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Status of the Dwarf Lizard *(Parvilacerta parva)* at the edge of its range in Armenia

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Studying the geographic distribution of the Dwarf Lizard (*Parvilacerta parva*) at the north-eastern edge of its geographic range in Armenia, we compiled a list of 31 locations in six regions (marzes) of northern and central Armenia. Three occurrences remain unconfirmed, and we interpret those as outliers in the context of the fundamental climate-driven niche we estimated using maximum entropy modelling. The species' niche is determined by the minimum temperature of the coldest quarter, the seasonality of precipitation, and the mean monthly diurnal range of temperature. While nearly 50% of this climate driven niche is currently occupied by developed lands, 10 out of 26 reasonably confirmed Armenian populations of *P. parva* (38.5%) have been lost over the past 110 years. Despite the documented decline of *P. parva* in Armenia, habitat protection measures for this species are lacking and there is a need for enhanced conservation strategy.

Introduction

The distribution of the Dwarf Lizard (*Parvilacerta parva*) extends throughout Eastern Turkey, where it is common and widely distributed (Bischoff & Franze, 1993; Sindaco et al., 2000; Kumlutaş et al., 2004; Sindaco & Jeremcenko, 2008; Şahin et al., 2022). The occurrence in Armenia is confined to several small and isolated populations at the north-eastern edge of its geographic range. The Dwarf Lizard is a small lacertid lizard (Figure 1) with a maximum size of 61 mm SVL and a life-span of 6-8 years (Yakin et al., 2012). In Armenia, dwarf lizard inhabits mountain steppes with rocky substrate and sparse herbaceous vegetation (Figure 2), often dominated by King's Spare (*Asphodeline taurica*), mugworts (*Artemisia ssp.*) and tragacanth astragals (*Astragalus cornutus*) (Arakelyan et al., 2011; Fayvush & Aleksanyan, 2016) and it is occasionally encountered in piles of rocks among agricultural fields. This lizard hibernates in deep voids in rock piles, as well as in burrows of Anatolian Ground Squirrel (*Spermophilus xanthoprymnus*) and possibly other rodents (Darevsky & Danielyan, 1986).

With only a handful of populations known, and many of them extinct due to land development for agriculture, *P. parva* is listed as Critically Endangered in Armenia (Danielyan, 1987; Aghasyan & Danielyan, 2010), while globally it listed as Least Concern (Tok et al., 2009). Due to the sparse distribution of dwarf lizard, little is known about its biology, population trends, and geographic distribution in Armenia. Here we report the results of surveys of historical localities, and report new localities found by us or reported to us during the past decade. We additionally explore its occurrences in the

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Figure 1. Adult female Dwarf Lizard (*Parvilacerta parva*) from Panik, Shirak, Armenia.

context of climatic variables, estimate the extent and the area of the climate driven fundamental niche of this lizard using maximum entropy modelling and discuss the ecological and conservation implications of our findings.

Material and Methods

To compile a list of sites associated with sightings of *P. parva,* we examined literature references (Chernov, 1939; Darevsky, 1957; Aghasyan & Danielyan, 2010) and museum vouchers. We clarified some locations after consulting with experienced researchers. To locate the rest of the locations, the patches of generally suitable habitat types of lizard, such as areas of open dry rocky steppes, rock aggregations between fields, or other passively used open land within 2-3 km of reported sites were identified, using high-resolution satellite imagery (Google Earth). Then, each of these patches was mapped and surveyed three times in different years, between 2010 and 2013. When such a habitat was occupied by Dwarf Lizards*,* we considered such localities to be substitutes for historical localities and mapped those as new monitoring locations. The field surveys were conducted on warm, sunny days in April-May, when short grass and sparse herbaceous vegetation enabled detection of basking lizards. Lizards were searched for visually, and by flipping natural cover objects (e.g., rocks), while walking through the habitat in a meandering pattern. In total, historical locations were surveyed for 186 person/hours over 56 field days. In addition, we surveyed earlier unexplored potential habitats between 2004 and 2022. The geographic locations of *P. parva* were recorded using handheld GPS units (Garmin Dakota 10, Garmin, Ltd. Olathe, KS, USA), habitat type documented, individual lizards photographed using a digital camera. All lizards were released after processing. The locations of sightings of the Dwarf Lizards were mapped with 5 m accuracy for internal use and utilized for ecological niche modelling via maximum entropy machine learning algorithms Maxent (Phillips et al., 2006; Phillips & Dudik, 2008, Phillips, 2021).

The sighting locations (n=31) were checked for duplicates and thinned to set the minimum distance between any two neighbouring locations to 1 km and ensure that each 1 km pixel contains no more than 1 lizard occurrence, to prevent the algorithm from factoring in densities. To

Table 1. The list of geographic locations of *Parvilacerta parva* in Armenia with notes.

No	Region	Location	Alt. (m)	Source	Population
1	Gegharkounik	Areguni	1934	Nikolski (1909)	Unconfirmed
2	Gegharkounik	Arpounk	2266	our data (2019)	Low Density
3	Gegharkounik	N of Geghamasar	2170	our data (2019)	Low Density
4	Gegharkounik	S of Geghamasar	2170	N. Sargsyan (2020), iNat. 58253105	Low Density
5	Lori	Jrashen	1902/2000	Darevsky (1957), our data	Low Density
6	Lori	Mets Parni	1702	Arakelyan et al. (2011)	Low Density
7	Lori	Shenavan	1730	our data (2011)	Low Density
8	Lori	Spitak	1560	Darevsky (1957)	Habitat Lost
9	Lori	Tsaghkaber	2267	Darevsky (1957)	Unconfirmed
10	Shirak	Anoushavan	1745	own data (2020)	Low density
11	Shirak	Arevik	1520	own data (2021)	Low Density
12	Shirak	Artik	1989	Darevsky (1957)	Habitat Lost
13	Shirak	Aygabats	1549	own data (2022)	Low Density
14	Shirak	Getap		own data (2021)	High Density
15	Shirak	Gtashen	1814	own data (2022)	Low density
16	Shirak	Gyumri	1540	Chernov (1939); Darevsky 1957)	Habitat Lost
17	Shirak	Hayrenyats	1654	Darevsky (1957)	Unconfirmed
18	Shirak	Jajur	1920	Darevsky (1957)	Habitat Lost
19	Shirak	Karaberd	1873	Darevsky (1957)	Unconfirmed
20	Shirak	Maralik	1895	Darevsky (1957)	Habitat Lost
21	Shirak	Lanjik	1949	Aghasyan & Danielyan (2010)	Unconfirmed
22	Shirak	0.7 km N of Panik	1724	own data (2020)	High Density
23	Shirak	2.6 km NE of Panik	1754	own data (2020)	Low Density
24	Shirak	Torosgyukh	1861	own data (2020)	Low Density
25	Shirak	Toufashen	1709	Darevsky (1957))	Habitat Lost
27	Aragatzotn	Mastara	1775	Darevsky (1957	Habitat Lost
28	Aragatzotn	Tsilkar	2100	our data (2020)	High Density
29	Ararat	Vedi riv. canion	Unknown	Chernov (1939)	Unconfirmed
30	Ararat	Arevshat	863	Chernov (1939)	Unconfirmed
31	Tavush	Tavush	Unknown	Aghasyan & Danielyan (2010)	Unconfirmed

further thin the sample, while providing a large sample of testing occurrence points, the entire set of locations was randomized 10 times, each split into two 50% subsets used for model calibration and testing. Spatial autocorrelation of the lizard locations was estimated using King's case Moran's I criterion (Moran, 1950 in ArcGIS (ESRI, Redlands, California). As Armenia is a small (29,743 km^2) and well explored county, we set the entire area of the country as our bias file and masked all raster data-layers to fit the national border of Armenia data-layer, extracted from a 1:100,000 topographic map (data layer produced by the American University of Armenia in 2021). The number of random background locations was set to 10,000.

Due to the low number of known occurrences, to reasonably increase the statistical power of our analysis, we aimed to use as few variables as possible and ended up calibrating the model using three climate variables (Worldclim 2: Fick & Hijmans, 2017). We selected our first variable (Minimum Temperature of the Coldest Quarter (Bio11, measurement unit = °C), after running Maxent model with the full set of 19 climatic variables (Worldclim 2: Fick & Hijmans, 2017. Then, we selected the smallest set of variables (Mean Diurnal Range - Bio 2, measurement unit = °C), (Precipitation seasonality - Bio 15, measurement units = mm), that did not strongly (>0.75) correlate with Bio 11, and among each other and represented annual variations of both temperature and precipitation. The correlation matrix was computed using ENM tools package (Warren, 2021). We selected model settings ("hinge" features, and regularization multiplier = 1, based on the combination of the training AUC = 0.87, AIC = 337.03, delta AIC = 33.9) after comparison of models calibrated using different settings (linear [L], quadratic [Q], linear and quadratic [LQ], and

Figure 2. Dry steppe habitat of *Parvilacerta parva* near Panik village, Shirak, Armenia.

hinge [H] features, and betta-multiplier between 1 and 5) using ENMeval 2 (Muscarella et al. 2014) package in R (R Core Team, 2021). To minimize redundancy among feature types, we intentionally avoided combination of features (LQH) (Elith et al., 2011). Then we ran 10 models on the above-mentioned random subsets using Maxent 3.3 package (Phillips et al., 2006; Phillips & Dudik, 2008, Phillips, 2021) and examined those in terms of heuristic gain scores of individual variables, response curves, receiver operating characteristic (ROC) values and the area under the curve (AUC) (Fielding & Bell, 1997; Phillips, 2021), and used omission rate (OR) curves to evaluate the fit of our model (Phillips, 2021, Bohl et al., 2019). To further test if AUC and OR rates of our model differ from those produced by chance (Olden et al., 2002; Raes & Steege, 2007; Bohl et al., 2019), we compared those of the empirical model with null distributions of AUC and OR, produced using 100 Monte-Carlo simulations of AUC and OR, generated using the procedure outlined in Bohl et al. (2019) and executed using ENMeval 2 package (Bohl et al., 2019; Muscarella et al., 2014). To outline priority areas for future search efforts and envision the extent of the fundamental climate niche for *P. parva*, we produced and examined raw relative occurrence rate (ROR) and scaled (logistic output) predictive maps. We estimated the area (km^2) of the fundamental niche of *P. parva* (as defined scaled ROR by values >0.75 of the logistic output map of the Maxent model) using ArcMap 10.6 (ESRI, Redlands, CA, USA).

Results

We obtained 31 locations of *P. parva* associated with 29 geographic landmarks across six regions (marzes) of northern and central Armenia (Table 1, Figure 3a). Fourteen sites (48%) were previously reported in the literature between 1909 and 1957 (48 years), two sites (7%) were reported between 2008 and 2010, and 13 sites (45%) have not been previously reported in the literature (Table 1, Figure 1a).

Spatial autocorrelation analysis of the occurrence points (n=30, Moran's I = 0.1203; Expected index = -0.03; Variance = 0.19; Z score = 0.34; p = 0.73) indicated that the sample of occurrences is not significantly different from random. Analysing the distribution of *P. parva* in the context of global climatic variables (Worldclim 2) using

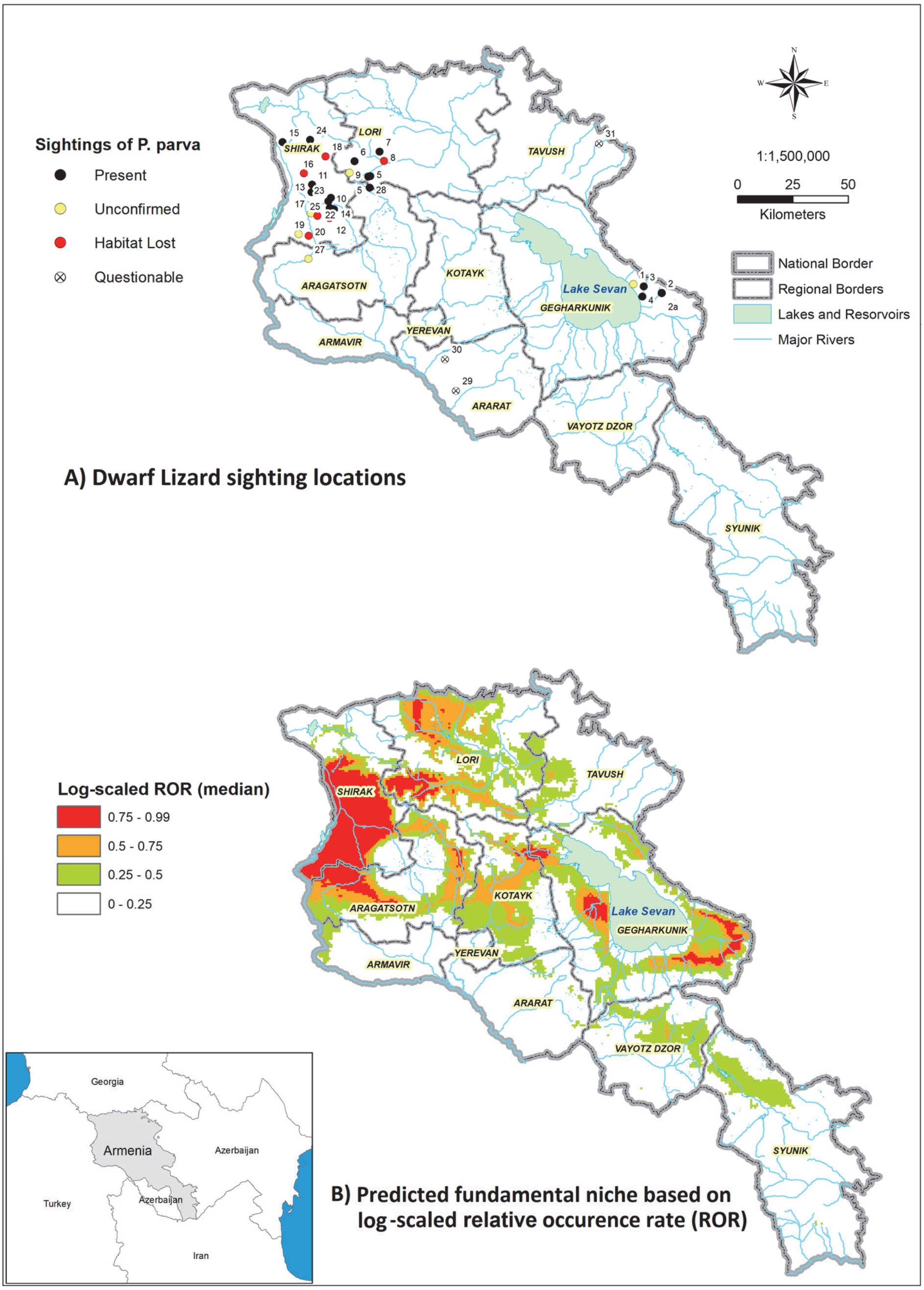

Figure 3. Distribution of *Parvilacerta parva* in Armenia. A) Dots represent actual locations. The numbers in the cycles indicate the location according to Table 1. Colours of dots indicate present status of population in each quadrant: present, unconfirmed, lost, questionable historical locality. B) Predicted fundamental niche based on logistic output values of Maxent model of *Parvilacerta parva* in Armenia. Darker colours (>0.50) represent areas principally suitable for *P. parva* in the context of climate variables used in the model.

Table 2. Variable contributions in maximum entropy model and correlations among variables. Bio 2 – mean diurnal range; Bio 11 – minimum temperature of the coldest quarter; Bio 15 – precipitation seasonality. *C* –percent contribution scores, *PI* – permutation importance, *r* – correlation coefficients.

	Correlation Matrix (*r*)		
	Bio 11	Bio15	Bio 2
Bio 11 (*C* = 45.4%; *PI* = 28.2%)	1.00	0.40	0.41
Bio 15 (*C* = 43.2%; *PI* = 29.4%)	0.40	1.00	0.35
Bio 2 (*C* = 11.4%; *PI* = 42.5%)	0.41	0.35	1.00

Maximum entropy modelling, we estimated that geographic distribution of *P. parva* in Armenia is determined by a fundamental climate-based niche (Figure 3b), imposed by the minimum temperature of the coldest quarter (Bio 11), precipitation seasonality (Bio 15) and mean monthly diurnal range of temperatures (Bio 2) (Table 2)

The model performed better than random based on AUC (Figure 4a), and omission/commission rate (Figure 4b). While the omission rate of our empirical model was lower ($p<0.05$) than an average of null distributions (Figure 4c), AUC values of our empirical model were significantly higher ($p<0.001$) compared with an average null model (Figure 4c).

We found neither extant populations, nor principally suitable mountain steppe habitat within the vicinity of sites in Tavush and Ararat regions (Table 1; Figure 3a, b). Maximum entropy model (Figure 3b) classified these three locations as having low suitability, based on drier and warmer climate conditions for *P. parva* across these lowland areas (Figure 3b). Therefore, localities in Ararat and Tavush regions were suspected to be questionable and requiring verification before being dismissed as erroneous reports. Confirmed populations of *P. parva* were restricted to the elevation range between (Mean ±SD = 1863.5±220.8; R=1520–2267 m a.s.l), which is significantly higher than unconfirmed occurrence sites in Ararat and Tavush regions (863 m a.s.l.).

On the other hand, the predicted fundamental niche (Figure 3b) includes some areas in the northern Lori, Aragatsotn, Kotayk and Gegharkunik regions, where *P. parva* have never been reported. After omitting questionable localities in Ararat and Tavush regions, the total area of the estimated fundamental niche to be estimated around 2,655 km^2. However, if we account for land and habitat lost due to agriculture use of land (1,342 km^2 or 50.6%), then only around 1,312 km^2 (49.4%) of the fundamental climatic niche is still available for *P. parva* to potentially occur in. The distribution within this extent is highly fragmented and consists of two clusters isolated by c. 129 linear km. The western (c. 1307 km^2) cluster spread over Aragatsotn, Shirak and Lori regions, and the smaller eastern cluster (c. 30 km^2) is restricted to the Areguni shore of Lake Sevan (Gegharkunik region; Figure 3a).

Six administrative regions of Armenia were comparatively evaluated in terms of number of known localities, and ratios among localities that suffered complete habitat loss, loss of population (defined as inability to confirm the presence of *P. parva* after three iterations of field surveys), extant populations known over 60 years, and new populations discovered within the past 10 years. The overgrazing and transformation of the steppe lands to agricultural sites are the major factors impact on loss of population. Shirak region leads the list by total number of known localities, populations that suffered complete habitat loss (31.3%) and otherwise unconfirmed populations (18.3%) resulting in an estimated 50% extinction rate, as well as a 50% new population discovery rate attributed to increased amount of search effort in this region. In the Lori region,

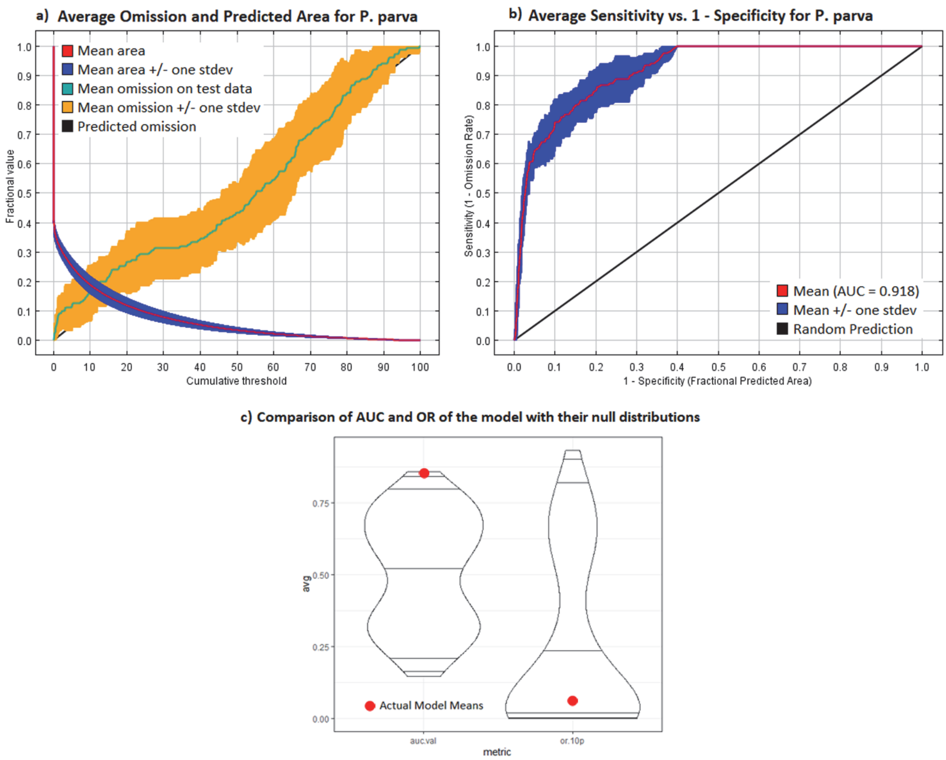

Figure 4. Maxent model evaluation metrics: a) Mean (green) and standard deviations (yellow) Omission curve is aligned along the predicted omission. b) The area under curve (AUC) or the receiver operating characteristic (ROC) indicated that the model predicted locations better than random c) Violine plots demonstrating AUC of the empirical model (red dot) being significantly higher (*p<0.001*) compared with null distribution, and the omission rate (or.10p) of the model (red dot) being lower (*p* = 0.04) than null distribution mean.

there are lower rates (17%) of complete habitat loss and population extinction (17%) adding up to a 33.3% extinction rate, and a remarkably high number (50.0%) of extant populations known since the 1950s. Gegharkunik region has experienced a 25% extinction rate, with a new population discovery rate of 75% attributable to a renewed interest of naturalists in this region. In Aragatsotn habitat loss and possible local extinction of *P. parva* in the only historical location in the western half of the region was documented, but a new locality near its north-eastern boundary was found, leading to an extreme regional rate of habitat loss and extinction rate (50%), and 50% new population discovery rate. After deducting three locations in Ararat and Tavush regions which may be erroneous (see above), 10 (38.5%) out of 26 known Armenian populations of *P. parva,* have been lost over the past 110 years.

Discussion

According to museum vouchers, specimens of *P. parva* were historically collected from six regions including Shirak, Lori, Aragatsotn, Gegharkunik (Chernov, 1939; Darevsky, 1957), as well as Ararat (Chernov, 1939) and Tavush (Aghasyan & Danielyan, 2010).

Our observations confirm and expand the extent of distribution of *P. parva* in the first four regions (Table 1; Figure 1). Unlike most observations situated in mountainous dry steppe habitats, two reported sites from the Ararat region (Chernov, 1939; Table 1) are situated in arid piedmonts of the Ararat Valley forming an outlier in terms of the climate driven fundamental niche depicted in our prediction (Figure 3b). Furthermore, we were unable to confirm the presence of lizards, or suitable dry steppe habitat near the reported sites in Ararat region, or in Tavush, leading to uncertainty regarding the veracity of reports from these areas. In the same way, the unconfirmed historical occurrences from Azerbaijan, where Dwarf Lizards were reportedly found by A. N. Kaznakov (1916, in Alekperov, 1978) in the vicinity of Julfa in Nakhichevan, and by Alekperov (1978) from the vicinity of Quba, and the Lankaran region are subjects of high level of uncertainty. However, should unconfirmed occurrences of *P. parva* be verified, those populations may represent a different climatic race, warranting more rigorous surveys around the sites associated with unconfirmed reports. As there are no museum specimens or vouchers, or any information associated with location in Tavush (A. Agasyan, pers. comm.), the fact that *P. parva* has ever been found there is very uncertain.

The probability of detection of animals is a key variable for estimating occupancy and population size, and estimating baseline detection probabilities requires study design involving repetitive surveys of a sample of sites (MacKenzie et al., 2006; Kerry & Royle, 2016, numbers of which may vary depending on actual detection rates. Three repetitive surveys used for historical sites in our study were insufficient for establishing baseline detection probability in *P. parva*. For example, at the cemetery of Mets Parni (Table 1), we found a single male *P. parva* in 2009, but no other individuals during repeated surveys in 2010 and 2011, leading to a detection probability of (0.33) between three years. Such lack of confirmation may be caused by low detection probability in sparse populations (Walsh et al., 2018), and represent a random effect rather than an indication of changes in population dynamics. Low detection probability may have contributed to low capture yields of visual surveys in the past, and driven conclusions about local extinction events. Thus, conclusions regarding absences produced by the present study, in areas where suitable habitat is still available, need to be interpreted with caution. Establishing baseline detection probabilities for *P. parva* in a variety of habitats, and re-sampling occupancy and abundance of this and other species using a larger and more systematic network of random sampling sites, warrants further work.

Land development, with or without regard for the conservation of native reptiles, remains a serious threat to several species, including *P. parva,* in Armenia (Arakelyan et al., 2011). The earliest records of Dwarf Lizard in Armenia, as well as from the former USSR were from the neighbourhoodof Areguni (Satanakhach) village of Gegharkunik region, north of Lake Sevan (Nikolski, 1909, 1913). Due to the lack of new reports since the 1950s, it has been believed to be extinct in that region (Darevsky, 1957; Arakelyan et al., 2011), and by 1980 only one population of *P. parva* near Spitak city was believed to have persisted in Armenia (Darevsky & Danieyan, 1986). Our findings suggest that *P. parva* is still present in the mountain steppes of Aragatsotn, Shirak, Lori and Gegharkunik regions and our predictive model indicates areas to be included in future search efforts (Table 1, Figure 3a, b). We revealed that around 50% of land underlying the climate-based niche for this species has been developed. Rates of extinction and preservation of populations vary between 16.6% and 66.6% over the 60-year period, among administrative regions, and suggest that more efforts may result in discovery of new populations. Documented regional extinction rates are attributable to habitat loss and true extinction of certain populations. However, new population discovery rates, and pseudo-absences because of low detection probability in low-density populations strongly affect these estimates.

Despite the critically endangered status of *P. parva* in Armenia (Danielyan & Aghasyan, 2010), habitat protection measures for this species are lacking. None of the localities of *P. parva* in Armenia are associated with the country-wide network of state protected areas (Sevan National Park, UNEP-WCMC, 2020). No alternative habitat protection and species conservation measures, such as state-mapped priority habitat for sensitive biodiversity, or private land trusts and conservation easements, are established in Armenia. In addition, the management of bioresources is centralized and executed almost exclusively by a single agency, while regional and especially municipal level institutions are lacking, which results in large scale underrepresentation of issues related to natural heritage – an essential, yet often overlooked public and national interest. Therefore, there is a critical need for the establishment and diversification of protective measures for *P. parva*. Results of this study are intended to be used for the delineation of Dwarf Lizard habitat and development of country-wide, regional, and local habitat conservation strategies.

The distribution of *P. parva* in Armenia is highly fragmented with populations being isolated by varying distances. While the effects of habitat loss are generally considered to be stronger and more immediate compared with those of habitat fragmentation (Fahrig, 1997; Walkup et al., 2017), these effects are difficult to differentiate. The Dwarf Lizard is known from the Kars plateau in Turkey (Bischoff & Franze, 1993, Sindaco et al., 2000; Sindaco & Jeremcenko, 2008, Sahin et al., 2022), which is separated from the Shirak plateau of Armenia by the river Araks. While Armenian populations of *P. parva* likely originated as a result of early radiation east from Anatolia, the gene flow between populations has not been studied, and effects of isolation on the conservation of populations of Dwarf Lizards are unknown and warrant further research.

Our findings suggest that the geographic distribution of *P. parva* in Armenia is driven by the temperature of the coldest quarter, precipitation seasonality and moderately high mean diurnal range of temperatures (Figure 3b, Table 2). Şahin et al. (2022), studying the distribution of this species in Anatolia, concluded that the current fundamental niche of *P. parva* across Anatolia is driven primarily by mean temperature of the driest quarter (Bio9), mean diurnal range (Bio2), precipitation seasonality (Bio15) and mean temperature of the wettest quarter (Bio8). Our models use very similar sets of variables, and the main differences between these approaches is merely a substitution of two warm-season quarter-wide temperature means, with a single cold season quarter-wide temperature means data layer (Bio11). Climate variables (e.g. Worldclim) are all correlated with elevation, and more or less collinear among each other, but those correlations vary depending on the extent of analysis. Furthermore, while some variable series, such as mean temperature and mean precipitation, represent different properties of climate, other variables (e.g. monthly, quarterly and annual means of temperatures) are essentially subsets or generalizations of the same variable – mean temperature, and, as such, are not independent and highly collinear. Calibration of simpler models tailored to answer specific questions have been strongly advocated for in recent literature (Elith et al., 2011; Merrow et al., 2013, Araujo et al., 2019). Therefore, given a small sample of lizard locations, we have chosen to include no more than one variable representing a particular property in our model. Furthermore, different populations of the same species may occupy somewhat different ecotones and develop local adaptations. In this regard, while our model fits well to the occurrence data, small sample size limited our ability to calibrate and rigorously test our model, and future work will be necessary to further test its generality.

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