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ORIGINAL ARTICLE

Dynamics of threatened mammalian distribution in Iran's protected areas under climate change

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Abstract

Iran has a diverse range of mammals. Climate change can alter the species' range, leading to expansion or contraction and affect the IUCN threatened species' distribution. We assessed the effects of climate change on the climatic niche and coverage of the protected areas for 16 threatened mammal species in Iran. The species' presence-only occurrence records, four predictor variables, two future climate scenarios (Representative Concentration Pathways 2.6 and 8.5) and two time steps (current and 2070) were used to build species distribution models by applying the ensemble approach in BIOMOD2. Species' responses to climate change under current condition showed different results: 8 of the 16 species are likely to gain climatically suitable space, but six species will probably lose climate range by 2070. Persian fallow deer and marbled polecat respond positively to the RCP 2.6 but will experience a range reduction in the RCP 8.5. Coverage of the protected area network will increase in both scenarios for six mammals. The coverage will maximize in RCP 2.6 for four species and decrease RCP 8.5 for another four species and vice versa. According to our model, the coverage will decrease for two species in both future scenarios. The overlap of the protected areas with the distribution pattern showed that in the next 50 years, climate change will negatively affect 60% of Iranian threatened mammals. The species' current and future distribution range and the designated refugia for climate change can be considered protected areas for conservation plans.

Keywords Conservation · Species distribution models (SDMs) · Protected areas · IUCN Red List

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Introduction

Climate change has affected both terrestrial and marine biodiversity (Root et al. 2003; Hobday et al. 2006), and these changes are expected to continue in the future, with associated altering in the phonological patterns (e.g., migration, flowering and earlier breeding), physiology (Fitter and Fitter 2002), species compositions (Stralberg et al. 2009) and distributions (Parmesan and Yohe 2003). Evidence shows that species adjust their geographic ranges as the climate changes (Parmesan et al. 1999; Hill et al. 2002). Climate change has been known as the primary driver of shifts in the distribution range (generally towards higher elevations and higher latitudes), range expansion or contraction, and species extinctions (Thomas et al. 2006; Levinsky et al. 2007). Therefore, assessing the rate and the extent of range shifts is essential to realize the impact of climate change on species (Williams and Blois, 2018).

Animal populations have undergone substantial declines in recent decades. One of the most critical factors in this reduction is climate change (Spooner et al. 2018). Over the past 100 years, major climate change events occurred due to anthropogenic greenhouse gas emissions (Zhao 2011; Zeebe 2013). Since the 1880s, the mean global surface temperature has increased by about 1 °C and is projected to increase to 6 °C in 2100 (Solomon et al. 2007; Nunez et al. 2019). The Southwest Asia countries, especially Iran, are particularly vulnerable to climate change (Evans 2009; Daneshvar et al. 2019). The Intergovernmental Panel on Climate Change (IPCC) estimates mean surface temperatures in the Middle East will rise over 4 °C by 2100. On the other hand, precipitation will decrease by 20% (Elasha 2010). For the next decade, temperatures in Iran will rise by 2.6 °C, with a declined precipitation by 35% (NCCOI 2014). In this regard, temperature projection models have shown that temperature may increase between 1.12 and 7.87 °C by 2100 in the country (Daneshvar et al. 2019). However, precipitation and snow-covered areas may decrease according to most future models and scenarios (Zarenistanak et al. 2015; Daneshvar et al. 2019). Several studies have also shown that heatwaves in West Asia countries, including Iran, will increase up to 30% by 2100 (Zhang et al. 2005; Rahimzadeh et al. 2009).

Species distribution models (SDMs) are used to estimate the potential range shifts of species under climate change (Sinclair et al. 2010; Bond et al. 2011; Porfirio et al. 2014). Forecasting the future distribution of species by SDMs is a crucial tool in evolution, biogeography, ecology and conservation management (Scott et al. 2002; Boone and Krohn 2002; Fertig and Reiners 2002). Knowledge of the species distribution range and habitat characteristics is essential in creating an effective conservation strategy (Koo et al. 2019). Mammals play a significant role in many ecosystems, and climate broadly defines their ecological niche (Levinsky et al. 2007). Therefore, the abundance and distribution of mammals are expected to be affected by climate change (Burns et al. 2003; Pacifici et al. 2017). The effects of climate change will be accompanied by the land use change-induced destruction of 18% of the world's land for carnivore mammals by 2040 (Di Minin et al. 2016). The exacerbated effects of climate change could increase the impact of land-cover change on mammals by up to 24% and alter the spatial distribution of threats (Mantyka-Pringle et al. 2015). Iranian terrestrial mammals include 192 species from 34 families, eight of which are endemic to the country. Nearly 13% of Iran's terrestrial mammal species are threatened, and 14% are near-threatened (Yousefi et al. 2019). In the present study, we quantified red list mammal species' (IUCN 2020) exposure to climate change across species climatic niche in the current climatic conditions (1979–2013) and future projections (2070) under the RCP 2.6 (optimistic scenarios) and RCP 8.5 (pessimistic scenarios) forcing climate scenarios. We also assessed the coverage of the protected areas and species distribution potential to gain an insight into the protected areas' role in buffering the impacts of climate change on species.

Materials and methods

Study area

Iran is located in the southwest of Asia between the latitudes of 25° and 40° North and the longitudes of 44° and 63° East and an average surface area of 1.6×10^6 Km^2. Iran is one of the most remarkable countries in the Middle East in the context of biodiversity due to its location between the two biogeographical regions of Palearctic and Oriental and its proximity to the Ethiopian region and crossing to the Saharo–Sindian desert belt (Karami et al. 2016).

The species

The IUCN Red List of Threatened Species is a reliable world-renowned listing according to which the species are classified into categories representing different extinction risk levels (IUCN 2020; Mace 2008). Several studies have addressed the vulnerability of the threatened species in the IUCN Red List to the effects of climate change (Lucas et al. 2017; Pacifici et al. 2017; Trull et al. 2018). For this reason and due to the mammals' quick response to climate change (McKelvey et al. 2013) and the expected range contraction, range shift, and abundance changes in the majority of the mammalian population as a result of climate change (McCain and King 2014), we in this study, examined the status of all Iranian mammals in the IUCN Red List and selected 24 threatened mammalian species (NT, VU, EN, CR; IUCN 2020; Appendix S1). We excluded eight species as their presence information in Iran was less than 10 points, and accuracy tends to decline severely beyond this threshold (Wisz et al. 2008; Bean et al. 2012). Sixteen remaining species, which are the subjects of our study, belong to the Carnivora, Artiodactyla, Perissodactyla, Chiroptera and Rodenta orders that all have shown a reaction to climate change (Pacifici et al. 2017). These species are Asiatic cheetah *Acinonyx jubatus venaticus,* Asiatic wild ass *Equus hemionus onager,* Asian black bear *Ursus thibetanus,* Brandt's hamster *Mesocricetus brandti,* Eurasian otter *Lutra lutra,* Goitered gazelles *Gazella subgutturosa,* Long-fingered bat *Myotis capaccinii,* Marbled polecat *Vormela peregusna,* Mediterranean horseshoe bat *Rhinolophus euryale,* Mehely's horseshoe bat *Rhinolophus mehelyi,* Mouflon *Ovis gmelini,* Persian fallow deer *Dama mesopotamica,* Persian leopard *Panthera pardus,* Striped hyena *Hyaena hyaena,* Urial *Ovis vegnei* and Wild goat *Capra aegagrus* (IUCN 2020).

Species occurrence data

Data on species distribution were obtained from the authors of this study, researchers and environmentalists, scientific journals, Atlas of Iranian Mammals and online databases of Global Biodiversity Information (GBIF). In those cases, where no coordinates but exact locality names were available, records have been georeferenced using the global gazetteer version 2.3 (http://www.fallingrain.com/world). All records' reliability was assessed by the polygons provided by the International Union for Conservation of Nature (IUCN) to describe terrestrial mammal geographical ranges (IUCN 2020; Fig. 1). Finally, to check the accuracy of the points, we reviewed various studies on the species studied in Iran. We deleted duplicate records created by collecting presence points from different ENM Tools environment sources (Warren et al. 2010). To prevent spatial autocorrelation and reduce the sampling error of presence points, we used the 'Global Moran's I' function in Arc GIS 10.8. Finally, to check the accuracy of the points, we reviewed various studies on the species studied in study areas (for example, the study of Michel and Ghoddousi 2020, which led to the elimination of 'Presence Uncertain' for Urial and Mouflon in central and southern Iran; The study of Yousefi et al. 2019 to confirm the distribution of Long-fingered bat and Mehely's horseshoe bat in the south of Iran).

Environmental data and climatic parameters

Climatic data were obtained from CHELSA for 1979–2013 (https://chelsa-climate.org/bioclim/); all 19 available bioclimatic variables (Karger et al. 2017) were initially used. We calculated Spearman's rank correlation coefficient between variables prior to statistical analysis. Based on the results of Dormann et al. (2013) correlation coefficient > 0.7 indicates a high correlation and should be considered strongly correlated variables as one variable. We used this rule and considered four variables for all 16 species that this variables included annual mean temperature (BIO1), temperature seasonality (BIO4), mean temperature of the wettest quarter (BIO8) and precipitation seasonality (BIO15) were selected, accordingly.

To evaluate the potential future distribution, we used the general circulation model (GCM): CCSM4 and Representative Concentration Pathways including RCP 2.6 (optimistic scenarios) and RCP 8.5 (pessimistic scenarios) for the range 2060–2080, hereafter referred to as 2070. RCPs are greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report in 2014 (https://www.ipcc.ch/report/ar5/wg2/). According to Meinshausen et al. (2011), the first scenario (RCP 2.6) represents an optimistic projection characterized by a low concentration and emissions levels of greenhouse gases. The second scenario (RCP 8.5) represents a pessimistic projection with high levels of concentrations and greenhouse gas emissions. Current and future (2070) climatic variables with an original spatial resolution of 30 arc seconds (1 × 1 km) were obtained from the CHELSA and Worldclim database version 2.0, respectively.

Species distribution modeling

BIOMOD2 (BIOdiversity MODelling) package uses different types of statistical modeling methods, aiming to maximize the predictive accuracy of current species distributions and the reliability of future potential distributions (Thuiller et al. 2009). The package provides a simple framework for building ensemble species distribution modeling techniques and is very popular among SDM users (Hao et al. 2019). We used eight different algorithms available within the BIOMOD framework to obtain an ensemble of predicted distributions: Generalized Linear Models (GLM), Generalized Additive Models (GAM), Multivariate Adaptive Regression Splines (MARS), Artificial Neural Network (ANN), Classification Tree Analysis (CTA), Flexible Discriminant Analysis (FDA), Random Forest (RF) and Boosted Regression Tree (BRT). We applied a cross-validation procedure by randomly splitting the data into calibration (70% of the data) and validating (30%) data sets with ten repetition runs to assess model performance stability. After calibrating the model, the predictive performance of all implemented algorithms was tested using the area under the curve (AUC) and true skill statistic (TSS) methods (Allouche et al. 2006; Pavlović et al. 2017). Then, all the algorithms were combined and the ensemble model was implemented and a pattern of species distribution was prepared for the current situation and the optimistic and pessimistic scenario of the future.

Coverage of protected area and species distribution potential

Using Arc GIS10.8, the percentage of the protected areas' coverage and the species distribution map were calculated in the current and future climatic conditions. There are four categories of PAs in Iran, which cover about 10.83% of the country. These areas include 31 National Parks (1.25% of the study area), 46 Wildlife Refuges (3.57% of the study area), 38 National Natural Monuments (because this category is not a polygon, we did not consider it in the gap analysis) and 169 Protected Areas (6% of the study area). In addition, there are 173 No-Hunting Areas as the least strictly protected area in Iran, which cover about 6.3% of the total area of the country; Data on protected areas were obtained from the Department of Environment of Iran (2019).

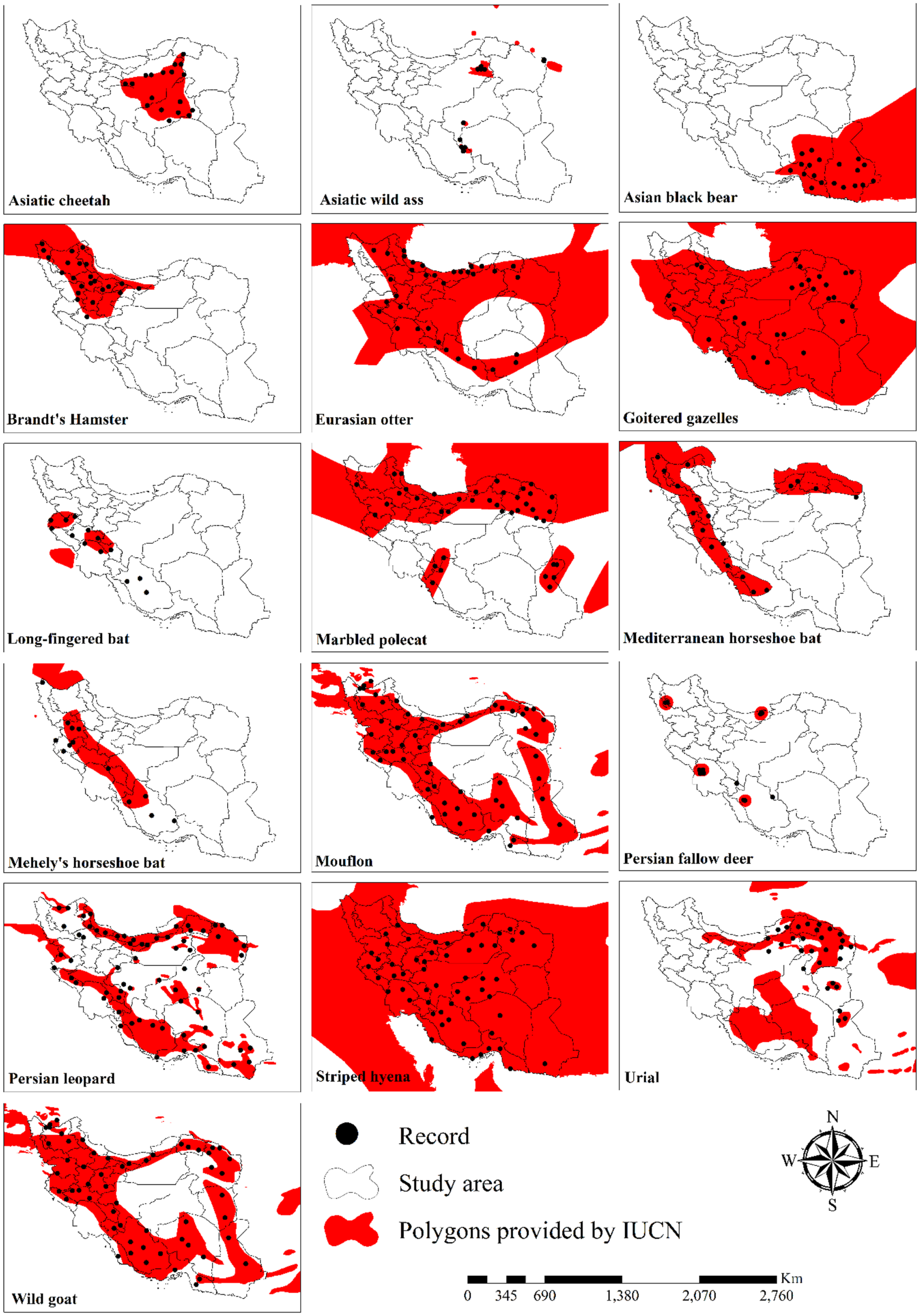


Fig. 1 Points of presence of studied species and location of protected areas in Iran

Results

Species distribution modeling

The results of suitable habitat modeling are shown in Fig. 2. In addition, the area of suitable habitat has been calculated in Fig. 3 and Appendix S2.

A. Asiatic cheetah: The distribution pattern of Asiatic cheetah in the current and the future climate conditions in the central part of Iran is predicted and corresponds to the defined range of IUCN for the species. The most extensive range of species distribution is related to the RCP 2.6 scenario but in the RCP 8.5 scenario, Asiatic cheetah responds differently to climate change and the distribution range is reduced (Fig. 2a). The suitable habitat area for the species is predicted to increase by 77% in the RCP 2.6. However, the growth is far less in RCP 8.5 and is calculated to be 35% (Fig. 3).
B. Asiatic wild ass: Predictions for the distribution of Asiatic wild ass show that some patches in the center and south of Iran have the potential for the species' distribution in the current condition, and the climatic conditions in 2070 with the RCP 2.6 scenario will not change that significantly and will increase by only 33%. However, the RCP 8.5 scenario will increase the species' distribution area around the current habitats by 142% and positively affect it (Figs. 2b, 3).
C. Asian Black Bear: Currently, the Asian Black Bear distribution area is relatively 15% larger than the species distribution area in RCP 2.6, but the species distribution area increases in RCP 8.5 about twice as much as it is in the current situation and will gain 93% more area (Figs. 2c, 3).
D. Brandt's Hamster: The distribution pattern for Brandt's Hamster in the current and future climatic condition overlaps with the IUCN geographical species range (Fig. 2d). In general, the range of Brandt's Hamster distribution will increase by 86% and 109% in the RCP 2.6 and RCP 8.5 scenario compared to the current situation (Fig. 3). In the RCP 8.5 scenario, the northern and northeastern regions have also been added to the species' distribution range.
E. Eurasian Otter: The distribution pattern of Eurasian Otter in the current climatic condition is limited to the north of Iran. In the future climatic conditions, the Northern parts of the distribution range will be narrowed and stretched to the northwest of Iran and show a 3% increase in the RCP 2.6 scenario and 30 ٪ Reduction of RCP 8.5 scenario (Fig. 3). The species' distribution pattern is not entirely consistent with IUCN geographical species' amplitude pattern (Fig. 2e).
F. Goitered Gazelles: The Goitered Gazelles' distribution pattern in the current condition is predicted in the south margin of Alborz and Zagros mountain ranges and the east and the central parts of Iran (Fig. 2f). This species showed a negative response to climate change in 2070 and, according to both RCP 2.6 and RCP 8.5 scenarios, will experience a reduction in its habitat range by 63% and 96%, respectively (Figs. 2f, 3).
G. Long-Fingered Bat: The distribution pattern of Long-Fingered Bat in the current condition is predicted in the Zagros Mountain and northeast in Iran (Fig. 2g). This species showed a negative response to climate change in 2070 and according to RCP 2.6 and RCP 8.5 scenarios, distribution in the UCN geographical Long-Fingered Bat range will contract 87% and 84%, respectively (Figs. 2g, 3).
H. Marbled Polecat: The distribution of Marbled Polecat in the current condition is predicted in the north, northwest, west and parts of the east of the country (Fig. 2h). This species showed a positive response to climate change in RCP 2.6 scenarios and will increase the habitat range by 122% (Fig. 3). However, according to RCP 8.5 scenarios, species distribution is limited to northwestern Iran compared to the RCP 2.6 scenario and up to 106% reduction of habitat area is predicted (Figs. 2h, 3).
I. Mediterranean Horseshoe Bat: Predictions of Mediterranean Horseshoe Bat distribution have coincided well with the IUCN geographical species range (Fig. 2i). Patterns of Mediterranean Horseshoe Bat distribution in the current condition are predicted in the Zagros mountain range, north and northeastern Iran. This species showed a positive response to climate change in 2070 according to both RCP 2.6 and RCP 8.5 scenarios and will increase by 357% and 300%, respectively (Fig. 3). According to the RCP 2.6 scenario, the habitats consist of several small patches in the species' distribution range, but in the RCP 8.5 scenario, three large habitat patches are predicted.
J. Mehely's Horseshoe Bat: The distribution range of Mehely's Horseshoe Bat in the current conditions is predicted to happen in the south of Zagros mountain range, a spot in the northwest and a spot in the northeastern Alborz mountain range (Fig. 2j). Mehely's Horseshoe Bat has shown different responses to climate change scenarios. According to the RCP 2.6 scenario, the spatial distribution pattern predicted in the northern, western and southern margins of Iran and the habitat range will increase by 112% (Figs. 2j, 3). According to the RCP 8.5 scenario, the species distribution range is concentrated in the Zagros Mountains and has the highest overlap with the IUCN geographical species range and its area is reduced by 5% compared to the current situation (Fig. 3).

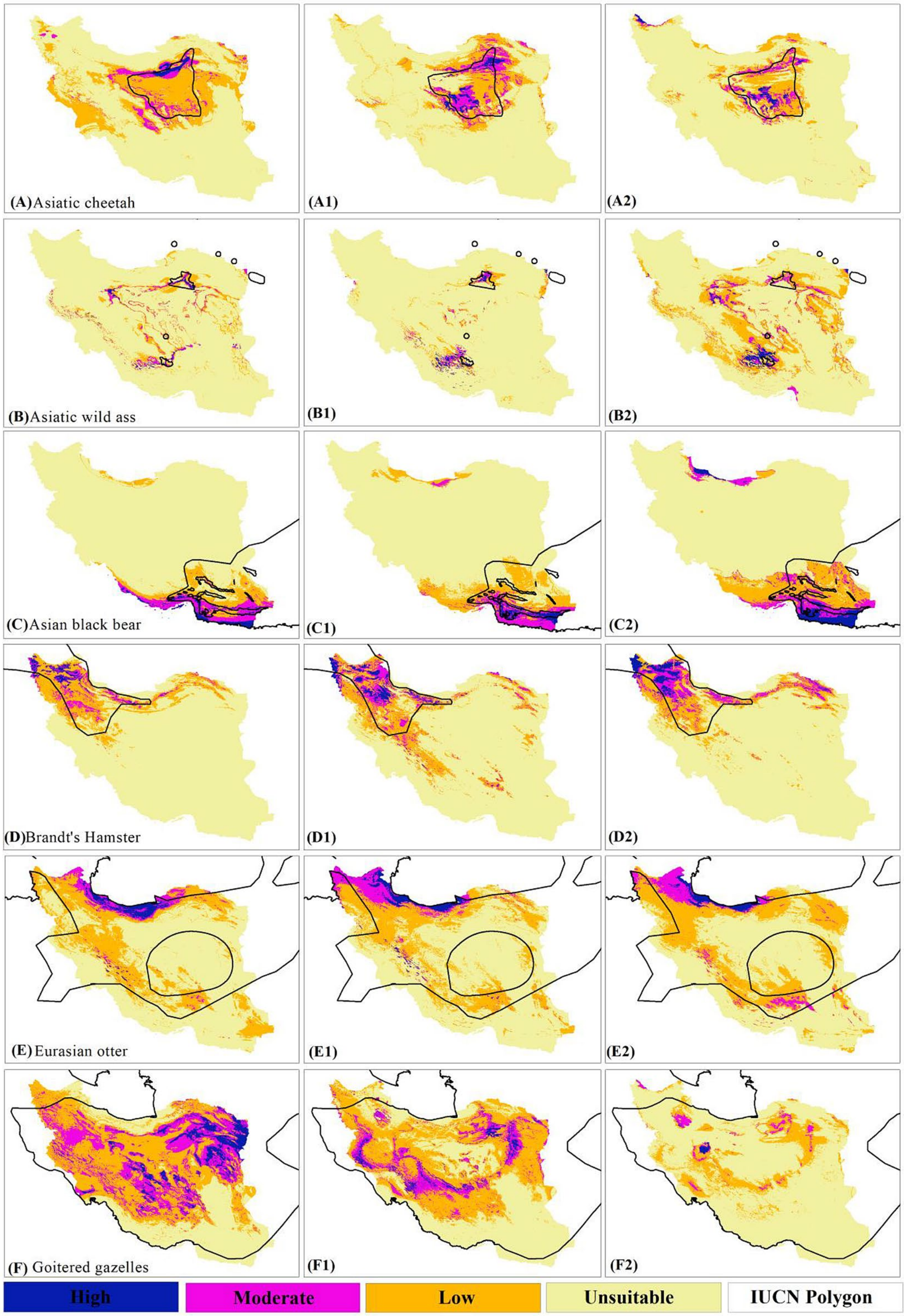
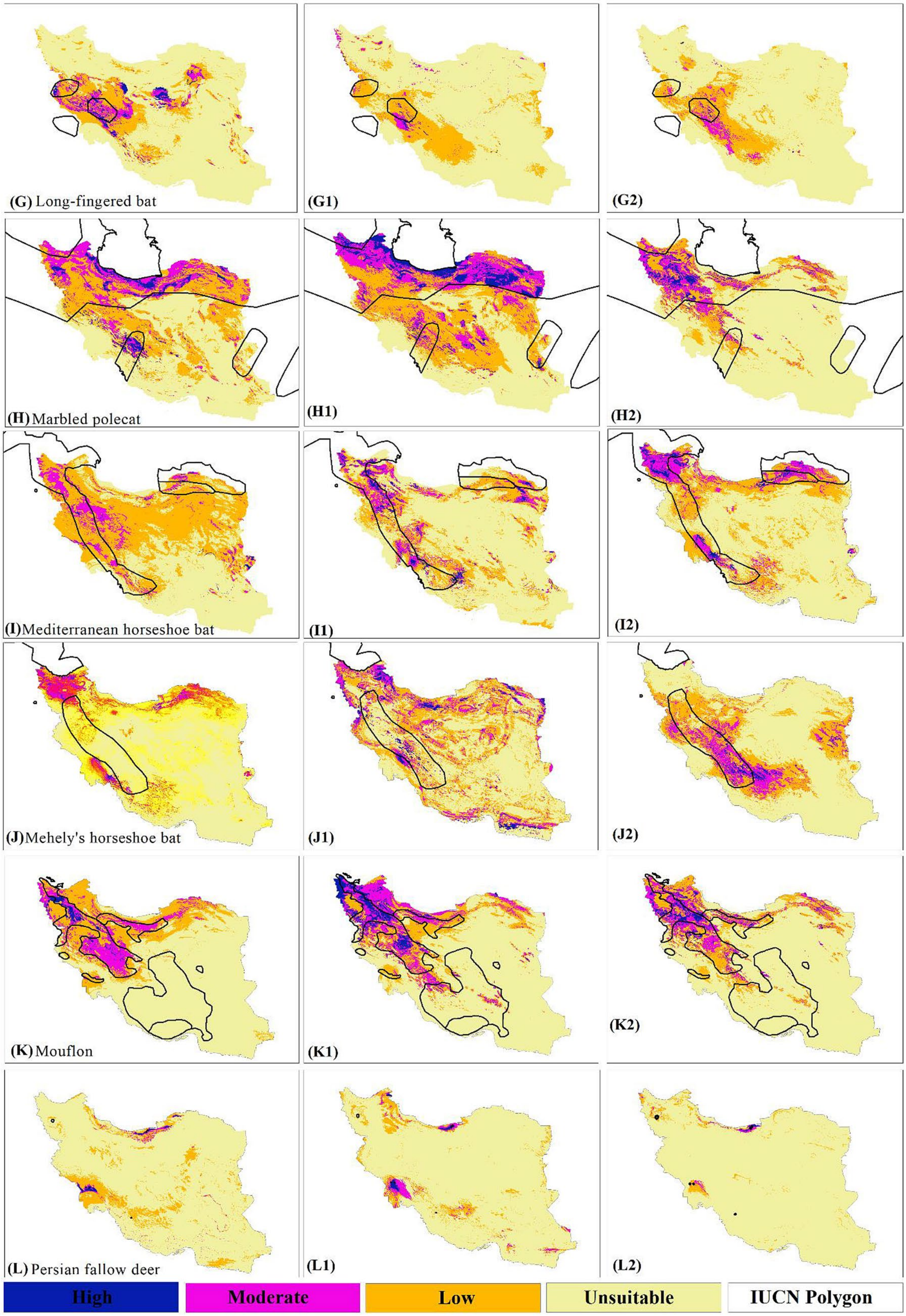


Fig. 2 Results of suitable habitat modeling in recent climatic conditions (1979–2013) and RCP 2.6 and RCP 8.5 scenario in 2070 for threatened mammals in Iran. **A**: Asiatic Cheetah, **B**: Asiatic wild ass, **C**: Asian black bears, **D**: Brandt's Hamster, **E**: Eurasian otter, **F**: Goitered gazelle, **G**: Long-fingered bat, **H**: Marbled polecat, **I**: Mediterranean horseshoe bat, **J**: Mehely's horseshoe bat, **K**: Mouflon, **L**: Persian fallow deer, **M**: Persian Leopard, **N**: Striped hyena, **O**: Urial, **P**: Wild goat



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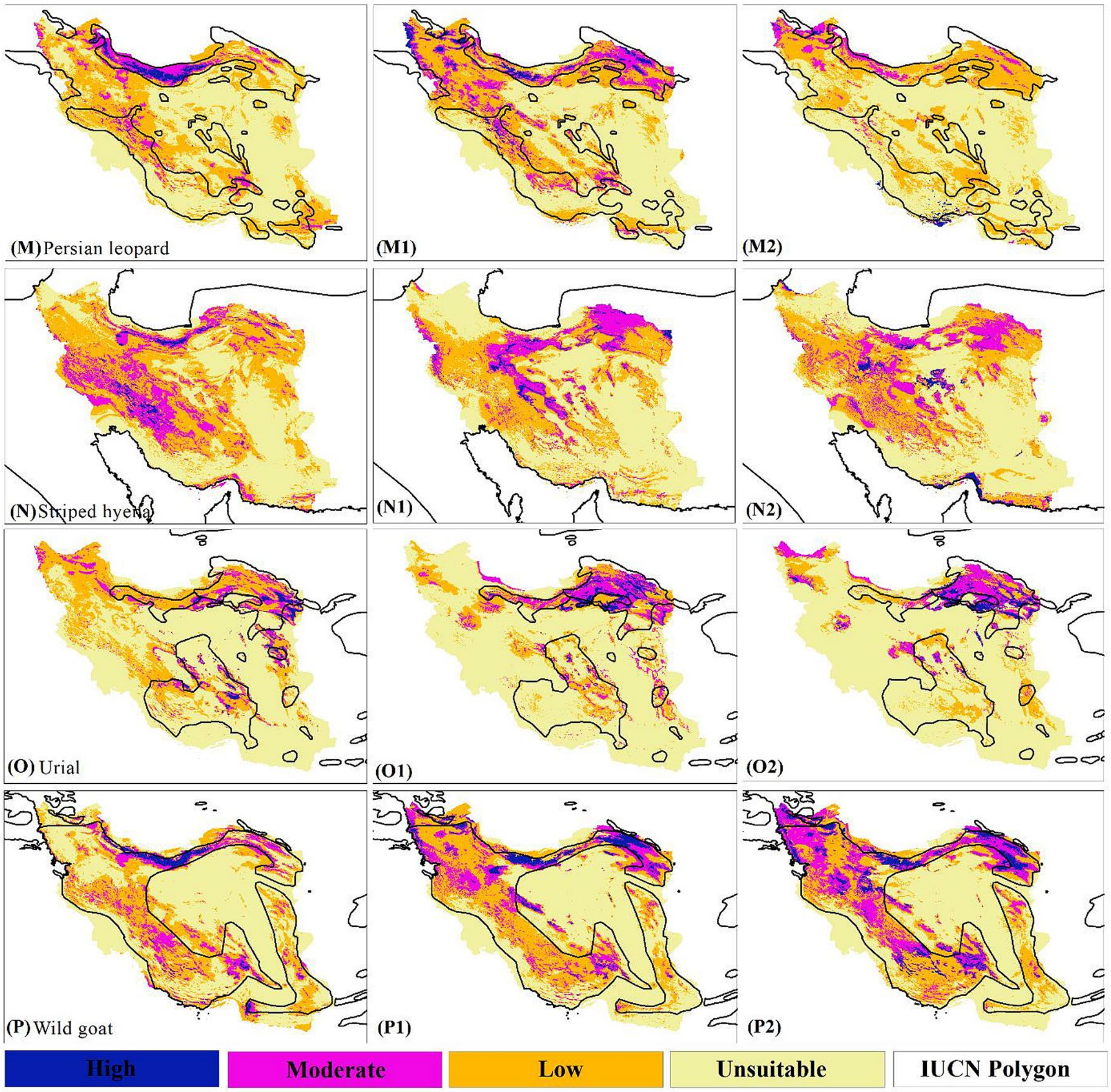

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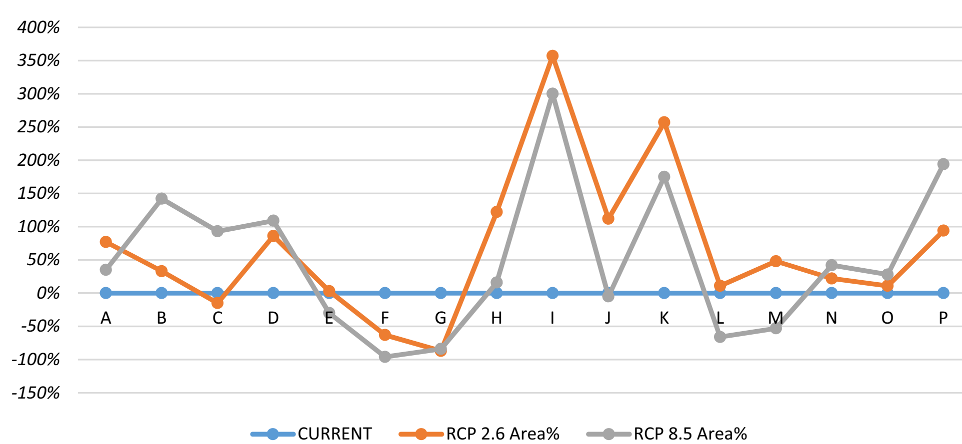

Fig. 3 Percentage of suitable habitat change in current climatic conditions (1979–2013) and RCP 2.6 and RCP 8.5 scenario in 2070 for vulnerable mammals in Iran

K. Mouflon: The current distribution pattern of Mouflon is predicted in the northwest of the country (Fig. 2k). This species showed a positive response to climate change in 2070 and, according to both RCP 2.6 and RCP 8.5 scenarios, will increase its habitat range by 257% and 175% in the northeast of Iran and the eastern end of the Caspian Sea (Figs. 2k, 3).
L. Persian Fallow Deer: IUCN geographical species range pattern is minimal. The prediction of species distribution shows that in addition to IUCN geographical species range, some regions in the north and west of the country also have the potential for Persian Fallow Deer distribution (Fig. 2l). The future distribution area will increase by 11% in the RCP 2.6 scenario and decrease by 66% according to the RCP8.5 scenarios (Fig. 3).
M. Persian Leopard: Significant reduction (53%) in the distribution range of Persian Leopard is predicted for the RCP 8.5 scenario that demonstrates the species' severe negative response to climate change (Fig. 3). The most suitable area for the species' distribution in the current climatic conditions is predicted to happen in northern Iran. In the RCP 2.6 scenario, Species distribution spots are scattered in the west, north and east of Iran and show more overlap with IUCN geographical species range and its area will increase by 48% (Figs. 2m, 3).
N. Striped hyena: Striped hyena distribution pattern in the current climatic condition with 23,972.92 km^2 area is concentrated in Iran's western and northern regions. However, it is predicted that the striped hyena response to climate change will be negative so that the species distribution area is reduced (22% and 42% reduction in the RCP 2.6 and RCP 8.5scenario, respectively), and the species' range shifts from west to east in the RCP 2.6 and RCP 8.5 scenarios (Figs. 2n, 3).
O. Urial: The current distribution pattern of Urial is predicted in Iran's central and eastern regions (Fig. 2o). This species showed a positive response to climate change in 2070 and according to RCP 2.6 and RCP 8.5 scenarios, the current distribution pattern has expanded by 11% and 28%, respectively (Figs. 2o, 3).
P. Wild Goat: The distribution pattern of Wild Goat in the current condition is predicted in the northern, northeastern and south highlands of Iran (Fig. 2p). This species showed a positive response to climate change in 2070 and, according to both RCP 2.6 and RCP 8.5 scenarios, will increase its habitat range by 94% and 194%, respectively (Figs. 2p, 3).

Model validation

The highest average predictive accuracy was for RF (AUC = 0.930), BRT (AUC = 0.861) and CTA (AUC = 0.860) models, respectively. The "Minimum Accuracy of Prediction" of these three models was significantly larger than other models. The validation results showed that the average accuracy obtained for GLM, RF and MARS models were 0.86, 0.85 and 0.82, respectively. These three models generally had a smaller range of changes than the other models, which confirms these models' better performance (Appendix S3, S4).

Coverage of the protected area network

The overlap of the protected areas' network with each species in the habitat suitability maps in the current and future conditions showed that the coverage to the species distribution in the current climate is better for Asiatic wild ass and Persian Fallow Deer than in the future in both scenarios. However, for the Asian Black Bear, Marbled Polecat, Mediterranean Horseshoe Bat, Mouflon, Urial and Wild Goat, the coverage of the protected area network increased in 2070, and according to the RCP 8.5 scenarios, it would reach 2.46%, 4.06%, 3.33%, 5.77%, 1.53% and 8.64%, respectively. The results also showed the coverage of the protected area network for Eurasian otter, Goitered gazelles, Mehely's horseshoe bat and Persian leopard maximized in RCP 2.6. The coverage of the protected area network for Mouflon, Urial and Asian black bear has not changed significantly in the RCP 2.6 and RCP 8.5; also, the overlap of the protected areas with the distribution of Asiatic cheetah, Brandt's hamster, long-fingered bat and Striped Hyena, RCP 2.6 scenario have the least overlap with protected areas and in RCP 8.5 scenario, the overlap is maximized (Table 1).

Discussion

We investigated the effects of current (1979–2013) climate condition and future (2070) climate change under the RCP 2.6 (optimistic scenarios) and RCP 8.5 (pessimistic scenarios) on the distribution changes of vulnerable mammals in Iran and the effectiveness of the protected areas. We used the climatic variables as determining factors of the species distribution and left out the possible effects of other environmental, geographical and anthropogenic factors such as the interaction between species land use change on the species

Table 1 Coverage of the protected area network for response of species to climate change compared to recent climatic conditions

Code	Species	Current	RCP 2.6	RCP 8.5	Coverage
A	Asiatic Cheetah	1.63%	1.45%	2.58%	−/+
B	Asiatic wild ass	1.23%	0.41%	0.93%	−
C	Asian black bears	1.23%	1.79%	2.46%	+
D	Brandt's Hamster	1.8%	0.60%	3.23%	−/+
E	Eurasian otter	2.1%	3.89%	1.87%	±
F	Goitered gazelle	2.4	2.63%	0.27%	±
G	Long-fingered bat	1.0%	0.47%	2.35%	−/+
H	Marbled polecat	2.2%	6.94%	4.06%	+
I	Mediterranean horseshoe bat	0.9%	1.94%	3.33%	+
J	Mehely's horseshoe bat	1.8%	3.79%	0.96%	±
K	Mouflon	1.3%	5.82%	5.77%	+
L	Persian fallow deer	0.3%	0.21%	0.09%	−
M	Persian Leopard	2.0%	16.53%	0.74%	±
N	Striped hyena	2.6%	1.80%	2.53%	−/+
O	Urial	1.3%	1.82%	1.53%	+
P	Wild goat	2.2%	5.47%	8.46%	+

range. Therefore, our results are based on a limited set of variables that may not be complete to illustrate a full picture of the species' future and cannot be considered the most probable destiny with certainty.

We examined the 16 threatened mammal species' response to climate change. Our model showed that not all species respond the same to climate change and some of them react to climate change by expanding their potential distribution range, which is consistent with previous studies' findings which stated that climate change is not likely to affect all species similarly and some species are expected to benefit from and others to suffer under altered climatic conditions (Fajer et al. 1989; Freedman 1989; Cammell and Knight 1992; Davis et al. 1998a, b).

The Asiatic wild ass, which is endemic to Iran, was categorized as endangered by IUCN reports (Hemami et al. 2015) and has been in severe decline for the past decades (Hemami and Momemi 2013). The distribution range of Asiatic wild ass will remain intact under the RCP 2.6 scenario but experience an increase in the RCP 8.5. This species' habitats are reported to be threatened by land conversion and overgrazing by domestic animals (Tatin et al. 2003), which can be problematic because even if the species' potential climatic niche increases, the mentioned factors can limit the species' ability to expand its distribution. The Asian Black Bear, which has been mentioned to be threatened by the effects of climate change (Farashi and Erfani 2018) and been in decline in its natural range in Iran due to habitat fragmentation and severe droughts (Ahmadzadeh et al. 2008), is in a relatively similar situation to Asiatic wild ass with its range being slightly contracted in the RCP 2.6 scenario and experience a rather significant expansion in the RCP 8.5.

Two wild-sheep species, the Mouflon and the Urial, which are mainly threatened by poaching and competition with livestock in Iran and Iraq (Bleyhl et al. 2019; Ghoddousi et al. 2016) and the Wild Goat that suffers from habitat destruction and fragmentation and illegal hunting (Morovati et al. 2014; Sarhangzadeh et al. 2013) are also among the species that respond positively to climate change and increase their range in both scenarios. Although the Wild Goat is distributed in mountainous areas, and it is challenging for mountain species to adapt to new conditions (Hannah 2014), our findings on Wild Goat are consistent with the study of Ebrahimi et al. (2019) which showed a positive response that our model demonstrates. The precipitation seasonality (BIO15) is one of the most critical variables for Wild Goat, which is consistent with the findings of Rahim (2016). Although the population of Brandt's Hamster has a decreasing rate (Kryštufek et al. 2008) and considered to be a rare species throughout its distribution countries (Kryštufek et al. 2009), the species shows a similar trend to Mouflon and Urial in our study and increases its range significantly in both scenarios.

Bats are generally among the species that respond to climate change (Rebelo 2010; Jones and Rebelo 2013). Several studies have shown that mammals, especially bats, are endothermic and highly sensitive to temperature (Morueta-Holme et al. 2010; Sherwin et al. 2012). Climate change can alter prey-predator dynamics in bats (Pryde et al. 2005) and cause also found that the risk of water stress leads to limitations for bats, especially efficient and fertile populations (Adams 2010). Furthermore, Newson et al. (2009) addressed the change or restriction of hibernation places for bats as an indicator of climate change. However, two out of three bats in our research reacted to climate change by expanding their potential range. Mediterranean Horseshoe Bat increases its range in both scenarios. Although the distribution range of Mehely's Horseshoe Bat experiences a minor contraction in the RCP 2.6 scenario, it will significantly increase in the RCP 8.5. *R. Euryale* is a western Palearctic species and has been reported to have a continuing decline of mature individuals (Juste and Alcaldé 2016). Mehely's Horseshoe Bat is mainly restricted to the Mediterranean with discontinuous distribution in other parts of Asia and Europe. This species population experiences extreme fluctuations and is reported to have declined in all parts of its range for which data are available (Alcaldé et al. 2016).

At present condition, the habitat of Mehely's Horseshoe Bat is located at altitudes of more than 2000 m (Karami et al. 2016). It seems that this species will expand its habitats in the highlands of the Zagros, Alborz and Kopet Dagh mountains in the future climate. Although this species may increase its distribution range, its low dispersal ability (maximum dispersal = 90 km; Karami et al. 2016) may cause the species to face a crisis. Therefore, the protection of habitats of Mediterranean Horseshoe Bat and Mehely's Horseshoe Bat is essential and should be given priority in conservation management programs. The remaining bat in our study, the Long-Fingered Bat, is vastly distributed in Europe and Asia and has declined in several localities (Paunović 2016). Our results show that the species will considerably reduce its range in Iran according to both scenarios.

The species' success to shift or adapt to a new distribution range depends on many factors including species interactions, characteristics of a species' climatic niche, species dispersal abilities and the variability and speed of changing conditions (La Sorte and Jetz 2012). Studies have shown that some species move to new habitats as a response to climate change, which leads to accidentally finding new suitable areas, thus, stabilizing the whole species distribution area and positively affecting the species (Avalos and Hernández 2015). Although in this study the distribution range for the mentioned species has expanded due to future climatic conditions, using new habitats depends on the ability of species to disperse and the connectivity between habitats. However, the new habitat may have suitable climatic conditions, species will not be able to move to a new habitat due to their inability to disperse or insufficient resources (food and refugia) in a new habitat or the lack of connection between habitats (Hof et al. 2012). Therefore, managing new habitats and creating corridors for this species is crucial (Bencharif 2010; Beier 2012).

As some species will supposedly react positively to climate change, others in our study will contract their range in both scenarios or respond differently concerning the optimistic or pessimistic scenario. Understanding the decline in biodiversity of the ecosystem due to climate change is a significant concern in recent years (Bellard et al. 2012). Species respond to climate change by staying in place and adapting to the new climate (e.g., population variability or phenotypic plasticity), moving and tracking the climatic conditions (via dispersal), or going extinct (Berteaux et al. 2004). Our results show that as climate changes, the critically endangered Asiatic cheetah (Jowkar et al. 2008) would experience range reduction in both scenarios. The species that once believed to occur in almost all the desert and steppe areas of Iran (Farhadinia et al. 2017) but its current distribution range comprises three main populations in Iran's central deserts with unknown connectivity status (Moqanaki and Cushman 2016). The habitat suitability of the Persian Leopard, the other felid of our study, has been reported to be highly affected by the future climatic condition (Ebrahimi et al. 2019). The species is listed as vulnerable on a global scale (Stein et al. 2020) and endangered on a national scale (Karami et al. 2016) on red lists. The species responds to climate change the same as the Asiatic cheetah and experiences a significant reduction in the RCP 8.5 scenario while witnessing a contraction in its highly suitable habitat patches in the RCP 2.6 (Fig. 2). As the species is mainly threatened by habitat destruction and fragmentation, prey depletion, human–wildlife conflict, unsustainable trophy hunting, poaching for body parts and indiscriminate killing (Datta et al. 2008; Packer et al. 2011; Athreya et al. 2011; Raza et al. 2012; Farhadinia et al. 2014; Swanepoel et al. 2015; Jacobson et al. 2016), range contraction will add additional pressure to existing ones and put the species survival into jeopardy. The range contraction trend stays the same for striped hyena as the species respond negatively to both scenarios and its range will reduce in Iran. The species face several threats that affect its occurrence and abundance (Abisaid and Dloniak 2015). Based on several studies (Wagner 2006; Alam 2011; Akay et al. 2011; Khorozyan et al. 2011), Striped Hyena is in decline in many places because of persecution (poisoning, killing and hunting), habitat alteration and destruction and the climate change-induced threat is evident for the species as well (Trouwborst and Blackmore 2020a, b). The other declining species in our study is goitered gazelle which is categorized as vulnerable (IUCN 2017). The species' populations in Iran suffer from habitat destruction and fragmentation, illegal hunting and environmental extremes and are projected to be affected significantly by climate change (Khosravi et al. 2016). The mentioned projection is consistent with our results, indicating a substantial reduction in the species' range in both future scenarios (Fig. 2). The predicted habitats will be fragmented in future climatic conditions, and habitat fragmentation can reduce populations' genetic diversity and increase the risk of extinction in the species (Bálint et al. 2011).

Marbled polecat, Persian fallow deer and Eurasian otter reacted to climate change considering which scenario is applied in the model; all three species expanded their range in the RCP 2.6 scenario and experienced range reduction in the RCP 8.5.

Although Marbled Polecat is a flagship species in steppe habitats (Abramov et al. 2016), limited studies have been conducted on this species worldwide. The results of our study showed that annual mean temperature (BIO1) and precipitation seasonality (BIO15) are the most important variables influencing the distribution of this species. As the average annual temperature and annual rainfall increase, the probability of species presence increases and then decreases. In general, this species responds positively to rising temperatures and can expand its distribution around current habitats and adapt to changing climate conditions. Kéfi et al. (2007) and Vale and Brito (2015) believed that species inhabiting steppe and desert areas are already physiologically adapted and will not be affected by climate change. That is concurrent with our results that indicate the species' positive response to the RCP 2.6 scenario. However, the distribution range of Marbled Polecat will contract considerably in the pessimistic scenario.

The Endangered Persian Fallow Deer that once was thought to be extinct in Iran, now mainly occur in a semi-captive condition and experience numerous pressures from habitat fragmentation, climate change and severe weather and native diseases (Werner et al. 2015). Although the species will slightly expand its range in the RCP 2.6, our results demonstrate that it will go through a substantial reduction in RCP 8.5.

Eurasian otter, which has proven to be susceptible to climate change Eurasian Otter (Cianfrani et al. 2018), follows the same trend considering the scenarios; a slight expansion in RCP 2.6 and a considerable reduction in RCP 8.5. Generally, the species' global distribution has shown a sharp decline in the past decades (Elliot 1983; MacDonald and Mason 1983) and has been placed in Appendix I of the CITES (2021) and the IUCN Red List of Threatened Species where it is classified as near-threatened (Roos et al. 2015). According to studies conducted by Hirzel et al. (2002), Araújo et al. (2004) and Hirzel et al. (2006), due to future climate change, species distribution may be concentrated in areas that were not previously suitable for species distribution (like Mehely's Horseshoe Bat in our study) or maybe on the margins of suitable habitats. Whereas areas that are now suitable for species distribution may become unsuitable or marginal in the future due to climate-changing conditions, this is consistent with the results of our study of some habitats of the species Goitered Gazelles and Persian Leopard (Fig. 2).

Although climate change is a threat that protected areas can not stop (Lemes et al. 2013), according to the results of this study and the reduction of protected area coverage on Asiatic wild ass, Persian fallow deer habitats in both Scenario and Asiatic Cheetah, Brandt's Hamster, Long-fingered bat, Striped hyena, Persian Leopard, Mehely's horseshoe bat, Goitered gazelle, Eurasian otter in one of two climatic scenarios, protected areas are thought to provide greater ecological opportunities to increase species resilience (Lovejoy 2006) and play a key role in protecting species from the effects of climate change (Nepstad et al. 2006). Although it should be borne in mind that in the field of biodiversity conservation, low quality and more protected areas should not be overcome (Pressey et al. 2015), because the current distribution of protected areas is designed with the current distribution of species Climate change and reducing the effectiveness of these areas in species protection is possible (Yousefi et al. 2019) It seems that the selection of protected areas, increasing the number and area of protected areas to protect these Mammals will be useful in the future.

Conclusions

The impact of climate change on species distribution is one of the most critical issues in recent years. Iran is one of the countries affected by climate change, but studies in this area are limited. In this study, using SDMs for the first time, the distribution range and coverage of the protected area network for 16 vulnerable mammals in Iran were examined in the current (1979–2013) and future (2070) climatic conditions. These mammals showed different responses to climate change in the future, with some contracting (Asiatic cheetah, Goitered Gazelles, Long-Fingered Bat, Persian Leopard, Striped Hyena and Eurasian Otter some expanding (Mehely's Horseshoe Bat, Mediterranean Horseshoe Bat, Wild Goat, Mouflon, Urial, Brandt's Hamster, Asiatic wild ass and Asian black bear) and some with different expanding in the optimistic scenario while contracting in the pessimistic one (Persian fallow deer, Eurasian otter and Marbled polecat) their distribution ranges. The coverage of the protected area network in 2070 will increase for Asian black bear, Marbled polecat, Mediterranean horseshoe bat, Mouflon, Urial and wild goat according to the pessimistic scenario while it would maximize for Eurasian otter, goitered gazelles, Mehely's horseshoe bat and Persian leopard according to the optimistic scenario. Based on our results and considering the model's uncertainties and limited data on the species distribution, the studied mammals react differently to climate change and some may expand their range. In contrast, others respond with contraction in range and habitat. As several species' future distribution will remain within or be limited to the boundaries of the protected areas, enforcing protection measures and ameliorate flaws is vital regarding conservation plans.

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Declarations

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