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Effects of Simulated Dusk and Dawn on Activity and Feeding of Puerto Rican Crested Toads (*Peltophryne lemur*) in Captivity

Brady P. Parlato[1] | Noah T. Dunham[1,2]

[1]Department of Biology, Case Western Reserve University, Cleveland, Ohio, USA | [2]Division of Conservation and Science, Cleveland Metroparks Zoo, Cleveland, Ohio, USA

Correspondence: Brady P. Parlato (bpp18@case.edu)

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ABSTRACT

Night light may affect captive amphibians in alternative ways. Captive amphibians may be more active and consume more prey if a dim light is provided at night that illuminates their surroundings, or light may deter them from emerging at night to avoid being detected. We examined how the presence of a dim night light simulating a natural dusk and dawn influenced the activity and feeding of Puerto Rican crested toads (hereafter "PRCTs"), a species of conservation concern currently raised in 17 AZA-affiliated breeding facilities across the United States and Canada. We used video cameras to monitor toads in three terrariums with no light at night for 10 days, then replicated this observation period with a dim night light turned on above each terrarium to mimic a natural dusk and dawn from 7 to 10 p.m. and 4 to 7 a.m., respectively. Toads did not differ in prey consumption between treatments, but toads showed trends of greater activity above the substrate and toads moved more frequently when a dim light was provided. The presence of a night light had no effect on when toads emerged at night or when they hid in the morning. Toads may have been more active above the substrate when a dim light was provided because it improved visibility and encouraged interaction with their surroundings. It remains to be determined how light at night affects other aspects of captive amphibian welfare, such as physiological markers of stress, reproductive ability, and susceptibility to disease.

1 | Introduction

Among amphibians, many environmental factors have the potential to influence their behavior. For example, amphibians are highly sensitive to shifts in temperature (Obert 1976; Reading 1998; Cayuela et al. 2016), and will only become active within specific thermal ranges. Similar to temperature, amphibian behavior is also highly dependent on levels of light exposure. Because many amphibians, particularly frogs and toads, rely on visual cues for orientation (Sinsch 2006; Daneri et al. 2015), patterns of activity can be heavily influenced by the availability of light. Some species reduce activity with greater moonlight (Fitzgerald and Bider 1974; Kusano et al. 2015) and artificial light at night (Russart and Nelson 2018) to avoid detection by predators. In contrast, other species are more likely to emerge from refugia at night under brighter conditions (Green et al. 2016; Bissattini et al. 2020), likely because prey can be more easily detected. Collectively, light is important to predicting amphibian activity patterns, but different species are most active at different levels across the light gradient.

Although limited information from studies of free-ranging populations suggests light at night can significantly affect the activity of amphibians (Kusano et al. 2015; Green et al. 2016), less is known about how light at night impacts the behavior and well-being of captive animals. Studies on the effects of light on

Summary

- Light at night did not affect prey consumption by Puerto Rican crested toads.
- Toads tended to hide less often and moved more frequently when night lights were used to mimic dusk and dawn.
- Night light had no effect on when toads hid in the morning or emerged at night.

amphibians housed in zoos and aquariums are lacking, but the importance of access to light at levels and times reflecting natural photoperiods to captive amphibian welfare has been supported by work on captive reptiles. Wild-caught male *Anolis* lizards that were exposed to artificial light at night were more likely to be awake at night, and during the day, were more likely to be asleep, moved more slowly, and females displayed less frequently (Taylor et al. 2022). Alternatively, anoles have also been found to be better able to locate and capture prey at night when light is available, providing the energy to grow larger and produce more eggs without increases in corticosterone levels (Thawley and Kolbe 2020). These studies suggest potential negative or positive effects of artificial light at night, but it should be noted that the lizards used in these studies are diurnal animals, and effects of light at night on the behavior of nocturnal animals, which includes most amphibians, may differ. Although these studies draw attention to the importance of some illumination outside of daylight hours, to our knowledge no study has investigated effects of nighttime light sources on captive amphibians. Additionally, although light regimes involving a simulated dusk and dawn are not novel (Taylor et al. 2022), there are no published reports, to our knowledge, comparing the activity of captive amphibians housed under a photoperiod that more gradually transitioned from day to night and vice-versa (i.e., a dusk and dawn) vs. an abrupt shift from daylight to complete darkness.

Offering light conditions that support healthy activity of captive amphibians is particularly crucial for species of conservation concern that have breeding and reintroduction programs, such as the Puerto Rican crested toad, *Peltophryne lemur* (hereafter "PRCT"). PRCTs are currently listed as Threatened by the U.S. Fish and Wildlife Service, and Critically Endangered by the IUCN (IUCN SSC Amphibian Specialist Group 2021). To combat declines of the species, the Association of Zoos and Aquariums (AZA) began a Species Survival Plan (SSP), the first SSP for an amphibian, in 1984. Currently, the PRCT reintroduction program is managed by the Amphibian Taxon Advisory Group (TAG). Several zoos throughout the United States have maintained breeding populations of PRCTs (U.S. Fish and Wildlife Service 2016). Although reintroductions have aided in the recovery of the PRCT population, we lack information on how light is affecting the behavior of captive animals. Even for nocturnal species, such as PRCTs, light is generally needed to detect prey (Pough 2007). However, there are currently no published studies examining the effects of light on PRCT behavior. Such an investigation would help us to better understand what environmental conditions best promote PRCT welfare, and in turn, healthy animals used for breeding would best promote the goals of the PRCT reintroduction program.

To better understand the impacts of lighting conditions on captive amphibian behavior, we investigated how the presence of a dim night light simulating a natural dusk and dawn affects the daily activity and feeding of PRCTs at the Cleveland Metroparks Zoo. To determine the effects of night light on activity over time, we first observed behavior of PRCTs without any light offered at night (i.e., their standard lighting regime), and then observed the same animals for the same duration of time with a dim ultraviolet bulb turned on above each enclosure at times simulating a natural dusk and dawn. We expected that toads would be active above the substrate for a longer period, toads would move more, and more prey would be eaten if a dim light was present at night to illuminate the surroundings of these visually oriented animals.

2 | Materials and Methods

2.1 | Activity Monitoring and Treatment Application

A population of PRCTs in a captive breeding program at the Cleveland Metroparks Zoo (Cleveland, OH 44109) was used to assess effects of night light on activity. Experiments were purely observational and took place in the zoo's PRCT off-exhibit breeding facility. Three 40-gallon toad terrariums (36 in. length × 24 in. width × 12 in. height) were included in this study, two of which housed three female toads and one of which housed two male and two female toads. To minimize disturbance to toads prior to the start of the upcoming breeding cycle in April, toads were not moved to equalize the number of individuals per enclosure. Each terrarium was constructed from transparent acrylic and included at least one shelter and one water dish for soaking. One ANNKE 5 MP Lite Security Camera was mounted above each terrarium and set to record toad activity over a 10-day period (Dunham et al. 2023). The toads were normally kept on a 12:12 light:dark cycle, with "day" lasting from 7 a.m. to 7 p.m., and "night" from 7 p.m. to 7 a.m., when they were in complete darkness. Here, each enclosure was equipped with three overhead lamps, with a different bulb in each: a Zoo Med 13 W ReptiSun 5.0 UVB bulb, a Zoo Med 25 W basking bulb, and a Zoo Med 25 W Moonlite bulb (hereafter "night light") to provide dim illumination at dusk and dawn (Figure 1). The night light was positioned above the center of each enclosure. All enclosures were initially observed for a 10-day period without any light at night (i.e., the night light was turned off), from February 19 to 28, 2024. After this initial period with no light ("Dark" period), the night lights were connected to a programmable timer and set to turn on from 7 to 10 p.m. ("Dusk") and 4 to 7 a.m. ("Dawn") each day. Lights were only set to turn on during these hours to simulate a natural dusk and dawn, and were left off between 10 p.m. and 4 a.m. to provide toads with a period ("Night") where little to no light is available, as they would experience in natural conditions. Toads were given a 5-day period to acclimate to the night lights before a second 10-day monitoring period (March 5–14, 2024; "Light" period). We acknowledge the possibility of seasonal differences in behavior of the toads between February and March, but conditions (e.g., temperature) remained unchanged in the 5 days separating the first and second observation periods, and thus seasonal differences are unlikely. After the second observation period was completed, night lights were turned off above all enclosures. While it was not possible to identify individual animals from the camera footage, we instantaneously recorded the number of toads visible above the substrate (i.e., active; Figure 2) and their position (on substrate or in soaking dish) at 15-min intervals. We also counted the number of full-body movements (i.e., a movement equal to the length of the toad's body) per hour and the number of crickets consumed per hour. Finally, we also recorded the times at which toads emerged at night and hid during the day. Because toad movements and feeding occurred almost entirely at night, we only recorded data on these variables between 7 p.m. and 7 a.m., when room lights were turned off.

2.2 | Statistical Analyses

All analyses were performed in the R statistical environment, version 4.4.2 (R Core Team 2025). Linear mixed effects models (function "lmer") with date and terrarium ID as random effects were generated to compare the proportion of toads active above the substrate and the proportion of toads soaking between night light treatments. Generalized linear mixed effects models (function "glmer") with Poisson error distributions and date and terrarium ID as random effects were constructed to compare the number of full-body movements per hour and the number of crickets eaten per hour between the night light treatments. Finally, linear mixed effects models with date and terrarium ID as random effects were also generated to compare the amount of time (minutes) between the room lights turning on and the last toad hiding, and the time between the room lights turning off and the first toad emerging between night light treatments. Models were summarized using the "ANOVA"

FIGURE 1 | Front view of one of the three Puerto Rican crested toad enclosures used in this study. The heat lamp is placed on the left, the ultraviolet night light in the center, and the UVB lamp on the right. All enclosures had lamps arranged in the same manner.

FIGURE 2 | A photo recorded by one of the ANNKE 5 MP Lite Security Cameras positioned above one of the Puerto Rican crested toad enclosures. One of the toads is visible in the top left corner of the enclosure, circled in yellow.

function followed by post hoc tests using the "emmeans" function and Tukey-adjusted *p*-values.

3 | Results

More toads were detected per terrarium at night relative to the day ($X^2 = 6632.133$; df = 1; $p < 0.001$). There was a significant effect of a dim light being on from 7 to 10 p.m. and 4 to 7 a.m., simulating dusk and dawn, respectively, on the proportion of toads active ($X^2 = 5.837$; df = 1; $p = 0.016$). Although toads tended to be more active during the period when a night light was on, we found only marginally significant pairwise differences in activity between our night light treatments during the day or night (Tukey $p = 0.074$ for both comparisons; Figure 3). Additionally, we did not mark animals, but anecdotally we tended to see multiple animals at different locations within the terrarium become more active under light at night, rather than a single individual consistently being more active. Differences in activity were most pronounced at night (i.e., between 7 p.m. and 7 a.m.), but also persisted during the day (Figure 4). Regardless of night light treatment, toad activity declined between 4 and 7 a.m. and increased between 6 and 7 p.m. The only time that activity was lower when a night light was provided was between 4 and 6 a.m. Although more toads soaked at night ($X^2 = 4193.176$; df = 1; $p < 0.001$), there was no difference in the proportion of toads soaking based on night light treatment ($X^2 = 0.035$; df = 1; $p = 0.852$).

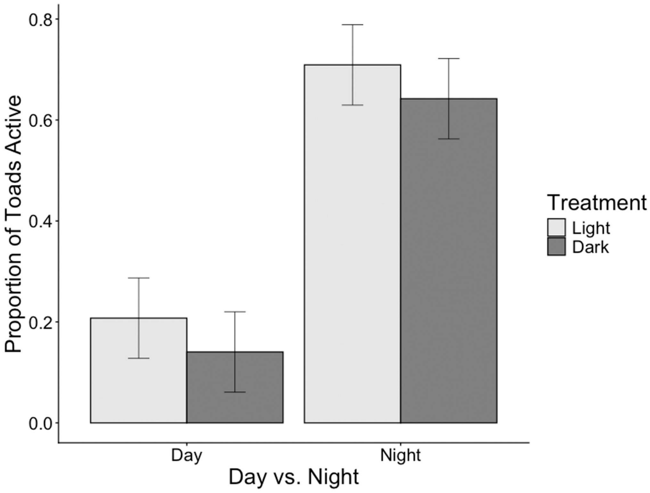

FIGURE 3 | Mean (±1 SE) proportion of Puerto Rican crested toads active and visible above the substrate, during the day vs. night and during the 10-day period without any light at night ("Dark") vs. the period with a dim night light ("Light").

Regarding specifically nocturnal behaviors (i.e., those only recorded between 7 p.m. and 7 a.m.), there was a significant effect of night lights on the number of full-body movements per hour ($X^2 = 28.118$; df = 1; $p < 0.001$). Toads always moved more frequently when a night light was provided, regardless of time period (i.e., dusk, middle of night, or dawn; Tukey $p < 0.001$ for all comparisons; Figure 5). There was also a significant effect of time period on the number of full-body movements per hour ($X^2 = 280.194$; df = 1; $p < 0.001$). Although toads did not differ in their number of movements between dusk (7 and 10 p.m.) and dawn (4 and 7 a.m.; $p = 0.13$), they moved more frequently during both these periods than during the middle of the night (10 p.m.–4 a.m.; Tukey $p < 0.001$ for both comparisons; Figure 5). Toads were observed consuming crickets very infrequently in both night light treatments. There was no significant effect of night light on the number of crickets consumed per hour ($X^2 = 2.757$; df = 1; $p = 0.097$), but toads ate more crickets at dusk than in the middle of the night (Tukey $p = 0.008$) or at dawn (Tukey $p = 0.007$; Figure 6). Toads did not change when they hid under substrate or in refugia, relative to when the room lights turned on (i.e., before "day" began) based on night light treatment ($X^2 = 1.678$; df = 1; $p = 0.195$). Similarly, toads did not change the time that they emerged from their refugia or under the substrate based on night light treatment ($X^2 = 0.417$; df = 1; $p = 0.519$).

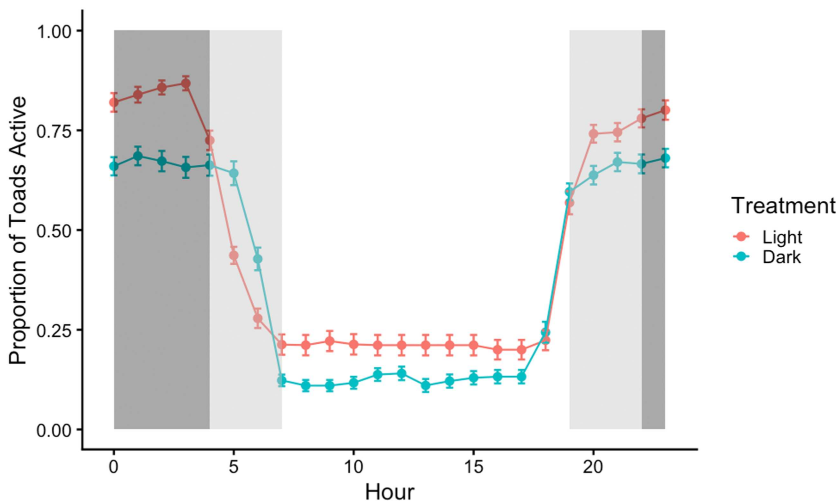

FIGURE 4 | Mean (±1 SE) proportion of Puerto Rican crested toads detected per hour over 24 h during the 10-day period without any light at night ("Dark") vs. the period with a dim night light ("Light"). Light gray shading denotes time periods (7–10 p.m., and 4–7 a.m.) when a dim night light was used to simulate dusk and dawn during the "Light" treatment period, whereas dark gray shading denotes the period with complete darkness (10 p.m.–4 a.m.).

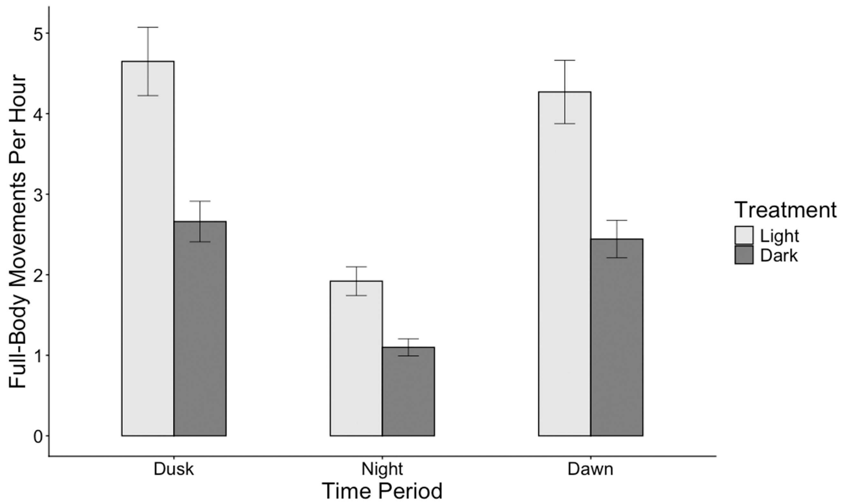

FIGURE 5 | Mean (±1 SE) number of full-body movements by Puerto Rican crested toads detected per hour during the 10-day period without any light at night ("Dark") vs. the period with a dim night light ("Light"). Observations are grouped by time period, such that "Dusk" represents 7–10 p.m., "Night" represents 10 p.m.–4 a.m., and "Dawn" represents 4–7 a.m. During the "Light" treatment period, a dim night light was turned on at "Dusk" and "Dawn".

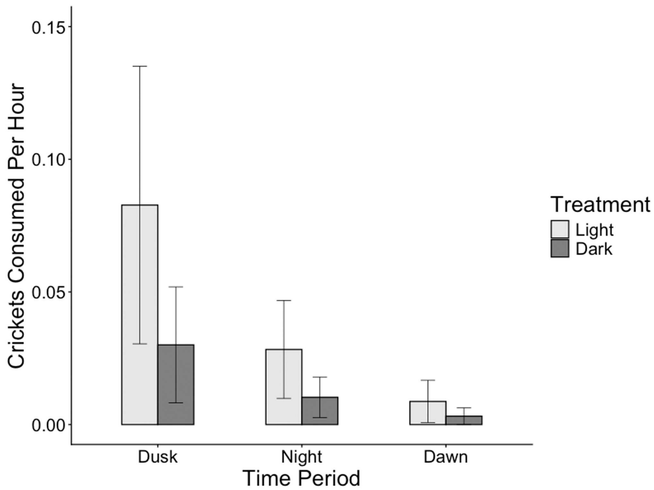

FIGURE 6 | Mean (±1 SE) number of crickets consumed by Puerto Rican crested toads per hour during the 10-day period without any light at night ("Dark") vs. the period with a dim night light ("Light"). Observations are grouped by time period, such that "Dusk" represents 7–10 p.m., "Night" represents 10 p.m.–4 a.m., and "Dawn" represents 4–7 a.m. During the "Light" treatment period, a dim night light was turned on at "Dusk" and "Dawn".

4 | Discussion

This study demonstrates that the availability of a light source at night is important to the activity of PRCTs, and by extension, it supports the importance of light for captive amphibians in general. Our specific objective was to determine if a dim night light, simulating a natural dusk and dawn, would influence the frequency of activity and feeding among PRCTs. Given associations between increased light at night and activity among some wild amphibians (Green et al. 2016; Bissattini et al. 2020) and captive reptiles (Thawley and Kolbe 2020; Taylor et al. 2022), we predicted that PRCTs would be more active and would consume more prey with a light source available during a portion of the night. Although there was no difference in the frequency of prey consumption, more toads tended to be active above the substrate and toads moved more frequently when a light source was available at night. However, night light did not influence when toads emerged in the evening or when they hid in the morning.

Toads may have been more active at night when light was provided for several reasons. Activity may have been greater when light was available at dusk and dawn because prey were easier to detect and the toads were taking advantage of this opportunity by moving more frequently (Green et al. 2016; Bissattini et al. 2020). We expected an extended photoperiod in the form of our dusk and dawn simulations to result in PRCTs finding and consuming more prey, which would serve to promote their reproductive potential in the reintroduction program. However, toads consumed crickets very infrequently during our study periods, regardless of whether a simulated dusk and dawn were provided. The lack of difference in prey consumption suggests that the ability to more easily detect prey may not have been a motivating factor for their increased activity. Despite the lack of a significant difference in prey consumption among PRCTs based on night light, toads with night light tended to eat more crickets ($p = 0.097$). The difficulty in tracking the small crickets through the sphagnum moss substrate may explain the lack of a significant difference and the low frequency of prey consumption by toads that we detected. Thus, the potential for night light to allow for increased feeding in these animals should not be dismissed. Alternatively, night light may have simply made navigating their habitat easier at a time when no other source of light was available. Frogs and toads generally rely heavily on visual cues for navigation (Sinsch 2006; Daneri et al. 2015), and will shift their behavior such that they are most active during the period in which their eyes are best adjusted to available light levels (Jaeger and Hailman 1981). The trend we observed was that, when the room lights in the PRCT breeding facility were turned on at 7 a.m. and "day" began, toads would quickly retreat, either into a refugia or under the substrate. The sudden shift from complete darkness at night to a fully lit room during the day may come as a shock to the PRCTs, triggering a flight response (Morgan and Tromborg 2007). Mimicking the natural transition between night and day, as we did here, may reduce the likelihood of spikes in stress caused by sudden light exposure (Forsburg et al. 2021), and may make it more likely that toads remain active for some time during the day.

Although PRCTs did not differ in their consumption of prey based on a simulated dusk and dawn, it should not be interpreted that light at night does not provide value to animals used in reintroduction efforts. Whether light at night is advantageous or disadvantageous to animal welfare can be expected to depend on whether lights are provided to explicitly reflect natural conditions vs. chronic exposure to artificial light throughout the entire night. For captive amphibians, providing dim light at night may help to mimic a natural photoperiod (Browne et al. 2007; Pough 2007). Although examples do not exist for nocturnal amphibians, some nocturnal reptiles rely on UVB light available at dusk and dawn to convert vitamin D_3 to photoproducts in the skin (Carman et al. 2000), and nocturnal amphibians may employ similar strategies. Light at night may also improve welfare of captive amphibians by promoting activity as a form of enrichment. For some amphibians in captivity, providing enrichment has been associated with reduced mortality and increased growth rates (Michaels et al. 2014). In a nocturnal species such as PRCTs, offering light at night may increase visibility and promote spatial learning by visual cues (Burghardt 2013), which has been shown in amphibians (Sotelo et al. 2015). Although some light at night is generally recommended for captive amphibians (Browne et al. 2007; Pough 2007), chronic exposure to artificial light throughout the entire night may be disadvantageous by disrupting natural light cycles. For example, exposure to artificial light throughout the night has been associated with reduced activity (Touzot et al. 2019) and reduced fertilization success in the common toad, *Bufo bufo* (Touzot et al. 2020). Artificial light during periods that would otherwise be naturally dark can also decrease the frequency of calling in some anurans, potentially having a negative impact on reproduction (Baker and Richardson 2006). Excessive exposure to UVB radiation may also lead to carcinoma in amphibians (Adkins et al. 2003; Martínez-Silvestre et al. 2011). Thus, whether night light does or does not promote amphibian welfare is likely highly dependent on the duration and timing of exposure and varies by species.

5 | Conclusions

In closing, this study tells us more about how light, an important habitat parameter for amphibians, affects the activity of PRCTs in captivity. Although there were no differences in rates of prey consumption, toads moved more frequently at night when a dim light mimicking dusk and dawn was provided. Additional work is needed on both the effects of light and the importance of other habitat parameters to captive amphibian welfare. Investigations are needed to determine whether physiological indicators of stress in captive amphibians fluctuate with light, if such fluctuations influence reproductive success, and if light availability has any impact on the incidence of diseases like Brown Skin Syndrome (Crawshaw et al. 2014). Additionally, the importance of other habitat parameters to PRCT behavior, such as the availability and diversity of refugia, has yet to be determined. More information on these factors would help professionals in breeding facilities to optimize the welfare of these animals, potentially increase their reproductive efforts, and promote the reintroduction plan for this species.

Author Contributions

Conceptualization: Brady P. Parlato and Noah T. Dunham. Data curation: Brady P. Parlato and Noah T. Dunham. Formal analysis: Brady P. Parlato. Funding acquisition: Noah T. Dunham. Investigation: Brady P. Parlato and Noah T. Dunham. Methodology: Brady P. Parlato and Noah T. Dunham. Visualization: Brady P. Parlato and Noah T. Dunham. Writing – original draft: Brady P. Parlato. Writing – review and editing: Brady P. Parlato and Noah T. Dunham.

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Ethics Statement

This research was performed on animals and all research protocols reported in this manuscript were reviewed and approved by Cleveland Metroparks Zoo's Scientific Review Committee (project number CS2024-003).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data (https://doi.org/10.6084/m9.figshare.28620686) and code (https://doi.org/10.6084/m9.figshare.28690895) for this project are available on Figshare.

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