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Research Article

Distribution modeling and evaluation of the habitat integrity of *Testudo graeca zarudnyi* (Testudines: Testudinidae) in the central and southeastern Iran

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Abstract

One of the initial measures to planning the conservation strategies is knowing the ecological needs of a species and its favorite habitat. Species Distribution Modeling (SDM) is an applicable tool to achieve this goal. Zarudny's spur-thighed tortoise or Iranian tortoise (*Testudo graeca zarudnyi*) is one of three subspecies of spur-thighed tortoises found in Iran. To assess the conflicts threatening the habitat of this subspecies, the Maximum Entropy Algorithm (MaxEnt) was used. The purpose of this study was to evaluate the integrity of the *T. g. zarudnyi* habitat and discuss the conflicts threatening the suitable habitat of this taxon in Iran. First, 25 ecological variables were considered to evaluate the habitat suitability, including topographic, land use land cover, and climatic layers (19 Bios). Among climatic variables, only five of them were selected using Pearson correlation analysis at the level of 75%. Finally, 11 variables contributed to running the model. The cell size were set based on Bios cell sizes to prevent biases, only one presence point kept at each cell; therefore, 108 presence points were remained out of 137 occurrence data. The obtained model had a high degree of predictability (AUC= 0.911). Results showed that Zarudny's tortoise favorites good to moderate vegetation structure. Hence, areas with higher vegetation cover and an annual average temperature of 20°C are optimal, which emphasizes the importance of landuse changes in both the range dynamics and the conservation of this subspecies in Iran. Considering the overlap of the protected areas with the suitable habitat of Zarudny's tortoise revealed that insufficient amounts of suitable habitat are protected. Hence, considering the vulnerable conservation status of Iranian tortoise, the importance of establishing more protected areas through the suitable habitat of his taxon is emphasized.

Keywords: MaxEnt modeling approach, Tortoise, Kerman and Yazd provinces, SDM, Environmental studies

Introduction

Up to now, 10 species of the order Testudines have been reported from Iran (Kamali, 2013). Among them, *Testudo horsfieldii* Gray, 1844 and *Testudo graeca*, Linnaeus, 1758 are the only terrestrial species. The first one is distributed in northeastern Iran, while the second one has a wide geographic range throughout the country (Kamali, 2013). So far and based on the most recent studies, there are three subspecies of *Testudo graeca* described from Iran (Parham et al., 2012; Mashkaryan et al., 2013; Javanbakht et al., 2017). *Testudo graeca buxtoni* Boulenger, 1921, distributed in the northwestern parts of the country along to the Zagros mountains in the west and some parts of Alborz mountains in the north of the country (from southern hills of Alborz mountains, most areas along the Zagros mountains and some parts of central Iranian Plateau). *T. g. armeniaca* Chkhikvadze and Bakradse, 1991, spotted in northwesternmost of the country and has overlapped range with *T. g. buxtoni*. The third subspecies, *T. g. zarudnyi* Nikolsky, 1896, could be found on the other side of the country, from the central Iranian Plateau to the east and southeast. Both subspecies *T.g. buxtoni* and *T.g. zarudnyi* have just been reported from Iran so far (Parham et al., 2012; Gracia et al., 2017). Tortoises are known to use vegetation as an important resource for food, providing hydration and shelter. Thus, it may be a limiting factor for this species (Zadhoush & Isailović, 2016, unpublished). Also, the temperature seems to have an essential role in the survival of this reptile, because they have temperature-dependent sex determination (TSD) and therefore, sex ratio and consequently, the rate of breeding may be affected by this parameter (Kallimanis, 2010; Mitchell & Janzen, 2010; Neuwald & Valenzuela, 2011). The suitable habitat for *T.* g. *zarudnyi* are steppes, open rangelands, hills, alluvial routes, gardens, cultivated lands, and plains surrounded by mountains covered with gravel and small to medium-sized rocks with scattered bushes, mostly with hot-arid climate (Kamali, 2013).

The conservation status of *T. graeca* was assessed as Vulnerable (VU) in the IUCN Red List; also, it is in the National Protected Species list of the Department of Environment of Iran (Kamali, 2013). Hence, we conducted a study on *T. g. zarudnyi*, a poorly known subspecies of the vulnerable spur-thighed tortoise with the aim of (1): modeling the distribution of *T. g. zarudnyi* in Iran, (2): assessing landscape integrity, and (3): investigating the anthropogenic conflicts threatening the habitat of *T. g. zarudnyi* through its distribution range. We hypothesized that the anthropogenic interventions (tensions) influence the integrity of the habitat of *T. g. zarudnyi*.

Material and methods

Study area and species occurrence data

Central Plateau of Iran and southeastern quarter of the country is the presence range of this subspecies. Therefore, Yazd, Kerman, South Khorasan, Hormozgan and, Sistan and Baluchistan provinces were selected to investigate (total area of 639510 km^2) (Figure 1).
The predominant vegetation of natural habitat is *Artemisia-Zygophyllum,* and these plants are also the primary food source for this subspecies. The substrate consists of medium-sized sedimentary rocks, gravel, and alluvial sediments. The soil texture is loamy-sand to sandy-clay with a mixture of coarse sand. The altitudinal range has been recorded from 400 to 3000 meters above sea level (asl). (400 m from Ghale-ganj County and 3000 m from Bardsir County, Kerman Province) (Zadhoush & Isailović, 2016, unpublished).

Figure 1. The presence provinces of *T. g. zarudnyi* in the southeastern quarter of Iran (study area).

Presence data was taken by field survey during activity seasons in years 2009, 2012, 2013, 2016, 2017, and 2018, in Yazd Province (Darreh-Anjir and Kalmand-Bahadoran Wildlife Refuges, Bafq Protected Area, and Marvar Hunting Prohibited Area), Kerman Province (Khabr National Park, Sang-e-Mess and Bahr-Aseman Protected Areas, Dalfard and Sarduiyeh region and Ghale-Ganj County), South Khorasan Province (Marak Plain, Birjand County), Hormozgan Province (Minab County and Fareqan region) and Sistan and Baluchistan Province (Iranshahr County and Taftan region). Coordinates were recorded by the Garmin GPS 62S device. Few coordinates were obtained from the literature (Anderson, 1979; Javanbakht et al., 2017) and personal communication with the other experts. One hundred thirty-seven presence points were collected and used as spatial data input in MaxEnt software.

Environmental variables

To determining the environmental variables associated to the Zarudny's tortoise distribution, after reviewing the literature (Rezazadeh et al., 2012; Javanbakht et al., 2017), expert opinion was applied to choose the variables, as follow: 19 bioclimatic variables, distance from agricultural lands, distance from cities, distance from rangelands, slope and elevation (25 primary variables). To eliminate additional variables and reduce the collinearity effect from the modeling and to enhance (improve) prediction, the Pearson Correlation Coefficient test was done by SPSS (Ver. 19) at the level of 75% ($r > 0.75$). After employing the test, variables were decreased to 11 (Table 1).

Data file preparation

The Bioclim variables were downloaded from www.worldclim.org/bioclim. The downloaded file has 899 m × 899 m cell size spatial resolution with "GCS_WGS_1984" projection. The variables related to land use-land cover was extracted from the produced map by Forests, Range and Watershed Management Organization of Iran, and topographic variables were extracted from the Digital Elevation Model produced by the Geological Survey and Mineral Exploration of Iran. To minimize inaccuracy caused by micro-scaling, cell size was changed with reference to the Bioclimatic data. The files were masked with the shapefile after re-projecting and checking every layer with the same spatial resolution and processing extent. The presence data of *T. g. zarudnyi* were pooled and used in the CSV format as per the requirement of the software.

Table 1. Variables used in the MaxEnt model.

Variable	Description (abbreviation)	Unit
Topographic	Altitude: Elevation above sea level (dem)	m
	Slope steepness (slope)	%
Cover-Use	Distance to croplands (agrifinal)	Degrees
	Distance to rangelands (modgood_range)	
	Distance to poor rangelands (poorrangefinal)	
	Distance to cities (urban)	
Bioclimatic	Annual Mean Temperature (Bio 1)	℃
	Max Temperature of Warmest Month (Bio 5)	
	Mean Temperature of Warmest Quarter (Bio 10)	
	Mean Temperature of Coldest Quarter (Bio 11)	
	Precipitation Seasonality (Coefficient of Variation) (Bio 15)	mm

Species distribution modeling

MaxEnt (Ver. 3.4.1) was applied for the present study to predict habitat suitability, since it is highly precise and has been used in many ecological niche modeling studies when absence data for the species are not available and has been proven as a powerful tool related to other presence-only methods (Phillips et al., 2006; Yousefi et al., 2015). While running the model, the model output chosen was logistic, model testing data selected was 20%, and the replicated run type was bootstrap. Jackknife analysis was performed to determine the value of variables, and Area Under the Receiving Curve (AUC) was calculated the accuracy of the model. MaxEnt models predicting the presence of tortoises were imported to ArcGIS 10.5 for display maps and other analyses such as area calculation, classifying, integrity evaluation map, and file export for correlation. Classifying the prediction range for suitability of habitat (0-1) was divided into four classes. They were arbitrarily regrouped as unsuitable habitat (0-0.33), slightly suitable habitat (0.33-0.55), moderately suitable (0.55-0.77), and highly suitable (0.77-1).

Results

After running the final model (Fig. 2), to estimate the reliability of it, AUC was used (AUC= 0.911). This shows that model had excellent accuracy and reliable performance (Duan et al., 2014). Among all variables used for SDM, moderate to good rangelands had the highest contribution in the Jackknife diagram, which means it is the most important variable impacting the distribution model. Analysis of the variable contribution table of MaxEnt models showed the average contribution of moderate to good rangelands across all to the quantum of 38.8%. Distance to poor rangelands was found to be the least important factor (percent contribution= 0.3%) (Table 2). Among land use-land cover variables, distance to urban was the second important factor impacting the suitability. Among bioclimatic variables, annual mean temperature (Bio 1) was the most crucial component.

Table 2. Relative contributions of the environmental variables to the MaxEnt model.

Variable	Percent contribution	Permutation importance
modgood-rangelands	38.8	26.4
Urban	20.9	39.3
Bio 1	15.4	1.3
dem	9.5	2.5
agrifinal (croplands)	3.9	10.6
Bio 5	3.7	1.3
Bio 15	2.8	1.9
Bio 10	2.4	6.7
Bio 11	2.1	7.9
slope	0.3	1.3
poor-rangelands	0.3	0.9

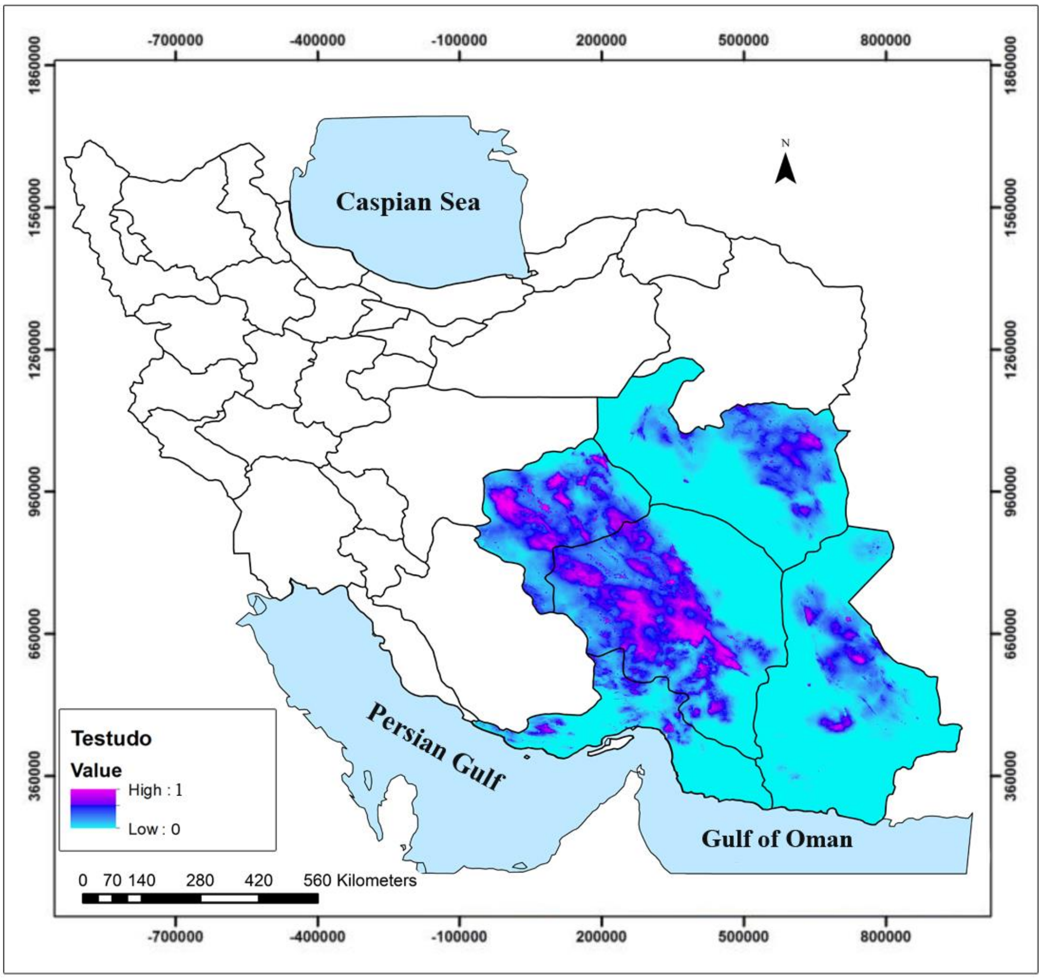

Figure 2. Predicted potential suitable and unsuitable habitats for *T. g. zarudnyi* in central and southeast Iran. The model includes all environmental variables, and purple color shows areas with the highest probability of occurrence.

Jackknife diagram predicting the contribution of variables to the construction of the model is presented in Figure 3. The blue bars show the value of each variable, the pale green bars show the result of excluding the variable from the prediction across the entire set of variables, and the red bar demonstrates the total contribution of all variables. This chart indicates that the most critical variables apart of land cover-land use were mean annual temperature (Bio 1), which played a significant role in species distribution, altitude (dem), the maximum temperature of the warmest month (Bio 5), seasonal rainfall (precipitation seasonality, Bio 15), mean temperature of warmest quarter (Bio 10), mean temperature of coldest quarter (Bio 11) and finally, the lesser essential variable was slope which had very little impact on distribution.

The habitat suitability map of Iranian tortoise is presented in Figure 4. Unsuitable habitat and potentially suitable habitat (slightly, moderately, and highly suitable) area derived from the model map is shown in Table 3. Central Iran is highly suitable for this subspecies under current climatic conditions and natural resources, particularly in Yazd and Kerman provinces.

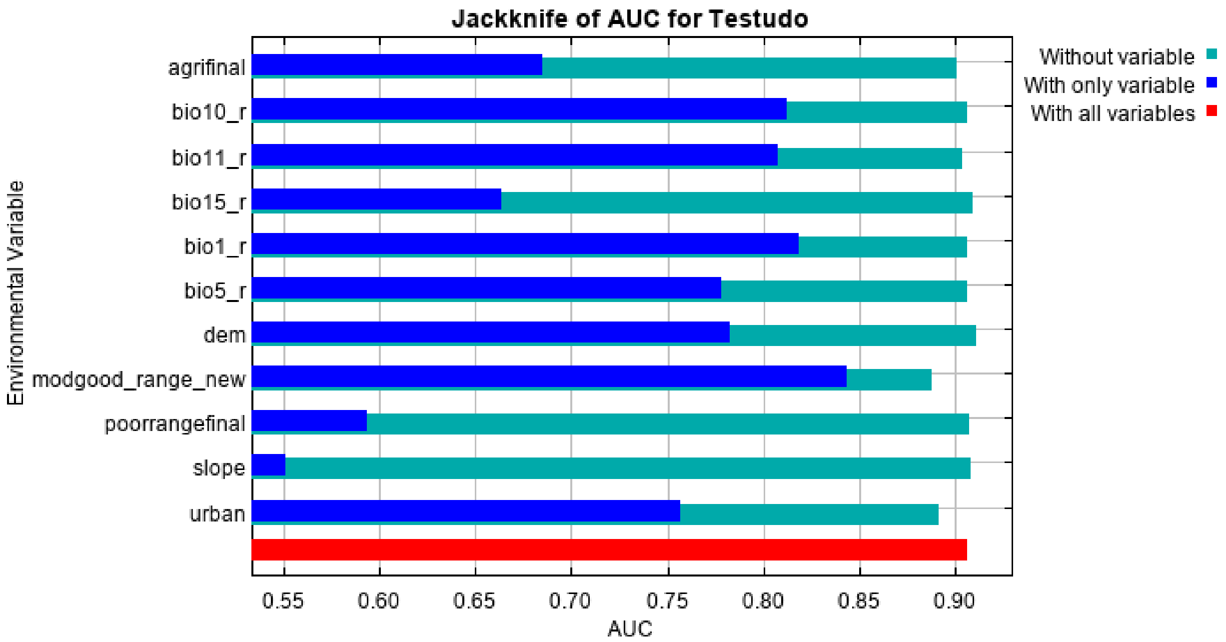

Figure 3. The relative predictive power of different environmental variables based on the Jackknife of Area under the curve of response in the MaxEnt model for *T. g. zarudnyi*.

Table 3. Habitat area (km^2) of different categories for Iranian tortoise in the southeastern quarter of Iran.

Suitability parameter	Unsuitable	Slightly Suitable	Moderate Suitable	Highly Suitable
Area km^2	536567	69262	29075	4606
% area	83.91%	10.83%	4.54%	0.72%

Although, it is suspected that this subspecies may exist in some parts of Fars and Esfahan provinces, but we were unable to collect any presence point from these locations. This vast study area is varied in climate characteristics, but most of it consists of arid and infra-arid regions with shrubby vegetation in natural habitat (Mansouri-Daneshvar et al., 2019).

Discussion

Species of the order Testudines are among the most threatened animal taxa globally (Lovich et al., 2018; Rhodin et al., 2017, 2018). Among these taxa, tortoises have a considerable ecological role in the ecosystem and are known as ecosystem engineers (Lovich et al., 2018). The supr-thighed tortoise has a wide range through Europe, North Africa and Asia (Gracia et al., 2017).

Testudo graeca zarudnyi is a poorly known subspecies of *T. graeca*. The information about biology, morphology, ecology, and conservation status of this tortoise is minimal. However, habitat distribution modeling, GIS tools, and statistical techniques can give us clues to enhance our knowledge about many species. For instance, these models can provide us with insights about species ecology, especially in habitat selection behavior. Habitat modeling can identify additional localities where the target species may already exist but have not yet been detected, recognize the localities where it can spread, and help to prioritize conservation measurements, especially for threatened species (Yousefi et al., 2015; Qin et al., 2017). In this study, the generated model using the Maximum Entropy Algorithm (MaxEnt) approach had a reliable accuracy. Therefore, this approach could be used for the future studies related to different presence locations that may record and thus, achieve a more comprehensive model. Also, the evaluation of landscape integrity at a large scale may be enlightening for future conservation actions.

Habitat selection behavior

Another useful outcome of Species Niche Modeling for conservation strategies is that indicating which environmental variables have high impacts on habitat selection and habitat extent suitability. For instance, in the present study, results showed that vegetation is the most important factor for habitat selection. As far as we know, overgrazing and landuse change are among the most destructive anthropogenic factors caused to habitat degradation or even vegetation loss. According to the model, increasing the distance to rangelands and croplands would decrease the suitability (Figure 4). As well as increasing the temperature-related variables showed a negative impact on suitability. The slope was another significant variable on the distribution that, with increasing of it, suitability will decrease. Variables like altitude indicated that the elevation range of 1000 to 2300m asl has a positive impact on distribution, as well as rising precipitation up to 80-90 mm. Distance to cities showed that from inside urban districts to 4 km away, the suitability is high. It may be due to the suitable conditions of human residency. This leads us that tortoises may have been caught from natural habitat and kept as a pet or release nearby the residence areas.

The results of the present study are approving the descriptive studies about habitat use done by Anderson (1979). Since this subspecies has a limited distribution from central to southeastern parts of Iran, and up to now, there was not any cohesive ecological study about it. On the other hand, the altitudinal range recorded for its presence, it seems that steppes and rangelands with a mean elevation of 2500m a.s.l would be the most suitable habitat. Due to the high variation of altitudinal range in Kerman Province, this elevation was found to 4500m a.s.l for the presence of this unique subspecies. Also, the least elevation was recorded was 23m a.s.l, around Minab County, Hormozgan Province.

According to Anadón et al. (2012) the altitudinal range of this species in North Africa and the western Mediterranean is about 2000m a.s.l, and the annual precipitation is between 116-1093 mm. Their study showed that the most significant climatic variable on the distribution of this species is precipitation and, in particular, the Precipitation of Wettest Quarter. Based on their results, the possibility of presence is optimum at the precipitation level of 60-180 mm. In comparison with the present study, temperature-related variables were indicated more impacts on suitability rather than precipitation (except for seasonal rainfall). It might be due to the different climatic characteristics of the humid conditions of North Africa because of the Mediterranean climate versus the hot and arid climate of the southeastern quarter of Iran. In fact, at the large scale of North Africa, the distribution will be restricted by amounts of precipitation in southern parts like the Sahara Desert. For *T. g. zarudnyi* it seems inhibitor factors for distribution are the Dasht-e Lut and Dasht-e Kavir deserts, which do not only have low precipitation but also have s high mean temperature (Nasab et al., 2013). Therefore they have little vegetation or even none. The main reason for the restricted spread to the western parts of Iran is likely due to geographical barriers such as the Zagros mountains and the Sahand-Bazman belt.

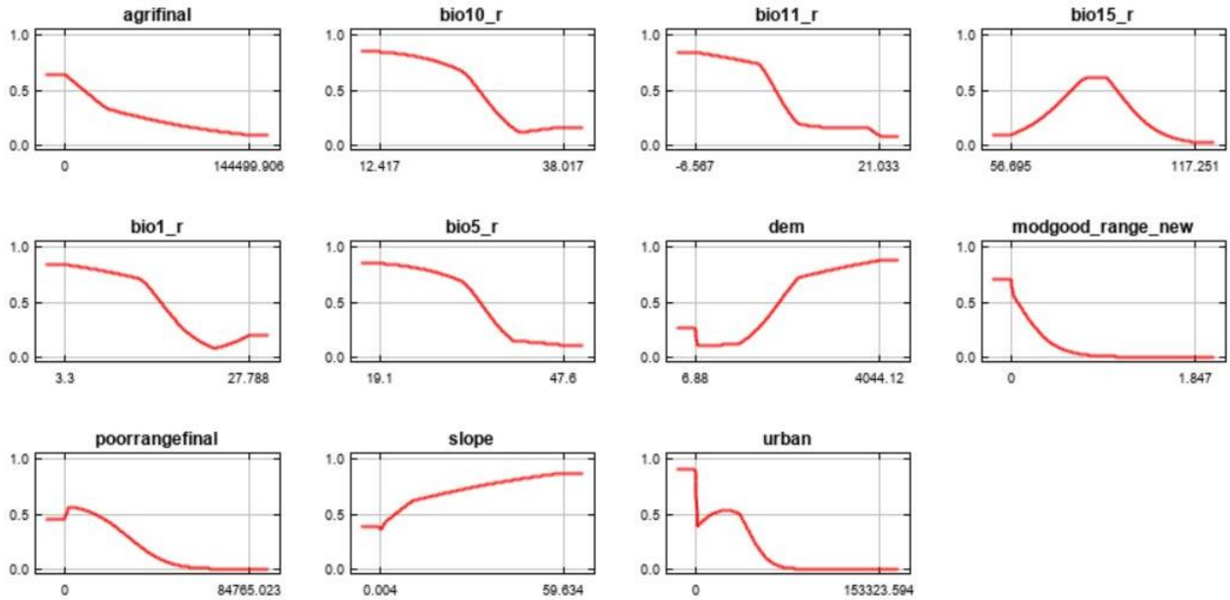

Figure 4. Response curves show how each environmental variable affects the MaxEnt prediction. The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.

The results of Waterson et al. (2016) showed that temperature is a determinant factor rather than precipitation in tortoises distribution. Based on their results, which was conducted at a universal scale on the different taxa of Testudinids, the mean temperature of coldest month had the most contribution percent in the MaxEnt model. In the present study, this variable was also a significant variable.

Based on the results of Javanbakht et al. (2017), which has been conducted by an N-dimensional hypervolume approach, the distribution of different subspecies of *T. graeca* is showed to be affected by precipitation, which is in opposition to the present study. It is necessary to notice that the accuracy of their model for *T. g. zarudnyi* was (AUC= 0.57), while in the present study, it was (AUC= 0.91), and due to different applied methods of their research, the comparison will be pointless.

Habitat integrity evaluation

In the following section, we discuss anthropogenic conflicts with identified hotspots (highly suitable habitat), suitable habitat, and the effectiveness of Protected Area Network (PAN) across the study area. As shown in Figure 5, roads and mines have the most impact on suitable patches, respectively. In general, railroads do not seem to disconnect the suitable habitat through the study area. On the other hand, PAN overlapping with hotspots almost do not appear anywhere, which reminding the necessity of expanding protected areas borders or establishing new boundaries. With a general look at the map, South Khorasan and Sistan and Baluchistan provinces have some potential areas away from other provinces and main suitable landscapes. During the years of the survey, very small populations have been found in these areas. The output map showed that the vast majority of the potential hotspots are located in Kerman and Yazd provinces (57,661 km^2 and 23,589 km^2 respectively, with 64% of the total suitable areas in this study) (Table 3), which indicates conservation measurements and management implications are strongly needed for these areas.

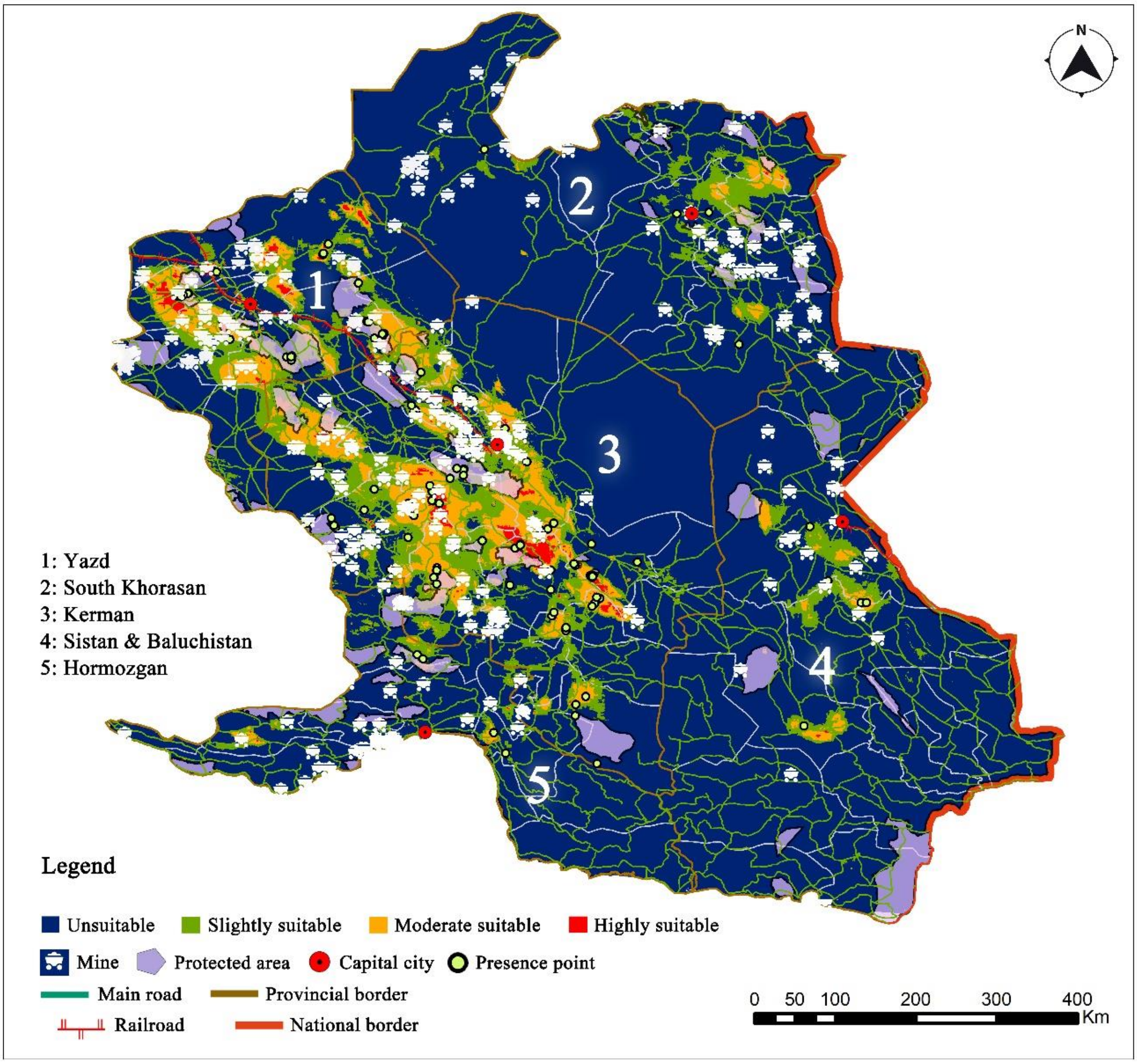

Figure 5. Anthropogenic conflicts and protected areas network overlapping with potentially suitable habitats.

Up to now, Yazd Province is considered as the starting point for the separation of *T. g. buxtoni* and *T. g. zarudnyi* (Javanbakht et al., 2017). Hypothetically, it may be due to a natural barrier like the discontinuous mountain belt of Sahand-Bazman (from northwestern to southeastern of Iran), and in some parts of Kerman and Hormozgan provinces, the Zagros mountains have separated the two subspecies from each other.

Through the study area, Kerman Province had the greatest potentially suitable areas. Nevertheless, it has more mines rather than Yazd Province. Instead, suitable habitats in Yazd Province are more affected by roads and habitat fragmentation. Moreover, regardless to the measure of PAN overlapping with suitable habitats, it appears that areas under the protection are the most in Kerman and Yazd, and less in South Khorasan, Sistan and Baluchistan, and Hormozgan, respectively. For testing the accuracy of the model, we carried out a survey in few highly suitable areas near Bastak County, Hormozgan Province, and also Birak Protected Area and Bazman Inhibited Hunting Area, both located between Khash-Saravan counties, in Sistan and Baluchistan Province. We could not find any specimen at Bastak, and self-declaration of local people was approved that. But three specimens from the two other mentioned areas in Sistan and Baluchistan were found.

Conclusion

Iranian tortoise distribution model for its known distribution range on the maximum entropy principle was of high-performance accuracy. Dense vegetation, mean annual temperature, and altitude were the most determinative environmental factors within the model, which altogether had a significant share in model development. The two most important climatic variables influencing the model were mean annual temperature and max temperature of the warmest month. Although precipitation was not among the most significant variables, it has a direct impact on vegetation, which is an important factor in distribution and food availability. Disturbing and stressful factors such as mining activities, roads, and railroads seem to have an enormous impact on disconnecting potentially suitable habitats. Other anthropogenic factors like landuse change were not counted in the present study. The hotspots for this tortoise are small related to the vast scale of the study area, which notifying the necessity of management actions. Isolated patches may be cutting off the gene flow between subpopulations and even could lead the small populations into the local extinction (Jordán et al., 2003; Schlaepfer et al., 2018). Also, the distribution range of this tortoise is limited to hot and arid areas. Climate change may affect this range to become a more harsh environment (Yousefi et al., 2019), and based on our study; the temperature is among the most important climatic factors for habitat suitability. Therefore, we suggest further modeling should be conducted under future climatic scenarios for this subspecies.

At last, the simple implication of this result is that the model prediction level (AUC= 0.911) is very high, which can be used with a higher degree of confidence in the planning and execution of the conservation projects.

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