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Embryo development and global change: how do reptile embryos respond to ecologically relevant thermal stress?

Abstract

Two components of global change, climate change and urbanization, both contribute to increased ambient temperatures that may induce heat stress or mortality in animals. Each phenomenon independently results in both increased mean temperatures and increased maximum day-time temperatures; however, there is also the potential for these components to act synergistically: extreme temperatures due to the urban heat island effect are likely to be exacerbated as the earth's surface warms due to climate change. Many animals can respond to harmful temperatures behaviorally, by altering their periods of activity or shifting their habitat use. Such behavioral compensation, however, is unavailable to embryos of ectotherms which typically develop inside eggs in the ground and receive little or no parental care. Thus, this early life stage is expected to be more vulnerable to harmful temperatures caused by aspects of global change, and yet, the effects of ecologically relevant thermal stress on these embryos has received little attention. We sought to understand the consequences of such extreme temperatures on embryological development by utilizing two species of lizard (*Anolis sagrei* and *Anolis cristatellus*) that commonly inhabit urban areas. We measured ground temperatures in an urban landscape where lizards nest and modeled daily thermal fluctuations that included brief periods of extremely high temperatures. We then subjected eggs of both species to various magnitudes and frequencies of these thermal fluctuations at multiple stages of embryo development. We report results of embryo survival and highlight the potential for extreme incubation temperatures to differentially impact species.

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Daniel A Warner

Evolution • Ecology • Behavior • Physiology

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Global Change – climate change

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Biodivers Conserv (2010) 19:1043–1062
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LETTER

Climate change threatens European conservation areas

Miguel B. Araújo,[1,2*†] Diogo Alagador,[1,3†] Mar Cabeza,[1,4] David Nogués-Bravo[1,5] and Wilfried Thuiller[6]

Abstract

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It is predicted that climate change will cause species extinctions and distributional shifts in coming decades, but data to validate these predictions are relatively scarce. Here, we compare recent and historical surveys for 48 Mexican lizard species at 200 sites. Since 1975, 12% of local populations have gone extinct. We verified physiological models of extinction risk with observed local extinctions and extended projections worldwide. Since 1975, we estimate that 4% of local populations have gone extinct worldwide, but by 2080 local extinctions are projected to reach 39% worldwide, and species extinctions may reach 20%. Global extinction projections were validated with local extinctions observed from 1975 to 2009 for regional biotas on four other continents, suggesting that lizards have already crossed a threshold for extinctions caused by climate change.

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BIODIVERSITY

Climate change and the ecologist

Wilfried Thuiller

The evidence for rapid climate change now seems overwhelming. Global temperatures are predicted to rise by up to 4 °C by 2100, with associated alterations in precipitation patterns. Assessing the consequences for biodiversity, and how they might be mitigated, is a Grand Challenge in ecology.

How serious is climate change compared with other factors affecting biodiversity?

Very — but it tends to act over a longer timescale. The ecological disruption wrought by climate change is generally slower than

the Northern Hemisphere may have to move northward by some 500 km (or 500 m higher in altitude) to find a suitable climatic regime. Higher temperatures are likely to be accompanied by more humid, wetter conditions, but the geographical and seasonal distribution of

photosynthetic pathway or 'woodiness', as well as the subterranean organisms associated with them. Likewise, an increase of anthropogenic atmospheric nitrogen deposition affects nitrogen-limited regions (temperate and boreal forests and alpine and Arctic regions) by con-

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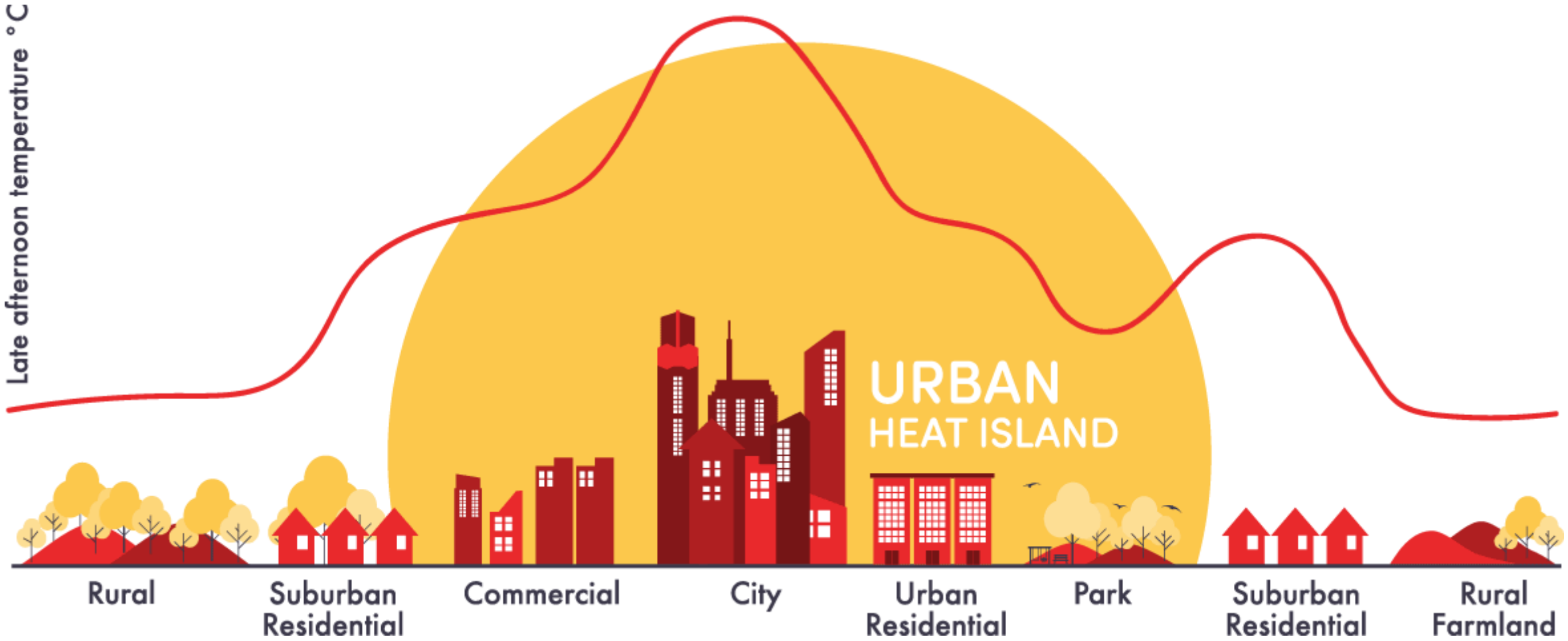
Global Change - urbanization

Urban heat island effect

Urban heat island effect



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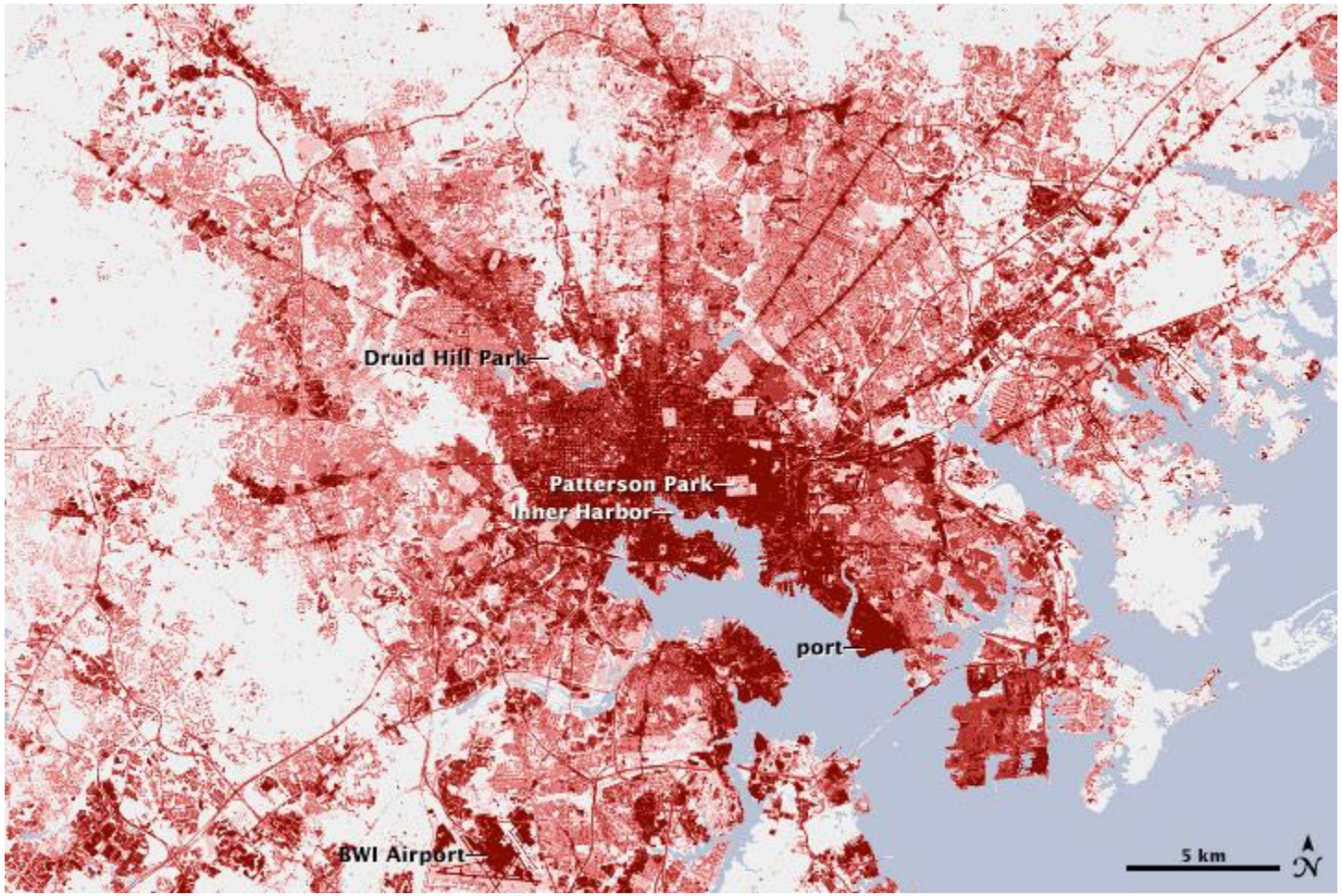
Urban heat island effect



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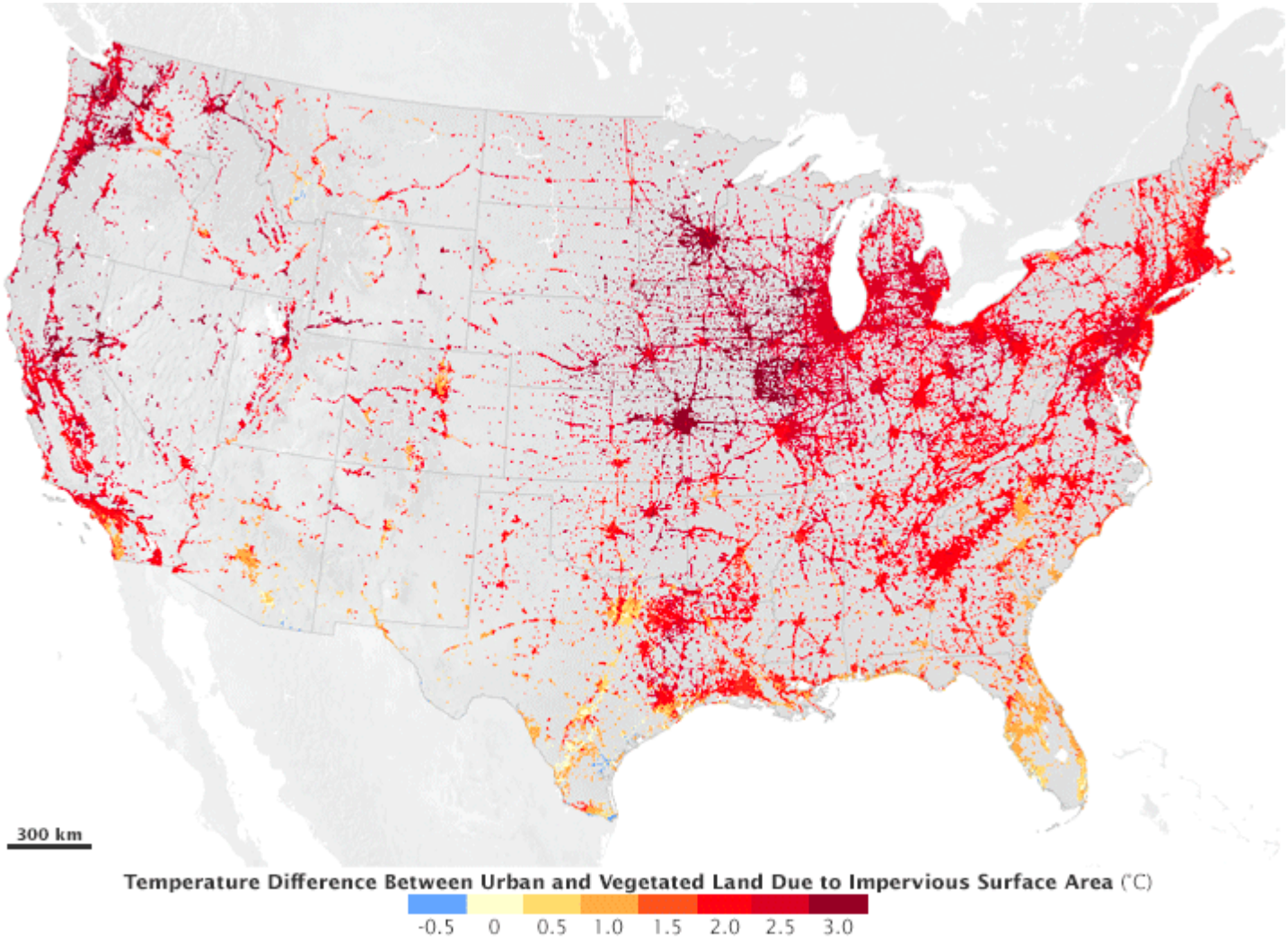

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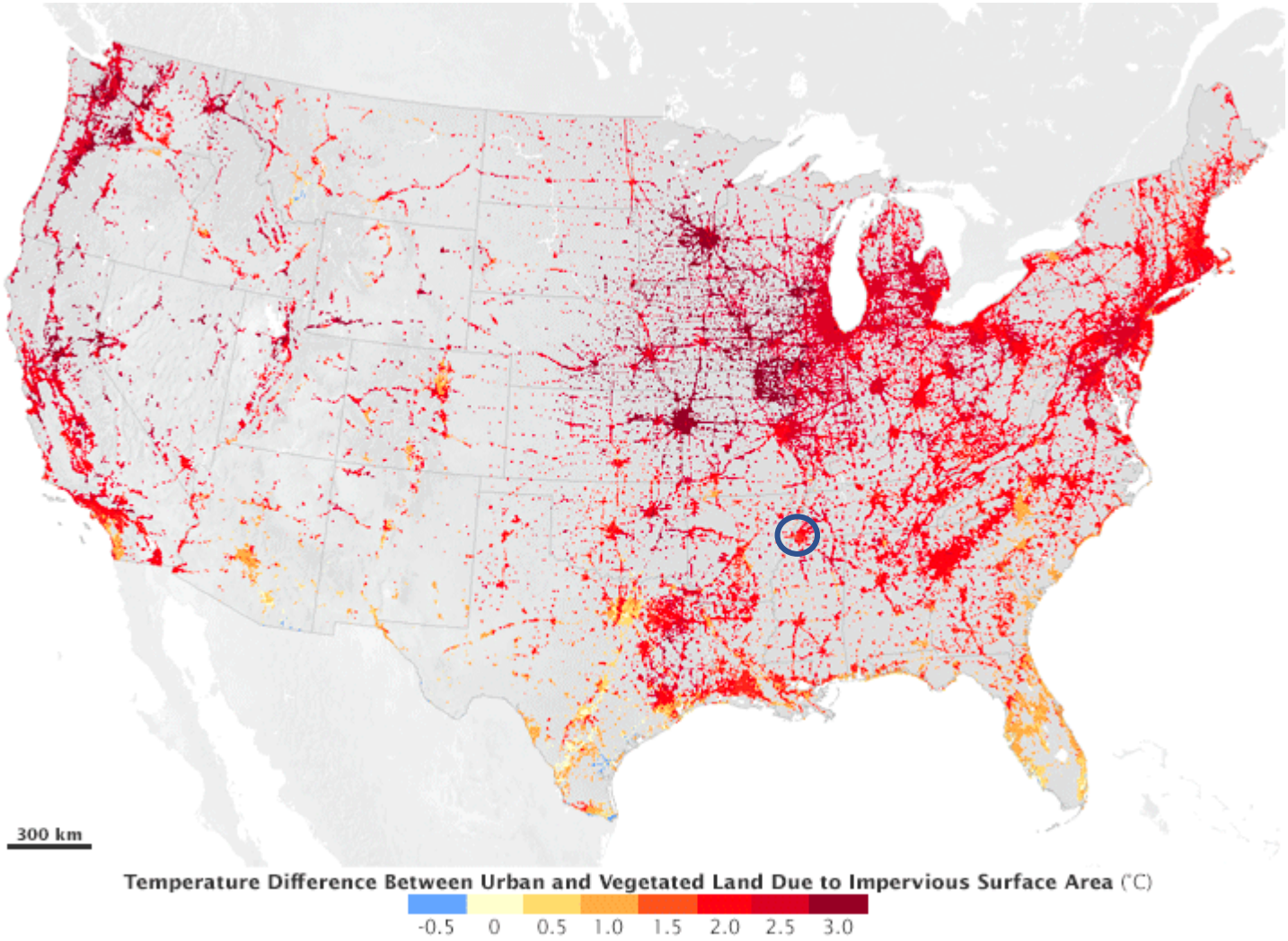

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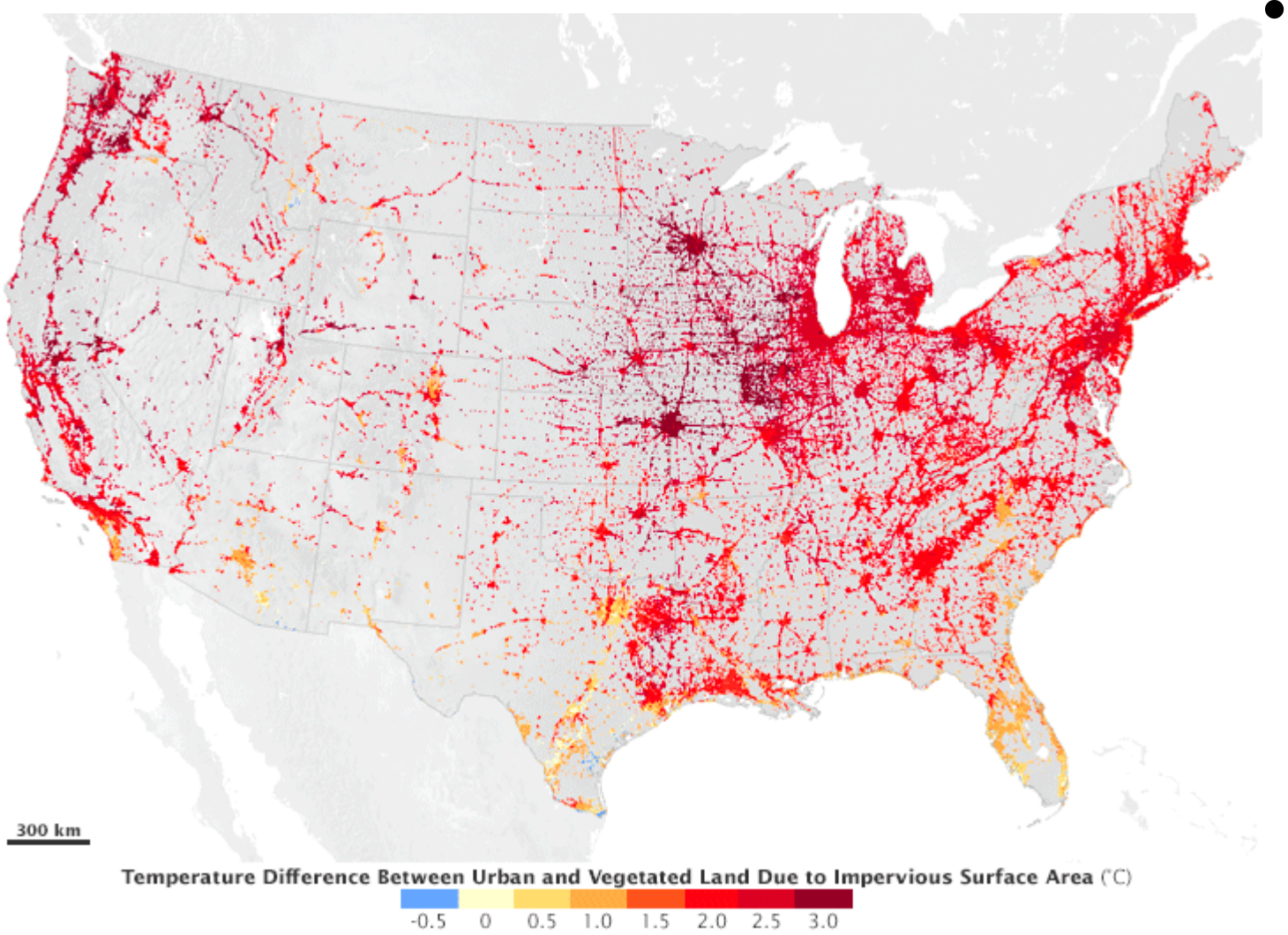

- Average **temperatures higher** in urban areas than natural sites

NASA

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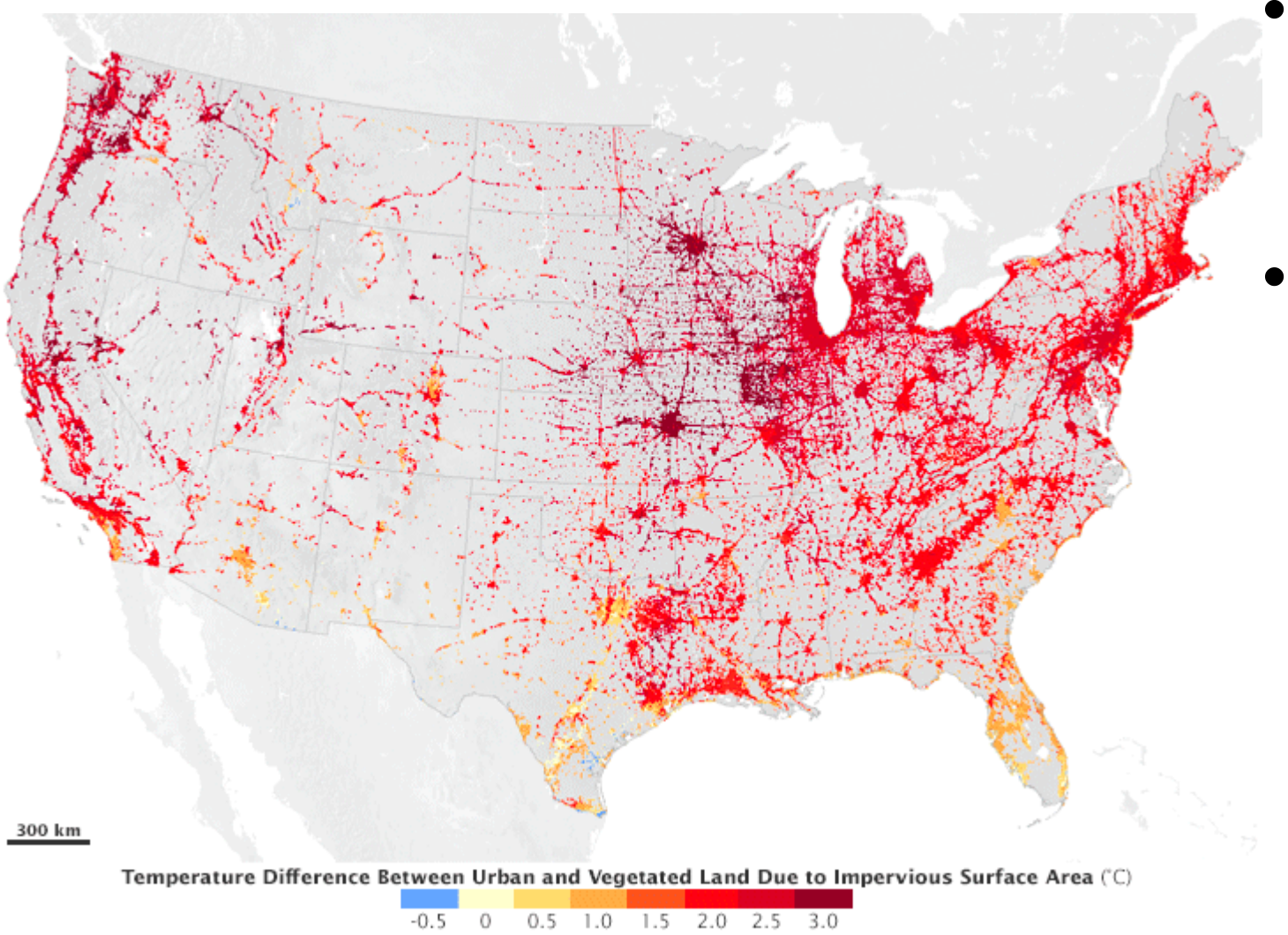

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NASA

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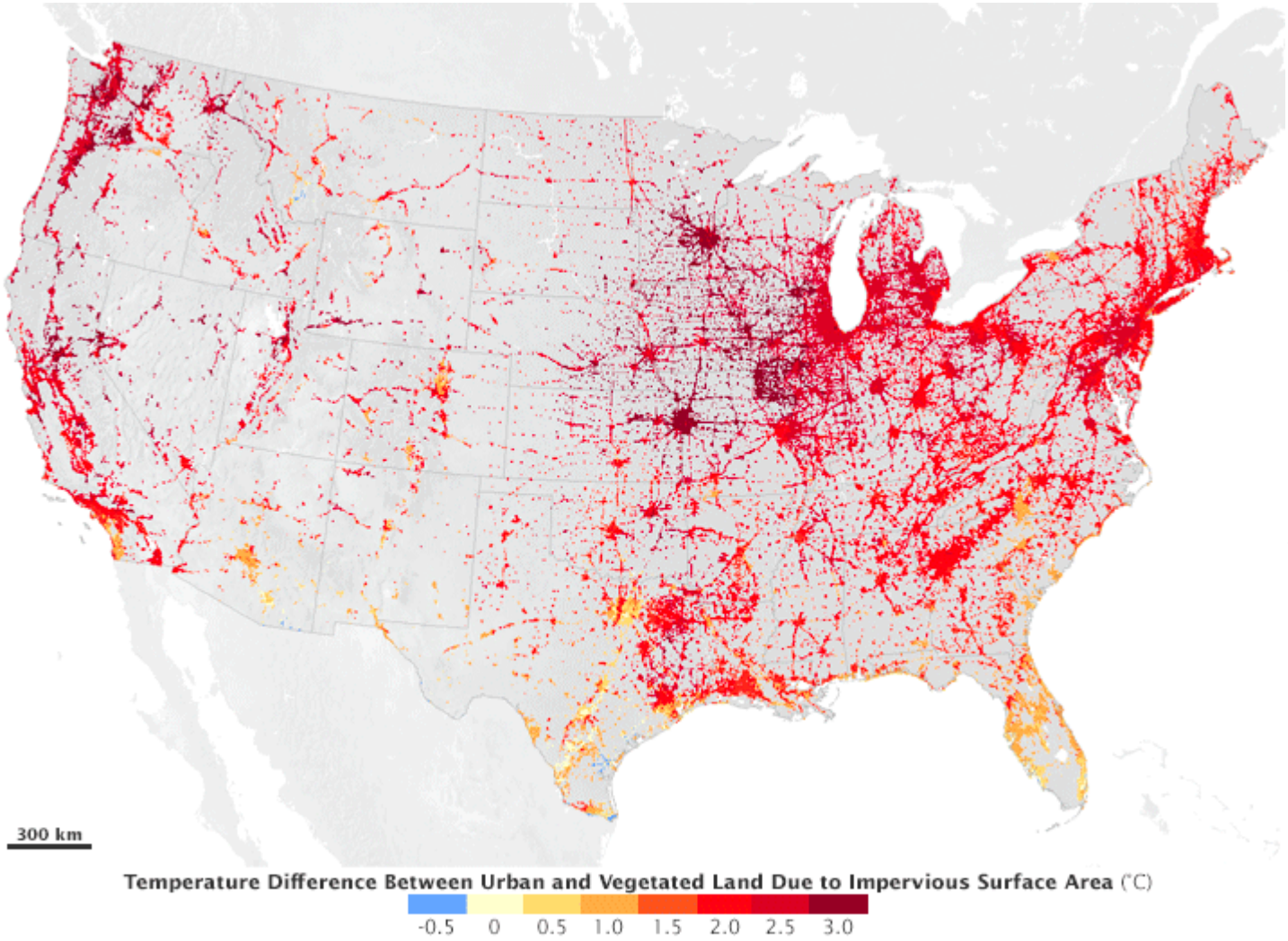

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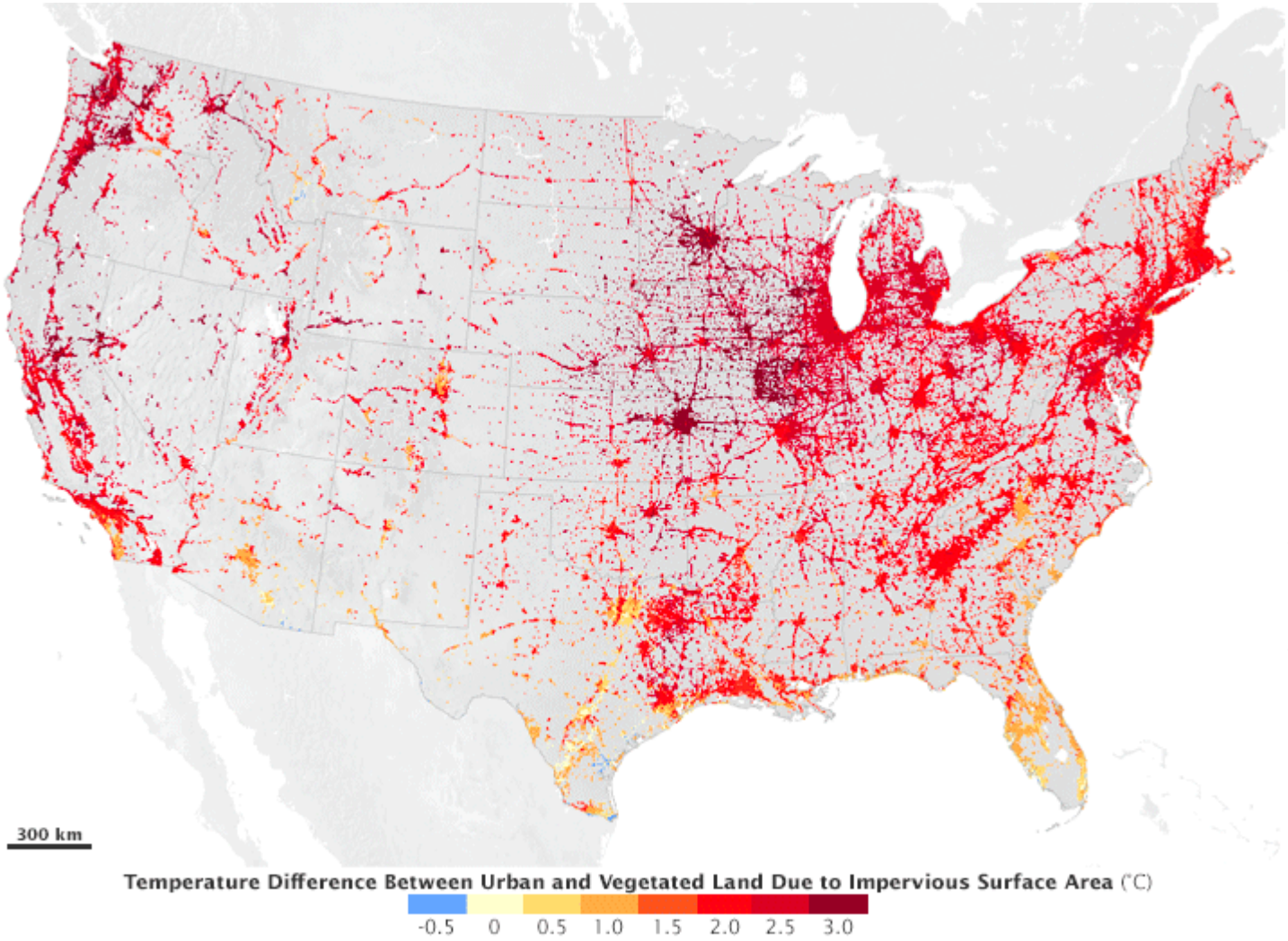

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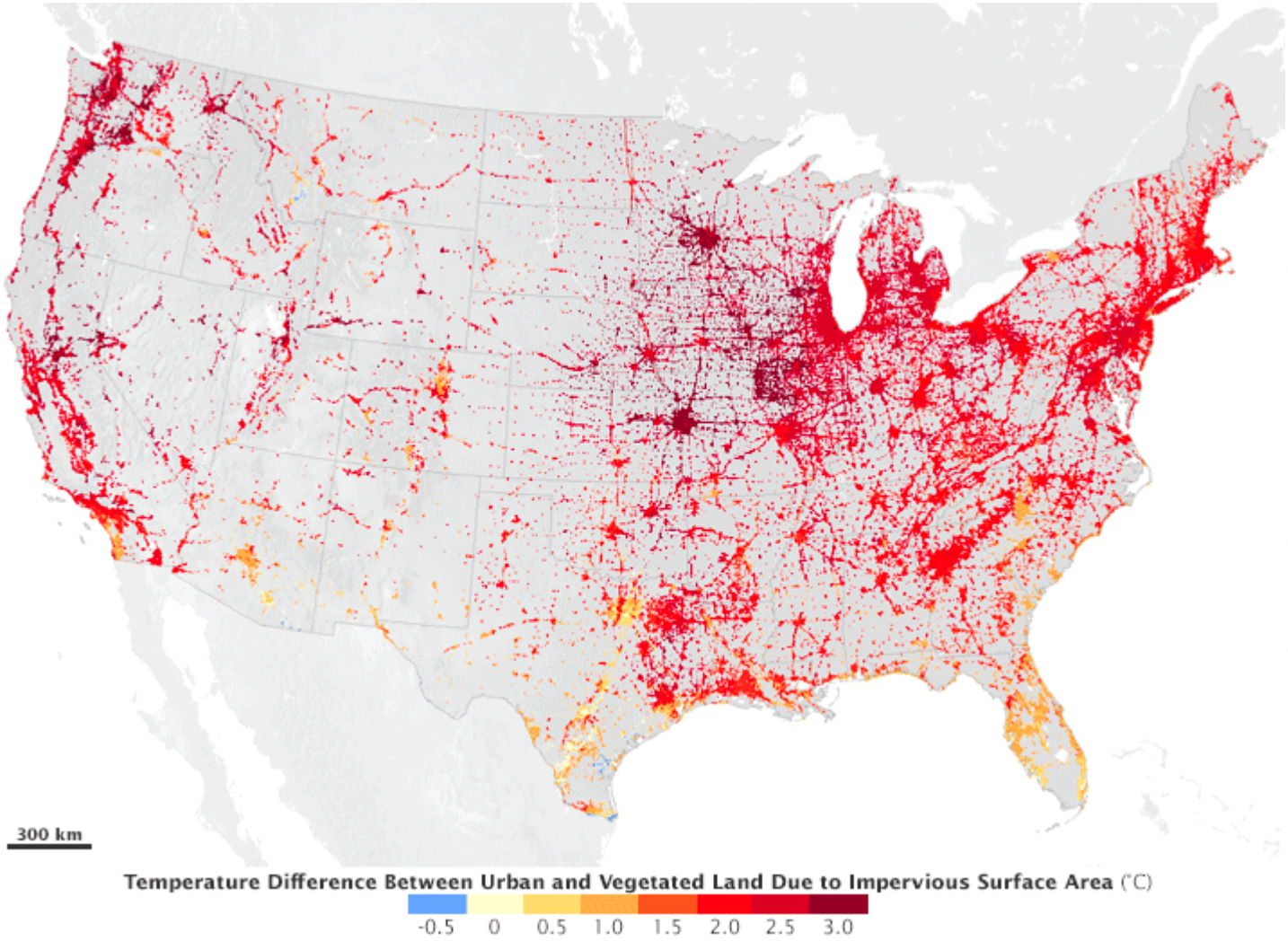

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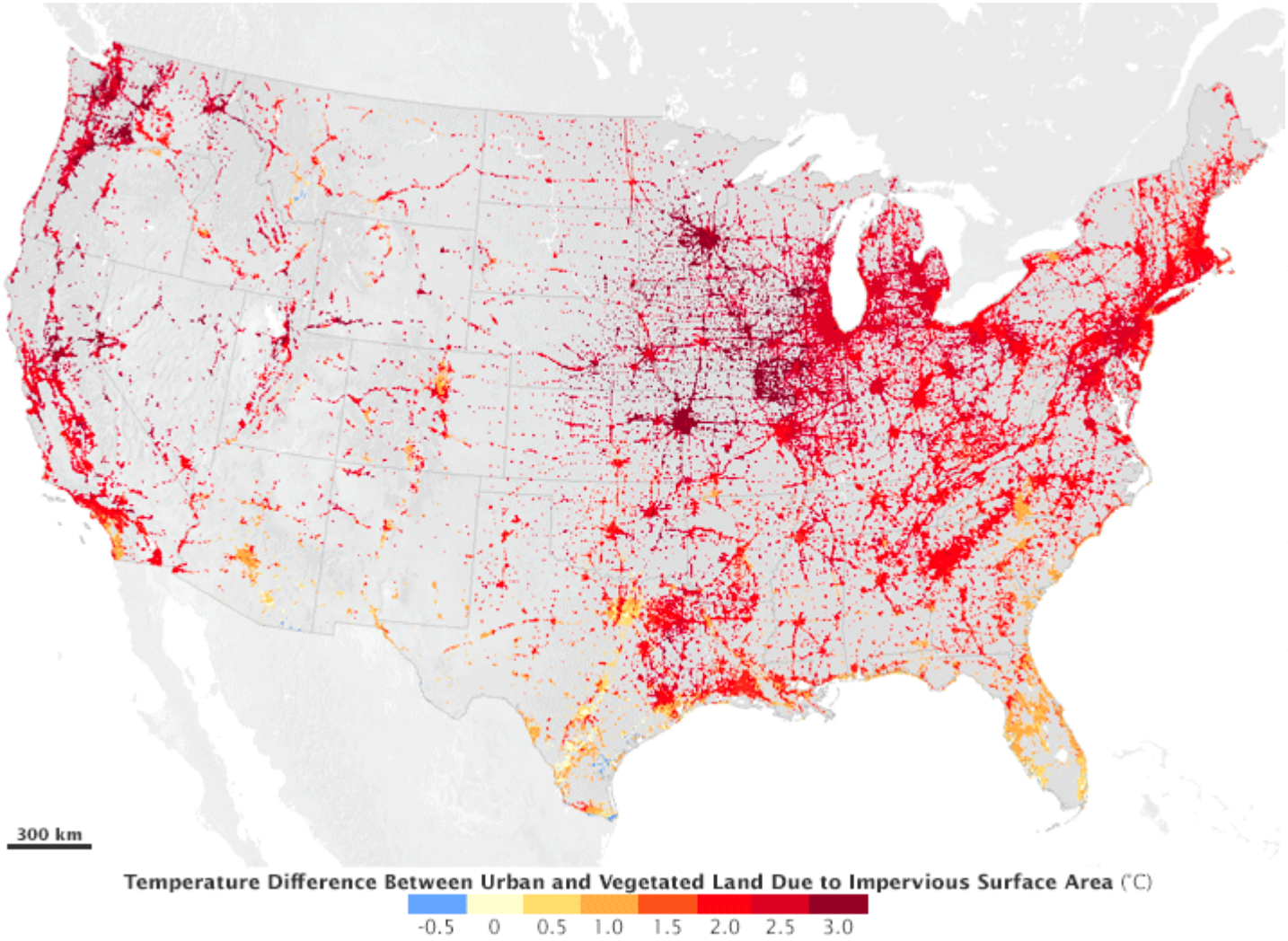

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  - Developing embryos?

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Reptile Embryos…

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- Are unable to **behaviorally compensate** for adverse conditions (can't run away)
- Influence population dynamics and **species distributions and persistence**

Pike. 2014. Glob Chang Biol 20: 7–15

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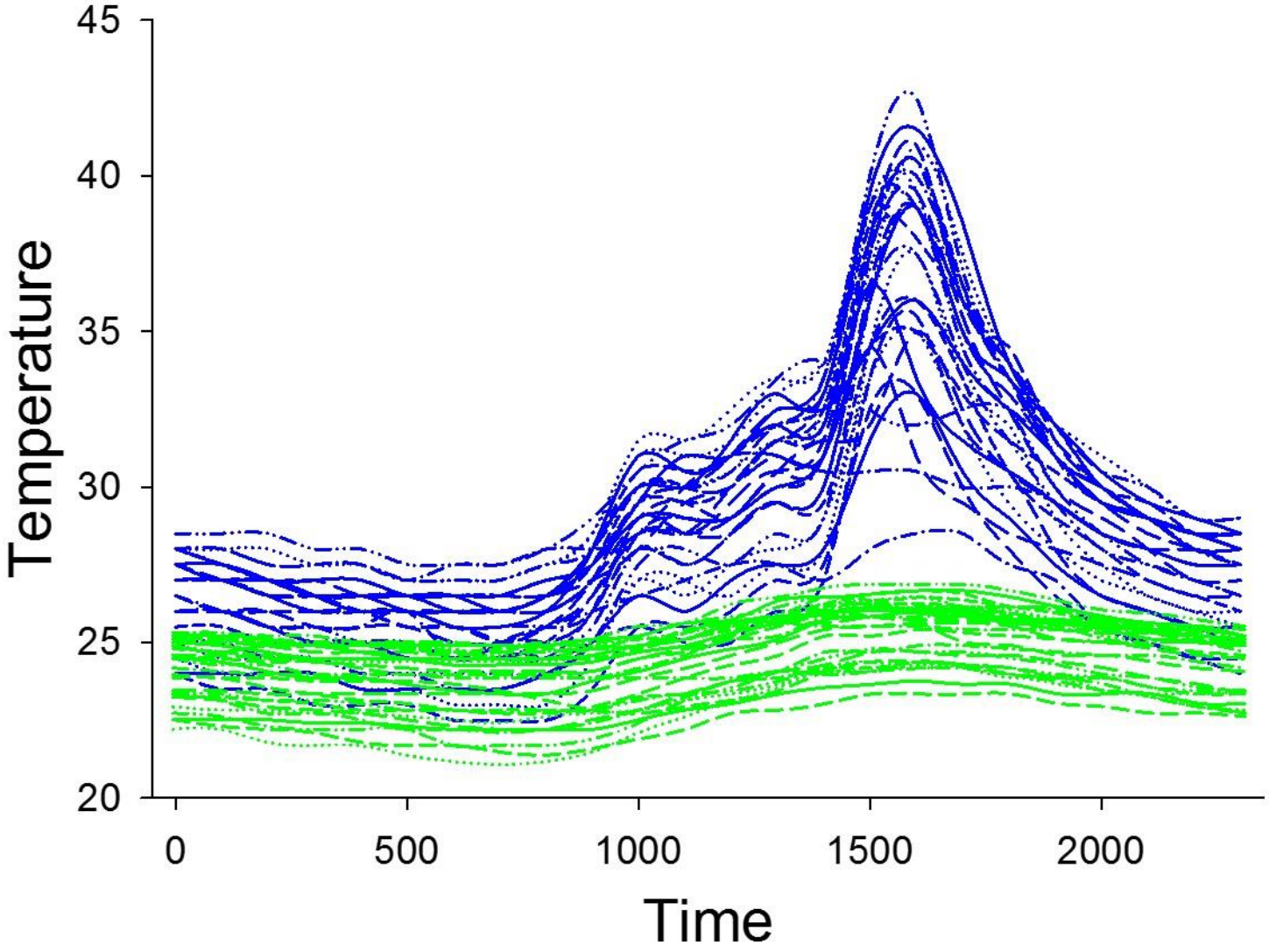

Ecologically relevant thermal stress

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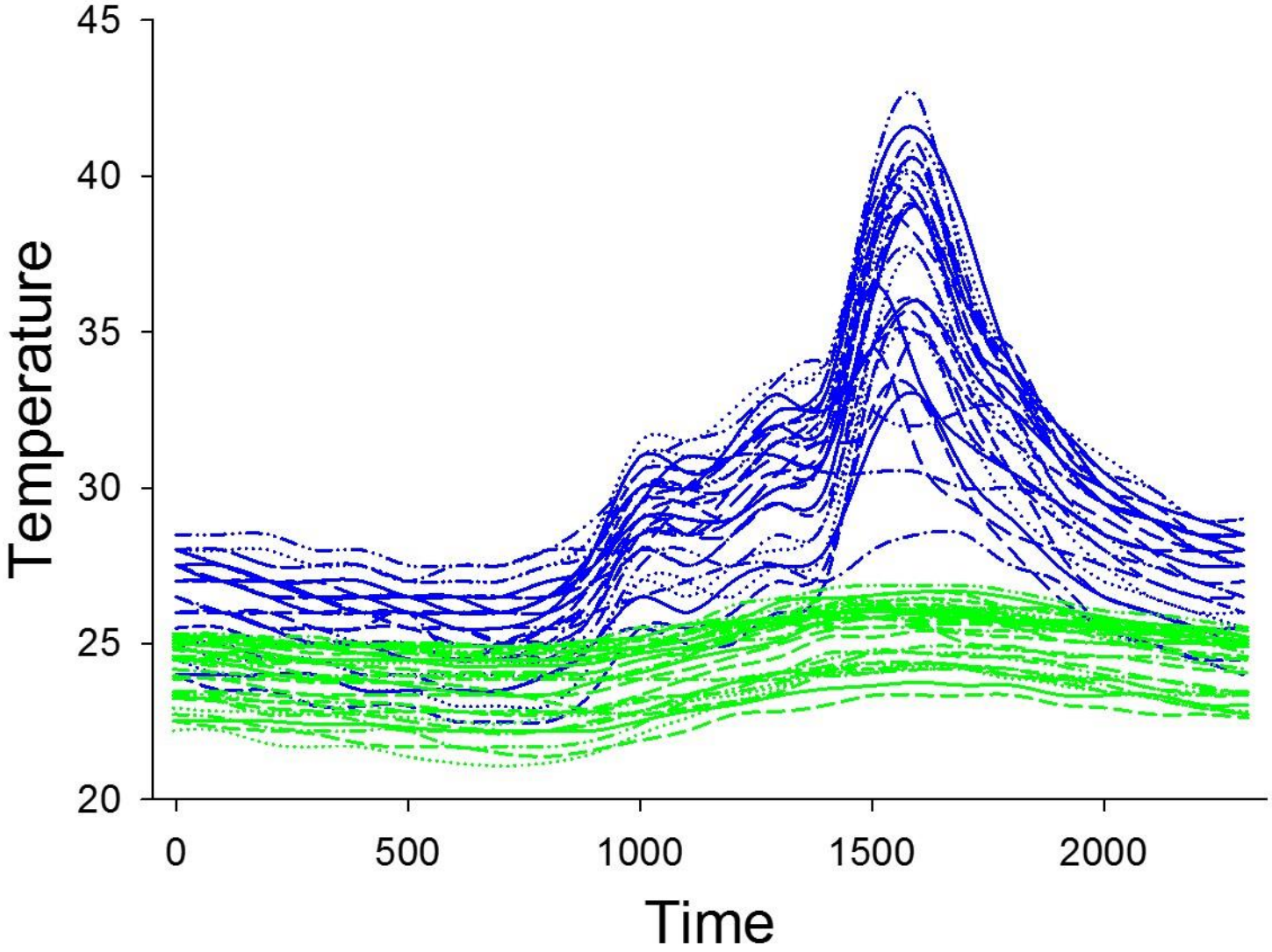
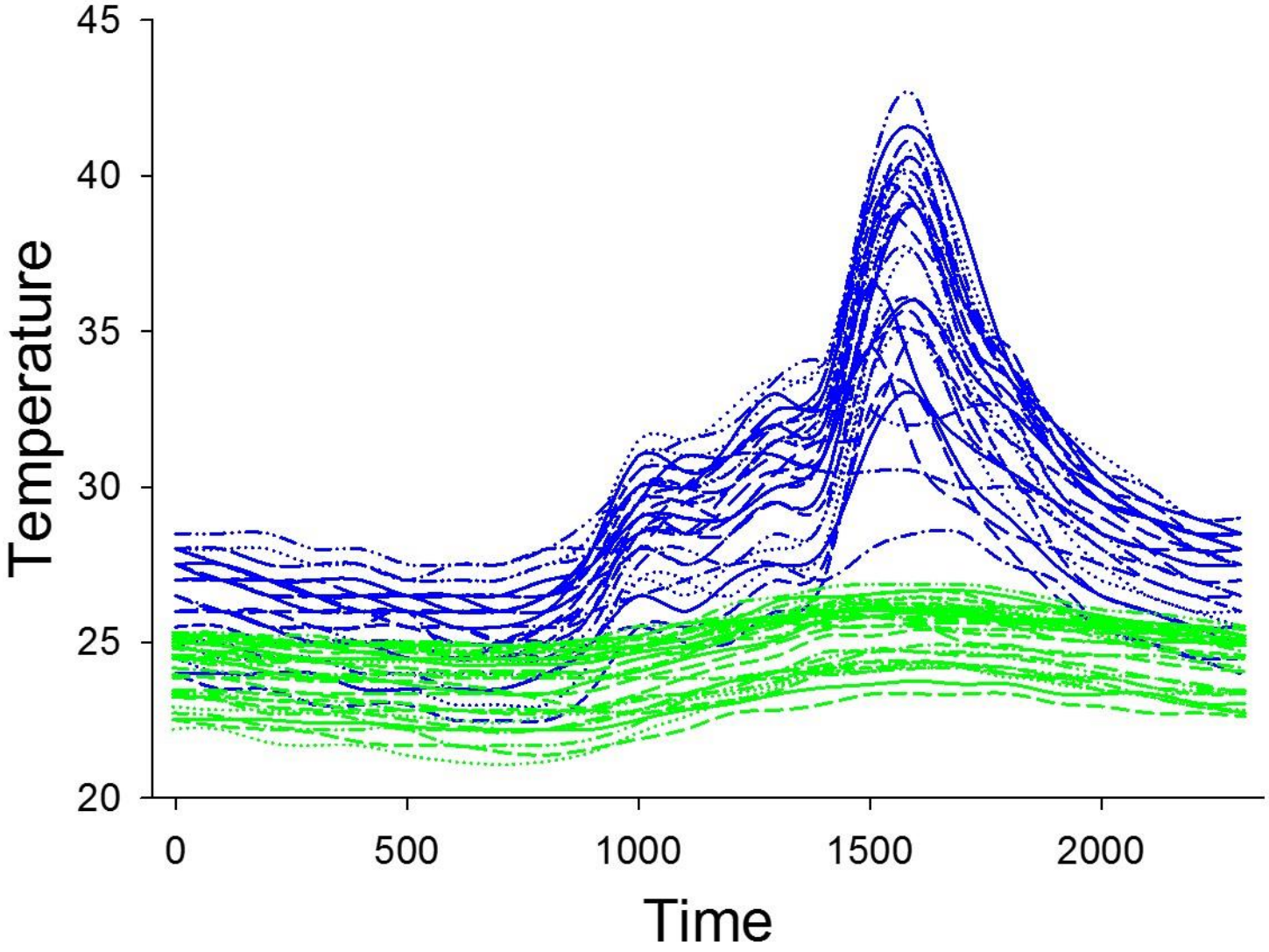
  - Heat shocks
  - Constant temperature incubation



Ecologically relevant thermal stress

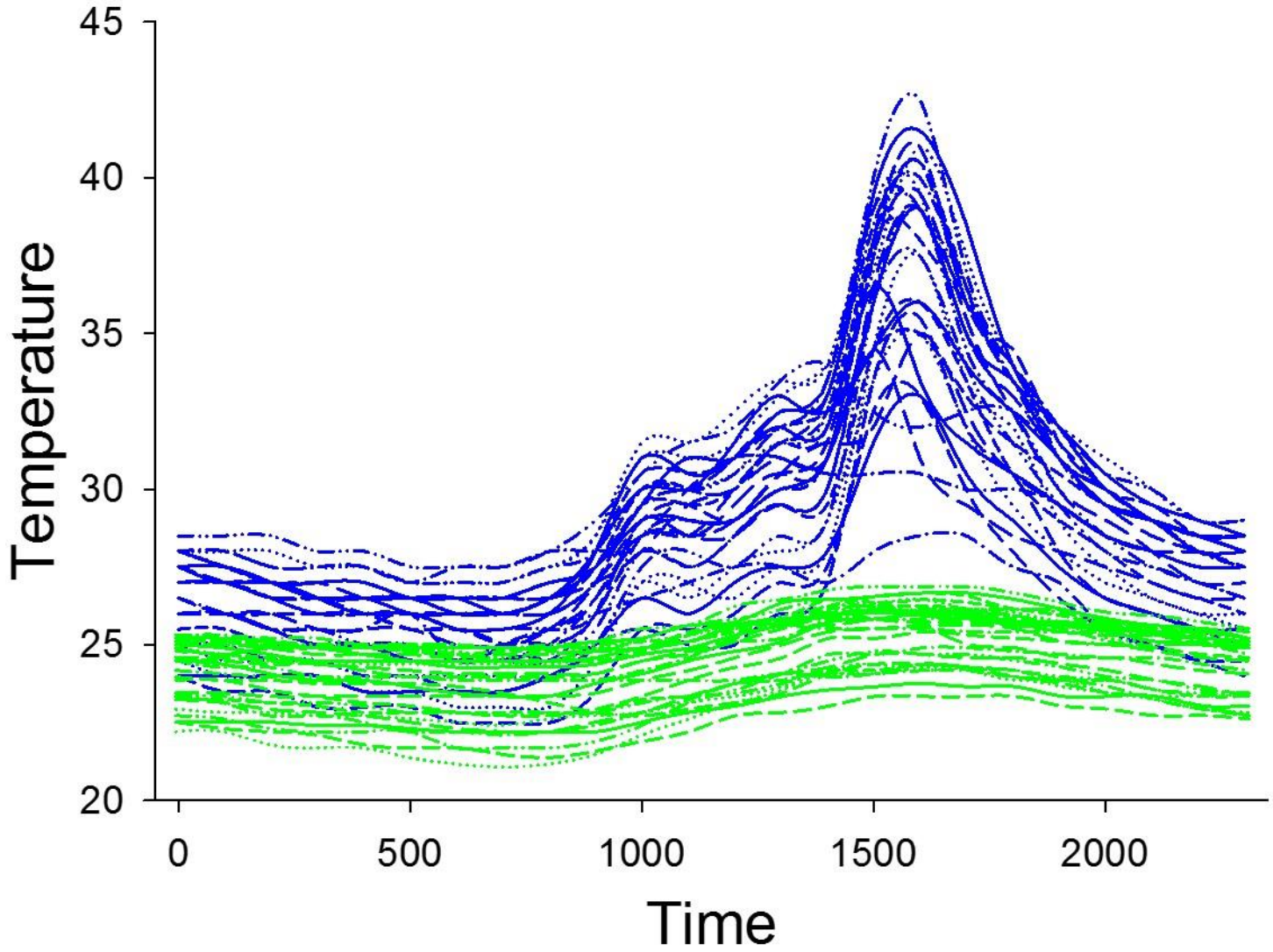
- Not Ecologically relevant
  - Heat shocks
  - Constant temperature incubation

Reduce egg survival by ~ 20%



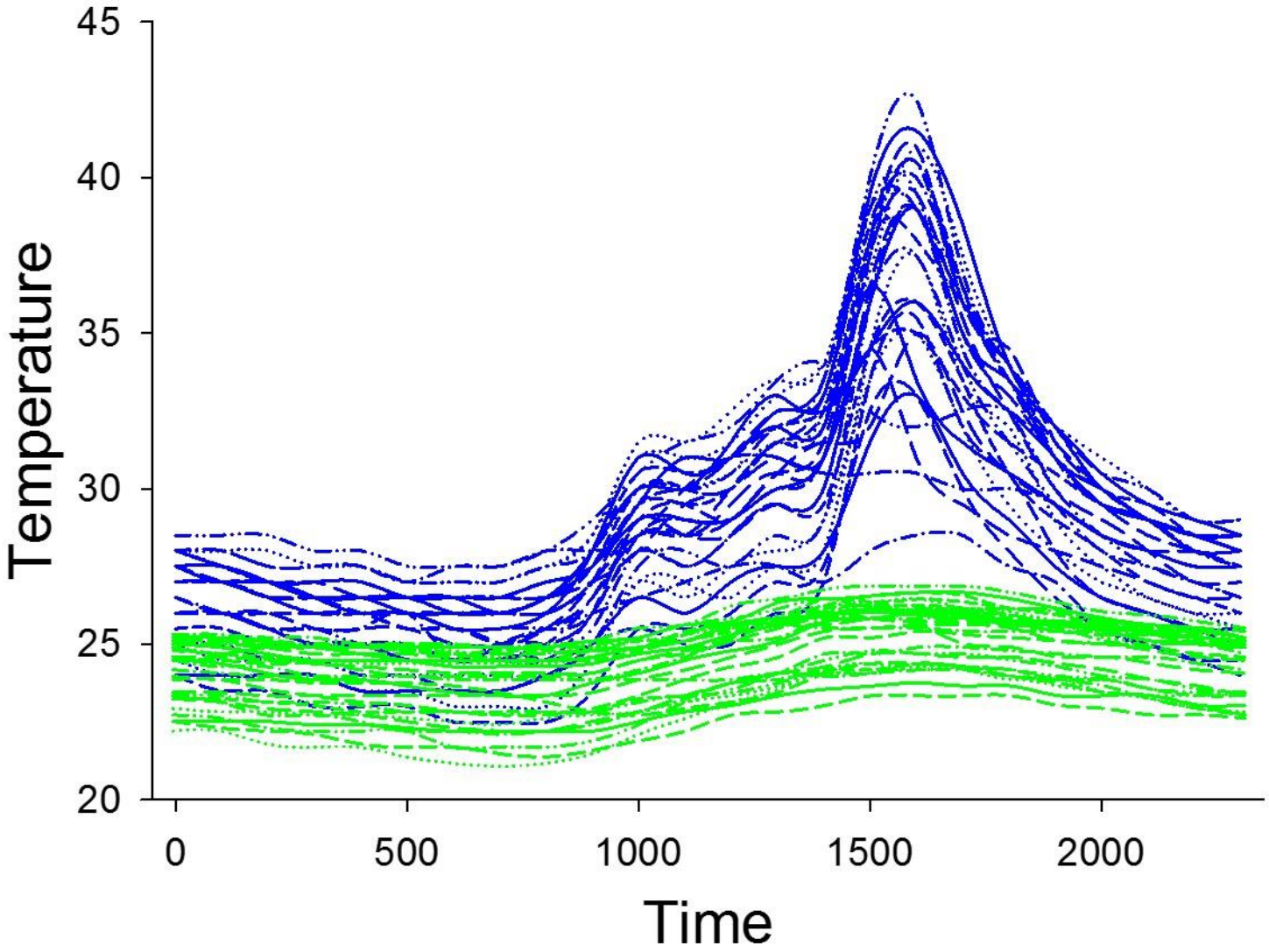
Hall & Warner. 2017. Biol J Linn Soc
Hall & Warner. 2018. J Exp Biol

Ecologically relevant thermal stress



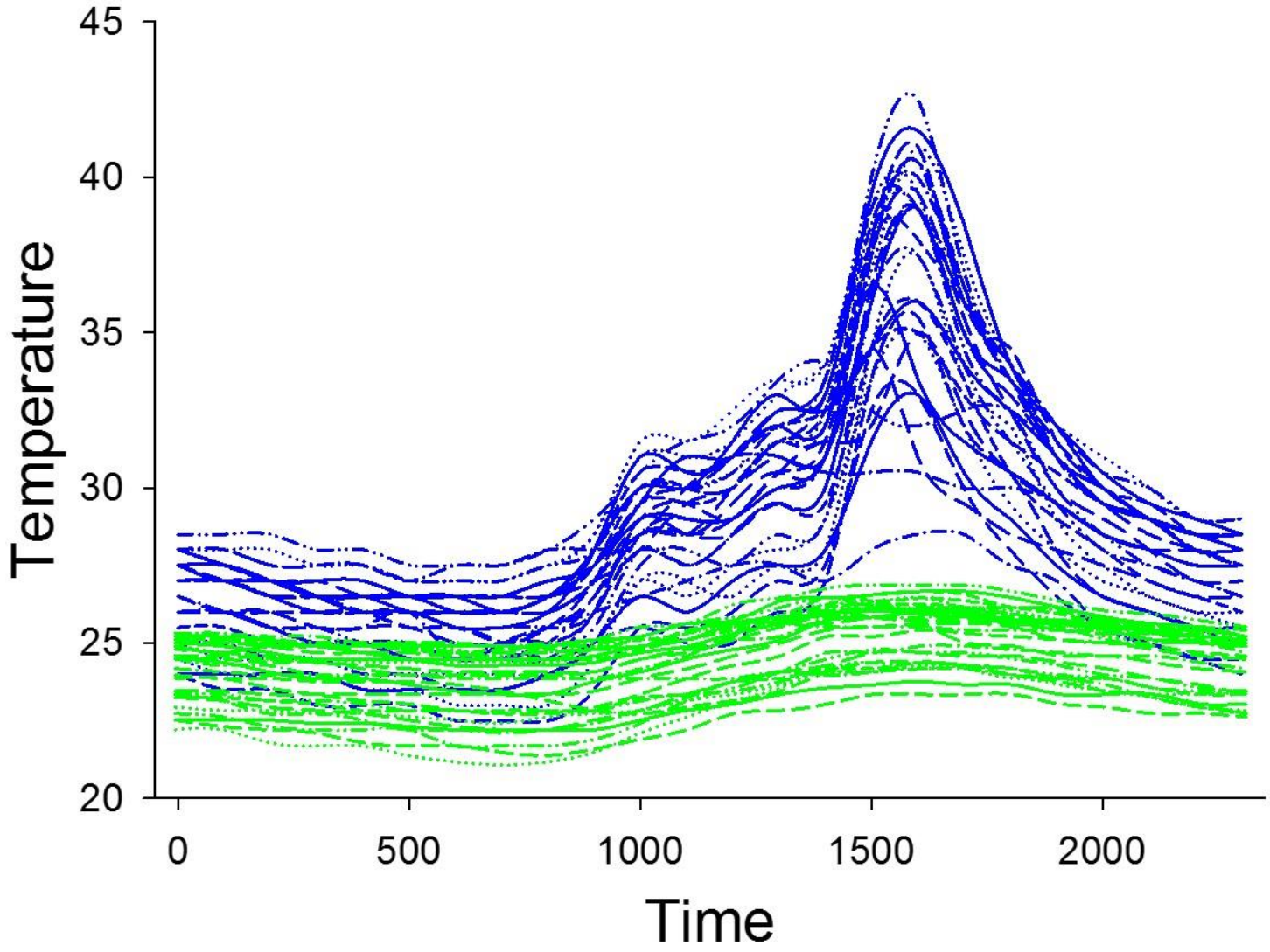
Ecologically relevant thermal stress

- Magnitude (how hot?)



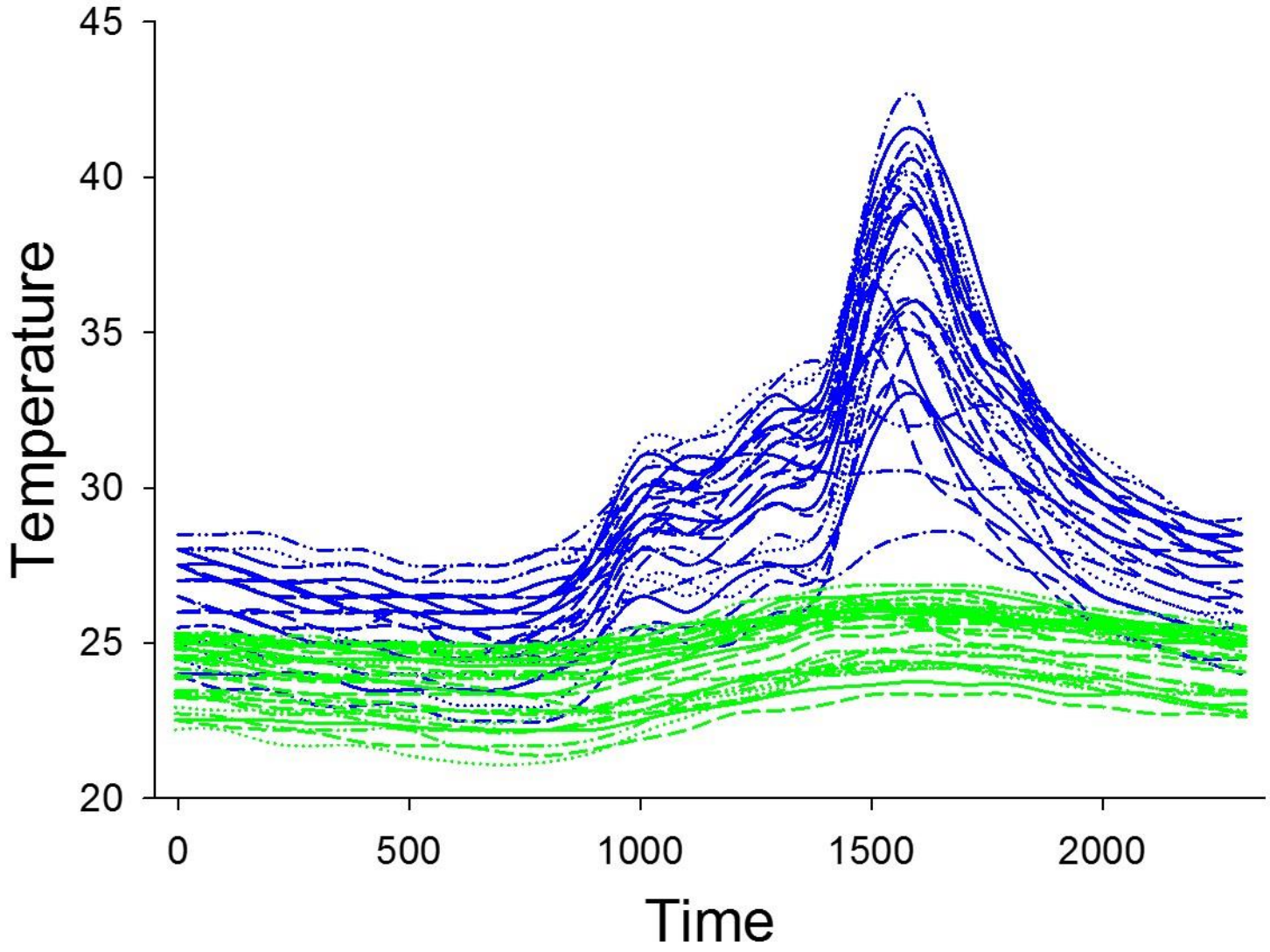
Ecologically relevant thermal stress

- Magnitude (how hot?)
- Frequency (how often?)



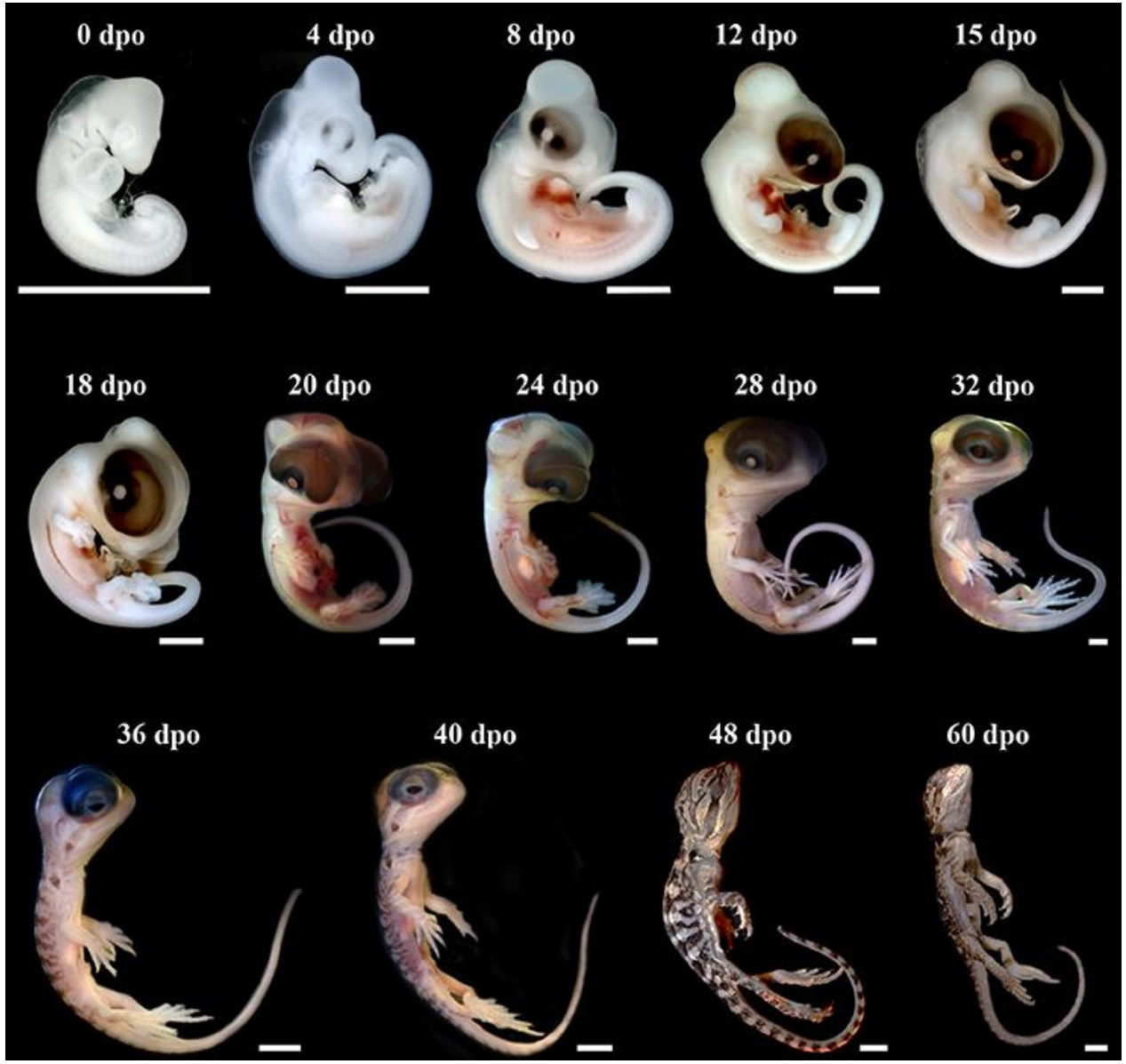
Ecologically relevant thermal stress

- Magnitude (how hot?)
- Frequency (how often?)
- Timing (how old?)



Ecologically relevant thermal stress

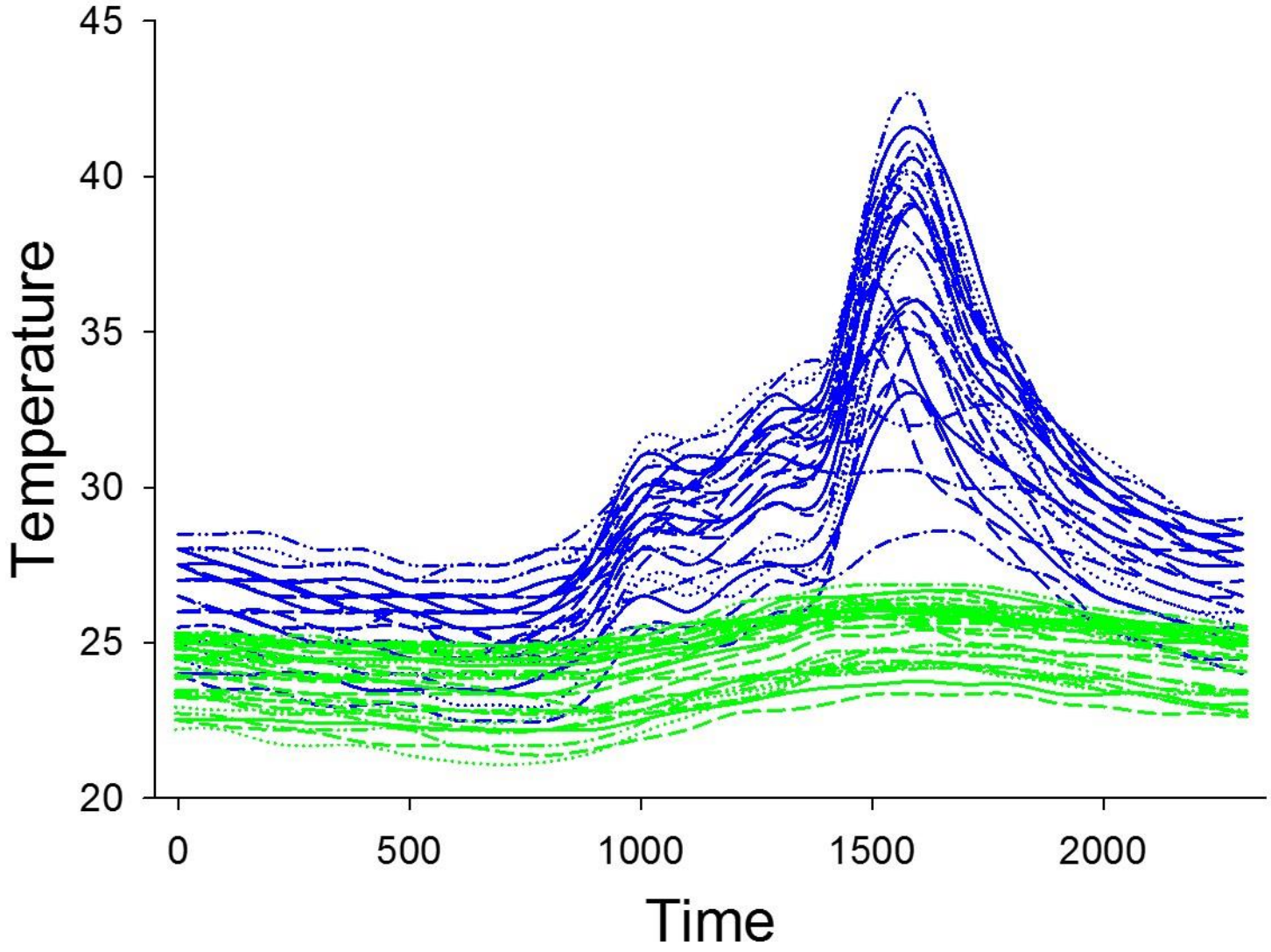
- Magnitude (how hot?)
- Frequency (how often?)
- Timing (how old?)



Ollonen et al. 2018. Front. Physiol.

Ecologically relevant thermal stress

- Magnitude (how hot?)
- Frequency (how often?)
- Timing (how old?)
- Species (how general?)

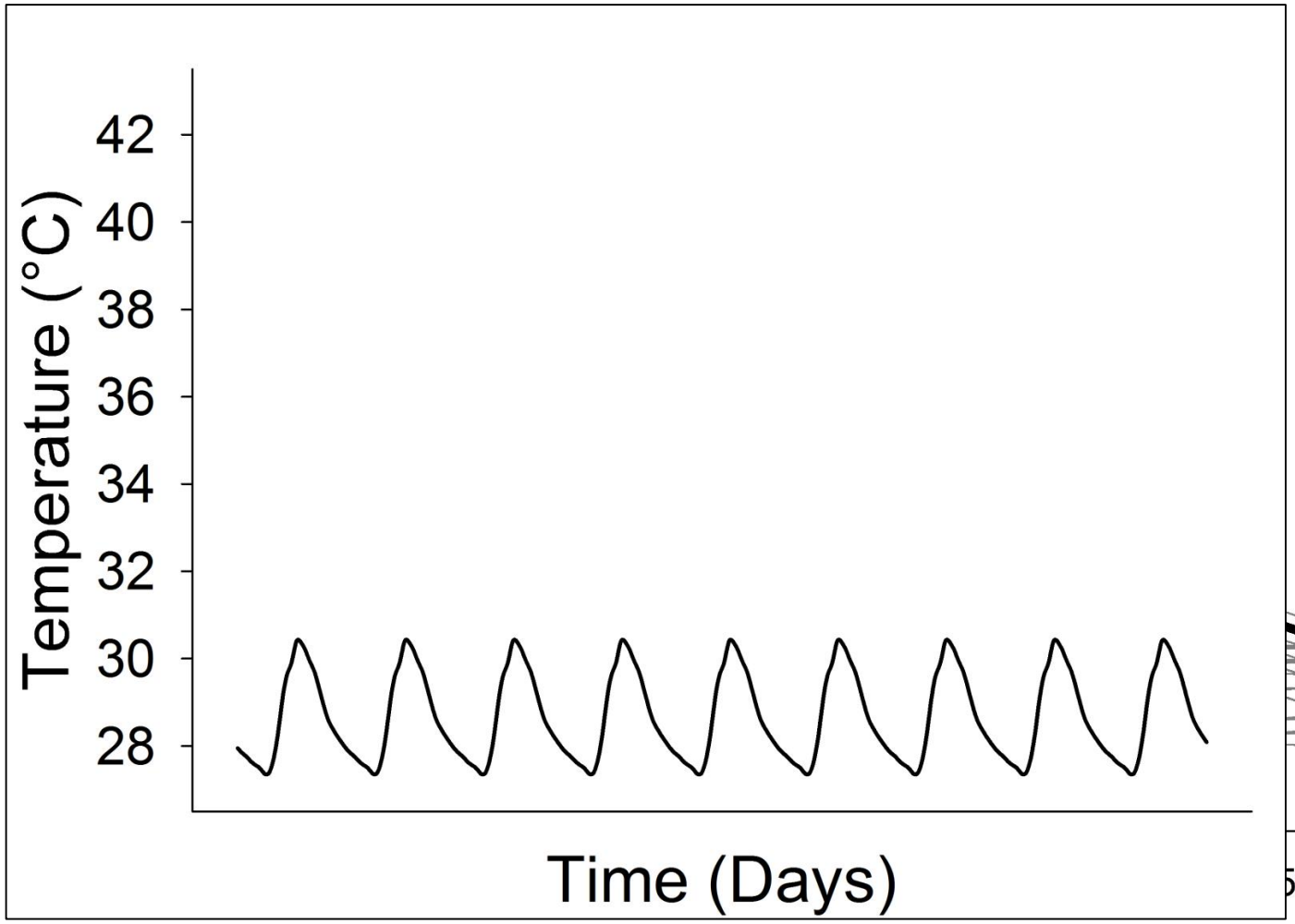


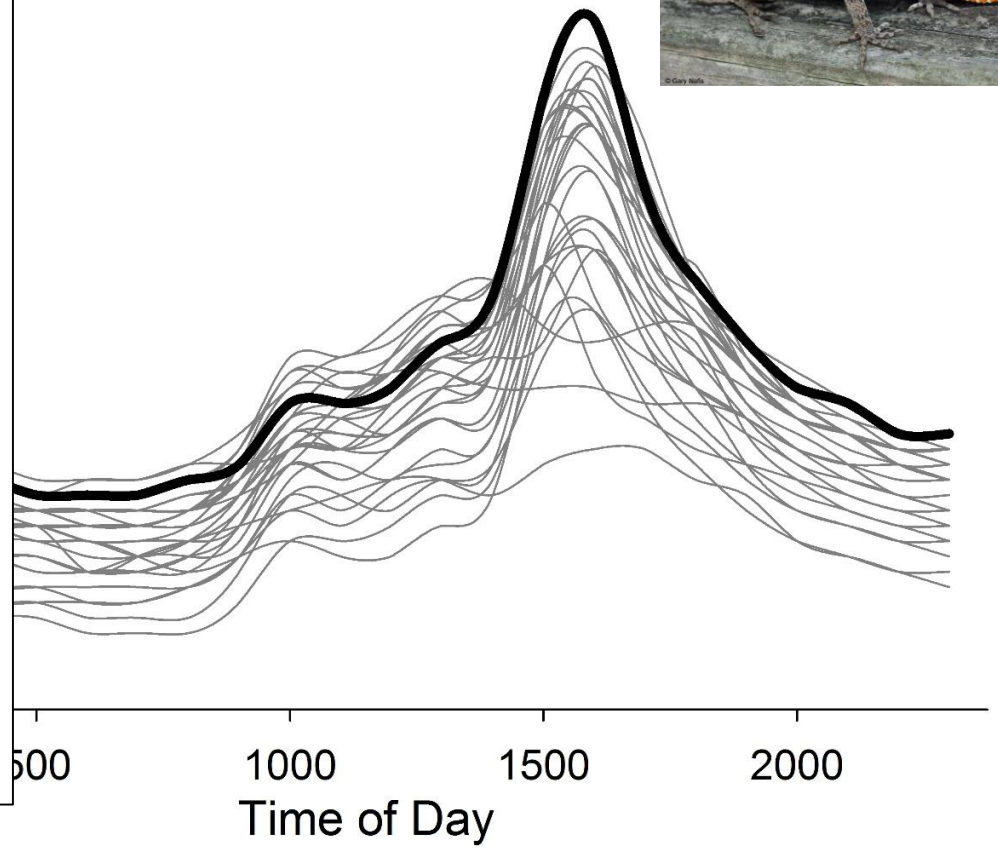
Experimental Design

Experimental Design

Experimental Design

Experimental Design





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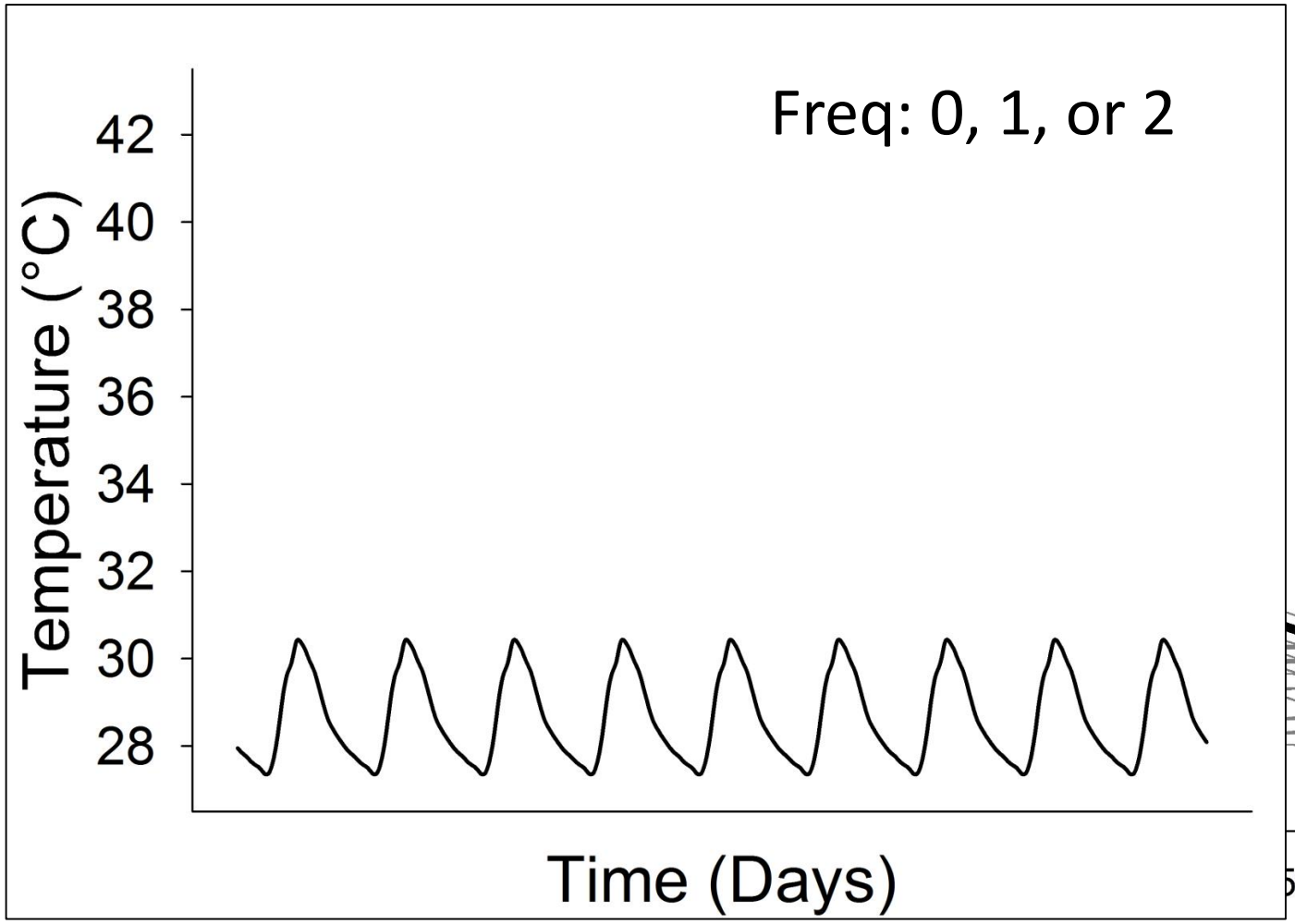

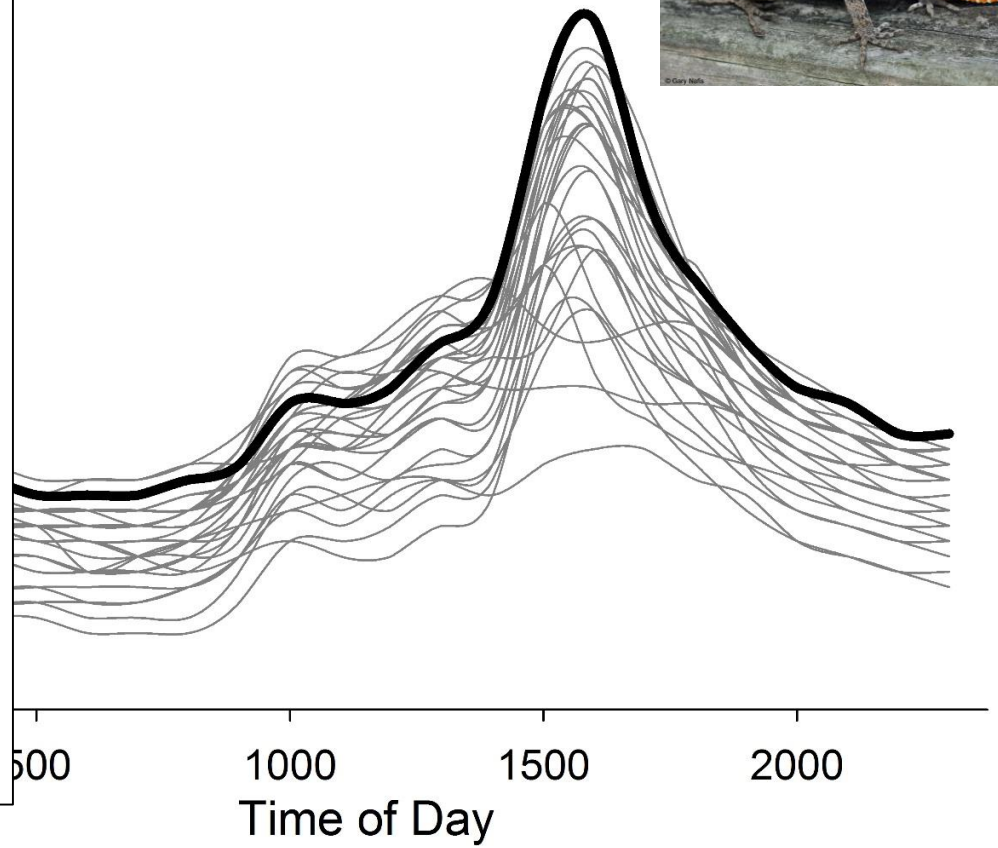

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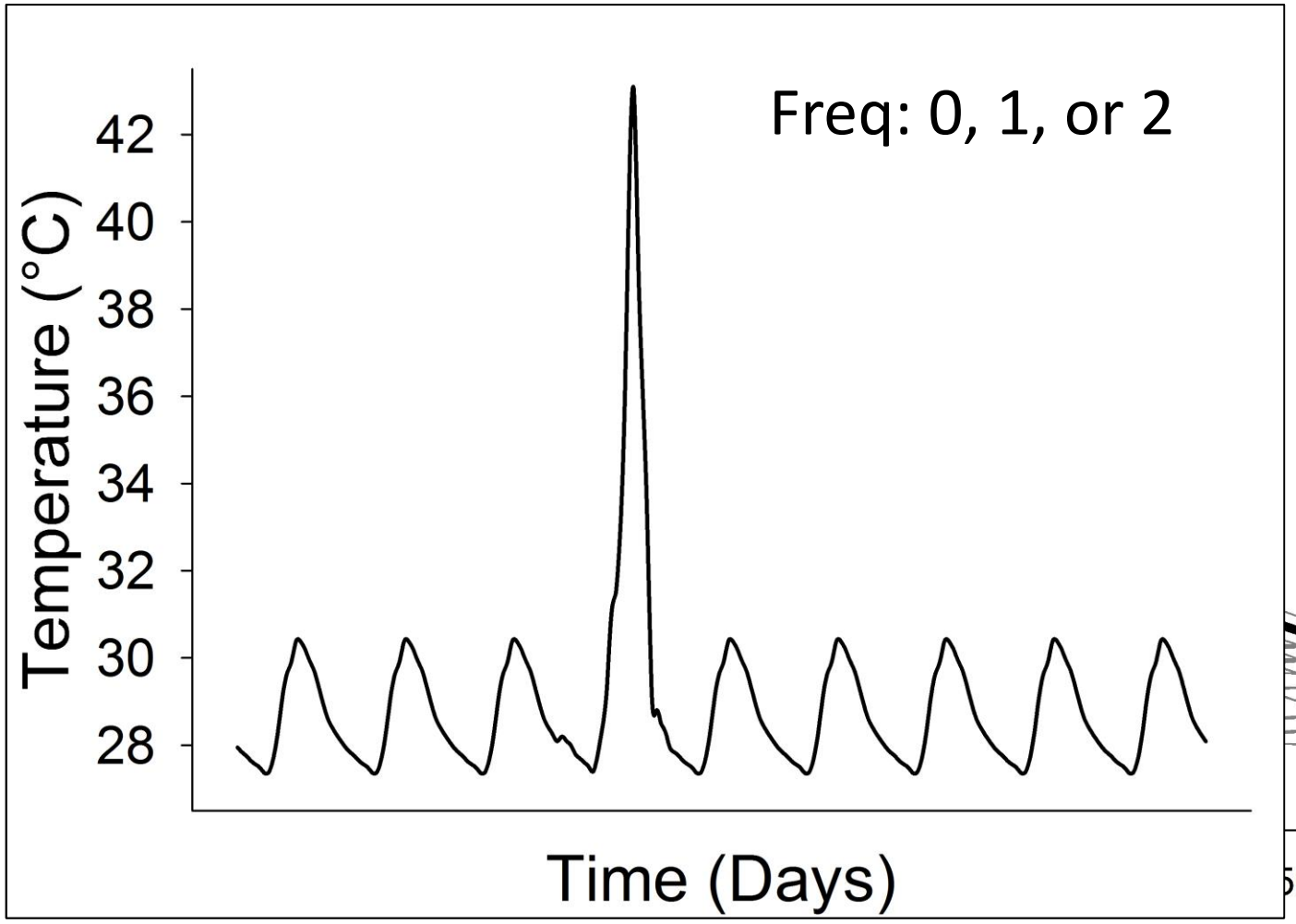

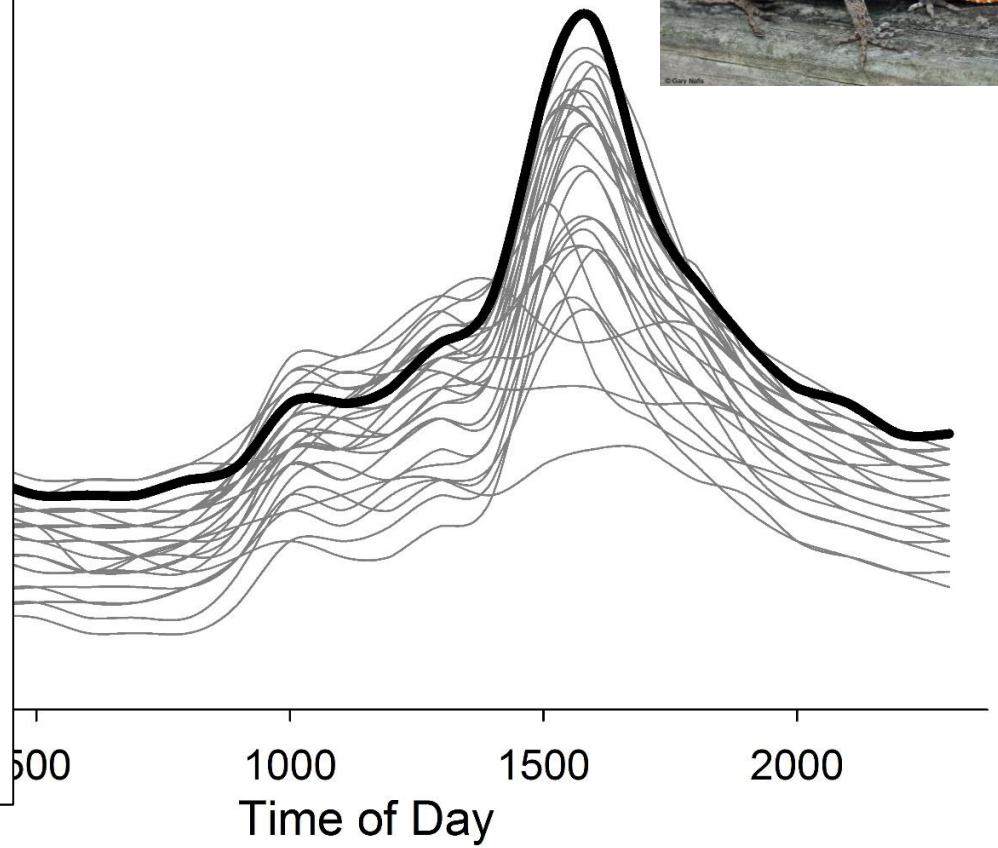

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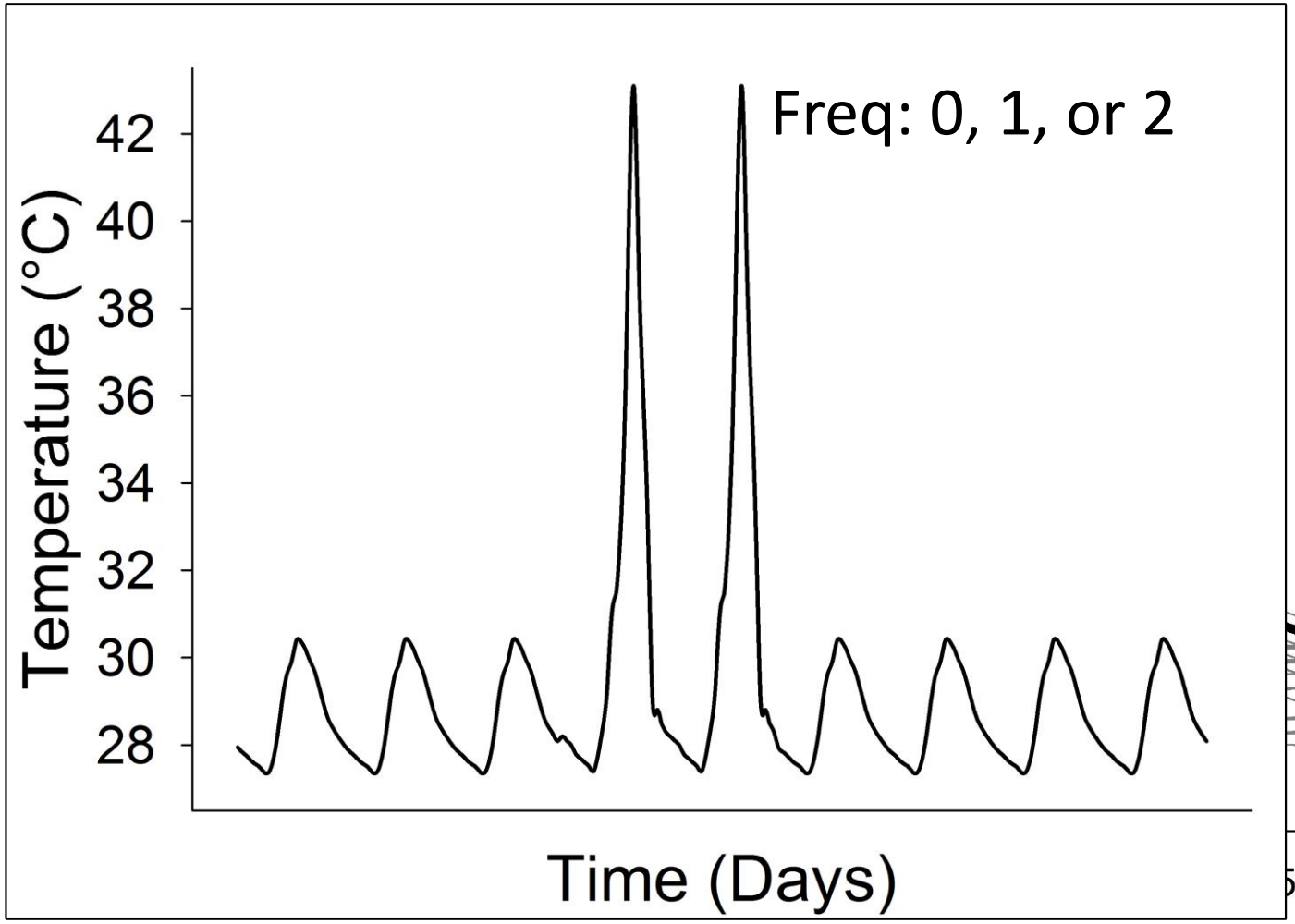

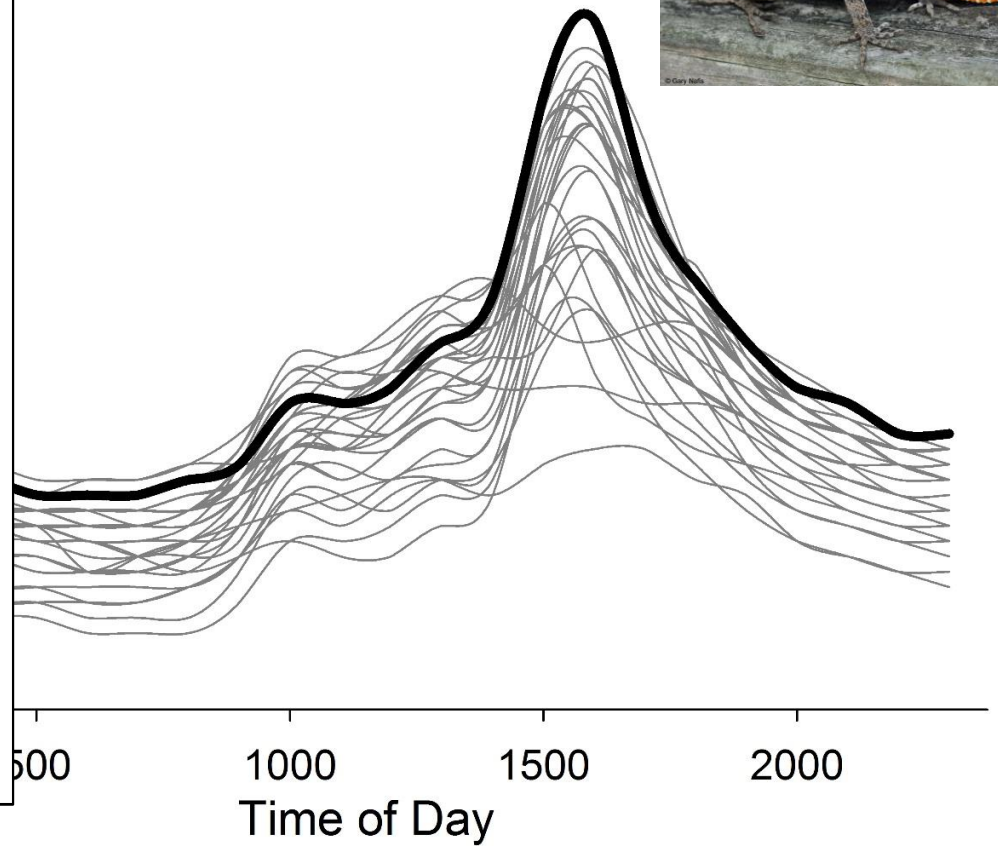

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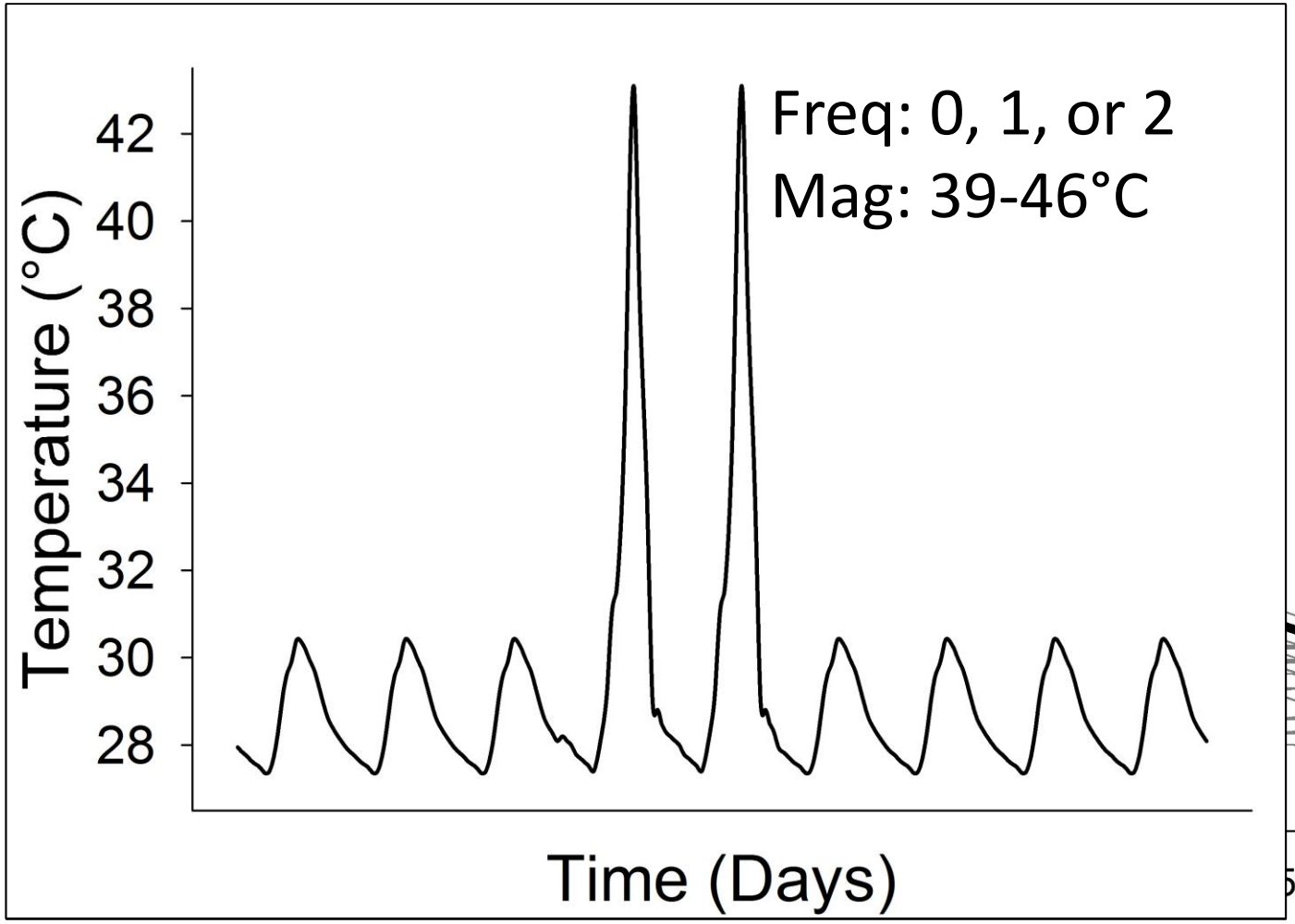

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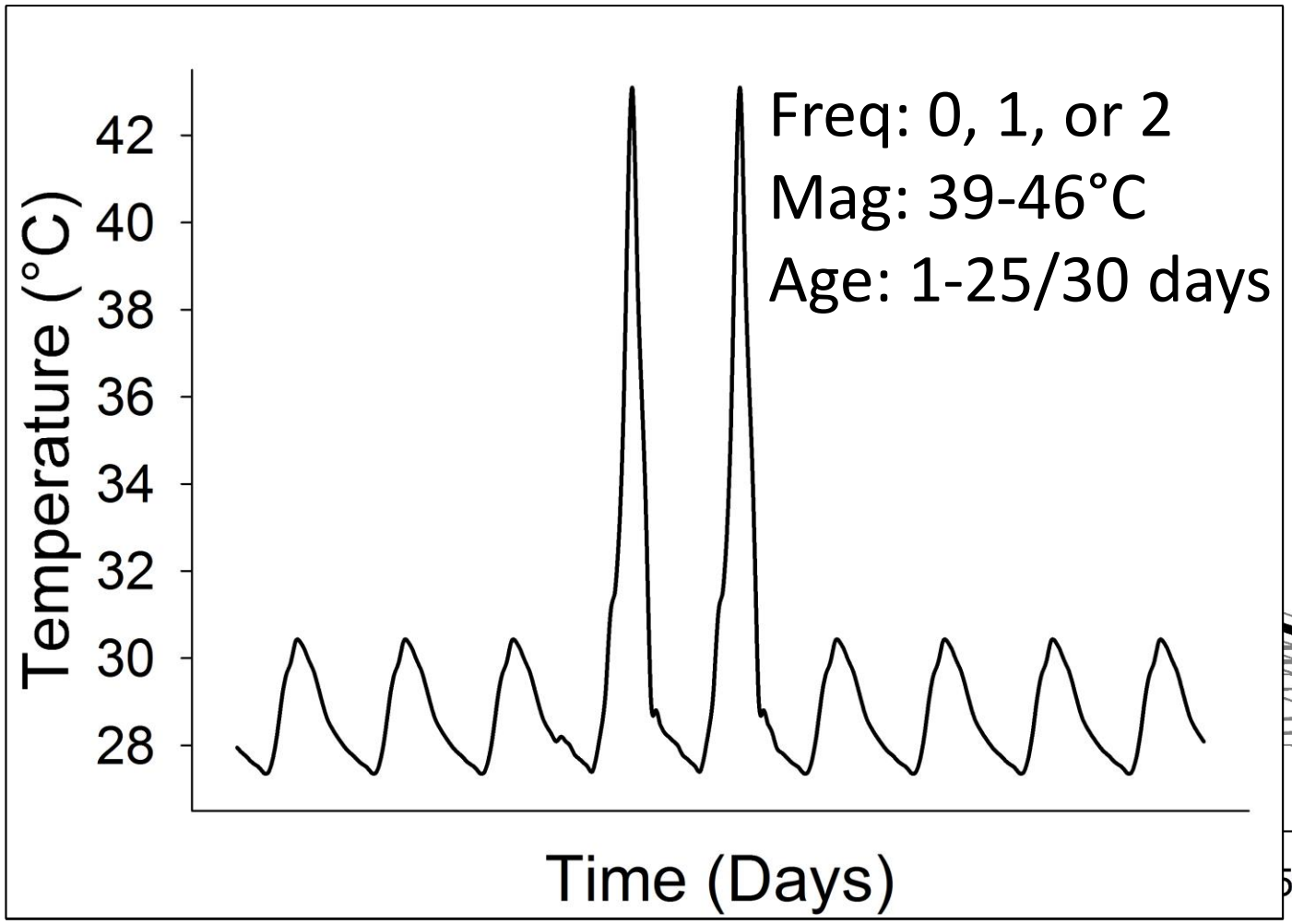

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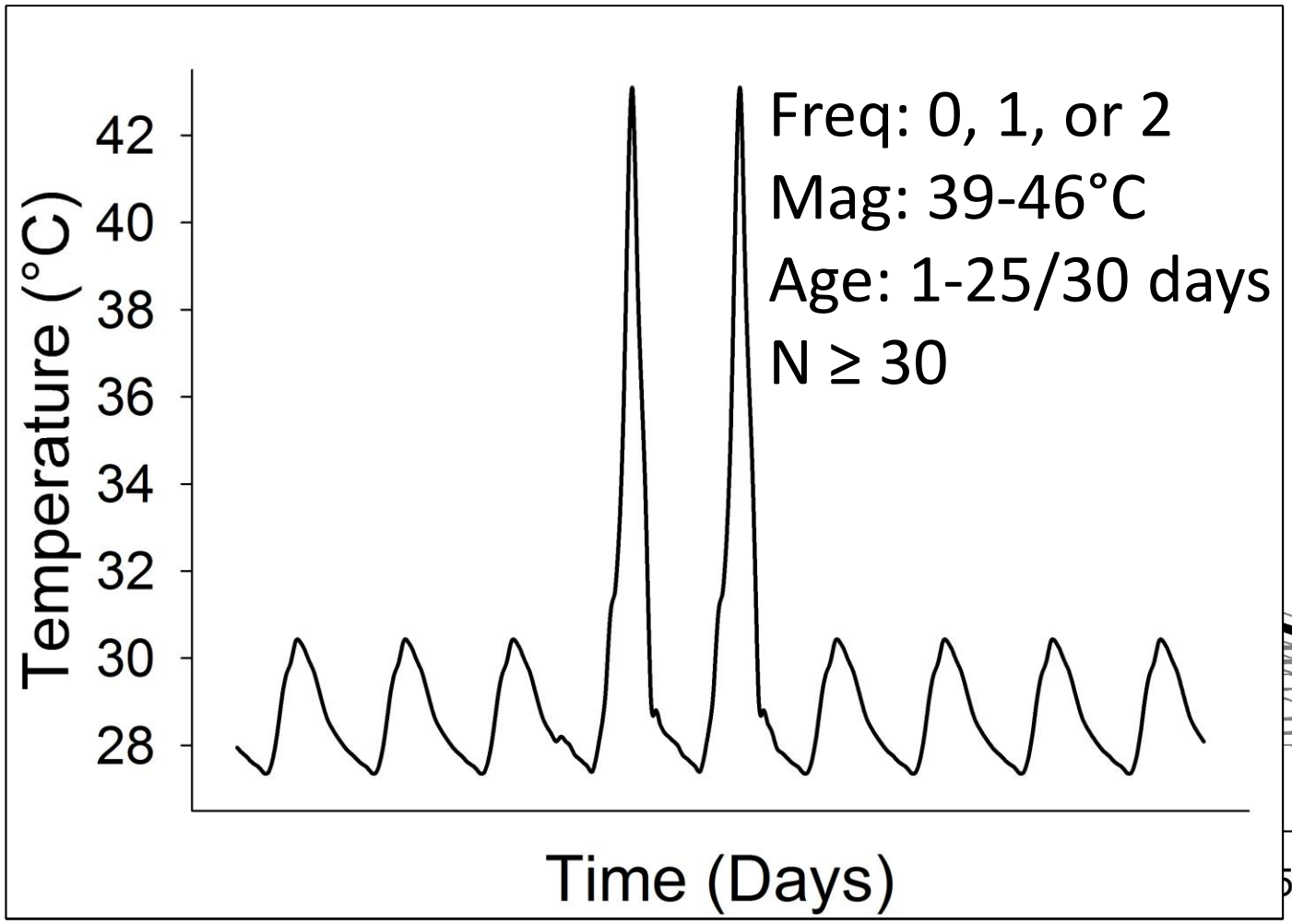

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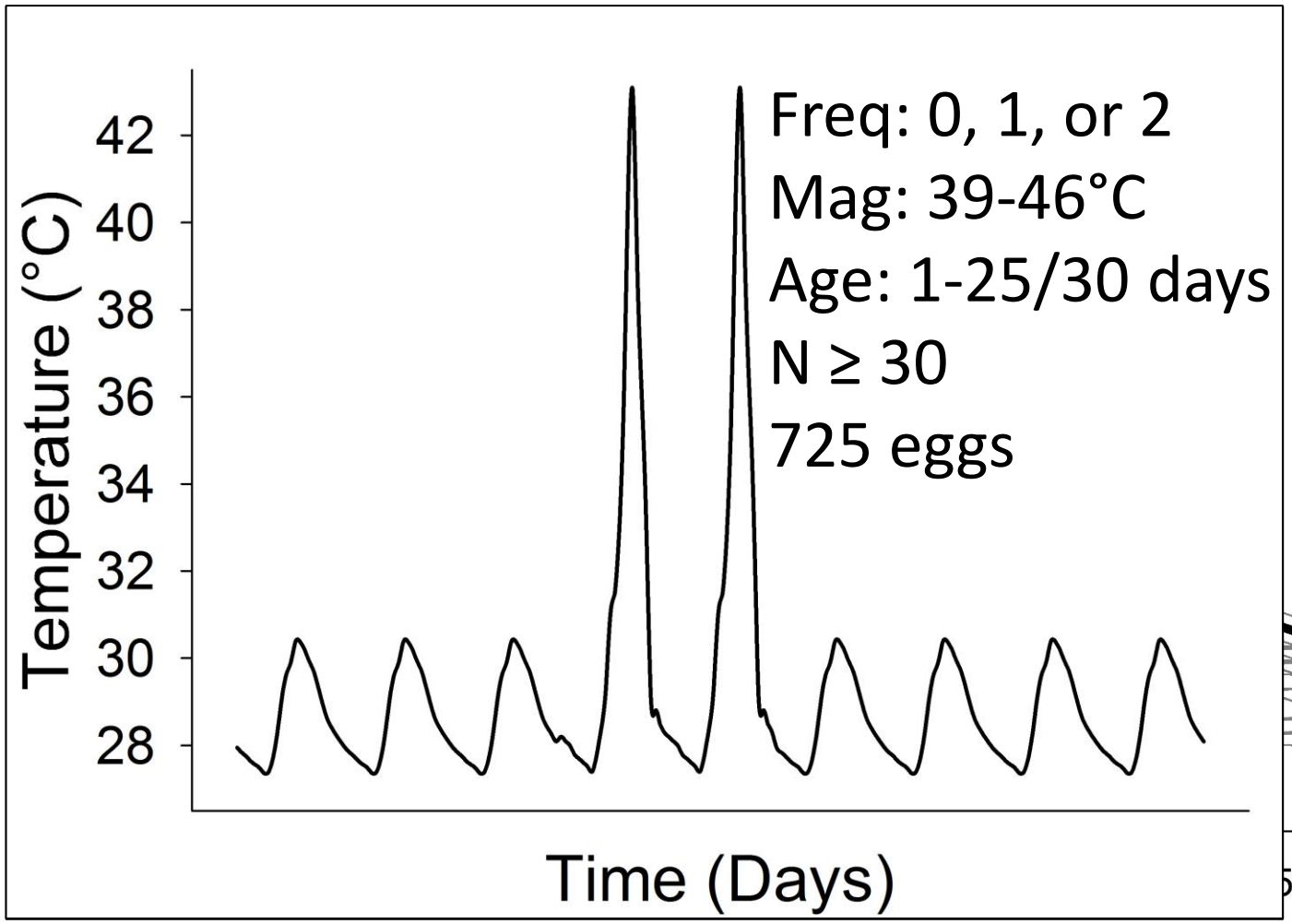

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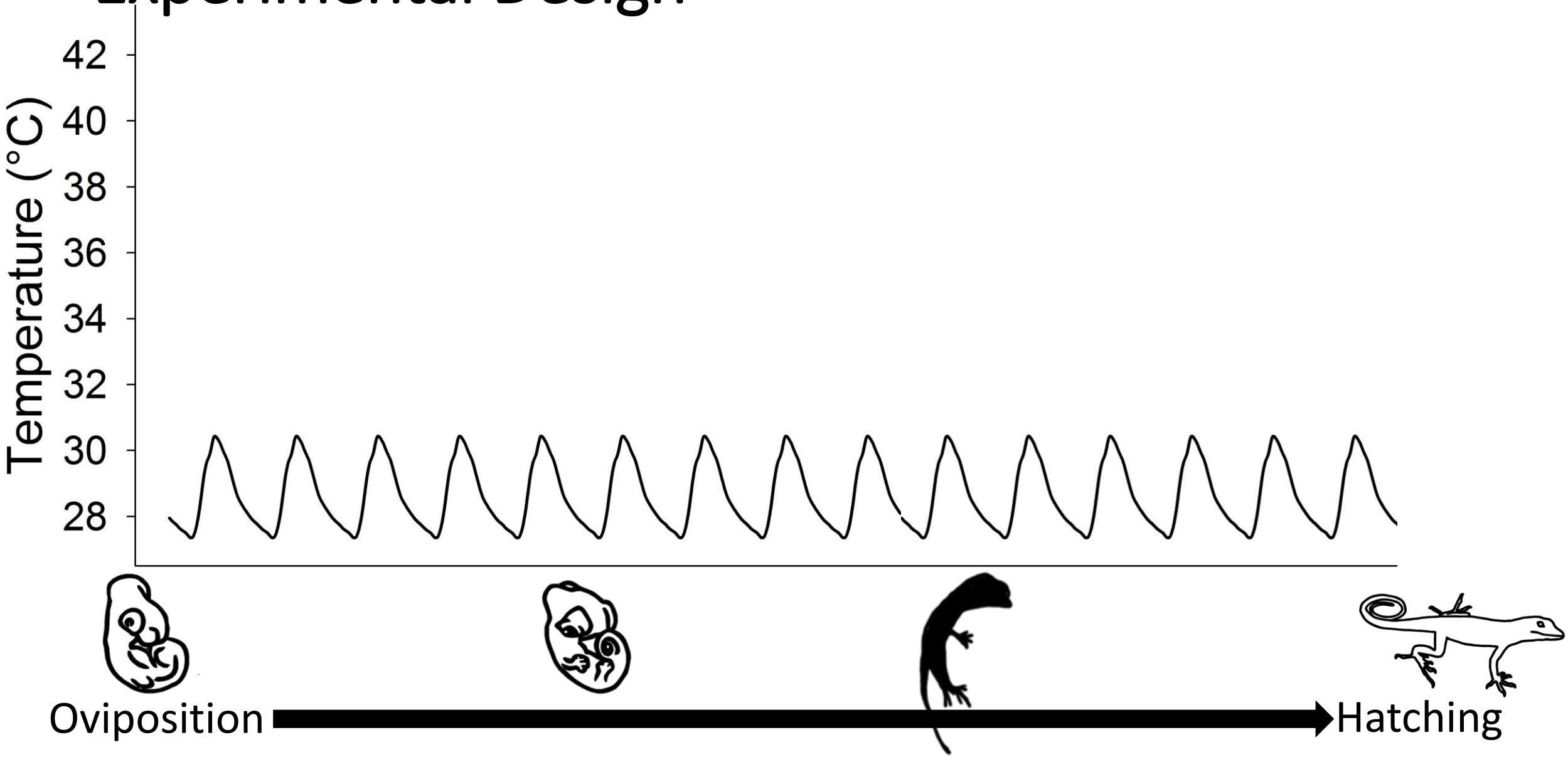

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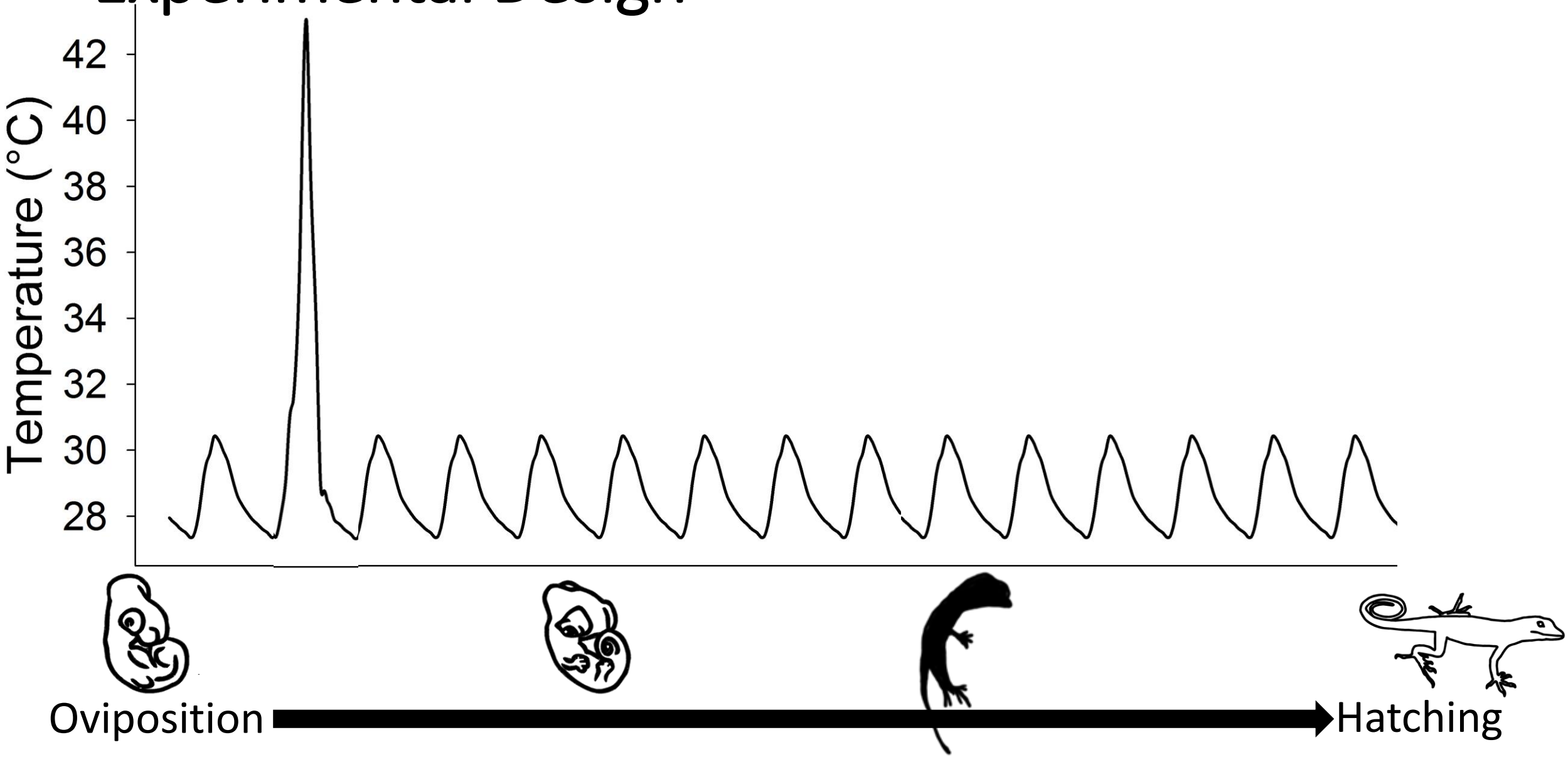

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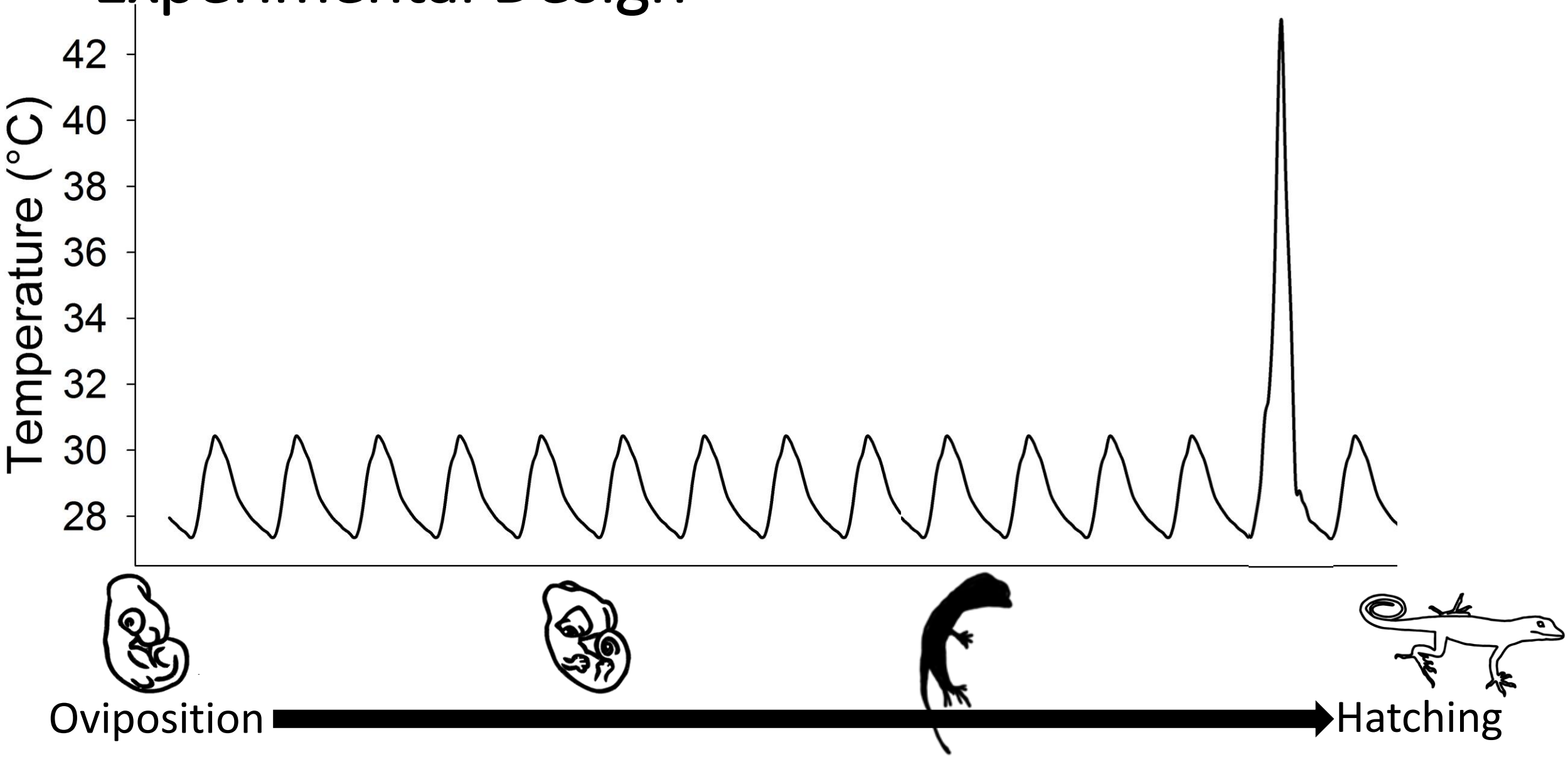

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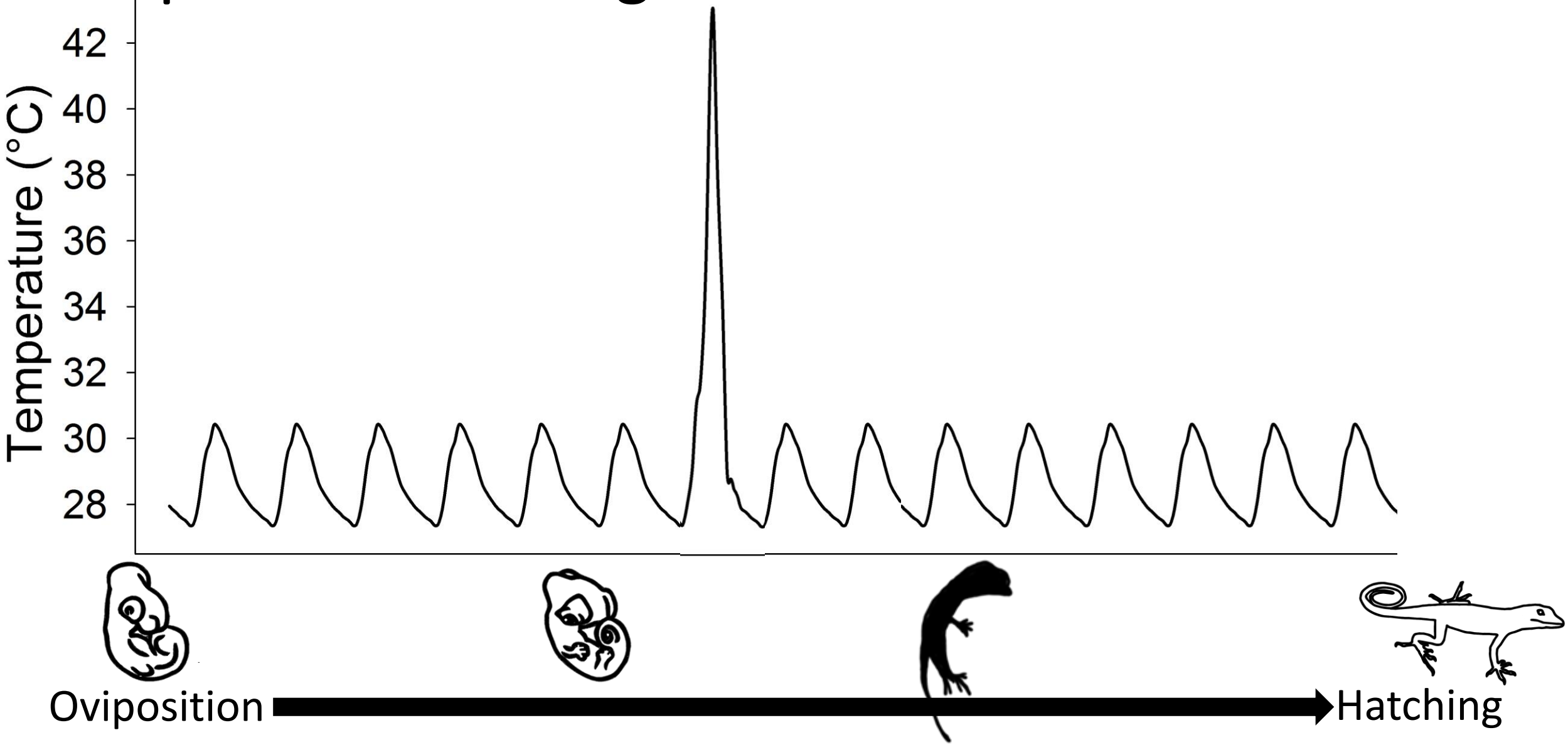

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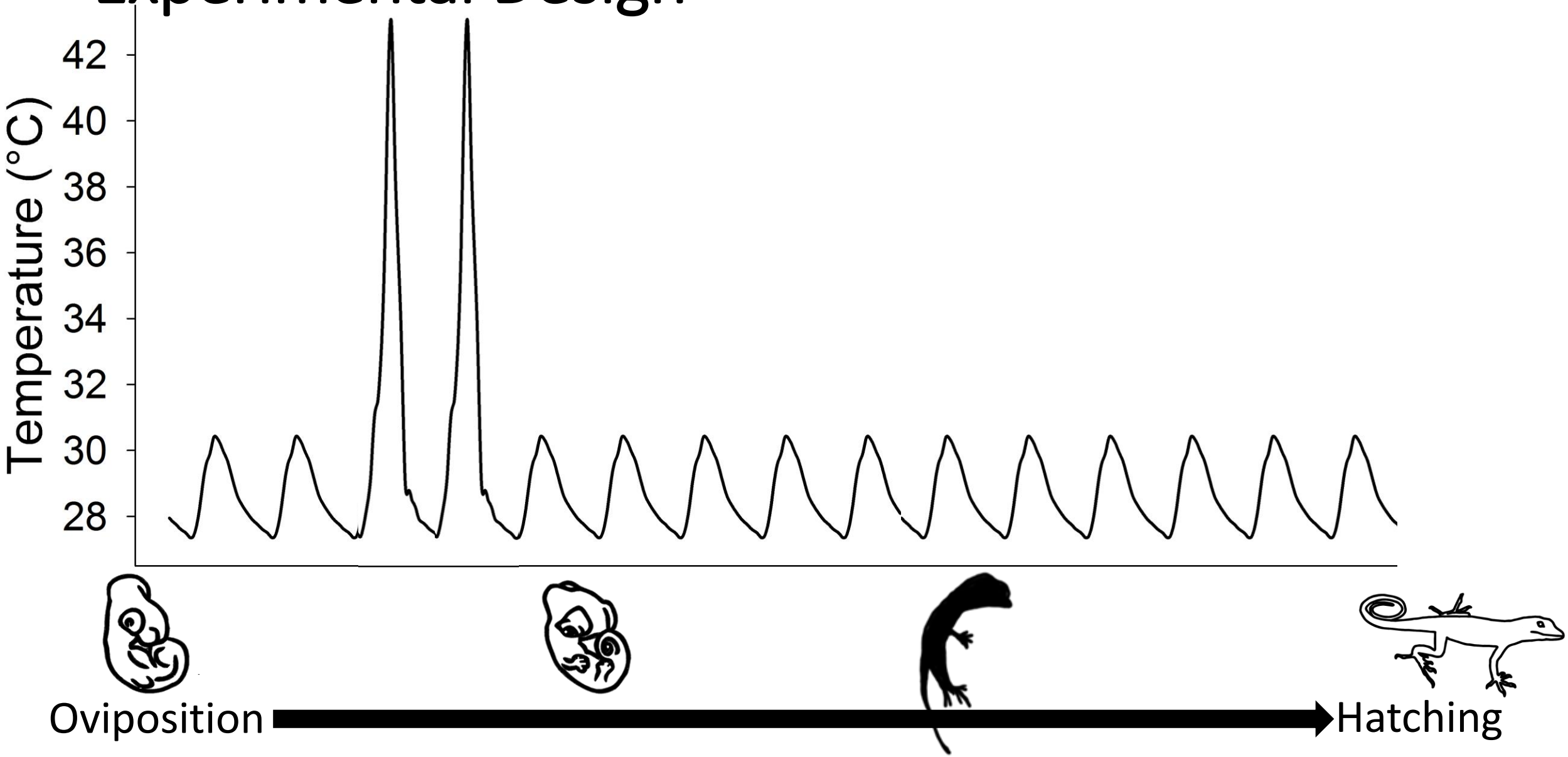
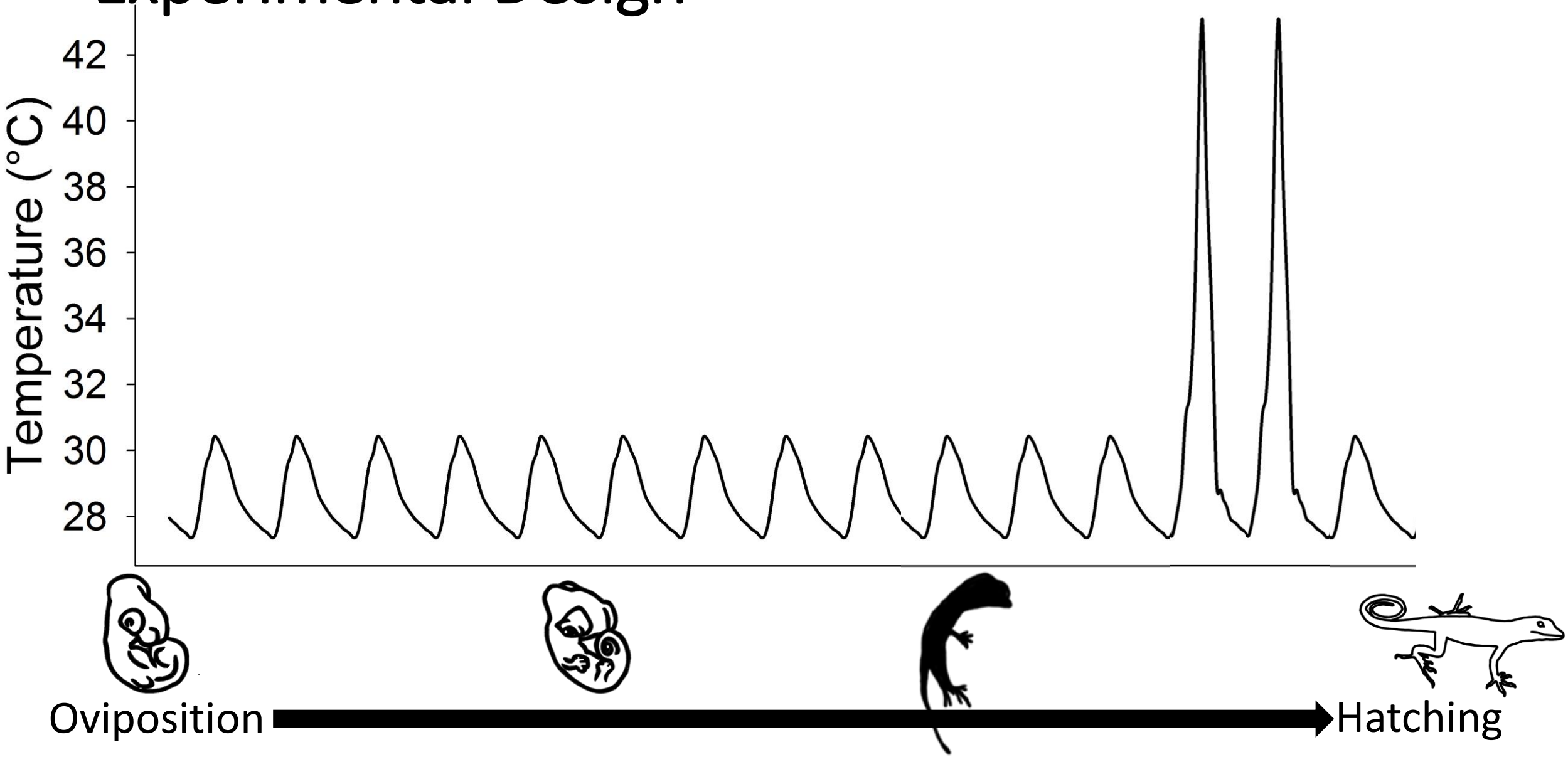
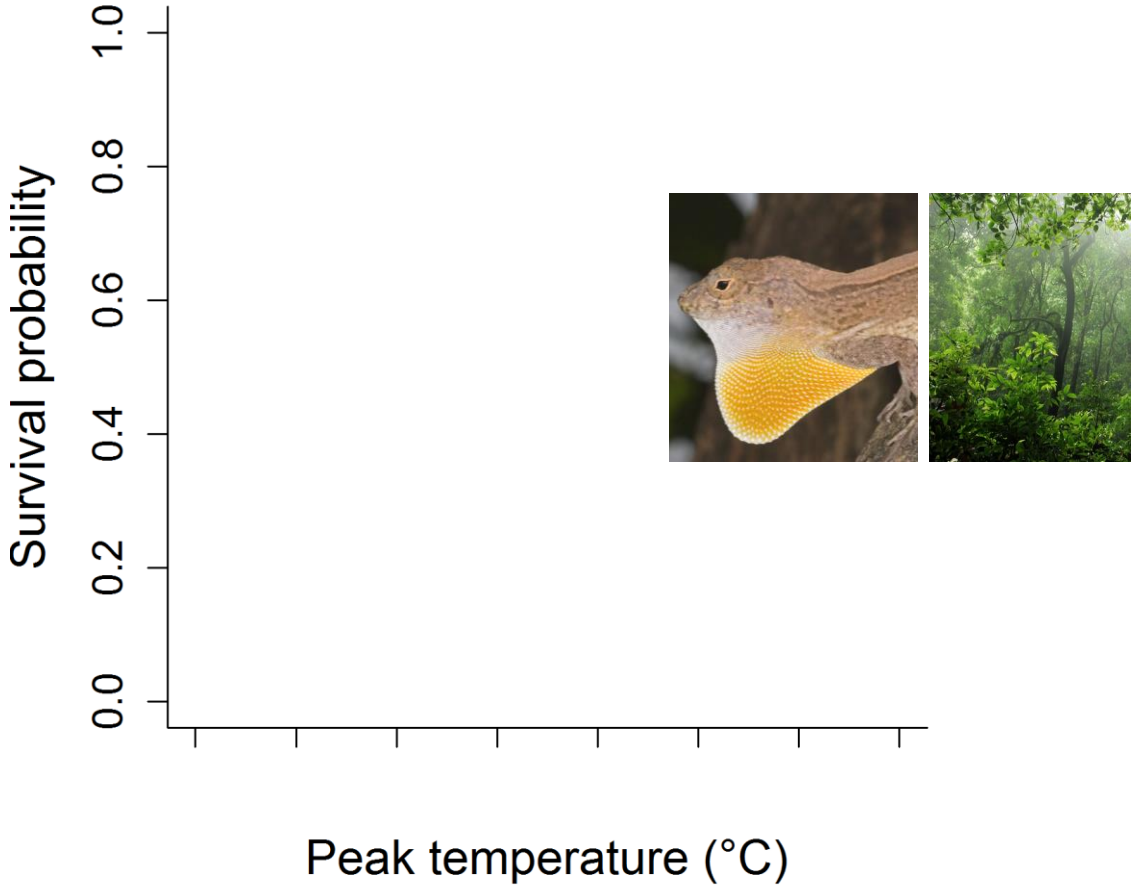
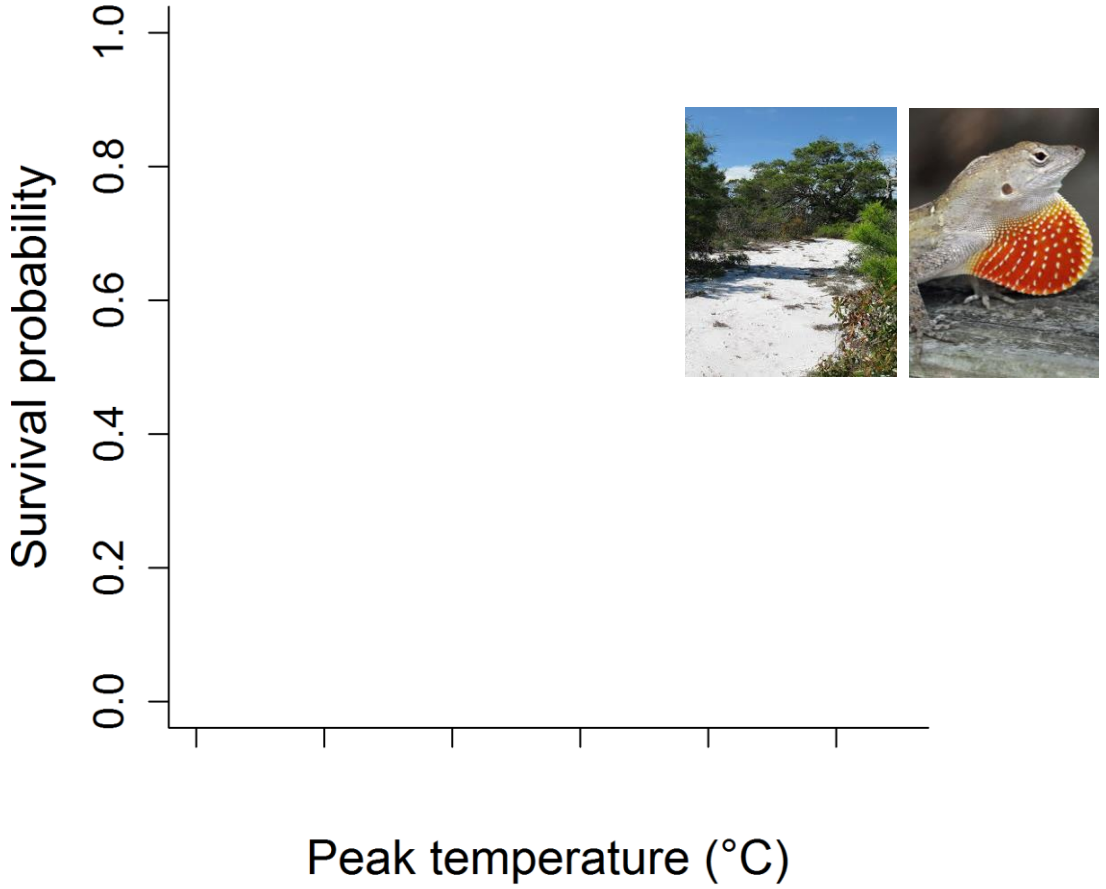


Experimental Design

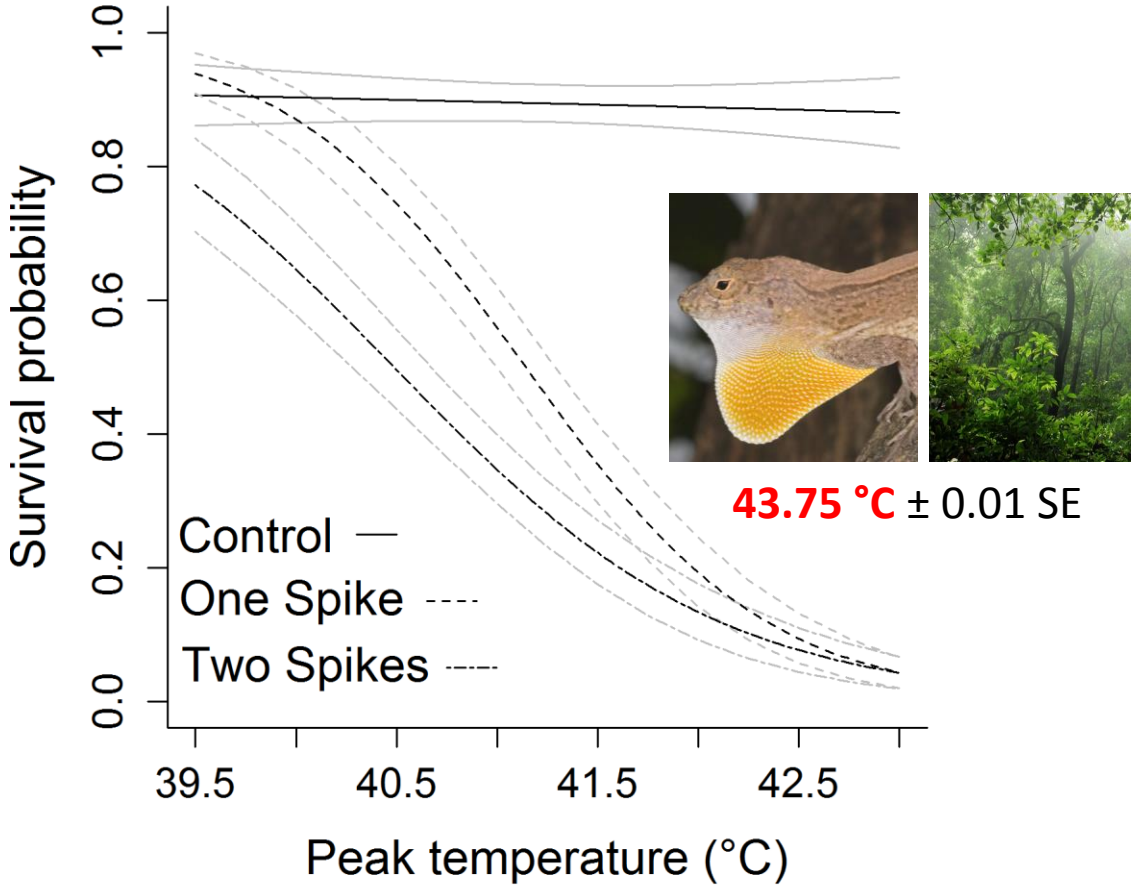


Embryo survival

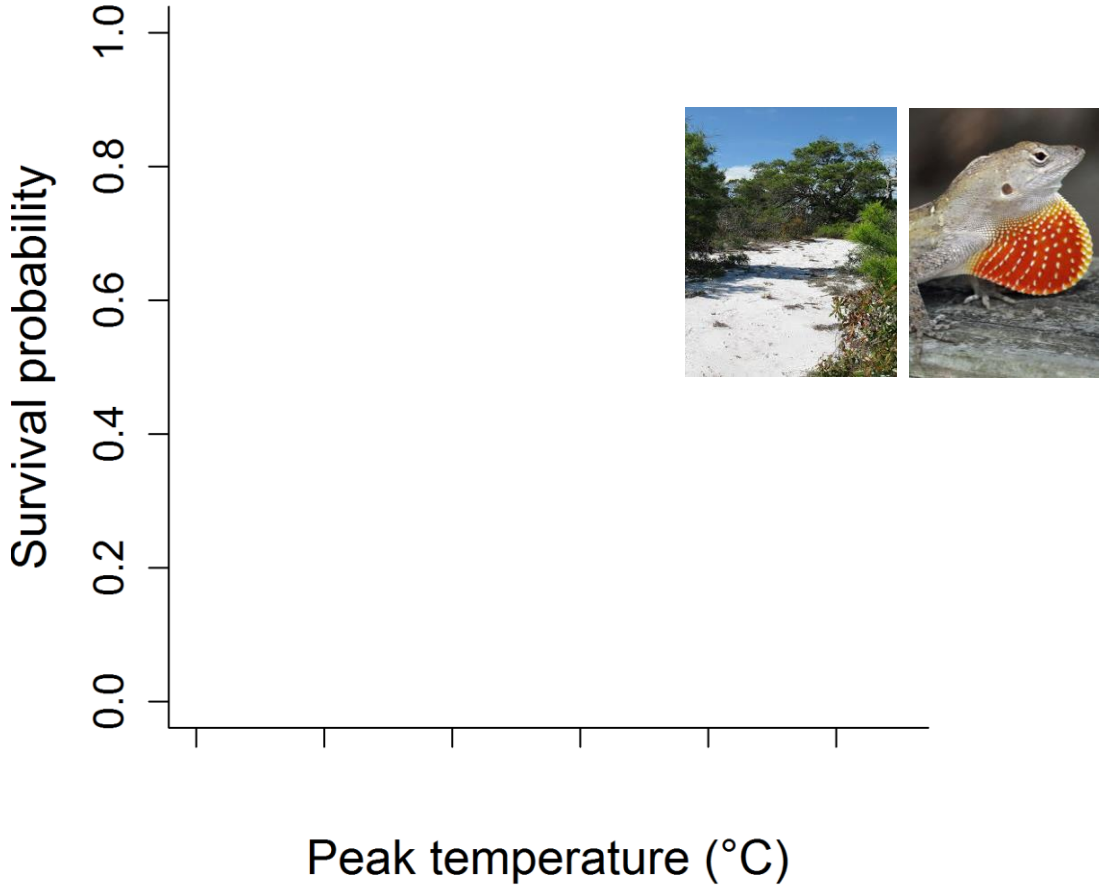




Embryo survival



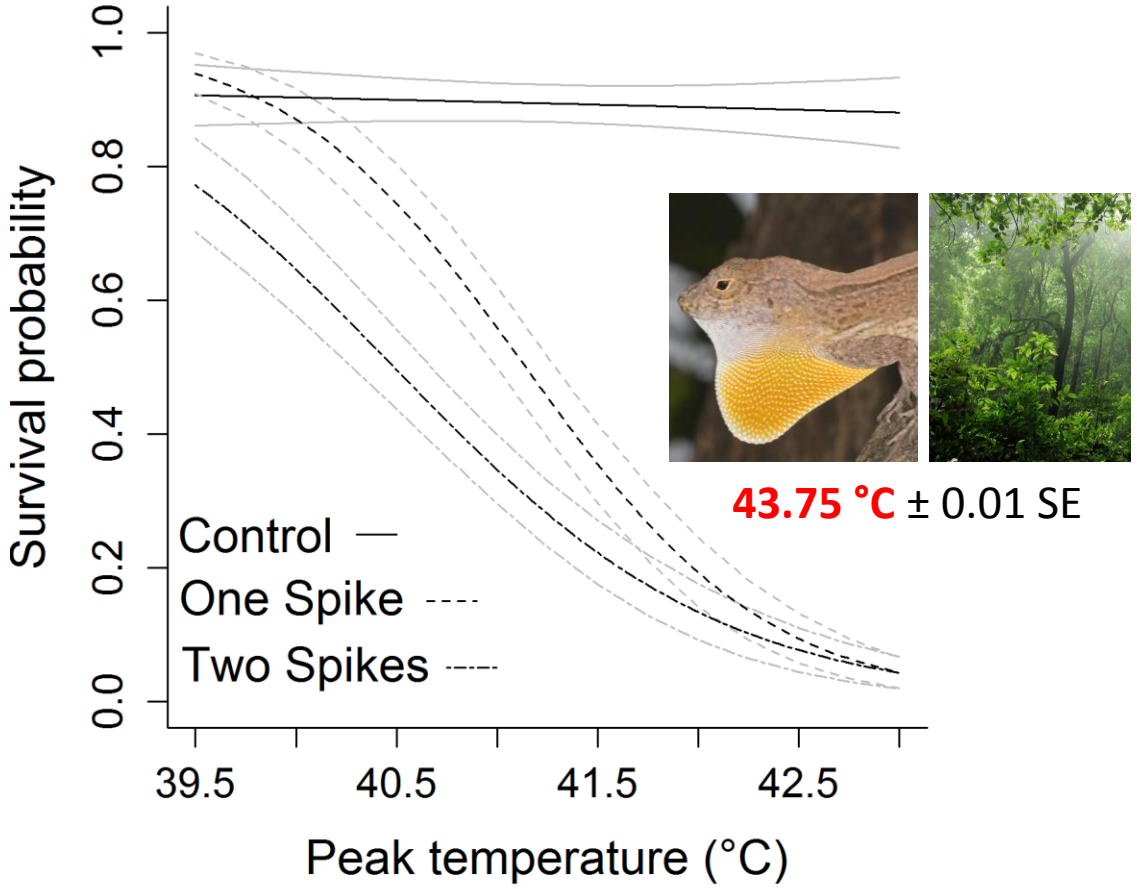
43.75 °C ± 0.01 SE



Treatment: χ^2_1=58.46; p<0.0001

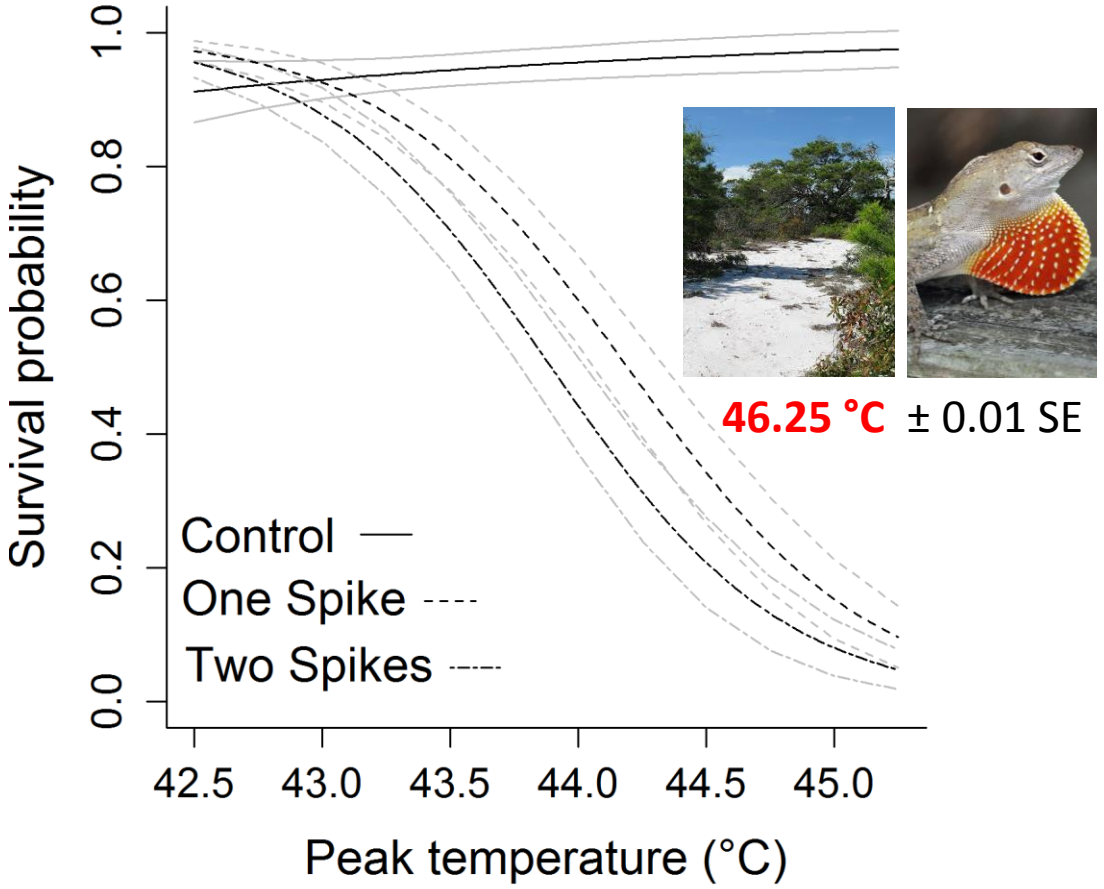
Treatment by Temperature: χ^2_1=51.52; p<0.0001

Embryo survival



Treatment: χ^2_1=58.46; p<0.0001

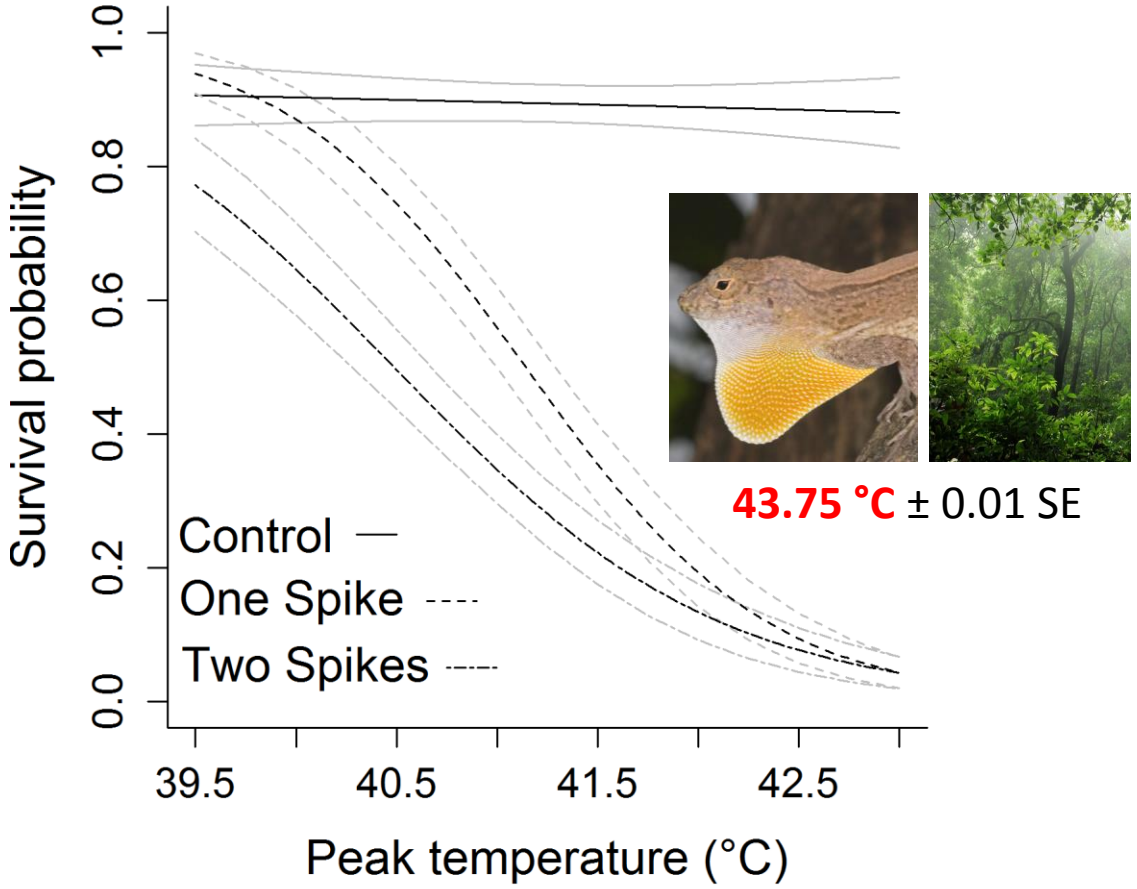
Treatment by Temperature: χ^2_1=51.52; p<0.0001



Treatment: χ^2_1=20.45; p<0.0001

Treatment by Temperature: χ^2_1=62.7; p<0.0001

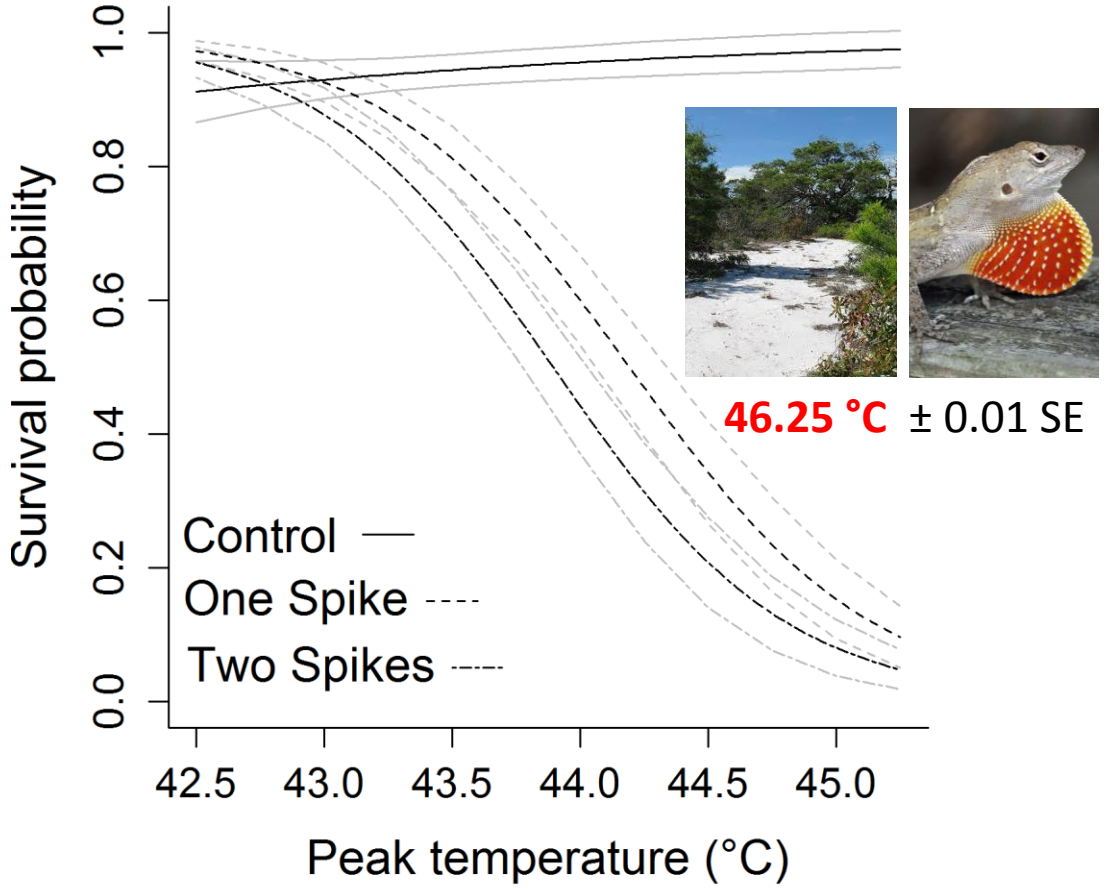
Effect of age?



43.75 °C ± 0.01 SE

Treatment: χ^2_1=58.46; p<0.0001

Treatment by Temperature: χ^2_1=51.52; p<0.0001

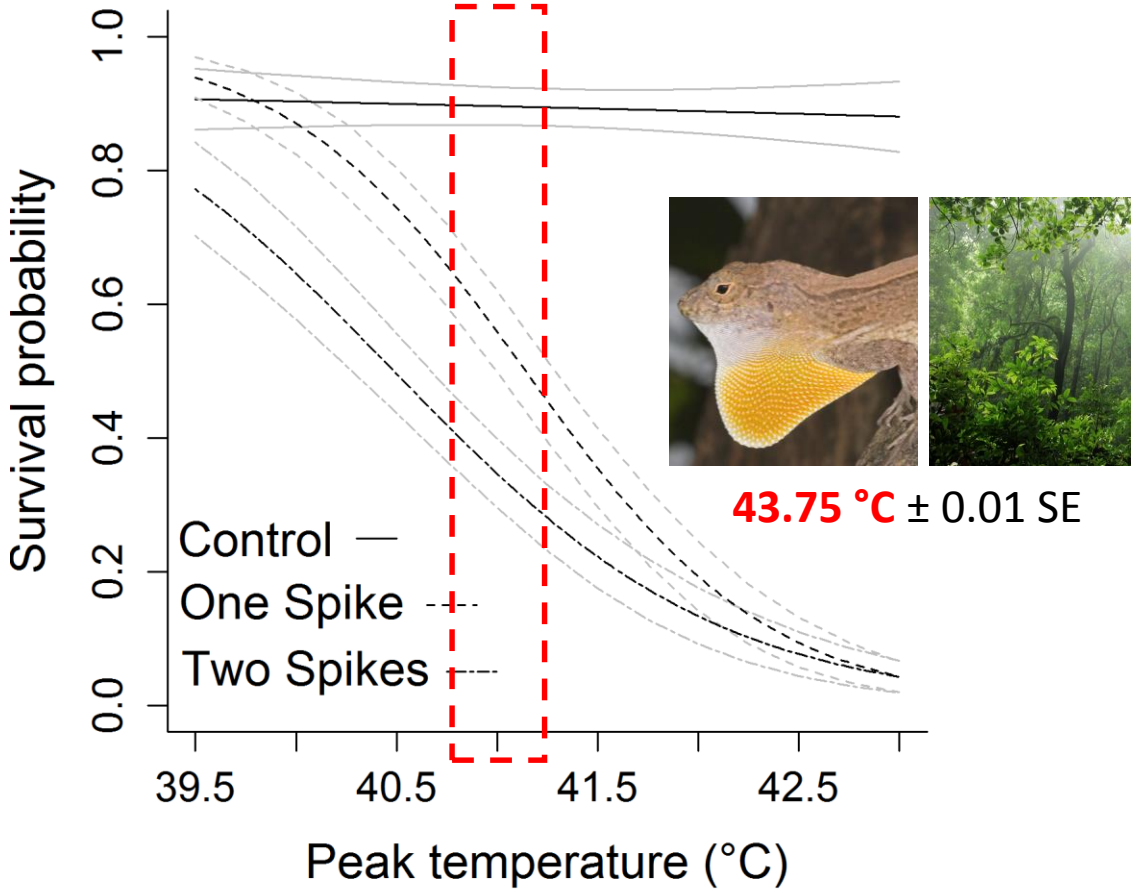


46.25 °C ± 0.01 SE

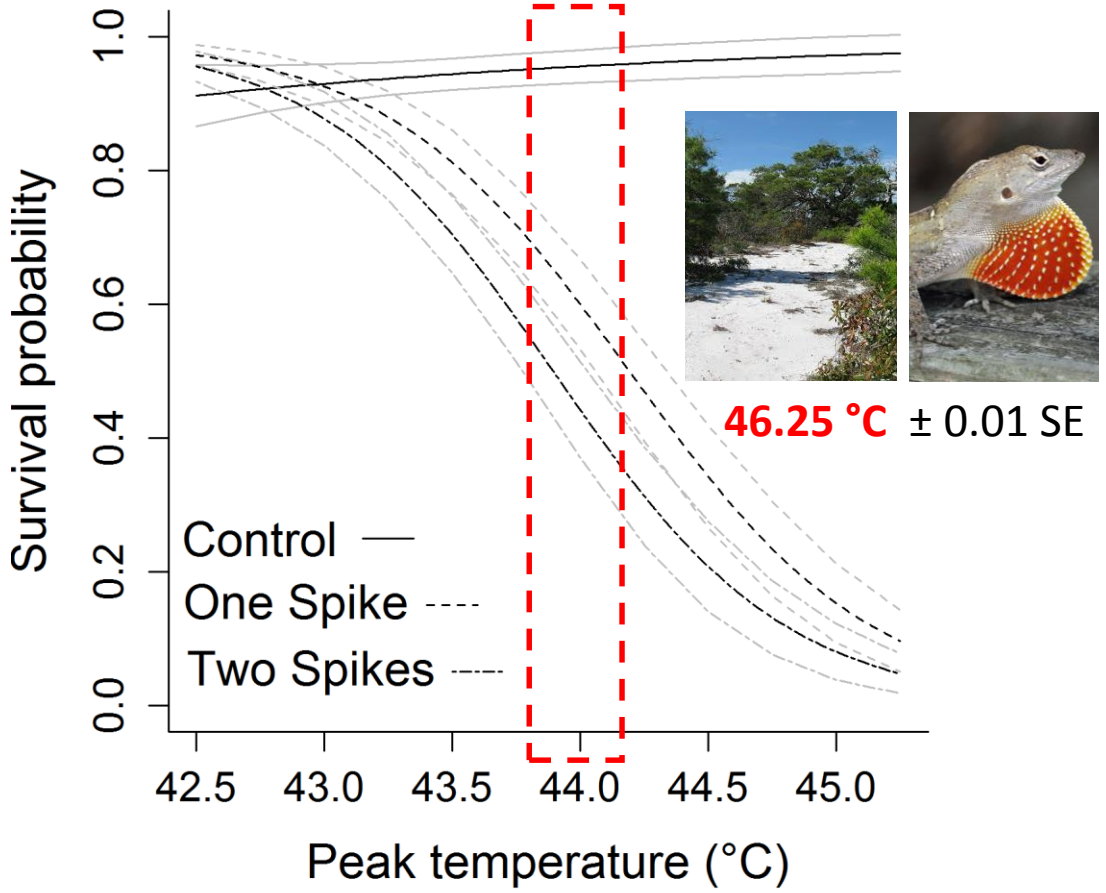
Treatment: χ^2_1=20.45; p<0.0001

Treatment by Temperature: χ^2_1=62.7; p<0.0001

Effect of age?

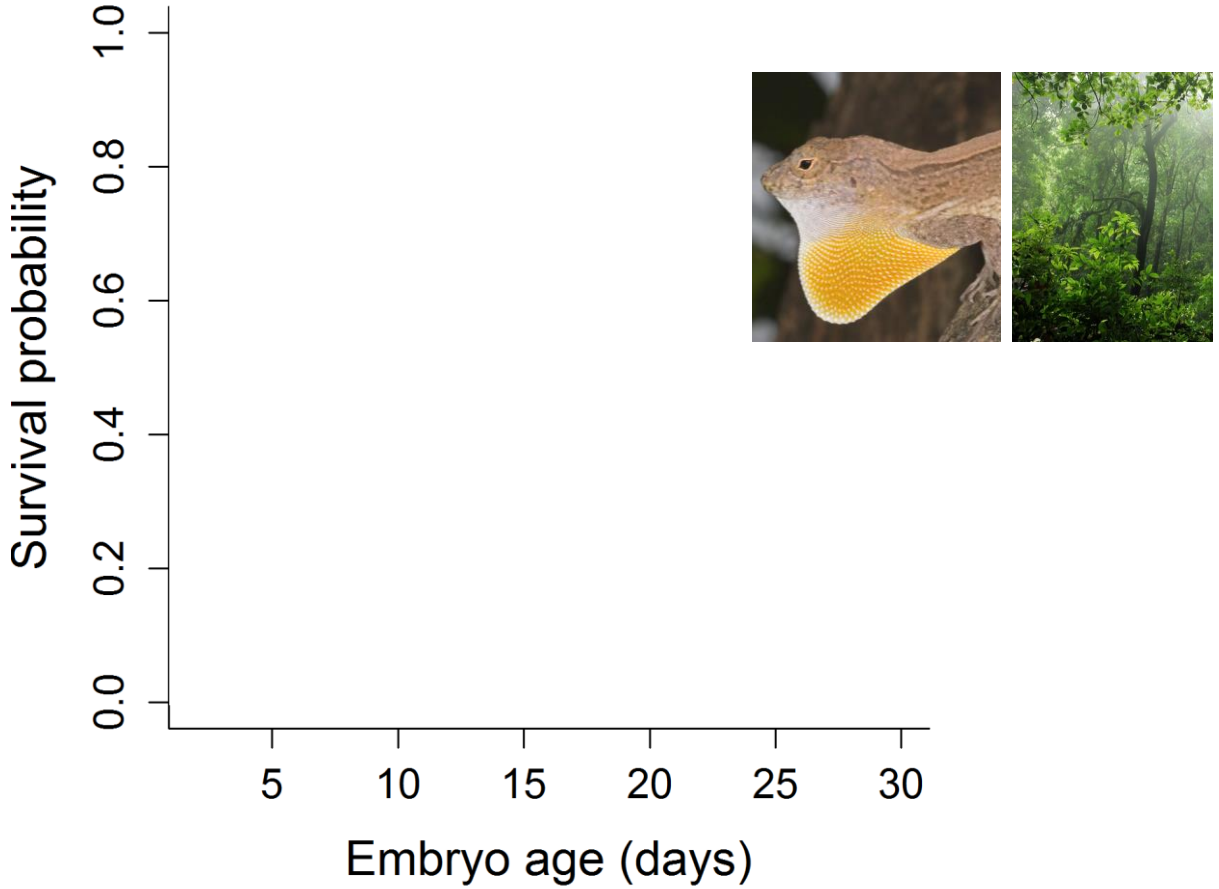


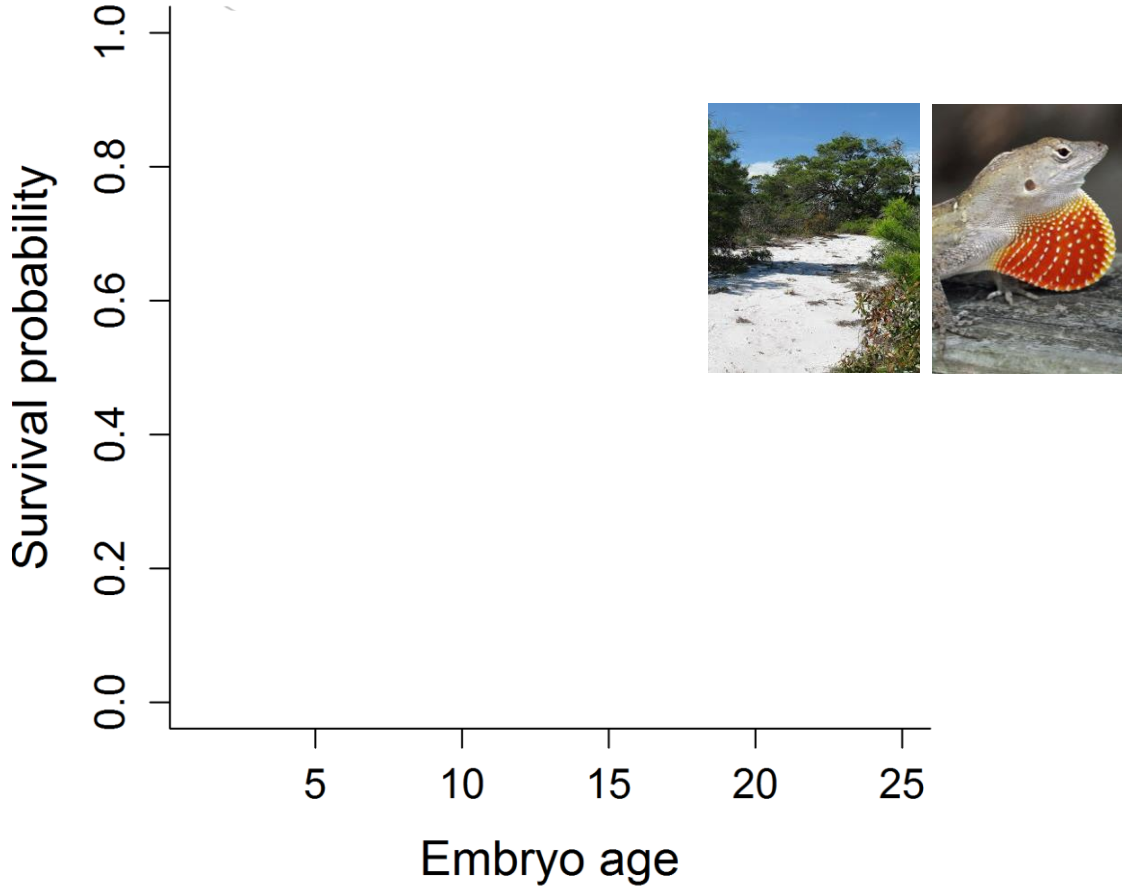
43.75 °C ± 0.01 SE



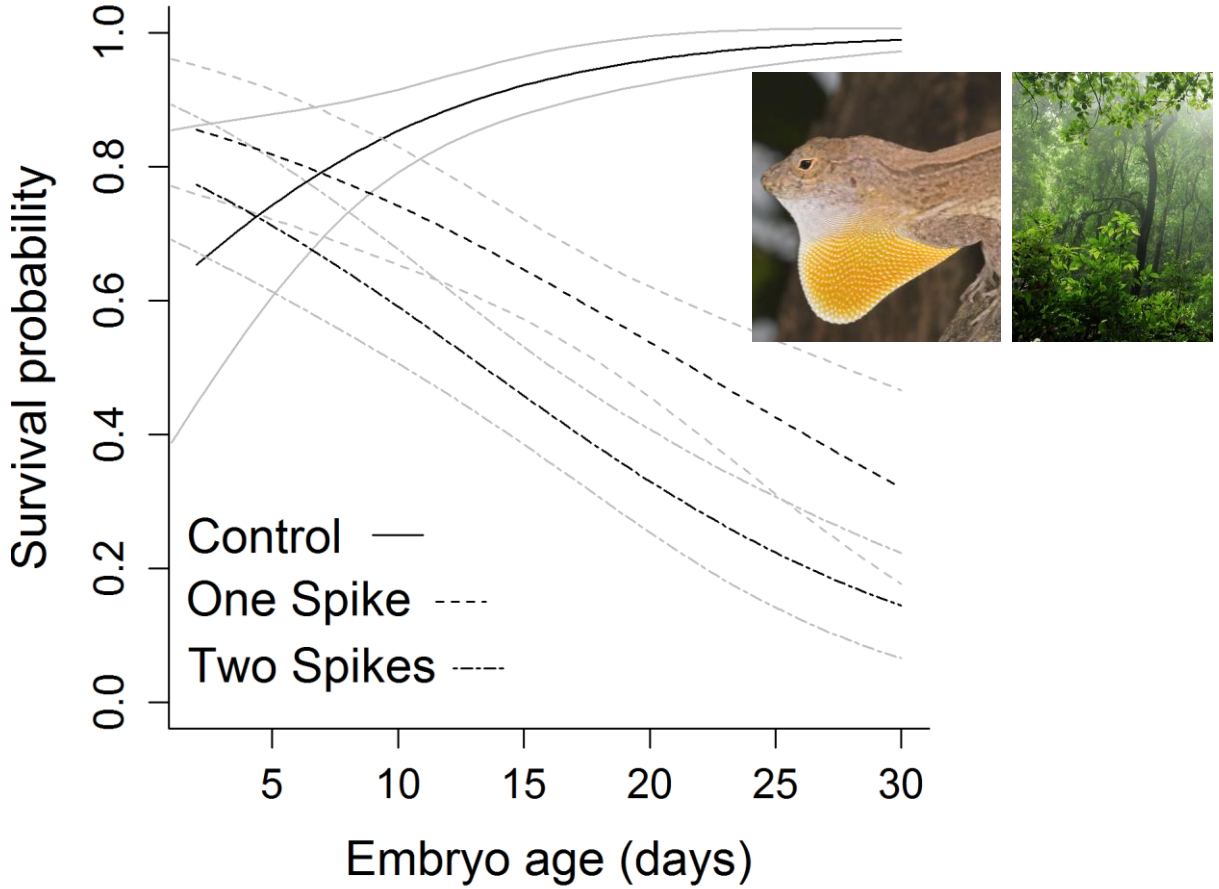
46.25 °C ± 0.01 SE

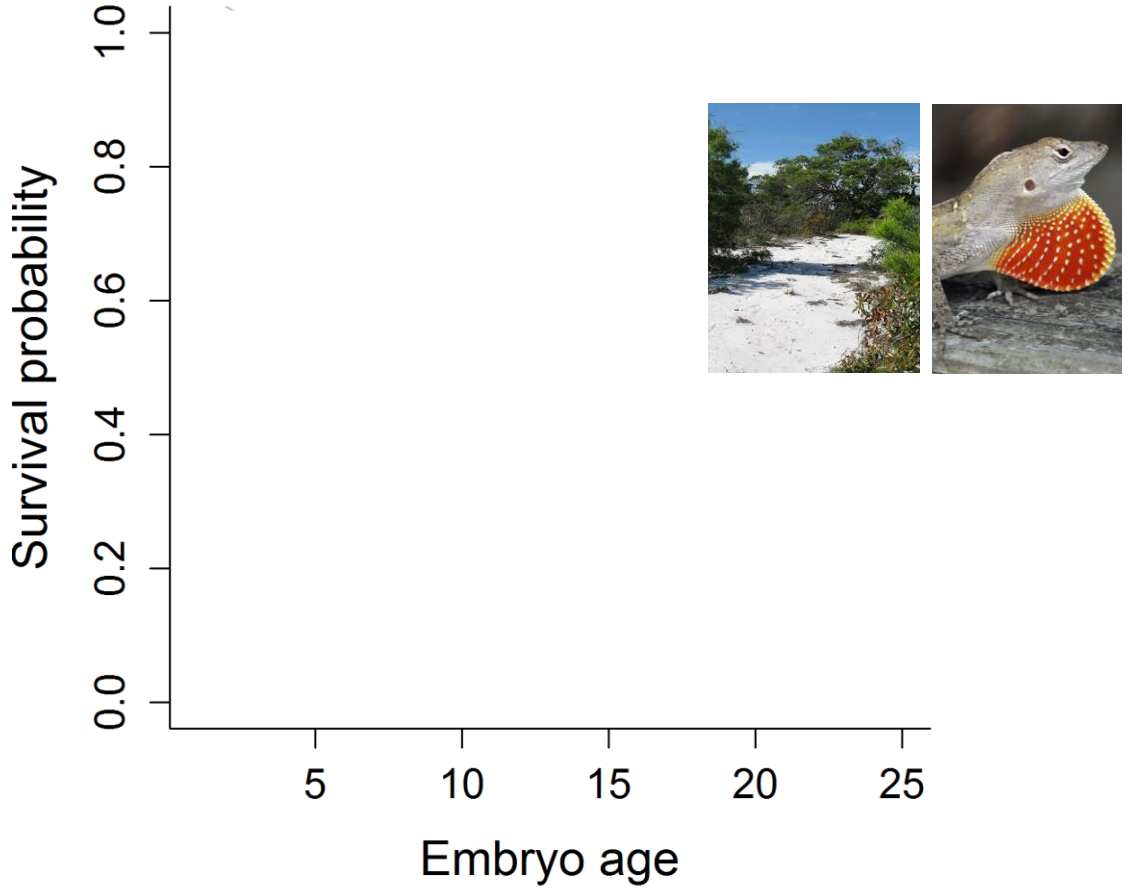
Effect of age?





Effect of age?

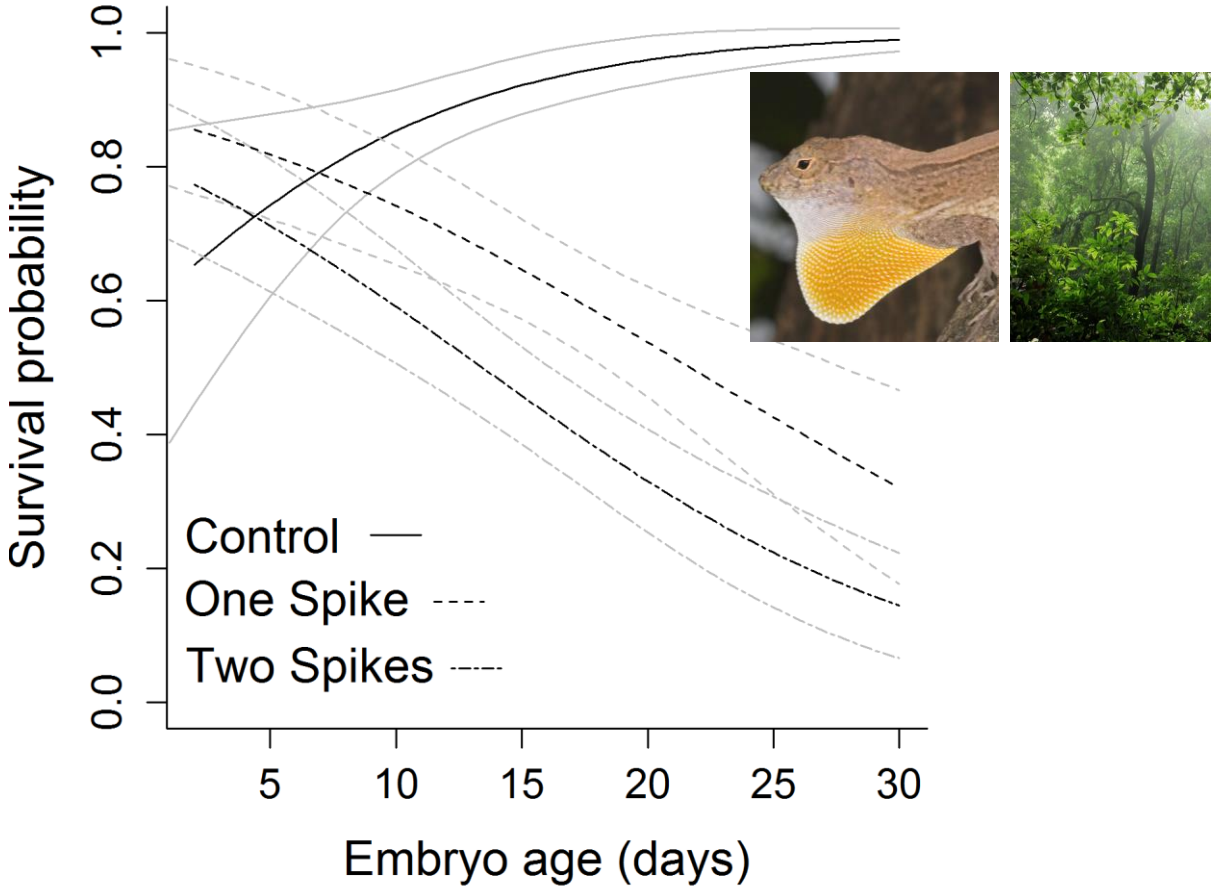




Age: χ^2_1=5.51; p=0.02

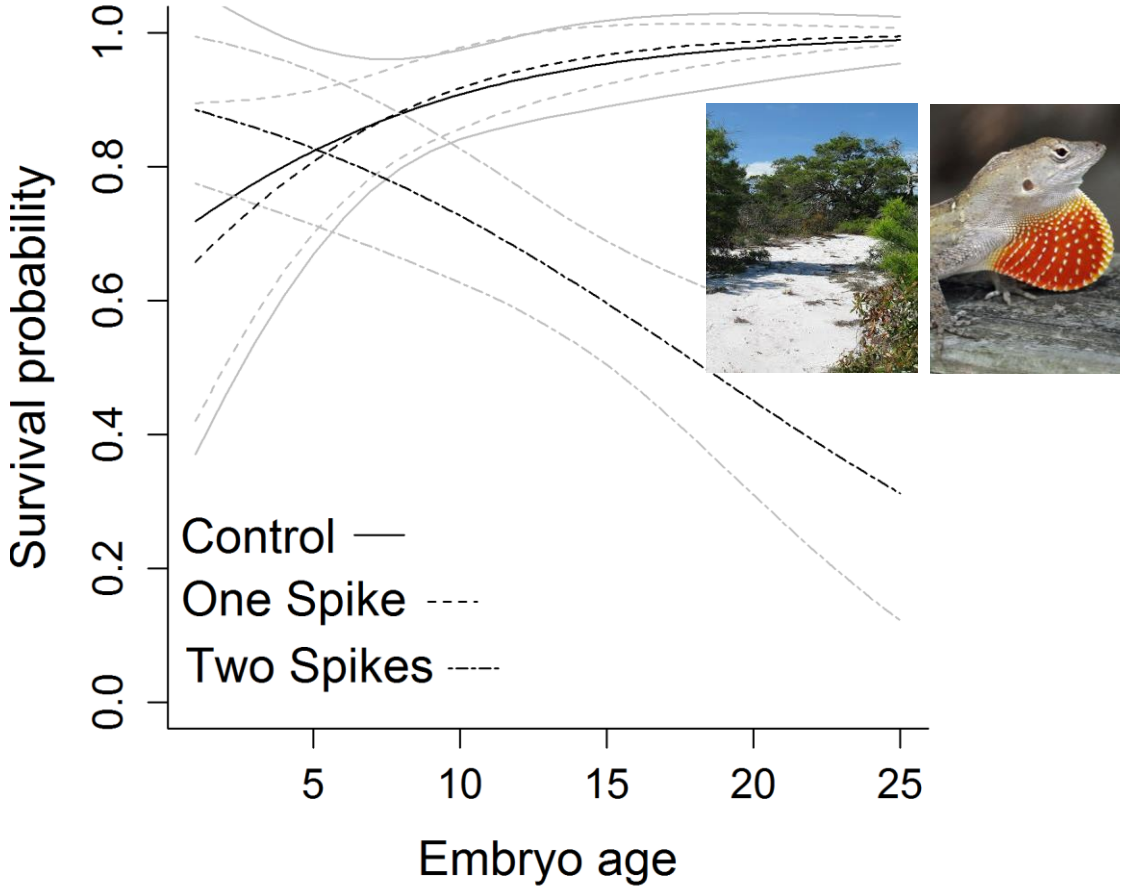
Age by Treatment: χ^2_1=5.14; p=0.02

Effect of age?



Age: χ^2_1=5.51; p=0.02

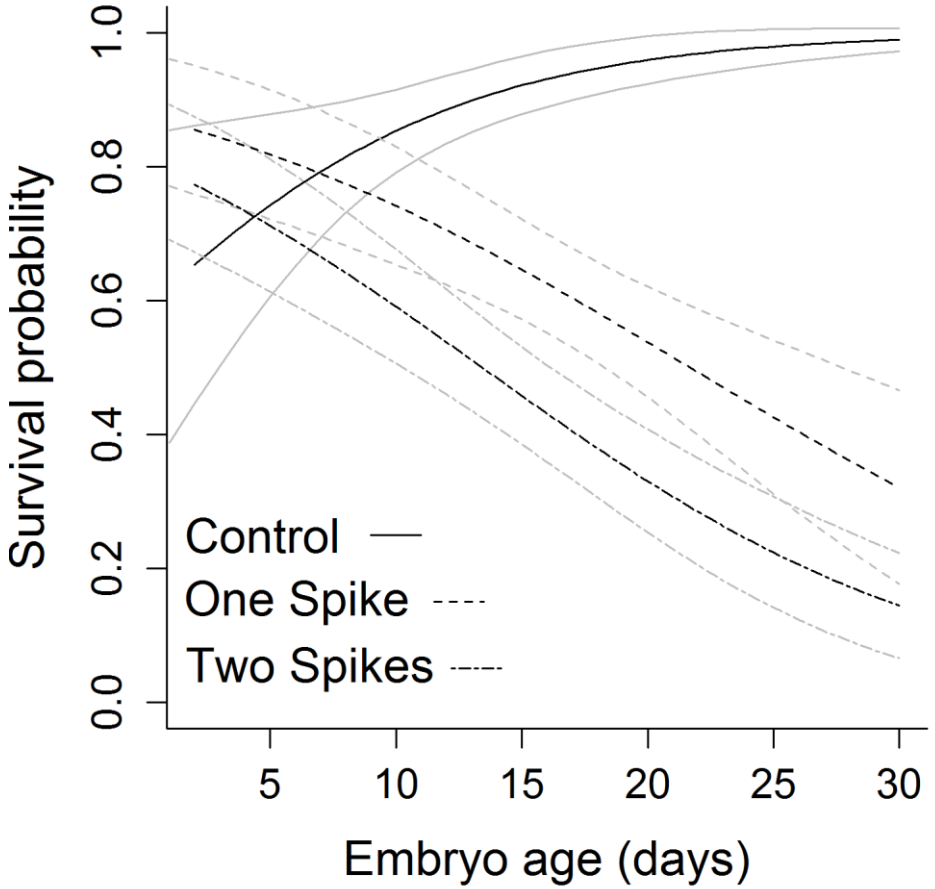
Age by Treatment: χ^2_1=5.14; p=0.02



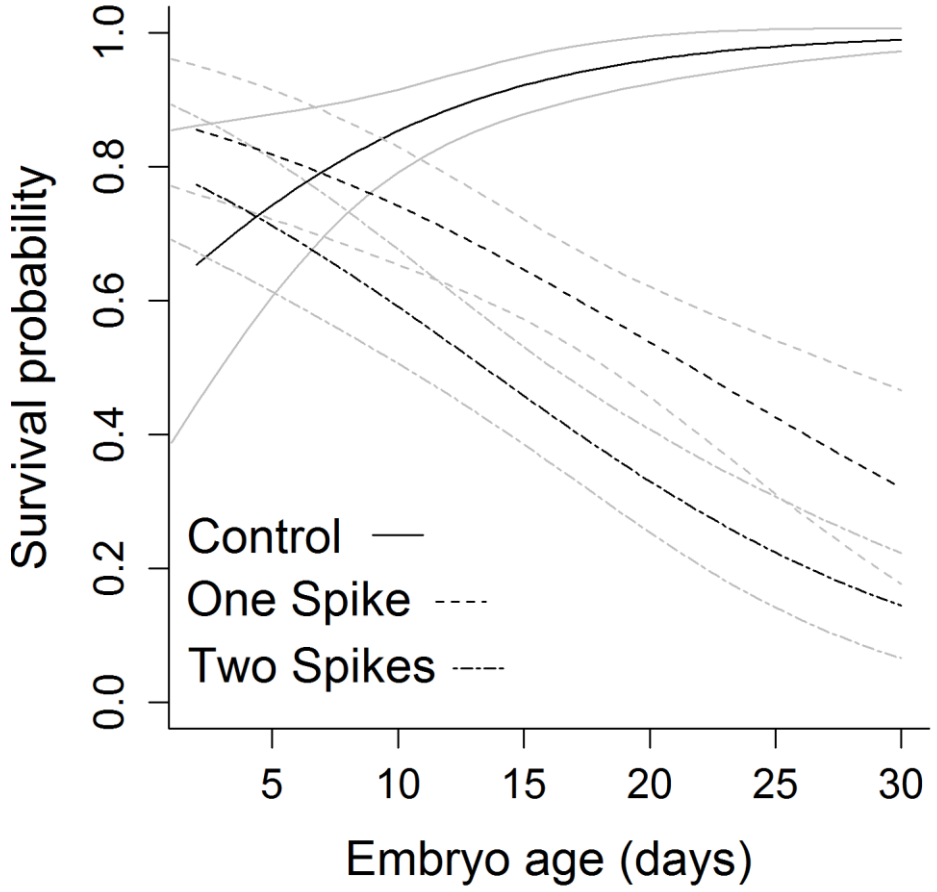
Age: χ^2_1=3.63; p=0.06

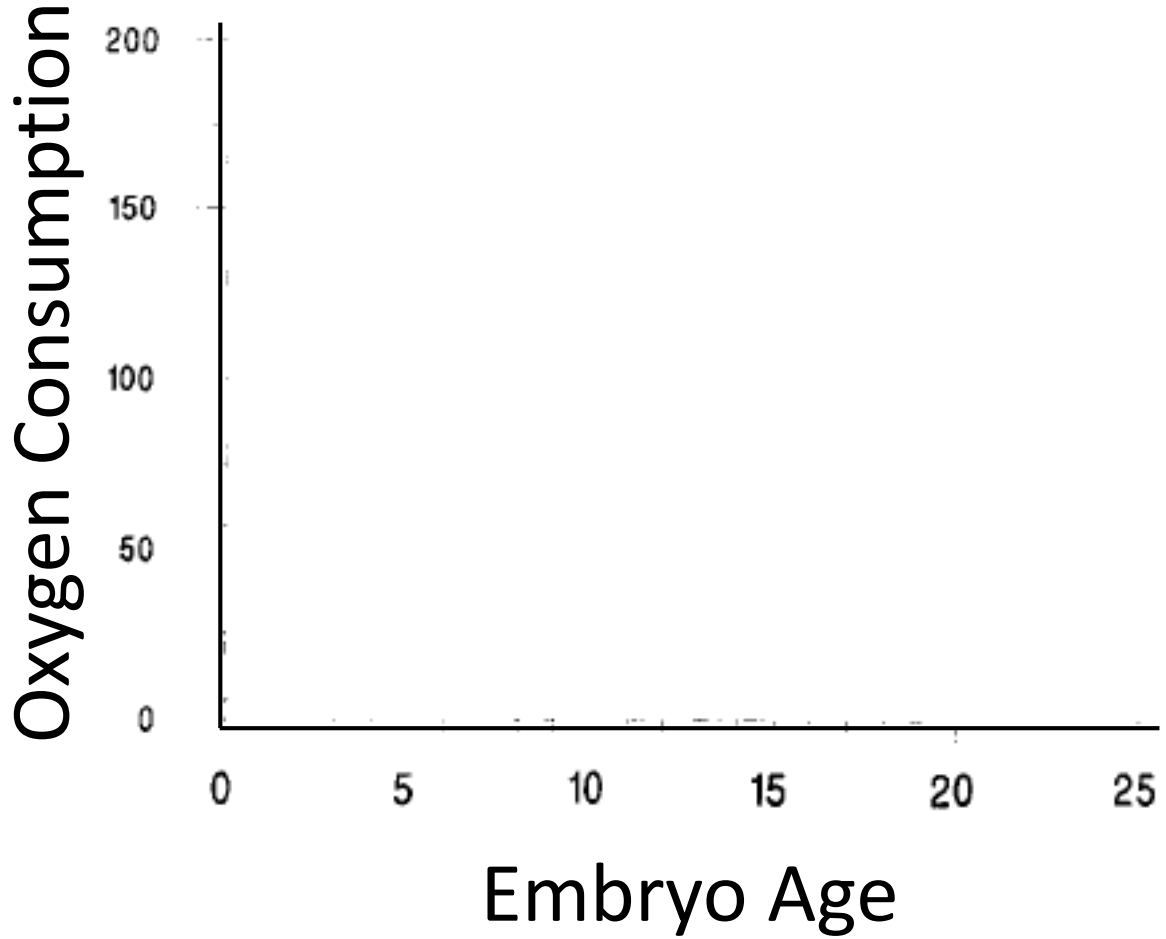
Age by Treatment: χ^2_1=4.87; p=0.03

Why are older embryos less robust?



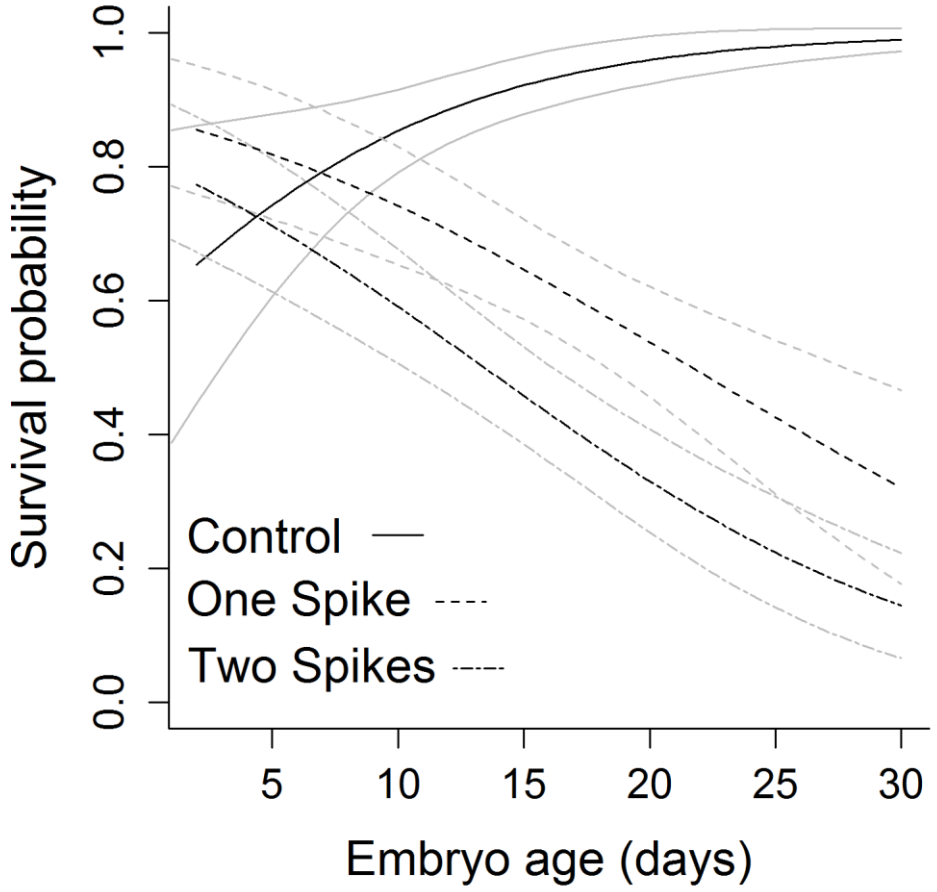
Why are older embryos less robust?

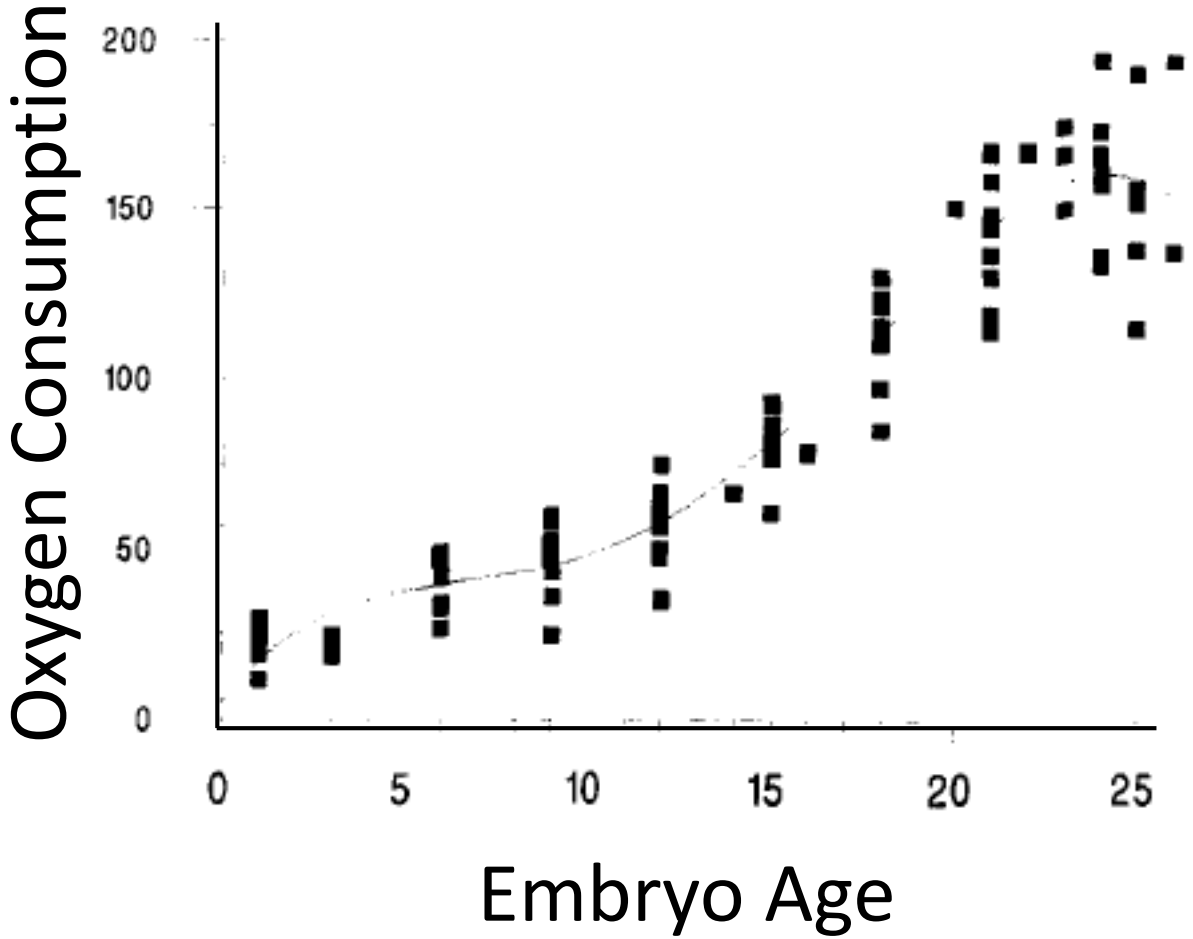




Thompson & Stewart; CBP 1997

Why are older embryos less robust?



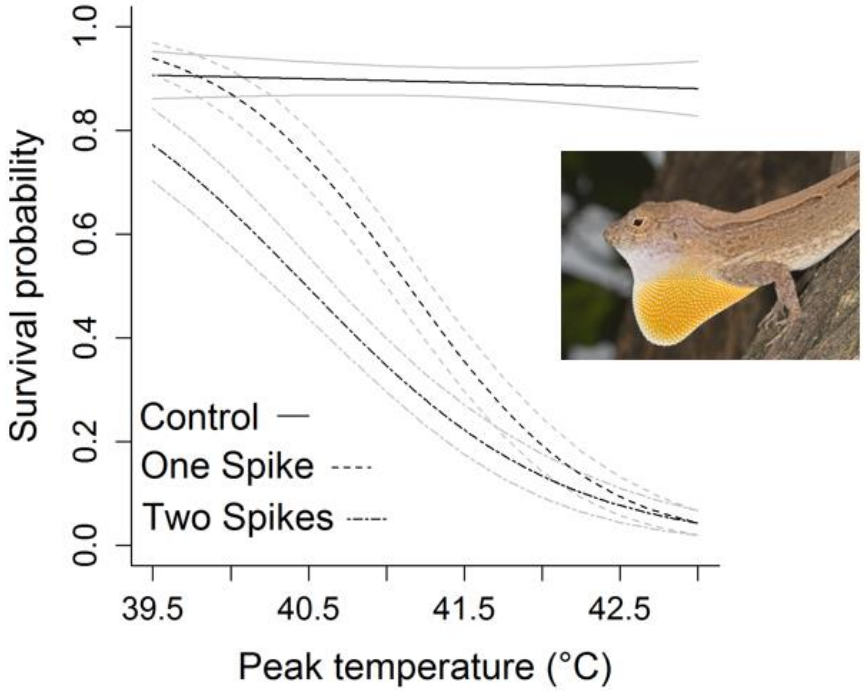


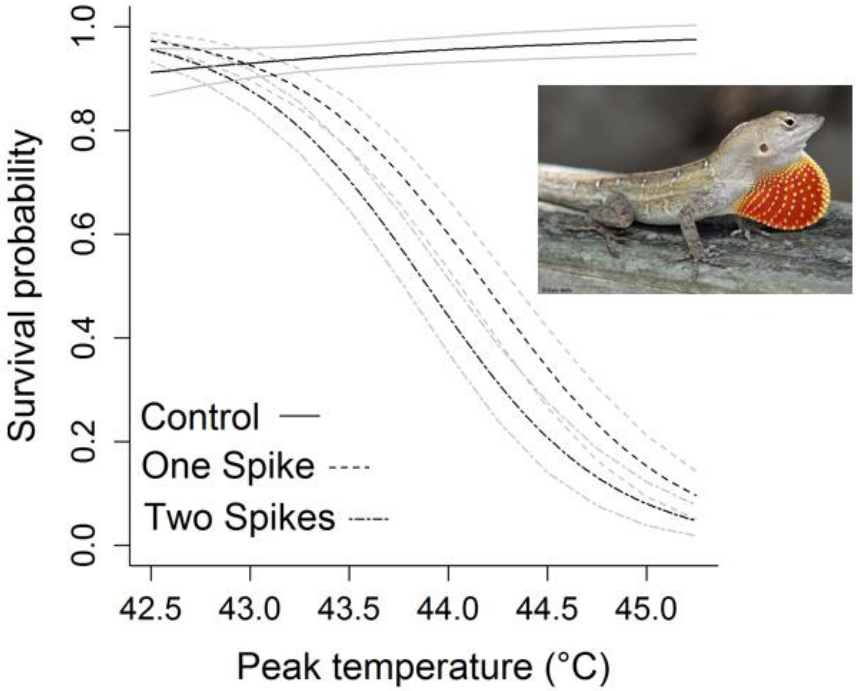
Thompson & Stewart; CBP 1997

Conclusions

Conclusions

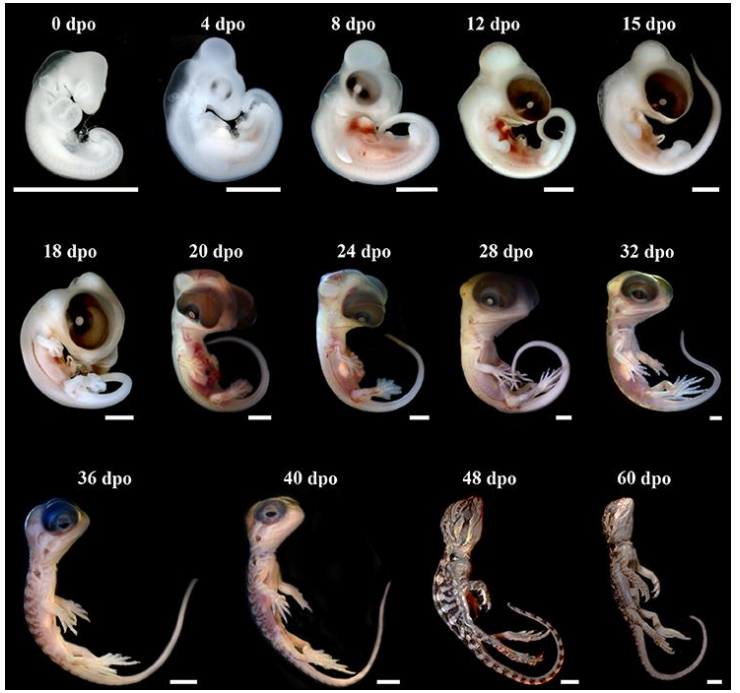
- Thermal tolerance of embryos may vary widely across species



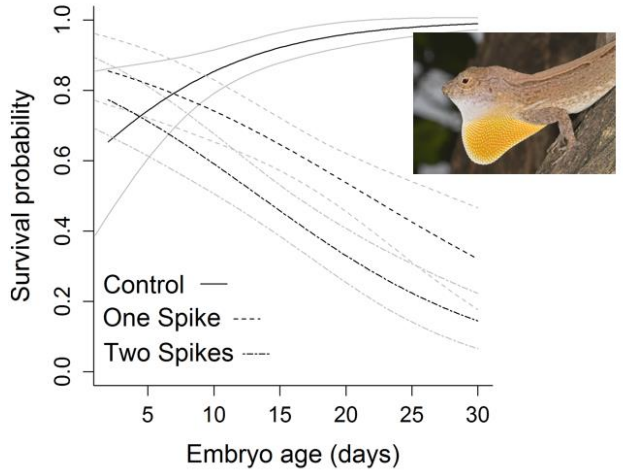


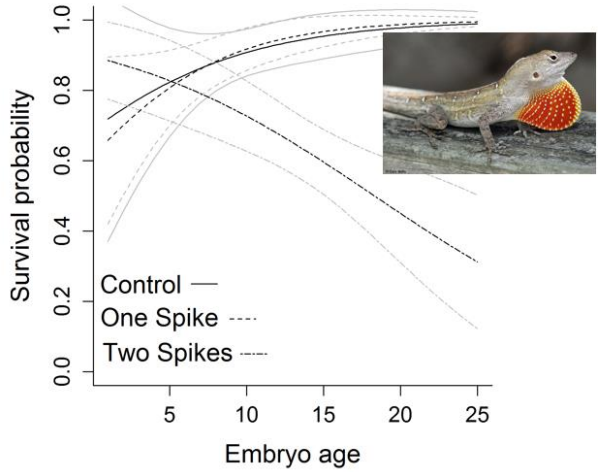
Conclusions

- Thermal tolerance of embryos may vary widely across species
- Tolerance changes through development



Ollonen et al. 2018. Front. Physiol.





Conclusions

- Thermal tolerance of embryos may vary widely across species
- Tolerance changes through development

Conclusions

- Thermal tolerance of embryos may vary widely across species
- Tolerance changes through development

REVIEW

Thermal tolerances of sea turtle embryos: current understanding and future directions

Robert Howard[1], Ian Bell[2], David A. Pike[1,*]

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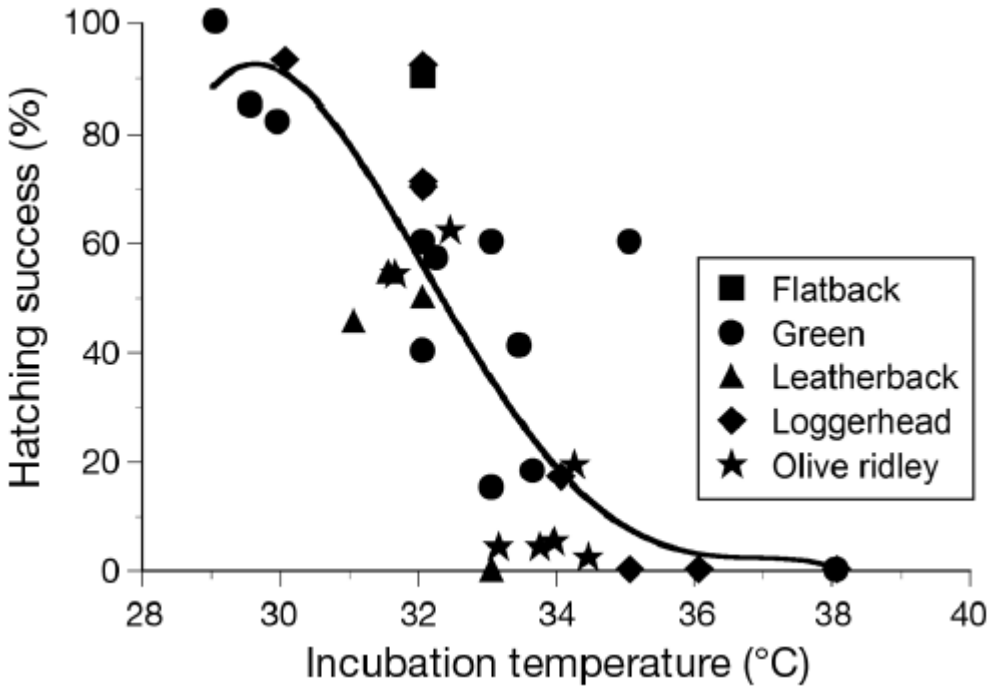

Conclusions

- Thermal tolerance of embryos may vary widely across species
- Tolerance changes through development

REVIEW

Thermal tolerances of sea turtle embryos: current understanding and future directions

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ture range that sea turtle embryos can withstand and at which they can successfully hatch, but have not yet determined whether temperature fluctuation and stage of embryonic development interact, such that the thermal tolerance of embryos changes during incubation. Research on olive ridley sea turtles *Lepido-*

Acknowledgements

Mentors
Dan Warner
Tim Mitchell
Renata Brandt

Undergraduates
Austin Hulbert
Kayla Wilson
Ryan Weesner
David Quinn
Chanel Reali

Collaborators
Jason Kolbe
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Funding
National Science Foundation

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Funding
National Science Foundation

Literature Cited

Hall, J.M. and Warner, D.A., 2017. Body size and reproduction of a non-native lizard are enhanced in an urban environment. *Biological Journal of the Linnean Society*, *122*(4), pp.860-871.

Hall, J.M. and Warner, D.A., 2018. Thermal spikes from the urban heat island increase mortality and alter physiology of lizard embryos. *Journal of Experimental Biology*, *221*(14), p.jeb181552.

Howard, R., Bell, I. and Pike, D.A., 2014. Thermal tolerances of sea turtle embryos: current understanding and future directions. *Endangered Species Research*, *26*(1), pp.75-86.

Pike, D.A., 2014. Forecasting the viability of sea turtle eggs in a warming world. *Global change biology*, *20*(1), pp.7-15.