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Influence of Past Climate Changes on the Current Distribution of a Rare and Endemic Species: Anatolian Spiny Mouse

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ABSTRACT

This research focuses on species distribution modelling (SDM) to have an idea of distribution of Anatolian spiny mouse, *Acomys cilicicus* in the Last Glacial Maximum (LGM), the mid-Holocene and present by using coordinates along Silifke which is the only location the species found. Three ensembled species distribution models (generalized additive models, maximum entropy and boosted regression trees) were used to project Anatolian spiny mouse environmental suitability. Results indicate that current distribution of *A. cilicicus* populations shifted east to west since during the Last Glacial Maximum and apparently eastern part of the Mediterranean region of Turkey is potential refugia for this species.

Keywords:
Species distribution modelling; *Acomys cilicicus*; Endemic species; LGM; Holocene

INTRODUCTION

Acomys cilicicus is a rare and endemic species that distributes naturally in a single and narrow geographical area in Mediterranean region of Turkey. Climatic variability and human activities do not allow to have a static geographical range for species (1). Özdemirel, Çetintaş (2) clearly indicated the Anatolian spiny mouse populations and settlements' negative correlation, thus underlined those human activities is a threat to the distribution of this rare species by a maximum entropy modelling on presence records and its surrounding areas.

Numerous scientific studies have observed effect of land-use on biodiversity. Distance to human settlements described as the most important environmental predictor for habitat suitability of Persian leopard (3). Li, Xiang-Yu (4) showed that by extensive industrialization in ecosystems since 1800s have resulted in the average population size of endangered species declining by about 25% every 10 years, and the population size has shrunk to about 5% of the size of its ancestors. Çetintaş, Matur (5) indicated that the *A. cilicicus* population trends display have dropped sharply from 21.42 to 2.75 over the last 20 years and the main anthropogenic treads are the loss of habitat due to urbanization and the construction of new highways.

On the top of being that live in a narrow and fragmented area and urgent need for conservation action for *A. cilicicus*, a few studies have been done in terms of genetic, morphometrics (for ex: 6, 7) to enlighten the history of *Acomys* included *A. cilicicus*. Current distribution and modelling studies are also rare (for ex: 2, 5) on Anatolian spiny mouse. However past distributions of this species have not studied yet which is quite important to understand of present distributions and biodiversity hotspots (for ex: 8) and therefore might contribute to informing conservation practices.

Thus, in this research SDMs have been employed to understand historical distribution of *A. cilicicus*. Modelling environmental suitability into past climates might help discovering areas of climate refugia, or regions that have the highest level of genetic diversity and stable population of a species is able to thrive in less favourable climates.

Here present study tries to fill in some of the gaps in our understanding about the impact of past climate change on narrow-ranging endemic species, Anatolian spiny mouse. For these purposes I ensembled three different models: generalized additive models, maximum entropy, boosted regression trees to predict different time slices' distribution of *A. cilicicus*. These models are extensively applied and tested for terrestrial species to understand the environmental suitability of species in past present and future climates.

The essential objective of this research is studying the climate influence on the spatial distribution of the species *Acomys cilicicus*.

MATERIAL AND METHODS

Occurrence Data

Spiny mice worldwide distribution map shown in Figure 1A. Anatolian spiny mouse has a small distribution area along Mersin, Silifke (Fig. 1B). Occurrence records searched from the Global Biodiversity Information Facility (9) https://www.gbif.org/), however there were only 3 records and all without coordinates. Therefore, presence data obtained by a detailed search on literature of such keywords: '*Acomys cilicicus*', 'Anatolian spiny mouse', 'Asia minor spiny mouse', 'Turkish Spiny Mouse' and 'Anadolu dikenli faresi'. Research on this species have been used to extract the locations, for instance: Çetintaş, Matur (5), Kryštufek, Vohralík (10), Kivanç, Eyison (11).

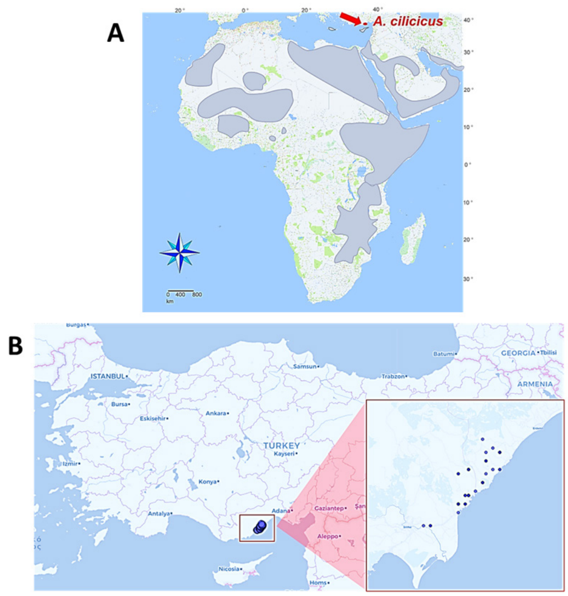

Figure 1. A- Geographical distribution of genus *Acomys* (range data information available in the International Union for Conservation of Nature [27] www.iucnredlist.org). Black dots inside rectangular represent *A. cilicicus*, B- *A. cilicicus* distribution in Silifke, Mersin

Bioclimatic Variables

All the climatic data retrieved by rbioclim package (12) in R 4.1.2 (R Core 13) is publicly available at WorldClim 2 (14). Five bioclimatic variables (BIO1: Annual Mean Temperature, BIO4: Temperature Seasonality (standard deviation *100), BIO12: Annual Precipitation, BIO13: Precipitation of Wettest Month, BIO15: Precipitation Seasonality (Coefficient of Variation)) were selected considering of this species environmental necessities. These five variables were used to calculate the current and past distribution projections of Anatolian spiny mouse.

Species Distribution Modelling

Models were generated with variables at 2.5 arc minutes resolution with 100 randomly selected pseudoabsence. I applied an ensemble method using the SDM (15) package in R 4.1.2 (13). Models were used: generalized additive model (GAM; 16), boosted regression trees (BRT; 17) and maximum entropy (Maxent; 18) which are algorithms for ecological niche modelling known for their good predictive performance.

Ensemble model run with 10 replicates for each cross-validate and subsampling replicate type. Hence 20 replicates for 3 models give us 60 total number of replicates per model. The area under the ROC curve (AUC), COR and True Skill Statistic (TSS) is used for evaluating the model performance.

Models were developed in a current climate scenario and projected to the past (LGM: 22.000 years ago, and Mid-Holocene: 6.000 years ago).

RESULTS

Selection of appropriate modelling techniques and methods of measuring accuracy are crucial to the outcome. This study assessed three different methods of measures of accuracy; AUC, COR and TSS on each of three types of correlative model; GAM, MaxEnt and BRT.

The ensemble models attained good results with AUC values varying between 0.97 and 0.98, COR coefficient varying from 0.81 to 0.85, TSS varying between 0.92 and 0.97 (Table 1).

Table 1. Accuracy assessments of three models (GAM, MaxEnt and BRT) that used to past and present distribution modelling of *A. cilicicus*

Methods	AUC	COR	TSS	Deviance
GAM	0.98	0.85	0.97	1.6
BRT	0.97	0.81	0.92	0.5
MaxEnt	0.98	0.81	0.96	0.39

There was some variability in the variable importance across models. After evaluating the ensemble model, I estimated Bio4 (Temperature Seasonality (standard deviation *100)) and Bio12 (Annual Precipitation) had the highest importance across all variables (relative importance > 0.50) (Fig. 2).

Z. Helvaci / Hittite J Sci Eng, 2023, 10 (1) 57–61

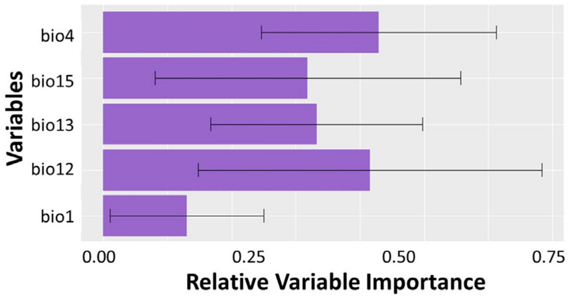

Figure 2. Relative variable importance for *Acomys cilicicus* based on three different algorithms. Bio1: Annual Mean Temperature, Bio4: Temperature Seasonality (standard deviation *100), Bio12: Annual Precipitation, Bio13: Precipitation of Wettest Month, Bio15: Precipitation Seasonality (Coefficient of Variation)

Distributions of the pixels (Fig. 3) shows which part of the environmental space are suitable for the species depend on Bio12 and Bio4 bioclimatic variables. According to suitable environmental space measurements, around 645 mm annual precipitation is suitable for Anatolian spiny mouse. The exact average precipitation is 665.1 mm for Mediterranean region (that *A. cilicicus* distributed) between 1991-2020 years depend on (19).

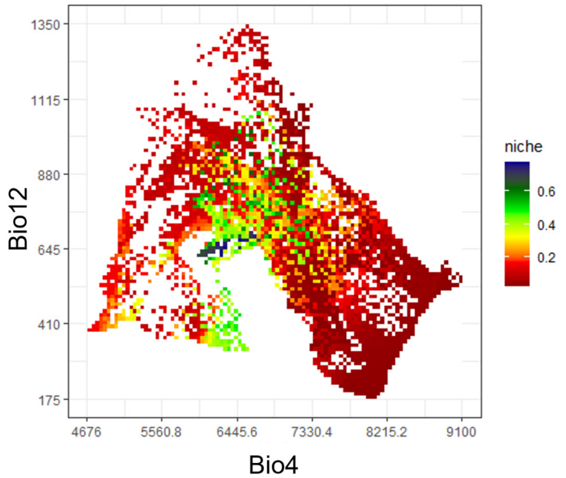

Figure 3. Ecological Niche described by: Bio4: Temperature Seasonality (standard deviation *100) and Bio12: Annual Precipitation

This study aimed to obtain a rare and endemic species *A. cilicicus* history by utilizing species distribution modelling. To evaluate of the past distribution of Anatolian spiny mouse, LGM (~22.000 years ago) and Mid-Holocene (~6.000 years ago) were projected. Comparing the projection of present SDMs (Fig. 4A) to Mid-Holocene (Fig. 4B) and LGM (Fig. 4C) climates, we see that the overall reconstructed distributions were dramatically different (more fragmented and discontinues) at the LGM and Middle Holocene, but that suitable areas were more continuous than in the present day.

I observed reduced continuity of the species' potential distribution area Mid-Holocene comparing the present day. There is a tendency to persist during the current and Mid-Holocene at lower altitudes than they occupied during the LGM (Fig. 4).

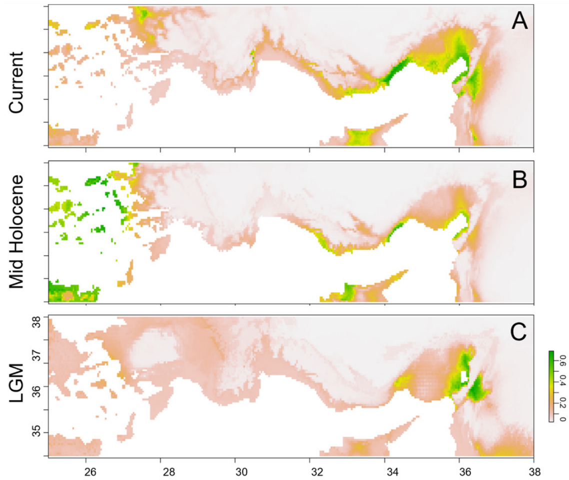

Figure 4. Coordinates that extract from literature used to investigate present and past climate changes on the distribution of endemic small mammal *A. cilicicus*: (a) express the predicted range of potential distributions of the study species under present conditions, (b) during the Mid-Holocene, and (c) during the Last Glacial Maximum (LGM).

During the Last Glacial Maximum bioclimatic conditions, areas of relatively high suitability were foreseen across Turkey-Syria border (Hatay, Kilis and Osmaniye provinces). Two separated, relatively large and close populations projected for approximately 22.000 years ago. Under the present bioclimatic conditions, a high degree of population connectivity was observed across much of the eastern part of the Mediterranean region. Depend on past ecological niche modelling results that the Anatolian spiny mouse survived the LGM in a glacial refugium around eastern part of Mediterranean region and Syria border, and then expanded its range from this LGM refugium to its Mid-Holocene range and then almost kept that range to have its present range (Fig. 4).

DISCUSSION

Understanding of past distribution has a key importance to enlighten the species' history and performing this research on a rare and endemic species is highly crucial for biological diversity, evolutionary history and ancestry. Three independent methods of species distribution modelling, GAM, BRT and MaxEnt used to generate past and present model predictions for *Acomys cilicicus*. In general, a high performance model has >0.9 AUC, moderate performance model has 0.7–0.9 AUC and poor model 0.5–0.7 AUC values (20). The resulting SDMs provided high AUC > 0.9 (Table 1) scores according to GAM, BRT and MaxEnt algorithm which demonstrates good model performance in this study. The findings indicated that the species distribution was mainly determined by the following aspects: temperature seasonality (standard deviation *100) (Bio4) and annual precipitation (Bio12).

Genus *Acomys* is well known respecting its diploid chromosome variations ranging between 2n=36 to 68. A further Rb fusion has led to 2n=36 in Turkey and Egyptian population from Cairo (6, 21, 22). Renaud, Hardouin (6) performed an outline analysis of the first upper molar and used external body measurements to contribute to the evolutionary history of the *cahirinus 'sensu lato'* group (Anatolian spiny mouse included). Cairo, Sahara and Turkey sharing both having the smallest addition of head and body length and centroid size of first upper molar in the *cahirinus 'sensu lato'* group. According to Aghová, Palupčíková (7) the western Mediterranean islands and south coast of Turkey were colonized during the ancient past by possibly commensal populations from one of the 11 *cahirinus* lineages (that they described five main species groups: *subspinosus*, *spinosissimus*, *russatus*, *wilsoni* and *cahirinus* and delimited 26 genetic lineages as potential *Acomys* species by using 700 genotyped individuals from 282 localities), likely from Egypt (23). The predicted habitat suitability for the LGM and mid-Holocene scenarios is not the same as the habitat suitability that is currently observed obviously. In the current study, species distribution modelling clearly shows that present distribution of *A. cilicicus* populations shifted east to west since during the Last Glacial Maximum. The climate in the mid-Holocene was warmer than during the LGM, which allowed for the expansion of many species. LGM projections showed that the species distributed mainly in the eastern part of Mediterranean region of Turkey and western part of Syria (Fig. 4). This area might be the refugia for *A. cilicicus* that remained during the LGM. Eastern part of Mediterranean region of Turkey and western part of Syria are also one of the main refugium areas of other species, for instance European chestnut according to Krebs, Conedera (24), Krebs, Pezzatti (25). Apparently the cold and dry climate of the LGM and then warming up until 7000 years before present during the mid-Holocene are major drivers of the distribution of *A. cilicicus* and many species in combination with the anthropogenic effect. Human activities since 1500s have caused declines in populations of many kinds of faunas and flora elements (26), potentially reducing intraspecific diversity (4). Observing the current distribution of this endemic rodent species might be dramatic evidence of human influence on biodiversity. In view of the fact that expected distribution of SDM is cover from Mersin to northwest of Syria, however presence data of Çetintaş, Matur (5) show that the species has two populations in Mersin (in the area between Silifke and Erdemli). In addition to current modelling results, suitable environmental space measurements (Fig. 3) in terms of precipitation and temperature seasonality also support the idea that human activities are reshaping presence of *A. cilicicus*.

Thus, applying different modelling techniques on past projections of *A. cilicicus* might make a significant contribution to its evolutionary history and in addition to that modelling of current projections on such vulnerable species is make major support for habitat restoration while conservation activities.

CONFLICT OF INTEREST

There is no financial conflict of interest with any institution, organization, person related to my article named "Influence of past climate changes on the current distribution of a rare and endemic species: Anatolian spiny mouse" or personal relationships that could have appeared to influence the work reported in this paper.

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