

Systematics and distribution of the Leopard Geckos *Eublepharis* Gray, 1827 (Sauria, Eublepharidae): A review

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Abstract

The eyelid bearing geckos Eublepharidae including six widely disjunct genera and 45 species which are distributed in tropical to temperate habitats of Eurasia, North-Central America and Africa. One of the eublepharid genera is the fat-tailed geckos of the genus *Eublepharis* Gray, 1827. The specific characters of *Eublepharis* involves flat basioccipital bone, deep axial pockets (armpit), eyelids well developed and movable, pupil vertical, dorsal small scales juxtaposed larger tubercles. The fat-tailed geckos as a vicariant group, encompass seven secretive, and nocturnal species: *E. angramainyu* Anderson and Leviton, 1966, *E. fuscus* Börner, 1974, *E. hardwickii* Gray, 1827, *E. macularius* (Blyth, 1854), *E. satpuraensis* Mirza, Sanap, Raju, Gawai and Ghadekar, 2014, *E. pictus* Mirza and Gnaneswar, 2022), and *E. turcmenicus* Darevsky, 1977 which are distributed from Turkey through the Iranian Plateau to India as following: south-eastern Turkey, Syria, Iraq, Iran, Pakistan, Afghanistan, Turkmenistan, and north-eastern and central India in a variety of habitats from dry karst topography regions with gypsum deposits and clay-gravel soil to stony foothills. The data used for the distribution maps were based on all available bibliographic records, and personal field observations. The results showed that among the three species located in Iran, *E. angramainyu* has the most widespread distribution and habitat diversity, and *E. macularius* has a very limited distribution in the border of Iran and Afghanistan. The range of species distribution depends on various factors including behavioral mechanisms of superior habitat selection, interactions with other living organisms and physico-chemical factors.

Key words: *Eublepharis*, *Eyelid geckos*, *Eublepharidae*, *Distribution*, *Asia*.

INTRODUCTION

The eyelid geckos of the Family Eublepharidae encompass six widely disjunct genera and 45 species: the cat gecko, *Aeluroscalabotes* (1 sp.) from Indonesia (Kalimantan), Malaysia (Sabah, Sarawak, west Malaysia), Singapore, Thailand (Seufer et al., 2005), *Coleonyx* (8 sp.) from Central and western North America, *Eublepharis* (7 sp.), and *Goniurosaurus* (25 sp.) from Asia, *Hemitheconyx* (2 sp.) from east and west Africa, and *Holodactylus* (2 sp.) from east Africa (Vitt and Caldwell, 2013; Mirza et al., 2014; Agarwal et al., 2022; Mirza and Gnaneswar, 2022). Boulenger (1885) based on movable eyelids, smooth digit, procoelous vertebrae, a single parietal bone separated Eublepharidae from the Gekkota lizards. Then Gadow 1901 reduced taxonomic level to subfamily and believed that they did not form a monophyletic



group (Gadow, 1923); Werner (1912) in recognized Boulenger's classification added *Holodactylus* to the Eublepharidae; Camp (1923) believed procoelous vertebrae of eublepharid geckos was secondarily derived and placed them in the Gekkonidae. Kluge (1967) based on presence of eyelid, an unpaired parietal bone, and a supratemporal bone separated eublepharids from other geckos as subfamily Eublepharinae (Kluge, 1967).

Grismer (1988) separated eublepharids from other geckos on the basis of cladistic analysis of morphological characters (skeletal system, scale morphology, meristic characters, and color pattern) and raised them to the family level. Phylogenetic analyses based on mitochondrial DNA sequences 12S and 16S ribosomal RNA genes (Ota et al., 1999; Fig. 1) and NADH dehydrogenase subunit 2 gene (ND2) and parts of 12S and 16S rRNA genes (Jonniaux and Kumazawa, 2008; Fig. 2) confirmed that the Eublepharidae are sister taxon of Gekkonidae. Based on molecular phylogenetic analyses, Jonniaux and Kumazawa (2008) proposed the Laurasian (Asian) origin of Eublepharidae, hence concluded that the genus *Coleonyx* may have migrated to North America by Early Cretaceous (around 150 million years ago (MYA)); they also inferred that the ancestors of African genera (*Holodactylus* and *Hemitheconyx*) evolved outside of Africa and entered Africa (around 90 MYA) during the time Africa was connected to Eurasia. Pyron et al. (2013) inferred that the African genera (*Holodactylus* and *Hemitheconyx*) form a sister group with the South Asian genus *Eublepharis*. Numerous studies have been carried out on karyology, phylogeny and eco-physiological variations of eublepharid geckos (e.g., Murphy, 1974; Ota et al., 1987; Dial and Grismer, 1992; Mirza et al., 2014). The aim of this study is to review systematics and distribution of the genus *Eublepharis* based on all the available evidence so far obtained.

Systematics account

Order Squamata Opperl, 1811

Infraorder: Gekkota Cuvier, 1817

Family Eublepharidae Boulenger, 1883

Genus *Eublepharis* Gray, 1827

The genus *Eublepharis* ('Eu' = true 'blephar' = eyelid) was first described based on specimens from Chittagong, Penang (Chittagong, now in Bangladesh) by John Edward Gray in 1827. The anatomical and morphological characteristics in the genus *Eublepharis* are as follows: flat basioccipital bone; deep axial pockets (armpit); digits short, cylindrical, with transverse lamellae beneath, clawed, the claw partly concealed beneath two or four lateral scale and an upper scale; eyelids well developed and movable; pupil vertical; males with preanal pores; dorsum is covered with small juxtaposed scales and larger tubercles; tail shorter than their snout-vent length (Leviton et al., 1992; Anderson 1999). The genus *Eublepharis* encompasses seven secretive, and nocturnal species: *E. angramainyu*, *E. fuscus*, *E. hardwickii*, *E. macularius*, *E. satpuraensis*, *E. pictus*, and *E. turcmenicus* which sporadically occur from southeast Turkey, Syria, Iraq, Iran, Pakistan, Afghanistan, Turkmenistan, and northeast and central India (Fig. 3) in a variety of habitats from dry karst topography regions with gypsum deposits and clay-gravel soil to stony foothills (Grismer 1988, 1989; Jonniaux and Kumazawa 2008; Karamiani and Rastegar-Pouyani 2021; Mirza and Gnaneswar, 2022; Uetz et al., 2022). In Iran, the leopard geckos comprise three species with a vicariant distribution: the Iranian fat-tailed gecko, *E. angramainyu* Anderson and Leviton, 1966, which occurs west and southwest of the Zagros Mountains (Karamiani and Rastegar-Pouyani, 2010) to southwest Kerman Province (Moradi and Shafiei, 2011); *E. macularius* (Blyth, 1854), of which the only known locality is in the eastern region of South Khorasan Province (close to the Afghanistan-Iran border); and *E. turcmenicus* Darevsky, 1977 from the Turkmen borders in North Khorasan, Khorasan Razavi and Semnan Provinces (Auer et al., 2008).

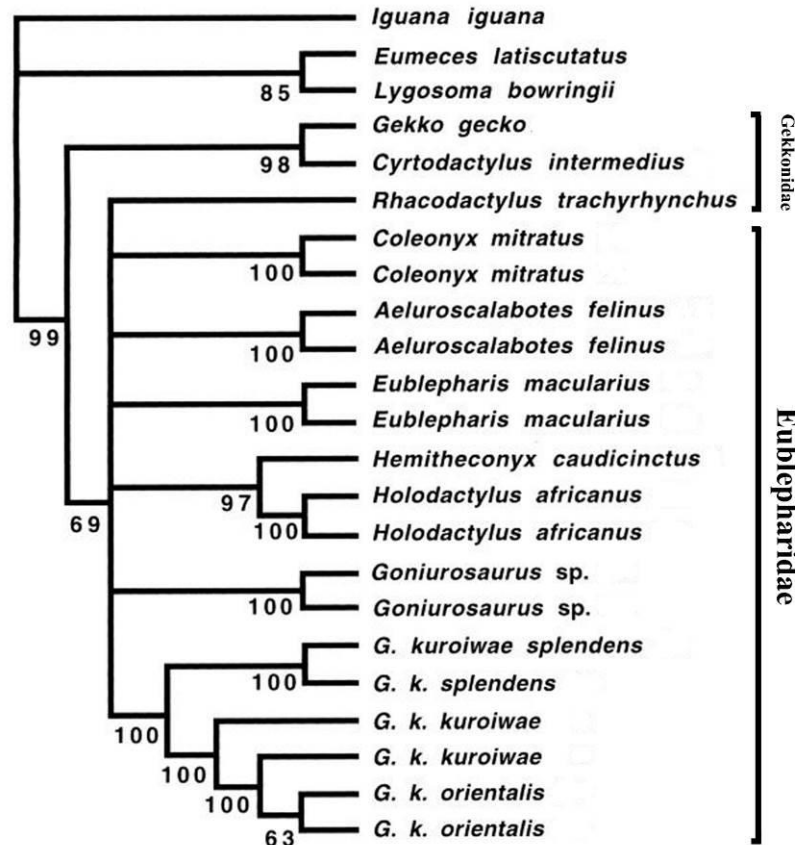


FIGURE 1. The majority-rule consensus tree deriving from parsimony analysis using nucleotide bases of 12S and 16S rRNA genes of the ingroup taxa, those belonging to the families Eublepharidae and Gekkonidae are shown (Ota et al., 1999).

Eublepharis angramainyu Anderson and Leviton, 1966

The Iranian fat-tailed gecko, *E. angramainyu* (Fig. 4) was described from an old road between Masjed Soleyman and Batvand, Khuzestan Province, Iran in 1966 by Anderson and Leviton. The Iranian fat-tailed gecko is distributed in limestone and gypsum foothills (small caverns in the gypsum deposits; Fig. 5), arid grasslands, and steppes from southern Turkey, north-eastern Syria, and Iraq to southern and south-eastern regions of the Iranian Plateau (Anderson, 1999; Al-Sheikhly et al., 2020). The morphological characteristics for diagnosis in *E. angramainyu* as following: subdigital lamellae smooth; mid-dorsal tubercles not as large as intertubercular spaces; chin shields in contact with first lower labials; 41-48 eyelid fringe scales; 27-38 longitudinal rows hexagonal ventral scales; some elements of color pattern of head and body linearly arranged in adults; males with uninterrupted series of 11-17 preanal pores, pores discernible in females (Anderson, 1999; Grismer, 1991). Karamiani and Rastegar-Pouyani (2017) in the anatomical study showed that *E. angramainyu* has 18 paired bones (maxillae, nasal, prefrontal, jugal, lacrimal, vomer, septomaxilla, palatine, pterygoid, ectopterygoid, epipterygoid, postfrontal, stape, squamosal, supratemporal, quadrate, prootic, otooccipital) and a single parietal in skull. In Iran, the leopard gecko is distributed from Kermanshah, Ilam, Lorestan, Khuzestan, Kohgiluyeh Va Boyer Ahmad, Fars to Kerman Provinces. Conservation status in the IUCN Red List categories and criteria for the species is Data Deficient. In Iraq, the leopard gecko is distributed from the ruins of Nineveh, in the upper Mesopotamian Plain, Kirkuk Province to Khanaqain area (Boulenger, 1885; Leviton et al., 1992; Anderson, 1999). The species was also recorded from Al-Khatonia in Al-Hasakah northeastern (Syria) and southern Turkey (Martens and Kock 1991; Rosler 1995; Göçmen et al., 2002).

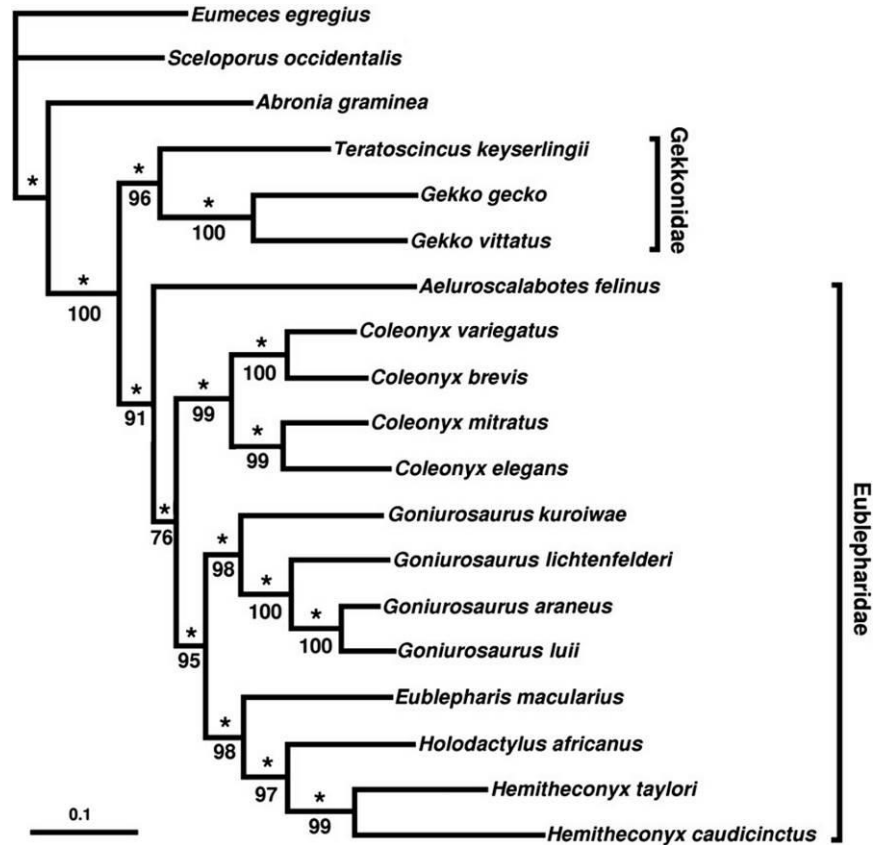


FIGURE 2. A Bayesian tree based on 2213 concatenated nucleotide sites from the ND2 region and two rRNA regions, showing relationships between Eublepharidae and Gekkonidae (Jonniaux and Kumazawa 2008).

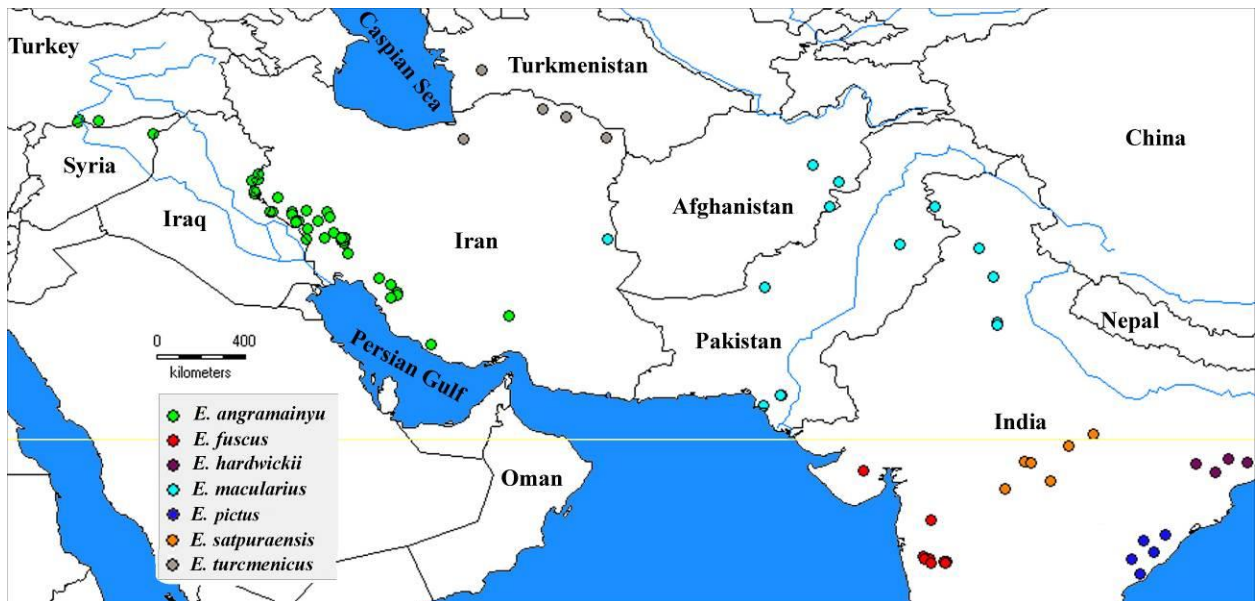


FIGURE 3. Distribution of the genus *Eublepharis*.

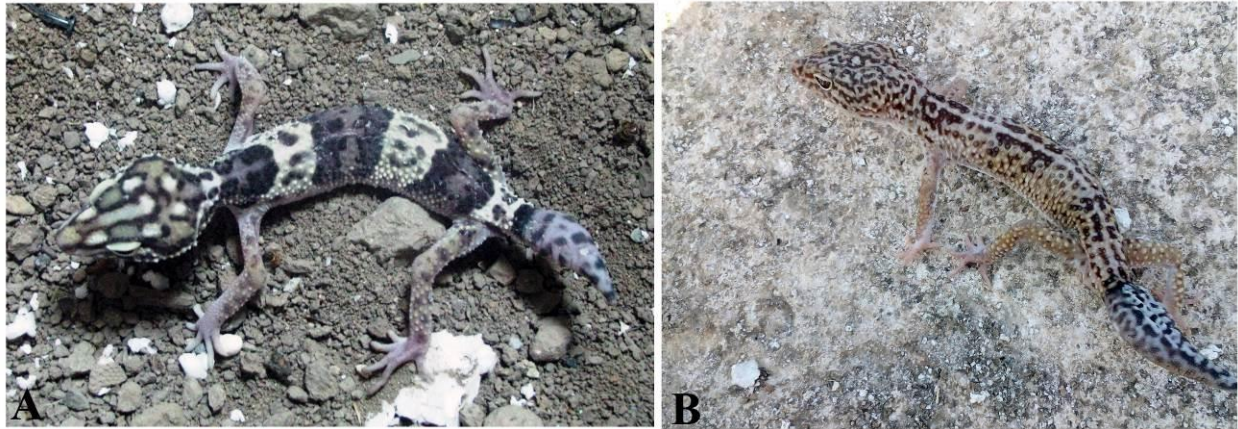


FIGURE 4. Alive subadult (A) adult (B) specimens of *Eublepharis angramainyu* with regenerated tail.

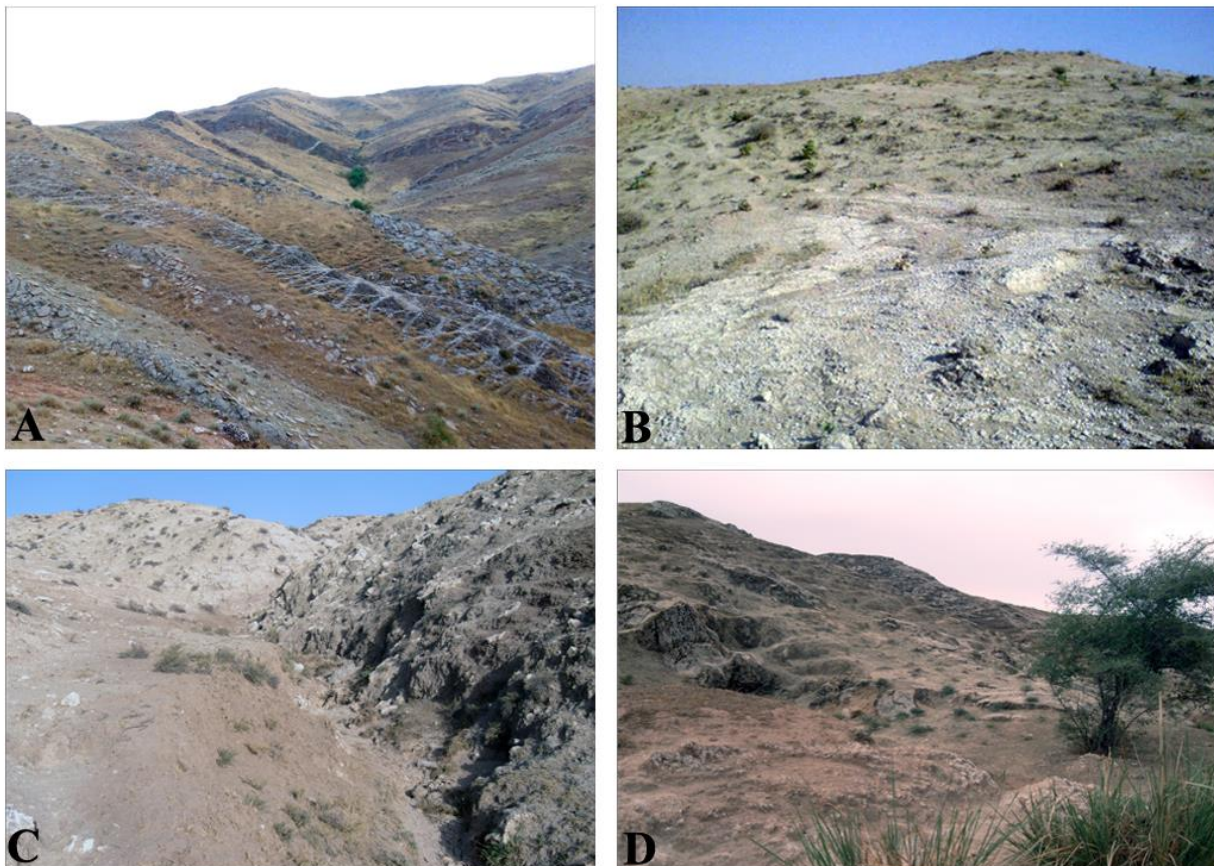


FIGURE 5. General aspect of habitat of *Eublepharis angramainyu* in Bazideraz Region, Kermanshah Province (A); Pol-e Dokhtar, Lorestan Province (B); Masjed-e-Suleiman (C), and Ramhormoz (D), Khuzestan Province (Karamiani and Rastegar-Pouyani, 2021).

Eublepharis macularius (Blyth, 1854)

The spotted fat-tailed gecko was described as *Cyrtodactylus macularius* from the Salt Range, Punjab, Pakistan by Blyth in 1854. The species is distributed in Afghanistan, Pakistan, India, and Nepal (Anderson, 1999; Rawat et al., 2019); the leopard gecko is reported from Rajputana and Khandesh Districts of India. In Pakistan it has been recorded from Azad Kashmir, North Western Frontier Province,



FIGURE 6. An adult specimen of *Eublepharis macularius* (Photo by Rune Midtgaard).

Punjab, Balochistan, and Sindh. In Nepal it is recorded from Surkhet, Banke, Nawalparasi, Kipilvastu Districts (Rawat et al., 2019). The morphological characteristics for diagnosis in *E. macularius* (Fig. 6) as following: subdigital lamellae each with several distinct small tubercles; mid-dorsal tubercles generally larger than intertubercular spaces; chin shields usually in contact with first lower labials; elements of dorsal color pattern not linearly arranged; 46-47 eyelid fringe scales; 21-30 longitudinal rows rounded ventral scales (Anderson, 1999; Grismer, 1991). Conservation status in the IUCN Red List categories and criteria for the species is Least Concern. Distribution in Iran: South Khorasan Provinces.

***Eublepharis turcmenicus* Darevsky, 1977**

The Turkmenistan leopard gecko, *E. turcmenicus* (Fig. 7) was described by Darevsky in 1977 based on three individuals from Bakharden, Chandyr and near Ashkhabat, Turkmenistan. The species is reported from southern Turkmenistan and north-eastern Iran. The morphological characteristics for diagnosis in *E. turcmenicus* are the following: subdigital lamellae with weakly developed small tubercles; chin shields not in contact with first lower labials; 54-55 eyelid fringe scales; 20-22 longitudinal rows hexagonal ventral scales; males with uninterrupted series of 5-9 preanal pores (Anderson, 1999; Kaverkin and Orlov 1996). Conservation status in the IUCN Red List categories and criteria for the species is Least Concern. Distribution in Iran: North Khorasan and Khorasan Razavi and Semnan Provinces.

***Eublepharis fuscus* Börner, 1974**

The West Indian leopard gecko, *E. fuscus* (Fig. 8) was described in 1974 by Börner as a subspecies of *E. macularius* from 60 km north of Mumbai (Bombay) in the Maharashtra State, west India. Das (1997) redefined the taxon, and upgraded it to a full species. This upgrade was adopted by subsequent authors (e.g. Daniel, 1983, 2002; Vyas, 2000a, b; Starostová et al., 2005, 2009; Mirza et al., 2014; Harshil and Vyas, 2019). The species is recorded from northern Karnataka, Maharashtra and Gujarat in the western India. The specific name "*fuscus*" means dark or dusky. The morphological characteristics for diagnosis in *E. fuscus*: subdigital lamellae smooth; middorsal tubercles that are smaller than their interspaces, eight postnasals bordering the nasals; small tubercles on the dorsum (Das 1997). Conservation status in the IUCN Red List categories and criteria for the species is Least Concern.



FIGURE 7. An adult specimen of *Eublepharis turcmenicus* (Anderson, 1999).

***Eublepharis hardwickii* Gray, 1827**

The East Indian leopard gecko, *E. hardwickii* (Fig. 9) was first described by Gray in 1827, based on a single specimen from Chittagong, Penang (Chittagong, now in Bangladesh). The species is distributed from Aushgram in Burdwan District West Bengal (Chandra et al., 1997), Chaibasa (Cantor 1847, Smith 1935), and Barajamda (Jharkhand), Belpahari (West Bengal), (Samanta et al., 2021), Similipal (Dutta et al., 2009) to Balasore (Odisha) (Agarwal et al., 2022). The morphological characteristics for diagnosis in *E. hardwickii*: smooth subdigital lamellae; tubercle-like moderately keeled scales across the dorsum intermixed with much smaller scales, a single pale band between the nuchal loop and caudal constriction; 16 precloacal pores. Conservation status in the IUCN Red List categories and criteria for the species is Least Concern.

***Eublepharis pictus* Mirza and Gnanaswar, 2022**

A recent molecular phylogenetic study of the genus *Eublepharis* Gray, 1827 revealed a new species. The painted leopard gecko *E. pictus* (Fig. 10) is recorded by Mirza and Gnanaswar in 2022 from near a temple in Vishakhapatnam, Andhra Pradesh eastern India. The morphological characteristics for diagnosis in *E. pictus*: smooth subdigital lamellae; 17–18 precloacal pores; tubercle-like moderately keeled scales across the dorsum intermixed with much smaller scales, a single pale band between the nuchal loop and caudal constriction. Conservation status in the IUCN Red List categories and criteria for the species is not recorded.

***Eublepharis satpuraensis* Mirza, Sanap, Raju, Gawai and Ghadekar, 2014**

The Satpura leopard gecko, *E. satpuraensis* (Fig. 11) was discovered from Satpura Hills, Central India based on detailed comparison of morphological parameters with congeners by Mirza et al (2014). The distribution range of the species was described as Satpura Hills which included Panchmari and surrounding areas of Satpura Tiger Reserve, Bhopal, Melghat Tiger Reserve, Pench Tiger Reserve,

Bandhavgarh Tiger Reserve and Jabalpur. Also was recorded from Boramdeo Wildlife Sanctuary and its adjacent forest patches in Chhattisgarh India. The morphological characteristics for diagnosis in *E. satpuraensis*: dome shaped tubercles lacking keels arranged in 20 rows on dorsum, inter-tubercular space more than width of a tubercle; 46–48 ocular fringe scales, three pale bands between the nuchal loop and caudal constriction; median subdigital lamellae smooth; 13–14 preanal pores which may be interrupted medially by a single poreless scale. Conservation status in the IUCN Red List categories and criteria for the species is Least Concern (IUCN 2022).



FIGURE 8. An adult specimen of *Eublepharis fuscus* (Mirza and Upadhye, 2010).

DISCUSSION

The family Eublepharidae originated in the Cretaceous to Jurassic age (Grismer, 1988; Jonniaux and Kumazawa, 2008; Agarwal et al., 2022). Grismer (1988) and Gamble et al. (2011) hypothesized a scenario for Asian or Laurasian ancestor for the eublepharid geckos, with *Coleonyx* dispersing to the New World through the Beringean land bridge. Agarwal et al. (2022) analyzed the phylogenetic relationship among the genera of eublepharid geckos based on one mitochondrial gene (*ND2*) and two nuclear genes (*RAG1* and *PDC*), and showed that the Eublepharidae family is divided into two clades, the *Aeluroscalabotes* + *Coleonyx*, and the *Eublepharis* + *Goniurosaurus* + *Hemitheconyx* + *Holodactylus* clade. Prior studies reported *Aeluroscalabotes* as the sister to taxon to other eublepharids (e.g. Grismer, 1988; Kratochvíl and Frynta, 2002; Jonniaux and Kumazawa, 2008). The genus *Eublepharis* is distributed in the eastern and south western Asia and included the species *E. angramainyu*, *E. fuscus*, *E. hardwickii*, *E. macularius*, *E. satpuraensis*, *E. pictus*, and *E. turcmenicus*. The most important diagnostic characters for Identification of the genus are as follows: number of preanal pores, first lower labial scales status (contact with postmental chin shield or no), subdigital lamellae scales status (smooth/ with small tubercles), number of eyelid fringe scales, and size of dorsal tubercles. Additionally, pholidopsis features and anatomical peculiarities (Grismer, 1988; Grismer and Ottley, 1998; Grismer, 1991; Anderson, 1999), molecular analyses (Ota et al., 1999; Jonniaux and Kumazawa, 2008; Agarwal et al., 2022; Mirza and Gnaneswar, 2022), and distribution pattern of species (Grismer, 1987; Auer et al., 2008; Mirza and Upadhye, 2010; Mirza et al., 2014; Basak et al., 2017; Naidu et al., 2020; Karamiani and Rastegar-Pouyani 2021) can separate species of the genus *Eublepharis*. The molecular phylogenetic study of the genus *Eublepharis* Gray, 1827 based on the *ND2* gene revealed that *E. angramainyu* is sister to all other species (Agarwal et al, 2022). Karamiani and Rastegar-Pouyani (2021) modeled range distribution of *E.*



FIGURE 9. An adult specimen of *Eublepharis hardwickii* (Prakash et al., 2014).

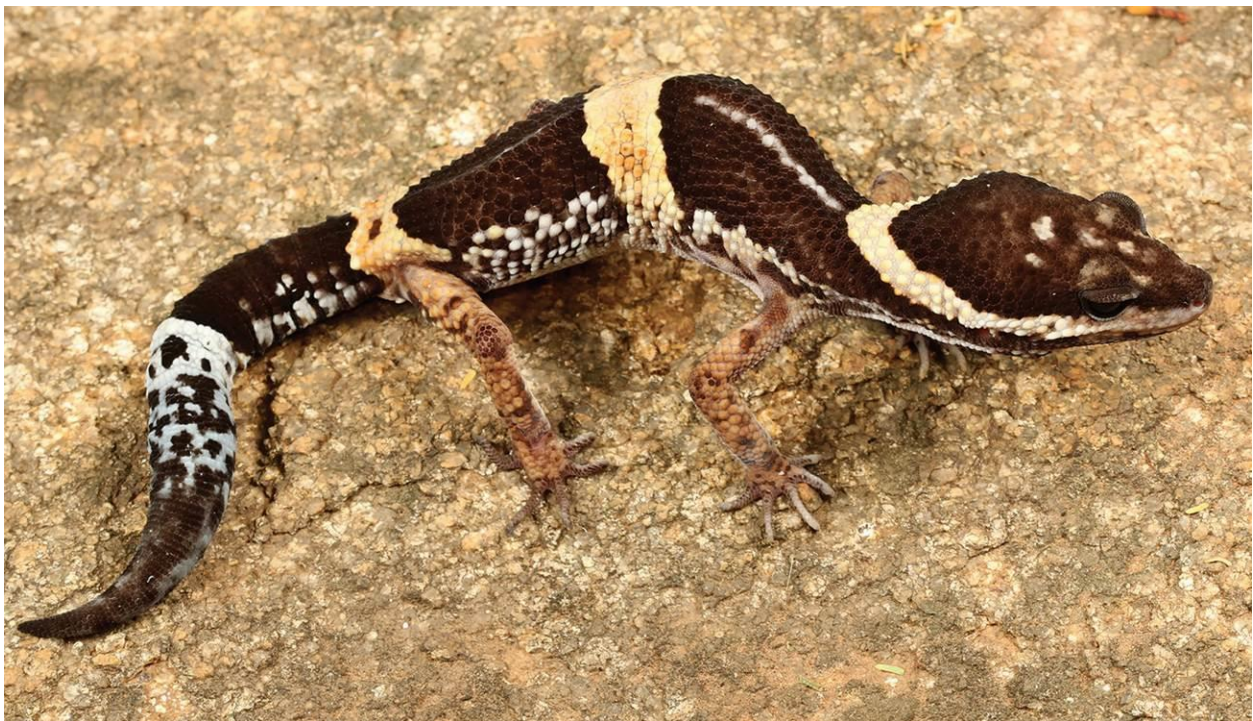


FIGURE 10. An adult specimen of *Eublepharis pictus* (Mirza and Gnaneswar 2022).

angramainyu and showed that it is restricted to the western and south-western regions of the Iranian Plateau, north-eastern Iraq, and southern Turkey to the Levant had a wide variety of area suitability for *E. angramainyu*.

Eublepharis macularius has been the subject of numerous studies, including: physiology and behavior (Viets et al., 1993; Flores et al., 1994; Sakata et al., 2002; LaDage and Ferkin, 2006; Starostov´a et al., 2009; Pallotta et al., 2017); embryology (Thorogood and Whimster, 1979; Crews et al., 1998; De Vosjoli et al., 2005; Wise et al., 2009; Xiong et al., 2016); phenotypic evolution (Kiskowski et al., 2019). Few studies such as record reports (Ananjeva et al., 2006; Auer et al., 2008), and captive breeding (Kaverkin and Orlov, 1996) have been published for *Eublepharis turcmenicus*. As previously mentioned, *E. fuscus* was first introduced as a subspecies of *E. macularius* by Borner (1981), but due to its several morphological differences with known congeners, and it was elevated to a full species by Das (1977).



FIGURE 11. An adult *Eublepharis satpuraensis* (Naidu et al., 2020).

Although *E. hardwickii* is the type species of the genus *Eublepharis* Gray 1827, but it has not been subject of any further studies. *Eublepharis pictus* and *E. satpuraensis* have recently described based on molecular and morphological studies, however they need to be more studied in future, although recorded range extension of *E. satpuraensis* (Basak et al., 2017; Naidu et al., 2020).

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