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The potential range and future distribution of the endangered lizard *Darevskia clarkorum* in the Caucasus Biodiversity Hotspot under climate change scenarios

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The Clarks' Lizard, *Darevskia clarkorum* is endemic to the Caucasian biodiversity hotspot, remarkable in terms of biogeography and evolutionary history in the Palearctic Realm. The purpose of this study is to evaluate the current distribution pattern of this species as well as its possible changes under various future climate scenarios. Fieldwork was conducted in Northeastern Anatolia and the Caucasus between 2019 and 2022, and 64 occurrence records and five bioclimatic variables were analysed using Ecological Niche Modeling (ENM) software. The annual temperature range is the most important variable influencing the distribution of this lizard species. The results showed that potential habitats for the Clarks' Lizard are wider than its present distribution. It is predicted that under current climate change scenarios, this species' range will be much more restricted than it is now. With rising greenhouse gas levels and solar radiation rates, the range of this species is expected to shift from northern Anatolia to the Caucasus mountainous areas, and would likely shrink in future. The remaining habitats of this lizard species may be significantly impacted by climate change and human-induced habitat modification.

Keywords: Anatolia; Caucasus; species distribution modelling; climate change; habitat loss; Clarks' Lizard

Introduction

The assessment of species' geographical distribution is highly important in the fields of biogeography, ecology, and biodiversity conservation, and helps understand phylogenetic processes (Scott et al., 2002; Alatawi et al., 2020; Nolan et al., 2022). The ecological niche is the most essential attribute that suggests a species will persist in a given location as long as the ecological conditions are unchanged (Van Valen, 1976). Geographic data on species distribution zones are crucial for studying their life histories (Meiri, 2018). Recent human activities and climate change have endangered numerous species and altered their distribution ranges, often leading to a decrease in their distribution areas (Kaky et al., 2020).

The Clarks' Lizard, *Darevskia clarkorum* (Darevsky & Vedmederja, 1977), is a medium-sized rock lizard endemic to the Caucasus biodiversity hotspot, which comprises Armenia, Azerbaijan, Georgia, and parts of Russia, Iran, and Türkiye. This hotspot is known for its rich plant and animal diversity, diverse landscapes, and cultural values

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(CEPF, 2003). The range of *Darevskia clarkorum* is confined to the Eastern Black Sea coastal region of Türkiye and Georgia's Autonomous Republic of Adjara. It has been classified as "Endangered" (EN) in the IUCN Red List of Threatened Species because its population is diminishing (Tuniyev et al., 2009). Locality data for this lizard species are scarce in the literature. The full extent of the distribution is not known, and the factors that influence the distribution pattern have not been studied. Therefore, this study seeks to fill gaps in its distribution with new locality records, assess its potential distribution in the current environment, and anticipate its future distribution based on future climate. Ecological Niche Modeling (ENM) was applied for this purpose.

Material and Methods

Field studies for obtaining new information on the distribution of *Darevskia clarkorum* were carried out between early April and late October in the years 2019 and 2022. I obtained 33 new occurrence data from Türkiye and Georgia. In addition, 31 georeferenced points were gathered from Franzen (1990; 1991), Darevsky and Tuniyev (1997), Sindaco et al. (2000), Schmidtler et al. (2002), Ilgaz (2007), Bülbül et al. (2016), Altunışık and Eksilmez (2018), Kurnaz and Kutrup (2018), and Arribas et al. (2021). Thus, a total of 64 presence records were used in this study, which are listed in Supplementary Table 1 and Figure 1.

For the purposes of the study, I firstly checked the precision of the geographical coordinates. Afterwards, in order to prevent spatial sampling biases, the locality data were rarified by retaining only one locality every 2 kilometres using SDM Toolbox 2.0 (Brown, 2014). Once, the rarefication was complete, 19 bioclimatic variables and elevation data were downloaded from Global Climate Data (version 1.4) (Hijmans et al., 2005, accessible at www.worldclim.org) (Supplementary Table 2). These data were derived using global ESRI grids at the highest resolution of 30 arc-seconds (approximately 1 km) for current conditions (~1970-2000). The Community Climate System Model (CCSM4) (Meehl et al., 2012), Hadley Centre Global Environmental Model (HadGEM) (Bellouin et al., 2011), and the Model for Interdisciplinary Research on Climate (MIROC) (Watanabe et al., 2011) were used for future predictions (2081-2100) with several greenhouse gas emission representative concentrations: These are named as representative concentration pathways (RCPs hereafter): While RCP 4.5 displays the least potential influence of the radiation force of greenhouse gases, RCP 8.5 demonstrates the highest potential impact. Using the Arc Toolbox (extract by mask) in the ArcGIS 10.6 software, each bioclimatic variable was retrieved for the study area (36–44° East Longitude and 39–43° North Latitude). To eliminate the contradictive effects of environmental variables, highly correlated ones were excluded from analysis by Pearson correlation coefficient ($0.75 < r < -0.75$) for ENM of *D. clarkorum* (Figure 2). After the correlation analysis, five bioclimatic variables were found to be suitable for keeping on the modeling performance: Isothermality (Bio 3), Highest Temperature of Warmest Month (Bio 5), Temperature Annual Range (Bio 7), Precipitation of Driest Month (Bio 14) and Precipitation Seasonality (Bio 15).

Due to its reliance on presence and pseudo-absence data, the R *kuenm* package integrated with Maxent 3.4.1 was chosen as the modeling tool for species distribution (Chambers, 2008; Phillips et al., 2009; Cobos et al., 2019). This algorithm enables a prediction for the probability of a prediction that varies between 0 and 1 (Phillips et al., 2009). A total of 10052 background points were used to assess the distribution. The contribution of bioclimatic variables is given in Table 1.

Overall, 527 candidate models with parameters reflecting all possible combinations of 17 regularization multiplier settings (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 8, 10), 31 class combinations of MaxEnt's five feature classes (hinge, threshold, product, quadratic, and linear) and one distinct set of environmental variables were evaluated. The statistical significance (Partial ROC), omission rates (OR), and Akaike information criterion corrected for small sample sizes (AICc) were used to assess the performance of the models (Hurvich & Tsai 1989; Peterson et al., 2008; Anderson et al., 2003; Rodríguez-Ruíz et al., 2020; Kurnaz, 2023).

Table 1. Percentage contribution and permutation importance of the environmental layers used in species distribution modeling of *Darevskia clarkorum*.

	Percent contribution	Permutation importance
Bio 3	0.9	1.0
Bio 5	23.7	26.9
Bio 7	40.5	38.2
Bio 14	32.4	29.4
Bio 15	2.5	4.6

Results

During field surveys carried out between 2019 and 2022, 33 locations new to the known range of the Clarks' Lizard were identified. The species was found for the first time in Ordu province, and the known distribution region of the species was enlarged to the west of the eastern Black Sea Region (Figure 3). Temperature Annual Range (Bio 7) (34.8%), Precipitation of Driest Month (Bio 14) (30.1%), and Maximum Temperature of Warmest Month (Bio 5) (25.5%) were found to be the most important bioclimatic variables influencing the distribution of *D. clarkorum*. Other variables contributed less than the tenth percentile (Table 1).

The ultimate model for defining the potential range of this species were selected based on the lowest AICc scores and supported with the average AUC scores. All 527 candidate models examined were statistically significant (pROC test; $P<0.05$). The areas considered to have potential habitats for *D. clarkorum* demonstrated a substantial area under the curve (AUC) of 0.919±0.031. However, only one of them met AICc criteria ≤2 (ΔAICc = 0.548). This model is a quadratic+product feature, with a mean area under curve ratio of 1.579. The results suggest that potential habitats for the Clarks' Lizard are relatively wider than the species' present distribution, and the distribution of the species may extend to the Central Black Sea region (Figure 3).

In addition to current distribution, the AUC values for all future scenarios are also sufficient to continue the analysis (CCSM4 RCP 0.45: 0.922±0.027; CCSM4 RCP 0.85: 0.917±0.026; HadGEM2 RCP: 0.45: 0.920±0.034; HadGEM2 RCP: 0.85: 0.918±0.043; MIROC RCP 0.45: 0.920±0.032; MIROC RCP 0.85: 0.920±0.025). In every future climatic scenario, the species' future distribution will be more restricted compared to its current bioclimatic conditions. By the end of the century, it is anticipated that the climatic conditions with raised carbon dioxide levels, radiation rates, and greenhouse gases would result in a reduction in the geographic range of the species.

In RCP 0.45 scenarios for each future models, there would be a remarkable decline in habitat suitability probability of Clarks' Lizard in the central and south-eastern parts of the Black Sea region (Figures 4a, c, 5b). As a result, in all future climate models (CCSM4, HadGEM and MIROC), the species would not find suitable conditions in between these two regions. Furthermore, it is predicted that that the species' distribution area in the north-eastern part would shift somewhat towards higher latitudes.

Regarding the RCP 0.85 level, similar decline pattern in habitat suitability probability of Clarks' Lizard would be expected with greater extent in future scenarios (Figures 4b, 5a). CCSM4 and HadGEM models indicate that the spreading areas of the species would become significantly restricted in both central and south-eastern Black Sea

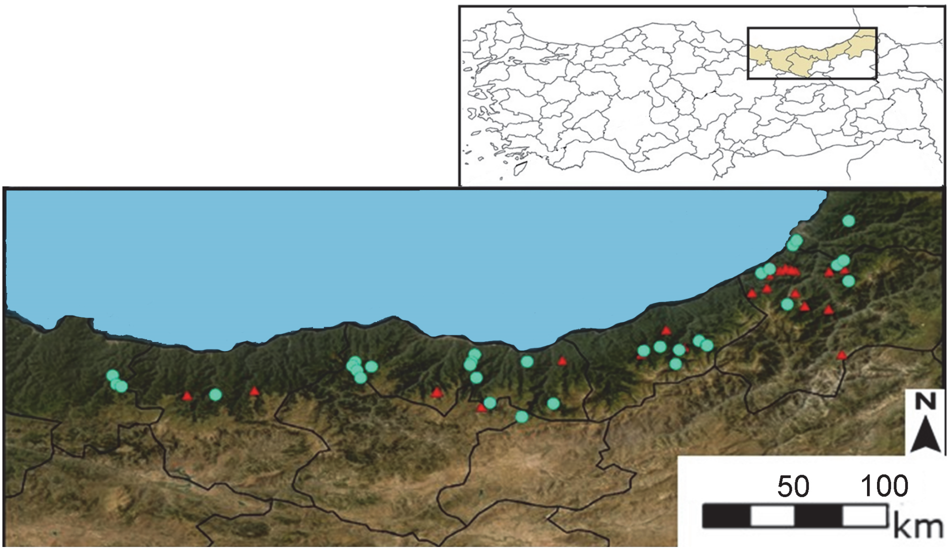

Figure 1. Distribution of *Darevskia clarkorum* in Caucasus Biodiversity Hotspot (red triangulars shows previously known localities, turquoise dots new localities).

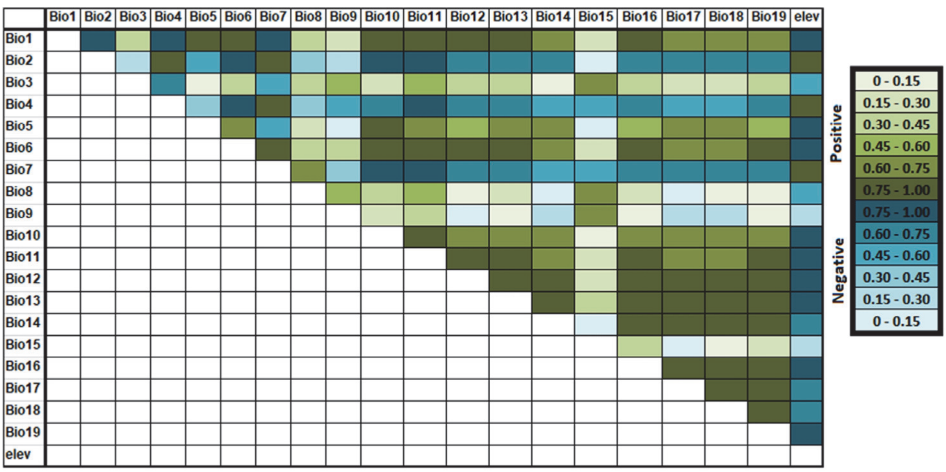

Figure 2. Correlation matrix of bioclimatic variables used in the analysis.

regions, resulting in a confined range. It is suggested that only a small area will remain for the species. In other words, the Eastern Black Sea Region and the Greater Caucasus were projected to have a climate suitable for *D. clarkorum*.

The MIROC RCP 0.85 climatic change model demonstrates the most severe decrease of spillover. In the event that this pattern occurs, almost no suitable areas would remain for the species. Based on this model, the species' distribution will be solely confined to a very small region in the northern part of the Greater Caucasus (Figure 5c). It signifies an extremely limited region, accounting for approximately 1% of the current range.

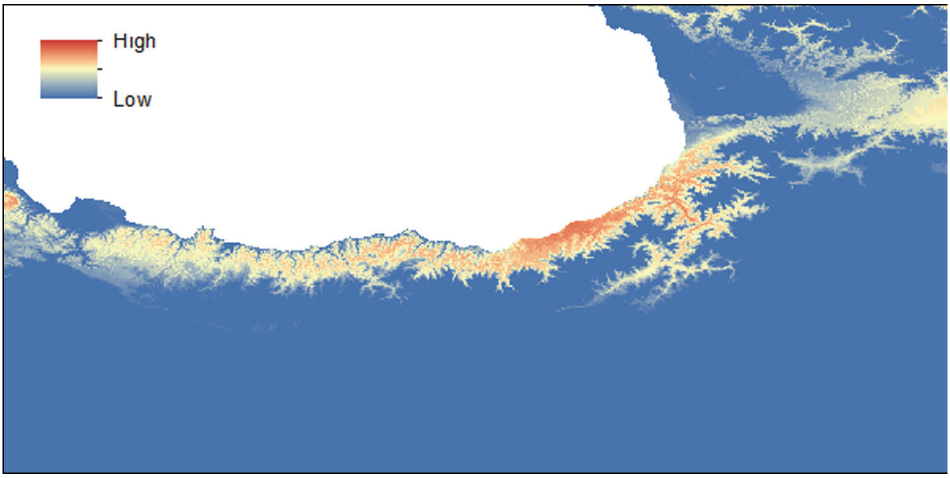

Figure 3. Habitat suitability of *Darevskia clarkorum* in the Caucasus Biodiversity Hotspot (warmer colours refer to the high suitability level).

Discussion

The Caucasian biodiversity hotspot is one of the three global hotspots located in the Anatolian Peninsula and Caucasus (Mittermeier et al., 2011; Kurnaz, 2020). The loss of biodiversity has occurred in this hotspot at an alarming rate due to the fact that half of the land has been transformed by anthropogenic activities (Zazanashvili, 2009). *Darevskia clarkorum*, which was chosen as a model for this study, has currently a restricted range in the eastern Black Sea region of the Anatolian Peninsula and the Lesser Caucasian region (Tarkhnishvili, 2012). The outputs of this study are compatible to this range, with a remarkable potential extension in Central Black Sea Region (Figure 3). However, the ecological niche models predict that under future scenarios of climate change, varies on the RCP level, the environmentally suitable area for this species reaches even an extinction risk by the MIROC scenario (RCP 0.85).

Although effects of general bioclimatic and topographic factors resulted with "expansion and contraction" trend were presented in numerous herptile species within the research area and its nearby geographical region (Gül et al., 2018; Hosseinian Yousefkhani et al., 2019; Kurnaz & Şahin 2021; Heidari 2021; Kurnaz, 2022; Bozkurt, 2022; Vaissi, 2023; Hosseinian Yousefkhani et al., 2023; Gül et al., 2023), few studies have so far been conducted on the climatic habitat suitability of *Darevskia* species (Kurnaz et al., 2016; Kurnaz et al., 2019; Petrosyan et al., 2019; Kurnaz & Hosseinian Yousefkhani 2020; Barateli et al., 2021; Tarkhnishvili & Iankoshvili, 2023). The climatic envelopes that shaped the distribution pattern of *Darevskia* species were different, and they had fewer bioclimatic variables in common. For instance, according to this study, five bioclimatic variables have an influence on the climatic pattern and distributional limits of *D. clarkorum*. Moreover, Temperature Annual Range (Bio 7), Precipitation of Driest Month (Bio 14), and Maximum Temperature of Warmest Month (Bio 5) account for 96.6% of the overall bioclimatic contributions (Table 1). On the other hand, Kurnaz and Hosseinian Yousefkhani (2020) found that the Minimum Temperature of the Coldest Month (Bio 6), the Mean Temperature of Coldest Month (Bio 8), the Mean Tempearture of Driest Quarter (Bio 9), the Mean Temperature of Coldest Quarter (Bio 11), and Precipitation of Driest Quarter (Bio 17) contributed the distribution pattern of *D. bithnyica*

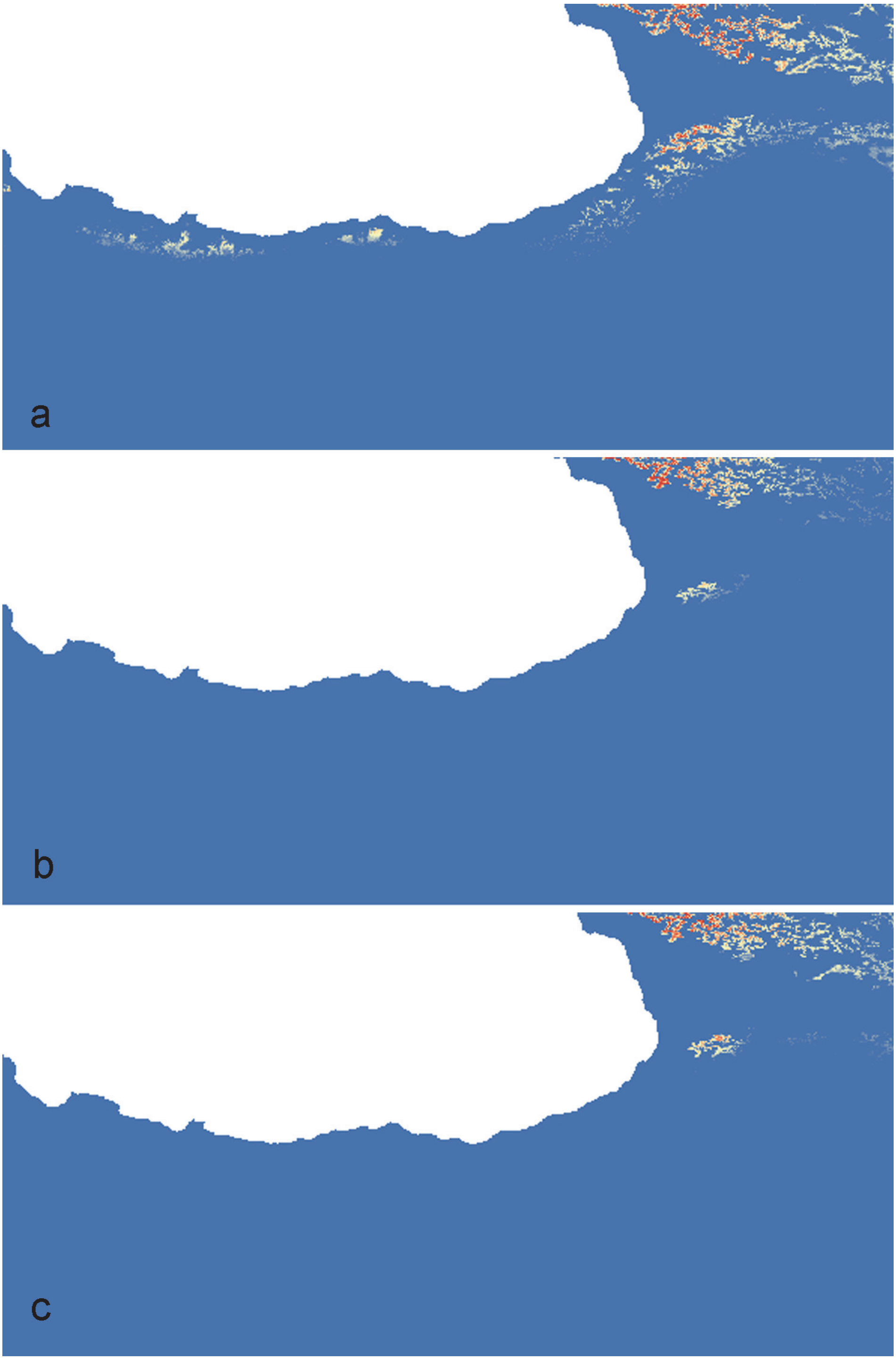

Figure 4. Distribution of *Darevskia clarkorum* under future climate suitability predicted with a. CCSM4 (RCP 0.45), b. CCSM4 (RCP 0.85), c. HadGEM2 (RCP 0.45).

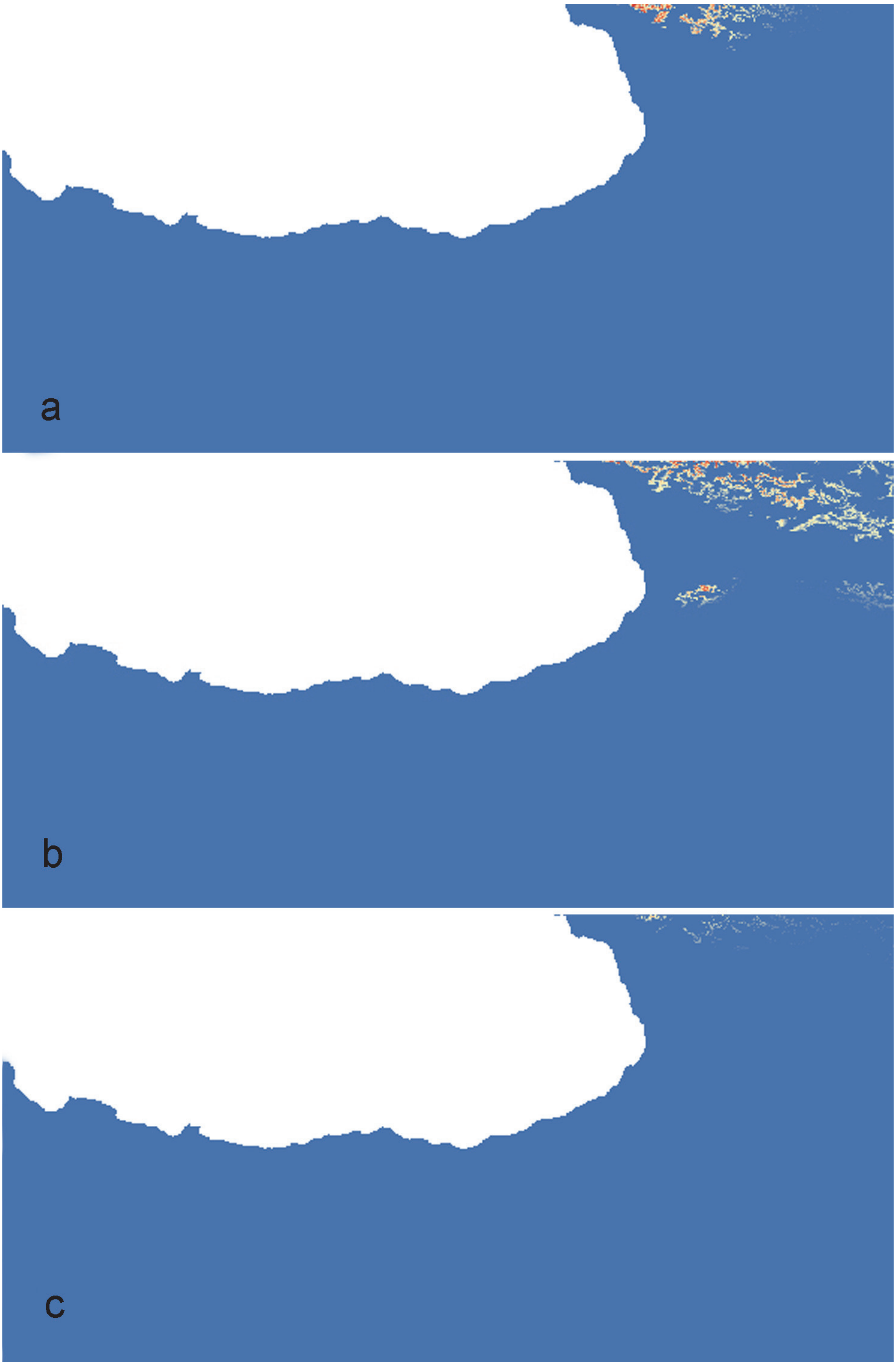

Figure 5. The range of *Darevskia clarkorum* future climate suitability predicted with a. HadG-EM2 (RCP 0.85), b. MIROC (RCP 0.45), c. MIROC (RCP 0.85).

and *D. rudis*. Petrosyan et al. (2019) revealed that the Mean Temperature of the Driest Quarter (Bio 9), Precipitation Seasonality (Bio 15), and Precipitation of Warmest Quarter (Bio 18) mainly shaped the distribution of *D. armeniaca, D. valentini* and *D. mixta*. Therefore, Clarks' Lizard has ecological requirements different from other rock lizards.

In comparison to the current distribution, future projections of *D. clarkorum* exhibit a more contractive, even extinctive pattern, depending on the level of greenhouse gas concentrations. It has been reported that many lizard species (e.g., *Sceloporus serrifer*, *Cnemaspis* sp., *Eurylepis poonaensis* from Nearctic and Indo-Malayan regions) would likely experience significant habitat loss as a result of climate change caused by an increase in greenhouse gas emissions and radiation levels (Martinez-Méndez et al., 2015; Srinivasulu et al., 2021). Moreover, unlike relatively generalist lizard species such as *Anatololacerta* and *Lacerta* genera in Anatolia (Bozkurt, 2022; Gül et al., 2023), a contraction pattern is expected for specialist species such as *D. clarkorum*. As the anticipated climate change, resulting from an increase in carbon dioxide and greenhouse gas levels, as well as radiation rates, occurs, the potential distribution of the species would undergo contraction risk compared to the present. Future scenarios, in which the relatively minimum effect of the radiation force of greenhouse gases (RCP 0.45 levels for CCSM4, HadGEM, and MIROC) could display a narrower distribution pattern. The continued presence of Clarks' Lizard in the Eastern Black Sea and Caucasus regions seems to be at high risk due to serious contraction predictions (Figures 4a-c, 5a, 5b). The species would even become extinct in the worst case scenario (MIROC (RCP 0.85)) (Figure 5c). It is evident that the temperature regime is crucial for Clarks' Lizard; these results indicate that an increase in temperatures is expected under all scenarios, resulting in more hostile environments for this lizard.

Disclosure statement

No potential conflict of interest was reported by the author.

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