

Article

Predicted Future Benefits for an Endemic Rodent in the Irano-Turanian Region

Suzanna E. J. Meeussen¹ and Anouschka R. Hof^{2,*} ¹ Wildlife Ecology and Conservation Group, Wageningen University, 6708 PB Wageningen, The Netherlands² Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences, 90183 Umeå, Sweden

* Correspondence: Anouschka.Hof@wur.nl

Abstract: Climate change is expected to have an impact on the geographical distribution ranges of species. Endemic species and those with a restricted geographic range may be especially vulnerable. The Persian jird (*Meriones persicus*) is an endemic rodent inhabiting the mountainous areas of the Irano-Turanian region, where future desertification may form a threat to the species. In this study, the species distribution modelling algorithm MaxEnt was used to assess the impact of future climate change on the geographic distribution range of the Persian jird. Predictions were made under two Representative Concentration Pathways and five different climate models for the years 2050 and 2070. It was found that both bioclimatic variables and land use variables were important in determining potential suitability of the region for the species to occur. In most cases, the future predictions showed an expansion of the geographic range of the Persian jird which indicates that the species is not under immediate threat. There are however uncertainties with regards to its current range. Predictions may therefore be an over or underestimation of the total suitable area. Further research is thus needed to confirm the current geographic range of the Persian jird to be able to improve assessments of the impact of future climate change.

Keywords: climate change; MaxEnt; rodent; species distribution modelling

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1. Introduction

Ecosystems all over the world are facing the consequences of anthropogenic environmental change [1,2]. Because of the increased amount of greenhouse gasses in the atmosphere, temperatures are predicted to rise with 1.5–5.5 °C on average by 2100, which will, amongst others, alter global precipitation patterns and extreme weather events [3]. Climate change is predicted to have a significant impact on many species [4], inducing for instance a shift in their geographic range [5]. Generally, species ranges are expected to shift towards the poles or to a higher elevation [1,5]. Endemic species, species with a small geographic range, and those with specific habitat requirements are deemed especially vulnerable to negative impacts of climate change [6–8] and even to extinction [9]. Climate change in high latitudes and in mountain areas is predicted to be especially pronounced [3,10]. This means that species inhabiting these areas are likely to be affected by climate change more so than many other species [11]. This may be exacerbated by the fact that they have limited ability to track their climate envelopes [12].

The Irano-Turanian region hosts many endemic species [13]. Because of its large range of geological and climatic conditions, a country like Iran, which is situated in this region, has a high biodiversity, hosting 191 mammal species, over 215 reptiles, 21 amphibians, 517 birds, and around 8000 plants [14]. However, it is predicted that ongoing and future desertification may severely impact this region, including through surface warming, wind and water erosion, and loss of nutrients [15,16]. Future climate projections suggest that although the regions mean annual precipitation will not significantly change, the occurrence of prolonged periods of drought alternating with heavy rainfall is expected to increase [17].

The effects of desertification, exacerbated by climate change, are expected to result in biodiversity loss [18]. Studies that investigate the impact of future climate change on species inhabiting the Irano-Turanian region are however rare. There are especially hardly any studies on small mammals, but see Mohammadi et al. [19]. Small mammal endemics receive little attention in general compared to large, more charismatic, mammals when it comes to conservation efforts [20]. This is in spite of small mammal extinctions, and rodent extinctions in particular, being over-represented when regarding all terrestrial mammal extinctions that occurred over the past few centuries [21,22]. Nevertheless, only 4% of rodents have been classified as threatened or endangered [21]. Lack of information about population trends and dynamics is thought to be one of the reasons for this and a common challenge when studying small mammals [20].

One such small rodent species inhabiting the Irano-Turanian region that hardly has received any research attention is the endemic Persian jird (*Meriones persicus*), from the Muridae family. Six subspecies are known for this species, which possibly diversified because of past climate change [23]. The species occurs mainly in Iran, but also in other countries in the region [23,24]. The Persian jird, inhabiting shrublands, grasslands, and rocky areas in semi-arid regions, is currently listed as Least Concern on the International Union for Conservation of Nature (IUCN) Red List [25] but it is assessed as vulnerable locally in Pakistan, and it has a near threatened status on the South-Asian Conservation Assessment and Management Plan on non-volant small mammals [26]. This local vulnerable and near threatened status was because of a, likely ongoing, negative population trend. Furthermore, it is believed to be negatively affected by long dry periods throughout its distribution range [25] since drought may have consequences for both the quantity and quality of its habitat [26]. Long periods of drought are unfortunately predicted to be increasingly common in future [17]. Little is known with regards to its small scale distribution, and its distribution range wide current population trend, population size, and the threats it is facing [25]. In this study, we assessed the impact of future environmental change on the geographic distribution range of the Persian jird. This will give more insight in the possible future threats to the species related to environmental change and may benefit its future conservation as well as that of associated species.

2. Materials and Methods

The Persian jird inhabits mountainous areas, where it occurs in the margins of forests, grasslands, or agricultural fields; however, it tends to avoid open fields [27]. The species is mainly found on elevations between 500 and 1500 m, although it has been reported at an altitude up to 3250 m [28]. Many Persian jirds live in isolated populations, because of the fragmented nature of the rocky areas they inhabit [28]. The species is nocturnal, omnivorous, and creates burrows, where it stores food for the winter [27]. These burrows are generally only made at places with vegetation cover and allow the species to escape harsh climatic conditions [29]. Its burrows are used by hamsters, snakes, toads, lizards, and beetles [28]. The Persian jird is known to be preyed upon by foxes (*Vulpes vulpes griffithi*), owls (*Ottus brucei* and *Ottus scops*), and stone martens (*Martes foina*) [28].

To define the climatic envelop of the Persian jird, the species distribution modelling algorithm MaxEnt version 3.4.1 [30] was used to investigate which environmental factors are strongly correlated with its current geographic distribution range and to predict the (future) suitability of the entire Irano-Turanian region for the species to occur. MaxEnt is generally considered as an appropriate tool when working with presence-only data [30] and is widely used to predict the potential impact of climate change on the future distribution of a range of species [7,8,31,32]. A comparative study between four species distribution models by Hernandez and colleagues [33] named MaxEnt as the model with best performance when the number of occurrence data were restricted, which is the case for the Persian jird (see below). MaxEnt calculates the probability that a species is present if a certain condition is fulfilled, and compares this with the overall probability of presence, to test whether this condition is a predictor of species occurrence [34]. Consequently, the resulting model is

used to identify areas where the species is likely to occur [34]. It is a prior assumption that the likelihood of species presence is equal throughout the background landscape [35].

Occurrence records ($n = 60$) between 1960 and 1990, to match the time period of the recent historic environmental data used, were obtained from the Global Biodiversity Information Facility (GBIF) [36] and were used to predict the current geographic range of the species. Because presence-only models are more strongly influenced by spatial sampling bias than models based on presence-absence data [35], maximum one randomly extracted occurrence record per 10 m^2 was used to reduce spatial bias, resulting in one occurrence record being omitted. Unfortunately, there still remained some over-representation of occurrence records in the western parts of its range in comparison to in the eastern parts of its range, roughly 80–20%, when considering meridian 59° east as the cut of between the western and the eastern part. Seeing that there were not many occurrence records and that only one occurrence record per 10 m^2 was used, we decided not to omit further occurrence records from the western part. The final dataset therefore consisted of 59 occurrence records. A total of 19 bioclimatic variables, 14 land use variables, elevation, and human population density were used as environmental variables to predict the distribution of the Persian jird. Elevation was included as a predictor variable despite findings by Hof et al. [37] that model performance for predicting mammal distributions is better when elevation is excluded as a predictor variable since this species inhabits mountainous areas. The 19 bioclimatic variables that were used were all related to temperature and precipitation and were retrieved from WorldClim [38] at a resolution of 30 arcseconds [39]. The bioclimatic variables reflecting the recent historic conditions were based on the average conditions in the years 1960–1990. Land use variables were obtained from the Land-Use Harmonization project (LUH2) [40,41] at a 15 arcminutes scale, the smallest scale available. The land use data were averaged over the years 1961–1990 for the recent historic conditions to match the time frame of the bioclimatic data. Data on human population density and elevation from the Center for International Earth Science Information Network (CIESIN) were obtained from DIVA-GIS [42] at the 30 arcseconds scale. The land use variables, having a lower resolution, were re-scaled to 30 arcseconds to match the resolution of the other variables.

Projections for the years 2050 (average predicted conditions of 2041–2060) and 2070 (average predicted conditions of 2061–2080) of the 19 bioclimatic and 14 land use variables were used to predict the future geographic range of the Persian jird [39]. Elevation and human population density were included as static variables. Due to unavailability of 30 arcseconds Coupled Model Intercomparison Project Phase 6 (CMIP6) data, Coupled Model Intercomparison Project Phase 5 (CMIP5) data were used. Data were used from two Representative Concentration Pathways (RCP); RCP4.5 and RCP8.5 from the Intergovernmental Panel on Climate Change (IPCC). RCP4.5 assumes a radiative forcing of 4.5 W/m^2 by 2100, and is an intermediate scenario, whereas RCP8.5 assumes a radiative forcing of 8.5 W/m^2 by 2100, which is a much higher forcing level [43]. RCP4.5 assumes a decline in cropland use, caused by reforestation, and a change in diet [43]. RCP8.5 is a consequence of a scenario with high population growth and relatively low technological development, resulting in high energy demands. Further, it projects a higher use of croplands than the other scenarios. Five different global climate models were used: (1) The Community Climate System Model version 4 (CCSM4) which is a coupled climate model that simulates the atmosphere, the ocean, land, land-ice, and sea-ice [44]. (2) The Centre National de Recherches Météorologiques Climate Model 5 (CNRM-CM5) which couples atmosphere, ocean, land surface, and sea ice models [45]. (3) The Hadley Centre Global Environment Model version 2 ES (HadGem2-ES), a widely used model which couples ocean-atmosphere models [46]. (4) The French Institut Pierre Simon Laplace low resolution Climate Model 5A (IPSL-CM5A-LR) which is an atmosphere-land surface model that is coupled to an ocean-sea ice model [47]. (5) The Model for Interdisciplinary Research on Climate- Earth System Model (MIROC-ESM) which is a general atmosphere–ocean circulation model,

developed by the University of Tokyo, the National Institute for Environmental Studies (NIES), and the Japan Agency for Marine Earth Science and Technology (JAMSTEC) [48].

The geographical extent that was used for model training was delineated by the study area extended with 1000 km from the outer species occurrences in northern, eastern, southern, and western directions (Figure 1). An extension of 1000 km was chosen to be able to safely assume that the variability within this region was high enough to capture the full climatic envelope of the Persian jird [24].

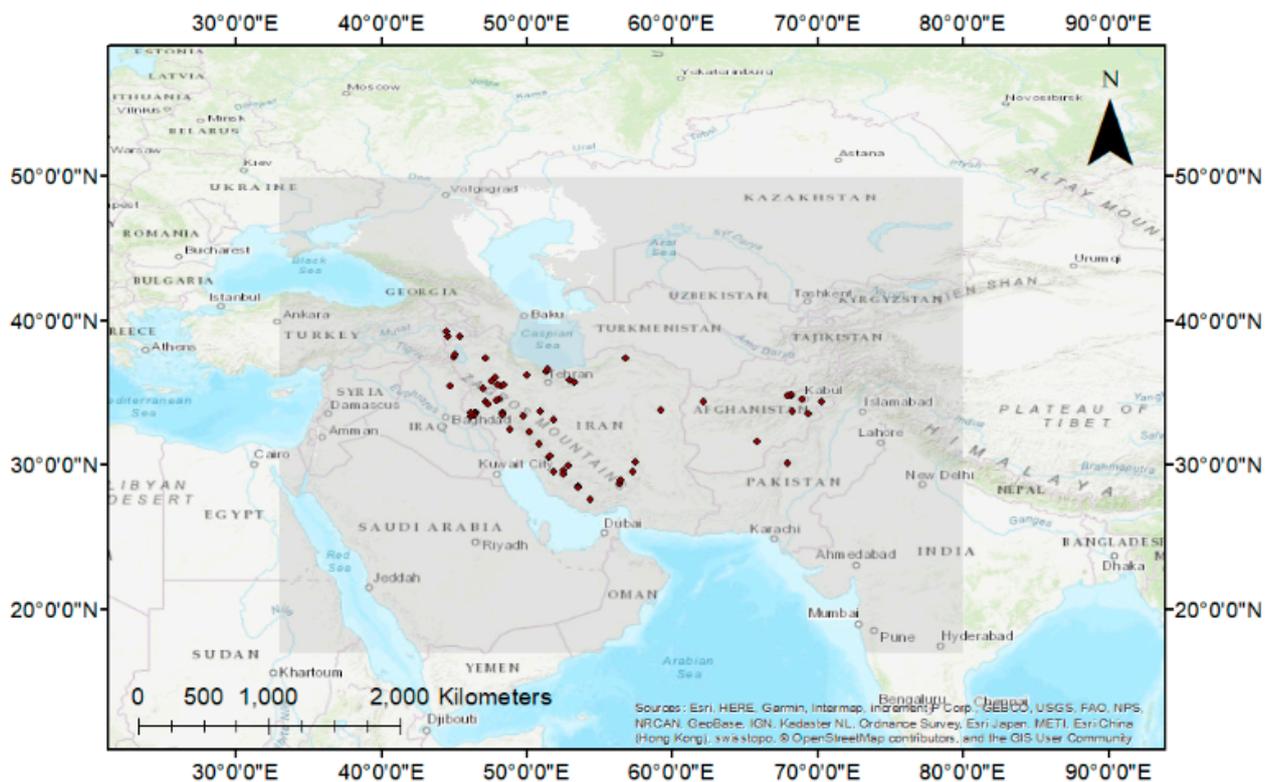


Figure 1. The study area (indicated in grey), with the occurrences of the Persian jird (in red) that were used for modelling.

The default number of 10,000 background points were used. The regularization multiplier of MaxEnt was used to reduce model complexity. Regularization gives a penalty for every added parameter in the model, in order to correct for a too high model fit. In this way, it is avoided that the model becomes too complex [34,35]. The regularization multipliers 1 to 5 were tested, and the one generating the best model (3) was used. Further, variables that contributed little according to a jackknife test and highly correlated variables (Pearson's $r > 0.6$) were removed, keeping only the best predictors. We used a conservative threshold of 0.6 rather than the, in species distribution modelling studies, more frequently used threshold of 0.7 because variables showing a correlation of "just" 0.6 have already been defined as strongly collinear [49]. This resulted in fifteen predictor variables that were used for modelling; eight bioclimatic variables, five land use variables, elevation, and human population density (Table 1). None of these remaining variables showed strong correlations with longitude (Pearson's r all < 0.15), signifying that there was no large variation in any of the environmental variables used for building our model from the east to the west. Which gives some support to using all occurrences rather than omitting more occurrences from the western part of the Persian jird's range as mentioned above. The complementary log-log (cloglog) was used for the model output as is recommended by Phillips et al. [50]. Models were replicated 30 times to capture model variations and to allow testing whether the predicted species' geographic range significantly increased or decreased in future, using a Welch Two Sample paired t-test. In total 600 models were run (30 times five climate models times two RCPs and two time periods). MaxEnt uses a

continuous probability distribution which we transformed into a binary presence–absence map using the maximum training sensitivity plus specificity cloglog as a threshold. The jackknife of regularized training gain was used to identify the most important predictor variables of the geographic range of the Persian jird [50].

Table 1. Variables that were used as input for the MaxEnt models.

Input Variables	Source
C3 nitrogen fixing crops	Land-Use Harmonization project
C4 perennial crops	Land-Use Harmonization project
Elevation	CIESIN
Human population density	CIESIN
Isothermality	Worldclim
Mean temperature of the coldest quarter	Worldclim
Mean temperature of the wettest quarter	Worldclim
Non-forested primary land	Land-Use Harmonization project
Precipitation of the coldest quarter	Worldclim
Precipitation of the wettest month	Worldclim
Precipitation seasonality	Worldclim
Rangeland	Land-Use Harmonization project
Secondary mean biomass	Land-Use Harmonization project
Temperature annual range	Worldclim
Temperature seasonality	Worldclim

To test the validity of the model, 70% of the occurrence records were used for model training, as recommended by Araujo and Guisan [51]. The other 30% was used for model testing. After validation, all occurrence records were entered in the final model to improve model performance. We used the model testing dataset to calculate a cumulative binomial probability distribution to evaluate performance of the model based on the training data and obtained a *p*-value of test-significance, following Peterson et al. [52]. The binomial was based on the number of occurrences in the testing dataset that were correctly predicted by the model outcome out of the total number of occurrences in the testing dataset [52]. The Area Under the Curve (AUC) of a Receiver Operating Characteristic (ROC) plot was used as threshold-independent indicator to further test model performance. The ROC graph plots sensitivity, the true positive rate, against 1—specificity, the false positive rate, for all threshold values [30]. Thus, the AUC is the probability that a random presence point is ranked above a random background point [35,53]. The value of the AUC can range between 0 and 1, with any value above 0.5 indicating that the model performs better than random [30]. An AUC value under 0.8 is seen as insufficient, values between 0.8 and 0.9 as fair, 0.90 and 0.95 as good, and 0.95 and 1 as very good [54].

3. Results

Model performance was good, with a mean AUC of 0.934 and a cumulative binomial probability of 0.88 ($p < 0.001$). The models predicted that the Persian jird should be able to expand its range in future. The extent of the expansion was however dependent on the climate model, RCP and timeframe considered (Table 2, One-way ANOVA: $F_4 = 891$, $p < 0.001$). Based on our models, the most important predictor variable determining the current distribution of the Persian jird was elevation (Figures 2 and 3) in which the highest suitability of the area was at an elevation of 1500 m.

Table 2. The predicted future expansion or contraction of the geographic range of the Persian jird compared to its predicted current range. Results are shown for the first quartile, the median, and the third quartile of the 30 replicates for the five climate models under two RCPs and for two timespans.

Climate Model	Quartile	RCP 4.5—2050	RCP 4.5—2070	RCP 8.5—2050	RCP 8.5—2070
HadGEM2-ES	1st	↑	↑	↑	↑
	Med	↑	↑	↑	↑
	3rd	↑	=	↑	=
CCSM4	1st	↑	↑	↑	↑
	Med	↑	↑	=	↑
	3rd	↑	↑	=	=
MIROC-ESM	1st	↑	↑	=	=
	Med	↑	↑	=	=
	3rd	=	↑	↓	↓
CNRM-CM5	1st	↑	↑	↑	↑
	Med	↑	↑	↑	↑
	3rd	↑	↑	↑	↑
IPSL-CM5A-LR	1st	↑	↑	=	=
	Med	↑	↑	=	↓
	3rd	=	↓	↓	↓

↑: >+50%; ↑: +30–+50%; ↑: +10–+30%; =: −10–+10%; ↓: −10–−30%; ↓: <−30%.

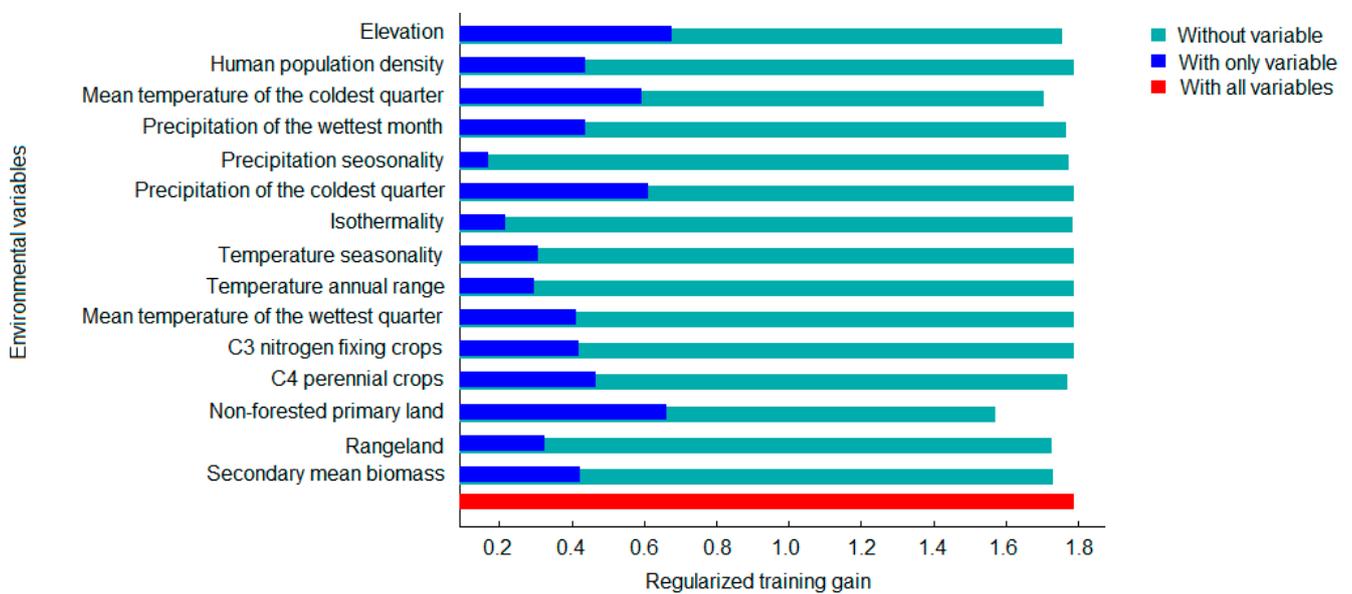


Figure 2. Results of the jackknife of analysis of variable importance for the regularized training gain of models predicting habitat suitability for the Persian jird. The shown values are averages of 30 replicate runs.

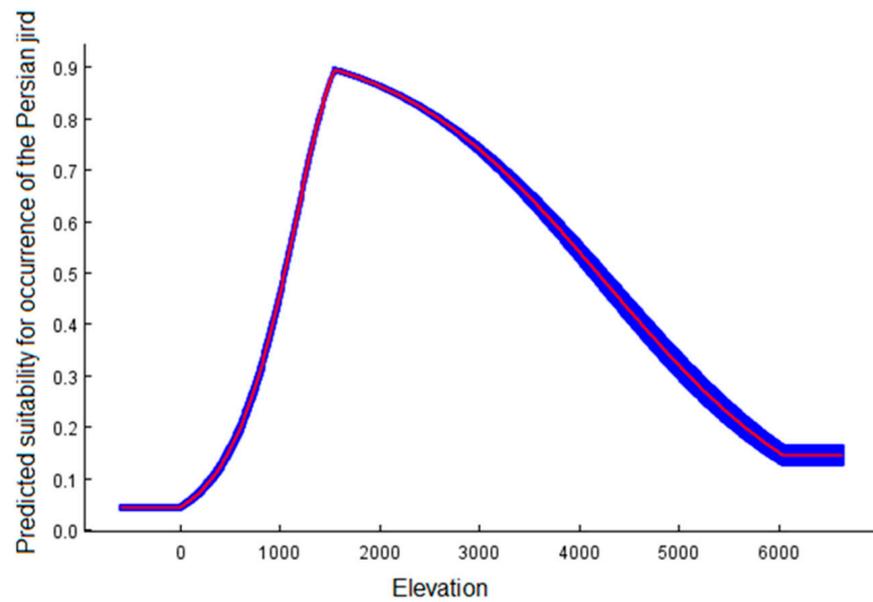


Figure 3. The average (in red) probability of presence of the Persian jird in response to elevation. The standard deviation is shown in blue.

The presence of non-forested primary land was also important in explaining the distribution of the species; suitable areas were largely void of non-forested primary land (Figure 4). The third most important variable was precipitation of the coldest quarter (Figure 5); areas suitable for the Persian jird receive more than about 100 mm of precipitation during the coldest quarter.

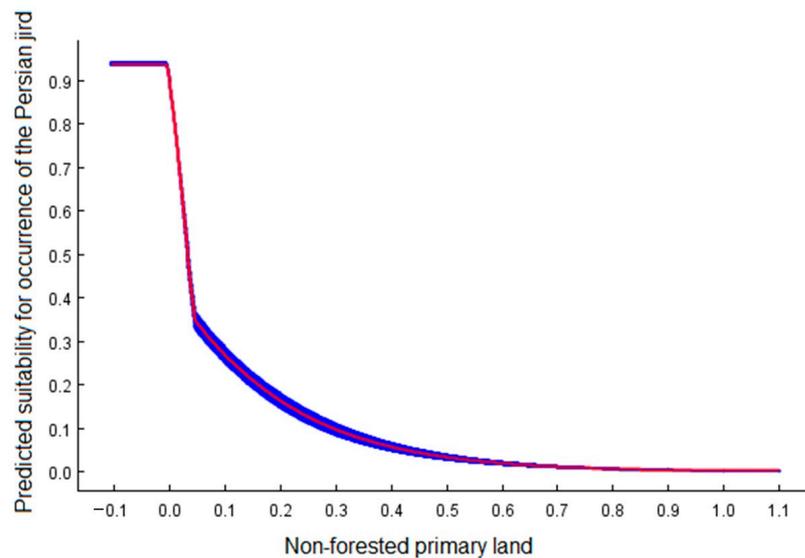


Figure 4. The average (in red) probability of presence of the Persian jird in response to non-forested primary land. The standard deviation is shown in blue.

New suitable areas will likely emerge in the western parts of the study region, in the northern part of Pakistan, as well as in fragments of the Himalayas and some larger parts in Turkey (Figure 6). Furthermore, near the edges of the Zagros mountains in Iran, new suitable area is predicted to appear. However, some areas will disappear in these regions as well. Depending on the climate change scenario, the amount of new suitable area is larger or smaller, and less or more fragmented. Nonetheless, the distance between the current estimated area and new suitable areas in the future is sometimes very large, up to some hundreds of kilometers from the core area (Figure 6).

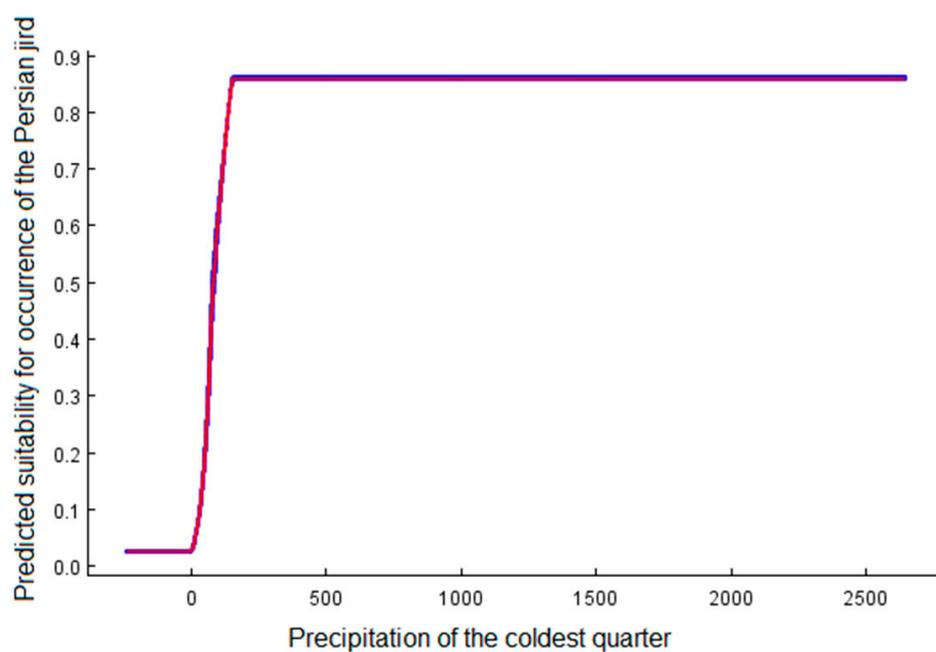


Figure 5. The average (in red) probability of presence of the Persian jird in response to precipitation of the coldest quarter. The standard deviation is shown in blue.

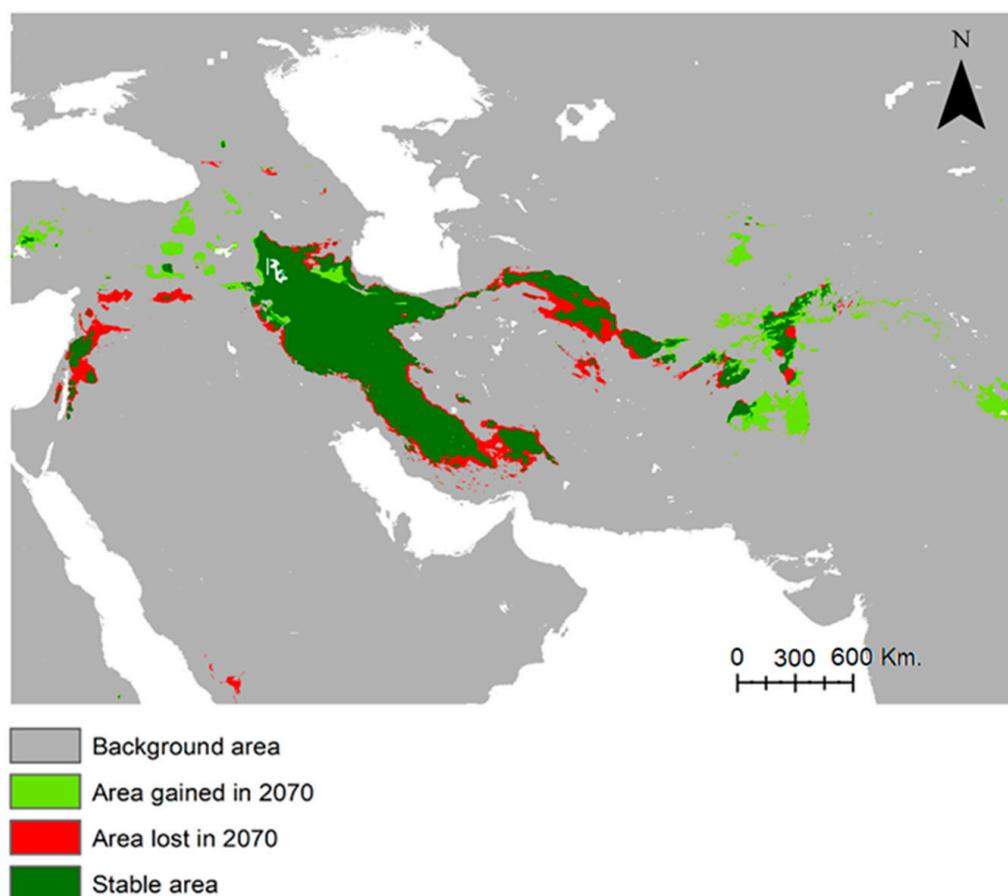


Figure 6. Predicted distribution of the Persian jird in 2070 based on the CCSM 8.5 model, using the median cut-off value.

4. Discussion

Based on our models, climate change and land use change may largely benefit the Persian jird in terms of potential habitat area. Especially change in climatic variables and land use as projected under the RCP 4.5 is predicted to be beneficial, suggesting that “slow” climate change is more favorable than “fast” climate change. Some scenarios showed a substantial increase in suitable area in the outer west and east of the study area, including parts of the Himalayas, the Caucasus, and central Turkey. However, these areas may not be accessible to the Persian jird, or at least not in this timeframe or without assisted migration. Whether the Persian jird can colonize these new areas depends on its mobility, of which, to our knowledge, nothing is known yet in literature. However, a considerable area directly adjacent to the current range is predicted to become suitable in the future, which the Persian jird may colonize in future. As it is generally reported as an abundant species in the areas where it occurs [23], there is no reason to believe that its existence is at immediate risk. Furthermore, the species is very reproductive; females have been reported to commonly have three litters with about seven pups per year [55]. This high reproductive capacity may lead to enhanced dispersal although it has been found that range expansion may be detrimental to the reproduction rate of a species as well [56]. Nevertheless, high reproductive capacity is frequently linked to lower vulnerability to climate change [7]. However, both the predicted current range and the future projections show a geographic range that is fragmented, and it is well known that (local) extinction risk of species is larger in fragmented habitats [57]. There appears to be a large suitable area where the Zagros mountains are located, and a smaller area in the northwest of Iran, near the border of Turkmenistan, reaching as far as Afghanistan. Further towards the east, in Pakistan, another large suitable area is found. The two large areas, roughly in the west and the northeast of Iran, are only connected by a small line of suitable habitat near the Caspian Sea, in the Alborz mountains. Reduced connectivity between populations could be a disadvantage for the Persian jird as it has been shown to be for other rodents [58]. Dianat et al. [23] found that in the past, the mountain ranges may have functioned as refugia for the Persian jird. They implicated that deserts probably hindered gene flow, leading to diversification of several subspecies [23].

Elevation was the strongest predictor of Persian jird presence, 1500 m being the most optimal elevation. This finding is comparable to the known elevation range of the species, which is mainly between 500 and 1500 m, but up to over 3000 m [29]. Although elevation was the strongest predictor, it is usually the environmental conditions on a certain elevation that determine the suitability of a region [59,60]. Based on our models, Persian jird presence is negatively correlated with the presence of non-forested primary land, defined as non-forest natural vegetation that has not been impacted by human activities since the year 850. As this factor strongly contributed to the model, it seems that avoidance of this land use type significantly limits the range of the Persian jird. Rangeland on the other hand related positively to the presence of the Persian jird, which is in accordance with findings from Denys et al. [27]. However, the contribution of rangeland to the model was not very large. Furthermore, the geographic distribution of the Persian jird was shaped by the amount of precipitation during the coldest quarter of the year. It is however important to keep in mind that other factors, not accounted for in the models, such as food availability and predator presence, may largely determine the suitability of a region for a species to occur. It is however often not possible to take such factors into account when predicting in future due to lack of reliable future projections.

Modelling a species' distribution using its environmental niche has some limitations. First, the quality of the outcome of such studies depends heavily on the accuracy of the input variables and the data used for model calibration, such as the occurrence data. When interpreting the results, it is important to take into account that both the occurrence data and the bioclimatic variables for the current climate data are not up-to-date and that there was a bias in occurrence records from the western part of its range. This means that some changes may already have occurred in the past thirty years that are now not captured or

that the suitability of the eastern part of its range may be an under-representation of its actual range although there was no strong correlation between environmental variables and longitude. A sensitivity analysis with varying numbers and spread of occurrences may improve predictions but cannot omit uncertainty completely. Furthermore, as already mentioned other factors not accounted for may determine the geographic range to a certain unknown extent, such as interaction with other species, and human activities [61,62]. Although land use variables and human population density were included, it is always possible that important input variables were missing. Omission of these factors, and also of other environmental factors, including weather extremes, may have influenced model accuracy negatively [63]. A further limitation of species distribution modelling is that it does not include the possibility that species will adapt to their changing environment [62]. Finally, one must bear in mind that even if an area has suitable environmental conditions, this does not necessarily mean that a species is capable of moving and establishing there. Species could have a low dispersal ability or face a geographical barrier that makes the area inaccessible [53,61,64,65]. In the case of the Persian jird, the Himalayas could form a barrier, or the inlands of Iraq and Syria, which have a much lower elevation compared to the mountainous areas of Iran where the Persian jird occurs. For all these reasons, the outcome of a species distribution model should be seen as a first approximation to indicate the effect of climate change on a species' distribution [64]. Furthermore, the current geographic range as predicted based on presence records from the GBIF differed strikingly from the geographic range of the Persian jird as indicated by the International Union for Conservation of Nature [25]. The clearest difference between them is the suitability of the areas with a lower elevation (central and south east Iran). There are no occurrences in the GBIF database that indicate the occurrence of the Persian jird here, whereas the area is covered in the range given by the IUCN, leading to a much larger total area. This range is presumably an overestimation, as we were not able to find evidence in literature that the Persian jird indeed occurs at lower elevations in central Iran [20,26,27]. Another possible explanation of this large difference is however, that the GBIF occurrences are biased. Nevertheless, as they are collected by different institutions over a long time period, we believe them to be sufficiently representative to produce a useful outcome. Furthermore, our current predicted distribution range visually shows a large extent of overlap with the current predicted range published by Dianat et al. [23], who used Maxent and occurrences from GBIF and the published literature to hindcast the distribution range of the Persian jird and assess its evolutionary history. A good approach to obtain a less biased occurrence dataset would have been to obtain occurrences from species surveys in the field, as has for instance been done by Lazo-Cancino et al. [66] who assessed the impact of climate change on an endemic rodent in Patagonia. In contrast to our findings that the Persian jird, favoring shrublands, grasslands and rocky areas in semi-arid regions, may benefit from climate change, they found that the Magellanic tuco-tuco (*Ctenomys magellanicus*), favoring dry grasslands as well, is likely to be negatively affected by climate change. This large contrast exemplifies the need to assess the future vulnerability of species and not to make inferences from other species' assessments.

We conclude that further studies are needed to confirm the current range of the Persian jird, as information about its distribution is at the moment contradictory and insufficient. This is a common challenge for species in the region studied [67]. If more data on the current occurrence of the species was available, it would be possible to construct a better performing model. Another topic requiring further investigation is the mobility of the Persian jird, which will influence its ability to colonize new suitable areas [53]. Therefore, it would be useful to gain more knowledge about its dispersal rate.

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