



Morphology, Biology, and Distribution of *Ichthyophis kodaguensis* (Amphibia:Gymnophiona), a Rare Caecilian from the Western Ghats, India

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Abstract

Of the amphibian orders, the Gymnophiona (caecilians) have the smallest number of species and are the least known. We report new information on the morphology, biology, range, and distribution of *Ichthyophis kodaguensis*, a striped ichthyophiid caecilian from the Western Ghats, India, that shows the first evidence of possible sexual dimorphism in this species. Based on the clutch size, limited range, relatively low fecundity, and agricultural practices in their habitats, we consider that *I. kodaguensis* is highly threatened when compared to other striped ichthyophiids from the Western Ghats biodiversity hotspot.

Introduction

The order Gymnophiona (caecilians) includes 221 described species distributed globally throughout most tropical and subtropical regions (Frost 2023). Caecilians are legless, and elongate amphibians; most species are primarily subterranean when adults, but a few species are semiaquatic (Taylor 1968). Of the ten recognized Gymnophiona families (Wilkinson et al. 2011; Kamei et al. 2012), the family Ichthyophiidae Taylor 1968 includes 57 described species in two genera: *Ichthyophis* (Fitzinger 1826), with 49 species, and *Uraeotyphlus* (Peters 1880) with eight species (Gower et al. 2008, Venu et al. 2020a, 2021a; Lalremsanga et al. 2021a). The genus *Ichthyophis* includes 29 striped species, distinguished by a lateral yellow stripe, and 20 unstriped species (Geissler et al. 2015; Wangyal et al. 2021; Lalremsanga et al. 2021b; Frost 2023). The genus *Ichthyophis* is endemic to Asia and is widely distributed in parts of India and south and southeast Asia, but not east of Wallace’s line (Taylor 1968; Nussbaum and Wilkinson 1989; Wilkinson et al. 2007; Frost 2023). *Uraeotyphlus* is endemic to the State of Kerala, in the southern Western Ghats, India (Wilkinson and Nussbaum

1996; Gower and Wilkinson 2007; Venu et al. 2011; Venu and Venkatachalaiah 2013).

Ichthyophis kodaguensis, commonly known as the Kodagu Striped Ichthyophis, inhabits the southern Western Ghats, and is the most recently described *Ichthyophis* species based on six females from Venkids Valley Estate, Coorg District of southern Karnataka, India, and a single female collected from an unspecified location (Wilkinson et al. 2007). Two specimens of *I. kodaguensis* of unspecified sex (Bhatta et al. 2011) were then reported from Basarekattae, Koppa Taluk, Chikkamagalur District of Karnataka about 125 km to the north of the type locality. Recently, Venu (2013) described karyotypic details of *I. kodaguensis* based on conventionally and differentially stained mitotic and meiotic chromosomes and Venu et al. (2021a) reported leucism in a female specimen of *I. kodaguensis* collected from Hegde Coffee Plantation (12.4730°N, 75.7808°E), located about 0.5 km north of Venkids Valley Estate, the type locality of *I. kodaguensis*. Due to its rarity, subterranean and fossorial habit, many aspects of the life history and the threats to *I. kodaguensis* are unknown (Wilkinson et al. 2007; Venu 2008;

Venu and Venkatachalaiah 2012; Bhatta et al. 2011; Venu et al. 2020b; 2021a), a lack of knowledge typical for many other Gymnophiona throughout their range (Himstedt 1996; Gower and Wilkinson 2005; Gomes et al. 2012; Venu et al. 2022).

In this paper, we present new data on *Ichthyophis kodaguensis*, a rare striped ichthyophiid caecilian from the Western Ghats of India, including its morphology, biology, range, and distribution. Based on the measurements of total length, body mass, and color pattern obtained from the sole male specimen of *Ichthyophis kodaguensis* known to date, we report male-biased sexual dimorphism for the order Gymnophiona for the first time.

Material and methods

A total of four specimens, three female and one male adult *I. kodaguensis* were collected between 2004–2012 during the monsoon seasons from four well-maintained coffee estates: Venkids Valley Estate (12.2619°N, 75.6892°E); Bolamudi Estate (12.2102°N, 75.4007°E); Sampigekhan Estate (13.3301°N, 75.4133°E); and Maskalmerdi coffee plantations (13.3481°N, 75.4155°E), situated in parts of the southern Western Ghats (Fig. 1). The collections were a part of cytogenetic analyses of caecilians of the Western Ghats, India (Venkatachalaiah and Venu 2002; Venu 2008; Venu and Venkatachalaiah 2012). Sampling was done, with permission from the landowners, by digging in loose and humus-rich soil or by the sides of perennial streams in the estates, with bladed hoes to a depth of up to ca. 30–45 cm and/or raking through leaf litter accumulated among the coffee plants and overturning the logs and stones (Fig. 2). Of the four specimens, one female (BUB1145) was collected from Venkids Valley Estate, the type locality for *I. kodaguensis*, and Bolamudi Estate situated about 10 km south of Venkids Valley Estate yielded one female (BUB1273). Sampigekhan Estate and Maskalmerdi coffee plantations, Tarikere Taluk, Chikkamagalur District, Karnataka, yielded one female (BUB1146) along with a clutch of 14 eggs and one male (BUB1308), (Fig. 3). Maskalmerdi

coffee plantations and Sampigekhan Estate are situated about 142 km and 145 km north of the type locality for *I. kodaguensis*, respectively. Basarekattae (13.3460°N, 75.3560°E), situated about 125 km to the north of Venkids Valley Estate, is the farthest recorded locality for *I. kodaguensis* to date. Our current findings of *I. kodaguensis* from Sampigekhan Estate and Maskalmerdi coffee plantations further extend the range distribution for *I. kodaguensis* ~145 km from its type locality,

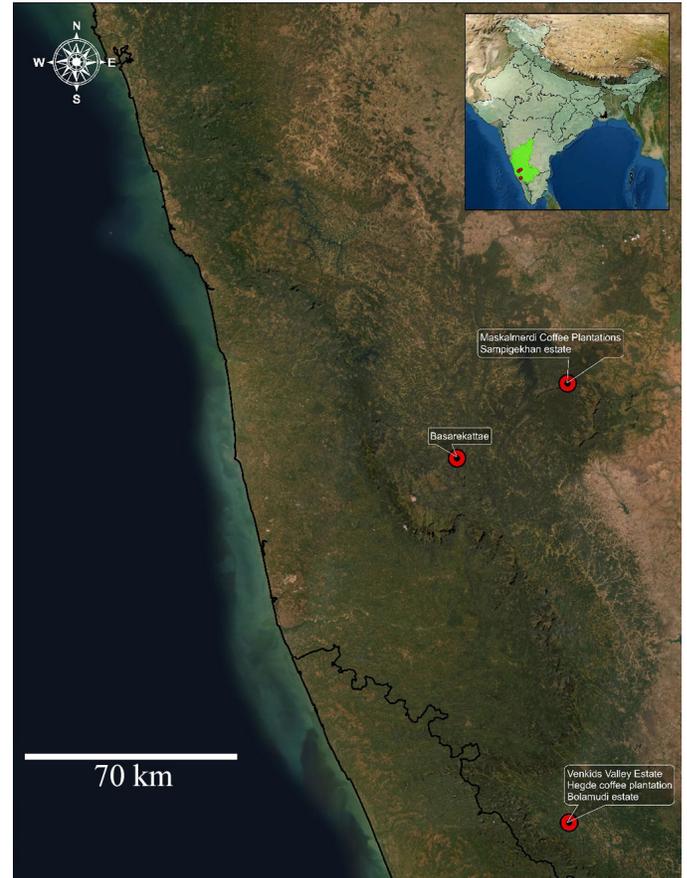


Figure 1. Map showing old and new localities for *I. kodaguensis* in southern Western Ghats, Karnataka, India. Sampigekhan Estate and Maskalmerdi Coffee Plantations, two new localities extend the range of *I. kodaguensis* by 20 km. Photograph by Govindappa Venu.

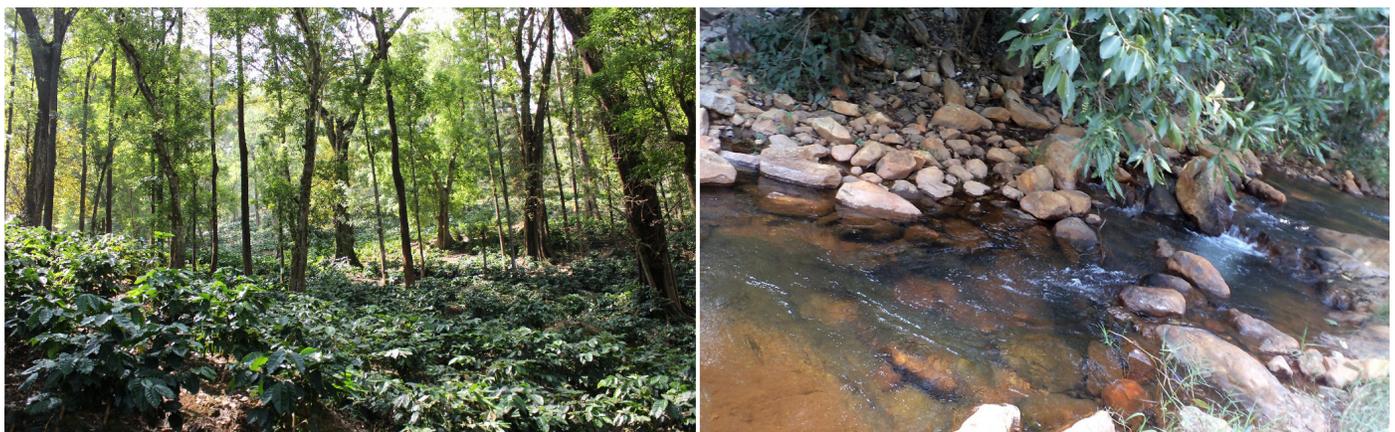


Figure 2. Type locality at Bolamudi Estate (left) and Maskalmerdi Coffee Plantations (right), two new localities for *I. kodaguensis*. Photograph by Govindappa Venu.



Figure 3. Dorsolateral views of female, BUB1146 (left) and male, BUB1308 (right) *I. kodaguensis*, in life. Photograph by Govindappa Venu.

and 20 km from its previous range at Basarekattae (Bhatta et al. 2011) (Fig. 1).

Specimens were transported in polythene bags to Bangalore University, then euthanized using 0.5% anaesthetic MS-222 (tricaine) and photographed in daylight using a Canon EOS 1200D DSLR camera fixed to a tripod stand (Fig. 3). Body mass of the specimens was measured to the nearest 0.1g using a portable pocket balance and, total length (TL) measured using thread and a ruler. Specimens were then fixed for 24 hrs in 10% formaldehyde solution, and then washed under running tap water, and stored in 90% alco-

hol. Sexes were assessed by examination of gonads through small incisions in the body wall. The specimens were identified as *I. kodaguensis* by referring to the species description and to the keys of Wilkinson et al. (2007) and Bhatta et al. (2011). Notes were taken on the color and extent of the stripe, the disc surrounding the vent, and the terminal cap by observing the specimens under a stereo zoom microscope. Morphometric and meristic data were recorded from the preserved specimens following the methods of Wilkinson et al. (2007: Table 1). The relative ratios of linear or linear derived meristic data were compared between the longest female

Table 1. Morphometric and meristic data for the three female and one male specimen of *I. kodaguensis*.

Character	BUB1145	BUB1146	BUB1273	BUB1308
Sex	F	F	F	M
Total length (mm)	222	260	279	306
Body mass (g)	11.85	16.03	17.92	24.98
Head length (mm)	8.3	9.66	10.55	11.98
Head width at eye (mm)	5.48	5.7	5.74	6.73
Head width at jaw angle (mm)	6.1	6.55	6.54	8.11
Head width at the back of the head (mm)	6.23	6.33	7.53	8.18
Distance between eye and tip of the snout (mm)	5.02	4.71	4.57	5.61
Distance between eyes (mm)	4.98	4.86	4.97	5.99
Distance between the nostril and upper lip (mm)	0.72	0.75	0.63	0.89
Distance between tentacles (mm)	4.34	4.76	4.62	5.59
Midbody circumference (changed to the area in excel as this relates better to weight than circumference) (mm)	22 (38.5)	26 (53.8)	28 (62.4)	35 (97.5)
Length of ventral disk (mm)	1.39	1.36	1.97	1.08
Width of ventral disk (mm)	0.68	0.96	1.18	0.81

Table 2. Morphometric ratios for the largest female (BUB1273) and male (BUB1308) *I. kodaguensis*.

Character	Ratio
Total length (mm)	1.09
Body mass (g)	1.39
Head length (mm)	1.13
Head width at eye (mm)	1.17
Head width at jaw angle (mm)	1.24
Head width at the back of the head (mm)	1.08
Distance between eye and tip of the snout (mm)	1.22
Distance between eyes (mm)	1.20
Distance between the nostril and upper lip (mm)	1.41
Distance between tentacles (mm)	1.20
Midbody circumference (changed to the area in excel as this relates better to weight than circumference) (mm)	1.25
Length of ventral disk (mm)	0.54
Width of ventral disk (mm)	0.68

and the male (Table 2). The study was conducted according to the guidelines of the ethical committee, Department of Zoology, Bangalore University, Bengaluru, Karnataka, India. The vouchered male (BUB1308) and female (BUB1145, BUB1146, BUB1273) specimens are deposited in the collections of the Department of Zoology, Bangalore University, Bengaluru (BUB), Karnataka, India.

Results

The lone male (BUB1308; 306 mm total length) was much larger than the females, at 27 mm longer than all known

specimens, including the specimens described here. The male had a body mass of 25 g, its diameter was 11.3 mm, its circumference was 35 mm at mid-body, compared to the three females' averages of 253 mm total length, 15.3 g, 8.8 mm diameter, and 25.3 mm circumference. With total length ratios adjusted between the longest female and the male, all head measurements for the male were larger (Table 1).

In both the sexes, the lateral stripe starts between the eye and jaw angle and then runs along the body till the end of the vent with one exception, where it is absent both at the first and second nuchal grooves in males, but present at the second nuchal groove in females (Fig. 3). In life, the lateral stripe is dark royal purple in females and was brownish purple in the males. Under preservation, the lateral stripe was beige yellow in females, almond brown in males and the ventral surface was mauve purple in females and cinnamon brown in males (Fig. 4).

Other sexual dimorphisms in *I. kodaguensis* included the disc surrounding the vent being cone-shaped in the male and sub-circular in females. In addition, in females, a nipple-like terminal cap is present at the end of the body, whereas in males the body tapers towards the end and is more pointed at its tip (Fig. 5).

Discussion

Coffee, one of the most significant plantation crops, is grown on over 292,000 acres mostly in southern India and brings in more than \$200 million in foreign money annually (Hegde et al. 2019). Because of the low temperature, year-round availability of water, and high organic soil content in coffee agroecosystems, many notable species of soil fauna, including caecilian amphibians, find a comfortable life there (Bhatta 1997; Venu 2008). However, coffee growers frequently employ agrochemicals to protect their crop from insect pests, which



Figure 4. Magnified views of the head of female (left) and male (right) *I. kodaguensis*, highlighting: the presence of lateral stripe on second nuchal groove in female and variations in dorsal, ventral and lateral stripe coloration in female and male specimens upon preservation. Scale bars = 1 cm. Photograph by Govindappa Venu.



Figure 5. Cloacal Disk shape and tail tip variation in *I. kodaguensis*: sub-circular in female (left) and cone shaped in male (right), tip of the body with a nipple-like cap in female (left) and a narrowly pointed tail in male (right). Scale bar = 1 cm. Photograph by Govindappa Venu.

has a detrimental effect on animals that are not the intended target (Hebrard et al. 1992; de Silva 2011). Recent research has shown that the amphibian species that live in the contaminated soil and water bodies in coffee plantations exhibit notable anomalies, a decline in health, and a significant decline in species richness and abundance (Rathod and Rathod 2013; Hegde and Krishnamurthy 2014; Venu et al. 2022).

To the best of our knowledge, there is no report of male-biased sexual dimorphism in lengths or color in Gymnophiona, and our sample size is too small to prove this in *I. kodaguensis*. However, the color pattern between the male and females was distinct, with the females having a broader dark grey dorsal color and a narrower yellow lateral stripe than males, and the males a dark grey color with mottled spots on the back (Fig. 3). The known clutch sizes among caecilians ranges from 3–144 (Pincheira-Donoso et al. 2021). The clutch size of *I. kodaguensis* was 14 eggs (Fig. 6), which is a much lower clutch size than the other Western Ghats species, *I. beddomei* (n = ~30 eggs) and *I. bombayensis* (n = ~60 eggs) (Seshachar et al. 1982; Bhatta 1999; Jadhav et al. 2007). According to Pincheira-Donoso et al. (2021), amphibians with lower fecundity are more predisposed to extinction risk than those with larger clutch sizes.

We consider *I. kodaguensis* as highly threatened based on the species' small clutch size in comparison with other ichthyophiids (Seshachar et al. 1982; Bhatta 1999; Jadhav et al. 2007; Venu 2008), and its apparently sparse populations and limited range (Wilkinson et al. 2007; Bhatta et al. 2011; Venu 2013; Venu et al. 2020b; 2021a). However, the species is currently listed as a Data Deficient species according to the recent IUCN Global Red List (Venu et al. 2020b). Clearly, there is a need for more comprehensive assessments of the threats and conservation status of not just *I. kodaguensis*, but all *Ichthyophis* species in the Western Ghats and additional extensive surveys to better delineate their range. Of all the *Ichthyophis* species from the southern Western Ghats regions of peninsular India, *I. kodaguensis* is the rarest among

the striped ichthyophiids, with only 14 known specimens to date. From a conservation point of view, *I. kodaguensis* should be an immediate target for a conservation breeding program for its *ex-situ* management (Browne et al. 2022; Karthikeyan et al. 2022).

The body of literature about ichthyophid caecilians is rapidly growing, especially in the southern Western Ghats. Recent findings include the unusual diet of *Ichthyophis* caecilians (Venu et al. 2016), first records of *I. longicephalus* from the states of Karnataka and Tamil Nadu (Venu et al. 2020a), leucism in *I. kodaguensis* (Venu et al. 2021a), B chromosomes in *U. gansi* (Venu et al. 2021b), and anomalies in Gymnophionans from India (Venu et al. 2022). It is clear that the southern Western Ghats in general, and the Coorg and Chikkamagalur Districts of Karnataka in particular, are highly productive regions for future Gymnophiona research.

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Figure 6. Egg clutch size in *Ichthyophis* caecilians at different developmental stages, from Western Ghats: Early clutch in *I. beddomei* (left), Intermediate clutch in *I. bombayensis* (center) and Late clutch in *I. kodaguensis* (right). Photograph by Govindappa Venu.

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