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New records and potential geographic distribution of Elongated Caecilian, *Ichthyophis elongatus* Taylor, 1965 (Amphibia, Gymnophiona, Ichthyophiidae), endemic to West Sumatra, Indonesia

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Abstract

We present new records of *Ichthyophis elongatus* Taylor, 1965 in West Sumatra. These records extend the known distribution of the species which was previously only known from the type locality in Padang, West Sumatra. We assess the morphology and habitats of this species and estimate its distribution. Predicted distribution based on maximum entropy modeling suggests a highly suitable habitat for the species throughout the Barisan Mountains at 500–1000 m above sea level. Our models suggest swamps, paddy fields, and secondary forests that are 100–150 m from rivers as the highest possible habitats for the species. Further surveys in two predicted areas based on the models discovered new populations of the species.

Keywords

Conservation, herpetofauna, spatial distribution model

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Introduction

Caecilians are the most poorly known group amongst all the members in the class Amphibia. Due to their fossorial habits, caecilians are challenging to find and, therefore, we lack comprehensive knowledge about their natural history and abundance (Wilkinson and Nussbaum 1999; Kupfer et al. 2004; Gower and Wilkinson 2005; Wang et al. 2015). Caecilians belong to the order Gymnophiona and are characterized as follows: legless, worm-like body, smooth skin, reduced eyes, a pair of tentacles between the eyes and nostrils, and mostly restricted to tropical forest areas (Gudyna et al. 1988). The general morphology of caecilians shows adaptations to fossorial life. However, some species are semi-aquatic, such as *Chthonerpeton indistinctum* (Reinhardt & Lütken, 1862) (Measey and Di-Bernardo 2003), or fully aquatic, such as the members of the genus *Typhlonectes* Peters, 1880 and *Potomotyphlus* Taylor, 1968. In Sumatra, there are currently six described species, all belonging to the genus *Ichthyophis* Fitzinger, 1826: *I. elongatus* Taylor, 1965, *I. nigroflavus* Taylor, 1960, *I. paucidentulus* Taylor, 1960, *I. paucisulcus* Taylor, 1960, *I. sumatranus* Taylor, 1960 and *I. billitonensis* Taylor, 1965 (Taylor 1960, 1965; Amphibian Species of the World 2020; AmphibiaWeb 2020).

Ichthyophis elongatus Taylor, 1965, is only known from the type locality in Padang, West Sumatra. The species is considered Data Deficient by the International Union for the Conservation of Nature (IUCN SSC Amphibian Specialist Group 2018). In addition, no single occurrence is available in Global Biodiversity Information Facility (https://www.gbif.org/) and the publications about the species has no geographic coordinates (Teynie et al. 2010). To support field sampling efforts, the maximum entropy algorithm (Phillips et al. 2006; Elith et al. 2011) was used to identify the potential distribution of *Ichthyophis elongatus*. The software MaxEnt was chosen as it gives satisfactory prediction with small numbers of occurrences (Yi et al. 2016; Ramos and Torres 2011; Adhikari et al. 2012; Yang et al. 2013; Padalia et al. 2014; Remya et al. 2015; Yuan et al. 2015; Pranata et al. 2019). The generated map from MaxEnt could be useful for future studies on *I. elongatus* specifically, and other Sumatran caecilians in general.

Methods

Field surveys and recording of ecological parameters. We conducted field surveys in four localities in West Sumatra: Padang (5–8 August 2017), Solok (20 December 2018), Tanah Datar (6–9 March 2019), and Pasaman (20–24 February 2020). We actively searched for caecilians by digging in soil with hoes, flipping rocks, leaf litter, and decaying plants, during daytime (09:00 AM–04:00 PM). The targeted habitats were trash dumps, paddy fields, riverbanks, and secondary forests. All the habitats were affected by low to high anthropogenic activities. Geographic coordinates (recorded with a Garmin GPS 64s), pH, and soil moisture (measured with a Takemura Soil tester dm 15) were recorded for each site where an individual was found (Table 1).

Morphological measurements. We euthanized the specimens with tricaine methanesulfonate (MS-222), fixed with 10% formalin and stored them in 70% ethanol. We followed the morphological measurements and diagnosis established by Taylor (1965) to identify the species as *I. elongatus* (Fig. 1). The characters are as follows: number of transverse folds (TF), number of maxillary-premaxillary teeth (MT), number of splenial teeth (ST), total length (TL), tail length (TAL), body width (WB). All the specimens were deposited in the Zoology Museum of Andalas University Padang, West Sumatra (MZA.Amph.0188-0189; 0311-0326).

Figure 1. A. *Ichthyophis elongatus* Taylor, 1965 from Pasaman, West Sumatra, Indonesia. **B.** Yellow stripe broken on collar region (MZUA.Amph.0325). Photo: Thoriq Alfath.

Table 1. Mensural and meristic data of *Ichthyophis elongatus* specimens collected in West Sumatra. Transverse folds (TF), number of maxillary–premaxillary teeth (MT), number of splenial teeth (ST), total length (TL), tail length (TAL), width of body (WB).

Voucher code	TL (mm)	TAL (mm)	WB (mm)	TF	MT	ST	Latitude	Longitude	Locality	New record site
MZA.Amph.0311	208	2.29	8.01	311	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0312	242	2.07	9.24	287	64	32	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0313	282	2.46	9.79	317	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0314	224	2.30	8.31	309	62	32	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0315	237	1.96	8.20	309	66	32	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0316	285	2.67	9.85	309	64	32	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0317	248	2.36	9.33	317	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0318	239	2.52	9.80	311	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0319	181	1.97	6.96	311	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0320	256	3.40	10.65	307	64	28	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0321	247	2.09	8.35	295	64	32	−00.3716	100.6022	Tanah Datar	1
MZA.Amph.0322	205	1.70	7.03	302	64	32	00.0288	100.1434	Pasaman	2
MZA.Amph.0323	154	0.97	5.86	297	64	28	00.0295	100.1426	Pasaman	2
MZA.Amph.0324	216	1.79	7.13	299	64	32	00.0288	100.1434	Pasaman	2
MZA.Amph.0325	235	1.89	9.10	312	66	32	00.0288	100.1434	Pasaman	2
MZA.Amph.0189	181	1.52	4.86	306	60	28	00.0288	100.1434	Pasaman	2
MZA.Amph.0188	168	1.67	4.68	268	64	28	−00.9055	100.6674	Solok	3
MZA.Amph.0326	299	2.18	10.21	319	64	32	−00.9092	100.4615	Padang	—
N.M.W.No.9094	290	3.40	7.60	274	64	28	—	—	Padang (Taylor 1965)	—
N.M.W.No.9092	270	3.50	8.00	287	57	32	—	—	Padang (Taylor 1965)	—

Species distribution modelling (SDM). We used a total of 18 occurrences recorded from our field surveys and unpublished records from surveys conducted by students at Andalas University, West Sumatra. The following spatial variables were included as predictors into the model: elevation, distance to the nearest river, land cover, and climatic variables. Elevation was derived from a digital elevation model (DEM) was obtained from SRTM (2020), distance from rivers was obtained from Indonesia Geospatial Portal (2020), land cover was obtained from Global Forest Watch (2020), and climatic variables were downloaded from Worldclim (2020). We used PCA to exclude highly correlated environmental variables. If two environmental variables were significantly correlated (value >0.8), only one was selected as a predictor. Raster data were resampled into the same dimension and were clipped to latitude −03.3500 to 00.9074 and longitude 098.5967 to 101.8929 using the Raster package (Hijmans 2015). We followed the recommended default values that were used for the convergence threshold ($<10^{-5}$) and a maximum number of 500 iterations (Pearson et al. 2007). On MaxEnt configurations, background samples were used for determining a good species location (Merow et al. 2013) with 10 replications based on subsamples.

We used the GeoCat Redlisting tool (Bachman et al. 2011) to assess the extinction risk of *I. elongatus* based on our combined field survey data. The analysis focuses on two aspects of the geographic range of a taxon: the extent of occurrence (EOO) and the area of occupancy (AOO). We used the standard IUCN cell size of 4 km^2 to derive AOO of this species.

After we generated a prediction map for *I. elongatus*, we undertook ground validation of the species distribution model by conducting further sampling at two locations predicted to be within the suitable range of the species (Sangir in Solok Selatan District and Surian in Solok District).

Results

Ichthyophis elongatus Taylor, 1965

New records. INDONESIA • 11 adults; Tanah Datar District, Sungayang; −00.3716, 100.6022; alt 475 m; 6–9 Mar. 2019; T.S Harapan et al. leg.; observed under rotten vegetation, local's garden, trash dumps, river; MZA. Amph.0311, MZA.Amph.0312, MZA.Amph.0313, MZA. Amph.0314, MZA.Amph.0315, MZA.Amph.0316, MZA. Amph.0317, MZA.Amph.0318, MZA.Amph.0319, MZA. Amph.020, MZA.Amph.021 • 5 adults; Pasaman District, Jorong Simpang; 00.0288, 100.1434; alt 475 m; 20–24 Feb. 2020; T.S Harapan et al. leg.; observed in human settlement nearby paddy field; MZA.Amph.0322, MZA. Amph.0323, MZA.Amph.0324, MZA.Amph.0325, MZA. Amph.0189 • 1 adult; Solok District, Koto Anau; −00.9055, 100.6674; alt 475 m; 20 Dec. 2018; M.J Putra leg.; observed in paddy field; MZA.Amph.0188.

Identification. The diagnostic characters of *I. elongatus* are the head a little wider than the body, a narrow lateral yellow stripe broken on the collar region (Fig. 1B), and acuminate tip of tail. In our specimens, the number of maxillary–premaxillary teeth was 62–66; the number of splenial teeth was 28–32; the number of transverse folds ranged from 287–319, and tail length ranged from 0.97–3.50 mm. These values are consistent with *I. elongatus* from Taylor (1965).

Comparison to related species indicates that the presence of splenial teeth distinguishes *I. elongatus* from *I. paucidentulus*, the number of transverse folds distinguishes *I. elongatus* from *I. paucisulcus* (250) and *I. nigroflavus* (416), and the presence of lateral stripes distinguishes *I. elongatus* from *I. sumatranus* and *I. biltonensis.* The stripe is broken at the neck similarly to *I. glutinosus,* but *I. elongatus* differs by the following characters: *I. glutinosus* has a longer tail length at 5.4 mm, and has a greater number of transverse folds (359) (Taylor 1960, 1965). All the mensural and meristic trait data and locations data for our specimens are provided in Table 1.

Habitats. The specimens were found in human-dominated landscapes. During the field surveys, *I. elongatus* was found under rotten stumps of *Musa* × *paradisiaca* L. in a house yard near a paddy field, in trash dumps, and some individuals were found under a flower pot in a garden (Fig. 2). The soil at each location where *I. elongatus* was found was slightly acidic (5–6.5) and moist (1.5–8) (Table 2).

Distribution map. The performance of the generated distribution model was rated good based on an AUC value = 0.808. The most important predictors were elevation (66.7%), land cover (17.4%), and distance from rivers (8.3%) (Table 3). Based on MaxEnt analysis, the suitable habitat for *I. elongatus* was about 500–1000 m above sea level and 100–150 m distance from rivers.

Figure 2. Microhabitats of *Ichthyophis elongatus* **A.** Human settlements (under flowerpot). **B.** Under leaf litter. **C.** Rotten vegetation. **D.** Trash dumps. **E.** House yard nearby paddy field.

Table 2. Soil parameter for habitats where *Ichthyophis elongatus* were captured.

Soil pH (scale 3–8)	Soil moisture (scale 1–8)	Land use
5.2 ± 0.2	8.0 ± 3.3	House yard
5.0 ± 0.3	8.0 ± 3.1	Rotten vegetation
6.0 ± 0.4	8.0 ± 0.8	Trash dumps
5.8 ± 0.1	1.5 ± 0.3	Pile of soil
6.5 ± 0.1	6 ± 1.5	River banks

Table 3. Estimates of relative contributions to the potential distribution of *Ichthyophis elongatus*.

Variable	Percent contribution (%)
Elevation	66.7
Land cover	17.4
Distance from rivers	8.3
Temperature seasonality	5.2
Mean diurnal range	2.4

Our SDM also found the highest presence of *I. elongatus* in swamps, paddy fields, and secondary forests. Our model suggested a highly suitable habitat for this species (>0.8) throughout the Barisan mountain range and along the border between West Sumatra and North Sumatra (Siabu, Panyambungan, and Nopan). Lima Puluh Kota and Solok Selatan (Sangir) were indicated as new sites with high probability distribution value.

The extent of occurrence of *I. elongatus* is approximately 4,627 km^2 and the area of occupancy is 4 km^2. According to the GeoCat assessment, *I. elongatus* might be considered as Endangered.

Field survey validation. In this study, after the prediction map was generated, we conducted a field survey to the south. After three days of survey, we discovered a species of unstriped caecilian, with 14 individuals caught in Sangir (P1) and four individuals caught in Surian (P2) (Fig. 4). These individuals were found on the banks of a waterway and in a paddy field. Our initial assessment suggests that these caecilians are a different species from *I. elongatus*, and they are tentatively identified as *I.* cf. *sumatranus*, which is the only completely unstriped *Ichtyophis* species presently known from mainland Sumatra. More detailed studies will be conducted to ascertain the identity of these populations that are presently identified as *I.* cf. *sumatranus*.

Discussion

Our surveys indicated that *Ichthyophis elongatus* are well adapted to living in human-dominated landscapes,

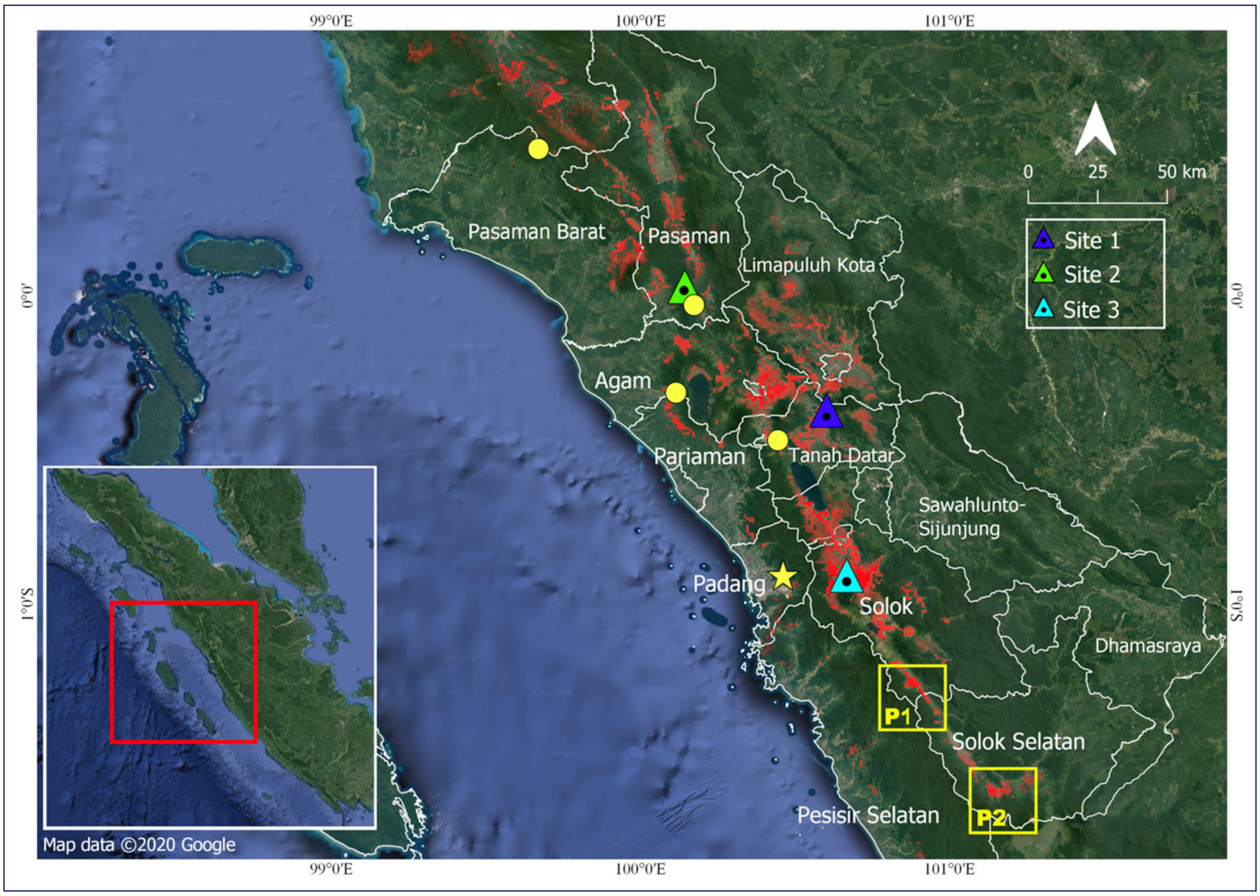

Figure 3. The recorded and predicted geographic distributions of *Ichthyophis elongatus*. Inset map shows the location of the sampling region on Sumatra Island, Indonesia. Symbols indicate collections sites: stars are previously known sites (Padang); triangles are new location records were collected (site 1: Tanah Datar; site 2: Pasaman; site 3: Solok); yellow circles are recorded occurrences from the field survey where specimens were not collected. Sites indicated by the yellow circles and the triangles were used to generate the SDM model. The SDM generated prediction map is provided in red (potential probability value ≥80%). Open yellow rectangles represent areas that were sampled based on the prediction map: P1 - Surian, P2 - in Sangir.

Figure 4. Unstriped *Ichthyophis* cf. *sumatranus*. **A.** From Sangir Solok Selatan District (P2 in Fig. 3). **B.** From Surian, Border between Solok and Solok Selatan Districts (P1 in Fig. 3). Photos: Ade Prasetyo Agung.

which is similar to the findings of Measey et al. (2006), who noted that Uluguru African Caecilian, *Boulengerula uluguruensis* Barbour & Loveridge, 1928, is more abundant in agricultural areas than native forests. Several studies have shown that caecilians are sparse in natural forests (Hebrard et al. 1992; Haft and Franzen 1996). The soil pH range we recorded suggests that *I. elongatus* may prefer mildly acidic soils, which concurs with previous studies that have recorded caecilians in soils with a pH range of 4–7 (Gundappa et al. 1981; Wake et al. 1994; Oommen et al. 2000; Kupfer et al. 2005).

Many studies use SDMs to predict species distributions but do not validate the model with further species sampling (e.g. Padalia et al. 2014; Remya et al. 2015; Pranata et al. 2019). The updated species distribution map for *I. elongatus* (Fig. 3) not only generated predictions of suitable habitat for the distribution of *I. elongatus* but also apparently predicted the distribution of a different caecilian species. This suggests that SDM models may be useful for finding suitable areas to look for new caecilian populations and new caecilian species.

The conservation of most species of caecilians is rarely mentioned, and about 92% of caecilians in Southeast Asia are listed as Data Deficient (Gower and Wilkinson 2005). In West Sumatra, caecilians are threatened by car traffic and direct killing by locals due to their resemblance with snakes.

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Authors' Contributions

TSH conceived the study, conducted field survey, and performed data analyses. APA wrote the manuscript, photographed the specimens, and supported the field survey. HH wrote, commented on, and revised the manuscript. DHT and WN advised for study design, commented on the manuscript, and revised the museum collection. KWT coordinated sampling design and commented on and revised the manuscript.

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