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Thermal Adapt Animal Behavior Model for Studying Wildlife Responses to Rising Environmental Temperatures

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Behavioral thermoregulation, Heat stress, Wildlife activity Patterns, Thermal adaptation, Nocturnality, Physiological stress, Cognitive performance
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Abstract
Behavior is expected to be the first response as environmental temperature increases, leading to changes in diurnal activity, habitat usage and movement patterns, as well as changes in social behavior. However most existing research either assesses behavioral and physiological responses independently or has explored it in species at a single time frame and spatial scale limiting understanding of broad ecosystem thermal adaptations. A Thermal Adapt Animal Behavior Model is proposed that connects behavioral responses and physiological indices of heat stress across a range of temporal and spatial scales. This model links habitat choice, altered diurnal activity patterns, altered spatial movement and tolerance limits to predict an animal's response to increasing thermal conditions. Supported by recent research exploring: temperature sensitive mammals, nocturnal refuge use, impacts of heatwaves on ungulates, assessing non-invasively stress responses, evidence for genetic adaptation, and cognitive changes due to increasing temperature. The proposed framework can predict adaptive capability. Multi-species testing needs to be done in the field to determine the predictive utility in different climates.

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Introduction

Wild animals are forced to rely on behavior in response to rising environmental temperatures, altering timing of activity, habitat utilisation, and movement patterns before physiological strategies come into play. Research on the behaviour of a heat-sensitive species across different spatial orders has shown that while behavioural thermoregulation occurs at microscale levels (microhabitat selection for shade), it is also present at larger scales (elevation shifts, seasonal range shifts), and studies that focus on single spatial levels miss some key elements of the species thermal response strategy (Verzuh et al., 2023). Studies investigating shifts in behaviour at night and role as a means of escaping heat have shown that some species increase nocturnal activity significantly. Despite an increase in the risk of predation, the animals are ready to give up part of fitness in exchange for avoiding thermal stress during the hottest part of the day (Brivio et al., 2024). Research has shown that the physiological effects of a summer heat wave on cold-adapted ungulates indicate that even short-term exposure to extreme heat can lead to a reduction in activity, heart rate, as well as body weight in the upcoming fall season, which indicates that behavior in response to acute heat is able to produce long-term effects beyond the event itself (Trondrud et al., 2023).

In a void identified by these diverse studies, The Thermal Adapt Animal Behavior Model conceptualises both multi-scale behaviour, temporal habitat use strategies and physiological responses to high temperatures yet presents one framework to connect behaviour at multiple spatial-temporal scales with its consequences on physiological stress states which are precisely what behavioural strategies of this type seek to avoid.

The three key contributions include: first the presentation of model architecture that conceptually depicts behaviour operating across space time simultaneously rather than as distinct levels of analysis. Second, the inclusion of behavioral adaptation to time/night use has been introduced and framed within an accepted trade-off. Third, behavioral response linked to direct physiological stress criteria.

The remaining portions of this paper are structured as follows: Section II describes major shortcomings in the current behavioral thermoregulation literature with attention to recent research conducted at the intersection of non-invasive quantification of heat stress, genetic footprints of thermal resilience, and cognition under conditions of heat exposure; Section III details the architectural configuration for a behavioral warming response model; Section IV covers behavior model outcome trends and discussion in relation to prior work in the behavioral thermoregulation field; and Section V summarizes this effort and sketches out possibilities for follow up and validation.

Gaps in Present Behavioral Thermoregulation Studies

Studies analyzing non-intrusive techniques to measure the impact of heat stress on livestock, particularly dairy cows, have indicated that physiological indicators like respiratory rate and body temperature can be obtained without having the animal physically restrained, but these techniques have been mostly implemented at farms and are not sufficiently tested in studies of behavioral thermoregulation in natural populations (Sejian et al., 2022). Studies on the genetic basis of therm Adaptation correlated to clines in life history of frogs have shown that populations along a temperature gradient show specific genetic differences related to thermoregulation, showing that the thermoregulation of the species may be affected by genetic differences along its distribution, but studies of behavioral thermoregulation hardly take genetic differences into account when correlating different behaviors of animals (Cayuela et al., 2022). Studies analyzing the influence of high temperatures on the cognitive capacities of southern pied babblers have revealed that when animals are subjected to the heat stress, it also negatively affects abilities to perform cognitive tasks, illustrating the extension of heat stress beyond locomotion into cognition, which is the aspect of thermal response rarely considered by behavioral thermoregulation studies (Soravia et al., 2023).

The study notes these recent results demonstrate a consistent range of lacunae in research into the behavior of modern thermoregulation. Research into non-invasive physiological monitoring demonstrated it was possible to track thermoregulatory behavior of animals without interfering with the animals: but to date this technology has tended to occur within animal management contexts rather than within natural populations, hence the basis for physiologic a data informing behavioral work in wild animal systems. Research on genomic thermoregulation demonstrates the range of behavioral responses across a species' habitat range is, at least partially, in response to regional variation in genetic thermal adaptation and that this is distinct from behavioral flexibility, which contemporary researchers are likely not accounting for these results demonstrate any useful model of the behavioral responses of wildlife to increased temperature will require some measure of non-invasive physiologic stress, some insight into whether behavioral variation corresponds to genetic variation in thermos resistance rather than behavioral flexibility, and a description of broader responses to increased temperatures and heat-based stresses (Lopez et al., 2023).

Model Structure for Warming-Response Simulation

Multi-Scale Behavioral Response Layer

To address behavior with a behavioral response layer which captures behavior in several ways at multiple spatial levels at the same time, given the finding that at least one heat-sensitive species altered behavior at fine and coarse spatial levels to a changing climate. At the fine level the behavior layer accounts for microhabitat use in shaded spots, near a water resource, or at exposed locations where air flow is high. The layer at a coarse spatial scale allows for shifts in habitat use along a climate gradient (e.g., across elevation gradients, over seasons, or across the geographic range) with longer term changes in climatic condition. Being able to combine both levels into the same layer enables representation of how changes in fine-level behavior may sometimes compensate for thermal stress, when such compensatory actions become insufficient.

Temporal Activity and Trade-Off Layer

Following this multi-scale behavioral response layer, the model explicitly incorporates an explicit temporal activity layer capturing changes in activity patterns, such as a tendency towards more nocturnal activity, as a thermoregulatory behavioral strategy. It explicitly represents the trade-off between the thermal benefits of reduced activity with activity during time, and the costs of activity at night such as high mortality risk, explicitly from the evidence that heat-stressed organisms do increase nocturnal activity despite this penalty. Representing the trade-off between risks and benefits allows us to predict when a species should trade-off the increased risk associated with nighttime activity for thermal relief.

Physiological and Cognitive Stress Integration

Finally, the third component of the model connects the indicators of behavior response with latent indicators of Physiological and Cognitive Stress outcomes: including non-invasive physiological measures of stress modelled upon previously established methods of Livestock Monitoring to suit Wild Population situations and cognitive function indicators consistent with emerging evidence showing an ability for heat stress to have impacts upon Cognitive Task Performance independent from its impact upon activity and movement. This links behavioral thermoregulatory outcomes, from the previous two components, to the latent Physiological and Cognitive Stress outcomes it serves to counteract explicitly.

Behavioral Outcome Trends and Result Discussion

Anticipated Behavioral Trends

Model's future predictions come from previous thermoregulation research, as the framework has not yet been empirically validated on a number of field-recorded behavior sets for multiple species. The model should reveal the behavioral, scale-dependent responses that animals undertake to increase thermal tolerance, such as modified habitat selection, movement patterns, and timing of activities when ambient heat increases. Given prior work highlighting disparate behavioral responses between mammal species sensitive to heat, coupled with the observation that more behavior occurs in nocturnal activity time under heat stress, anticipate that the model is capable of producing behavioral shifts, balancing thermotolerance with other life history considerations like predation pressure.

Comparison with Existing Thermoregulation Research

In contrast to typical thermoregulation research considering only a single level behavioral or physiological trait response, the conceptual model is presented as a multi-scale integrated model of how wild animals will respond to warming heat. It draws on existing theoretical approaches for understanding the selection decisions and modifications in behavior/activity/movement and physiological indicators of stress that will, all together, allow us to assess and better interpret the relative importance of different thermal adaptations. The integration, however, overcomes many weaknesses of existing multi-scale analyses to develop a more coherent view on thermal adaptation.

Implications and Limitations

Implications of the Thermal Adapt Animal Behavior Model on wildlife conservation can be seen in the behavior trade-off made by animals between seeking shade to avoid excessive heat and avoiding ecological threats like predation. The Thermal Adapt Animal Behavior Model indicates that conservation of habitat continuity and refuge zones can increase the ability of the species to survive in situations of extreme heat. The addition of the physiological and genomic adaptations in the model further strengthens the assessment of thermal behavior of each individual species. However, the model needs to be validated using data collected over a period of time in the field.

Conclusion

In conclusion, the model described in this paper, the Thermal Adapt Animal Behavior Model, provides a conceptual tool for the study of animal reactions to increasing temperatures in environment by combining multiple aspects of behavioral adjustment, changes in the time of activity and physiological and cognitive stress markers into one coherent concept. In addition to bridging the gaps in previous studies on the lack of utilization of non-invasive physiological measurement in field conditions, genetic thermal adaptation's influence on behavioral diversity and heat stress' impact on cognition, the model gives the basis to predict wildlife population behavior under rising temperature and the moment when the behavioral strategy becomes insufficient to prevent physiological deterioration. The field application of the model, which would allow testing it on different species and in different climatic and habitat conditions, is another area of research that requires further work, along with the adaptation of non-invasive physiological measurements for use in wild populations.

References

[1] Brivio, Francesca, Marco Apollonio, Pia Anderwald, Flurin Filli, Bruno Bassano, Cristiano Bertolucci, and Stefano Grignolio. "Seeking temporal refugia to heat stress: increasing nocturnal activity despite predation risk." *Proceedings of the Royal Society B* 291, no. 2015 (2024): 20231587. https://doi.org/10.1098/rspb.2023.1587

[2] Cayuela, Hugo, Yann Dorant, Brenna R. Forester, Dan L. Jeffries, Rebecca M. Mccaffery, Lisa A. Eby, Blake R. Hossack, Jérôme MW Gippet, David S. Pilliod, and W. Chris Funk. "Genomic signatures of thermal adaptation are associated with clinal shifts of life history in a broadly distributed frog." *Journal of Animal Ecology* 91, no. 6 (2022): 1222-1238. https://doi.org/10.1111/1365-2656.13545

[3] Lopez, Laura K., Michael A. Gil, Philip H. Crowley, Pete C. Trimmer, Amelia Munson, Isaac Y. Ligocki, Marcus Michelangeli, and Andrew Sih. "Integrating animal behaviour into research on multiple environmental stressors: a conceptual framework." *Biological Reviews* 98, no. 4 (2023): 1345-1364. https://doi.org/10.1111/brv.12956

[4] Sejian, Veerasamy, Chikamagalore Gopalakrishna Shashank, Mullakkalparambil Velayudhan Silpa, Aradotlu Parameshwarappa Madhusoodan, Chinnasamy Devaraj, and Sven Koenig. "Non-invasive methods of quantifying heat stress response in farm animals with special reference to dairy cattle." *Atmosphere* 13, no. 10 (2022): 1642. https://doi.org/10.3390/atmos13101642

[5] Soravia, Camilla, Benjamin J. Ashton, Alex Thornton, and Amanda R. Ridley. "High temperatures are associated with reduced cognitive performance in wild southern pied babblers." *Proceedings of the Royal Society B: Biological Sciences* 290, no. 2011 (2023): 20231077. https://doi.org/10.1098/rspb.2023.1077

[6] Trondrud, L. Monica, Gabriel Pigeon, Elżbieta Król, Steve Albon, Erik Ropstad, Jouko Kumpula, Alina L. Evans, John R. Speakman, and Leif Egil Loe. "A summer heat wave reduced activity, heart rate, and autumn body mass in a cold-adapted ungulate." *Physiological and Biochemical Zoology* 96, no. 4 (2023): 282-293. https://doi.org/10.1086/725363

[7] Verzuh, Tana L., Savannah A. Rogers, Paul D. Mathewson, Alex May, Warren P. Porter, Corey Class, Lee Knox et al. "Behavioural responses of a large, heat-sensitive mammal to climatic variation at multiple spatial scales." *Journal of Animal Ecology* 92, no. 3 (2023): 619-634. https://doi.org/10.1111/1365-2656.13873