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Habitat suitability modeling of a Subterranean mammal in Iran: case study of the Western Mole-Vole *(Ellobius lutescens*)

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SUMMARY

Rodentia is the largest order of mammals in Iran, distributed in almost all types of habitats. Subterranean mammals, such as the Western Mole-Vole, have an important role as ecosystem engineers by creating underground burrows and tunnels and aerating, propagating seeds, and building shelter for other small mammals and animals. They are also a keystone part of the food source for other prey vertebrates. However, many areas are considered pests, and their habitats are fragmented due to human activities, which causes a reduction in their habitats and colonization. Habitat Modeling tools help us to predict a suitable niche for conservation planning. The purpose of this study is to predict habitat suitability for Western Mole-Vole in Iran by using the MaxEnt method to determine which part of Iran is a desirable habitat for this species. The result indicated that the northwest of Iran, especially the southern slopes of the Alborz Mountains and the Eastern slopes of the Zagros Mountains, provides suitable habitats for the western Mole-Vole. The environmental variables that are more influenced by the distribution of this species are elevation of 1800 to 2500 meters, human activities such as roads, and rainfed farms. Approximately 7% of Iran is a suitable habitat for the Western Mole-Vole.

Keywords: *Subterranean mammals; Ellobius lutescens; Habitat modeling; Iran*

INTRODUCTION

Rodentia are considered the largest order of mammals, and they are distributed worldwide in almost all types of habitats and even human settlements (Al Malki et al., 2024; Branco et al., 2024). Rodents play important roles in ecosystems. In addition to propagating seeds and controlling insects, they are also part of other prey vertebrates' food webs and chains in their habitats. (Al Malki et al., 2024; Branco et al., 2024; Kirillova et al., 2024), Therefore, biodiversity conservation and habitat management of these mammals are important for food resources and plant production in the ecosystems.

Subterranean mammals are highly specialized and adapted for burrowing and living underground (Gündüz et al., 2023). Subterranean mammals dig with their teeth, and they have more developed incisor teeth while their limbs are usually regressed (Savić et al., 2017; Süt et al., 2020). These mammals display a set of morphological traits associated with a fossorial lifestyle, including a cylindrical body, short tail, short soft pelage, reduced ears, and a highly modified skull with prominent extrabuccal incisors (Csorba et al., 2015; Coşkun et al., 2016; Savić et al., 2017; Volodin et al., 2021). Iran is one of the most important countries in the Middle East for biodiversity conservation (Farashi & Shariati, 2017). It is located in several biogeographical realms that support a wide range of fauna and flora (Mohammadi et al., 2018; Yousefi et al., 2022). However, rodent taxonomy, ecology, and biogeography of small mammals have been less studied than those of other species (Haddadian Shad et al., 2014; Yousefi et al., 2022; Noori et al., 2024). Several species of subterranean mammals live in Iran, one of which is the Western Mole-Vole. According to the IUCN Red List Category and Criteria – Global Assessment, *E. lutescens* has been considered as the Least Concern (Kryštufek and Shenbrot, 2016), but, based on the literature review, there is a lack of information about their ecological niches and conservation status in Iran.

Transcaucasian or western Mole-Vole, *Ellobius lutescens* (Thomas, 1897), belonging to the *Cricetidae* family. These rodents are highly specialized for life in subterranean habitats (Coskon and Uluturk, 2003; Kaya and Coskun, 2015; Kryštufek and Shenbrot, 2016; Yusefi et al., 2019). Western Mole-Vole is a Palearctic species, distributed in Transcaucasia, the Middle East, and East Anatolia (Moradi and Moradi, 2013; Coskun, 2016; Kryštufek and Shenbrot, 2016; Yusefi et al., 2019; Rey-Rodríguez et al., 2020). The morphology includes short, dense fur resembling that of moles; the eyes are small, and the external ears are atrophied, completely hidden within the fur. The fore and hind feet are of moderate size, armed with very small claws, there are five palmar and six plantar pads as usual, the plantar pads being all moderately developed or small. The lateral borders of the fore and hind feet are fringed with stiff hairs, those on the outer margins being especially well developed (Coskun, 2016), and thus, the body is morphologically adapted to the subterranean lifestyle. This species creates underground tunnel systems by scratching the soil with its incisors and pushing behind its body by using its fore and hind limbs (Coskon and Uluturk, 2003; Kaya and Coskun, 2015; Coskun, 2016). It turns and transports the soil with its head and breast and is solely observed outside the burrow while pushing dirt out.

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Western Mole-Vole eats all kinds of vegetation, mainly subterraneous edible parts of various plants such as roots and tubers (i.e. corns, bulbs, tubers, rosette, and rhizomes), which they collect while burrowing through the ground and hoarding in their nest (Karami et al., 2012; Kaya & Coşkun, 2015). Moreover, there is no relationship between species distribution and the micro-climate of the habitat (i.e., temperature, precipitation, and humidity) (Coşkun & Uluturk, 2003).

The expansion of agricultural land, one of the most widespread human land-use activities worldwide, is fragmenting the habitats of animal species. In many areas, considered a pest that has led to species declines (Langraf et al., 2022).

Habitat suitability models, also known as ecological niche modeling species are crucial for effective conservation action (Lumbierres et al., 2022; Dasanayake et al., 2024; Liang, 2024; O'Connor et al., 2024) in ecological and biogeographical research, which are widely used in analyzing the impact of habitat fragments and change on species.

The habitats of wildlife are becoming severely fragmented due to human activities and climate change, resulting in a decline in habitat quality and genetic diversity (Shi et al., 2023). Habitat suitability modeling tools predict a potential distribution of species based on the species-environmental variables relationship (Kirillova et al., 2024; Nkosi, 2024).

The purpose of this study is to determine suitable habitats for the Western Mole-Vole in Iran. Rodents are one of the most abundant groups of mammals and have been extensively studied for various taxa and diseases. However, there is a lack of information about their geographical distribution and ecological niches. All that is especially true for subterranean species. Understanding these aspects is important, as it can help identify and evaluate their habitats, which are crucial for the conservation of other animal and plant species.

MATERIALS AND METHODS

Study area

Iran covers 1,648,194 square kilometers, situated in southwest Asia, which is commonly referred to as the Middle East. It is geographically lying in several regions: the Palearctic, Afrotropical, Saharo-Arabian, and Oriental (Karami et al., 2008; Yusefi et al., 2019) that support diverse fauna and flora (*Figure 1*).

Figure 1. **Map of the study area, the Middle East, Iran**

Iran displays high topographic complexity, with elevation ranging from -60 to 5,671 meters. Over half of the country is mountainous and is above 1,000 meters, with two principal mountain ranges of Alborz and Zagros that extend from north to east and north to west, respectively. The country comprises a wide variety of ecosystems with a gradual transition of biomes and a large variety of habitat types, from wetlands, dense forests, and high mountains to extremely hot deserts (Yusefi et al., 2019). Lying on the cross of several biogeographic and topographic factors is reflected in a diverse mammalian fauna.

Distribution models

Habitat suitability models are a fundamental tool in ecological research and operate by correlating the presence and absence of species to environmental variables to estimate potential distribution across areas (Martínez-Fonseca et al., 2024). Various types of models have been used for predicting desirable habitats

DOI: 10.34101/ACTAAGRAR/1/15286

that can estimate spatial distribution based on occurrence–presence only or presence/absence-data and environmental factors. To balance the benefits of reduced costs and time savings on one hand, and the challenges posed by limited information and access to accurate absence data on the other hand (Baasch et al., 2010; Bassi et al., 2015), this study utilized the Maximum Entropy algorithm (MaxEnt). This algorithm, rooted in niche theory, analyzes habitat characteristics by employing a set of occurrence data along with environmental variables (Fu et al., 2023; Shi et al., 2023; Dasanayake et al., 2024) to predict the habitat model for Western Mole-Vole.

To accomplish this study, the MaxEnt software version 3.4.4 was downloaded from (http://biodiversityinformatics.amnh.org/open_source/MaxEnt).

Envenvironmental variables

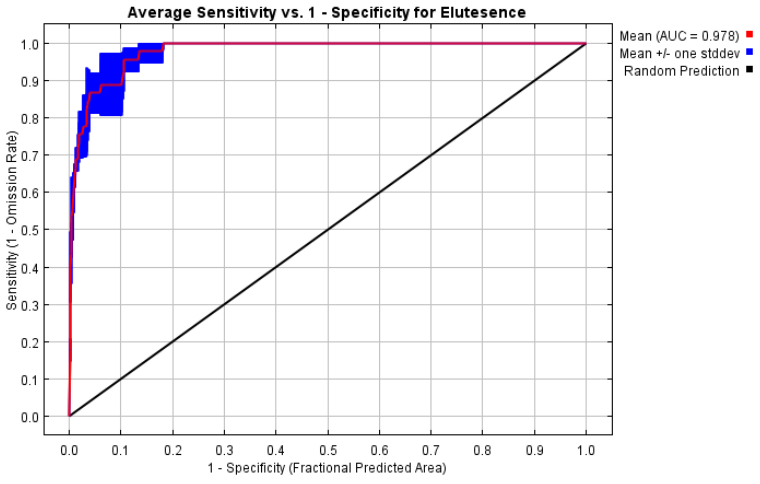
According to the pre-requisite environmental variables to predict habitat suitability modeling by MaxEnt, variables encompass: land use, climatology, topography (altitude), soil, vegetation, water resources, and human development variables. were downloaded from (https://www.fao.org, https://land.copernicus.eu/en, https://diva-gis.org/). Additionally, a slope map percentage was created using the Digital Elevation Model (DEM) (https://www.opendem.info/link_dem.html). Besides, the information on the occurrence data was gathered from fieldwork (DoE's rangers), published papers, and books.

Environmental variables data were classified based on species characteristics, in terms of diet and habitat conditions. Therefore, we selected five categories of environmental datasets with 24 environmental variables. All variables were converted to raster format. We also calculated the Euclidean distance, treating all variables as continuous, and clipped according to the border. Then, for compatibility with MaxEnt, the occurrence data and environmental variables were transformed into CSV and American Standard Code for Information Interchange (ASCII) file formats using ArcGIS 10.8, respectively. We determined the correlation coefficient matrix and eliminated highly correlated variables, using only variables with less than 85% correlation. The presence of variables with a correlation of more than 85% in the analysis can lead to large eigenvalues in the results. To build the model for Western Mole-Vole, a partition was created by randomly selecting 75% of the presence localities as training data, and the remaining 25% of the data was used for testing (Fu et al., 2023; Shi et al., 2023; Nkosi, 2024). The number of iterations was set at 5000 and 10,000 background points to reduce uncertainty. In addition, three replicates were provided throughout the modeling.

RESULTS AND DISCUSSION

The MaxEnt model predicted and evaluated suitability using the Area Under Curve (AUC), the Receiving Operator Characteristics (ROC), and the Jackknife's plot, which helps researchers to interpret and understand the outcome of the model. The ROC curve plots the true positive fraction (sensitivity) that represents the absence of omission error, against the false positive fraction (1-specificity) that represents the proportion of incorrectly predicted observed absences (commission error). In this case, specificity tends to minimize omission errors at the expense of commission errors, and AUC assesses the accuracy of the species distribution model, which ranges from 0–1. Therefore, the higher the AUC value resembles 1, the further the prediction is from the random distribution, and the more strongly the environmental variables are correlated with the anticipated species distribution (Buebos-Esteve et al., 2023; Shi et al., 2023; Liang, 2024; Nkosi, 2024). The ROC result indicated an excellent performance with a high accuracy, with an AUC value of 0.978 (*Figure 2*).

Figure 2. **ROC curve- average sensitivity vs specificity for Western Mole-Vole**



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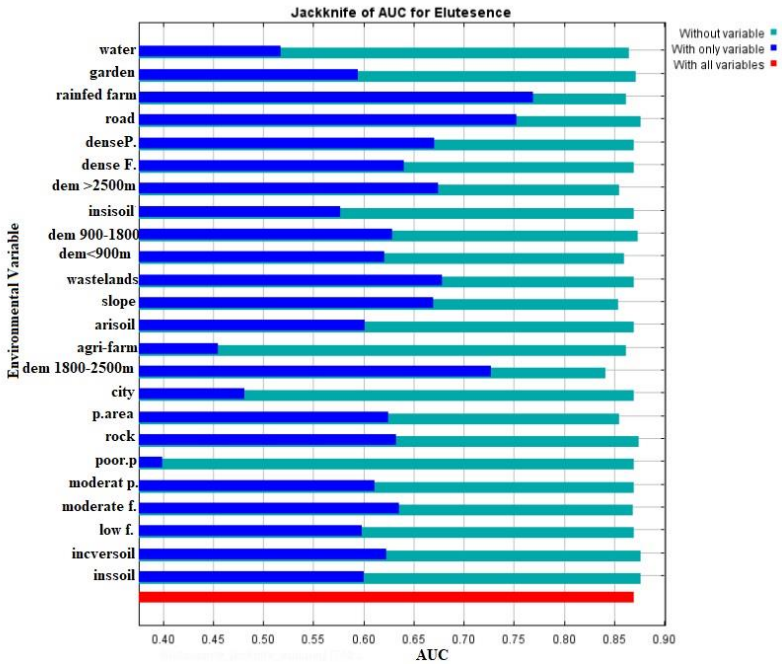
It is crucial to understand which variables influence the suitability and occurrence of species. Thus, MaxEnt uses the Jackknife plot to illustrate how the model uses all variables and detects the importance of each environmental variable in choosing an area as suitable for species (Shi et al., 2023; Dasanayake et al., 2024; Liang, 2024). The Jackknife test typically reveals the relative contribution of individual factors and their effectiveness in MaxEnt predictions. There are three conditions for this test: no variables, a single variable, and all variables combined. The Jackknife test of factor importance in the MaxEnt model indicated that rainfed farms and roads were the most significant variables influencing the habitat selection of the Western Mole-Vole (*Figure 3*).

Figure 3. **Jackknife Test of Environmental Variables**



Environmental variables significantly impact the distribution and presence of species, influencing the desirability of habitats for the Western Mole-Vole. To understand these effects, response curves for each predictor variable were generated using MaxEnt. According to the response curves, the suitability of habitat for the Western Mole-Vole declines as the distance from rainfed farms increases, and there's a marked decrease in suitability at elevations between 1800 and 2500 meters, as well as in pasture and protected areas. This suggests that the Western Mole-Vole thrives in regions with moderate pasture, elevations above 1800 meters, and proximity to both protected areas and rainfed farms. Conversely, the probability of occurrence rises as the distance from roads increases, with optimal conditions found at elevations below 1800 meters and in rocky terrains. This indicates a preference for habitats that are situated away from human settlements and associated activities. The response curves highlight that the Western Mole-Vole responds differently to various environmental factors, which may stem from geographical barriers and the presence of competing species.

The MaxEnt model predicted the suitable habitat for Western Mole-Vole in Iran. Based on the generated map, determined that a high presence of Western Mole-Vole was observed in habitats located in pastures with medium coverage, elevation of more than 1800 meters to 2500 meters, and close to rainfed farms adjacent to or within the boundaries of protected areas. The distribution model suggests that the potentially suitable habitat for the Western Mole-Vole is fragmented, extending from the northwest region to the southern slopes of the Alborz Mountain range and across the eastern slopes of the Zagros Mountain range. This fragmentation in habitat could lead to varying responses among populations, influenced by different environmental factors that may arise from geographical barriers and the presence of competing species (*Figure 4*).

The suitability map for Western Mole-Vole was generated based on the results and interpretation from the Jackknife test, response curves, and ROC, utilizing only presence data. Finally, the map was entered into ArcGIS 10.8 and converted to the raster format so that, according to the threshold value obtained from the MaxEnt, it could be divided into two binary maps (suitable/unsuitable habitat). According to the model obtained from MaxEnt, it can be concluded that the Suitable habitat for this species has been predicted to be fragmented, which will lead to a decrease in genetic diversity in the future and a subsequent decrease in the species' population (*Figure 5*).

DOI: 10.34101/ACTAAGRAR/1/15286

Figure 4. **Response curves for selected variables: (22) Roads, (16) Dem 1800–2500m, (12) rainfed farms, (17) density pasture**

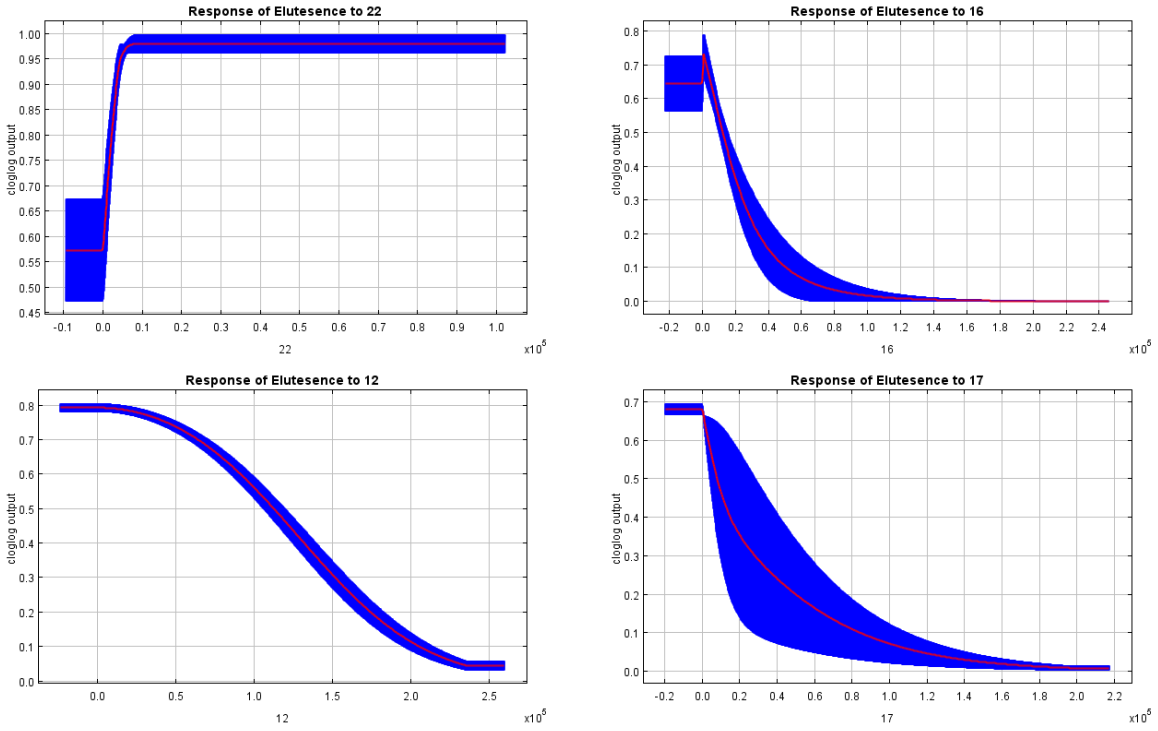
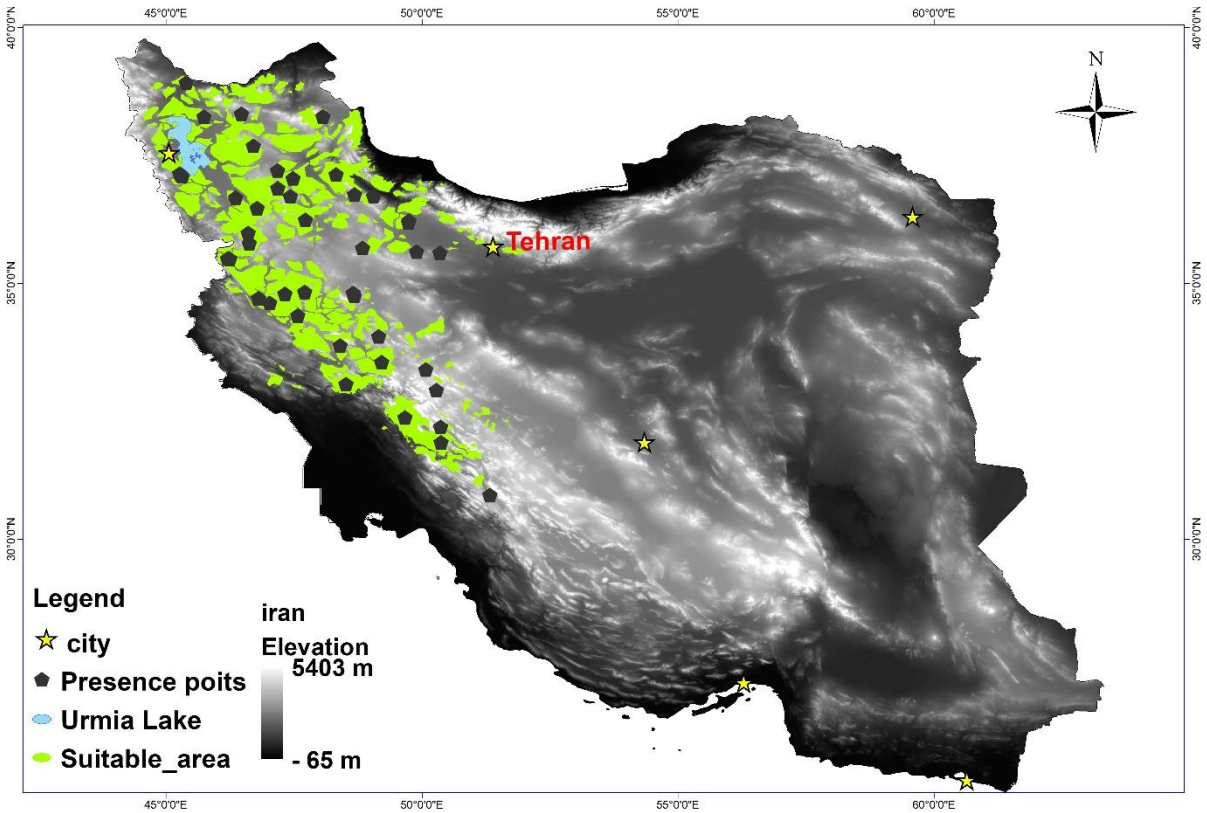


Figure 5. **Predicted habitat suitability for *Ellobius lutescens* in Iran by using MaxEnt 3.4.4**



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CONCLUSIONS

Iran is situated in several regions that cover a high complexity and richness of fauna and flora. Rodentia is the largest order of mammals, whose members are adapted to almost every terrestrial habitat in Iran (Karami et al., 2008).

Rodents in general play an important role in their habitats (Al Malki et al., 2024), and subterranean Western Mole-Vole as being ecosystem engineers creating underground tunnels and burrows, besides air flow, propagating seeds, and increasing plant productivity. They also provide shelter for arthropods and reptiles as well as a food source for numerous carnivores, snakes, and hunting birds.

Habitat Modeling provides a relationship between the habitat types and species' presence in the ecosystem (Lumbierres et al., 2022; Fu et al., 2023; Shi et al., 2023; Németh et al., 2024). Habitat modeling tools have an important role in protecting biodiversity (Zhang et al., 2022), conservation planning, assessing the impact of precipitated land use, and environmental change (Fu et al., 2023; O'Connor et al., 2024). The MaxEnt is a machine-learning model that predicts the habitat by calculating the probability distribution of maximum entropy (Liang, 2024; Nkosi, 2024).

Western Mole-Vole is completely compatible with the subterranean lifestyle and feeds on almost all types of vegetation (Coskun and Uluturk, 2003; Kryštufek and Shenbrot, 2016); therefore, in this study, to achieve high-quality prediction, we used other variables that have an important role in the distribution in the area. Individuals are distributed in many types of soils except moving sand. Based on the Jackknife test, soils are important in burrowing and extending their galleries except for rocks. The response curves showed the highest suitability when the area was far from rocks.

The Other variable that affects habitat suitability is the elevation of the sea level. The MaxEnt result illustrates that Western Mole-Vole is distributed in elevations more from 1800 meters to less than 2500 meters in Iran. The response curves showed that suitability decreased with increasing distance from these variables. Other studies showed the elevation distribution is from 1500 to about 2800 meters (Coskun, 2016).

Human activities always conflict with wildlife habitats and ecological niches because of the degradation and fragmentation of habitats, and this causes separated niches and populations within that unit area. For instance, roads, the response curves, and the Jackknife test showed that roads as an important variable in the suitability because they cause fragmented habitats and obstacles to extend their galleries. But, some of the variables like rainfed farms have a positive role in the distribution due to creating suitable conditions for burrowing, feeding, and being close to their habitats, on the other hand, agricultural variables have a negative role in the distribution, it is considered as a pest due to the damages it causes to the crops.

The suitability map indicates that the desirable habitat for Western Mole Vole is mainly located in the central, western, and northwestern regions of Iran. Additionally, research conducted by Haddadian Shad et al. (2014) on the taxonomy of the Family Cricetidae confirms that this species is found in the central and western parts of Iran.

Overall, the distribution of Western Mole-Vole is not more related to the geographical structure, because most environmental variables do not limit individual dispersal, such as temperature, humidity, soils, and vegetation. However, only some ecological conditions can be considered as the restricting factor of their distribution in the ecosystem, such as human activity and other subterranean mammal species. The study showed that approximately 7% of the area is considered a desirable habitat for Western Mole-Vole, mostly located in the northwest of Iran.

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