Chapter

Modeling the Past and Current Distribution and Habitat Suitability for Two Snake-eyed Skinks, *Ablepharus grayanus* and *A. pannonicus* (Sauria: Scincidae)

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Abstract

The study of the climate variability in the past and present, correlating those with changes in the distribution range of species, has attracted considerable research interest. The genus *Ablepharus* consists of 10 recognized species, of which *A. bivittatus*, *A. grayanus*, and *A. pannonicus* are documented from Iran. In the present study, we modeled with MaxEnt the potential distribution areas and determined the suitable habitats in the past [mid-Holocene (MH) and the last interglacial (LIG)] and their current distribution for two species of snake-eyed skinks (*A. grayanus* and *A. pannonicus*) separately. Models of the species indicated good fit by the average high area under the curve (AUC) values (*A. grayanus* = 0.929 ± 0.087 and *A. pannonicus* = 0.979 ± 0.007). Precipitation of the driest quarter of the year, mean temperature of the coldest quarter of the year, and precipitation of the driest month variables made important contributions to *A. grayanus*. Two important climate variables contributed importantly to *A. pannonicus*: temperature seasonality and mean temperature of the wettest quarter of the year and one topographic variable, slope. We conclude that these variables form a natural barrier for species dispersal. The MH and the LIG models indicated a larger suitable area than the current distribution.

Keywords: climate condition, suitable habitat, potential distribution, mid-Holocene, last interglacial

1. Introduction

Climate change plays an important role on the species distributions of biota. The response of species to persistent climate changes may be as follows: (1) consistently in situ at their tolerance limits, (2) changing ranges to regions where climate is within the species tolerance limits, and (3) extinction [1, 2]. During the Pleistocene, several ice sheets in the Northern Hemisphere occurred at intervals of around 40,000–100,000 years [2]. The glaciations were separated by interglacial periods [3].

During interglacial periods, the climate warmed, and forests returned to areas that once supported tundra vegetation [2]. During the last interglacial period (LIG: 150,000–120,000 years), temperature gradient increased in polar regions toward lower latitudes and caused sea level rise and reduction of ice sheets [4]. Briefly, the climate of the last interglacial had a relatively stable warm period [5]. Kerwin et al. [6] simulated terrestrial conditions at the mid-Holocene (6 ka) that indicated summer temperatures were warmer than at present in the high-latitude Northern Hemisphere. But during the mid-Holocene, northern Africa, Arabia, and southern Asia underwent conditions much wetter than at present, these conditions resulting in both African and Asian monsoons [7, 8].

Analyzing species distribution models can help in conservation planning [9] and in understanding theoretical research [10] on ecological and evolutionary processes [1]. Species distribution models can be used to investigate the effect of climate changes on distributions and abundances of species [11], to determine biodiversity [12] and biogeographical patterns [13], to predict potential distribution [14], and to appraise possible future changes in the diversity [15]. Lizards, like other ectotherms [16], provide excellent models for analysis of species distribution under climate change [2]. MaxEnt is a general approach for characterizing probability distributions from small sample sizes [17–19]. MaxEnt estimates the probability distribution of maximum entropy (i.e., closest to uniform) based on environmental variables spread over the survey area [20, 21].

The Scincidae family has more than 25% of all living genera and species of lizards [22]. The genus *Ablepharus* (Fitzinger, 1823) encompasses 10 valid species: *A. bivittatus* (Menetries, 1832), *A. budaki* (Göcmen, Kumlutas & Tosunoglu, 1996), *A. chernovi* (Darevsky, 1953), *A. darvazi* (Jeremčenko & Panfilov, 1990), *A. deserti* (Strauch, 1868), *A. grayanus* (Stoliczka, 1872), *A. kitaibelii* (Bibron & Bory, 1833), *A. lindbergi* (Wettstein, 1960), *A. pannonicus* (Fitzinger, 1824), and *A. rueppellii* (Gray, 1839) which are distributed in Europe, Turkey, Syria to Egypt, Azerbaijan, Armenia, Caucasus, Tajikistan, Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan, Afghanistan, Iran, Iraq, United Arab Emirates, Pakistan, and NW India [23–28]. The genus *Ablepharus* in the molecular phylogenic aspect is a sister taxon of the central and East Asian *Asymblepharus* [29]. *Ablepharus bivittatus* (Menetries, 1832), *A. grayanus* (Stoliczka, 1872), and *A. pannonicus* (Fitzinger, 1824) occur in Iran [30, 31].

Ablepharus grayanus was first described as *Blepharosteres grayanus* from Waggur District, northeast Kutch, India [26]. Later, Fühn [24] regarded it as a subspecies of *A. pannonicus* based on examination of a few specimens (three *A. grayanus*, four *A. pannonicus*). *Ablepharus grayanus* (Stoliczka, 1872) is now regarded as a distinct species. *Ablepharus grayanus* (Stoliczka, 1872) has a distribution range from northern and western India through Pakistan and Afghanistan to Eastern Iran [30, 31]. Researchers based on the morphological characters identified different species and subspecies—*A. brandtii* (Strauch, 1868) from Samarkand, Turkestan; *A. pusillus* (Blanford, 1874) from Basra, Iraq; *A. brandtii* vs. *brevipes* (Nikolsky, 1907) from Dech-i-Diz and Karun River, Iran; *A. persicus* (Nikolsky, 1907) from Shahrud, Iran; and *A. p. pannonicus* and *A. p. grayanus* [24]—in wide distribution range of *A. pannonicus*, that all species regarded to synonym *A. pannonicus* by Anderson [30].

The general aim of this chapter is (1) to identify potential areas of distribution during three periods of the past, last interglacial (LIG: ~120,000–140,000 years BP) and mid-Holocene (MH: ~6000 years BP), (2) to describe current (~1950–2000) distribution and suitable habitat, and to understand the biogeographical patterns of the two mentioned species in Asia.

2. Material and methods

2.1 Study area and records

The study area encompasses the whole Iranian territory. We assembled the species occurrence data for each species based on a systematic biological survey by walking randomly through the habitat from 09:00 to 12:00 AM and 15.00 PM to evening (much of the activity time of species) during spring to summer 2010 and 2015. We used localities mentioned in previous studies (e.g., Anderson [30]; Vyas [28]). *Ablepharus grayanus* specimens were collected, and their distribution data were recorded (34 recorded) from Sistan and Baluchestan and Kerman Provinces, southeastern Iran. We gathered distribution data of *A. pannonicus* specimens collected under rocks or leaves on the floor of oak forest in the Zagros Mountains and in between the meadow grass in the Darvishab River Park (Baghmalek, Khuzestan Province) and recorded the exact location using the global positioning system (GPS). In other areas (Esfahan, Ilam, Kermanshah, Khorasan Razavi, Kurdistan, Lorestan, Mazandaran, Qum, Semnan, Zanjan, and Yasuj Provinces), we observed *A. pannonicus* in between the grasslands, shrubs, and steppes, and exact coordinates were marked with GPS (108 recorded).

2.2 Data set and analysis

We implemented maximum entropy modeling (MaxEnt, 3.3.3e http://www.cs.princeton.edu/~schapire/MaxEnt) of species geographic distributions with default parameters of the data to test samples. We examined 19 bioclimatic variables and 2 topographical variables with grids approximately 1 km^2 precision (30 s × 30 s) for contemporary (~1950–2000) and 10 km^2 precision (5 min × 5 min); we also examined 19 bioclimatic variables in the past (LIG and MH) in the related part of the world (Asia) [32, 33] (www.worldclim.org) (see the Appendix). To identify the correlation ratios between variables and presence records, openModeller (V. 1.0.7) [34] was used. Then we used SPSS IBM (version 22) for Pearson correlation coefficient [17]. We selected variables with a Pearson correlation lower than 0.75 to choose the variables that are ecologically important for species separation according to our observations and to describe habitat [35]. We conducted MaxEnt software with 10 replicates of the analysis that yield the best model for the studied species. MaxEnt provides state distribution models by the receiver operating characteristic (ROC) plots; ROC curves plot true-positive rate against false-positive rate [21, 36]. A value of the area under the curve (AUC) of 0.5–0.7 is taken to indicate that the result is a stochastic prediction [37, 38], values of 0.7–0.9 suggest useful models, and the values more than 0.9 indicate high accuracy [39]. We used DIVA-GIS 7.3.0.1 software for the mean predicted map and a logistic output of present records with suitability ranging from zero (unsuitable habitat) to one (the best suitable habitat) [40].

3. Results

The final models in the present study showed good match and closely fitted the presence of the two species recorded in the study areas, as suggested by high AUC values (*A. grayanus* = 0.929 ± 0.087 and *A. pannonicus* = 0.979 ± 0.007). Moreover, two variables contributed for both species (BIO3 and slope), six variables for *A. grayanus*, and six variables for *A. pannonicus* were detected separately (**Table 1**). The last models in the mid-Holocene simulated high AUC values (*A. grayanus* = 0.975 ± 0.019

and *A. pannonicus* = 0.988 ± 0.006). In addition, three variables were important for both species, one variable for *A. grayanus*, and three variables for *A. pannonicus* were identified separately (**Table 2**). The last interglacial showed high AUC values (*A. grayanus* = 0.975 ± 0.019 and *A. pannonicus* = 0.988 ± 0.006) (**Table 3**). During this time, four variables for *A. grayanus* and six variables for *A. pannonicus* were recognized separately.

The model for *A. grayanus* predicted the distribution range presence of the species in the riparian and wet areas of northwest India, through Pakistan and Afghanistan, and oases and palm groves of the eastern and southeastern Iran. That distribution of the species was verified by using a comparison of environmental variables. Moreover, the climate variable model suggests that there are more suitable potential regions in the United Arab Emirates, Oman, Saudi Arabia, Iraq, Jordan, central Turkey, north Syria, south Turkmenistan and Uzbekistan, and west of China. The MH and the LIG simulated the distribution model for *A. grayanus*

Variable	Description of variables	*A. grayanus*	*A. pannonicus*
BIO2	Annual daily temperature difference (minimal temperature maximal temperature)		0.5
BIO3	Isothermality [(BIO2/BIO7) × 100]	11.4	8.2
BIO4	Temperature seasonality (standard deviation × 100)		27
BIO5	Maximum temperature of the warmest month	1.1	
BIO8	Average temperature of the wettest quarter of the year		18.5
BIO9	Average temperature of the driest quarter of the year	23.3	
BIO11	Average temperature of the coldest quarter of the year		16
BIO14	Precipitation of the driest month	18.4	
BIO15	Seasonality of precipitation (coefficient of variation)		10.5
BIO17	Precipitation of the driest quarter of the year	24	
BIO19	Precipitation of the coldest quarter of the year	15.4	
Slope	Slope	6.5	19.2

Table 1.
Relative of variables (in percentages) at the current period (1950–2000) used in MaxEnt model for the two studied species of the genus Ablepharus.

Variable	Description of variables	*A. grayanus*	*A. pannonicus*
BIO2	Annual daily temperature difference (minimal temperature maximal temperature)	2.1	0.6
BIO3	Isothermality [(BIO2/BIO7) × 100]	22.8	33.9
BIO4	Temperature seasonality (standard deviation × 100)		27.5
BIO7	Temperature annual range (BIO5–BIO6)	59.7	1
BIO8	Average temperature of the wettest quarter of the year		16.6
BIO9	Mean temperature of the driest quarter of the year	15.3	
BIO15	Seasonality of precipitation (coefficient of variation)		20.3

Table 2.
Relative of variables (in percentages) at the mid-Holocene, 6000 years ago (6 ka), used in MaxEnt model for the two studied species of the genus Ablepharus.

Variable	Description of variables	*A. grayanus*	*A. pannonicus*
BIO2	Annual daily temperature difference (minimal temperature maximal temperature)		15.5
BIO3	Isothermality [(BIO2/BIO7) × 100]		28.8
BIO4	Temperature seasonality (standard deviation × 100)		17
BIO7	Temperature annual range (BIO5–BIO6)		7.2
BIO8	Average temperature of the wettest quarter of the year		20.7
BIO9	Average temperature of the driest quarter of the year	8.5	
BIO14	Precipitation of the driest month	56	
BIO15	Seasonality of precipitation (coefficient of variation)		10.7
BIO17	Precipitation of the driest quarter of the year	16.4	
BIO19	Precipitation of the coldest quarter of the year	19.2	

Table 3.
Relative of variables (in percentages) at the last interglacial, 120,000 years ago (120 ka), used in MaxEnt model for two species of the genus Ablepharus.

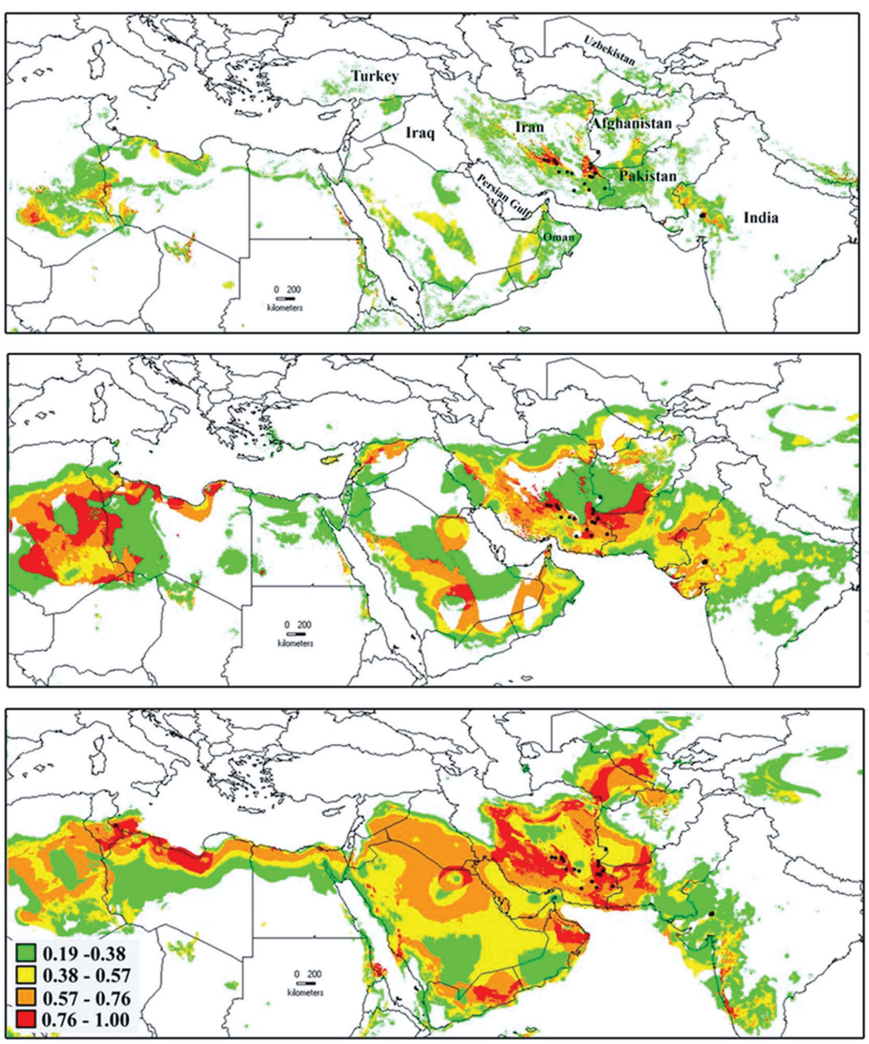

Figure 1.
Distribution map of Ablepharus grayanus in southwestern Asia and much of their potential distribution pattern in the region during: (A) current period (1950–2000); (B) the mid-Holocene, 6000 years ago (6 ka); and (C) the last interglacial, 120,000 years ago (120 ka). The four colored squares on the bottom left indicate the result of stochastic prediction of present species. The black circles refer to the collected specimens.

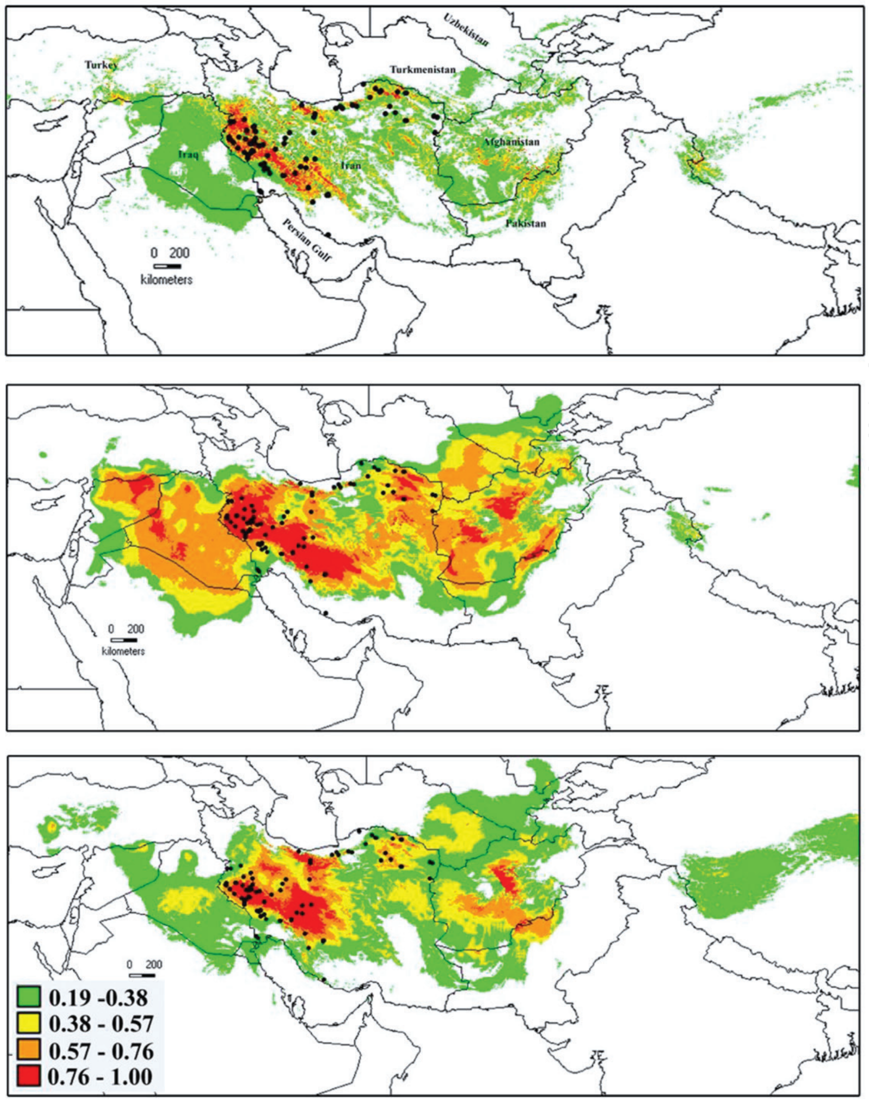

Figure 2.
Distribution map of Ablepharus pannonicus in southwestern Asia and much of their potential distribution pattern in the region during: (A) current period (1950–2000); (B) the mid-Holocene, 6000 years ago (6 ka); and (C) the last interglacial, 120,000 years ago (120 ka). The four colored squares on the bottom left indicate the result of stochastic prediction of present species. The black circles refer to the collected specimens.

that were more suitable areas than present in southwestern Asia today (**Figure 1**). The model for *A. pannonicus* predicted the occurrence of range of the species in steppe areas, grassy, rocky hills separated by oak forest of the Zagros Mountains in the west, and palm groves in southwestern Iran. In addition to the mentioned habitat, the distribution range model of the species predicted that *A. pannonicus* occurs in Iraq, Kuwait, Pakistan, Afghanistan, Tajikistan, Turkmenistan, Uzbekistan, and suitable potential northeast in Syria, Turkey, Kazakhstan, and patchwork areas of northern India. The simulated MH distribution range model for *A. pannonicus* had continuous restriction in east Syria, throughout Iraq, and north Saudi Arabia toward southeastern Turkmenistan. Also, simulated suitable potential fragmented areas of north India and central China were demonstrated. The LIG simulated distribution ranges were the same as the MH suitable potential habitat (**Figure 2**).

4. Discussion

Our results verify the known distribution of the minor snake-eyed skink (*A. grayanus*) and Asian snake-eyed skink (*A. pannonicus*) based on current climatic conditions. The eastern regions of the Iranian Plateau, part of the areas of Afghanistan, northwest India, and Pakistan had the highest suitability for *A. grayanus*, during three time periods (current, MH, LIG). In the eastern Iranian Plateau, *A. grayanus* occurs in the natural parks (e.g., Khobar National Park and the area of the Presidential Museum in Rafsanjan, Kerman Province) and palm graves (Sistan and Baluchestan Province). Recorded from Pakistan at oases, grasslands, backyard gardens, grass fields in the Indus riparian system by Khan [41, 42]. Vyas [28] mentioned three localities (Wagger village of Kutch district, Gujarat; Mount Abu of Sirohi district, Rajasthan; Jessore Wildlife Sanctuary, Gujarat) from India for the species. Model ranges of current distribution predicted areas of western Afghanistan that had conditions suitable as for the same regions mentioned in Pakistan. The model predicted the presence of *A. grayanus* in the United Arab Emirates and Oman but recorded by Gardner [43] as *A. pannonicus*.

Figure 3.
Habitat of Ablepharus pannonicus in Kermanshah, Ilam Provinces, western Iran (A, B), Khuzestan (C), and Fars (D) Provinces, southwestern Iran. The specimens were collected under a relatively small plate stone or under the dead oak leaves, grassland, or steppes. (E, F) Habitat of Ablepharus grayanus in southeastern Iran. The specimens were found under the dead palm leaves and grassland in parks.

The suitable habitats for *A. pannonicus* were in Iran, Pakistan, Afghanistan, and Central Asia (Tajikistan, Turkmenistan, and Uzbekistan). In Iran, *A. pannonicus* was present in the majority of habitat types [30] except deserts, showing the effect of barriers on dispersion of the terrestrial species. This lizard inhabited palm groves (Abadan and Mahshahr), Karoon River shore region, and Darvishab River Park of Khuzestan Province, southwestern Iran (**Figure 3**). It was absent in the steppes of northwestern Iran, probably, due to competition with *A. bivittatus*. Therefore, *A. grayanus* and *A. pannonicus* prefer different climatic conditions across the Middle East and Central Asia. In addition, our results showed that the distributions of these species are restricted by different climatic conditions.

The occurrence and the presence of *A. grayanus* are more influenced by precipitation of the driest quarter of the year (24%), mean temperature of the coldest quarter of the year (23.3%), and precipitation of the driest month (18.45%). Therefore, it is more likely to be found in hot regions under the influence of the rainy monsoon. The prevalence of *A. pannonicus* is more impacted by temperature seasonality (27%), slope (19.2%), and mean temperature of the wettest quarter of the year (18.5%). Due to relationship between temperature and humidity, we claim that seasonal temperatures, especially during the spring, are the most effective factors for suitable habitat.

The models simulated at the MH distribution of *A. grayanus* were highly influenced by precipitation of the driest quarter of the year (59.7%), isothermality (22.8), and mean temperature of the driest quarter of the year (15.3) which resulted from both African and Asian rainy monsoons. Those established damp environments and stable habitats for *A. grayanus*. Another species was highly (79.6%) dependent on temperature (isothermality, temperature seasonality, mean temperature of the wettest quarter of the year, and temperature annual range) that indicated the importance of temperature in range extension for *A. pannonicus*. The models simulated at the LIG distribution of *A. grayanus* was influenced by precipitation of the driest month and the driest quarter of the year (72.7%). *A. pannonicus* (89.2%) was dependent on temperature.

From the last simulation models (6 and 120 thousand years ago), it is clear that in those times wider distribution ranges and areas that are now part of unsuitable habitat, at that time, due to better climatic and environmental conditions influenced by monsoon rainfall, would have been a favorable habitat. Finally, study of the effective bioclimatic variables in a species' distribution over time provides heuristic methods for the management of important habitat by conservation assessments of current habitats and identification of habitat suitability. According to results obtained based on this study, the minor snake-eyed skink, *A. grayanus*, and the Asian snake-eyed skink, *A. pannonicus*, are good indicators for assessing the effects of climatic changes on distribution range of the species over time and for understanding biodiversity patterns in Asia.

5. Conclusion

It is expected that lizards inhabiting open habitats are more susceptible to a predator attack than those inhabiting forest habitats [44], since bushy habitat may provide suitable refuges for lizards. The Asian snake-eyed skink, *Ablepharus pannonicus* (Fitzinger, 1823), was found in the Zagros Mountains among sparse annual grasses, near thorny bushes, natural parks, and under the dead oak leaves. The minor snake-eyed skink *Ablepharus grayanus* (Stoliczka, 1872) lives in palm groves and near rivers in southeastern Iran.

According to results obtained based on this study, the minor snake-eyed skink, *A. grayanus*, and the Asian snake-eyed skink, *A. pannonicus*, are good indicators for assessing the effects of climatic changes on distribution range of the species over time and for understanding biodiversity patterns in Asia.

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A. Appendix

Characters	Definition
Altitude	Altitude
BIO1	Annual mean temperature
BIO2	Mean diurnal range [mean of monthly (max temp–min temp)]
BIO3	Isothermality [(BIO2/BIO7) × 100]
BIO4	Temperature seasonality (standard deviation × 100)
BIO5	Maximum temperature of the warmest month
BIO6	Minimum temperature of the coldest month
BIO7	Temperature annual range (BIO5–BIO6)
BIO8	Mean temperature of the wettest quarter of the year
BIO9	Mean temperature of the driest quarter of the year
BIO10	Mean temperature of the warmest quarter of the year
BIO11	Mean temperature of the coldest quarter of the year
BIO12	Annual precipitation
BIO13	Precipitation of the wettest month
BIO14	Precipitation of the driest month
BIO15	Precipitation seasonality (standard deviation / mean)
BIO16	Precipitation of the wettest quarter of the year
BIO17	Precipitation of the driest quarter of the year
BIO18	Precipitation of the warmest quarter of the year
BIO19	Precipitation of the coldest quarter of the year
Slope	Slope

Table A1.
Climatic variables used to elaborate the models (www.worldclim.org).

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