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High Diversity and Endemism of Herpetofauna in the Zagros Mountains

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ABSTRACT

Aims The Zagros Mountains are a part of the 20th global hotspot, the Irano-Anatolian biodiversity hotspot. In this study, we aim to develop a comprehensive checklist of endemic herpetofauna species in the Zagros Mountains as one of the biodiversity hotspot regions, to provide more information about this important area and the necessity of conservation programs to protect it.

Materials & Methods The Zagros Mountains, with an area of about 533,543km2, ranges from Turkey and Iraq to western and southwestern Iran along the eastern edge of the Persian Gulf. A list of endemic species has been collected from the literature review.

Findings This region contains 3 species and 7 subspecies of endemic amphibians belonging to three genera and two families, the Salamandridae (8) and the Bufonidae (2). Neurergus and Calliopersa are endemic to this hotspot. There are 40 species and 6 subspecies of endemic reptiles belonging to 24 genera and 10 families. The families with the greatest number of endemic species are the Gekkonidae, Phyllodactylidae, and Colubridae. Three genera, Asaccus, Mediodactylus, and Eirenis, dominate the region, with 32 endemic taxa. There are also two endemic genera, Parsigecko and Lakigecko.

Conclusion Many amphibians in the Zagros Mountains, especially all the species of the genus Neurergus, are categorized in IUCN (the International Union for Conservation of Nature) Red List and CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). The habitats of the Zagros Mountains herpetofauna, especially those of endangered and endemic species, should be protected and managed to maintain or restore populations of the declining species.

Keywords Biodiversity; Amphibians; Reptiles; Endemic; Iran

CITATION LINKS

[1] Hotspots ... [2] Biodiversity ... [3] Hotspots ... [4] Global ... [5] Biodiversity ... [6] Hotspots ... [7] Austral ... [8] Endemism ... [9] On the ... [10] Evolutionary ... [11] Systematics ... [12] Endemism ... [13] Assessing ... [14] Mapping ... [15] Systematic ... [16] The coincidence ... [17] On areas ... [18] Areas ... [19] Historical ... [20] Conservation ... [21] Plant ... [22] The ... [23] The roles ... [24] Annotated ... [25] Endemism ... [26] The ... [27] Estimating ... [28] Predicting ... [29] Timing ... [30] Iranian ... [31] Convergence ... [32] The ... [33] The ... [34] Amphibians ... [35] The ... [36] Snakes ... [37] Molecular ... [38] A study ... [39] Annotated ... [40] A new ... [41] Description ... [42] A new ... [43] A new ... [44] Identifying ... [45] The complete ... [46] A new ... [47] Phylogeny ... [48] A new species ... [49] Sustainable ... [50] Description ... [51] Alpine-Himalayan ... [52] A new species ... [53] A new ... [54] Topographic ... [55] Topographic ... [56] Environmental ... [57] Climate ... [58] Genetic ... [59] Biogeographical ... [60] Three ... [61] Deep ... [62] A novel approach ... [63] Quaternary ... [64] Visions ... [65] Molecular ... [66] Effects ... [67] Habitat ... [68] Challenges ... [69] Biodiversity ... [70] Prediction ... [71] Widespread ... [72] Climate ... [73] The amphibian ... [74] Global ... [75] Status and ... [76] Additive threats ... [77] Population ... [78] 2004 IUCN red list ... [79] The conservation status ... [80] Accelerated ... [81] Climate ... [82] Diagnoses of new ... [83] mit einem ... [84] Notes ... [85] Trois formes nouvelles d'amphibies ... [86] A new form ... [87] A new subspecies ... [88] Über eine neue ... [89] Taxonomic revision ... [90] A new species ... [91] Two new species ... [92] Ein neuer Hemidactylus ... [93] A new species ... [94] VI.-Descriptions ... [95] Remarks on some geckos ... [96] A new species ... [97] Description of a new ... [98] Reptiles et amphibiens ... [99] Zwerggeckos aus ... [100] A new species of ... [101] Lacertas of south ... [102] A new species ... [103] A new species ... [104] Eine neue Unterart ... [105] Beschreibung eines ... [106] Über eine sammlung ... [107] Beschreibung eines ... [108] A new genus and ... [109] A new species ... [110] A new species ... [111] Retraction of Ptyodactylus ... [112] Herpetologische Notizen ... [113] A new species ... [114] Description of a new ... [115] sp.(Colubridae, Serpentes) ... [116] Reptilien aus ... [117] Coluber ... [118] Prime linee ... [119] Notes on a ... [120] A new species ... [121] A new species ...

Introduction

The main purpose of conservation biology is identifing areas of high biodiversity and to aid in managing conservation priorities [1]. Hence, many investigations have been carried out to examine how to recognize regions with high diversity. Recent studies suggest that 34 hotspots include at least 42% of terrestrial vertebrate species and 50% of known plant species, mainly due to their endemic species and habitats [2, 3]. In addition to their importance due to their species richness, biodiversity hotspots are valuable for studying factors influencing diversification and associated mechanisms. Endemic species are useful in recognizing biodiversity hotspots and highly endangered species [2, 4-6]. Additionally, identifying areas of endemism is an important part of regional conservation planning management.

Areas with high endemism are geographic regions that contain the congruent distributions of two or more monophyletic species that probably resulted from common biogeographical events such as geological, ecological, or evolutionary processes [7-10]. Generally, biogeography and evolutionary studies focus on illuminating the development of areas of endemism, whereas ecological research concentrates on centers of endemism due to their importance in planning conservation actions [2, 11-17]. Recognizing and presenting information on areas of endemism is a fundamental tool used in investigating historical and ecological biogeography. However, it is challenging to examine these areas from a conservation perspective, especially in cases where protected areas are delineated based on diversity hotspots since endemism is found outside the highly diverse regions [4, 18-21]. Based on studies by Myers *et al*. and Mittermeier *et al*., north and west of Iran are presented as parts of the Irano-Anatolian biodiversity hotspot, the so-called 20th global hotspot region [2, 3]. Mittermeier *et al*. defined hotspots based on their exceptional species endemism and extensive loss of habitat. The 34 identified hotspots include at least 42% of terrestrial vertebrate species and at least 50% of known plant species within the extant habitat that covers only 2.3% of the earth's land surface [3]. Sindaco and Jeremčenko (2008) showed the southwest of Iran to be a hotspot for reptiles of the western Palearctic zoogeographical region [22]. Hosseinzadeh *et al*. showed Khuzestan province, southwestern Iran, as one of the richest hotspots of the Iranian reptiles [23].

According to Eskandarzadeh *et al.*, the percentages of the Iranian endemic herp species are as follows: 28.45% of reptiles (66 from 232 reptilian species in Iran) and 22.73% of amphibians (five out of about 22 species) [24]. As reptiles and amphibians have relatively narrow distributions as compared to other vertebrates, the diverse geographical and environmental conditions in Iran have generated herpetofaunal biodiversity. Therefore, the two groups are important in terms of conservation programs and future studies. In addition, the number of endemic herp species in the Zagros Mountains and the western foothills of the Zagros is remarkable [25, 26].

The Zagros Mountain range is located in the Irano-Anatolian biodiversity hotspot, as the 20th hotspot region [3]. The Zagros Mountain range is the major geographic barrier between the central Iranian plateau and the Mesopotamian plain in western Asia, and it also provides a corridor for the southward distribution of northern faunal elements [25]. According to Noroozi *et al.*, the Zagros Mountains, contain the largest identified areas of endemism [6]. In Iran, data about the number of species, especially endemic species, their distribution, and ecology are certainly inadequate and underestimated, and the issue is especially serious in the case of amphibians and reptiles [22, 23, 27, 28]. This study aimed to develop a comprehensive checklist of endemic herpetofauna species in the Zagros Mountains, one of the biodiversity hotspot regions, and to provide more information about this important area and the necessity of conservation programs to protect it.

Materials and Methods

The Zagros Mountains, with an area of about 533,543km^2, ranges from Turkey and Iraq to western and southwestern Iran along the eastern edge of the Persian Gulf (Figure 1). The part of northwestern-southeastern the Zagros Mountains, which is a part of the alpine Himalayan mountain orogeny, extends for about 2000km from the East Anatolian fault in eastern Turkey to the Makran subduction in southern Iran [29]. The Zagros Mountains are located on the boundary between the Arabian and Eurasian lithospheric plates, which was an orogenic reaction to a collision between Eurasia and advancing Arabia during the Cenozoic [29-31].

Numerous northwest/southeast trending parallel folds were formed as a result of the collision and are now represented as spectacular, high amplitude anticlines and mountain peaks that rise between 3,000 and 3,650m above sea level [32]. In addition, the evolution of the landscape in the northwestern Zagros has been influenced by erosion due to rivers. Because of its considerable altitude, rainfall is distinctly heavier over much of the plateau. As a result, the Zagros Mountains exhibit irregular appurtenance, higher summits, and a few deeper basins or river valleys [33].

The source materials in this paper is based on some literatures as follows: Baloutch & Kami, Anderson, Latifi, ÖZ *et al*., Afrasiab and Mohamad, Gholamifard, Hosseinzadeh *et al*., Šmíd *et al*., Safaei-Mahroo *et al*., Safaei-Mahroo *et al*., Torki, Fathinia *et al*., Torki, Chefaoui *et al*., Rancilhac *et al*., Fathinia *et al*., Safaei-Mahroo and Ghaffari, and Torki [23, 25, 26, 34-48].

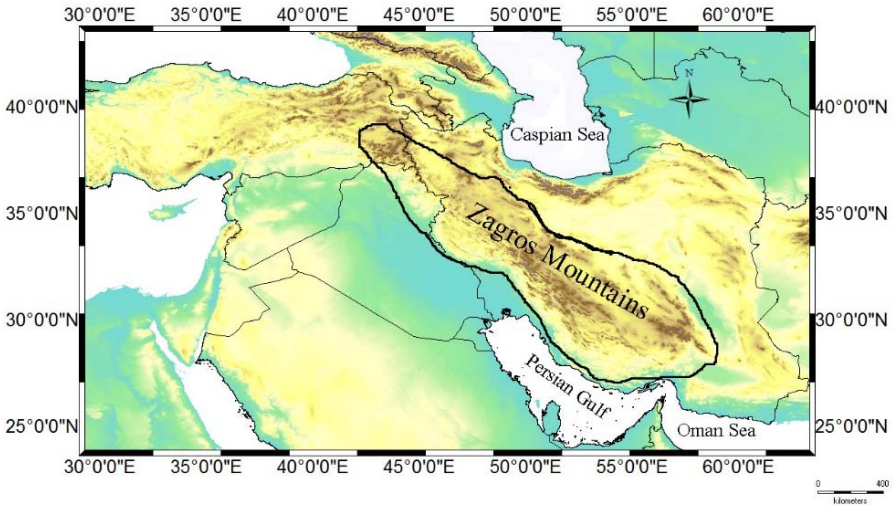

Figure 1) Place of the Zagros Mountains

Findings

There are seven frogs, nine toads, five newts, one salamander, one crocodile, one worm lizard, 170 lizards, 86 snakes, and 12 turtles and tortoises in Iran (Table 1). So far, five endemic amphibians and 73 endemic reptilian species from Iran have been described (Table 1), of which 46 endemic reptilian species (40) and subspecies (6) are distributed in the Zagros Mountains. The Zagros Mountains contain ten species and subspecies of endemic amphibians belonging to three genera and two families, the Salamandridae (eight) and the Bufonidae (two; Table 2). Neurergus and Calliopersa are endemic amphibian genera to this hotspot. There are 46 endemic reptiles belonging to 24 genera and 10 families in the Zagros Mountains (Table 3). The families with the greatest number of endemic species are the Gekkonidae, Phyllodactylidae, and Colubridae. Three genera, Asaccus, Mediodactylus, and Eirenis, dominate the region, with 32 endemic taxa. There are also two endemic genera, Parsigecko and Lakigecko.

Table 1) The number of endemic amphibian and reptile species of the Zagros Mountains and Iran

Taxon	Number of species		
	Endemic species and subspecies of Zagros Mountains	Endemic species of Iran	Iran
Frogs	-	1	7
Toads	2	2	9
Newts	7	2	5
Salamanders	1	-	1
Snakes	13	14	86
Lizards	33	59	170
Amphisbaenians	-	-	1
Turtles and Tortoises	-	-	12
Crocodiles	-	-	1

Table 2) List of family and genus names of endemic amphibian species found in the Zagros Mountains

Family	Genus	Species
BUFONIDAE Gray, 1825	Calliopersa Safaei-Mahroo & Ghaffari, 2020	*Calliopersa luristanicus* [82] *Calliopersa surdus annulatus* [83]
SALAMANDRIDAE Goldfuss, 1820	Neurergus Cope, 1862	*Neurergus crocatus* [84] *Neurergus derjugini derjugini* [85] *Neurergus derjugini microspilotes* [85] *Neurergus kaiseri* [82] *Neurergus strauchii barani* [86] *Neurergus strauchii munzurensis* [87] *Neurergus strauchii strauchii* [88]
	Salamandra Garsault, 1764	*Salamandra infraimmaculata semenovi* [85]

Table 3) List of family and genus names of endemic reptile species found in the Zagros Mountains

Family	Genus	Species
Agamidae	Phrynocephalus	*Phrynocephalus ananjevae* [8]
Eublepharidae	Eublepharis	*Eublepharis angramainyu* [90]
Gekkonidae	Cyrtopodion	*Cyrtopodion persepolense* [91]
	Hemidactylus	*Hemidactylus romeshkanicus* [92]
	Lakigecko	*Lakigecko aaronbaueri* [48]
	Mediodactylus	*Mediodactylus aspratilis* [93] *Mediodactylus heterocercum heterocercum* [94] *Mediodactylus heteropholis* [95] *Mediodactylus ilamensis* [96] *Mediodactylus stevenandersoni* [97]
	Microgecko	*Microgecko helenae helenae* [98] *Microgecko helenae fasciatus* [99] *Microgecko laki* [100] *Microgecko varaviensis* [53]
	Parsigecko	*Parsigecko ziaiei* [40]
Lacertidae	Apathya	*Apathya yassujica* [101]
	Eremias	*Eremias isfahanica* [52] *Eremias montana* [102]
	Iranolacerta	*Iranolacerta zagrosica* [103]
	Timon	*Timon kurdistanica* *Timon princeps* [94]
Phyllodactylidae	Asaccus	*Asaccus andersoni* [104] *Asaccus elisae* [105] *Asaccus granularis* [106] *Asaccus griseonotus* [107] *Asaccus kermanshahensis* [108] *Asaccus kurdistanensis* [109] *Asaccus nasrullahi* [110] *Asaccus zagrosicus* [50] *Asaccus saffinae* [38] *Asaccus barani* [50]
Scincidae	Ophiomorus	*Ophiomorus persicus* [111]
Varanidae	Varanus	*Varanus nesterovi* [112]
Colubridae	Eirenis	*Eirenis* (*Pediophis*) *punctatolineatus condoni* [113] *Eirenis* (*Pediophis*) *rechingeri* [114] *Eirenis* (*Pseudocyclophis*) *nigrofasciatus* [98] *Eirenis yassujicus* [46]
	Dolichophis	*Dolichophis andreanus* [115]
	Platyceps	*Platyceps najadum schmidtleri* [116]
	Rhynchocalamus	*Rhynchocalamus levitoni* [41,43]
	Spalerosophis	*Spalerosophis microlepis* [117]
	Telescopus	*Telescopus tessellatus tessellatus* [118]
Typhlopidae	Xerotyphlops	*Xerotyphlops wilsoni* [119] *Xerotyphlops luristanicus* [42]
Viperidae	Montivipera	*Montivipera kuhrangica* [120]
	Pseudocerastes	*Pseudocerastes urarachnoides* [121]

Discussion

The results show that the Zagros Mountains contain ten species and subspecies of endemic amphibians belonging to three genera and two families. Twenty-two amphibian species are found in Iran, and most of the endemic amphibian species are found in the Zagros Mountains [26, 34, 39, 47]. The largest endemic amphibian family belongs to the Salamandridae and extensively dominates the region, with eight species and subspecies, representing 80% of the total endemic Zagros Mountains amphibians. All species of the Neurergus genus need conservation because they are categorized in the

IUCN Red List and CITES [26, 34, 49].

To recapitulate, the Zagros Mountains contain 46 species and subspecies of endemic reptiles belonging to 24 genera and 10 families. The largest endemic reptile families are the Gekkonidae, Phyllodactylidae, and Colubridae. These three families extensively dominate with 32 species of the total endemic Zagros Mountains herpetofauna, representing 80% of the total endemic Zagros Mountains reptiles and the endemic reptilian genera to the Zagros Mountains are Parsigecko and Lakigecko [26, 35, 36, 38, 40-45, 50-53].

Some studies have shown that topographic dissimilarity is a significant environmental factor for species richness [54-57]. Geologically, the uplifting of the Zagros took place from Oligocene to the Miocene, 20-35 million years ago (Ma), leading to important climatic changes on two sides of the mountain range [29]. Although the northwestern Zagros have a wet climate that corresponds to the Mediterranean basin weather, the southern Zagros is influenced by the arid climate of the Arabian plate. The diverse ecological condition sustains different habitats and causes speciation [58]. Furthermore, uplifting of the Zagros and Alborz chains obstruct the movement of humidity from the Mediterranean basin and the Caspian Sea into the central plateau of Iran [29, 33]. The effect of the topography of the Zagros Mountains from the the northwest to the southeast of Iran is evident in the isolation of populations, as they cause speciation by separating the fauna of the central Iranian Plateau from that of the Mesopotamian plain. In addition to the contribution of mountain chains to create an effective barrier for such species, the location of Iran on the boundary of the Palearctic, Afrotropic, and Indo-Malay biogeographic realms supports a special condition leading to a high degree of endemicity among the tetrapod species [23, 39]. The Zagros Mountains are one of the regions with high numbers of endemic species, because of which they are named as hotspots for endemic species [6, 59]. Recently, Torki described three new species of Hemidactylus from the Zagros Mountains based on morphological characters named *H. achaemenidicus*, *H. pseudoromeshkanicus,* and *H. sassanidianus* [60]. The authors expressed doubt about the newly defined species, and it did not congruent with the molecular study of Hosseinzadeh *et al.*. Hence, the new species has not been included in the data of the research [61].

In addition, local refugia in the Zagros Mountains have been found during climatic fluctuations during glacial and interglacial periods, reducing the risk of extinction [62-65].

The important role of the Zagros Mountains in the separation, isolation, and evolution of some Iranian lizard species has been confirmed, as it has been observed in the genus Asaccus and Tropiocolotes [25].

As has been discussed, the conservation of endemic species is necessary, especially in hotspots. The hotspot approach incorporates habitat loss and species endemism to make map for regions of high conservation importance [2], an idea that gained strength in the early 2000s, mostly due to the recent alarming rates of global habitat loss [66, 67]. In recent years, forests and other vegetation of many parts of the Zagros Mountains have been changed into urban areas and agricultural and industrial regions [68, 69]. These activities have caused the destruction of animal habitats, and they have probably pushed them into the endangered category. According to Farashi and Shariati, only 10% of biodiversity hotspots are located in protected areas, so the Iranian mammal, bird, and reptile species have not received enough protection [69]. On the other hand, endemic species are sensitive and are commonly influenced by the oscillation of the environmental factors that limit the species to a particular region [70]. In the last few decades, the oscillation of environmental factors and climate change have affected conservation biodiversity and have also been the main reason behind species extinction in some areas [71]. Generally, reptiles and amphibians are lack of ability to move long distances and, therefore, are very sensitive to climate change [72]. Many species of amphibians globally have declined in abundance and have seen a restricted distribution range over recent decades [73-75], and 30% of these species are now threatened with extinction [76]. The causes for these declines and extinctions are habitat loss and fragmentation, unsustainable harvesting, climate change, environmental contaminants, increasing UV radiation, introduced predators, and emerging diseases [74, 77, 78]. Some studies have demonstrated that 15-44% of the world's reptile species are threatened [79, 80]. Moreover, changing climate and global warming are additional threats for

biodiversity and can influence distribution patterns of species, especially endangered species and local populations [81]. Therefore, redefining protected areas is an important approach to conserving habitats [3]. Owing to the environmental changes observe globally, it is necessary to redesign the range of protected areas for the future and conserve threatened species.

Conclusion

The following principles and criteria are recommended to promote the sustainable management of the Zagros Mountains herpetofauna. Many amphibians in the Zagros Mountains, especially all the species of the genus Neurergus, have featured in the IUCN Red List and CITES. The habitats of the Zagros Mountains herpetofauna, especially those of endangered and endemic species, should be protected and managed to maintain or restore populations of declining species. Numerous and diverse habitats should be protected and managed to conserve and perpetuate the Zagros Mountains herpetofauna. Conservation programs for the Zagros Mountains herpetofauna should be managed to assure adequate public access without being detrimental to the species, populations, habitats, or ecosystems. The Zagros Mountains provide unique opportunities and challenges in the sustainable management of their highly diverse herpetofauna and hotspot.

The sustainable management of the Zagros Mountains herpetofauna requires adequate biological knowledge of taxonomy, population genetics, critical habitat components, and the effect of climate change on species distribution.

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