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When the forest is gone: heat risk and thermal tolerance in tadpoles of the mountain treefrog *Zhangixalus moltrechti* (Boulenger, 1908) in Taiwan

Jh-Yu You[1] and Ming-Feng Chuang[1,2,*]

Climate change has become a major issue in conservation biology (Pfenning-Butterworth et al., 2024). In amphibians, global climate change is linked to population declines in approximately 39% of species, a figure exceeding declines attributed to habitat loss (Luedtke et al., 2023), since amphibians are ectotherms with complex lifecycles (Bickford et al., 2024). To evaluate the vulnerability of amphibian populations in warming environments, critical thermal tolerance, particularly critical thermal maximum (CT_{max}), is a useful indicator (Angilletta Jr et al., 2002; Kim et al., 2022). By calculating the buffer range between CT_{max} and the environmental temperature (CT_{max} - tmax), we can gain insight into the warming tolerance of individuals (Sanabria et al., 2021).

During a field survey to Xiangyang, Taitung, Taiwan (23.2476°N, 120.9861°E, 2300m elevation; Fig. 1), we encountered a small population of *Zhangixalus moltrechti* (Boulenger, 1908) tadpoles inhabiting an abandoned artificial waterfall. The site was a small clearing within the forest, characterised by a stagnant pool formed below a waterfall adjacent to a traffic lane. The surrounding trees had been removed and replaced by grassland, leaving no canopy cover to shade the water body. Notably, the water felt palpably warmer than human body temperature upon touch. Since the CT_{max} of this species is around 40 °C (You et al., 2025), we sought to quantify the thermal buffer margin, between the water temperature and the critical thermal tolerance of the tadpoles living there. We placed HOBO Pendant temperature data loggers (HOBO MX2201) in the water where the tadpoles were living and continuously recorded water temperature every 30 minutes for ten days. Afterward, the tadpoles were brought back to the laboratory, where their CT_{max} was measured using the Hutchison's dynamic method (Gutiérrez-Pesquera et al., 2022): tadpoles were heated by the water bath at a constant rate of approximately 0.25 °C per minute until the onset of muscle spasms and loss of righting response (LRR), but could still recover once returned to the acclimation temperature. The water temperature at this point was recorded as the CT_{max} of the individual.

We tested a total of 12 individuals, whose CTmax ranged between 39.7–40.8 °C. Since the highest

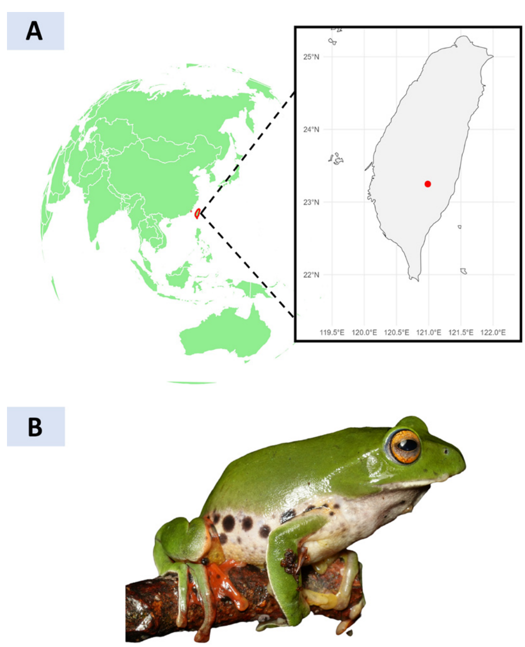

Figure 1. Study location and species. (A) Sample collecting site in this record. (B) Adult frog of *Zhangixalus moltrechti*. Photo by J.-Y. You.

[1] Department of Life Sciences, National Chung Hsing University, Taichung 40227, Taiwan.
[2] Global Change Biology Research Center, National Chung Hsing University, Taichung 40227, Taiwan.
[*] Corresponding author. E-mail: mfchuang@nchu.edu.tw

Table 1. Summary of body length, weight and Gosner stage, as well as CT_{max}, and warming tolerance of the tested individuals.

ID	Body length (mm)	Weight (g)	Gosner stage	CTmax (℃)	Warming tolerance (℃)
XY01	24.42	0.23	25	40.4	3.34
XY02	23.6	0.15	25	40.3	3.54
XY03	25.57	0.16	25	40.6	3.24
XY04	24.66	0.18	25	40.4	3.34
XY05	19.52	0.1	25	30.4	3.24
XY06	21.44	0.1	25	39.7	2.64
XY07	18.46	0.08	25	39.9	2.84
XY08	19.13	0.07	25	40.2	3.14
XY09	18.84	0.1	25	40.8	3.74
XY10	18.94	0.06	25	39.8	2.74
XY11	19.17	0.08	25	40.2	3.14
XY12	21.2	0.1	25	40.6	3.53

recorded water temperature was 37.06 °C, the warming tolerance of these tadpoles was approximately 2.64 °C to 3.74 °C (Table 1). Compared with the results of Simon et al. (2015), who reported an average warming tolerance of about 7.8 °C in three anuran tadpole species from the Brazilian Caatinga and about 10.3 °C in seven anuran tadpole species from the Brazilian Atlantic Forest, our result represents an extremely low value. In addition, the total thermal range of water temperature we record was 24.62 °C, indicating a highly variable microenvironment, likely driven by radiative cooling at night in high elevations. Current studies indicate that heat tolerance is less spatially variable than cold tolerance, a pattern known as "Brett's heat-invariant rule" (Brett, 1956). This pattern may be associated with greater vulnerability, as environmental temperatures are often closer to the critical heat limits of organisms and their ability to adjust thermal tolerance is relatively low. This case shows the importance of habitat protection in amphibian conservation. If preferred microhabitats are lost, population may be forced to utilise suboptimal habitats subject to higher thermal stress. For species that breed in still waterbodies, canopy cover above the water is particularly important (Cheng et al., 2023), as stagnant water lacks the thermal buffering provided by flow & turnover (Sinokrot and Gulliver, 2000).

The experiment was conducted in accordance with the ethical standards of National Chung Hsing University. The use of animals was reviewed and approved by the IACUC of NCHU (Approval No. 113-026). All tadpoles were released back into their habitat after the critical thermal tolerance tests.

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