the goitered gazelle which lives in the steppe habitat of the GNP in the north of Iran and is highly threatened by human activities.

Despite the obvious need for efficient habitat protection efforts, ecological studies on how to protect the *G.s. subgutturosa* and develop a plan for reconnection of the habitat patches in the area are insufficient. Moreover, the required ecological and biological information about the *G.s. subgutturosa*, necessary for its conservation is rare. A combining different sets of biotic and abiotic data though models can be of high value in these instances (26, 49,7). For *G.s. subgutturosa* in the GNP, habitat suitability was extracted from physical and biological data using ecological modelling and GIS. The ENFA procedure was used to depict the following features: 1) environmental factors which limit the current distribution of the species, 2) human activities which have affected the distribution of the species, 3) the most suitable habitats for the *G. s. subgutturosa*, 4) how to reconnect the habitat patches, and 5) can we suggest habitat management strategies to improve the current population status of gazelles?

## 2. Materials and Methods

### 2.1. Study Area

The GNP is located in the north-eastern part of Iran to the east of the Caspian Sea between 37°24'N to 55°58'E

(37.403°N and 55.976°E) (6). In order to perform the ENFA, a wider geographical area where the *G.s. subgutturosa* was selected; therefore, even though the study base was located in the GNP, the boundaries of the study area extended outward, to the steppe area of the Ghorkhood preserve as well. The GNP has an area of approximately 91,859 hectares and the study area was 62,800 hectares. The boundary of the study area was different from that of the GNP because the park does not cover habitats of all gazelles in the region. Moreover, the park area comprises high mountain ranges and dense forests unsuitable for this species. Initial field surveys were implemented where we thought the species should be present in GNP. After intensive surveys and interviews with the local people, the study area was defined according to the locations of the gazelles' presence and those areas rarely or never used were omitted (Fig 1).

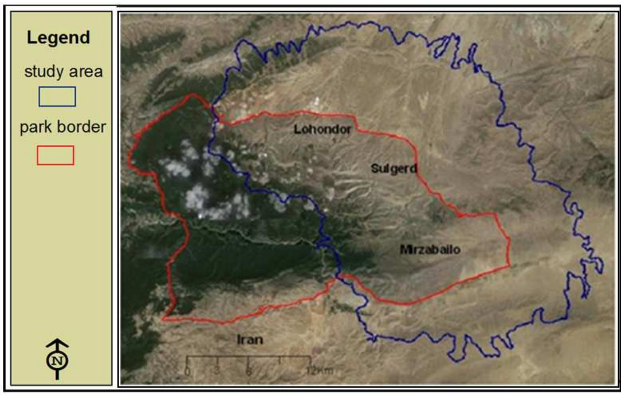



***Fig 1.*** *Geographic location of the study area and Golestan National Park (Google Earth 2010)*

The maximum and minimum elevations are 2,411 m and 450 m, respectively. The park includes mountainous areas, hills, fields, and plains. The steppe habitats of the GNP are scattered throughout the northern and eastern parts. The main plant coverage includes bushy shrubs and annual vegetation which belongs mostly to the Iran-o-Turanian elements. The *Artemisia* species is an endemic and main species of this element. These parts of the GNP have warm and dry summers and cold winters. The annual average precipitation is 400 mm; the annual average temperature varies between 11.5 to 17.5 °C; the absolute minimum temperature is -25 °C and the reported maximum is 45 °C. Vegetation growths are occasionally accompanied by *Rosa* and *Tamarix* species. The density and variety of this vegetation is higher in the valleys. The *Artemisia* species, annual species, and steppe communities cover the hills and valleys creating a shrub land that is a suitable habitat for park animals such as gazelles, red deer, many rodents, and reptiles. *G.s. subgutturosa* is currently present in Mirzabailo and its surrounding areas in the southern parts of the park, in Sulgerd and the northern part of the park up to Lohondor.

## 2.2. Gazelle Distribution Data

The presence data set consisted of 213 detailed point locations of the *G. s. subgutturosa*. This distribution data came from field observations using a global positioning system (GPS) and map-guided interviews with local shepherds, hunters, biologists, and park managers from regional environmental agencies and were verified through visiting the areas where gazelles were reported. The target species distribution data were also obtained by means of interviews with rangers and staff from the environmental office in the GNP. Only the data confirmed in at least three questionnaires were considered. This restrictive criterion was used to avoid the inclusion of false presences in the statistical models (47, 2). Then, all the recorded presence data were embedded in a geo-referenced database, UTM 10×10 m squares, and represented by Arc GIS 9.3 (ESRI). The presence data of the *G. s. subgutturosa* gathered from this study is shown in Fig 2.

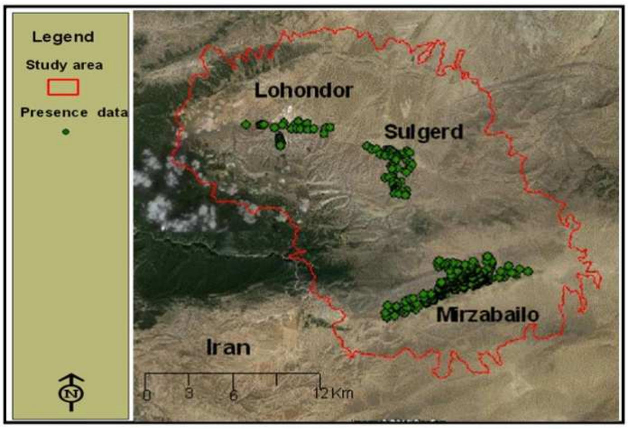



***Fig 2.*** *Presence data of the G.s. subgutturosa in the Golestan National Park and its vicinity.*

## 2.3. Environmental and Human Related Data

The Eco-geographical variables (EGV) were geomorphologic features (e.g. altitude, slope, aspect and curvature), distance to human-made structures (e.g. distance to the human residential areas, distance to road, distance to the watercourses, distance to environmental office and distance to livestock), the Normalized Difference Vegetation Index (NDVI) as a habitat structure, and panther as a predator (Table 1).

Based on studies by Acevedo et al. (3, 1) and Quevedo et al. (48) in the Iberian Peninsula, many factors such as human activities, bioclimatic and ecological parameters affect the population abundance and distribution of ungulate species. Therefore, in this study, eleven variables were selected that could act as determinants of the current distribution of the *G. s. subgutturosa* in the GNP (Table 1), eight accounting for environmental traits (habitat structure and geomorphology), and two accounting for human impacts and areas where the panther (*Panthera pardus saxicolor*) is present as a predator. The geomorphologic variables were calculated from the 10×10 m DEM. The NDVI was calculated using bands 3 and 4 of the Landsat TM images of the area acquired on august 2007 and then used as a surrogate of the habitat structure. Five other variables that accounted for the human impact on the *G. s. subgutturosa* territories included the maps for roads and villages prepared by Google Earth (2010) and the National Cartographic Centre of Iran (NCCI) using the best and most up-to-date images; while others maps of human-related variables such as water points, environmental office and livestock places were prepared by a research team in the study area. The *P. pardus saxicolor* is the main predator that hunts on the *G. s. subgutturosa* in this area. Data on the *P. pardus saxicolor* came from a recent study in the area by Erfanian et al. (21) that also included field visits and close inspection of the accuracy of the point recordings. All the EGV maps were prepared on the Arc GIS software 9.3 (ESRI).

***Table 1.*** *Variables used in the spatial modelling of G.s. subgutturosa habitat in the Golestan National Park.*

| Egv | Description and Sources |
|---|---|
| Geomorphology | |
| Altitude | Digital Elevation Model (DEM) |
| Slope | Using “Slope steepness” function (percentage) based on DEM |
| Aspect | Using “Aspect” function (percentage) based on DEM |
| Curvature | Using “Convexity/concavity” function based on DEM |
| Human Impact | |
| Distance to road (m) | NCCI and Google Earth (2010) |
| Distance to villages (m) | NCCI and Google Earth (2010) |
| Distance to watercourse points(m) | Researcher team |
| Distance to environmental offices (m) | Researcher team |
| Distance to livestock herds (m) | Researcher team |
| Habitat Structure | |
| Normalized Difference Vegetation Index (NDVI) | Based on red and near infra-red band of Landsat TM, (2007) |
| Predator | |
| Distance to Panther (m) | Erfanian et al (2013) |

No climatologic variables were considered as the study area is characterized by a relative climatic homogeneity, with only slight differences related to topographic variations (Similar to 48, 1).

The prepared maps of the EGVs and the presence points of the species were imported and processed into the IDRISI Kilimanjaro 32 (ESMAN). DistAN and CircAN modules were used to obtain distance and frequency maps with the CircAN for all attractive resources (food, shelter, etc.) and DistAN was used for disturbance (mainly human impact) variables (For more details see Hirzel et al. (26) and FAQ in “www.unil.ch/biomapper/fag.html” as well as WikiBiomapper).

## 2.4. Statistical Analysis

### 2.4.1. Habitat Modelling

We only considered the presence data. An ENFA using presence only data was carried out using the Biomapper 4.0 software to assess the environmental and human-related factors that affect the species in question (26). The ENFA is a modelling technique based on Hutchinson’s Ecological Niche Theory (1957), and calculates the habitat suitability indices from environmental predictor variables and presence-only data of a species (26). The main role of the ENFA is to compare the distributions of the EGVs between the presence data of the species and the study area.

The EGVs were normalized using the Box–Cox (26) transformation. Similar to the principal component analysis (PCA), in the ENFA several EGVs are summarized into two independent factors that contain more information. The first factor, marginality, explains the differences between suitable conditions for the species from the mean habitat in the study area, (26). The marginality factor, demonstrates the correlation between each EGV and the factor. The species tend to live in average conditions throughout the study area if the marginality factor is low (close to 0), whereas a high value (close to 1) indicates a tendency to live in extraordinary habitats. Furthermore, a positive value for the marginality coefficient illustrates that the species prefers high values of the respective EGVs, but a negative value demonstrates that the species prefers low values. The subsequent coefficients are specialization factors, which define how the species responds to environmental variables. The interpretation of the specialization factor is difficult because of its range from 1 to infinity. Therefore, the tolerance factor is used instead, which measures the tolerance of the species towards the available range of environmental variables in the studied area. The tolerance factor is the inverse of the specialization factor (1/S) that ranges from 0 to 1. A low tolerance indicates that the species tend to live in a narrow range of the current conditions, while a high value indicates the reverse (26).

After calculation of the ENFA factors, the habitat suitability scores for each map pixel were computed in accordance with the response of the species to each factor. Partial suitability scores were computed for each factor as the percentage distance to the median score of the observed presences. The habitat suitability was then obtained as a weighted average of these partial suitability scores according to the variability explained by each factor (26).

### 2.4.2. Model Validation and Accuracy

A habitat suitability map (HSM) was drawn using the median algorithm, showing the highest Boyce Index .In order to evaluate how the results of a suitable model describes the observed data, two factors, the Explained Information (ExI) and Explained Specialization (ExS), were used. The ExI of the model determined the number of factors included in the habitat suitability map and means the amount of variance of the data explained by marginality and specialization. The ExS means the amount of variance of the data explained by the model (26).

The intensity and predictive power of the habitat suitability model were considered by a cross-validation procedure (16, 26). The locations of the species were randomly partitioned into *k* mutually exclusive but identically sized sets. Each *k* minus 1 partition was used to compute a habitat suitability model and the partition that was left out was used to validate it based on independent data. This process was repeated *k* times, each time by leaving out a different partition. This process resulted in *k* different habitat suitability maps, and the comparison of these maps and how they fluctuated provided an assessment of their predictive power. Four partitions were used. Each map was reclassified into i bins, where each bin i covered some proportion of the study area (Ai) and contained some proportion of validation points (Ni) (validation points were the observations left out during the cross-validation process). Three bins were also used. The area-adjusted frequency for each bin was computed as Fi = Ni/Ai. The expected Fi was 1 for all bins if the model was completely random. If the model was good, a low value of habitat suitability should have a low F (below 1) and vice versa with a monotonic increase in between. The monotonicity of the curve was measured with a Spearman rank correlation on the Fi (16, 29). Eventually, the habitat suitability map was reclassified into three classes of suitability (<33, 33-66, >66).

# 3. Results

## 3.1. Direct and Surrogate Causes of the Limited Distribution of the G.s. Subgutturosa

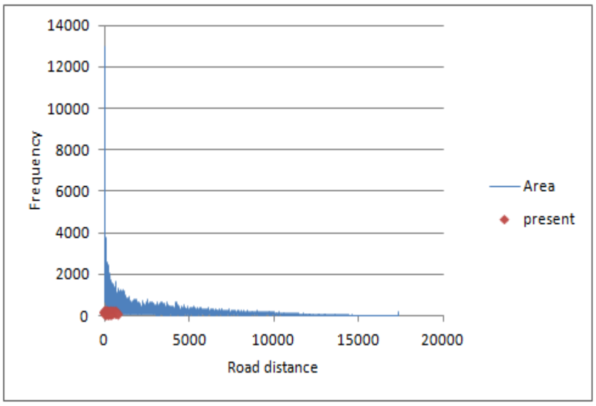
Gazelles showed a tendency to occupy particular niches in GNP and its vicinity (marginality score = 1.40 and tolerance factor = 0.46). The two factors retained out of 10, accounted for 75% of the total sum of the Eigenvalues (that is, 100% of the marginality and 75% of the specialization). The marginality factor alone accounted for 21% of the total specialization, a significant indication that gazelles display a restricted range in the study area.

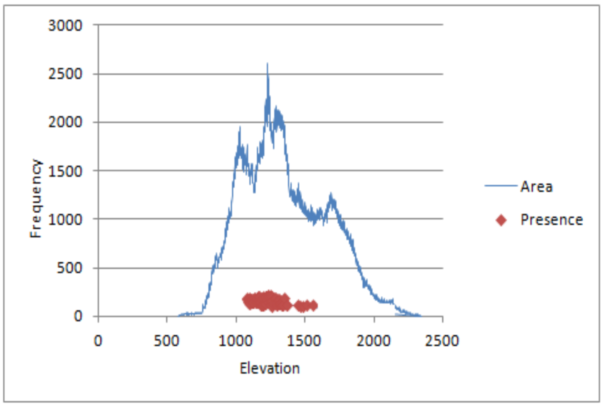
According to the marginality factor which was negative, the potential distribution of the gazelles was highly correlated with the human-related variables such that gazelles preferred being close to all human-made structures (Appendix 1). The subsequent factors explaining specialization showed that the gazelles are negatively associated with the environmental variables such as slope, Dem, NDVI and curvature (Appendix 1), indicating a preference for flat plains with low elevations and low vegetation densities. Meanwhile, the positive relationship between the presence of the gazelles and the occurrence of the *P. pardus saxicolor* by the specialization factor represented the tolerance of the gazelles to the presence of the predators in the study area.

Human-related variables had a greater effect on the specialization factors of the *G. s. subgutturosa* than marginality. With the exception of the livestock grazing areas, the presence of the gazelles was positively related to roads, water sources, environmental protection office and the villages according to the specialization factor (Appendix 1). For livestock occurrence gazelles avoided being near to competing species. In fact, the *G. s. subgutturosa* is distributed on the eastern edge of the park throughout the north to the south, where most of the human structures and settlements are located.

Furthermore, the marginality factors indicated that gazelles are found in locations with lower than average cell values with regards to distances to road and water sources, meant altitude and slope (Appendix 1). The altitude and NDVI presented high coefficients for the specialization factors of the *G.s. subgutturosa* (Appendix 1).

A histogram assessment showed that most of the gazelles were found at a distance of less than 1,000 metres from roads and villages. In the steppe area of the GNP, the highest frequency of gazelle populations was found at a distance of less than 10 kilometres from water sources. Based on the results, gazelles are sensitive to shifts from their optimal conditions on these axes. Altitude was the next important factor which accounted for more specialization, showing some sensitivity to a shift away from its optimal value. Therefore, gazelles were more inclined to select middle elevations (1000-1600 m) and avoided high elevations (>1600 m). Gazelles preferred slopes of less than 20% (Fig 3).



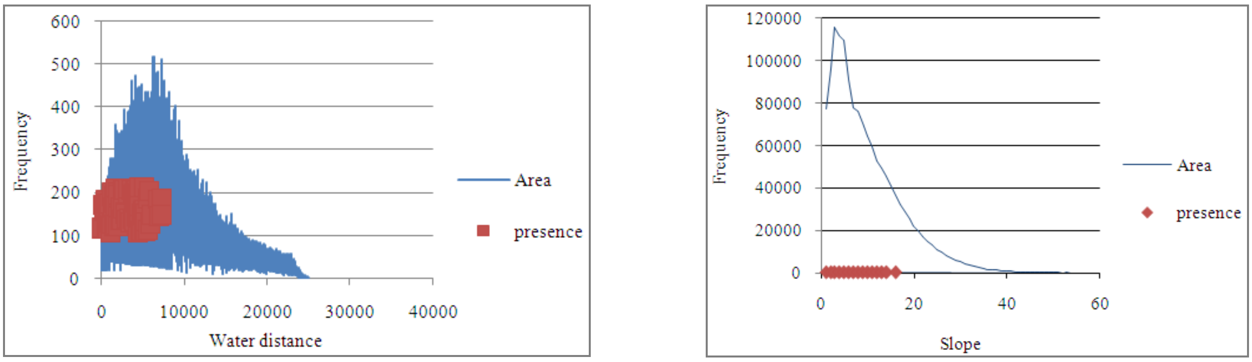



***Fig 3.*** *The distribution of G.s. subgutturosa in the study area contrasted with distribution of four most important environmental factors that affecting gazelle habitat suitability.*

## 3.2. Habitat Suitability Area for G.s. Subgutturosa Distribution

Four habitat suitability maps were derived by computing different algorithms and according to the highest Boyce index, the median algorithm was best to draw a habitat suitability map (Table 2). The values of the habitat suitability index (HSI) ranged from 0 to 100; in which 0 refers to the least suitable habitat and 100 to the most suitable (Fig 4).

***Table 2.*** *The comparison of Boyce index among different algorithms*

| Algorithm | Boyce index ± Sd |
|---|---|
| Median | 0.259 ± 0.458 |
| Geometric mean | 0.156 ± 0.457 |
| Harmonic mean | 0.173 ± 0.432 |
| Minimal distance | 0.14 ± 0.439 |

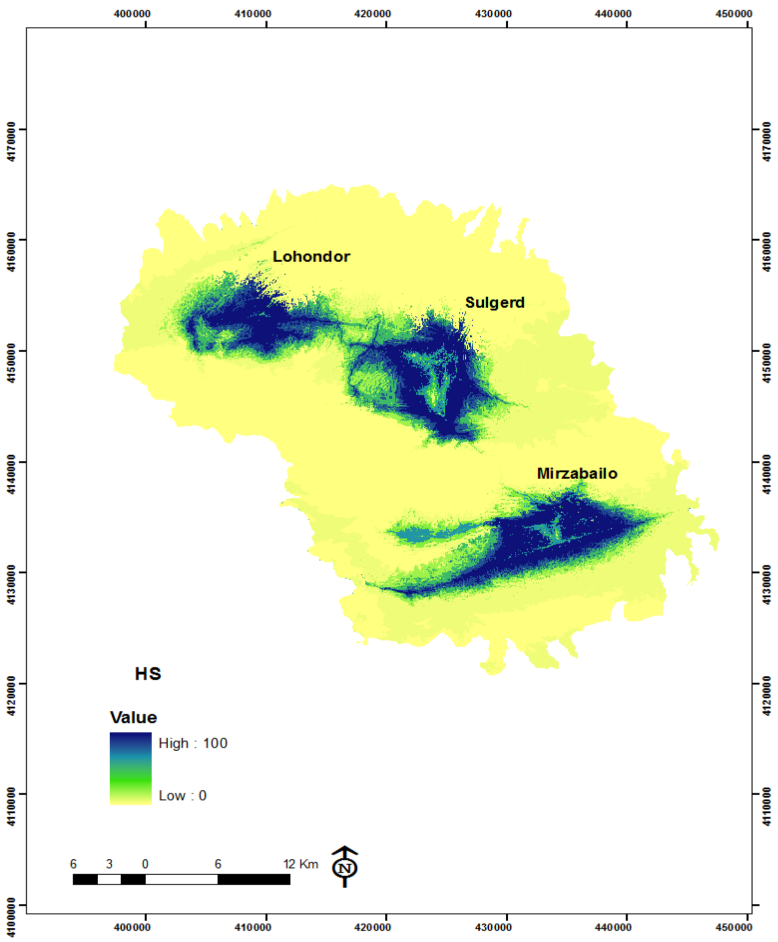



***Fig 4.*** *The habitat suitability map (based on median algorithm) for the G. s. subgutturosa in the study area has been produced by the ENFA. The scale shows the habitat suitability values (0 indicating low/unsuitability and 100 indicating the highest suitability).*

The habitat suitability map (Fig 5) classified the study area according to the following suitability percentages; highly suitable - 3.66% (23 $km^2$), moderately suitable - 12.73% (80 $km^2$), less suitable - 33.43% (210 $km^2$) and unsuitable - 50.15% (315 $km^2$). The suitable areas have mostly been located in the steppe region and in the low elevations of the Mirzabailo plain, and the Solegerd and Lohondor areas in the eastern part of the GNP towards the Ghorkhood preserve, including the border area between the park and the preserve (Fig 5). The most suitable areas outside the park are occupied by farmlands, villages, and livestock herding. The GNP highway, that connects the two main provinces of Golestan and Khorasan-Razavi in the north of Iran, passes through the park and the preserve. Despite the good natural suitability of the preserve for the presence of gazelles, they suffer from a high level of human disturbance in this area.

Highly suitable areas without current records of the presence of the species (Fig 5) indicated the ability of the ecological model to identify suitable areas in unanticipated regions. The presence of gazelles at low suitable areas inside the GNP under the protection of the DoE indicated that safety is an important factor in the distribution and presence of the gazelles (Fig 5).

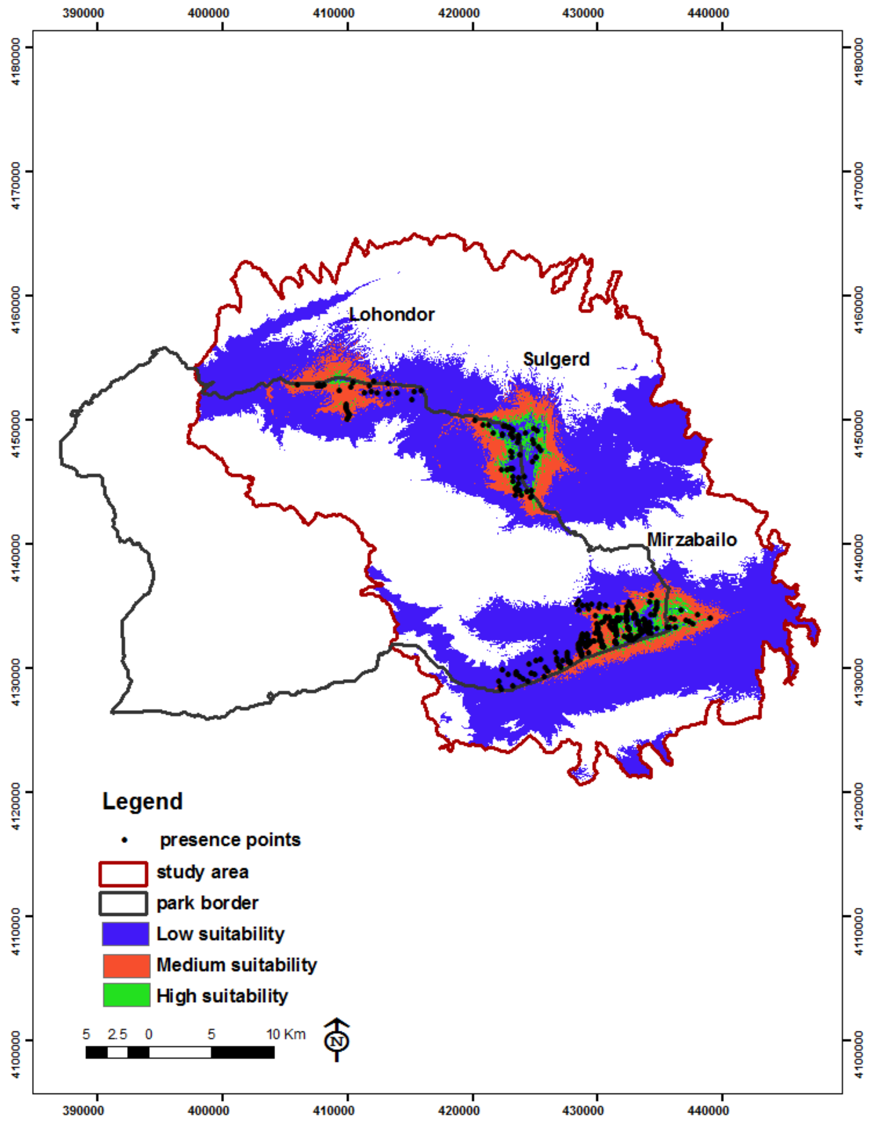


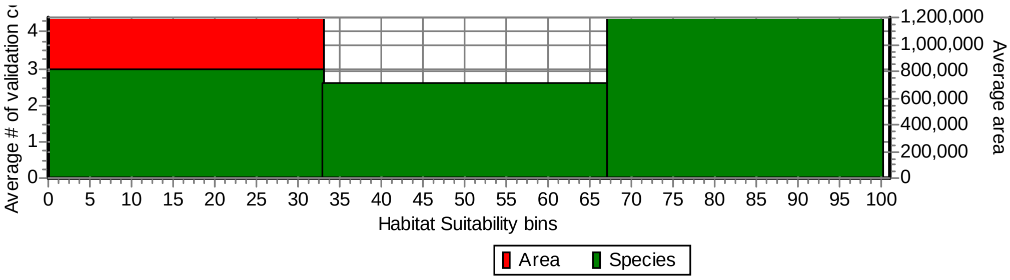

***Fig 5.*** *The map of distribution and different level of habitat suitability of G. s. subgutturosa in the study area (red border) and Golestan National Park (black border). Most gazelle presence points were recorded in high suitable area of park and its vicinity.*

A cross-validation of the model demonstrated that most of the gazelle records fell within the most suitable habitat, which probably indicates that the gazelles are selective ruminant which prefers high quality areas (Table 3 and Fig 6). Moreover, the heavy presence of the gazelles in the highly suitable areas emphasizes the accuracy of the ecological model. Moreover, the accuracy of the predictive model by a cross-validation procedure was considered to be good as there was no overlapping among the three classes of habitat suitability under the species distribution (Fig 6A). The explained information of the model was 0.877 and the explained specialization was 0.755.

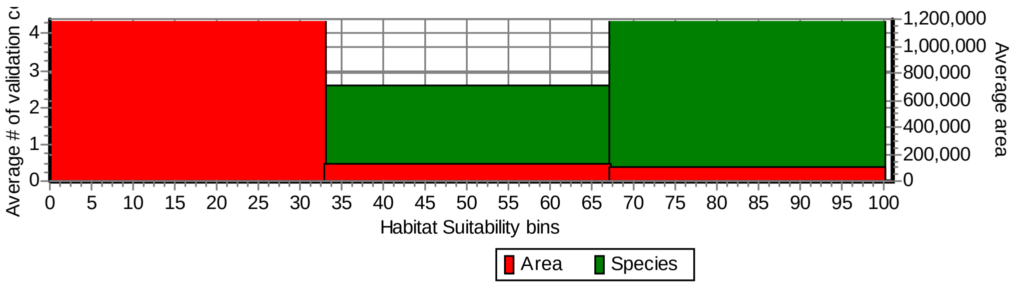
***Table 3.*** *Summary of the habitat suitability map (HSM) and distribution of G.s. subguttorosa at 3 classes of habitat suitability*

| | *HS 1 | HS 2 | HS 3 |
|---|---|---|---|
| | **0-33** | **33-66** | **66-100** |
| The area of gazelle suitability habitat | 210 $km^2$ | 80 $km^2$ | 23 $km^2$ |
| Gazelle density | Medium | Low | High |

*Habitat suitability (HS) scores were derived from Cross-validation procedure, categories from 1 to 3 to represent the suitability of the study area to present *G.s. subguttorosa* according to marginality and specialization factors. Thus, score 1 show area of low suitability and score 3 indicates an area of high suitability for gazelle presence. Although, most of study area located in low suitable class, but most gazelle presences was recorded in high suitable class.




(A)




(B)

***Fig 6.*** *Frequency histogram of the distribution of G.s. subguttorosa (green bar in figure A) and proportion of study area (red bar in figure B) under 3 suitable classes by habitat-suitability bin according to cross-validation procedure.*

## 4. Discussion

The interpretation of factors in terms of its EGVs turned out to be very consistent with the experience of field specialists. In particular, the EGVs that correlated with the marginality factor were precisely those that were most often particularly relevant for the ecology of the gazelles.

The ENFA as a robust model built on presence-only data (27) cannot extract causality relations. Nonetheless, it provides important clues about preferential conditions, and remains a powerful tool to draw potential habitat maps (26). As the data for this study came from surveys concerned with species presence, the ENFA was used to create suitability maps of the *G. s. subgutturosa*.

### 4.1. Relationship between Human Activities and Environmental Factors with Regard to the Distribution of the G.s. Subgutturosa

The narrow distribution of the *G.s. subgutturosa* in the study area suggests that the species prefers a small range of environmental factors for their habitat confirmed by the high marginality and low tolerance scores. Recent studies about the interaction between human activities and the presence of the gazelle have shown that a negative relationship exists between the presence of the species with most types of human interference (57, 32, 61, 62) whereas in our study the reverse was true. The main/transit road of the GNP and its surrounding villages with their high marginality and specialization factors encompassed the main human activities, positively related to the occurrence of the *G.s. subgutturosa*. Most of the human settlements and villages around the GNP were located amidst agricultural lands along the border of the main road. Also, as reported in previous studies, cultivated lands, and gardens are important food sources for gazelles throughout the year because of the palatable wheat, wild alfalfa, green wild forage and artificial water sources (46, 22). Therefore, most of the gazelle distributions in the study area were spotted near the main road and villages and the frequency of the gazelles up to 1,000 m distance from road and human settlements were rare (Appendix 1 and Fig 3). On the other hand, many road accidents and casualties have been reported by the Iranian Department of the Environment (DoE) when gazelles attempt to cross the road to reach the agricultural lands and gardens. Hence, tendency of gazelles to farmlands is of the main problems. Fluctuations in the population of this species are affected by this tendency.

In contrast to asphalt roads, it seems that unsealed/secondary roads have a lesser effect on the distribution of gazelles because of much less traffic. Therefore, in the present study; secondary roads were lumped with the main road. However, the secondary roads inside the park would make it easier for poachers to reach the gazelle habitats.

The presence of competing species, such as livestock, limits the occurrence of the gazelles, as suggested by the specialization factor (Appendix 1). A considerable population of livestock graze on the flat plains of the preserved area on the border of the GNP throughout the year. Domestic animals force the gazelles from the flat areas of their habitat toward the hilly terrain where most of the predators, such as leopard and cheetah, live. Moreover, herd dogs also chase the gazelles and force them to leave their normal habitat (22). In fact, domestic sheep and goats share somewhat similar dietary habits as well as other life-history traits with gazelles (17, 58). Therefore, an ecological competition may occur between livestock and the gazelles leading to threatening situation for the gazelle population in the near future in view of their small population size in GNP.

The gazelles were highly dependent on water sources (Appendix 1), similar to the results by Mendelssohn (43) and Farhadinia et al. (22), but, according to the histogram in Fig 3, the highest frequency of gazelles was concentrated homogeneously at a radius of less than 10 km around watercourses. This rather great distance from water sources could be explained by the fact that most of the watercourses on the GNP are dried or contaminated. In addition, this study was not able to consider the two factors which are affecting the amount of water consumed by the gazelles, which are: 1) The farmlands around the GNP which attract the gazelles during the night provide the water requirements of the gazelles by means of the green and succulent crops, and also the waterholes in these farmlands, such as the canals, streams and springs, can be a notable source of water for the gazelles. 2) It is supposed that the *G.s. Subgutturosa* also tend to supplement a considerable proportion of their water requirements by consuming plants with high water content in their habitat (60, 22). Hence, it can be hypothesised that succulent plants in gazelle habitat and cultivated farmland around the park could be further sources of water beside watercourses for the *G. s. subgutturosa*.

As a result, the negative impact of human activities on gazelle distribution through restriction of the connections between ecologically suitable areas and habitat fragmentation, habitat loss, hunting, competition with livestock, inefficient administration/enforcement of legislation and inadequate protected area coverage, were considered as major reasons for the degradation and loss of habitat, and subsequently for the decrease in the gazelles' population in our study and in those conducted in other parts of the world (41, 18, 51). Despite all of these limitations, gazelles are still absorbed to human-made structures such as cultivated land and gardens throughout the year confirmed by several daily visual observations of gazelle herds. As such, there is a conflict of interest between human activities and the presence of the gazelles, and this will lead to the continued loss of this species in the area.

Among all the environmental factors, the occurrence of the *G. s. subgutturosa* is negatively correlated mostly with slope and altitude, explained by the specialization factor (Appendix 1). The low density of leopards and cheetahs in the study area has resulted in a tendency of the gazelles to close in on the hilly areas near the habitats of predators, as indicated by the marginality factor (Appendix 1). According to the results of Fig 3, the highest frequency of gazelles was focussed on the low relief areas, including the 1000-1600 m altitude and a 20% slope, where a combination of flat plains with hilly areas seems the most preferred habitat for gazelles, as previously reported by other studies (4, 57, 22).

Based on the specialization factor (Appendix 1), the presence of gazelles was restricted in areas with a high curvature as these areas are mostly close to mountains with high elevation and unsuitable slope for gazelles. Although the hilly terrain provides greater security against poachers, particularly during the night when they are active with spotlights, but, the risk of being trapped by predators cannot be ignored. In another study about the habitat selection of the Tibetan gazelle (*Procapra picticaudata*), Wangdwei and Fox (57) found that although small breaks and gentle curvatures in hilly terrain would be suitable places for the small gazelle to hide in, these also put them at risk from predators.

As indicated by the specialization factor, the occurrence of the *G.s. subgutturosa* is negatively associated with the NDVI (Appendix 1). This means that the gazelles avoid denser vegetation parts of the habitat. In another study, it was found that gazelles preferred vegetation types which were dominated by shrubs, such as the *Artemisia herba-alba*, with a maximum canopy cover of 30% (9). Also, based on direct observation, most gazelle traces (pellet groups and tracts) were left in an open, flat area and empty spaces between shrubs such as the *Artemisia herba-alba*. However, there is a significant relationship between the NDVI and the occurrence of the Mongolian gazelle, as reported by Muller et al. (45). They found that gazelles prefer an intermediate range of NDVI that provides adequate forage quantity and quality, as well as most of their resource requirements. It may be quite likely that an area with low NDVI values may not provide adequate forage for gazelles. Although areas with high NDVI values are associated with higher amounts of mature forages and high productivity rates; plants at a mature stage have less nutritional quality and digestibility (37, 11). Therefore, gazelles, being small ruminants, require high nutritional forage in small amounts, which are provided more in the intermediate range of the NDVI. This could be due to the small rumen size and high energy requirements of the gazelle (15).

### 4.2. Suitable Habitat Area and Conservation Concept

During the past two decades, the population of the gazelle has declined dramatically in their natural habitats in the GNP of Iran, and the remaining population is highly fragmented and endangered. Therefore, to manage the remaining population and habitat of *G.s. subgutturosa* in GNP, we strongly suggest that the identification of the critical areas for conservation and boundary modification be conducted immediately. The habitat suitability map of the *G. s. subgutturosa* identified the suitable areas as being mostly in the steppe and low relief regions of the GNP and in the Ghorkhood preserve. The model also showed that the habitat suitability map for the *G. s. subgutturosa,* is somehow extended outside the park while the presence data in our study were restricted to the border of the GNP (Fig 5). Overall, 50% (313km$^2$) of the study area was predicted to be suitable, of which approximately 3.66% (23 km$^2$) had high suitability. The model showed that a considerable portion of the suitable area was located outside the park in the Ghorkhood preserve, which is under weak protection rules. The preserve has a good, natural suitability but suffers from a high level of human disturbance and activity, which acts as an “attractive sink-like” habitat or “ecological trap” (34). Therefore, in order to protect the remaining population of the gazelles in the GNP, it is necessary to focus management efforts on specific areas outside the park and provide the necessary links and even a change in GNP current boundary.

The GNP , as the most important and valuable national park in Iran, is the first Iranian national park in UNESCO’s World Heritage list and one of the 50 biosphere reserves. The Park became protected from 1957, and in 1971, another area called Ghorkhood, with 34,000 hectares, became attached to the eastern part of the park, and the title of the park was changed to National Park. The *G. s. subgutturosa* is the only species of gazelles which is widely distributed in the steppe area of the National Park (from the eastern part of the Wild Park to the Ghorkhood preserve). However, after 1979, the Ghorkhood area and the Wild Park were again separated from each other and the name of the current park was changed to GNP with an area of 91,895 hectares. After the separation, the large gazelles’ population, numbering around 600 individuals, which could formerly be seen in wide areas of the National Park, declined to only 220 gazelles. During the same period, the gazelles’ population were extirpated in the Ghorkhood preserve, where once a large population of gazelles were living (25). This species has been experiencing the greatest population reduction in their habitats at the GNP over the two last decades, and is exposed to the risk of habitat loss, fragmentation, and excessive hunting. Although individuals or small groups of gazelles are seen in a small range of the Ghorkhood preserve, higher concentrations of population are now limited to the eastern steppe of the GNP at the Mirzabylo plain, the Solegerd and Lohondor areas. Recently, a variety of human development, conversion and habitat destruction have been dramatically occurred in wildlife habitats throughout the world (51, 13, 4), similar to our study area. Therefore, in order to protect the remaining population of the gazelles in the study area, it is strongly suggested that any form of development be prevented, at least in the predicted suitable habitats outside the park.

Low habitat connectively risks the viability of isolated populations (13, 1) and the results of our study has also demonstrated meta-population fragmentation for the gazelles. In spite of the connectivity between suitable and fragmented habitats in the study area (Fig 5), most of the corridors areas are located in “attractive sink-like” habitats as there is a high level of human disturbance in the fragmented area.

Our results show that human-made structures around the GNP are the main reasons for habitat loss, fragmentation and population isolation rather than environmental variables for the *G. s. subgutturosa*. The existence of ecological corridors is the first step in conservation biology (1, 12). Therefore, a re-evaluation of habitat management strategies is recommended to design potential dispersal corridors that facilitate the exchange of individuals between fragmented habitats and even a change in GNP boundary. As a result, we strongly recommend- that the current results of predictive habitat mapping be used for the recognition of probable corridors and the effective protection of gazelle paths in future researches.

### 4.3. Biological Characteristics and Extinction Risk

All species do not respond in the same way to habitat-induced changes; some species are able to deal with the changes in the natural ecosystem and are flexible, while others are sensitive to habitat fragmentation and likely to become extinct (51) as has been shown for the *G. s. subgutturosa* in the current study. Despite the landscape transformation, several life-history characteristics of *G. s. subgutturosa* increases the risk of their vulnerability of the fragmented and small populations such as small home range size (annual average 3.55 km2;20) and low annual dispersal rate (50-60 km; 53 cited in 14); low population size and density (19, 10); high selectivity in food habits (58, 11), low survival rate (0.5 for an adult gazelle) and low fecundity rate (0.4 for an adult female) (19). The last two traits influence reproduction and the mortality rate of gazelles.

## 5. Conclusions

The gazelles in Iran are worthy of strong research and conservation efforts as they are currently endangered. If conservation efforts are not implemented for this species in the near future, its status could be changed to the Extinct (EX) category (33). In GNP, habitats of this species have been fragmented into three patches located near human settlements. Therefore, compared to other wild herbivores like deer, wild goats and sheep, gazelles have been more exposed to risk from human activities.

Knowledge of the ecology of the *G. s. subgutturosa* gazelles and their biological parameters required for efficient conservation measures are currently not enough in Iran. According to our modelling results, the occurrence of the *G. s. subgutturosa* was negatively affected by human activities compared to other ecological factors. Geomorphologic factors restricted the distribution of the *G. s. subgutturosa*, but due to the relief of the area, the topographic factors do not seem to deter the dispersal of the gazelles in the study area. On the other hand, we found that most human activities such as land use, human settlements and constructions had resulted in loss of habitat and fragmented the gazelles' distribution in isolated areas at the GNP border. Moreover, our findings show that irregular hunting, habitat alteration and occupancy have a higher share in the declining trend of the gazelles' population than the low predator population density factor. Hence, poachers from adjacent villages seem to be the main threat to the gazelles, especially during the night when they are active with spotlights. As the only natural population of the *G.s. subgutturosa* in the north of Iran is found in the GNP, the urgent need for gazelles' conservation has long been obvious and affirmed by this study. The study also helped in confirming the need to perhaps modify the current boundary of the GNP and reconnect the remaining habitat patches within and without the Park.

Considering the gazelles' habitat fragmentation in the GNP and the nearby areas as indicated by their proximity to roads, it is now incumbent upon the officials of the environmental protection office to devise corridors for connecting various important habitat patches and eventually modify current park borders to accommodate the gazelles' need. The persistent tendency of gazelles to be drawn to agricultural fields has become a challenge to conservation efforts and has given rise to disputes with the local people. The issue needs to be settled to ensure a stable future for the gazelles in this area. To do so, an appropriate public participatory strategy should also be devised and implemented.

Gazelles have also shown a tendency to stay near the environmental protection office. Hence, to facilitate their movements between suitable areas it may be helpful to have a more intense presence of wildlife guard posts. Re-routing or, if possible, closure of some of the roads in the area can be considered as other management measures. Being close to roads, water points, livestock routes and villages are all signs of clashes with the presence of humans in the area. This again calls for a participatory resource management with the local people around the park.

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## Appendix 1.

*Scores of the ten factors that explain most of the variation in the occurrence of G.s. subgutturosa in the Golestan National Park*

| EGV | Marginality | Spec.1 | Spec.2 | Spec.3 | Spec.4 | Spec.5 | Spec.6 | Spec.7 | Spec.8 | Spec.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance to Road | -0.526** | 0.057 | 0.354 | 0.673* | -0.186 | -0.012 | 0.060 | -0.091 | -0.023 | -0.059 |
| Distance to Water sources | -0.440** | -0.060 | -0.173 | -0.273 | -0.290 | -0.141 | -0.373 | -0.470 | 0.705* | -0.156 |
| Distance to Environment office | -0.368 | -0.074 | -0.161 | 0.228 | 0.525* | 0.553* | 0.093 | 0.493 | -0.036 | -0.389 |
| Distance to Livestock | -0.356** | 0.071 | -0.360* | -0.144 | -0.222 | -0.150 | 0.250 | -0.165 | -0.317* | -0.348* |
| Distance to Village | -0.350 | 0.084 | -0.423 | -0.173 | -0.034 | -0.111 | -0.100 | -0.162 | -0.205 | 0.679* |
| Slope | -0.277 | 0.085 | 0.203 | -0.250 | 0.216 | -0.530* | 0.266 | 0.509 | 0.068 | 0.064 |
| Distance to Predator (Panther) | -0.234 | 0.211 | 0.593* | -0.502 | 0.254 | 0.340 | 0.070 | 0.254 | -0.586 | 0.479 |
| Dem | -0.109 | -0.961* | 0.311 | -0.215 | 0.056 | 0.300 | -0.127 | -0.166 | -0.009 | 0.016 |
| NDVI | -0.039 | 0.006 | -0.096 | 0.096 | -0.076 | -0.178 | -0.822* | 0.179 | -0.111 | -0.055 |
| Curvature | 0.002 | -0.012 | -0.105 | -0.022 | -0.660* | 0.348 | 0.092 | 0.301 | 0.037 | 0.047 |

EGVs are sorted by decreasing absolute value of coefficients on the marginality factor. Variables marked with ** in the first column explain the marginality of the species and factors marked with * in the remaining columns explain the specialization. The specialization factors are ranked by decreasing amounts of explained variance. The first column shows 100 percent marginality. Positive values (+) under the marginality factor indicates that gazelles are found in locations with higher than average cell values; Negative values (-) indicate that gazelles are found in locations with lower than average cell values. The sign of the coefficients has no meaning under specialization factors.

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