

Observation on rapid physiological color change in Giant tree frog *Rhacophorus smaragdinus* (Blyth, 1852) from Namdapha Tiger Reserve, Arunachal Pradesh, India

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Abstract

Many poikilotherms have the ability to change body color for homeostatic regulation, conspecific communication or predator deterrence. Physiological color change is a rapid, reversible mode of color change regulated by neuromuscular or neuroendocrine system and has been observed in several anuran species. Here we report the occurrence of physiological color change in the tree frog *Rhacophorus smaragdinus* (Blyth, 1852) (Amphibia, Anura, Rhacophoridae) for the first time from Namdapha Tiger Reserve, Arunachal Pradesh, India. Probable proximate causes of the behavior are discussed along with an overview of physiological color change in species of the family Rhacophoridae and nature of color change observed.

Key Words

anuran behavior, reversible color change, camouflage, physiological stress, thermoregulation, Rhacophoridae, *Rhacophorus maximus*, *Theloderma*, *Raorchestes*, *Pseudophilautus*

Introduction

The ability to change body coloration is widespread among poikilotherms and is displayed by a diverse group of animals including cephalopods (Norman 2000, Hanlon 2007), crustaceans (Thurman 1988), insects (Hinton and Jarman 1972, Filshie et al. 1975), fishes (Kodric-Brown 1998), amphibians (King et al. 1994, Garcia and Sih 2003), and reptiles (Cooper and Greenberg 1992).

Based on the mechanism involved, color change can be of two types: (i) morphological color change, which involves changes in morphology and density of pigment-containing cells (chromatophores) in the dermis and occurs at relatively longer time scales spanning from days to months (Sugimoto 2002), and (ii) physiological color change, which involves dispersion or aggregation of pigment granules within chromatophores and occurs at shorter time scales ranging from milliseconds to hours

(Thurman 1988, Nordlund et al. 1998). Physiological color change is regulated by neuromuscular or neuroendocrine system and; hence, is rapid and reversible (Sumner 1940, Fujii 2000). Depending upon the taxon under consideration, color change may serve one or a combination of following adaptive functions: (i) predator avoidance (through crypsis or aposematism; Kats and van Dragt 1986), (ii) conspecific communication (Stuart-Fox and Moussalli 2008), and (iii) homeostatic function (thermoregulation or hydoregulation; King et al. 1994). The phenomenon is well studied in anurans especially in tree frogs of the family Hylidae (Kats and van Dragt 1986, Kang et al. 2016). Although similar in body form and its arboreal habitat, little is known about color changing ability in Afro-Asian tree frogs of the family Rhacophoridae (Cott 1934). Here we report the occurrence of rapid physiological color change in the rhacophorid, *Rhacophorus smaragdinus* (Fig. 1) for the first time.

The species formerly known as *Rhacophorus maximus* Günther, 1858 was recently assigned to the nomen *Rhacophorus smaragdinus* after recovery of type specimens of *Polypedates smaragdinus* Blyth, 1852 from ZSI collections (Ohler and Deuti 2018). Type locality of *P. smaragdinus* is “Naga hills, Assam”, India. *R. smaragdinus* (Blyth, 1852) is characterized by its large size, green dorsal coloration, brown on flanks and complete, uniform greyish webbing between fingers and toes (Anders and Rai 2002). Distribution of the species ranges from Nepal to India, Southern China, Western Thailand, Northern Bangladesh, Myanmar, Laos, Cambodia and northern Vietnam. In India, it is recorded from the states of West Bengal, Sikkim, Arunachal Pradesh, Nagaland, Assam, Meghalaya, and Manipur (Ohler and Deuti 2018). It is a crepuscular species and inhabits lowland and submontane moist evergreen forests.

Observation

On 12 October 2016, at 20:00 hrs, a single adult female of *R. smaragdinus* (SVL=12.6 cm) was observed perched on a tree branch at about 3 m height from the ground near Deban (27.4971°N, 96.3911°E ; 361 m asl.) in Namdapha Tiger Reserve, Changlang district, Arunachal Pradesh, India. The individual was identified as an adult female owing to its large size and absence of nuptial pads and vocal sac (male secondary sexual characters). The habitat was characterized by lowland tropical evergreen rainforest formation with dense canopy cover. The color of the individual was noted to be lime green, but as soon as it was placed on a tree trunk with brownish bark for taking

photographs, the dorsal coloration started to change. In a span of few minutes, the color changed from green to dull brown, reducing the contrast with background and making the animal less conspicuous. As we left the individual undisturbed, it started changing its color back to green (Fig. 2). It took approximately 25 minutes for the frog to change its color from brown back to green, although it would have taken still more time for it to regain its original lime green coloration (as observed when the individual was captured). The initial color change from green to brown was faster than the color reversal but the time taken was not accurately quantified.

Discussion

It is unlikely that the response had any homeostatic function, as ambient temperature conditions before and after the capture of individual were not significantly different. The possibility of conspecific communication can also be ruled out as individuals of the same species were neither heard nor seen in close proximity. It is most likely that the disturbance caused by handling had elicited a predator deterrence response in the individual causing it to rapidly change dorsal body color to match with the background. Background matching by rapid color change can be particularly advantageous for species living in heterogeneous environments and frequently moving between different kinds of substrates, to conceal itself from visual predators (Kang et al. 2016). Alternatively, color change could be a by-product of hormone release associated with other processes such as amplexus or in this case physiological stress and may not serve any particular adaptive function



Figure 1. *Rhacophorus smaragdinus* (Blyth, 1852) in its habitat.



Figure 2. Sequence of color change from brown to green in *Rhacophorus smaragdinus* (Blyth, 1852).

Table 1. List of rhacophorid species (apart from *Rhacophorus* sp.) exhibiting rapid physiological color change and nature of color change observed.

Species	Nature of color change	Literature source
<i>Chiromantis xerampelina</i> Peters, 1854	Skin coloration varies from dark brown to white presumably for thermoregulation	Shoemaker et al. 1989
<i>Gracixalus tianlinensis</i> Chen, Bei, Liao, Zhou, & Mo, 2018	Dorsal coloration varies from brown to beige or dark brown; coloration of throat varies from grey to brown	Chen et al. 2018
<i>Kurixalus eiffingeri</i> (Boettger, 1895)	Dorsal coloration changed from uniform grey or brown to greenish while the individual was on a greenish substrate	Kuramoto and Wang 1987
<i>Mercurana myristicapalustris</i> Abraham, Pyron, Ansil, Zachariah, & Zachariah, 2013	Dorsal coloration changed from rusty brown to dull brown resembling the color of forest floor, where the individuals (in amplexus) just moved to	Abraham et al. 2013
<i>Polypedates maculatus</i> (Gray, 1830)	Individuals placed in sunlight turned light in color (light grey, tan or yellow) whereas those placed in shaded area turned darker in color	Lillywhite et al. 1998
<i>Pseudophilautus femoralis</i> (Günther, 1864)	Dorsal coloration changes from green to yellow; always green during capture (at night)	Inger et al. 1984
<i>Pseudophilautus viridis</i> (Manamendra-Arachchi & Pethiyagoda, 2005)	Dorsal body coloration changes from dull green to brownish (presumably) to match with soil color	Bopage 2015
<i>Pseudophilautus wynaadensis</i> (Jerdon, 1853)	Dorsal coloration changes from reddish brown at night to pale grey or brownish grey during daytime	Kuramoto and Joshy 2003
<i>Raorchestes gryllus</i> (Smith, 1924)	Dorsal coloration varies between different combinations of black, grey, brown, red, green and yellow depending on physiological condition of the individual	Orlov et al. 2012
<i>Raorchestes luteolus</i> (Kuramoto & Joshy, 2003)	Body coloration changes from pale yellow at night to brownish during daytime	Kuramoto and Joshy 2003
<i>Raorchestes tuberothumus</i> (Kuramoto & Joshy, 2003)	Dorsal coloration becomes darker and body markings more prominent during daytime	Kuramoto and Joshy 2003
<i>Theloderma auratum</i> Poyarkov, Kropachev, Gogoleva, & Orlov, 2018	Dorsal coloration light beige to cream nocturnally but turns darker during daytime; coloration varies with respect to diel period and microhabitat conditions	Poyarkov et al. 2018
<i>Theloderma lacin</i> McLeod & Norhayati, 2007	Dorsal coloration changes from solid white to white mottled with brown on handling; coloration varies in response to stress and presumably with respect to diel period and microhabitat conditions	McLeod and Norhayati 2007
<i>Theloderma nebulosum</i> Rowley, Le, Hoang, Dau, & Cao, 2011	Coloration changes from lighter to darker shade. Dorsal pattern more distinct at night.	Rowley et al. 2011
<i>Theloderma palliatum</i> Rowley, Le, Hoang, Dau, & Cao, 2011	Dorsal coloration changes from brown patches on white background in the morning to a less contrasting brown on dull white at night	Rowley et al. 2011
<i>Theloderma vietnamense</i> Poyarkov, Orlov, Moiseeva, Pawangkhanant, Ruangsawan, Vassilieva, Galoyan, Nguyen, & Gogoleva, 2015	Dorsal coloration changes from greyish brown or dark beige at night to dark chocolate brown during daytime; color of belly is dark brown with purple tint nocturnally which changes to darker blackish brown with violet tint diurnally; pigmentation of parts of skin varies in response to stress, diel period and microhabitat conditions	Poyarkov et al. 2015

as such (Kindermann et al. 2014). *Rhacophorus lateralis* Boulenger, 1883 from India and *Rhacophorus prominans* Smith, 1924 from Malaysia exhibit rapid physiological color change, presumably in response to stress (Bennet et al. 1998, Molur and Molur 2010, Marcus 2017). Bennet et al. (1998) observed calling *R. lateralis* with dark brown dorsum turn pale green when handled while Molur and Molur (2010) noted calling individuals with bright green

dorsum and neon green dots turn bright brown with coffee colored dots on handling. *R. prominans* observed on a dark substrate changed dorsal coloration from bright green to dark green-brown in less than 5 seconds. The behavior was suspected to be elicited by the disturbance caused by observers (Marcus 2017). Ostroshabov et al. (2013) noted *Rhacophorus hoanglienensis* Orlov, Lathrop, Murphy, and Ho, 2001 and *Rhacophorus viridimaculatus* Ostro-

shabov, Orlov, and Nguyen, 2013 from Northern Vietnam to exhibit varying dorsal colors and patterns depending on physiological condition although the proximate cause of the behavior was not discussed.

Besides *Rhacophorus*, rapid physiological color change is also known to occur in species belonging to the genera *Chiromantis* Peters, 1854; *Gracixalus* Delorme, Dubois, Grosjean, and Ohler, 2005; *Kurixalus* Ye, Fei, and Dubois, 1999; *Mercurana* Abraham, Pyron, Ansil, Zachariah, and Zachariah, 2013; *Polypedates* Tschudi, 1838; *Pseudophilautus* Laurent, 1943; *Raorchestes* Biju, Shouche, Dubois, Dutta, and Bossuyt, 2010 and *Theloderma* Tschudi, 1838 of family Rhacophoridae (Table 1). While one must be careful in drawing inferences regarding adaptive function of the behavior from these studies which are mostly based on opportunistic observations, diel period (Inger et al. 1984, Kuramoto and Joshy 2003, Rowley et al. 2011, Poyarkov et al. 2015, Poyarkov et al. 2018), microhabitat conditions (Kuramoto and Wang 1987, Abraham et al. 2013), ambient temperature (Shoemaker et al. 1989, Lillywhite et al. 1998) and physiological condition of the animal (Bennet et al. 1998, McLeod and Norhayati 2007, Molur and Molur 2010, Orlov et al. 2012, Marcus 2017) seems to play a significant role in eliciting the behavior in Rhacophorids. Some Rhacophorids such as *Rhacophorus malabaricus* Jerdon, 1870 are known to exhibit ontogenetic color change (Biju et al. 2013), which in most cases is a form of morphological color change (Booth 1990), the discussion of which is beyond the scope of this manuscript. Our understanding regarding color-changing ability, factors influencing the behavior and its adaptive function in anurans is currently limited by a dearth of natural history observations and carefully designed experimental studies.

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