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Journal of Thermal Biology 30 (2005) 93–102

Journal of THERMAL BIOLOGY

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Physically modeling operative temperatures and evaporation rates in amphibians

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Received 20 April 2004; accepted 1 July 2004

Abstract

(1) We designed a physical model that simulates the thermal and evaporative properties of live Western toads (*Bufo boreas*).
(2) In controlled tests, the model tracked the body temperature of live toads with an average error of 0.3 ± 0.03 °C (test range = 4–30 °C).
(3) It estimated the evaporative water loss of live toads with an average error of 0.35–0.65 g/h, or about 14% (test range = 0.7–9 g/h).
(4) Data collected with this physical model should provide an effective way for biologists to better understand habitat selection in toads and other amphibians

Keywords: Western toads; Amphibians; Thermal ecology; Water loss; Physical models; Operative temperature; Evaporation; Model; *Bufo boreas*

1. Introduction

Ectotherms such as amphibians depend on their environment for heat and moisture and probably select habitats that provide suitable amounts of each. Because body temperatures (T_b) selected by ectotherms affect their development, physiology, and behavior (Huey, 1982; Smits, 1984), tracking variations in T_b of ectotherms is critical for understanding their ecology. The importance of terrestrial habitats to amphibians for dispersal, foraging, and, for some species, hibernating is becoming increasingly recognized (Bartelt, 2000; Muths, 2003; Pilliod et al., 2002; Semlitsch, 1998). For amphibians, because hydroregulation may be as important as thermoregulation (Tracy et al., 1993), characterizing the water relationships of habitats may be as important as tracking amphibian T_b.

Physical models simulate the thermal properties of an animal in steady-state. By integrating a number of environmental variables and physical attributes of an animal, they produce one meaningful measurement called operative environmental temperature (T_e; Bakken and Gates, 1975), an approximation of an animal's body temperatures (Bakken, 1992). Because measures of T_e characterize the equilibrium temperatures available to an animal within its environment, physical models have helped researchers learn about thermoregulation in ectotherms (Bradford, 1984; Peterson, 1987), about the consequences of retreat-site selection (Huey et al., 1989),

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0306-4565/$ - see front matter
doi:10.1016/j.jtherbio.2004.07.007

and about the effects of feeding (Dorcas et al., 1997) and pregnancy (Cobb and Peterson, 1991) on their thermoregulatory behavior.

Physical models also have been used to study the thermal biology of amphibians (Bradford, 1984; O'Connor, 1989; Spotila and Berman, 1976; Wygoda and Williams, 1991). The design and use of amphibian models are complicated by the cooling effect of evaporation on amphibian T_b (Carey, 1978; Tracy, 1976); for this reason, amphibian models must be kept wet. In addition to cooling, evaporation can lead to desiccation (Boutilier et al., 1992; Spotila et al., 1992; Tracy, 1976). Because hydroregulation may be a more important concern to amphibians than thermoregulation (Tracy et al., 1993), measuring rates of evaporative water loss (EWL) is important. In some studies, amphibian models were kept wet by manually and frequently rehydrating them. Researchers measured rates of EWL by periodically reweighing porous plaster models (O'Connor, 1989; Wygoda and Garman, 1993). While this method yielded important information on rates of EWL, it was labor-intensive. A model that simultaneously measures T_e and EWL for extended periods of time without the need for continuous attention would be a powerful tool for studying amphibian ecology (Spotila et al., 1992). To our knowledge, no such method has previously been described.

Many amphibian populations are declining (Alford and Richards, 1999; Houlahan et al., 2000; Stebbins and Cohen, 1995). A number of different factors have contributed to these declines (e.g., introduced species, Bull and Marx, 2002; Pilliod et al., 2002; disease, Carey et al., in press), including habitat alteration. Habitat alteration has affected some amphibians negatively (deMaynadier and Hunter, 1995; Green, 1997; Lowe et al., 1990) and others positively (*Bufo boreas*, P.S. Corn, pers. comm.). Studies that link animal behavior and thermal biology with variations in environmental temperature and moisture would be an effective way to study habitat selection in amphibians, and would help explain how habitat alteration affects amphibian populations (Pounds et al., 1997; Spotila et al., 1992).

In this paper we describe, evaluate, and field test a physical model (and supporting electronics) for Western toads (*B. boreas*) that we used in a larger study of their habitat relationships (Bartelt, 2000). The model simulates the thermal and evaporative properties of toads and simultaneously measures T_e and rates of EWL for weeks or months. We tested the accuracy, limitations, and applicability of the model with the hypotheses that: (1) there is no difference in the heating and cooling rates of the model and toads, and (2) like the model, toads have no physiological control over EWL. Although specifically designed for Western toads, the model could be modified to measure T_e and EWL for other species of amphibians.

2. Materials and methods

The operation of the model is assisted by a strain gage and electronics. In the field, only the model and two dataloggers were visible on the soil surface; all the other components were buried below ground, protected within a plastic container (Fig. 1).

2.1. The physical model

The model consisted of a hollow copper tube cut and partially flattened to approximate the size (7 cm × 3.5 cm) and shape of an adult toad (mean (±SE) weight of four models = 73.9 ± 0.29 g). A wet, brown, cotton cloth sleeve covered the entire tube to provide evaporative cooling (mean weight of four wet sleeves = 4.28 ± 0.12 g). The reflectance of this cloth (measured with a Beckman DK-2A dual beam, ratio-recording spectroreflectometer) in the visible range (400–700 nm) was 3% and total reflectance (290–2600 nm) was 8.1%, similar to the total reflectance of dark-skinned boreal toads in Colorado (8%; Carey, 1978). To keep the cloth sleeve wet, we cut it long enough to wick water from a reservoir (250 ml Nalgene rectangular bottle). To control free evaporation from the bottle, we covered its mouth with a square of plastic wrap (cut from a sandwich bag and held in place with a small rubber band) and extended the cloth sleeve through a slit cut into the plastic.

2.2. Measuring T_e

We suspended a thermistor in the center of the model with a rectangular piece of cardboard and plugged both

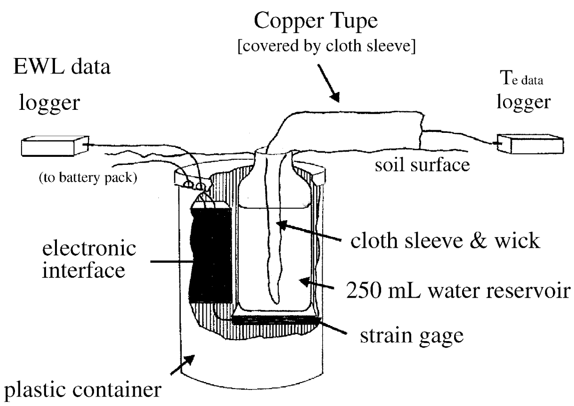

Fig. 1. Details of the physical model. Illustrated are the model (copper tube with cloth sleeve), water bottle reservoir, and the electrical components to measure and record T_e and EWL. *Not illustrated* are the plastic film covering the mouth of the reservoir, the plastic film between the model and soil surface, or the 16 "D" size batteries that power the strain gage.