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Research Article

Modelling habitat suitability and connectivity of the Caspian pond turtle (*Mauremys caspica*) in Central Zagros, Iran

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Abstract

Habitat loss, fragmentation, and alteration are among the most critical threats to freshwater pond turtles. There is scarce data on the distribution of suitable habitats and landscape connectivity of pond turtles in Iran. In this study, the maximum entropy algorithm (MaxEnt) was used to predict the habitat suitability of the Caspian pond turtle (*Mauremys caspica*) in Chaharmahal va Bakhtiari province in the Central Zagros Mountains, Southwest Iran. Our findings showed that 10.46% (1729 km^2) of the study area could be considered as suitable habitat for the Caspian pond turtle. In contrast, only about 6.23% (107.72 km^2) of these suitable habitats are covered by conservation areas. Distance to the river (43.6%), distance to agricultural lands (14.5%), and minimum temperature of the coldest month (Bio6) (11.2%) were identified as the most important variables contributing to habitat selection by the species. The findings showed that while there is relatively good connectivity between many habitat patches, weak connectivity was predicted between some habitat patches. This study emphasizes the conservation priorities focusing on habitat protection, facilitating the movement of individuals between habitat patches and habitat connectivity.

Keywords: Chaharmahal va Bakhtiari, connectivity, freshwater pond, habitat patches, turtles, *Mauremys capsica*

Introduction

The increasing human population and the development of human activities have turned ecosystems into mosaics of cities, villages, farms, industrial areas, and scattered patches of natural habitats. Land use change in recent years has led to the destruction and fragmentation of natural habitats, resulting in the loss of a significant portion of biodiversity (Ceballos & Ehrlich, 2002; Crooks & Sanjayan, 2006; Berger, 2008; Liu et al., 2013). Habitat loss and fragmentation are among the most critical challenges in wildlife management and conservation (Crooks & Sanjayan, 2006; Berger, 2008; Farashi & Shariati, 2017). Habitat fragmentation severely affects the movement behavior of living organisms, can reduce connectivity between habitats, and so may lead to a reduction in population fitness (Crooks & Sanjayan, 2006). On the other hand, populations living in small and isolated habitat patches that are unable to meet their vital needs may be at risk of local extinction (Hilty et al., 2012; Habibzadeh & Ashrafzadeh, 2018).

Estimating the geographic distribution, and identifying suitable habitats of the species, and evaluating the connectivity between habitat patches are among the essential strategies for wildlife management and conservation (Rodríguez-Soto et al., 2013; Habibzadeh & Ashrafzadeh, 2018). The use of species distribution models as one of the efficient methods in identifying suitable habitats and estimating the vital needs of species is based on examining the relationship between species presence/absence and a suite of environmental variables (Guisan & Thuiller, 2005). The species distribution modeling has been recognized as one of the practical approaches in conservation programs. The maximum entropy (MaxEnt) is one of the most popular methods for species distribution modeling (Phillips & Dudik, 2008).

Aquatic turtles play an important role in cleaning the environment and removing water pollutants (Yadollahvand & Kami, 2014). Caspian pond turtles (*Mauremys caspica* Gmelin 1774) are common in the Middle East and are widely distributed in north, west, and southwest of Iran (Vamberger et al., 2013). The species often prefer freshwater habitats covered by canebrake with muddy and marshy beds (Yadollahvand & Kami, 2014). Habitat destruction and fragmentation caused by anthropogenic activities such as urban and rural development, agriculture, road construction, and river impoundment are the most important threats to pond turtles (Yadollahvand & Kami, 2014; Jazayeri et al., 2020). Environmental pollutants such as heavy metals, pesticides, radioactive wastes, poaching and harvesting of turtles, use of pond turtles as pets, collecting of turtle eggs (Yadollahvand & Kami, 2014; Jazayeri et al., 2020), and introduction of invasive species to natural habitats (Mozaffari et al., 2014) are other factors threatening Caspian pond turtles.

Furthermore, improper management of water resources threatens many populations of the species across its natural range (Vamberger et al., 2013; Yadollahvand & Kami, 2014). The role and importance of freshwater turtles in nature and the declining population size and geographical range in recent years (Yadollahvand & Kami, 2014) necessitate the development of effective strategies to protect the populations of the species. In this study, modeling habitat suitability of the Caspian pond turtle in Chaharmahal va Bakhtiari province was performed using the maximum entropy algorithm (MaxEnt). In addition, due to the importance of the permeability of landscapes in wildlife management, we predicted connectivity between suitable habitat patches.

Material and methods

Study area

Chaharmahal va Bakhtiari province (about 16,532 km^2) is situated in the Central Zagros, where mountains and hills make up about 85% of its area and plains and wetlands make up 15%. The altitudinal range in this area falls between 783 to 4178 m above sea level. The average annual precipitation in the province is about 560 mm. The average annual air temperature is about 10 ° C (Ashrafzadeh *et al*. 2019a).

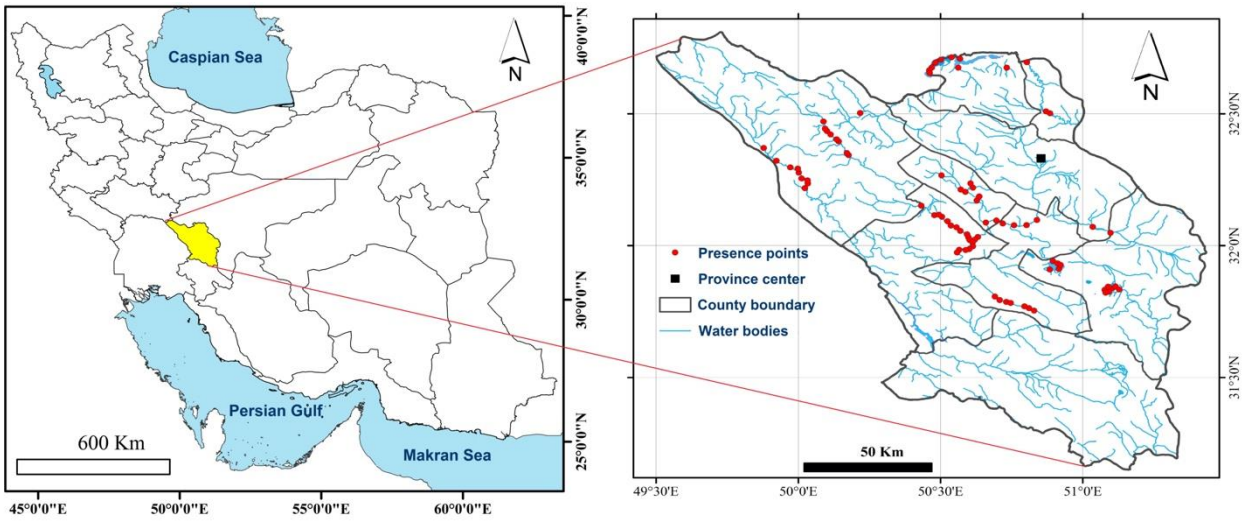


Figure 1. Location of Chaharmahal va Bakhtiari Province in southwest of Iran (left) and presence points of Caspian pond turtles (right).

Data collection

We collected 144 records of Caspian pond turtle's occurrence. To reduce the spatial autocorrelation, all multiple occurrences of points within a minimum distance of 1 km (Millar & Blouin-Demers, 2012) were excluded (Brown, 2014) (corresponding to the maximum distance traveled by some species of pond turtles, i.e., 250 m per day; and the mean annual home range length, i.e., 1 km (Hamernick, 2000)). Finally, 84 occurrence sites were used in modeling (Fig. 1).

Environmental and anthropogenic variables

We used bioclimatic, land cover, topographic and anthropogenic variables as the predictors of the turtle distribution (Millar & Blouin-Demers, 2012; Stryszowska et al., 2016; Dailey, 2017; Friedrichs-Manthey et al., 2020). At first, we obtained 28 variables, including 19 climate variables extracted from the WorldClim Global Climate data (www.worldclim.org), elevation, slope, terrain ruggedness index (Riley et al., 1999), distance to forest areas, distance to rangelands, distance to agricultural lands and gardens, distance to villages, distance to rivers, and human footprint. Land cover/land use data were extracted from the layer prepared by the Iranian Forests, Rangelands and Watershed Management Organization (IFRWMO, 2014). The human footprint variable was used to consider human effects on species distribution (Sanderson et al., 2002). This variable has been created based on data on population density and human access, and the existence of infrastructures

such as roads and land use changes. All variables having a spatial resolution of ~1 km^2 were projected onto the UTM grid (WGS84 datum). To evaluate the multicollinearity of the variables, Variance Inflation Factor (VIF) was used, and variables with 3 < VIF were excluded from the analyses (Zuur et al., 2010). Also, we tested for correlation among environmental variables by calculating Pearson's correlation coefficients and considered an r<0.7 value to select the independent predictors to include in the distribution model. Finally, 13 uncorrelated variables were used in analyses (Table 1).

Table 1. Uncorrelated variables used in modeling the Caspian pond turtle distribution and their relative importance

Variables	Relative importance
Distance to rivers	43.6
Distance to agricultural lands	14.5
Minimum temperature of the coldest month (BIO6)	11.2
Temperature Seasonality (BIO4)	8.1
Distance to forest areas	5.1
Precipitation of the warmest quarter (BIO18)	3.9
Mean diurnal temperature range (BIO2)	3.7
Mean temperature of wettest quarter (BIO8)	3.4
Annual precipitation (BIO12)	2.4
Terrain ruggedness index	1.7
Distance to rangelands	1.5
Distance to villages	0.5
Human footprint	0.3

Modeling

We employed the maximum entropy model, using MaxEnt version 3.3.3 (Phillips et al., 2006), to predict the distribution of suitable habitats for the Caspian pond turtle. We used 25% of the occurrence points as test data and 75% of the occurrences as training data. The map of suitable habitats was prepared based on 15 model replications with 10,000 iterations. The area under the ROC (Receiver Operating Characteristic) curve (AUC) was used to evaluate the model accuracy. Also, the response curves were used to visually consider the relationship between the environmental suitability and individual variables.

The electrical-circuit theory approach (McRae et al., 2008) in Circuitscape 4.0.5 software (www.circuitscape.org) was applied to estimate the potential connectivity of habitat patches of the Caspian pond turtle. In this study, habitat patches were considered as electrical nodes and habitat suitability maps as an index of conductance (McRae et al., 2008). Therefore, the current flow between cells or habitat patches was estimated as the connectivity between patches. To evaluate the efficiency of the conservation network, the suitability map was overlaid with the designated conservation network in this area.

Results

The predictive accuracy of the model was evaluated with a high score (AUC = 0.95), where the maximum entropy model has provided excellent discrimination power. According to the model, 10.46% (1729.02 km^2) of the study area can be considered as suitable habitat for the Caspian pond turtle (Fig. 2a). Also, the suitable habitat patches were detected based on the threshold related to the equal test sensitivity and specificity (≈ 0.169) (Fig. 2b). Based on the findings, the central parts of the study area were most suitable, maintaining the largest habitat area for the Caspian pond turtle.

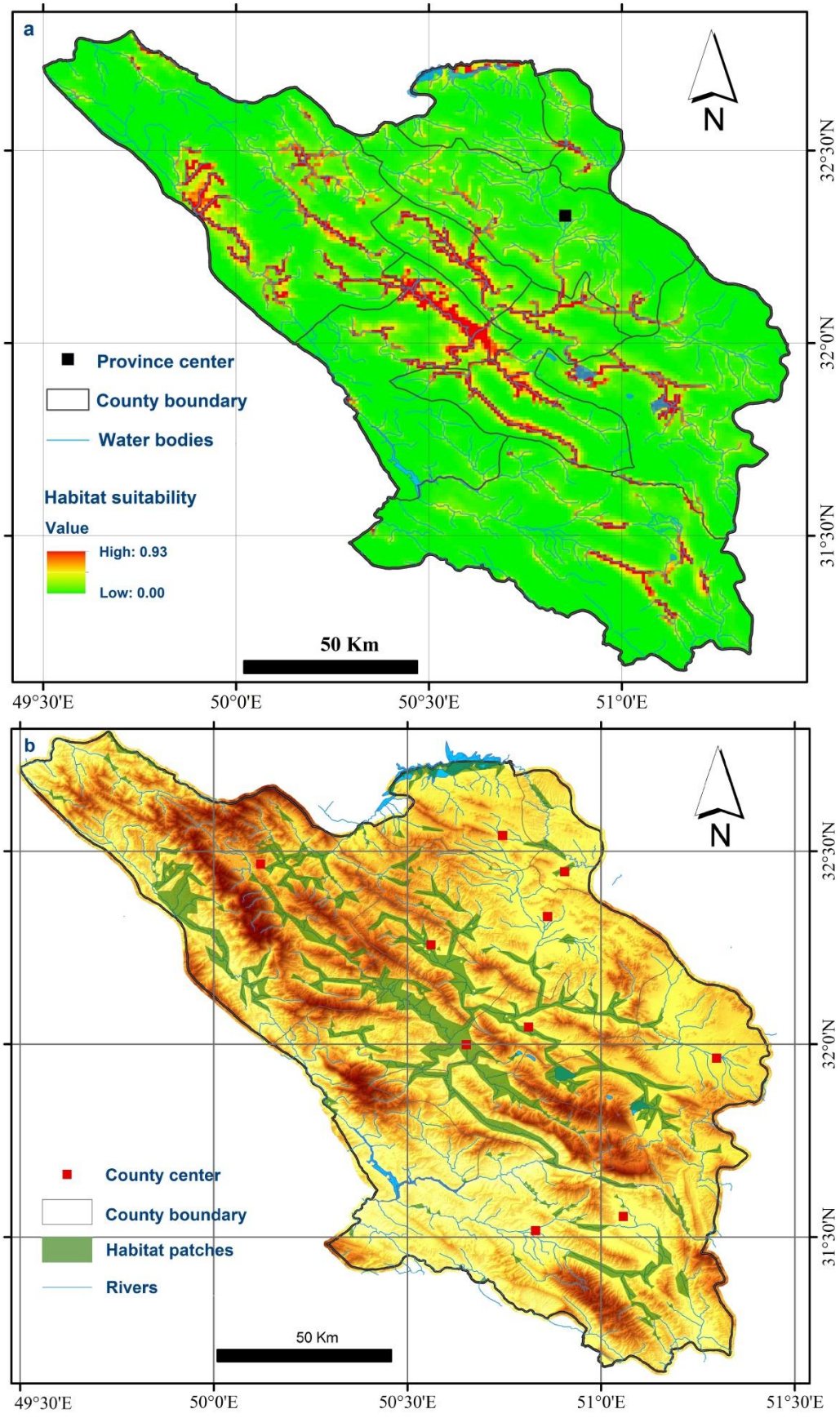
Distance to the river (43.6%), distance to agricultural lands (14.5%), and minimum temperature of the coldest month (11.2%) were identified as the most important variables in habitat selection by Caspian ponds turtles (Table 1). The response curves (Fig. 3) showed that very close distances to rivers could be identified as a high degree of habitat suitability for the species. In addition, suitability decreased with increasing distance from agricultural lands. The minimum temperature of the coldest month in the suitable habitats ranged from -4 to -11 ° C.

Based on the findings, it seems that there is relatively good connectivity between most habitat patches. However, weak connectivity was predicted between some habitat patches (Fig. 4). About 6.23% (107.72 km^2) of suitable habitats were covered by the conservation network (Fig. 4).

Discussion

Evaluating the distribution and identifying suitable habitats of the species are very important in the wildlife management and conservation (Natuhara, 2008). Habitat loss and fragmentation reduce the suitable habitat area and confines populations to small, isolated habitats that lead to increased inbreeding, reduced genetic variation, and increased extinction risk of the populations (Markle & Chow-Fraser, 2014; Allen & Singh, 2016). The present study shows that suitable habitats of Caspian pond turtle (*Mauremys caspica*) cover about 10.46% of Chaharmahal va Bakhtiari Province and the central part of the area covers the highest proportion of suitable habitats for the species. According to our findings, distance to rivers, distance to agricultural lands, and minimum temperature of the coldest month made the greatest contribution (≈ 70%) to model performance. Habitat suitability was higher in localities close to the rivers and agricultural lands and decreased with an increased distance from these resources. The importance of this issue is related to water resource management that has an important role in the potential distribution of Caspian pond turtle. The observation of this species in the canebrake around wetlands, rivers, and agricultural lands, especially in irrigation canals, confirms this inference.

Previous studies have emphasized that climatic conditions and land cover/land use are among the most important predictors of the distribution for reptiles (Tingley & Herman, 2009; Millar & Blouin-Demers, 2012). Additionally, there is a positive relationship between wetland area and habitat suitability for freshwater turtles (Millar & Blouin-Demers, 2012) that emphasizes freshwater turtles are present in a wide range of eutrophic wetlands (Joyal et al., 2001; Millar & Blouin-Demers, 2011). Millar and Blouin-Demers (2012) suggested that open water area, wetland area, and temperature variables play a key role in habitat selection by the semi-aquatic turtle (*Emydoidea blandingii*), and they showed that variables such as forest cover and terrain ruggedness have medium importance in habitat suitability of this turtle. Also, they suggested that human settlements were of less importance.



Figures 2. Predicted distribution (a) and habitat patches detected based on the equal test sensitivity and specificity (0.169) (b) for Caspian pond turtle in Chaharmahal va Bakhtiari Province

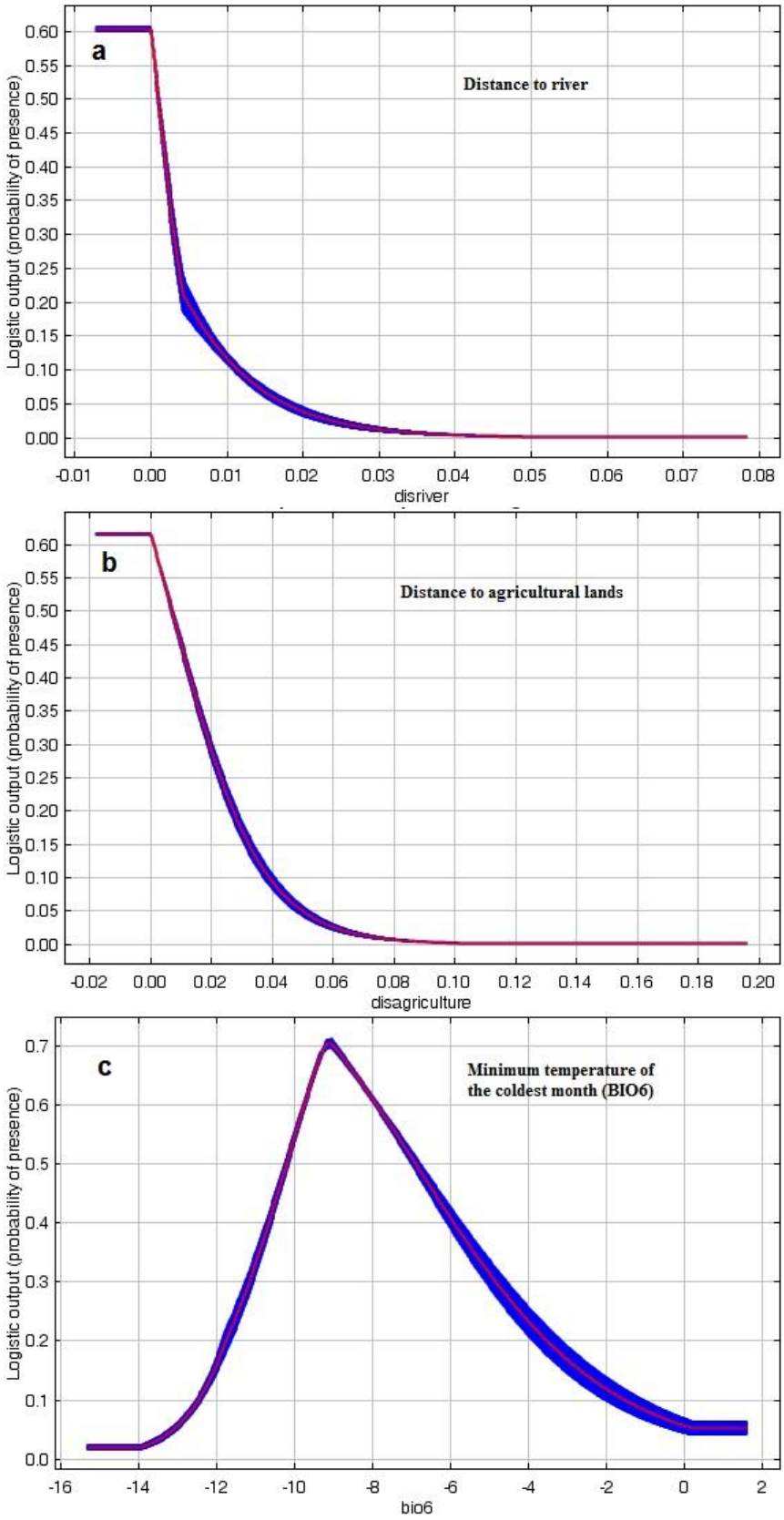


Figure 3. Response curves for the most important predictors of the distribution of Caspian pond turtle; a) Distance to rivers, b) Distance to agricultural lands, and 3) Minimum temperature of the coldest month (BIO6)

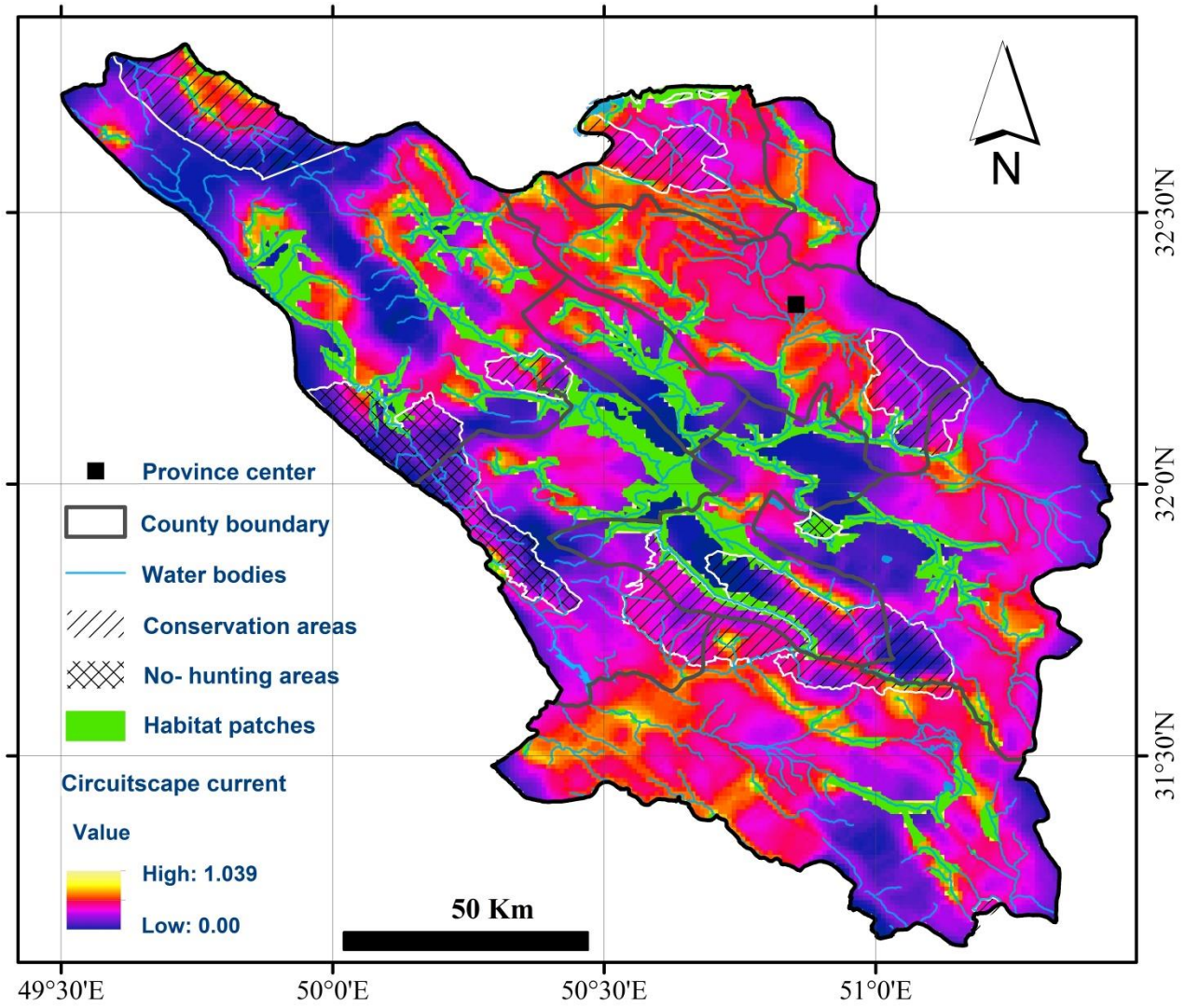


Figure 4. Habitat connectivity of Caspian pond turtles in Chaharmahal va Bakhtiari Province and also an overlay of conservation network with the suitable habitats for the species

Temperature and precipitation can affect vital processes of amphibian and reptile populations, including biological activity, habitat selection, and migration (Millar & Blouin-Demers 2012; Dhanjal-Adams et al., 2016). Temperature is one of the important factors in the hatching success of turtle eggs; sex ratio and growth of turtles is directly dependent on the environment temperature. Turtles are cold-blooded animals and rely on the temperature changes. Turtles not only need some hours of sunlight a day they need to rest in the shade of plants and rocks; Thus, the existence of suitable shelters for creating shade and regulating body temperature is known as one of the key factors for the survival of pond turtles (Parlin et al., 2017). Therefore, agricultural lands, in addition to providing food (plant and animal), their suitable vegetation cover as a shelter play an important role in habitat suitability of pond turtles (Adams et al., 2016). Due to the dependence of pond turtles on water resources such as rivers and reduction of habitat suitability with increasing distance from the river, it can be noted that water is the most important environmental variable affecting habitat selection. If pond turtles move away from the ponds and in the lack of water, their physical activity dramatically reduces, and in female turtles, spawning is delayed or canceled (Rifai & Amr, 2004).

Adak (2019) indicated that habitat loss and fragmentation, use of pesticides, dam construction, reduction of suitable areas for nesting, poaching, destruction of nests, drought, and improper fishing methods (such as the use of explosive, toxic substances, and electricity) are the most important threatening factors for Euphrates turtle (*Rafetus euphraticus*). Circuit theory revealed that currently, there is relatively good connectivity between many habitat patches of Caspian pond turtle in the study area, while human activities and climate changes may have wide negative consequences on habitat connectivity. Today, wetlands, rivers, forests and grasslands have been severely damaged by human activities. Habitat destruction by human activities is one of the most important factors threatening biodiversity in the Zagros Mountains (Ashrafzadeh et al., 2019b).

Habitat destruction and fragmentation can make it difficult for the movement of species with low dispersal ability, such as the Caspian pond turtle (Velo-Antón et al., 2013). Changing habitat conditions can reduce habitat connectivity and gene flow between populations, and cause an increase in the risk of extinction and reduce the probability of recolonization after local extinctions. The reduced gene flow between populations may lead to the loss of genetic diversity that can reduce the adaptability of the species to environmental changes such as climate change (Hermes et al., 2018). According to the findings, about 6.23% (107.72 Km^2) of the suitable habitats of Caspian pond turtles in the study area were covered by the existing conservation areas. However, species distribution modeling and connectivity analysis are important in designing and developing conservation area networks (Ashrafzadeh et al., 2019b).

Conclusion

In general, the present study shows that climate and land cover/land use variables play an important role in habitat selection by Caspian pond turtles. Other studies emphasize that quantity and quality of water resources have a crucial role in the biology of freshwater turtles and other species inhabiting these ecosystems (Joyal et al., 2001; Millar & Blouin-Demers, 2011; Ashrafzadeh et al., 2019b). In addition, previous studies emphasize that the Zagros mountain region has been one of the most vulnerable areas in Iran due to droughts and global warming in 30-year modeling (Jowkar et al., 2016; Ashrafzadeh et al., 2019a). Therefore, it is important to identify the conservation priorities focusing on habitat protection, facilitating the movement of individuals, and habitat connectivity (Wan et al., 2018). The maps created by the present study are useful in establishing new protected areas and improving the existing protected areas in the study area.

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