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Thermographic record of predation of *Rhinella ornata* (Spix, 1824) (Anura:Bufonidae) by *Xenodon neuwiedii* Günther, 1863 (Squamata:Dipsadidae) with feeding behaviour notes

Renata Ibelli Vaz[1,*] and Jesús Eduardo Ortega Chinchilla[1]

Knowledge about the natural history of animals is fundamental to many areas of study, including ecology, evolutionary biology, physiology and conservation (Greene and Losos, 1988). In the past decades, detailed studies on snakes from southeastern Brazil have improved our knowledge about the natural history of this group (e. g., Laporta-Ferreira et al., 1986; Oliveira, 2001; Martins et al., 2002; Bizerra et al., 2005; Hartmann and Marques, 2005; Marques et al., 2006). However, basic information about several species is limited because observations, especially of feeding behavior, are sparse or lacking (Fitch, 1987; Mushinsky, 1987).

Infrared (IR) thermography is a new tool for field studies; it offers a non-invasive method for measuring the surface temperature of ectotherms and provides real-time output (Zalameda and Winfree, 2005). This method has been used primarily in thermal physiology studies to understand biological aspects of animals (Tattersall and Milsom, 2003; Tattersall et al., 2004, 2006, 2009; Scott et al., 2008; Hunt et al., 2011). For example, this method can aid in the detection of injuries and inflammations, assist in the diagnosis of infectious diseases and pregnancy, provide information on animal behaviour and help understanding microthermal aspects of the environments in which animals live, especially nocturnal ones (Cilulko et al., 2013; Tattersall and Cadena, 2013). Here we report the first thermographic record of predation of the toad species *Rhinella ornata* (Spix, 1824) by the forest false pitviper, *Xenodon neuwiedii* Günther, 1863, and provide information on this species' feeding behavior.

Xenodon neuwiedii (Dipsadidae) is a snake widely distributed from the northeast to the south of the Atlantic Forest of Brazil and also found in Paraguay and Argentina (Giraudo and Scrocchi, 2002; Cacciali et al., 2016; Moura et al., 2017). In the municipality of São Paulo (Brazil), this species occurs in all regions except the central and western regions (Barbo et al., 2011). This terrestrial snake is active during the day (Jordão, 1996), has a continuous reproduction (Marques, 1998) and is considered a mimic of the venomous *Bothrops jararaca* (Wied-Neuwied, 1824) (Sazima, 1992). *Xenodon neuwiedii* forages actively (Hartmann et al., 2009) and feeds mostly on anurans, with species of Brachycephalidae, Bufonidae, Craugastoridae, Hylidae, Leptodactylidae, and Odontophrynidae recorded as prey, especially species of the bufonid genus *Rhinella* (Sazima and Haddad, 1992; Jordão, 1996; Marques and Sazima, 2004; Costa et al., 2012; Oliveira et al. 2017).

Rhinella ornata (Bufonidae) is a toad found along the Atlantic Forest of Brazil from southern Espirito Santo to northern Parana state. It is also possibly found in Misiones and Corrientes Provinces of northeast Argentina (Baldissera, 2010). Moreover, this species is believed to be fairly tolerant of habitat modification (Abrunhosa et al., 2006).

The feeding behavior of *X. neuwiedii* was recorded with infrared images along a path on the east side of Morro da Anta (24.445° S 48.668° W, 900 m elevation) in Parque Estadual Intervales (PEI). This is a strictly protected area in the Atlantic Forest between the municipalities of Iporanga, Ribeirão Grande, and Sete Barras, in the southeastern state of São Paulo, Brazil, between 800 and 1005 m elevation.

On February 15, 2017, between 4:20 and 5:20 p.m., we fortuitously observed the feeding behaviour of a

[1] Laboratory of Ecophysiology and Evolutionary Physiology, Departamento de Fisiologia, Instituto de Biociências, Universidade de São Paulo, São Paulo, Brazil.
* Corresponding author. E-mail: rezinha.vaz@gmail.com

specimen of *X. neuwiedii* (snout-vent length [SVL] ca. 810 mm), from the attack to the complete swallowing of a toad, *Rhinella ornata,* (SVL ca. 70 mm). Observation was made at 1m from the animals, using a thermal imaging camera (FLIR C2) with a thermal sensitivity of 0.1°C. This camera detects radiation at infrared wavelengths (7.5–13 µm) emitted by objects. We used an emissivity level of 0.95, a reasonable estimate for biological tissues according to Tattersall et al. (2004, 2009) and Blumberg et al. (2002). For the analyses of the thermographs we used the software FLIR ResearchIR.

We started recording when the snake captured the toad by its hind limbs; the toad immediately assumed a prone position (Fig. 1A). Over the next 35 min, the snake started swallowing the toad to the point where the snake's snout was at the level of the toad's pectoral girdle, but with the toad's hind limbs out of the snake mouth (Fig. 1B). This position impairs swallowing because of the resistance offered by the toad; it uses alternate movements of its forelimbs in contact with the substrate to try to escape (Jordão, 1996). The toad also inflated its body and tried to kick the snake's face. The snake then stopped swallowing the toad and began to release him, holding the toad only by its left leg (Fig. 1C). After 10 minutes of this release behaviour, the snake dropped the toad, chased and grabbed it again, by its head. This second capture took place 20 cm from the site of the first capture. The snake grabbed the toad from its prone position but managed to turn the toad's body in such a way that the prey remained in a supine position. This allows the snake to pierce the toad's lungs and reduce its volume (Vanzolini et al., 1980; Vitt, 1983). Additionally, this position favours swallowing since the toad loses its purchase on the ground (Strüssmann, 1992). After 15 min the snake managed to swallow the toad completely (Fig. 1D). The whole feeding sequence took one hour; during this period the snake used its tail to grab its body to a trunk, possibly to have greater stability. After feeding, the snake slithered into the forest.

In terms of IR thermography (Fig. 2) recorded, the snake and toad's skin temperatures were 24.8°C and 23.8°C respectively (Capture). During the feeding activity, the temperature increased for both animals; the snake's skin temperature was higher than the toad's until regurgitation (27.7°C for the snake and 26.7°C for the toad; Submission). This increase in body temperature of both animals may be due to the physical activity of the snake and the manipulation of the toad. After regurgitation, both animals' skin temperatures dropped to 24.2 °C (Regurgitation). This decrease in temperature may have occurred due to the decrease in the activity of the snake and the contact of the toad with the temperature of the environment. At the end of the

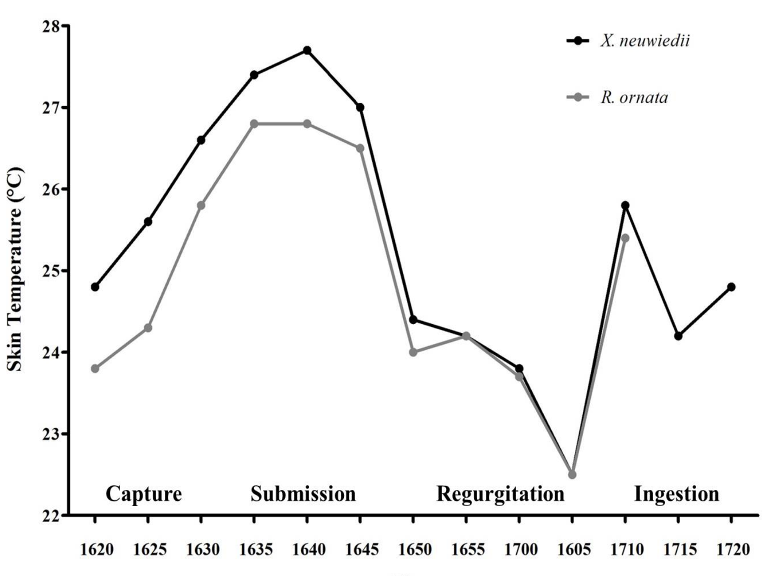

Figure 2. Skin temperatures of *X. neuwiedii* and *R. ornata* from capture to total ingestion.

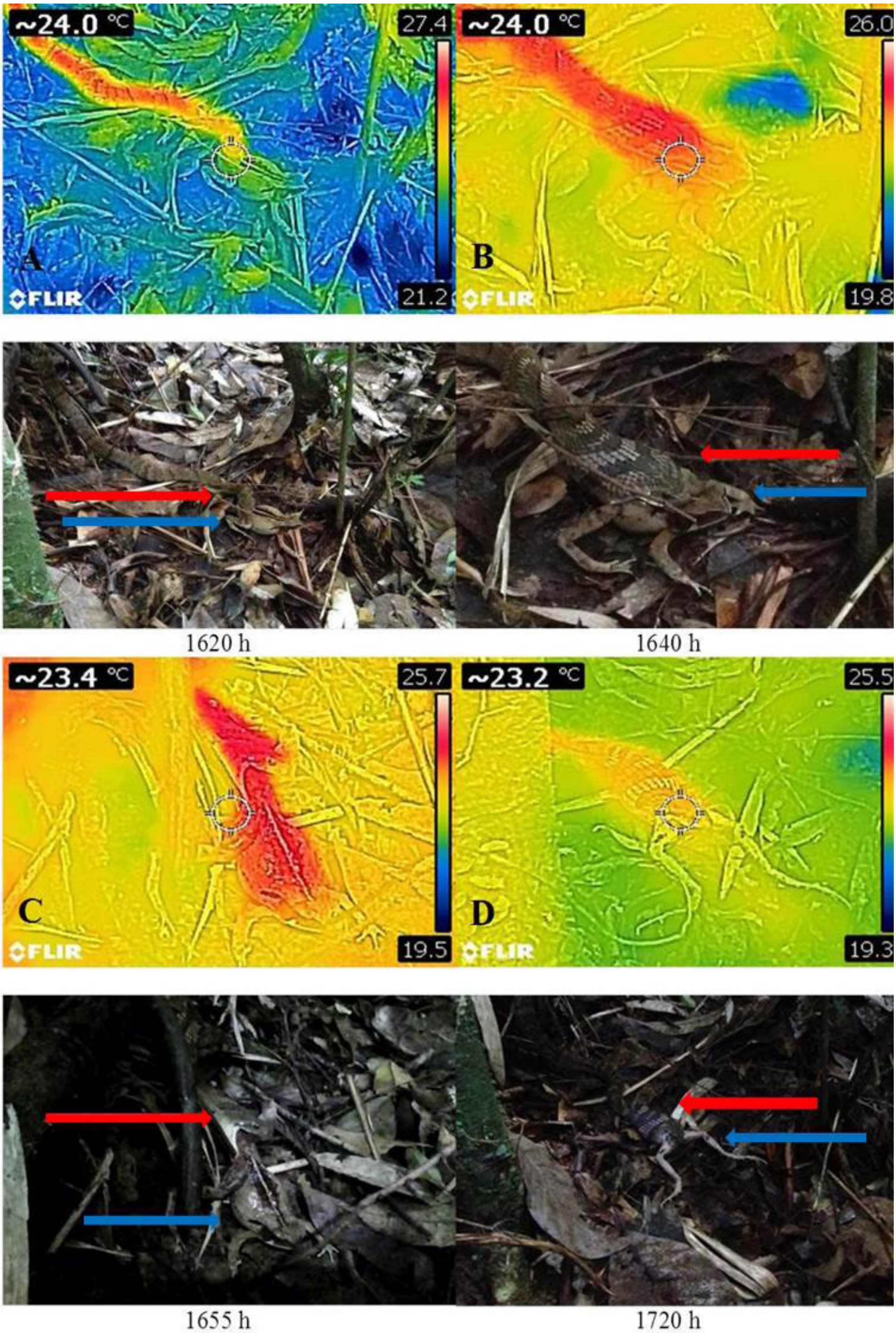

Figure 1. Infrared and digital register of the feeding behaviour of *Xenodon neuwiedii* (red arrow) capturing (A), subduing (B), regurgitating (C) and ingesting an adult of *Rhinella ornata* (blue arrow) (D). Parque Estadual Intervales, Ribeirão Grande, São Paulo, Brazil.

feeding activity, the snake's skin temperature increased again reaching 24.8 °C (Ingestion). This increase in temperature may be explained by the beginning of the digestion process in which the metabolism of the snake increases and so their body temperature (Tattersal et al. 2004).

Our data corroborate that *X. neuwiedii* feeds opportunistically and during the day (Lavilla et al., 1979; Vanzolini et al., 1980; Sazima and Haddad, 1992; Hartmann et al., 2009). Furthermore, such feeding behaviour is similar to the one reported by Jordão (1996) under experiment conditions. In addition, we confirm that *R. ornata* is a prey for *X. neuwiedii* as has been reported by Pontes et al. (2008), and we complement the literature review by Oliveira et al. (2017) which did not report this predatory event. Ultimately, we report that infrared thermography may be helpful to understand aspects of the thermal ecophysiology of animals given the opportunity to monitor skin temperature during different types of behaviour. Although some studies evaluate the post-prandial body temperature of snakes (body temperature after feeding) (Tattersal et al. 2004), there are no reports on how the body temperature changes during the predation behavior. Because of this, it is difficult to evaluate the reasons for the changes in body temperature of the snake. Therefore, we suggest experimental studies that evaluate not only the post-prandial body temperature, but also the body temperature during the predation behavior in order to better understand the context of body temperature in physiology and behavior of snakes.

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