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Research Article

Species richness and areas of endemism of Lacertidae and Gekkonidae (Reptilia: Squamata) in Iran

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Abstract
The aim of this study is to detect areas of endemism in lizards in Iran. This is the first study of its kind focusing on this subject. Areas of endemism for two families of lizards (Lacertidae and Gekkonidae) that have the highest number of endemic species than other lizard families in Iran were identified by Parsimony Analysis of Endemicity (PAE). Distribution data were collected from previous studies on the Iranian lizards and also from the recent literature on the descriptions of new endemic species. A total of 81 species of lizards were available for analysis. The study area was divided into a 2° × 2° grid of 63 Operational Geographic Units (OGUs). PAE was applied to the data matrix to detect areas of endemism and detected eight areas of endemism in southwestern Iran and near the Persian Gulf. Southern Iran is the main region where most species from Arabia came into Iran and were stopped in their dispersal. Two grids in southern and northeastern Iran were recognized as the areas with the highest density of species in the studied families. Lacertidae and Gekkonidae did not have a shared endemic species in the region (cells 59 and 60) but the area of endemism identified by PAE in the Persian Gulf region suggests that exchange between Iranian and Arabian herpetofauna was very high during interglacial periods. The distribution pattern of the endemic species of these families is concentrated in the region of the Alborz and the Zagros Mountains, but the single area of endemism in southern Iran has an important role in the historical biogeography of the Iranian herpetofauna. During interglacial periods, the Persian Gulf acted as a corridor between the herpetofauna of the two sides and this suggests the importance of this area of endemism for the Gekkonidae family. Also, the OGUs with the highest density of species are located around the country and, the lowest density is in the Central Plateau. PAE detected eight areas of endemism in southwestern Iran, but according to the number of species per units, two OGUs can be identified as high density in northeastern and southern Iran.

Keywords: Gekkonidae, historical biogeography, Lacertidae, parsimony analysis of endemicity (PAE), Zagros Mountains

Introduction

The geological history of the Iranian Plateau has had a definitive role in the diversification and speciation in two families of lizards, Lacertidae and Gekkonidae. The reasons for this diversity are different and indeed several factors such as geological and climatological events, refuges in the Zagros and the Alborz Mountains, and areas of contact or transition in the herpetofauna are very important to determine areas of endemism with a high density of species. Several mountain chains in Iran have an important role in the speciation of some lizards and other animals, by acting as barriers to gene flow (Anderson in Fisher, 1968; Rastegar-Pouyani et al., 2010).

Gekkonidae and Lacertidae are the two largest lizard families in Iran and many species are restricted (endemic) to Iran. Forty-two species from Lacertidae and thirty-nine species from Gekkonidae have been recorded and described in Iran and the most speciose genera are *Eremias, Mediodactylus*, and *Cyrtopodion*, all of which have many endemic species in Iran (Anderson, 1999). One genus of the family Lacertidae, *Eremias*, has been hypothesized to be from Central Asia, with some populations of this genus reaching Iran. Because of the special structure of Iran's mountains, several barriers and corridors have developed and isolated the ancestral populations of this genus. After this event, several species evolved from those ancestral ones and diversified into Iran.

Parsimony analysis of endemicity (PAE), first proposed by Rosen (1988), is one of the most commonly used quantitative methods for identifying areas of endemism. In PAE, areas or localities are treated as taxa and species as characters in the primary data matrix, and grouped by their shared species by means of a maximum parsimony algorithm to detect nested sets of areas whose branching pattern may represent their biotic history (Morrone & Crisci, 1995). PAE offers an accurate, reproducible, technique for the detection of areas of endemism, avoiding the subjectivity implied in defining such areas without using quantitative methods, which is the major aim of quantitative biogeography (Crovello, 1981; Birks, 1987). The original method was modified by Morrone (1994), who defined areas of endemism as regions that have two or more endemic species, i.e. species restricted to those areas (see also Harold & Mooi, 1994). It's difficult to argue about these areas phylogenetically since the method cannot tell us about the cause of endemism area creation and has two factors that the method is based on, the most parsimonious position but each of the biogeographic units might have a long history (Morrone & Crisci, 1995; Riddle, 1996). The approach of PAE by Morrone (1994) proposes that areas of endemism can be found using data from different taxa, but this procedure cannot help to distinguish between the histories of an area and discuss it with a phylogenetic hypothesis. Despite some criticisms (Brooks & van Veller, 2003; Santos, 2005; Garzon-Orduna et al., 2008), PAE has been demonstrated to be a useful technique for the analysis of patterns of endemism based on presence/absence data (Nihei, 2006), with many applications to several groups of organisms already reported (e.g. Cracraft, 1991; Silva & Oren, 1996; Posadas et al., 1997; Luna-Vega et al., 1999; Morrone et al., 1999; Ron, 2000; Bisconti et al., 2001; Trejo-Torres & Ackerman, 2001; Garcia-Barros et al., 2002; Morrone & Escalante, 2002; Aguilar-Aguilar et al., 2003; Rojas-Soto et al., 2003; Silva et al., 2004; Dominguez et al., 2006; Goldani et al., 2006; Huidobro et al., 2006; Quijano-Abril et al., 2006; Vasquez-Miranda et al., 2007; Huang et al., 2008; Sanchez-Gonzalez et al., 2008; Escalante et al., 2013). PAE also becomes especially important in the context of conservation biogeography (Whittaker et al., 2005), when phylogenies of the species under study are not available and presence/absence data based on species checklists may therefore be the only information resource to allow the detection of areas of endemism that can be targeted as potential conservation units (Cavieres et al., 2002; Huang et al., 2010). In this study, PAE was used to detect areas of endemism and investigated the species richness of lizards in Iran. The results were then discussed according to known events in the geographical history.

Materials and methods

Study area

The study area includes the whole Iranian territory and consists of two mountain chains, the Alborz Mountains with a west to east direction and the Zagros Mountains with a northwest to a southeast direction (Fig. 1).

A set of 63 quadrats with 2° × 2° (200 × 200 square km) each, covering the whole Iranian territory, were used as Operational Geographic Units (OGUs: Crovello 1981) to identify areas of endemism and units of high density for lizards. Reptiles in Iran have generally a low density per square km and for this reason, units smaller than 200 × 200 km could introduce a bias in the estimate of species richness in each unit (Fernandez-Rubio, 1991; Martin et al., 2000). The correlation between quadrant size and species density led us to use larger units for estimating species density.

Endemic species data from Iran

Locality data for the species of the families Lacertidae and Gekkonidae in Iran were obtained from the available literature and recently published papers on extension ranges or descriptions of new species (Smid et al., 2014; Rastegar-Pouyani et al., 2016; Gholamifard et al., 2016; Nasrabadi et al., 2017; Hosseinian Yousefkhani et al., 2018). As a first step, we used the records of species distribution to detect the unit densities. When one species had two records in the same unit, the additional one was removed to simplify the dataset. The final data matrix included 81 species of lizards of the families Lacertidae and Gekkonidae occurring in Iran.

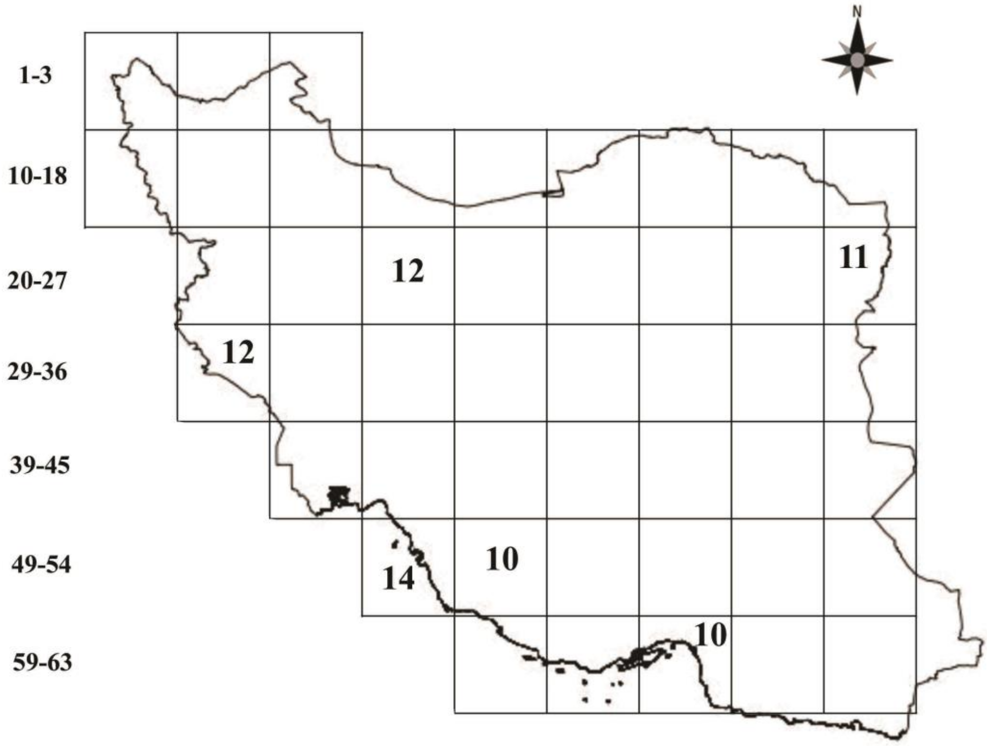

Figure 1. Map of Iran, with the OGUs (quadrat cells), superimposed on it. OGUs with 10 or more species are labeled with the number of species found in each.

Data analysis

The data matrix of 64 grid cells (rows) and 81 species (columns) was analyzed by Parsimony Analysis of Endemicity (PAE), after the protocol proposed by Morrone in 1994. An additional row coded as 0 for all species was included to root the resulting trees. The data matrix was analyzed using the program TNT, version 1.1 (Goloboff et al., 2008). Minimum-length trees were searched with the New Technology search algorithm, applying all default options. A strict consensus tree was obtained for summarizing the results of the parsimony analysis and the areas of endemism detected were depicted on a map of Iran. Species richness and endemicity statistics were computed from the data matrix by means of a program written in C++ by one of the authors (MJC) using the NEXUS Class Library (Lewis, 2003) and available upon request.

Results

Five most parsimonious trees, with 164 steps, were found in the PAE. The strict consensus tree (Fig. 2) showed eight areas of endemism, each including between two to four OGUs (Fig. 3). Table 1 lists the areas of endemism detected in the PAE, with the species names and OGU numbers in each, based on the distribution of characters (species) on the consensus tree.

Statistics of species richness and endemicity, computed from the same data matrix used in the PAE, are shown in Table 2. It can be seen that the majority of species in the two families occurring in Iran (42%) were recorded in only one OGU, with an additional 12.3% of the species being recorded in two OGUs only.

Table 1. List of species defining the areas of endemism for the families Lacertidae and Gekkonidae in Iran, according to the PAE results.

Area of Endemism	Cells	Species
1	17,18,26,36	*Eremias grammica, Eremias lalezharica, Eremias lineolata, Mesalina brevirostris, Acanthodactylus khamirensis, Eremias fasciata, Eremias acutirostris, Eremias strauchi, Cyrtopodion brevipes, Cyrtopodion golubevi, Eremias kopetdaghica, Darevskia chlorogaster*
2	22,23	*Eremias nigrolateralis, Darevskia chlorogaster, Darevskia defilippii, Mesalina brevirostris, Acanthodactylus khamirensis, Bunopus tuberculatus, Bunopus crassicauda, Crossobamon eversmanni, Eremias acutirostris, Eremias kopetdaghica, Eremias velox, Eremias papenfussi*
3	20,29,30	*Darevskia defilippii, Microgecko latifi, Bunopus crassicauda, Hemidactylus romeshkanensis, Timon kurdestanica, Acanthodactylus nilsoni, Lacerta strigata, Tropiocolotes naybandensis, Mediodactylus kotschyi, Mediodactylus ilamensis, Hemidactylus turcicus, Cyrtopodion agamuroides, Eremias kavirensis, Timon princeps*
4	31,40,50	*Darevskia defilippii, Mesalina brevirostris, Mediodactylus heteropholis, Pseudoceramodactylus khobarensis, Microgecko persicus, Microgecko latifi, Hemidactylus romeshkanensis, Cyrtopodion scabrum, Cyrtopodion hormozganum, Cyrtopodion gastrophole, Lacerta strigata, Iranolacerta brandti, Mediodactylus heterocercus, Apathya coppadacica, Iranolacerta zagrosica, Crossobamon eversmanni*
5	59,60	*Darevskia defilippii, Mesalina brevirostris, Acanthodactylus blanfordi, Tenuidactylus turcmenicus, Hemidactylus persicus, Cyrtopodion agamuroides, Ophisops elegans, Tropiocolotes studneri, Mediodactylus aspratilis, Microgecko helenae, Cyrtopodion persepolense, Bunopus crassicauda*
6	49,39	*Mesalina brevirostris, Tropiocolotes steudneri, Stenodactylus doriae, Pseudoceramodactylus khobarensis, Hemidactylus romeshkanensis, Bunopus crassicauda, Lacerta strigata, Ophisops elegans, Acanthodactylus schmidti, Mediodactylus russowii, Hemidactylus persicus, Cyrtopodion kirmanense, Cyrtopodion hormozganum, Cyrtopodion agamuroides, Mesalina watsonana, Microgecko latifi*
7	15,16	*Eremias nigrolateralis, Eremias strauchi, Darevskia steineri, Acanthodactylus khamirensis, Eremias acutirostris, Eremias kopetdaghica, Mesalina brevirostris, Crossobamon eversmanni, Eremias lineolata, Darevskia valentini, Tenuidactylus longipes, Mediodactylus stevenandersoni*
8	2,11	*Eremias persica, Lacerta media, Darevskia praticola*

Table 2. Distribution of species richness of families Lacertidae and Gekkonidae in Iran, according to the number of areas (OGUs) in which they occur.

Species occurring in	Species richness	%
One area	34	42
Two areas	10	12.3
Three areas	10	12.3
Four areas	12	14.8
Five or more areas	15	18.6

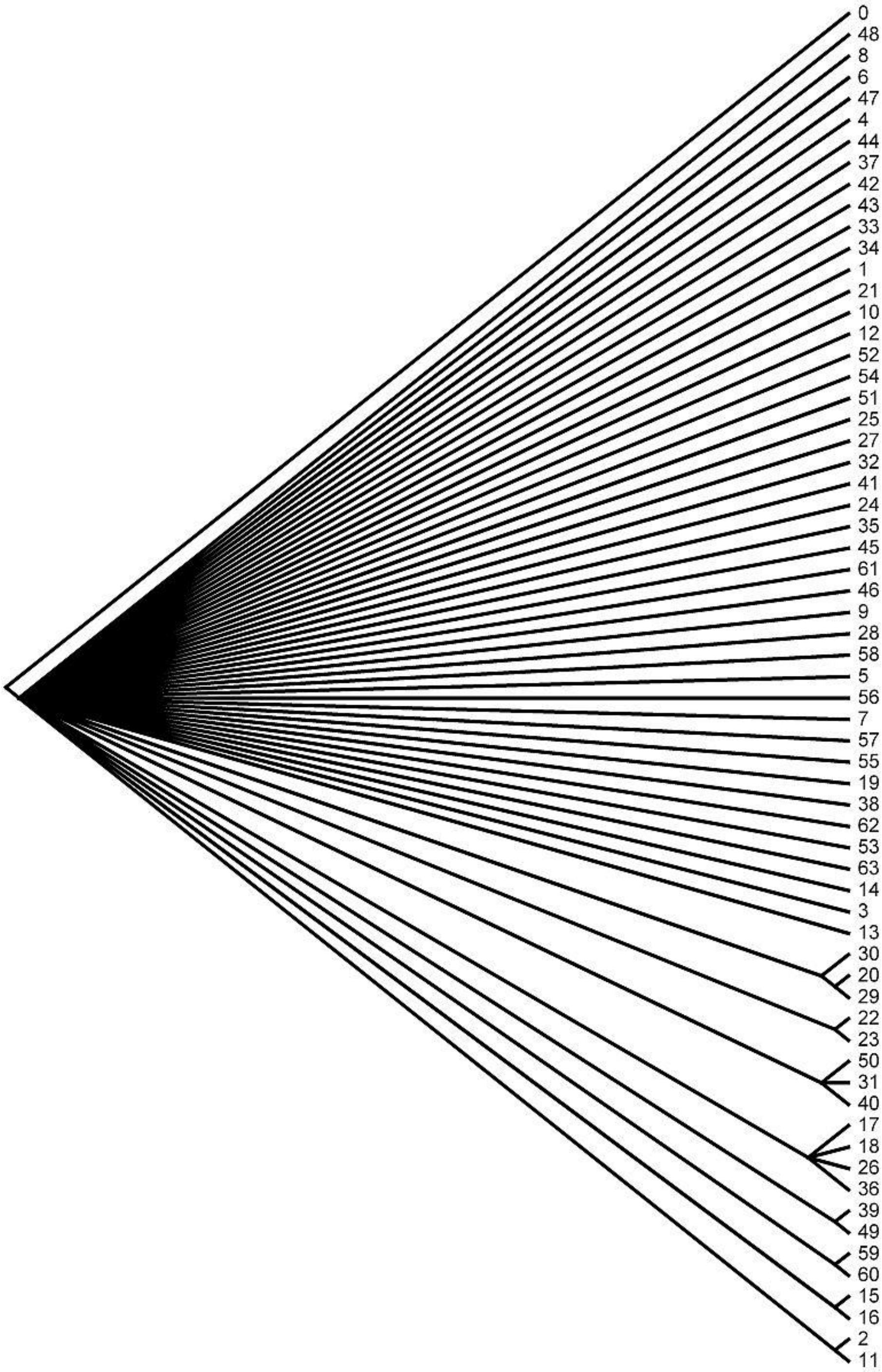

Figure 2. Strict consensus tree resulting from the Parsimony Analysis of Endemicity (PAE), based on 81 species of lizards from the families Lacertidae and Gekkonidae occurring in Iran.

Discussions

Lacertidae and Gekkonidae are the most diverse families of lizards in Iran and are the most speciose families in Iran (Gholamifard, 2011). These families do not have any shared endemic species in the region (OGUs 59 and 60) but the area of endemism identified by PAE in the Persian Gulf region suggests that the Zagros Mountains may have acted as an efficient geographic barrier to most species occurring in Iran with affinities to the Afro-tropical region, since those species do not occur in the central part of the Plateau. The Zagros Mountains have 40 reptile species that endemic to the area and Gekkonidae from the lizard is the more diverse families. This means that high endemicity in Zagros Mountains may be effected by variable climate condition from north to the south (Kazemi & Hosseinzadeh, 2020). The distribution pattern of the endemic species of these families is concentrated in the region of the Alborz and the Zagros Mountains, but the single area of endemism in southern Iran plays an important role in the historical biogeography of the Iranian herpetofauna because we assume that species entering into the Iranian fauna were trapped along the coastal regions of the Persian Gulf. During interglacial periods, the Persian Gulf acted as a corridor for the herpetofauna between the two sides and this suggests the importance of this area of endemism for the Gekkonidae. Also, the OGUs with the highest density of species are located around the country and, as shown in Figure 3, the lowest density is in the Central Plateau. Qom province is located on the eastern edge of the Zagros Mountains and the northwestern corner of the central plateau but shows a relatively low richness and hotspot (grids 22 and 23 in Fig. 3) rather than other grids (Almasieh et al., 2019). PAE detected eight areas of endemism in southwestern Iran, but according to the number of species per unit, two OGUs can be distinguished as of high density in northeastern and southern Iran. The northeastern areas that were recognized as areas of endemism by PAE, may be related to the Kopet Dagh history.

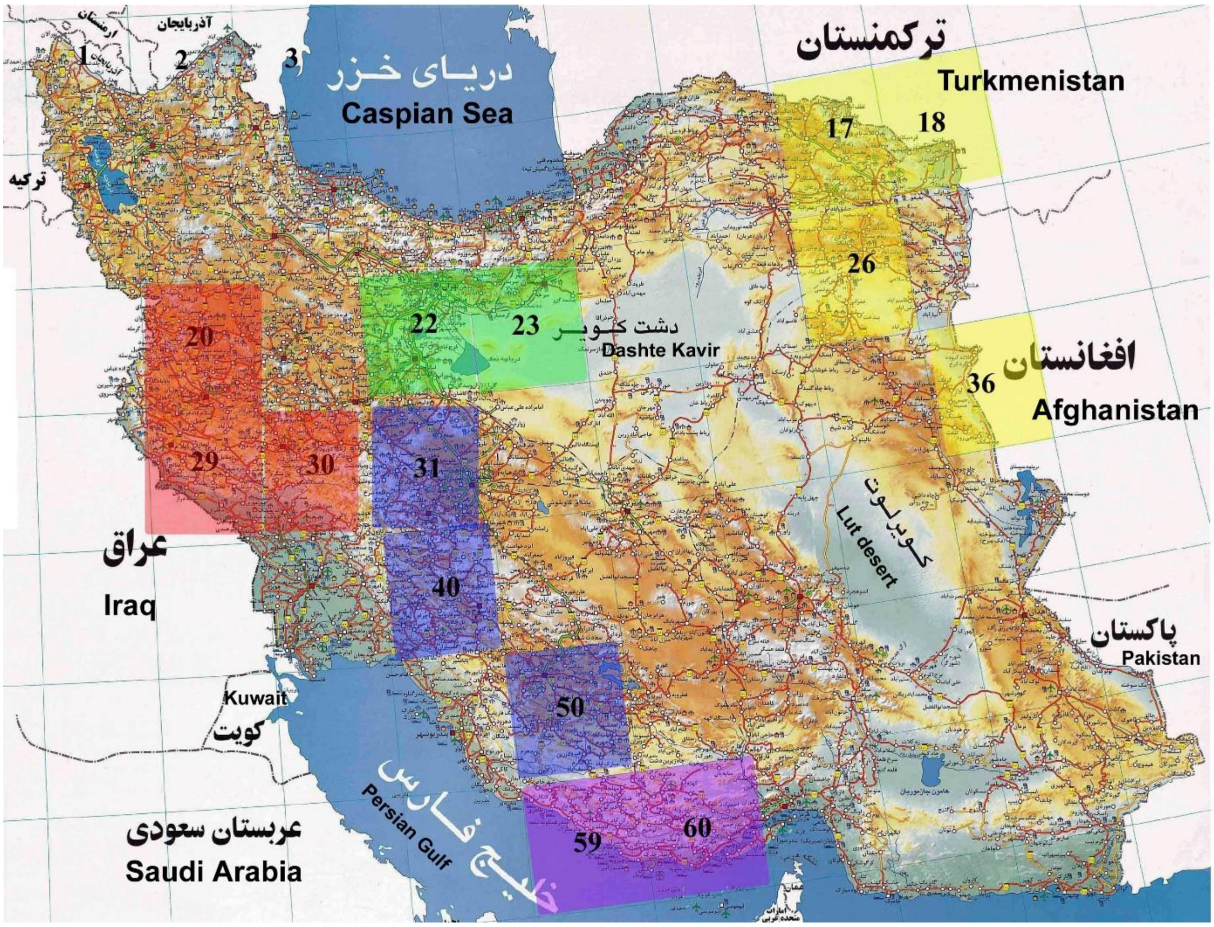

Figure 3. The areas of endemism detected in the PAE.

The region was a plate between the Turan plain and the Central Iran plate about 7 MYA and more species were dispersed to Iran and vice versa. Because of the uplifting of Kopet Dagh around 5-6 MYA (Rastegar-Pouyani et al., 2012), connections between the populations of these species were interrupted and they became isolated from each other. Diversification in one group of lizards is paralleled by other groups and also some species distributed in the Central Iranian Plateau became isolated, like *Mediodactylus russowi* which is restricted to a small area in the Taybad region. The Kopet Dagh formation plays a key role in the diversification of the genus *Eremias* in the family Lacertidae (Rastegar-Pouyani et al., 2012), with about 5 species of this genus restricted to northeastern Iran. Another species to be considered is *Paralaudakia erythrogastra* (family Agamidae), which is endemic to the Kopet Dagh Mountains and whose historical biogeography can be explained as discussed below. This species is related to the *P. caucasia* complex (Macey et al., 1998, 2000), with 3 species of the genus *Paralaudakia* (*P.caucasia*, *P.microlepis*, *P. erythrogastra*) which originated from a common ancestor. The first species that diverged from them is *P.erythrogastra* (Macey et al., 2000) but the relationship between *P. caucasia* and *P. microlepis* is still unclear.

The Alborz Mountains also play an important role as an area of endemism (Mozaffari & Parham, 2007; Rastegar-Pouyani et al., 2012), by separating populations of *Eremias velox* in two clades (north and south side of the belt) and probably contain many yet unknown populations of this genus. As an example, one of these populations was described as a new species, *Eremias papenfussi* (Mozaffari & Parham, 2007), endemic to the Alborz Mountains from the Karaj region. The Zagros Mountains' endemicity is more important than that of other Iranian mountain systems because this region played two roles for several taxa, either as a biogeographic corridor or as a barrier. Some species of Lacertidae, such as *Iranolacerta brandti, Iranolacerta zagrosica, Timon princeps, Eremias nigrolateralis, Eremias mountanus,* and *Apathya yasujica* (Kapli et al. 2013) are endemic to this mountain belt and this fact points to the role of the Zagros Mountains during glaciation periods in regard to expansion and contraction of the populations of the ancestors of these species. Genus *Acanthodactylus* is one of the African genera that are present in Iran, distributed along the coastal regions of the Persian Gulf but restricted by the Zagros Mountains.

Conclusion

The results of this study suggest that several mountain chain systems in Iran play a key role in determining the endemicity of reptiles in the region, especially in the two families Lacertidae and Gekkonidae as here analyzed.

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