



Natural History of Ghate's Shrub Frog, *Raorchestes ghatei* (Rhacophoridae), from the Northern Western Ghats, India

Amit Sayyed and Anand Padhye

Wildlife Protection and Research Society, 40 Rajaspura peth Satara, Maharashtra, India (amitsayyedsatara@gmail.com)

Photographs by the senior author.

Amphibians employ a remarkable diversity of reproductive strategies (Crump 2010) exhibiting as many as 40 different methods (Gururaja 2010). Reproductive modes are classified based on egg deposition sites, egg type, and patterns of embryonic development (Wells 2007), but classification is difficult and often arbitrary (Lehtinen and Nussbaum 2003). Most anuran reproduction involves aquatic larval stages, but direct development is not uncommon (Stuart et al. 2008). Parental care increases offspring survivorship in species (Trivers 1972) and parental behaviors are highly responsive to changes in the environment (Royle et al. 2014; Seshadri and Bickford 2018). Parental care is uncommon in frogs, Günther's Bush Frog (*Raorchestes chalazodes*; Rhacophoridae) is the only species in the genus in which parental care has been reported, with males attending eggs to protect them from conspecific males (Seshadri and Bickford 2018).

Rhacophorids employ a variety of reproductive modes, with reproduction in the genus *Raorchestes* characterized by direct development. Ghate's Shrub Frog (*Raorchestes ghatei*) is a recently described species from the northern Western Ghats (Padhye et al. 2013), currently known only from the type locality and nearby areas (Fig. 1). Herein we describe the breeding biology and natural history of this little-known species.

Methods

We observed *Raorchestes ghatei* at the type locality of Chalkewadi (17.59°N, 73.84°E; elevation 1,082 m), Satara, Maharashtra, India in June to October 2013 with breeding during August. We used a Yamayo Digimatic Caliper (Yamayo India, Mumbai, India) for morphometric measurements to the nearest 0.1 mm; a PL83-S Mettler Portable Balance (Mettler-Toledo, Columbus, Ohio, USA) for weights to the nearest 0.001 g; an Infrared Thermometer TES1326 (TES Electrical Electronic Corporation, Taipei, Taiwan, ROC) for temperatures of frogs, soil at egg-laying sites, and water in the adjacent stream to the nearest 0.01 °C; and a Mini Environmental Quality Meter 850070 (Sper Scientific, Scottsdale, Arizona, USA) for atmospheric temperatures and relative humidity.

Results and Discussion

Raorchestes ghatei occurs on plateaus, slopes with shrubby vegetation, and in densely forested areas as well as vegetation near human habitation. Peak activity of adults begins with the first rains in early June and continues through the rainy season into October. Males call from trees and bushes, usually beginning around 1800 h but sometimes earlier, and continuing past midnight and often throughout the night. However, some males will call during the day, especially during light rain. Calling often ceases during heavy rainfall. From



Fig. 1. The districts (green) of Maharashtra, India, where Ghate's Shrub Frog (*Raorchestes ghatei*) is known to occur.

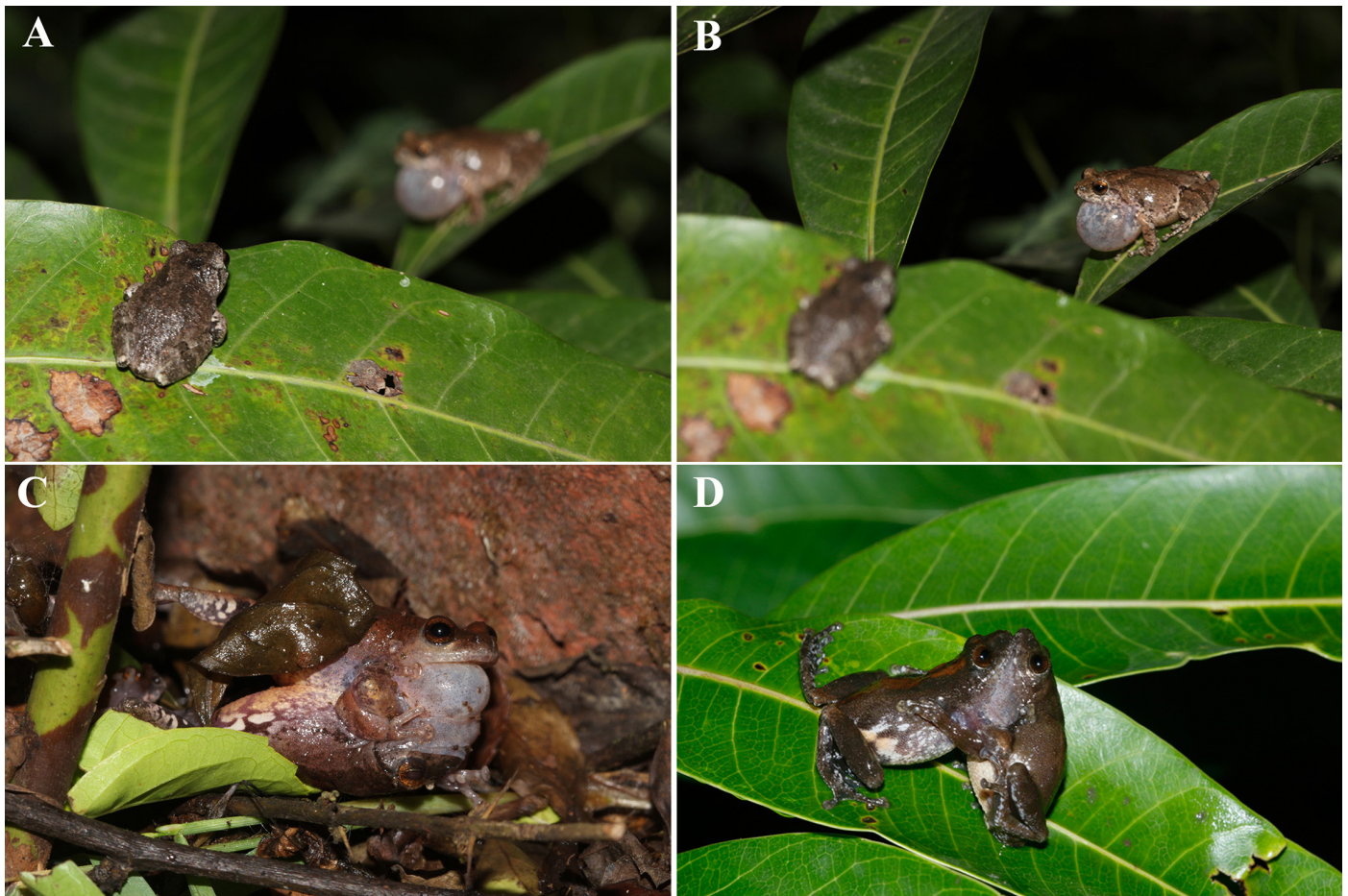


Fig. 2. Territorial behavior of Ghate's Shrub Frog (*Raorchestes ghatei*): Vocalization (A & B) and combat on the ground (C) and on the leaf of a tree (D).

the first showers in June until August, males generally call from low perches close to the ground, where females occur in large numbers. Later in the season, males call from shrubs or trees at heights of 3–5 m. Calling males are territorial, using distinct territorial calls in addition to mating calls to define a territory. They also will resort to fighting to defend territories (Fig. 2), occasionally throwing the loser from the elevated perch. Males that lose vocal interactions or fights sometimes cease calling and remain silent within the territory of a dominant male.

Females were usually on the ground (Fig. 3A). When a female approached a bush with a male emitting the most frequent and loudest calls (Fig. 3B), she climbed the bush (Fig. 3C), approached the male, who mounted her and engaged in axillary amplexus (Fig. 3D). The amplexing pair then descended to the ground and searched for stones (Fig. 3E), beneath which eggs usually are laid. However, if a pair does not find a suitable stone, ovideposition takes place in wet leaf litter on the forest floor (Fig. 3F).

Clutch size is between 40 and 60 eggs (Fig. 4; Table 1). After ovideposition, the male climbs the original bush, assumes the calling position, and starts calling. The female usually leaves the clutch. However, after the monsoon, we

found females guarding eggs under the stone where they were laid. We never encountered this during heavy rains and assume that their presence near eggs after the monsoon is to keep the eggs moist with water or urine (Fig. 5A). If disturbed, a female shows aggressive behavior by elevating her body toward the threat (Fig. 5B), clearly demonstrating that females are protecting their fertilized eggs from potential predators and also maintaining sufficient moisture to assure hatching in less than ideal conditions. In the absence of an attending female, we observed eggs parasitized by insects and subjected to fungal infections.

During this period, we collected and measured a few individuals (Table 2). Females were larger than males. Snout-vent lengths (SVL) of adult males were 21.33–21.93 mm and those of females 25.16–29.69 mm. Padhye et al. (2013) had listed sizes of males as 19.1–25.5 mm and those of females as 15.4–29.8 mm. Weights of males, including subadults, were 0.763–1.089 g, whereas non-gravid adult females weighed 1.124–1.128 g and gravid females 1.131–1.137 g. The abdomens of non-gravid females measured 15.19–15.78 mm, whereas those of gravid females measured 18.82–19.28 mm. Body temperatures of all frogs were 17.05–17.09 °C. Temperatures at which eggs developed were 20–22 °C, soil



Fig. 3. Reproduction in Ghaté's Shrub Frog (*Raorchestes ghatei*): Gravid female (A), calling male (B), female approaching male (C), amplexus (D), amplexing pair searching for an appropriate place to lay eggs (E), and eggs (F).

temperatures where clutches were found were 18.07–19.05 °C, and water temperatures near the egg-laying sites were 20.00–20.05 °C. The average diameter of eggs in the three clutches for which data are available was 2.49–2.53mm. Time required to complete development varied from 21 to 30 days depending on local conditions (Fig. 6; Table 1). Heart rates of froglets were 89–93 beats per minute on day 20. Hatchling frogs in each clutch all emerged within 24–48 h.

We selected one clutch to observe changes in egg diameter and development (Table 3). The outer egg membranes

became increasingly thin and transparent. Eyes of the larvae were initially lateral but migrated dorsally during development of the limbs. Once tails are resorbed, hatchlings are ready to emerge (Fig. 7). Adult frogs were less frequently encountered in September and October when recent hatchlings are abundant. Calling decreased noticeably in December.

Prey of adult frogs included crickets (adults and nymphs), grasshoppers, other small insects, and small spiders. Hatchlings fed on mosquitoes and other small insects. We observed the Saw-scaled Viper (*Echis carinatus*), Bamboo

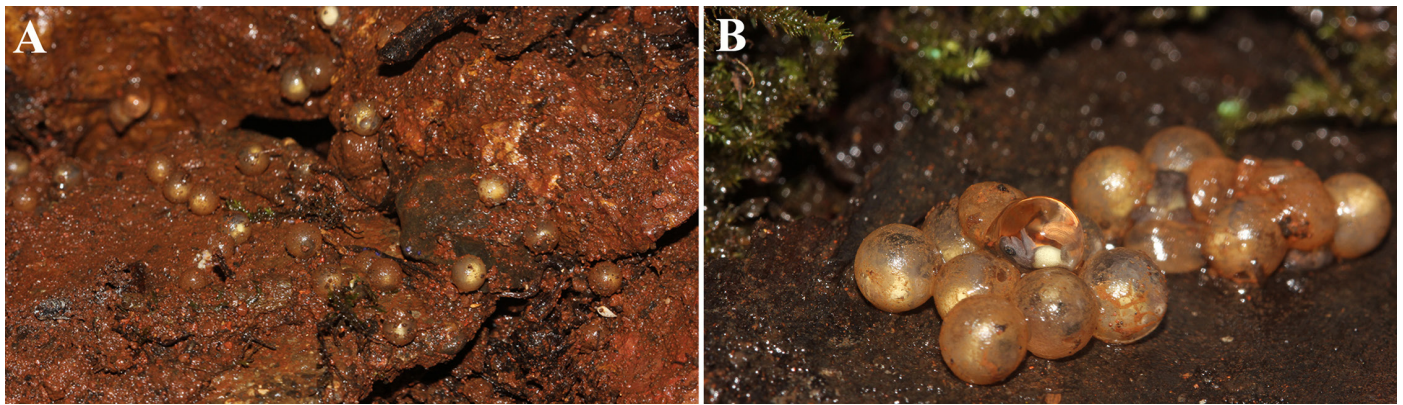


Fig. 4. Two egg clutches of Ghate's Shrub Frog (*Raorchestes ghatei*).

Table 1. Data from three egg clutches of Ghate's Shrub Frog (*Raorchestes ghatei*) at Chalkewadi, Satara.

Date of Oviposition	Site	Clutch Size	Egg Diameter (mm)	Date of Hatching	Duration
21 July 2013	under a stone	59	2.50–2.53	16–18 August 2013	29 days
27 July 2013	leaf litter	43	2.49–2.54	18–20 August 2013	25 days
07 August 2013	under a stone	54	2.49–2.52	27–28 August 2013	21 days

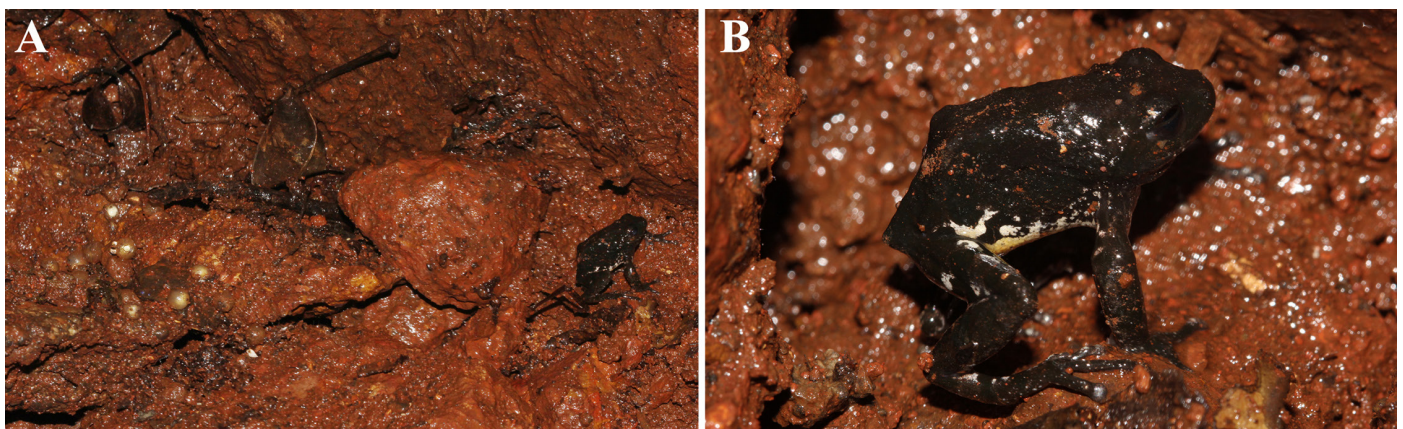


Fig. 5. Female Ghate's Shrub Frog (*Raorchestes ghatei*) protecting her eggs.

Table 2. Morphometric data for Ghate's Shrub Frog (*Raorchestes ghatei*) at Chalkewadi, Satara. SVL = snout-vent length. Dashes indicate not-applicable information.

Sex	Remarks	SVL (mm)	Weight (g)	Temperature (°C)	Abdominal Girth (mm)	
					Before Oviposition	After Oviposition
M	—	21.88	1.081	17.09	—	—
M	—	21.33	0.912	17.07	—	—
M	subadult	18.71	0.763	17.08	—	—
M	—	20.68	0.869	17.07	—	—
M	—	21.93	1.089	17.06	—	—
F	gravid	25.66	1.131	17.09	18.82	15.34
F	gravid	29.69	1.137	17.08	19.28	15.78
F	gravid	27.36	1.134	17.09	19.13	15.46
F	non-gravid	25.16	1.124	17.09	—	15.19

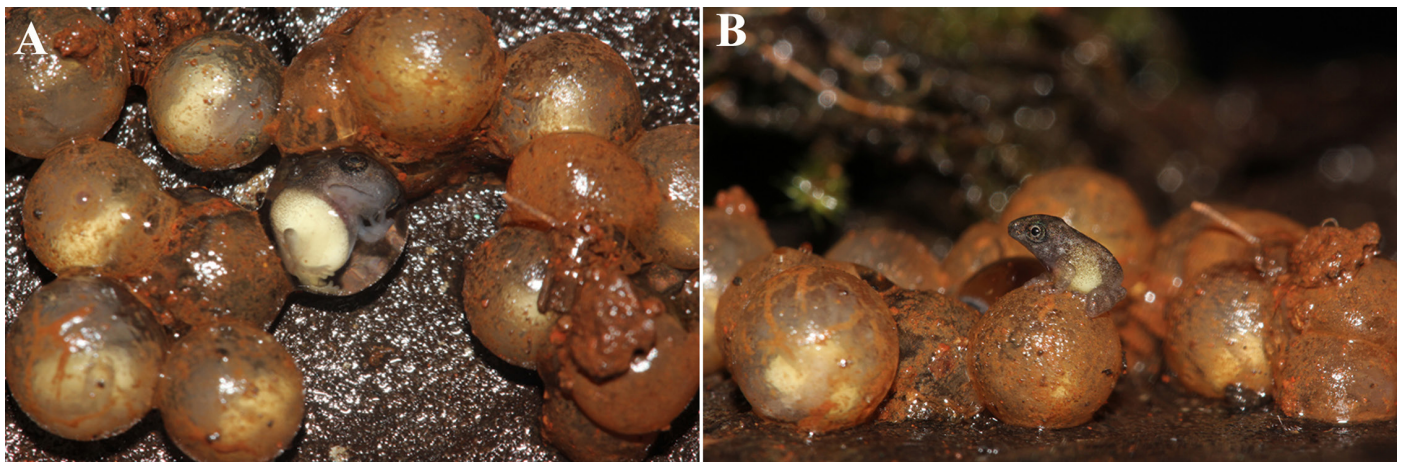


Fig. 6. Development of Ghate's Shrub Frog: Larvae in eggs (A) and an emergent froglet (B).

Table 3. Ghate's Shrub Frog (*Raorchestes ghatei*) eggs and hatchlings in one clutch at Chalkewadi, Satara. All measurements in mm.

Date	Day	Egg Diameter				
		Egg 1	Egg 2	Egg 3	Egg 4	Egg 5
07 August 2013	1	2.50	2.49	2.50	2.52	2.50
08 August 2013	2	3.20	3.20	3.20	3.21	3.20
12 August 2013	6	3.41	3.40	3.41	3.43	3.41
15 August 2013	9	3.67	3.65	3.66	3.67	3.66
17 August 2013	11	3.90	3.89	3.89	3.91	3.90
20 August 2013	14	4.28	4.26	4.28	4.29	4.26
23 August 2013	17	4.42	4.40	4.41	4.43	4.42
25 August 2013	19	4.58	4.56	4.57	4.60	4.58
28 August 2013	22	4.71	4.69	4.72	4.74	4.72
		Hatchling SVL				
28 August 2013		4.27	4.21	4.35	4.47	4.33

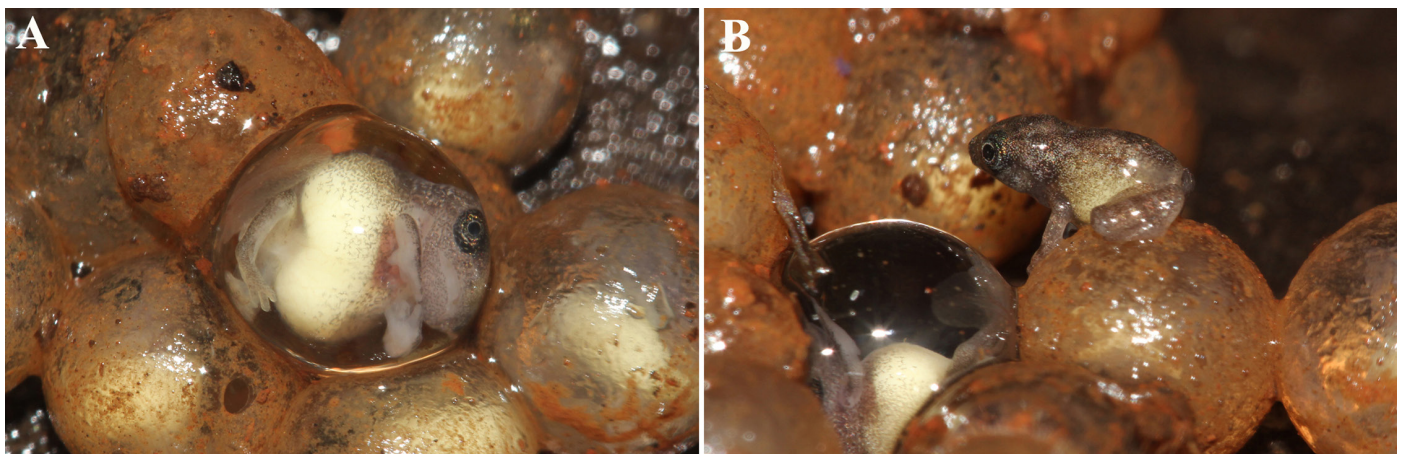


Fig. 7. Development of Ghate's Shrub Frog: Limb formation and degenerating tail (A) and an emergent froglet (B).

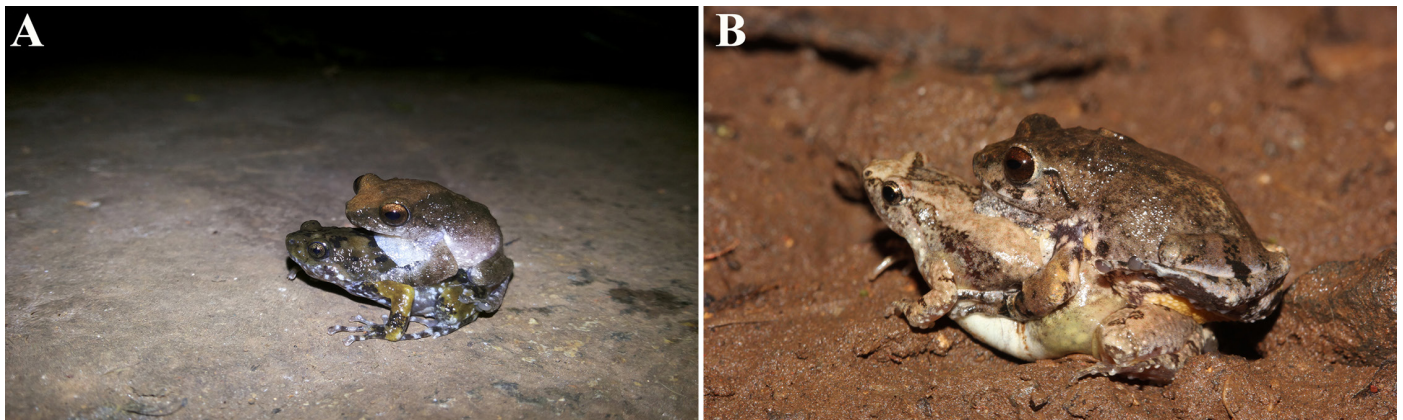


Fig. 8. Interspecific amplexus: Male Ghat's Shrub Frogs (*Raorchestes ghatei*) in amplexus with a female Mottled Globular Frog (*Uperodon marmoratus*; Microhylidae) (A) and with a gravid female Ornate Narrow-mouthed Frog (*Microhyla ornata*; Microhylidae) (B); note the eggs visible in the abdomen of the latter.

Pitviper (*Trimeresurus gramineus*), Changeable Lizard (*Calotes cf. versicolor*), Forest Lizard (*Calotes nigrilabris*), and White-throated Kingfisher (*Halcyon smyrnensis*) preying on *R. ghatei*.

Interspecific amplexus has been reported in the family Rhacophoridae (Sayyed 2013; Sayyed and Nale 2017), and Yadav and Yankanchi (2014) reported intergeneric amplexus between a Maharashtra Bush Frog (*Raorchestes bombayensis*) and an Ornate Narrow-mouthed Frog (*Microhyla ornata*). On 2 October 2015 at Ragnafort, Kolhapur, Abhijit Nale and Devendra Bhosle (Wildlife Protection and Research Society members) observed interspecific amplexus between *Raorchestes ghatei* and a Mottled Globular Frog (*Uperodon marmorata*) (Fig. 8A) and, on 8 November 2015, the senior author encountered a male *R. ghatei* in amplexus with a gravid female *Microhyla ornata*, (Fig. 8B) at Parli, Satara. Interspecific amplexus is most commonly seen in explosive breeders; in some toads (Bufonidae), individuals do not always distinguish the sex of conspecifics and interspecific amplexus between congeners and even confamilial species is a relatively common event (Wells 2007). Contributing factors could include stress triggered by competition for breeding sites or even a disproportionate number of females at some locations (e.g., Machado and Bernarde 2011; Sayyed and Nale 2017).

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