Embryo development and global change: how do reptile embryos respond to thermal stress in urban environments?

Joshua M Hall
Daniel A Warner

Evolution • Ecology • Behavior • Physiology
WARNER LAB

AUBURN UNIVERSITY

Beyond the Mean

SICB Annual Meeting 2016
January 3-7, 2016
Oregon Convention Center - Portland, OR

Symposium: Beyond the mean: Biological impacts of changing patterns of temperature variation

Changing climate is having far-reaching impacts on ecosystems around the globe. Much research has documented changes in mean temperature and correlated shifts in the distribution, phenology, abundance of organisms and their populations and species. Much less work has evaluated biological impacts of changes in temporal and spatial variation in temperature, and in the frequency of extreme events. Mean temperatures may be far less relevant for physiology and life history of most organisms, so understanding the biological impacts of these other aspects of temperature change is a critical emerging challenge. We are on the cusp of an explosion of work in this area. This is a prime time to drive the field forward by bringing together established and early-career biologists for a wide-ranging discussion of theory and data approaches to the problem.

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Integrative and Comparative Biology

Integrative and Comparative Biology, volume 56, number 1, pp. 98–109
doi:10.1093/icb/icw004

Society for Integrative and Comparative Biology

SYMPOSIUM

How Extreme Temperatures Impact Organisms and the Evolution of their Thermal Tolerance

Lauren B. Buckley[1] and Raymond B. Huey

Department of Biology, University of Washington, Seattle, WA 981951800, USA

From the symposium "Beyond the Mean: Biological Impacts of Changing Patterns of Temperature Variation" presented at the annual meeting of the Society for Integrative and Comparative Biology, January 3–7, 2016 at Portland, Oregon.

[1]E-mail: lbuckley@uw.edu

Beyond the Mean

- Thermal extremes can drive the evolution of performance and tolerance

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Beyond the Mean

- Thermal extremes can drive the evolution of performance and tolerance
- Potentially more so than mean temperature

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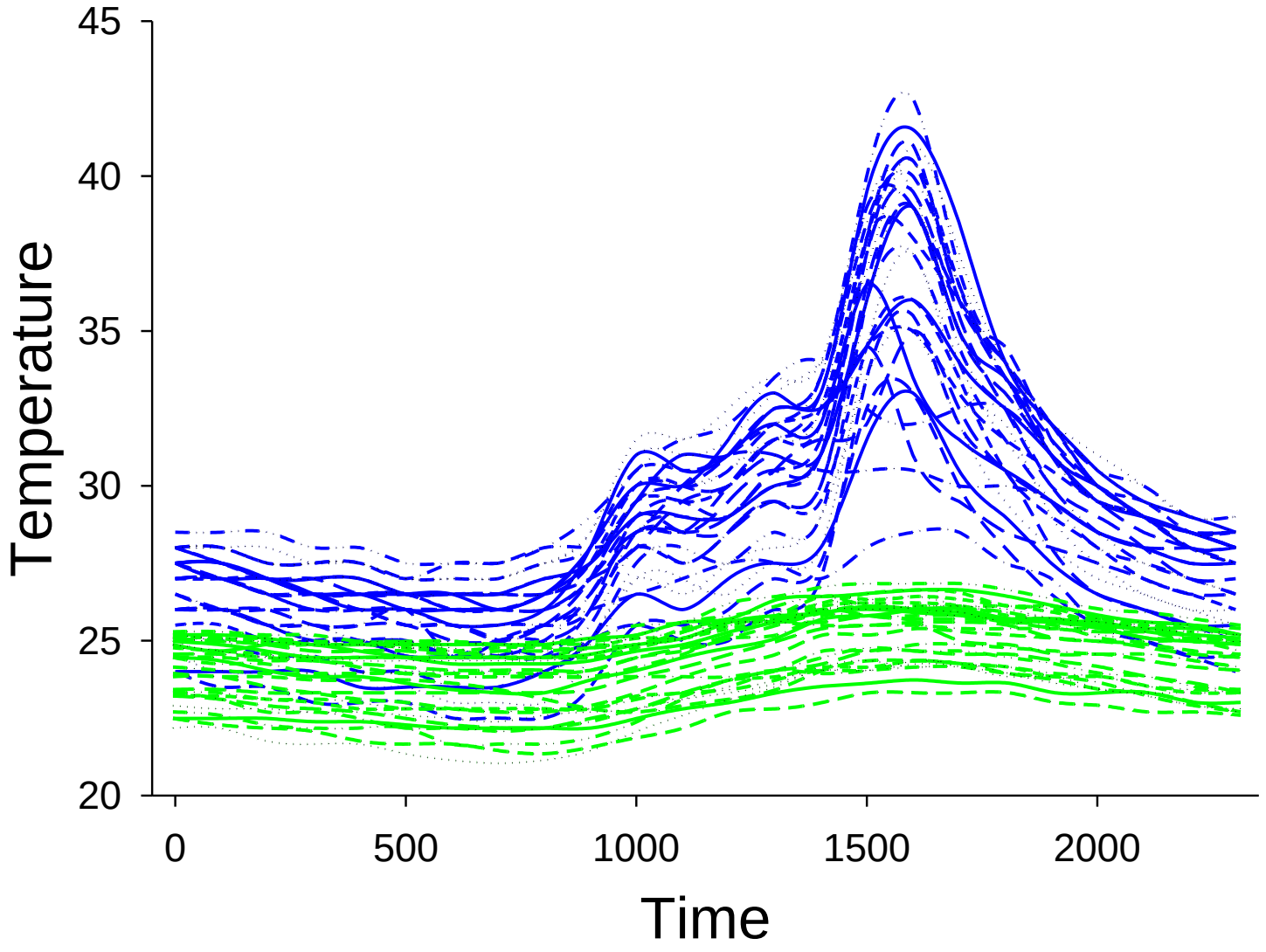
Urban Heat Island Effect



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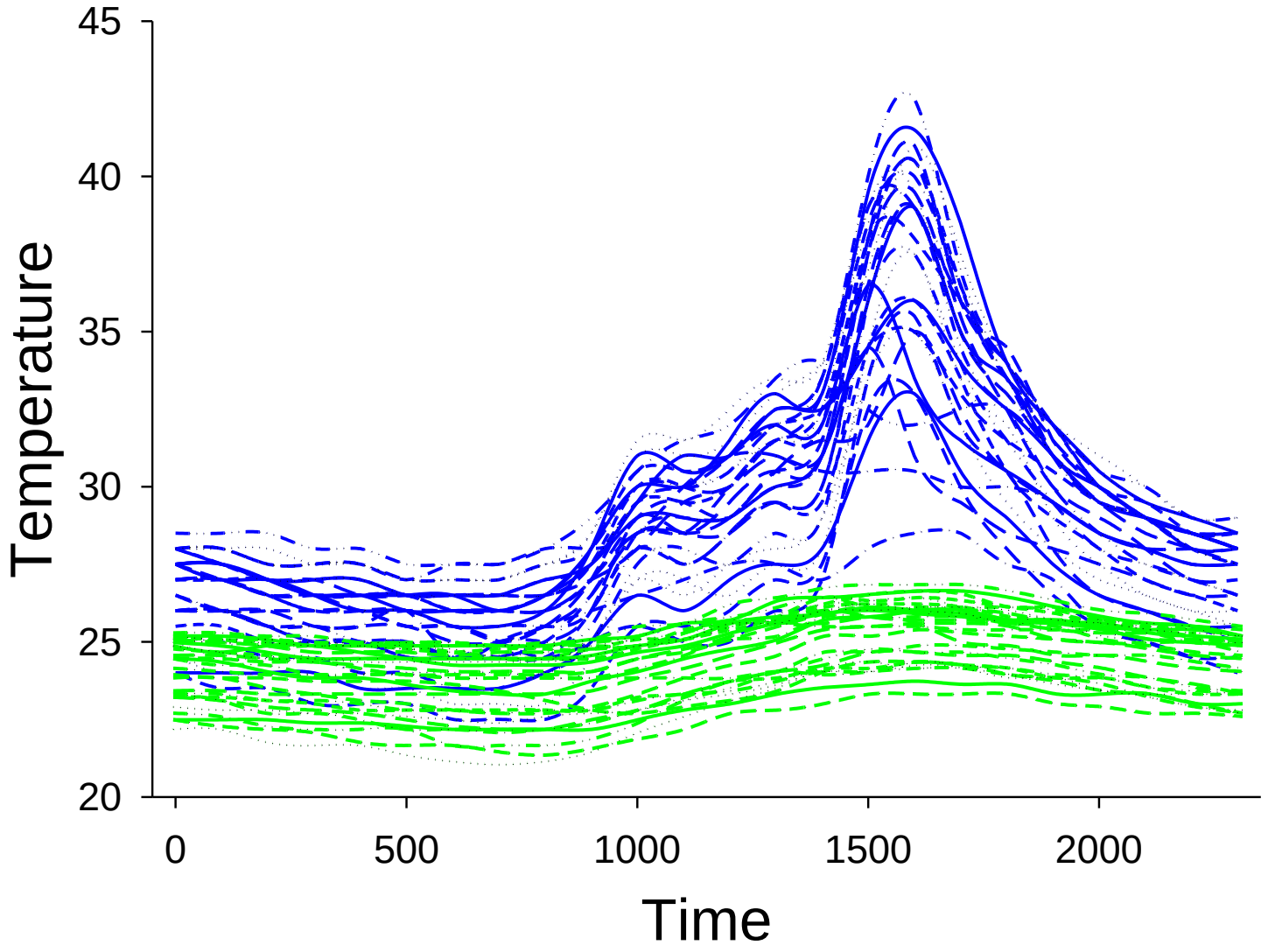
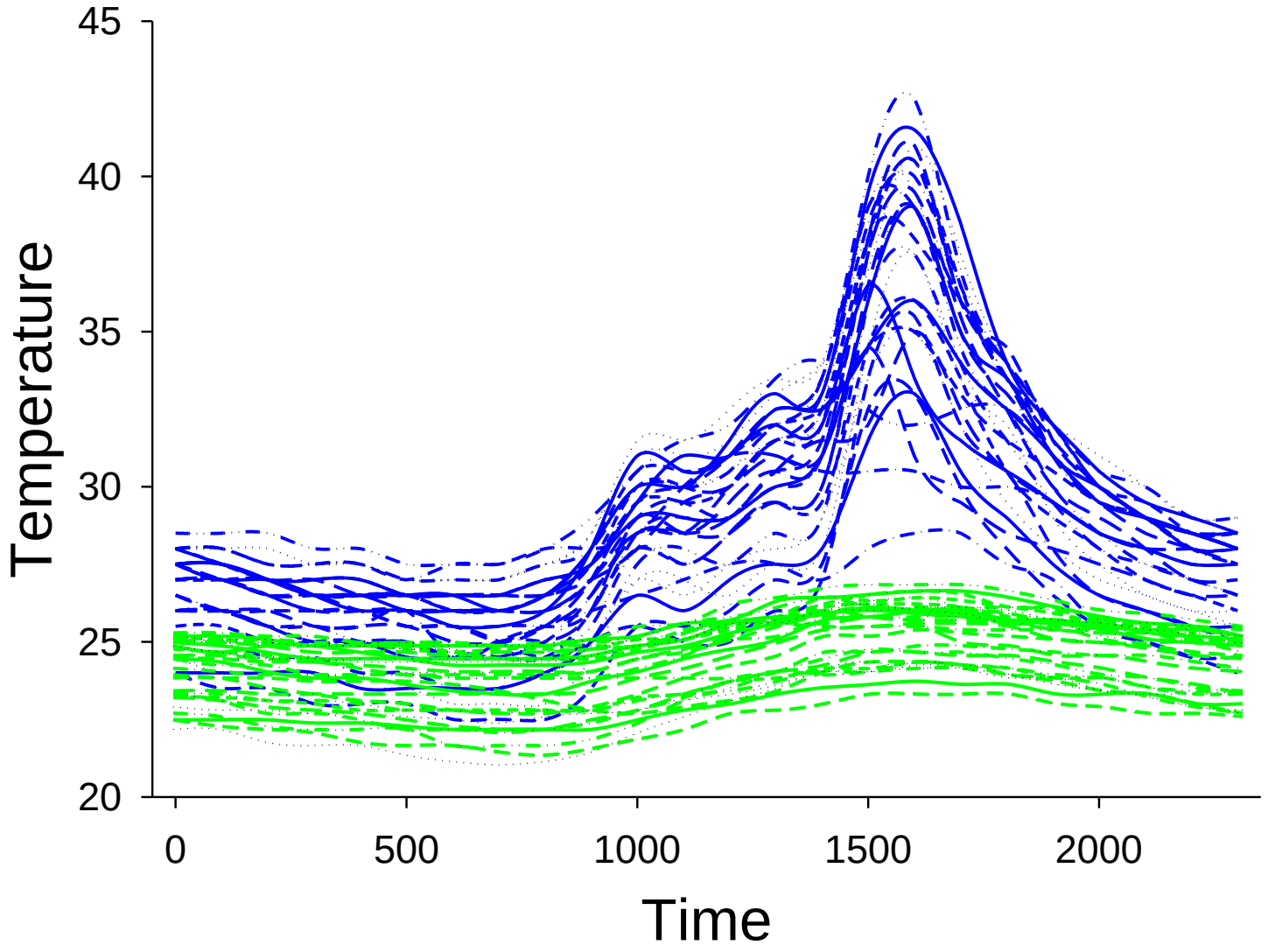


- Average temperatures higher in urban areas than natural sites
- Thermal fluctuations, thermal spikes, more extreme in urban areas
- Implications for ectotherms
  - Adults
  - Developing embryos?

Global Change



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- Are unable to **behaviorally compensate** for adverse conditions
- Influence population dynamics and **species distributions**

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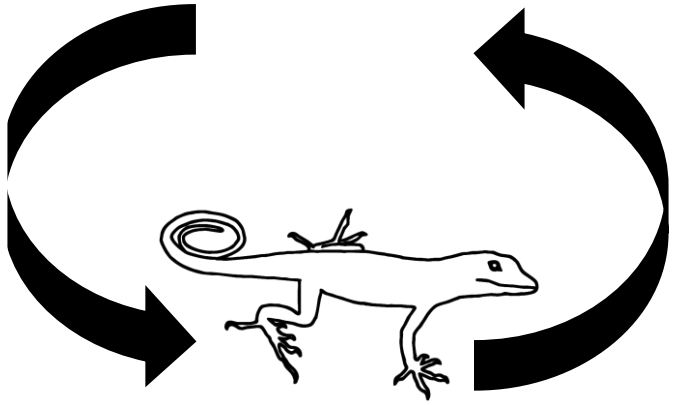

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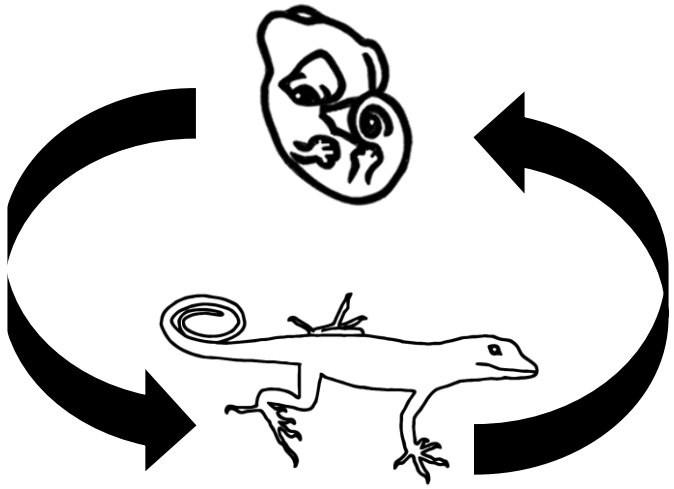

Embryos…

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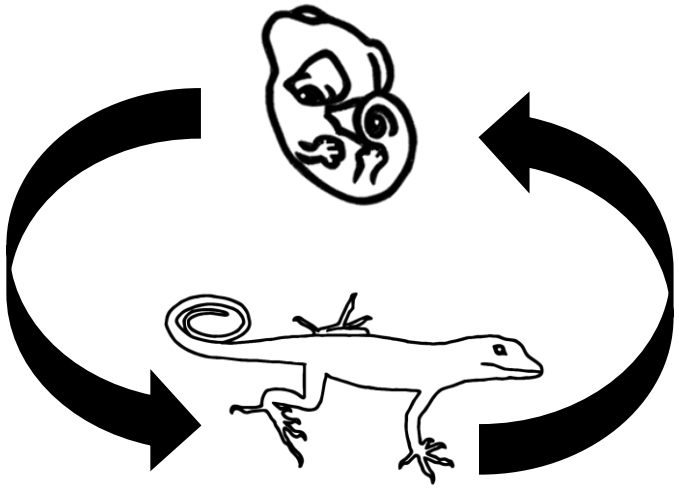
Development

(temperature; moisture)



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ECOLOGY LETTERS

Ecology Letters, (2017) doi: 10.1111/ele.12877

LETTER

Recurrent sublethal warming reduces embryonic survival, inhibits juvenile growth, and alters species distribution projections under climate change

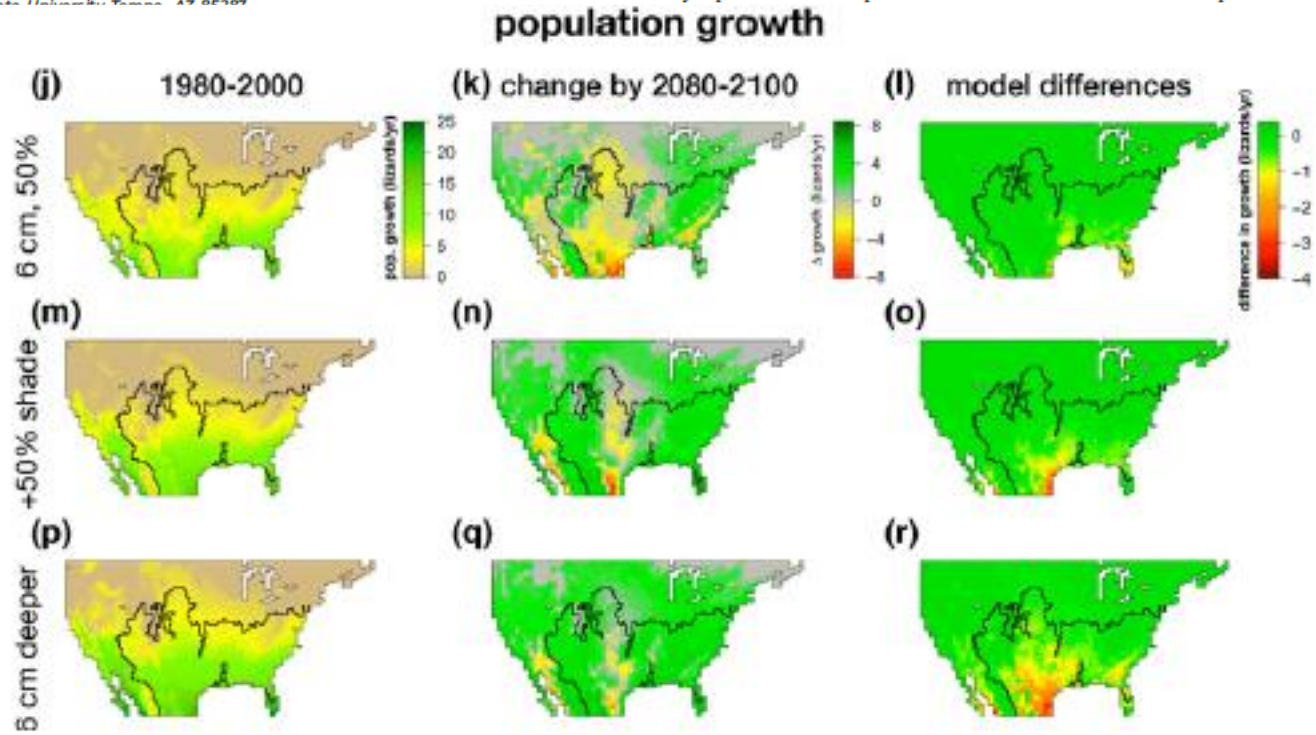
Michael A. Carlo,[1]* Eric A. Riddell,[1] Ofir Levy[2] and Michael W. Sears[1]

[1]Department of Biological Sciences Clemson University Clemson, SC 29634, USA

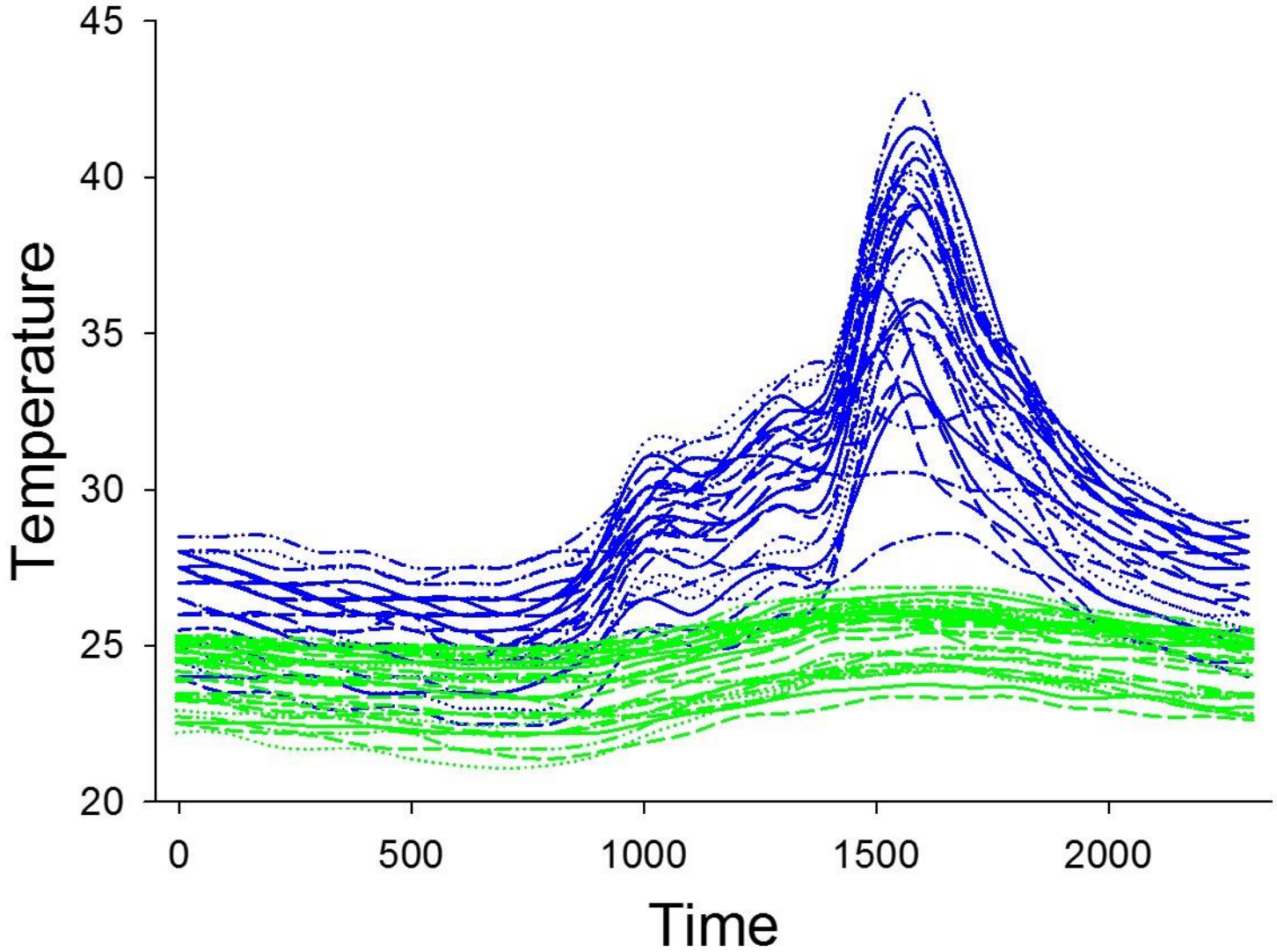
[2]School of Life Sciences Arizona

Abstract

The capacity to tolerate climate change often varies across ontogeny in organisms with complex life cycles. Recently developed species distribution models incorporate traits across life stages; however, these life-cycle models primarily evaluate effects of lethal change. Here, we examine impacts of recurrent sublethal warming on development and survival in ecological projections of climate change. We reared lizard embryos in the laboratory under temperature cycles that simulated contemporary conditions and warming scenarios. We also artificially warmed natural nests to mimic laboratory treatments. In both cases, recurrent sublethal warming decreased embryonic survival and hatchling sizes. Incorporating survivorship results into a mechanistic species distribution model reduced annual survival by up to 24% compared to models that did not incorporate

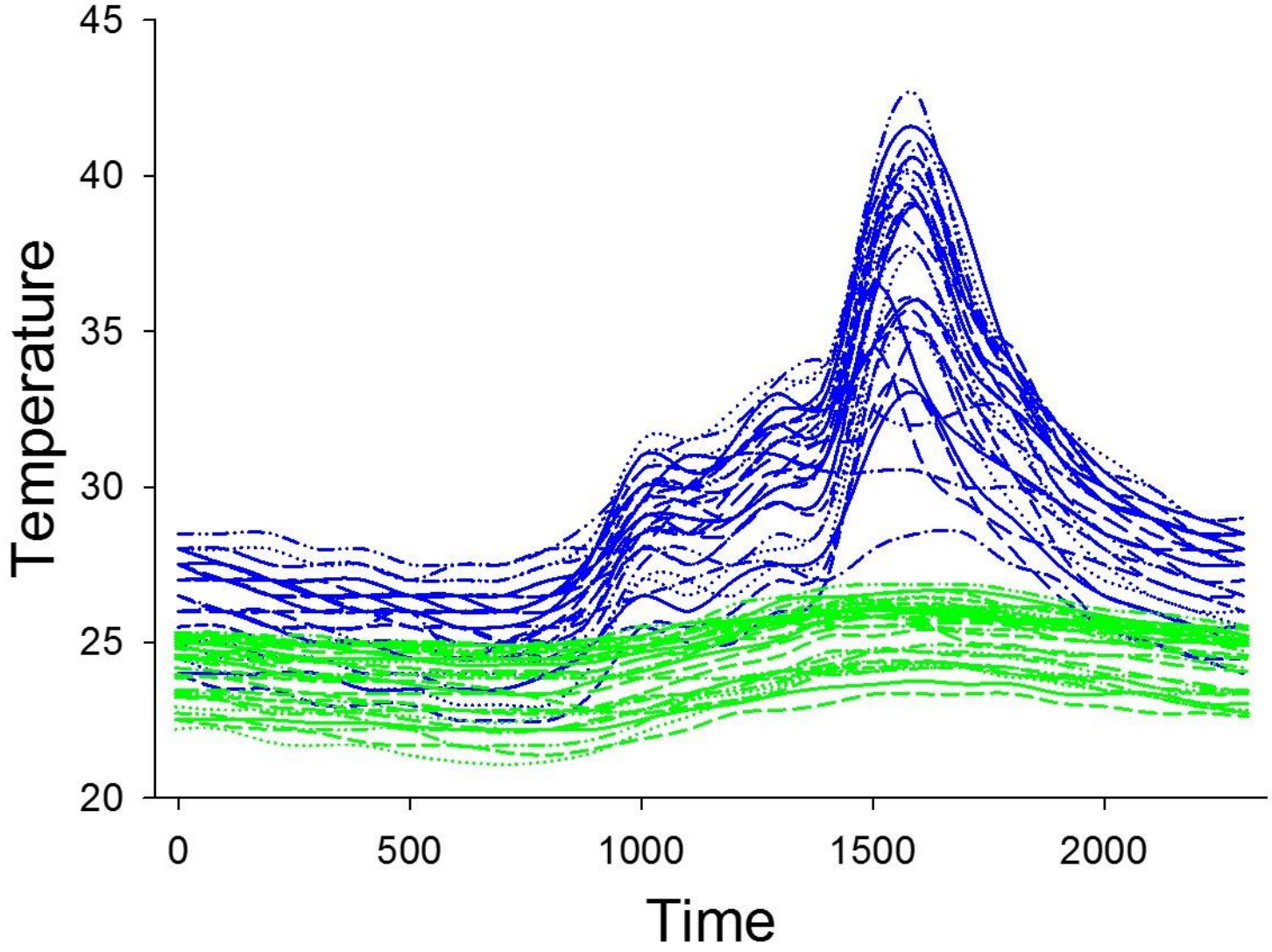


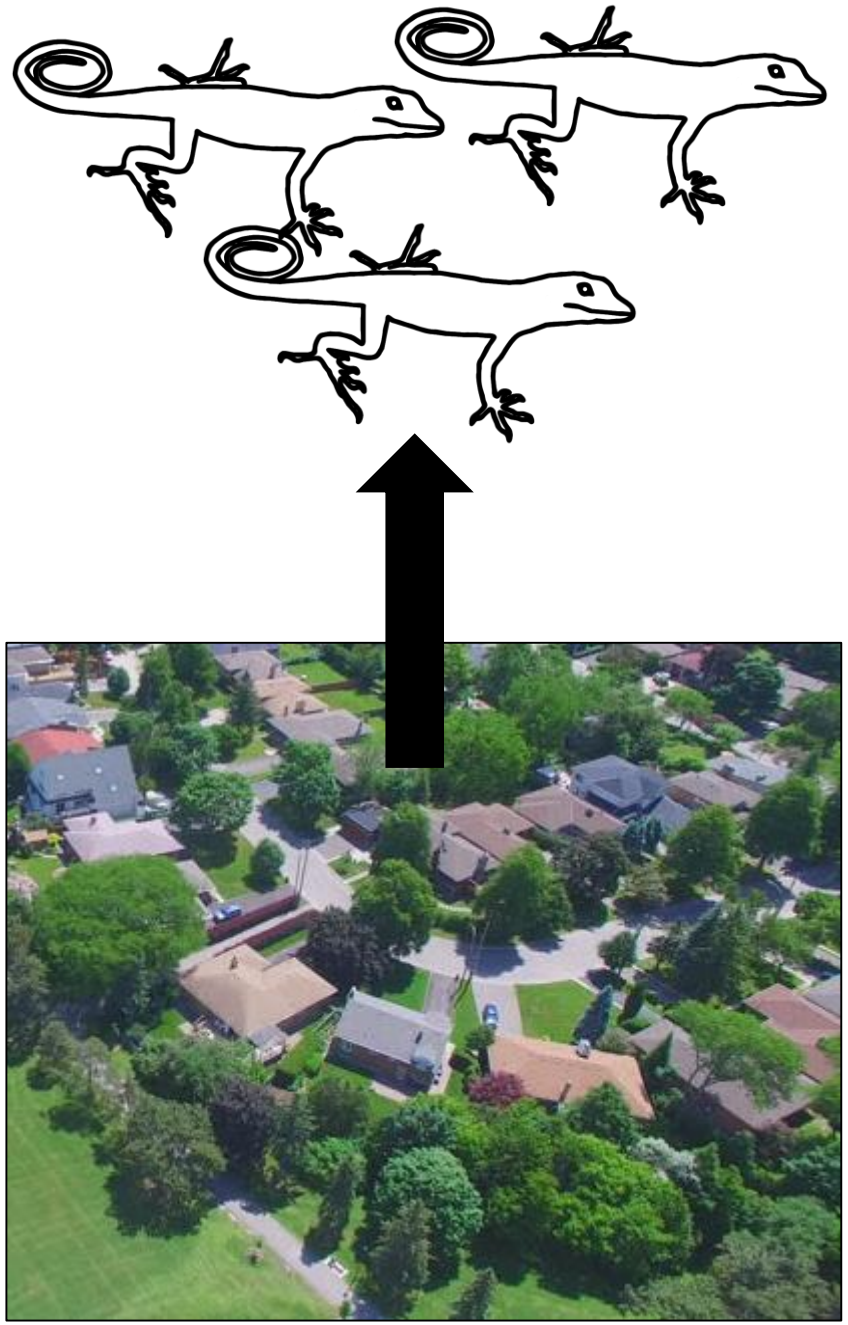
Thermal Extremes

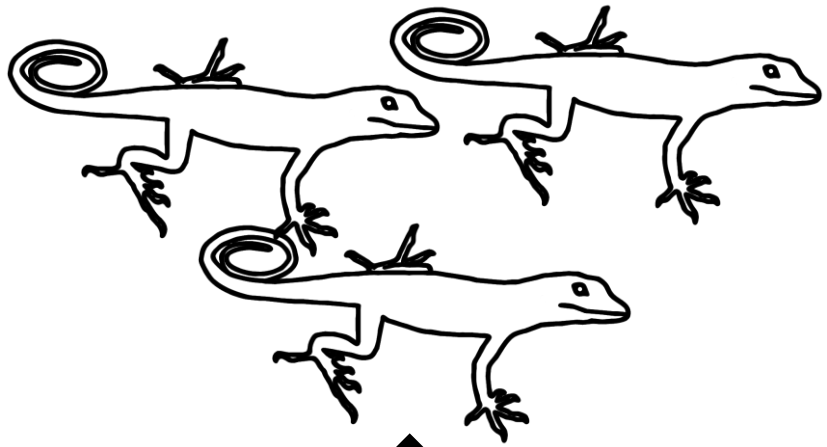


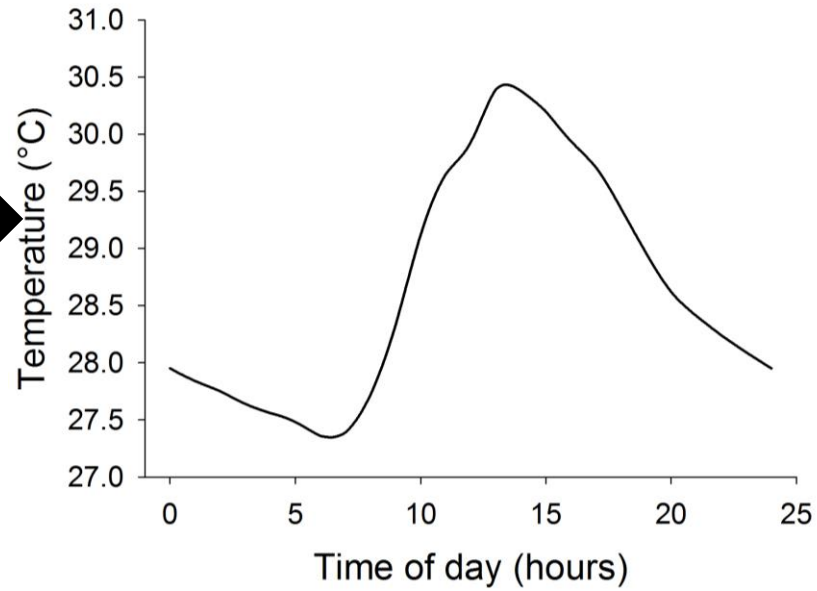
Thermal Extremes

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





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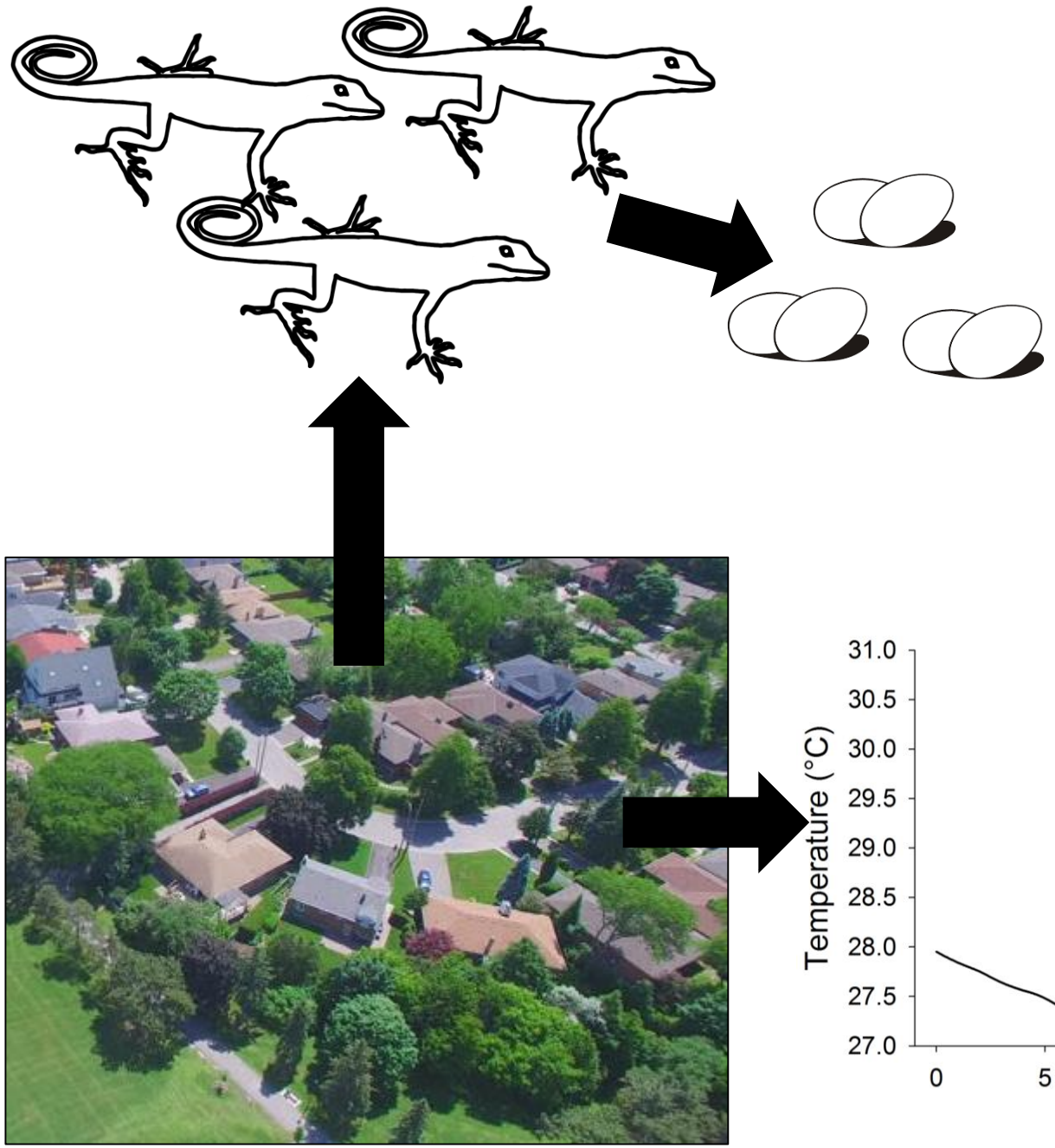
Time of day (hours)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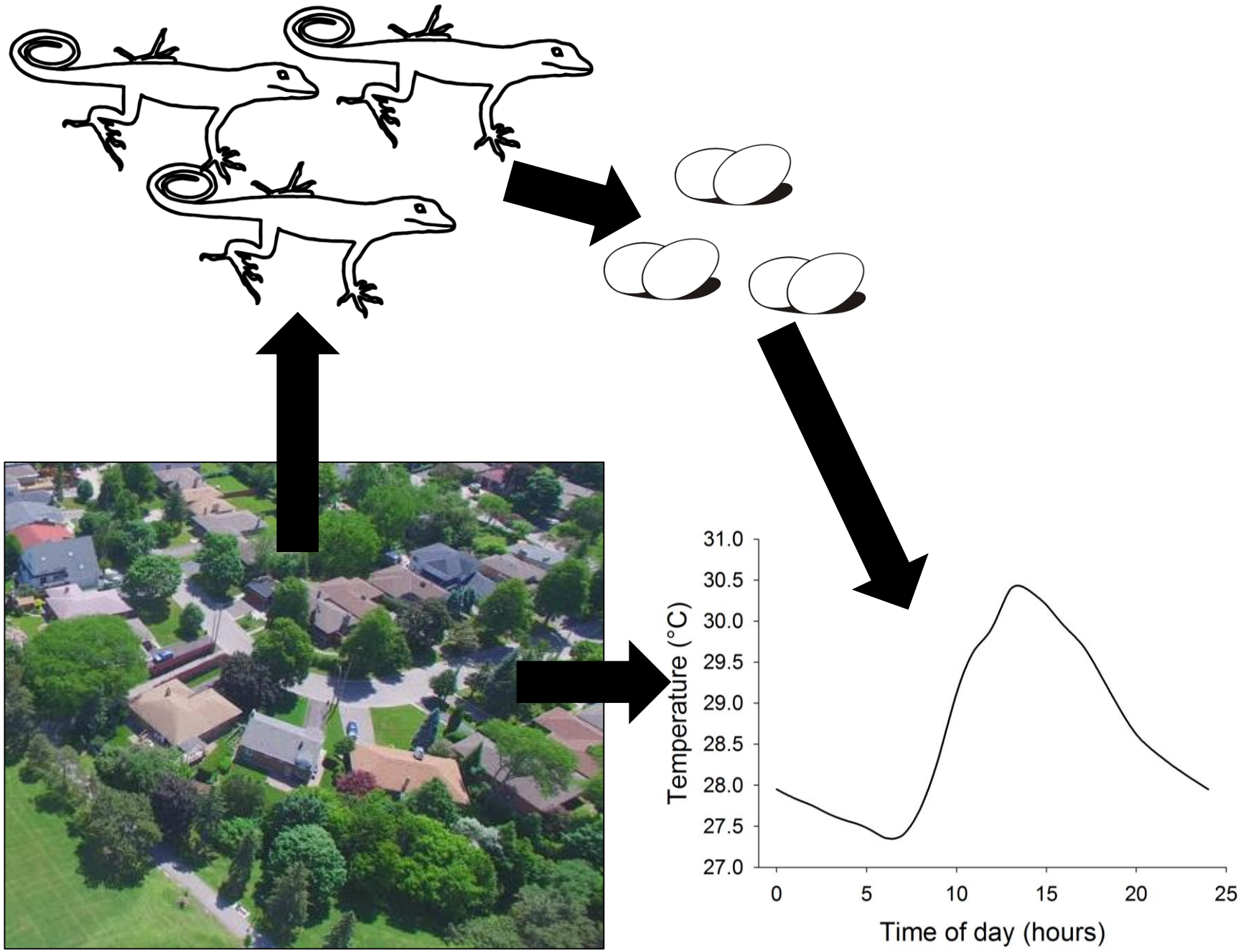
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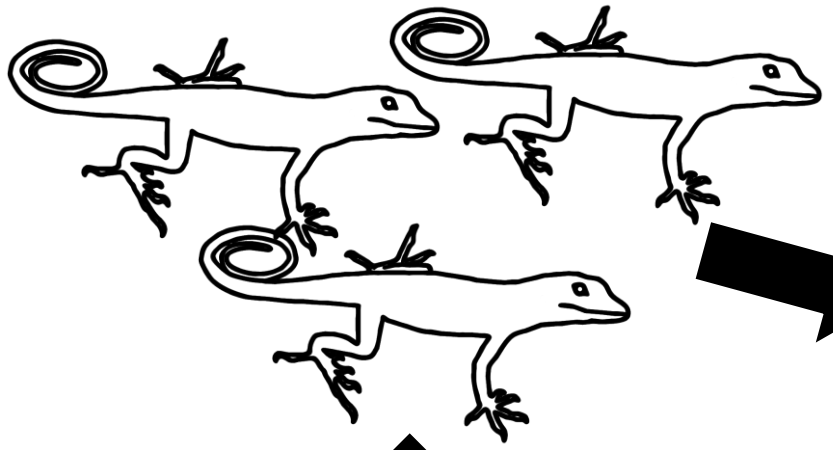

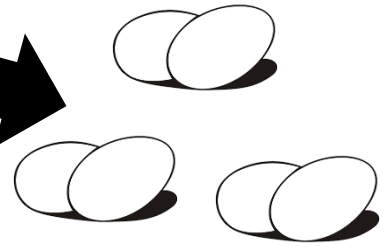

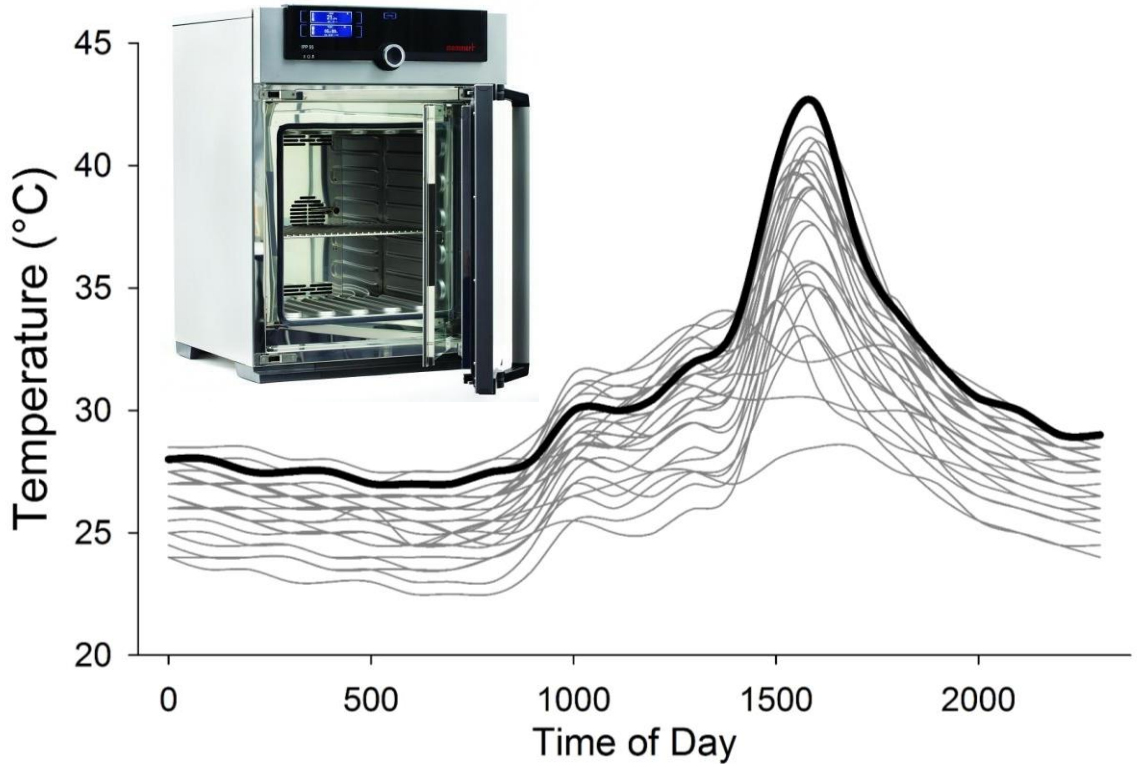
Temperature (°C)
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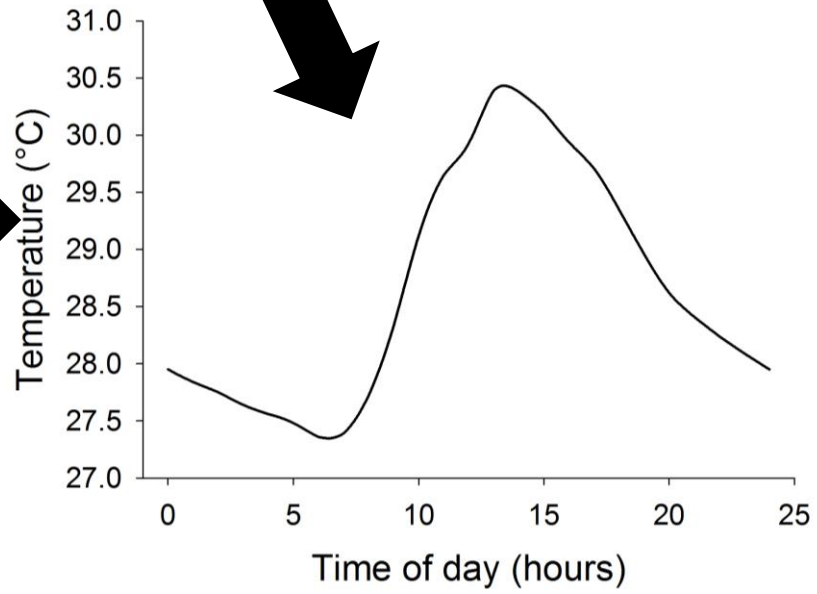
Time of Day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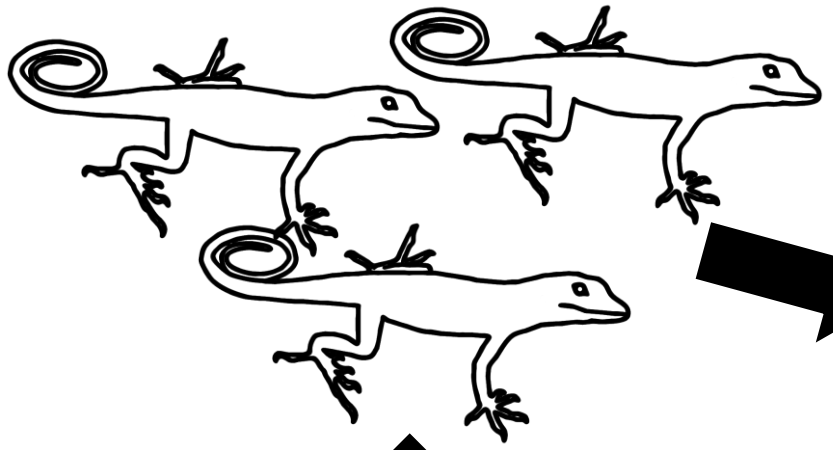

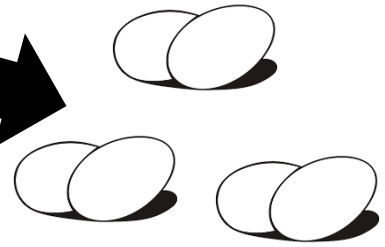

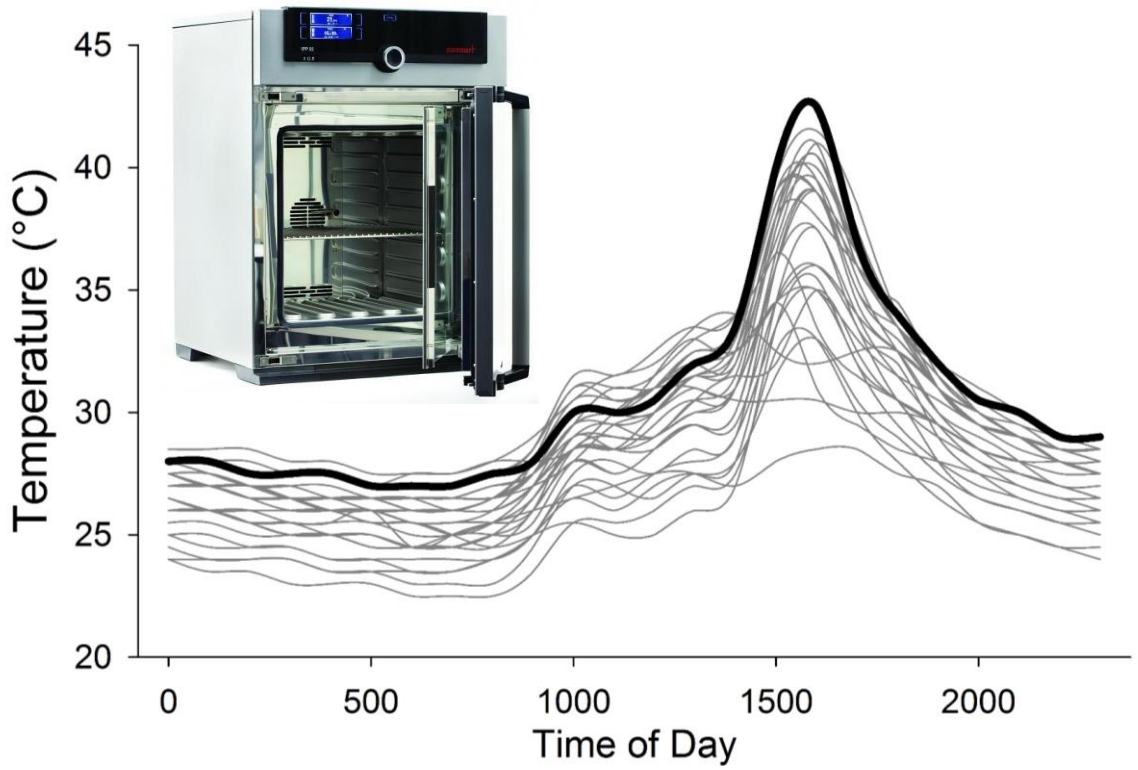
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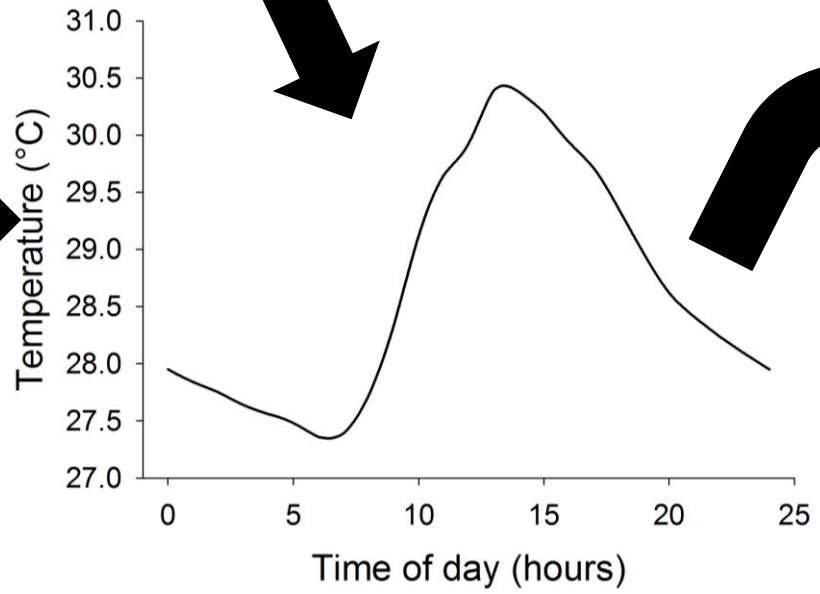
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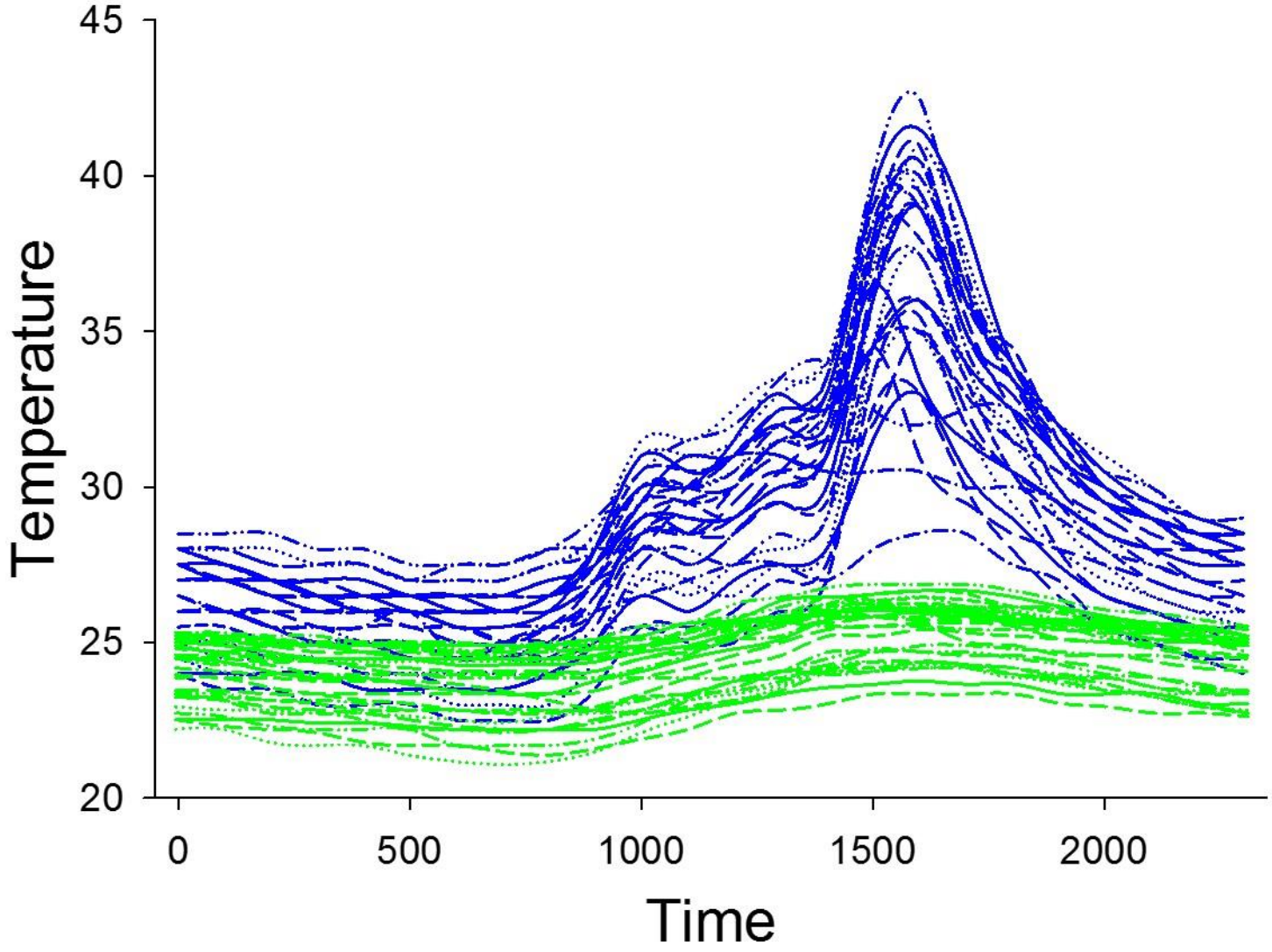

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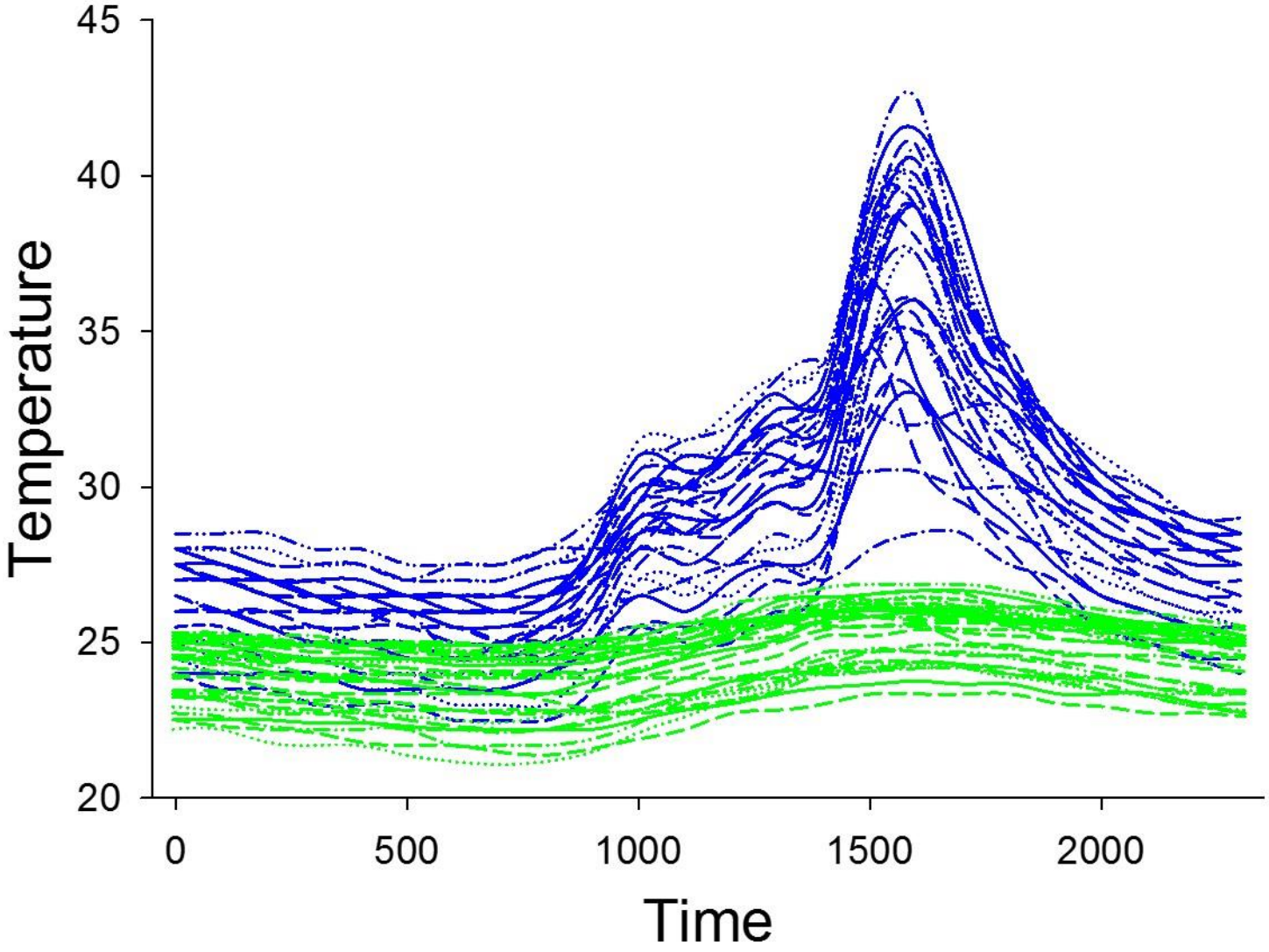
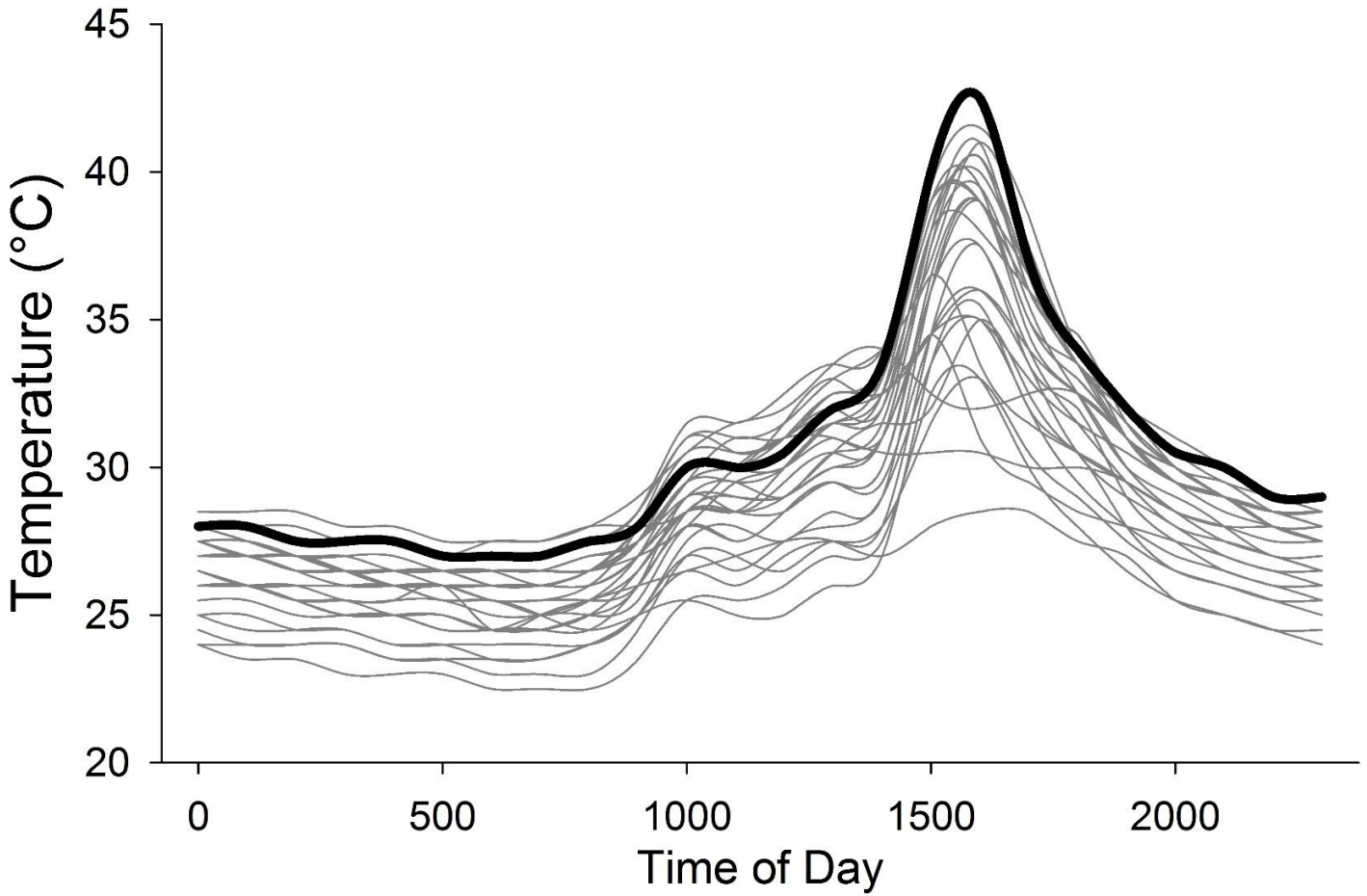


Experimental Design – Mag, Freq, Age



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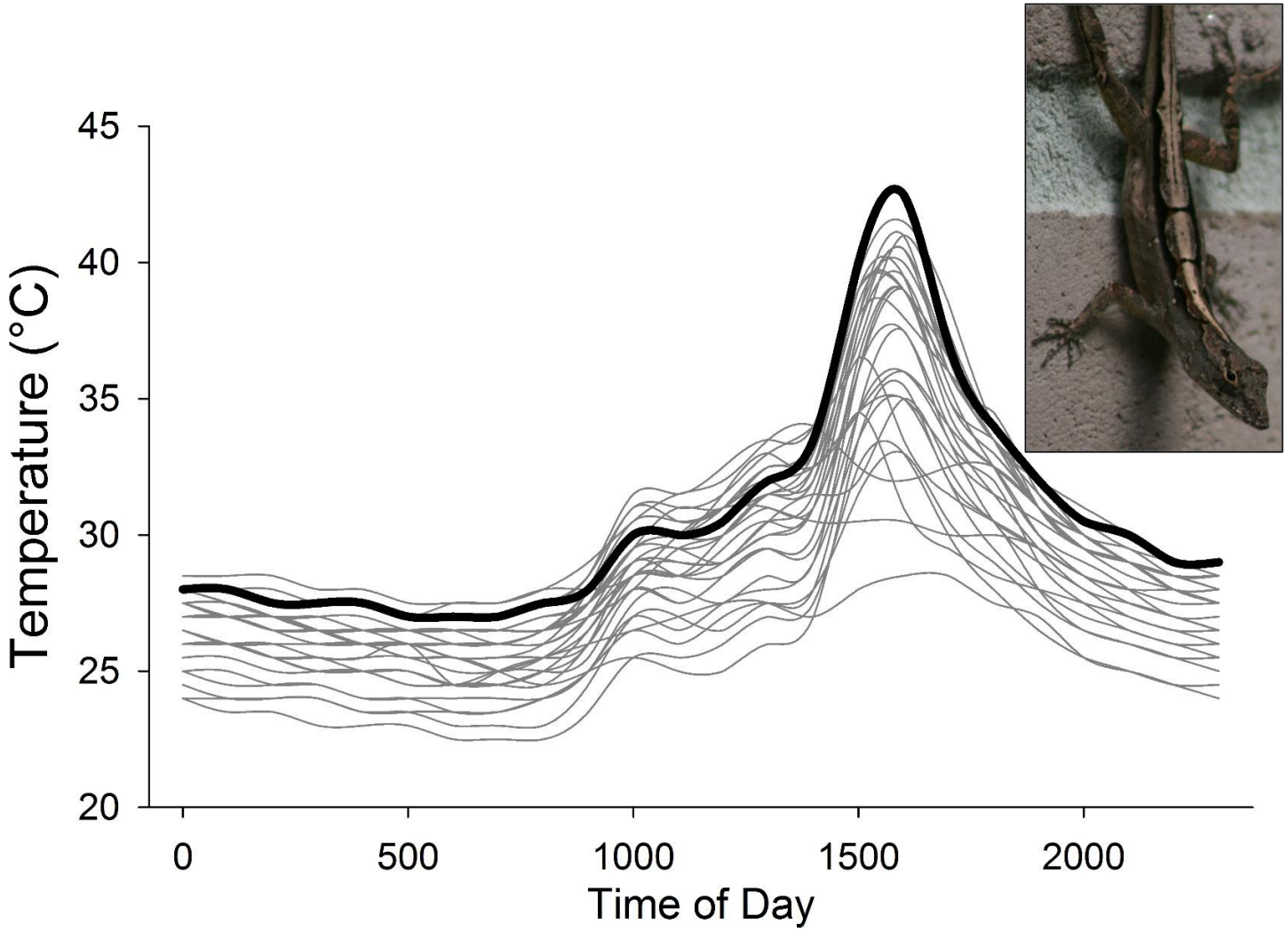

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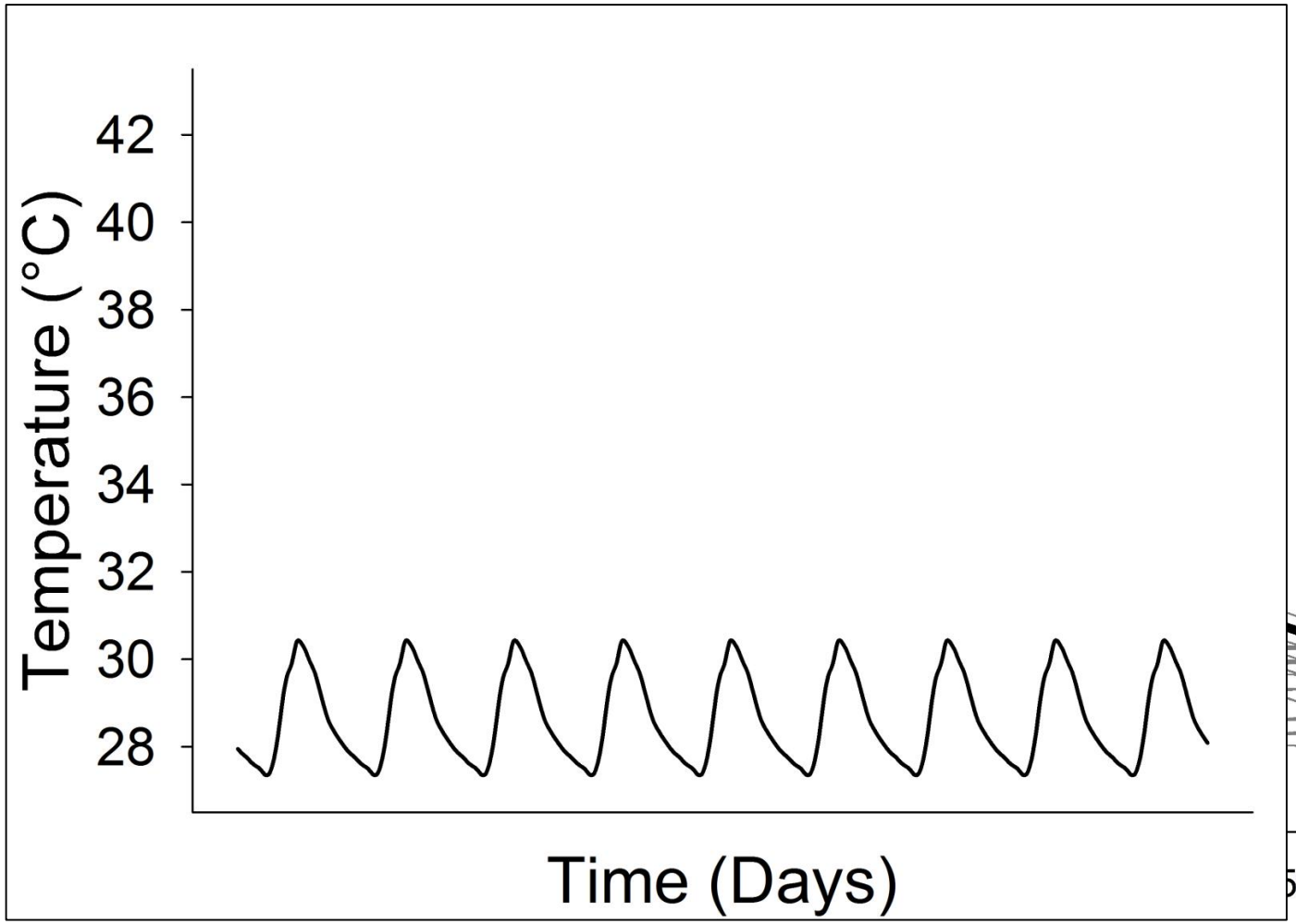

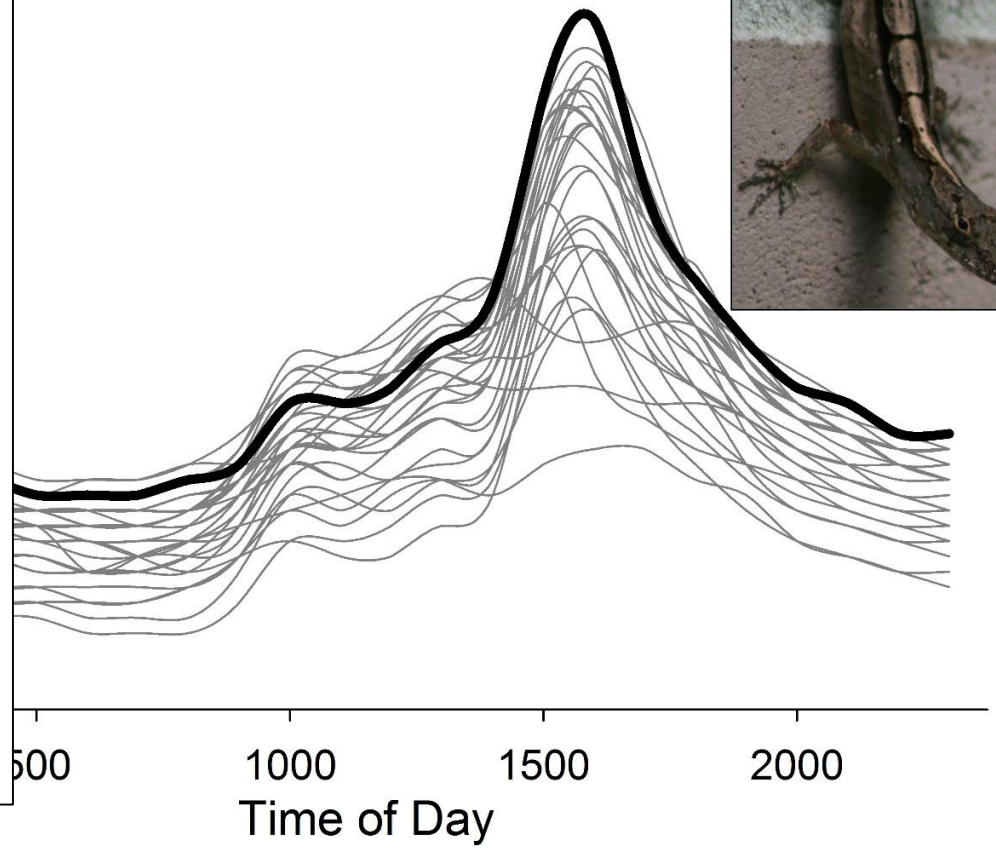

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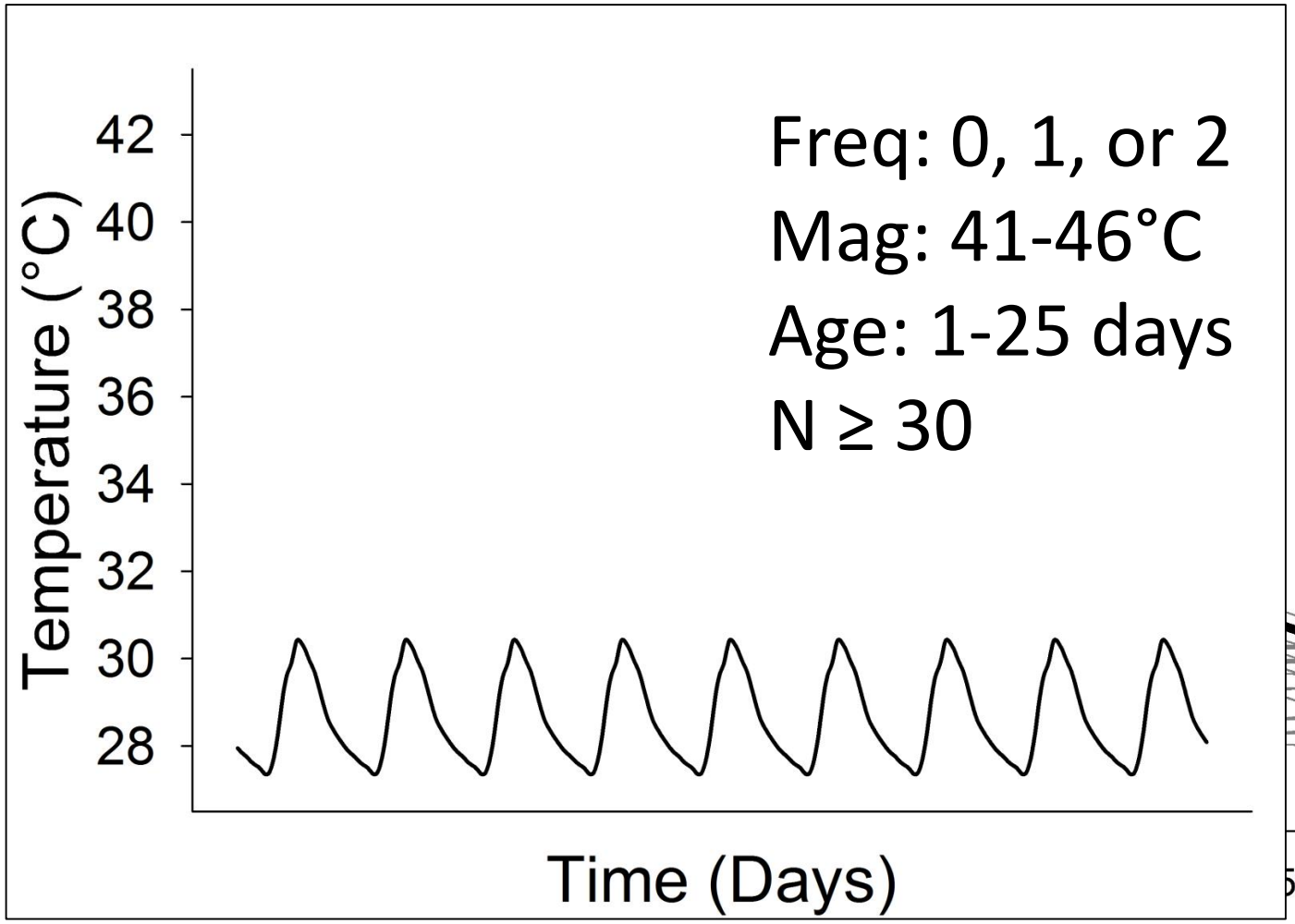

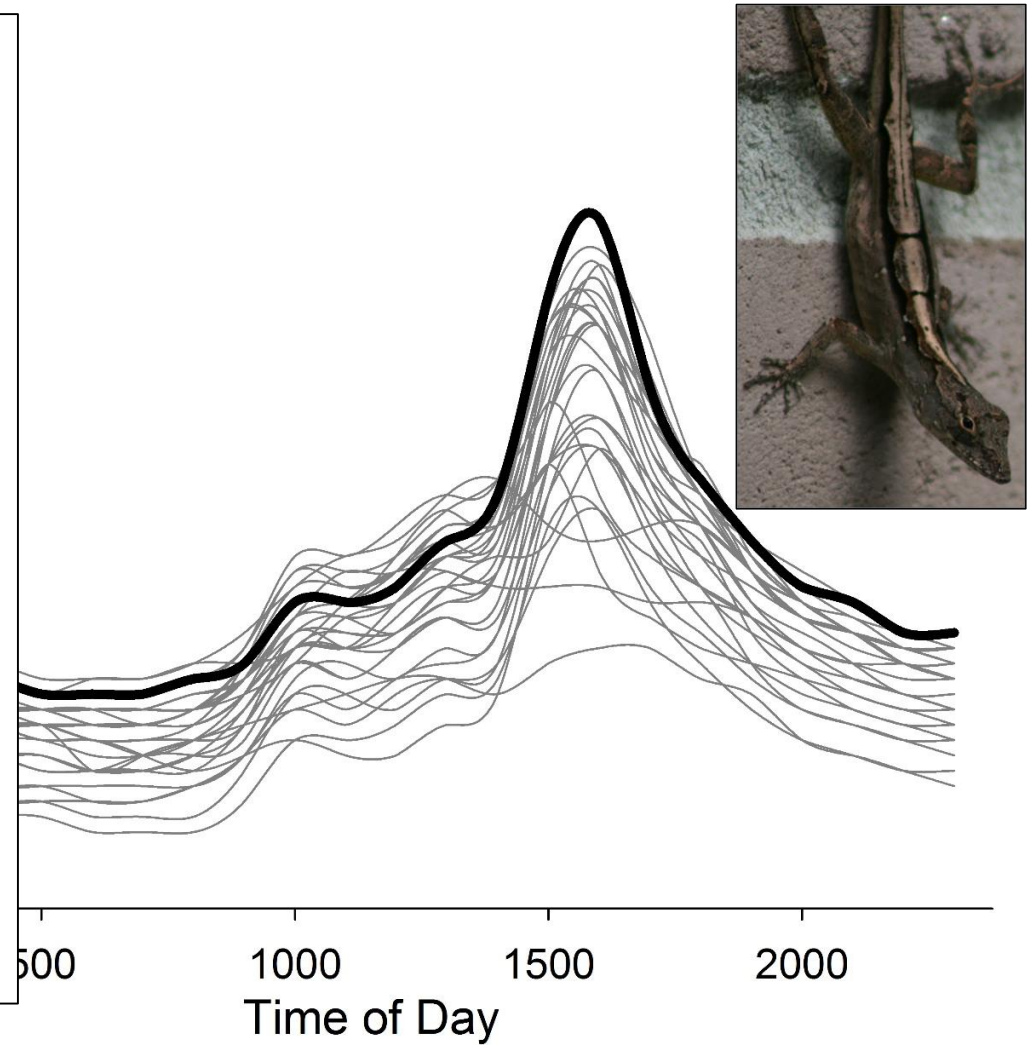

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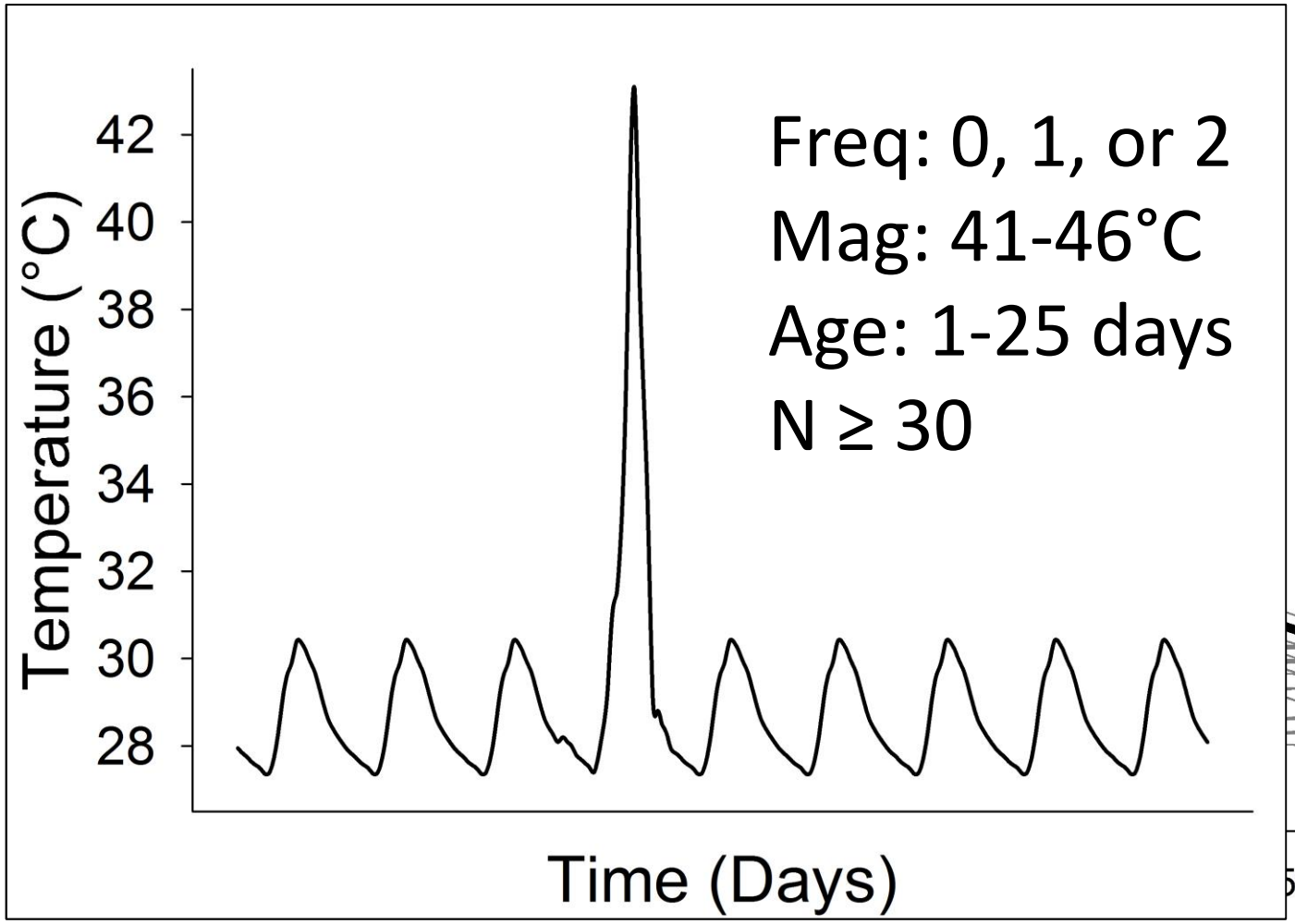

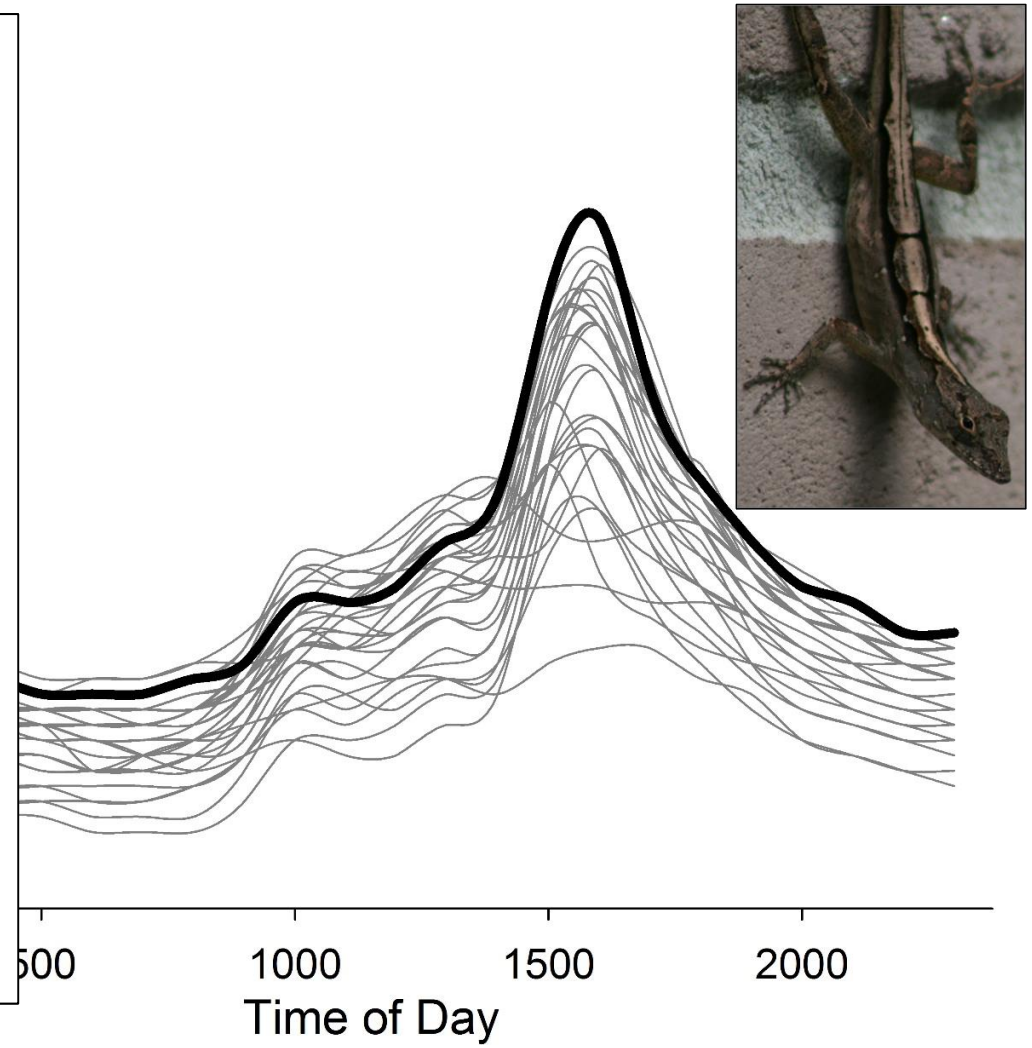

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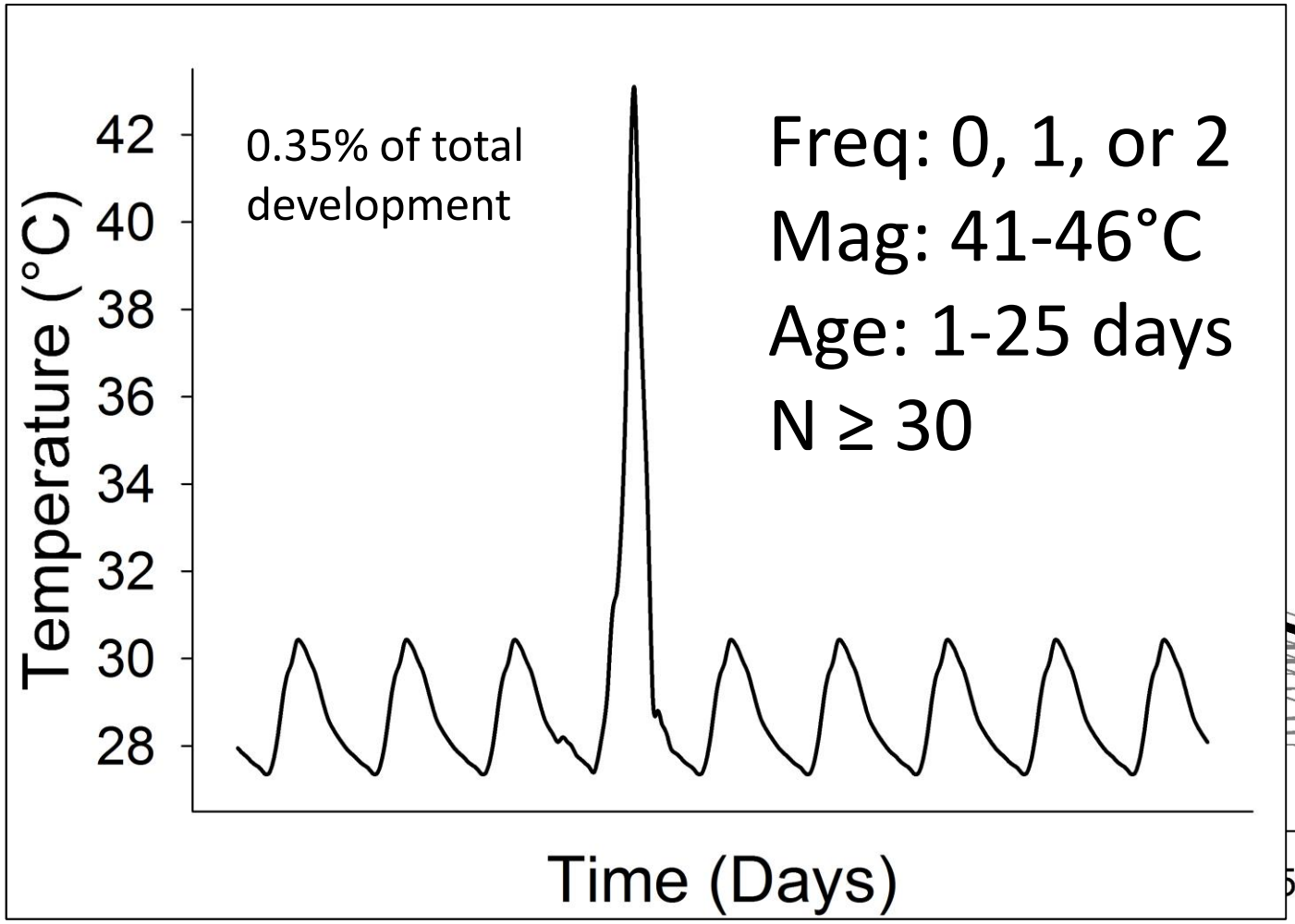

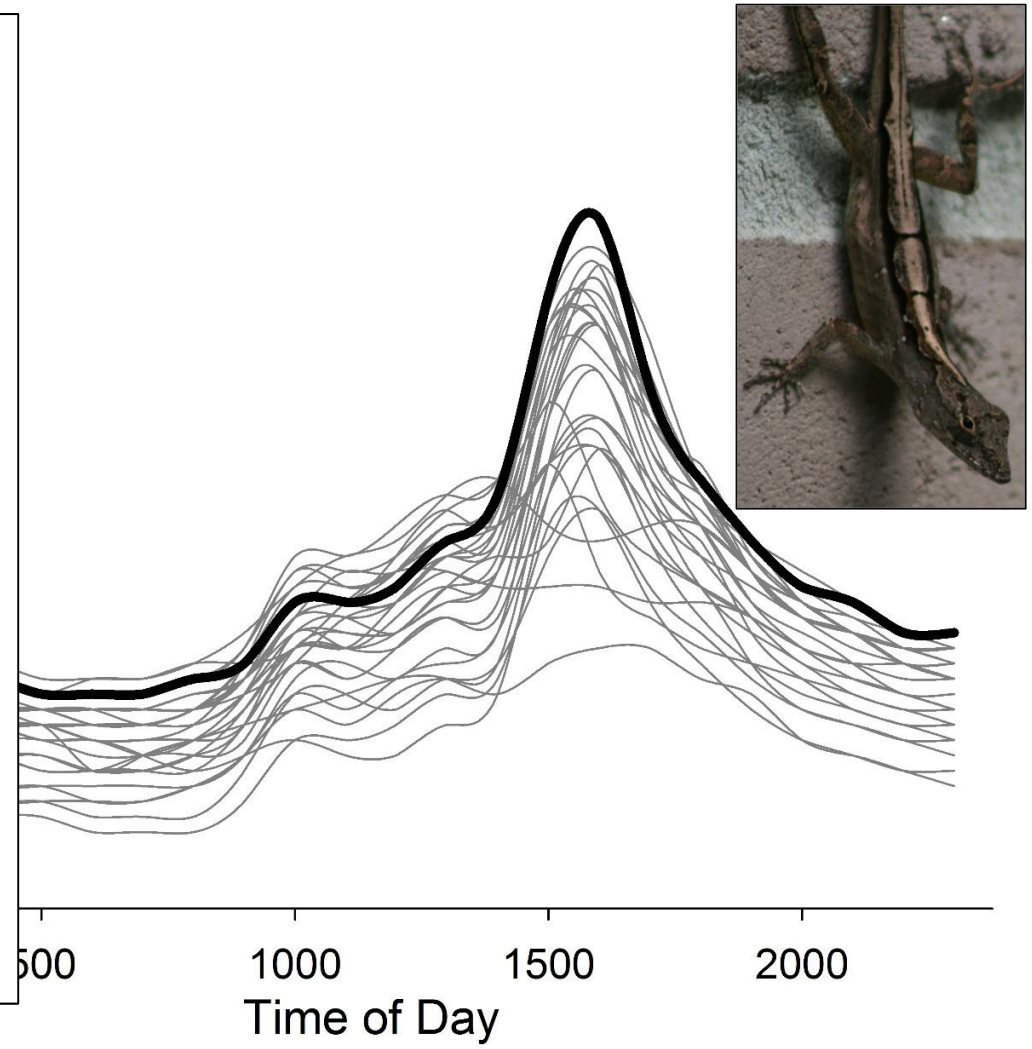

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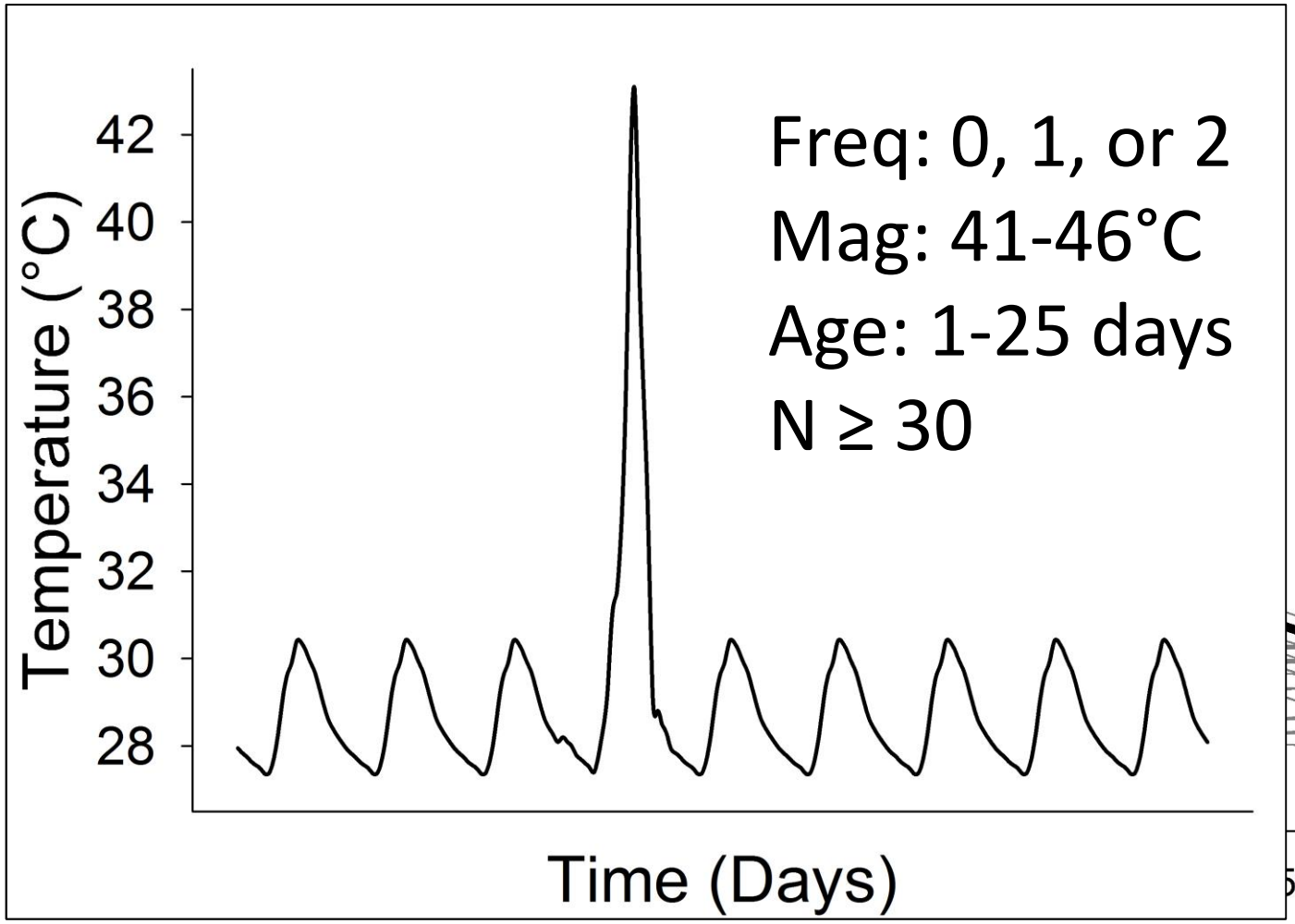

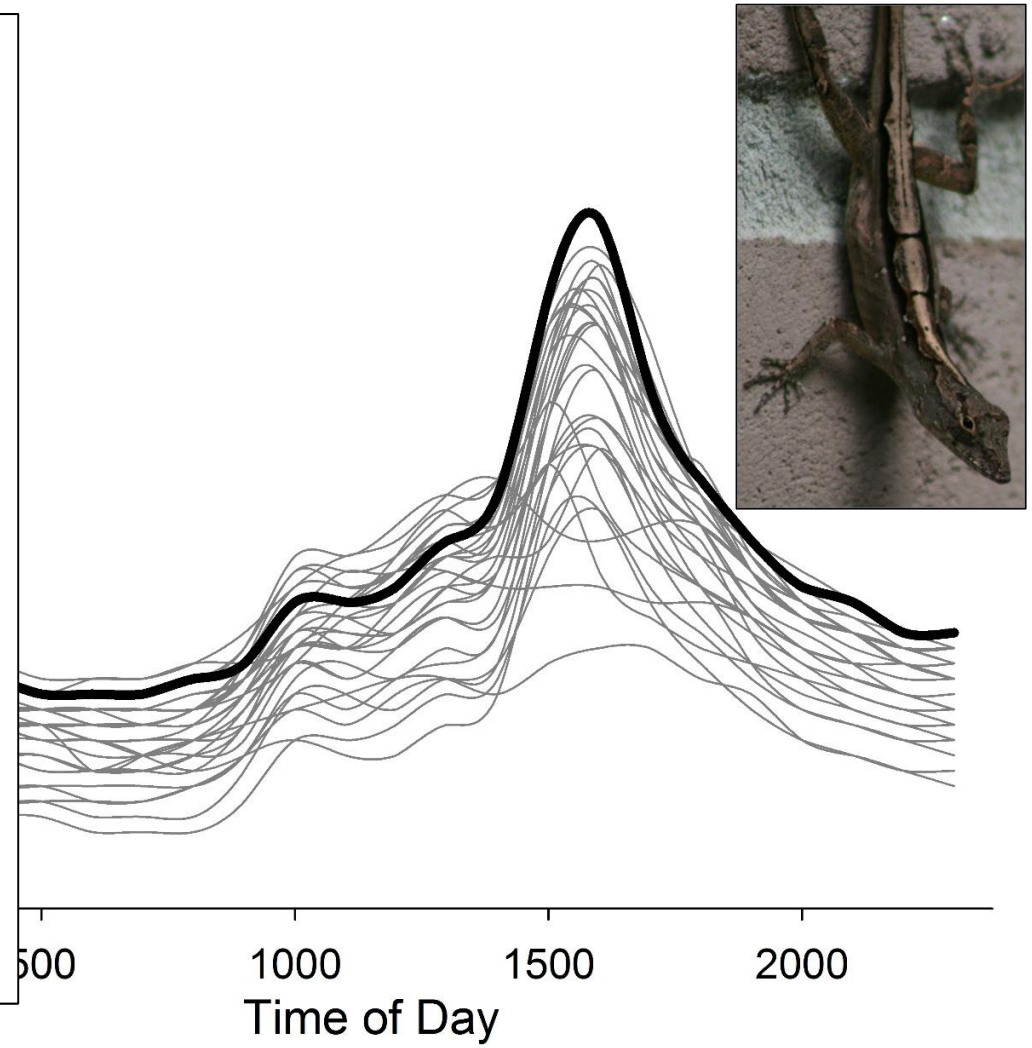

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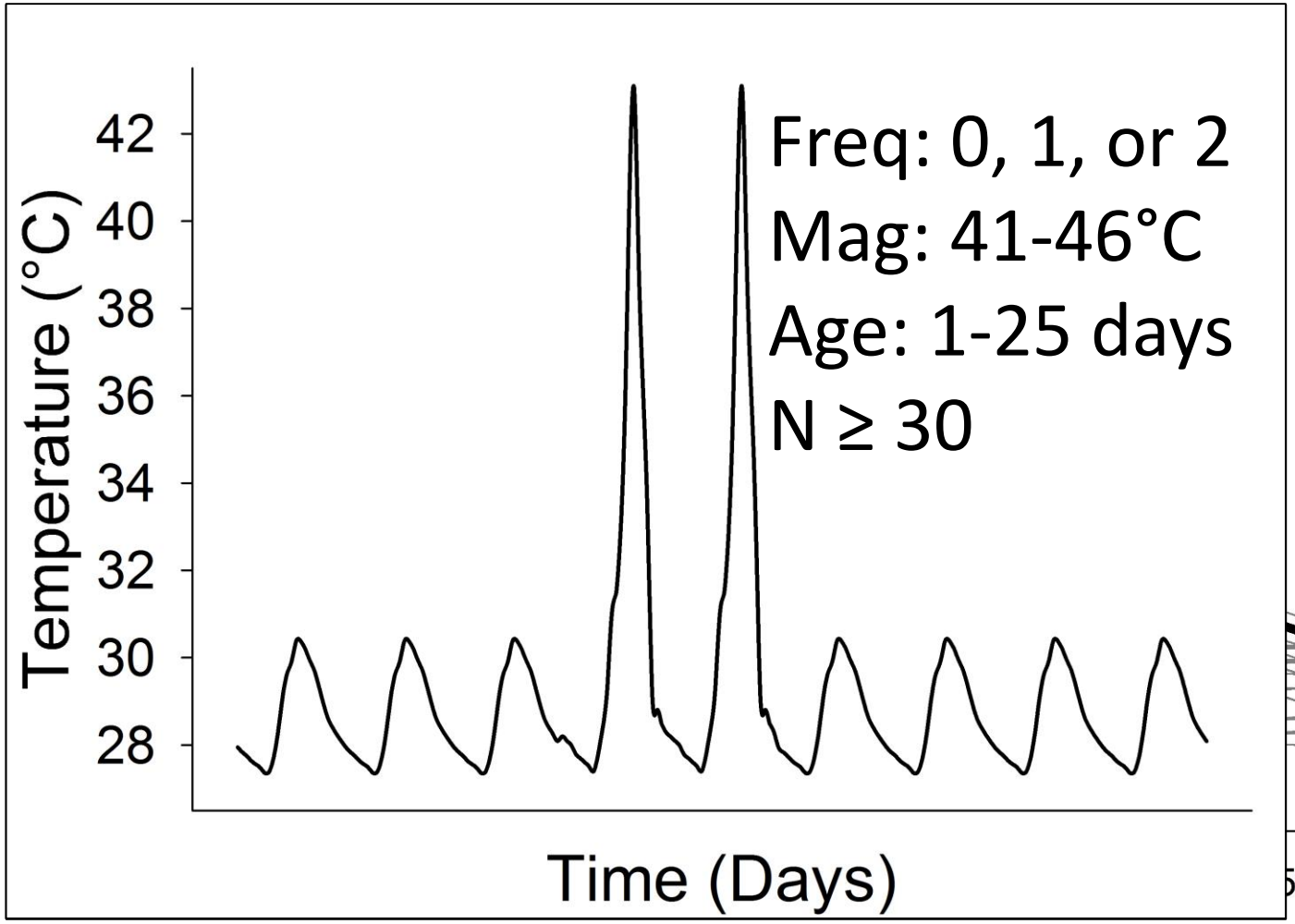

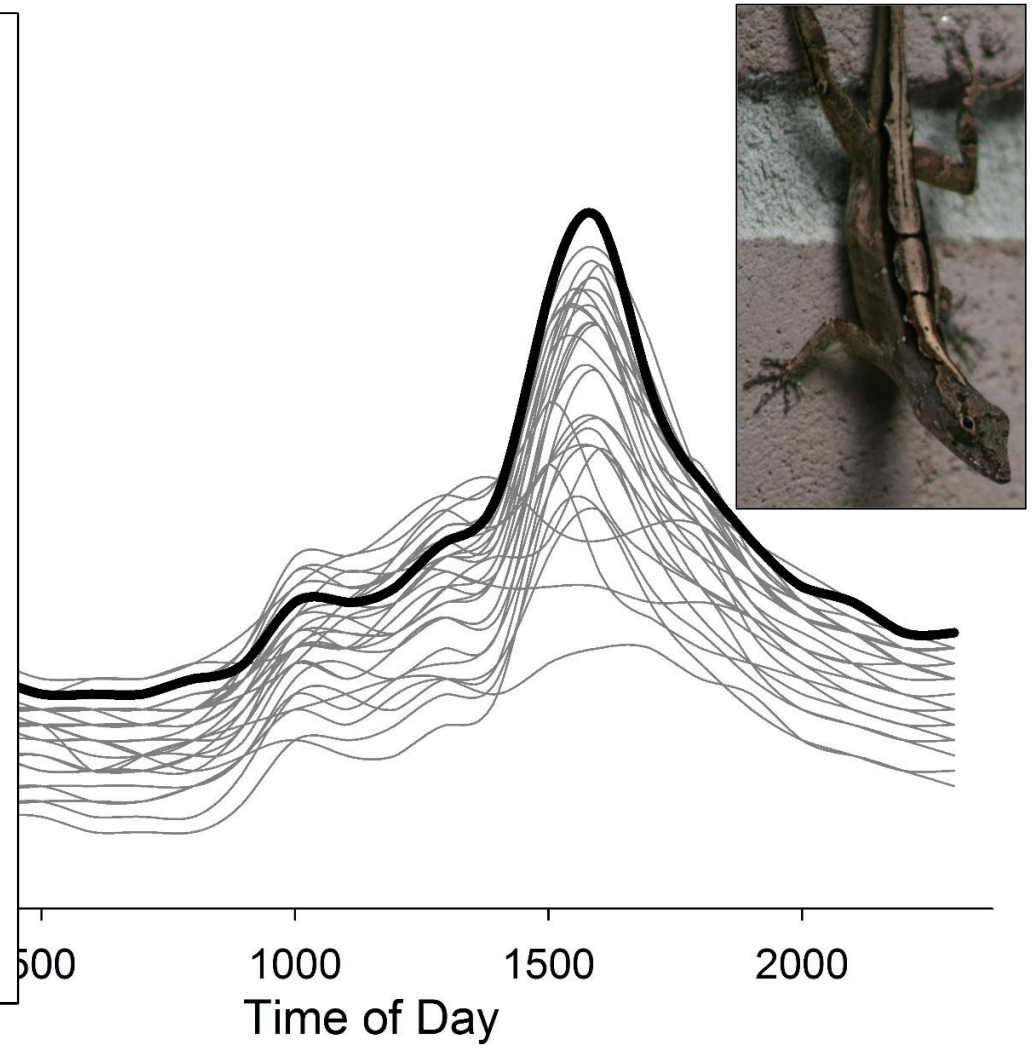

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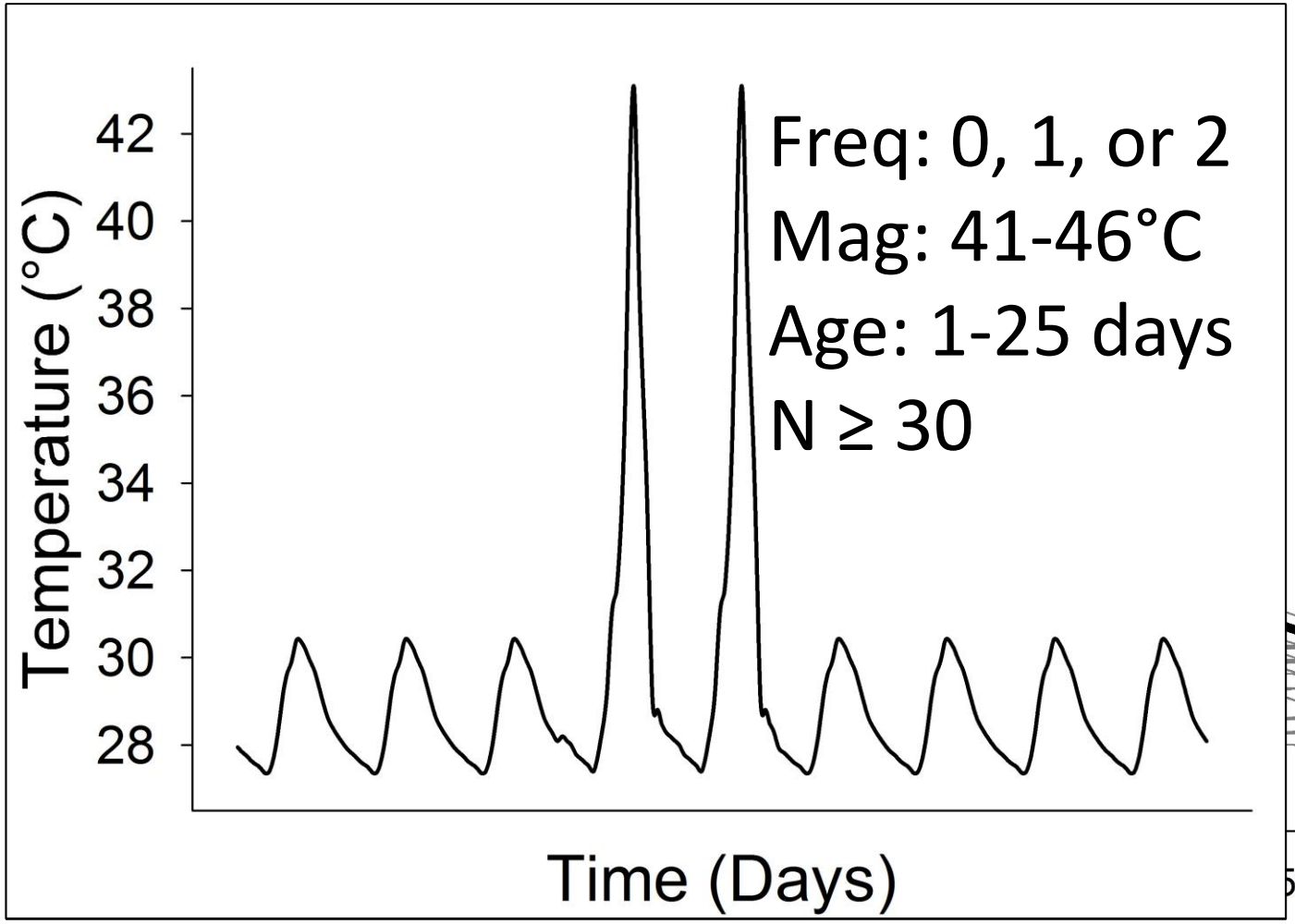

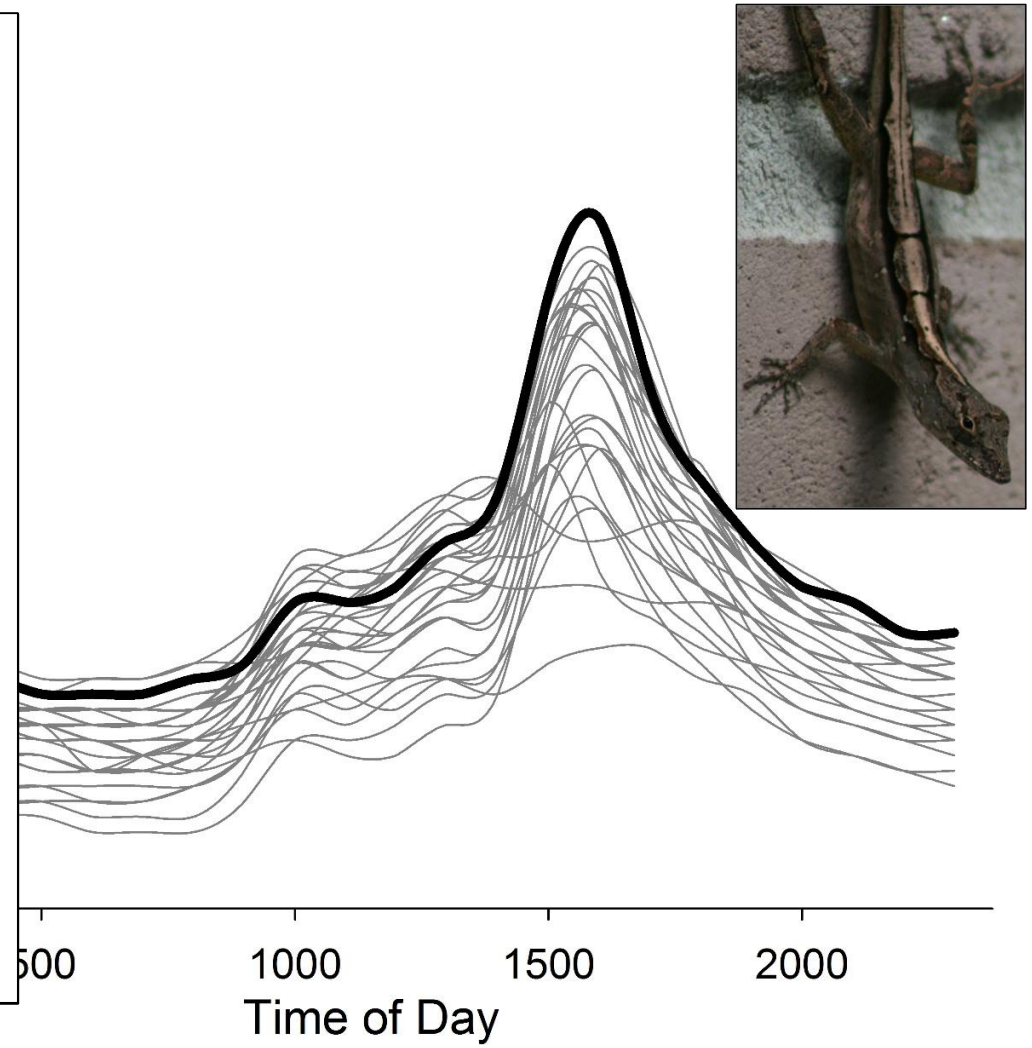

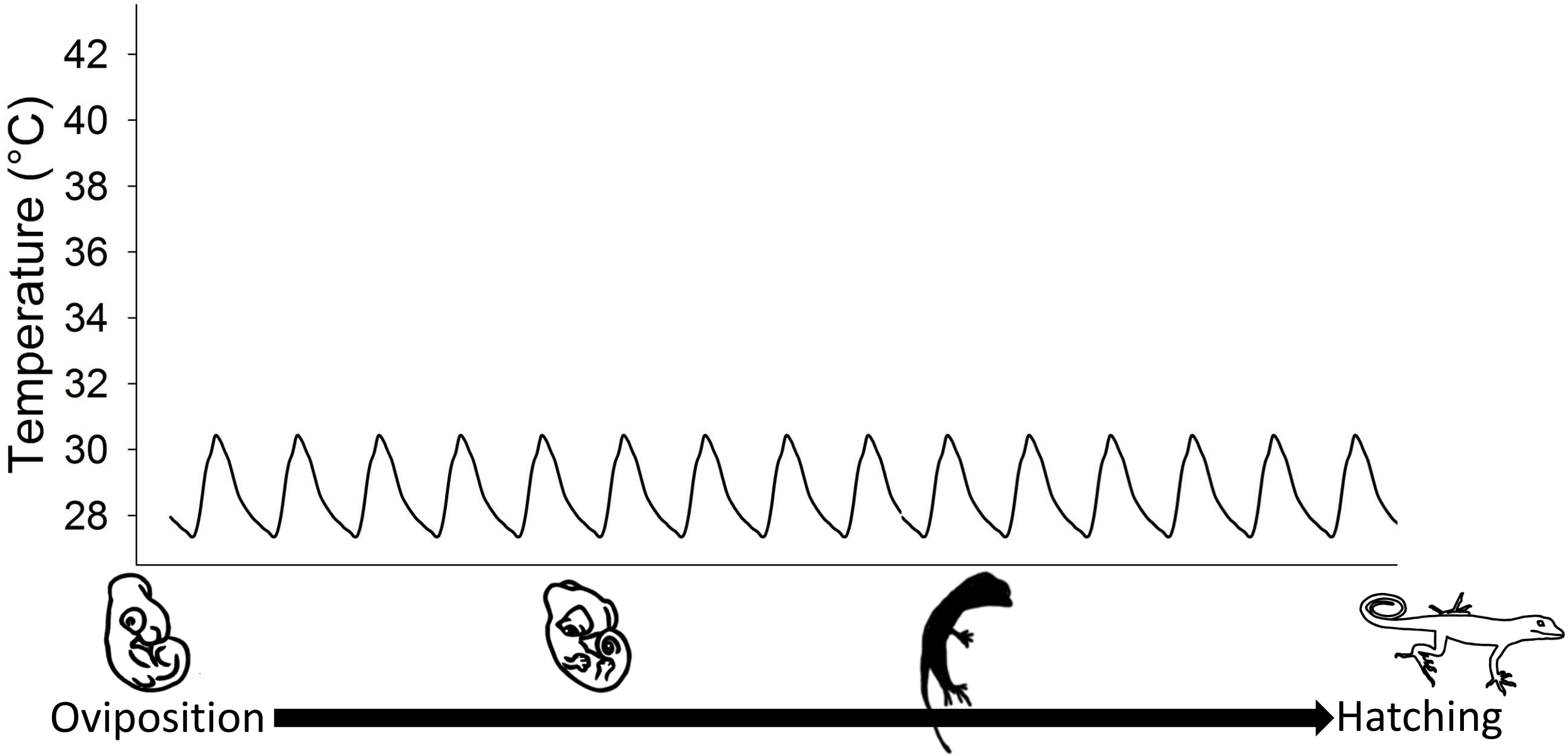
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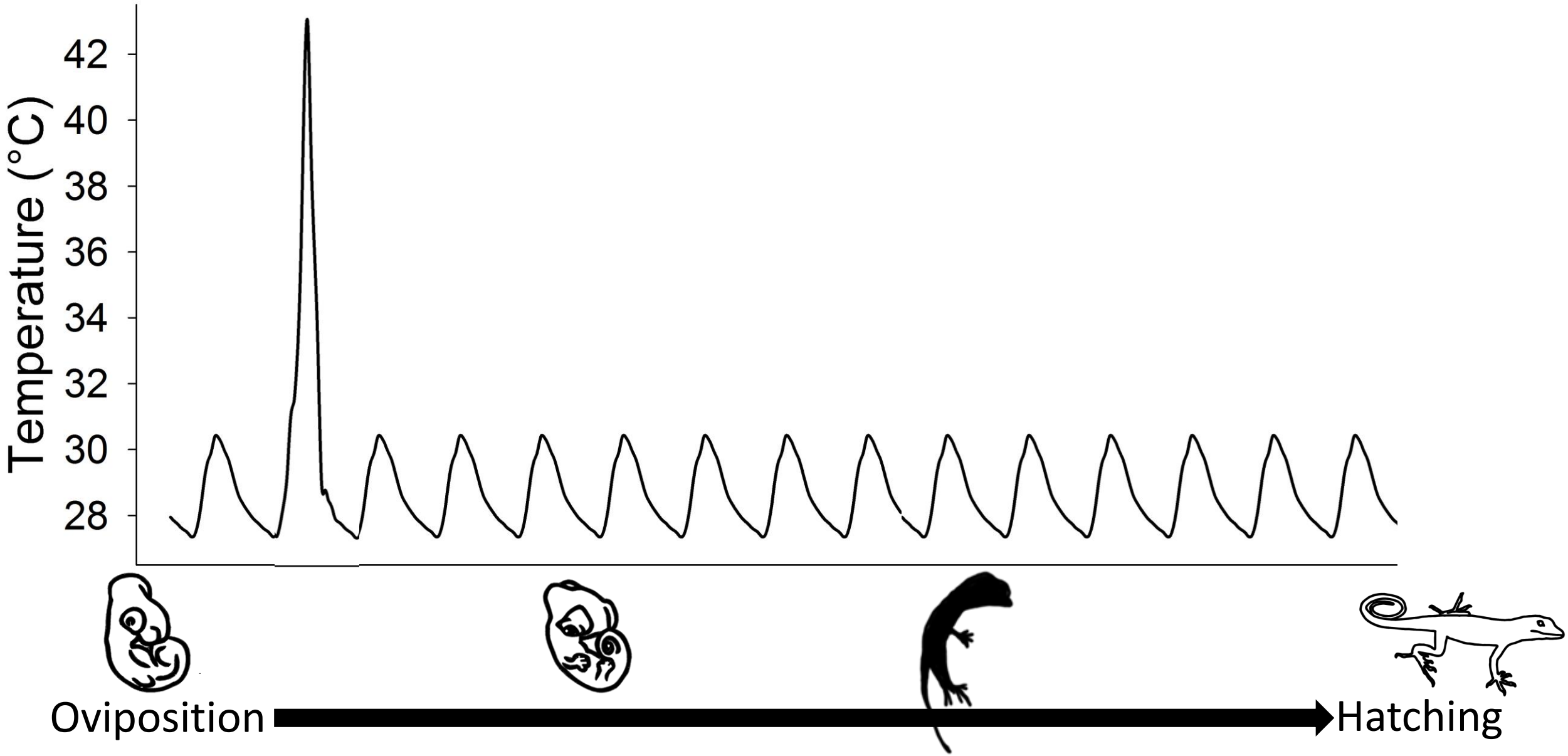
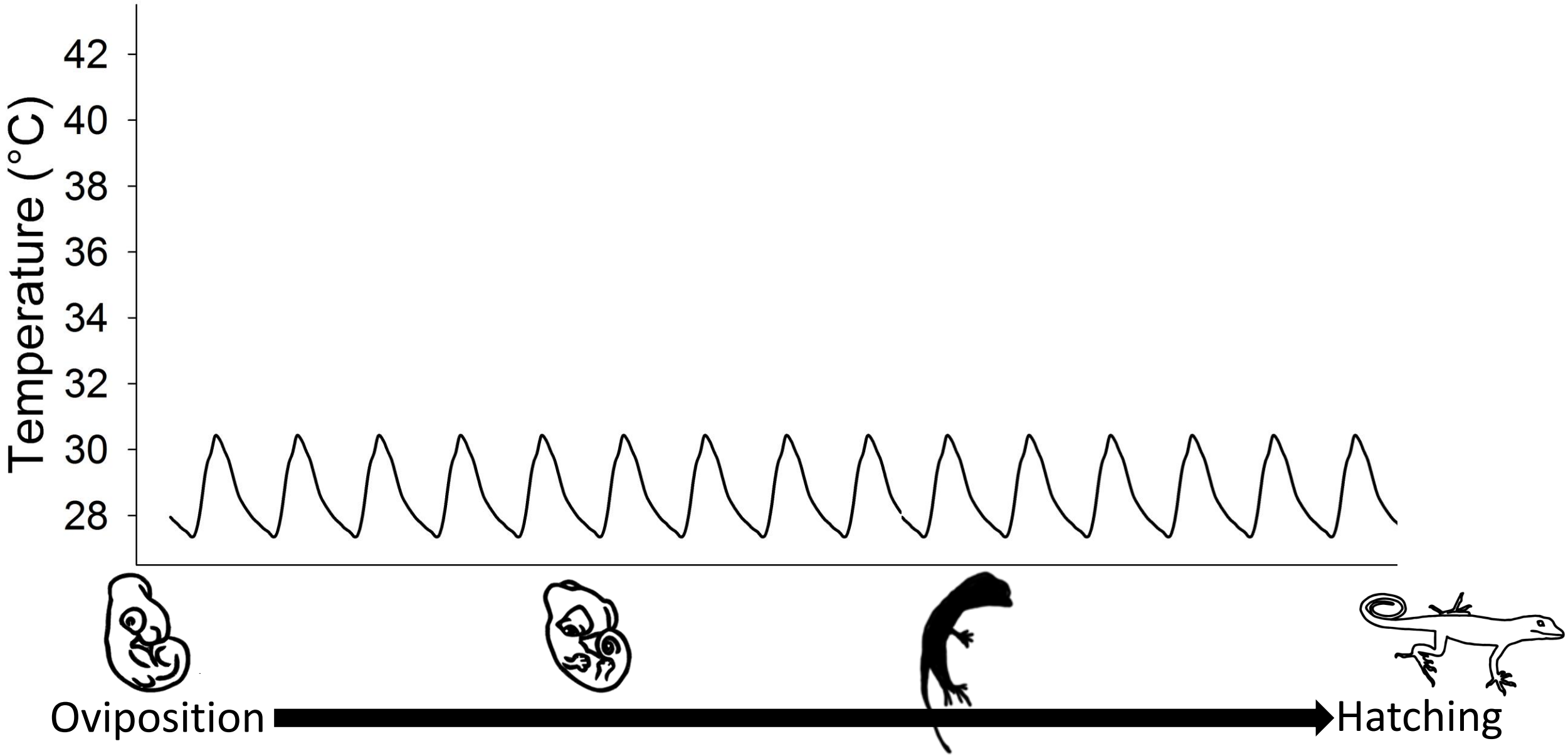
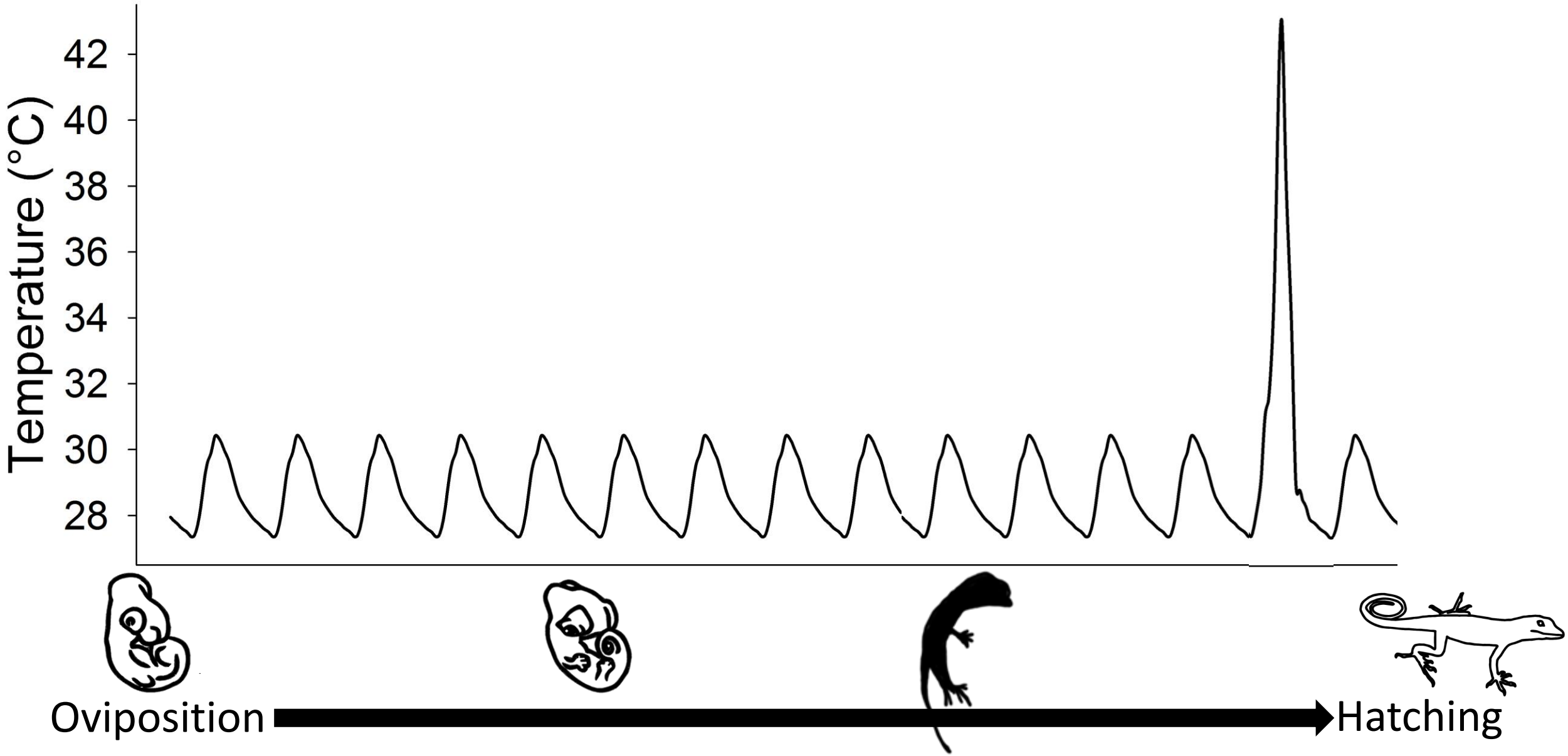
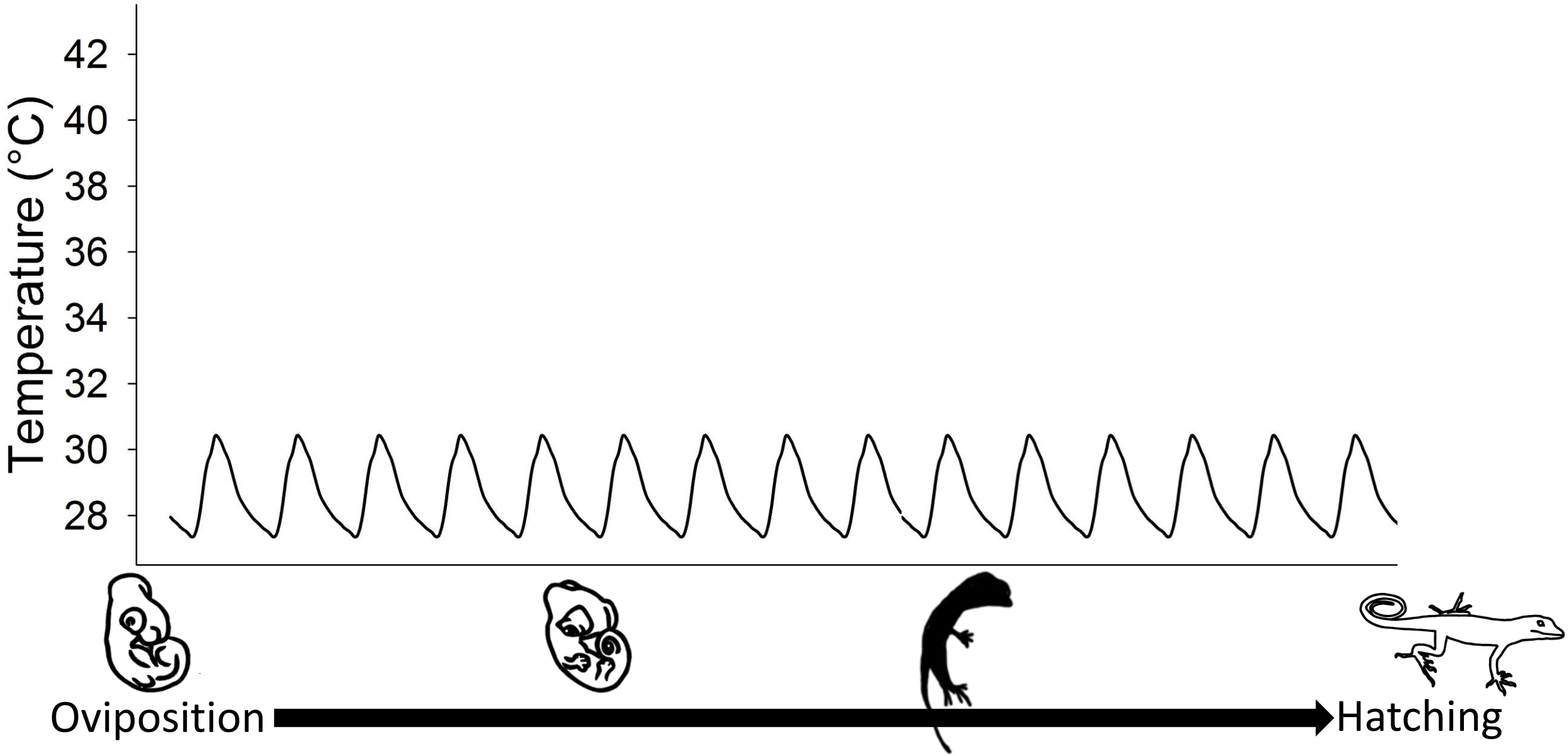
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
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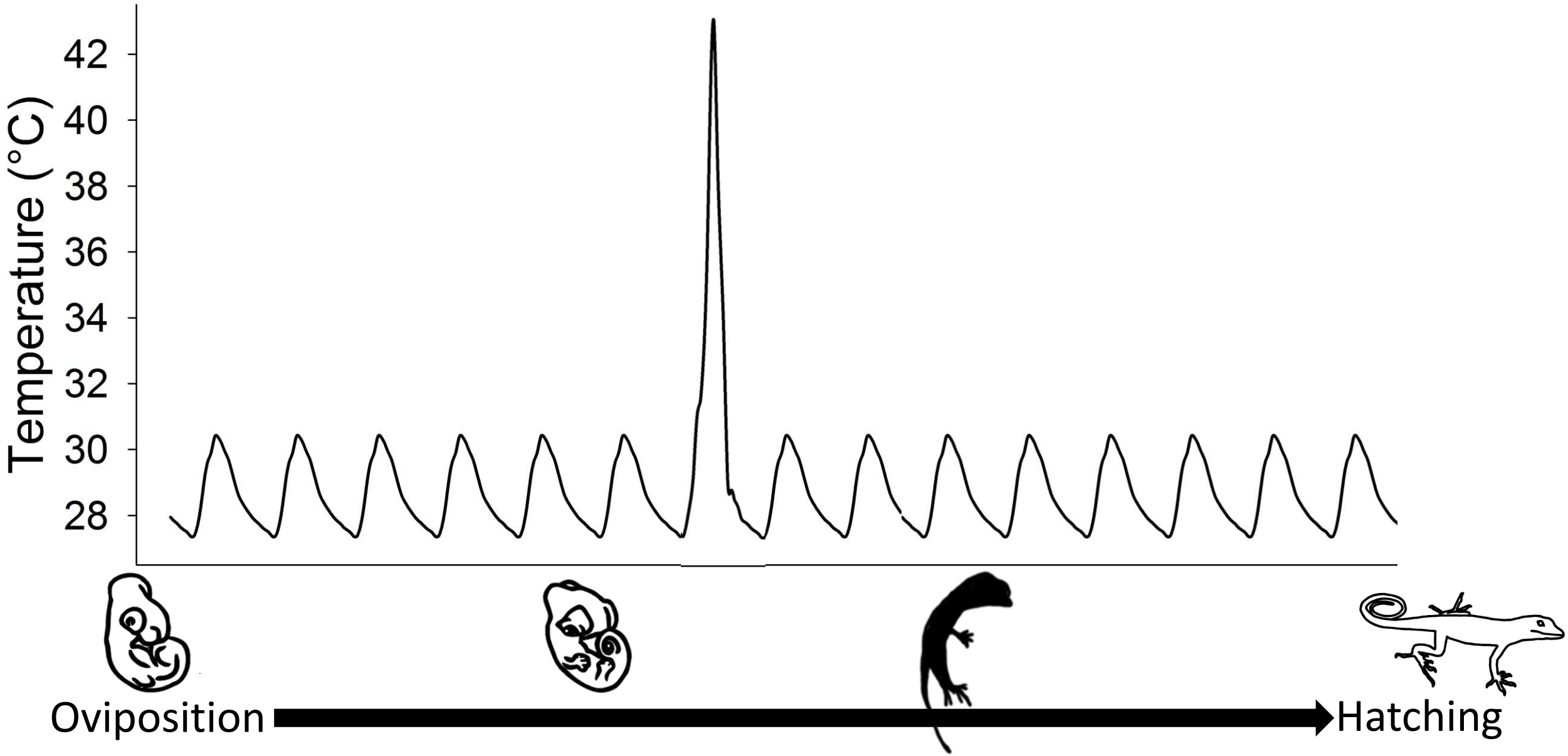
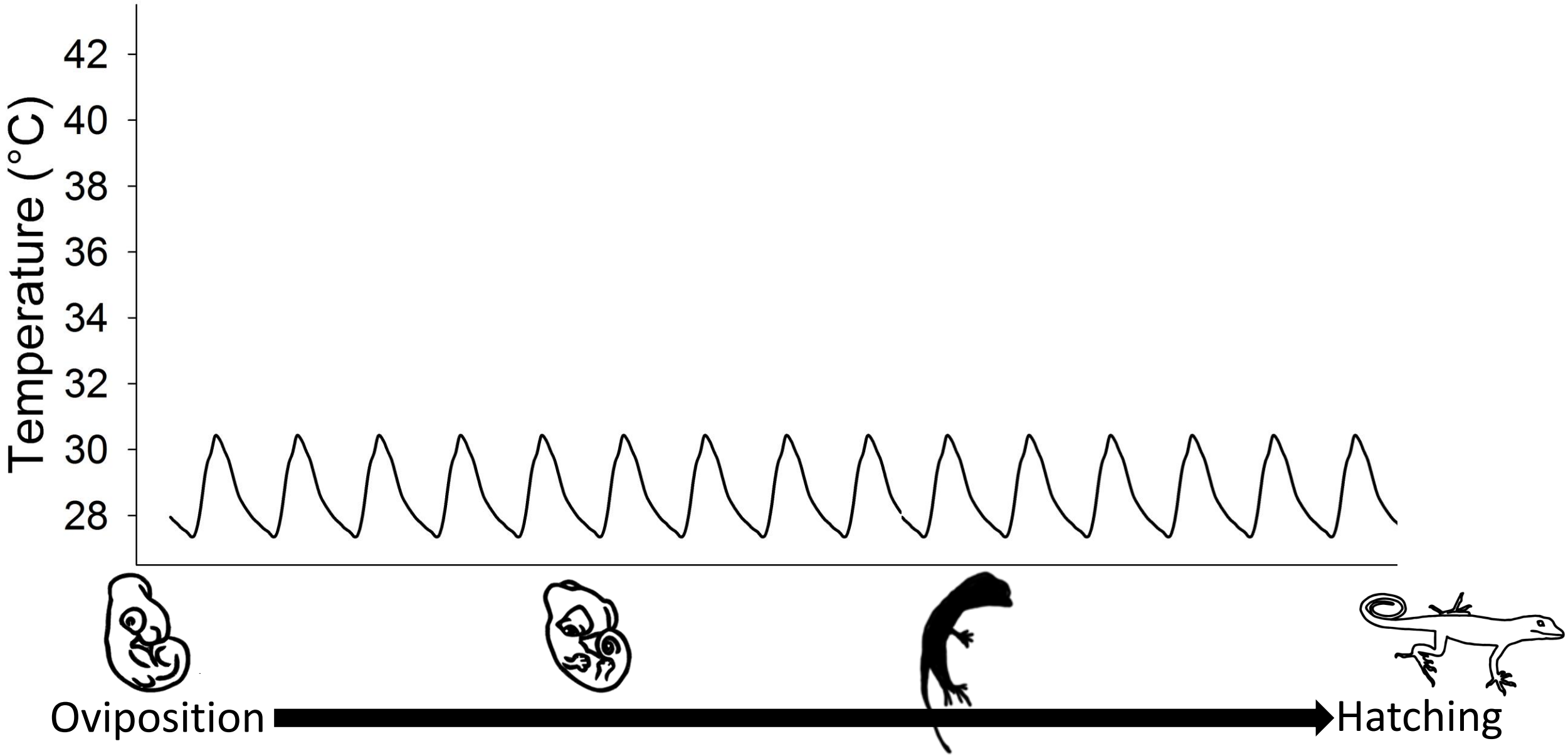
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
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34
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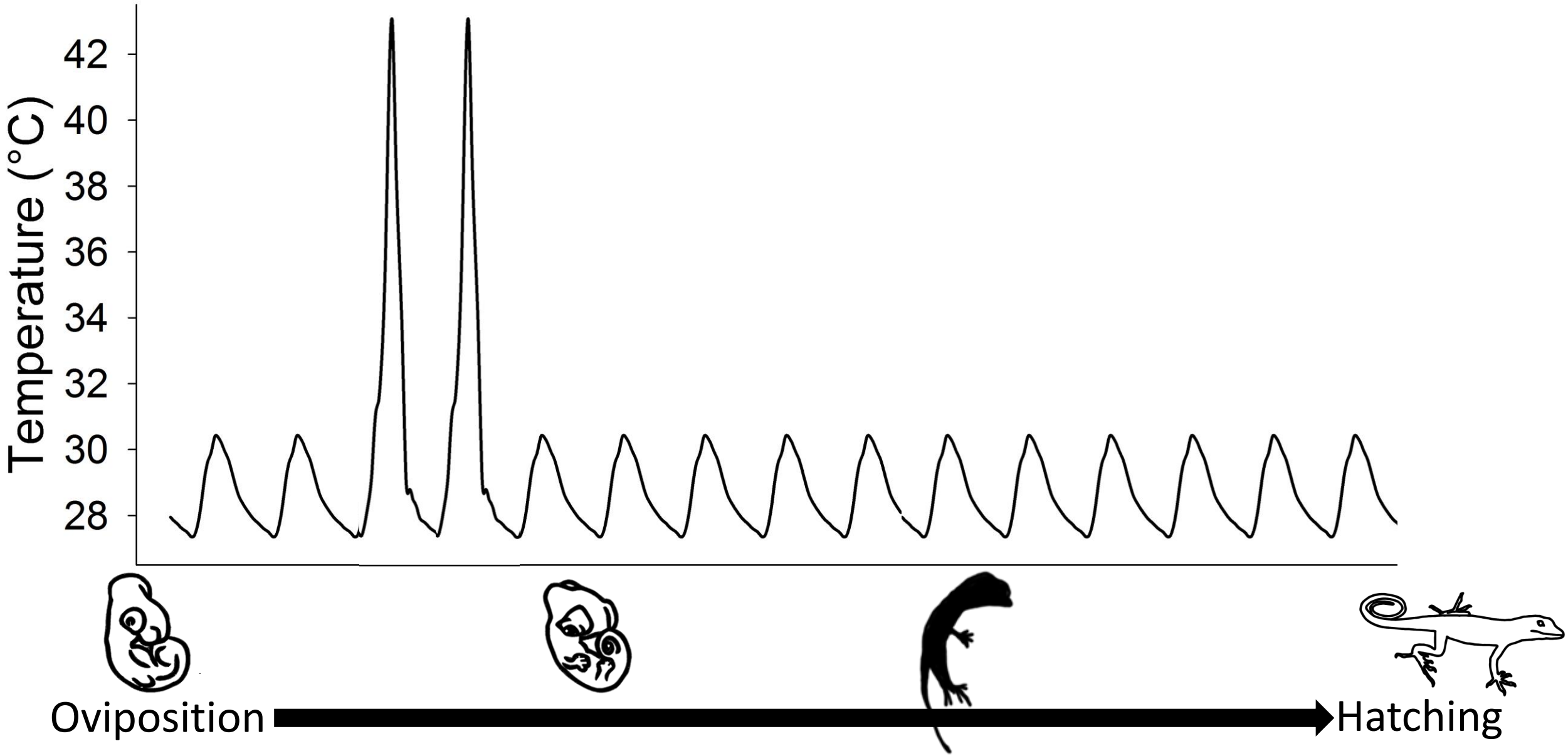
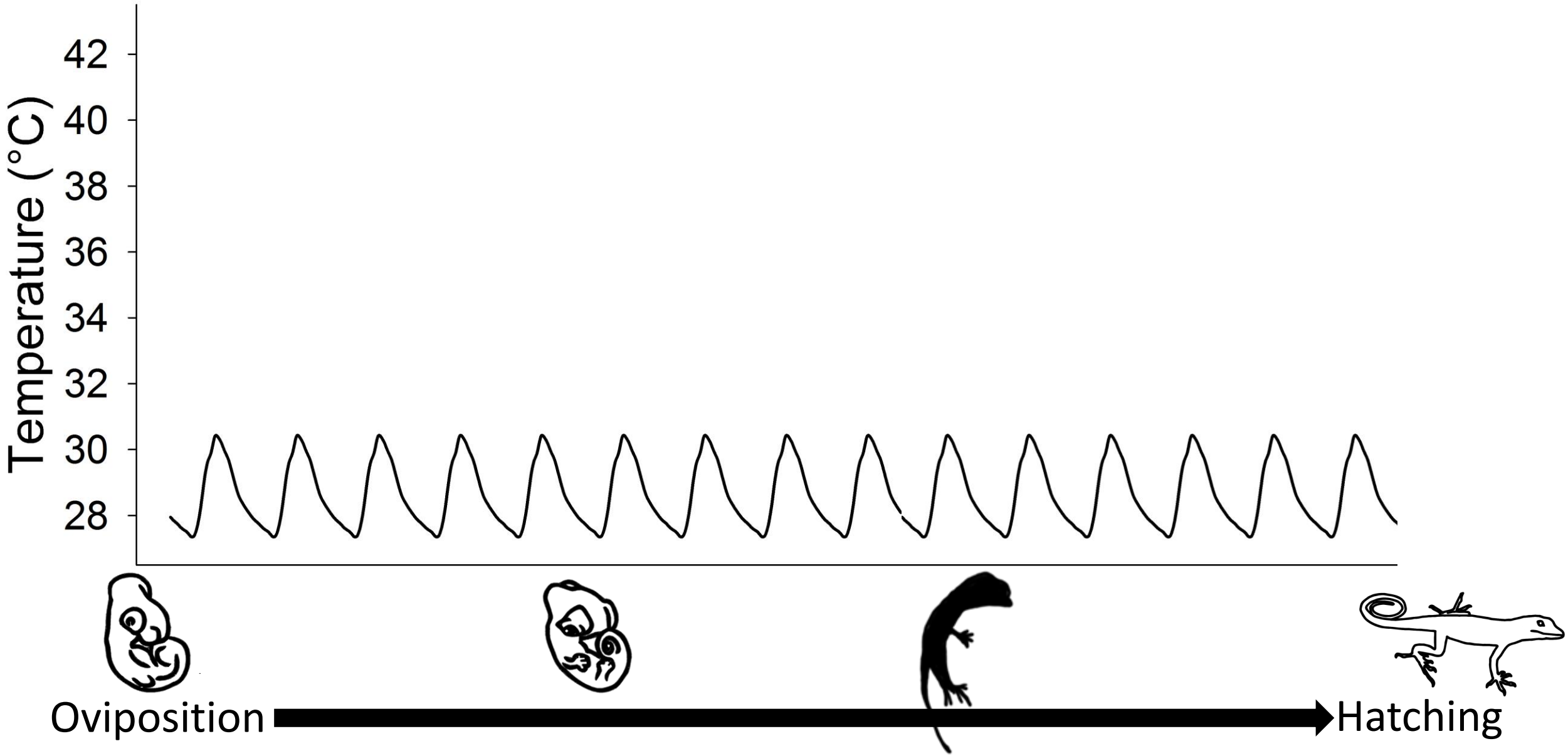
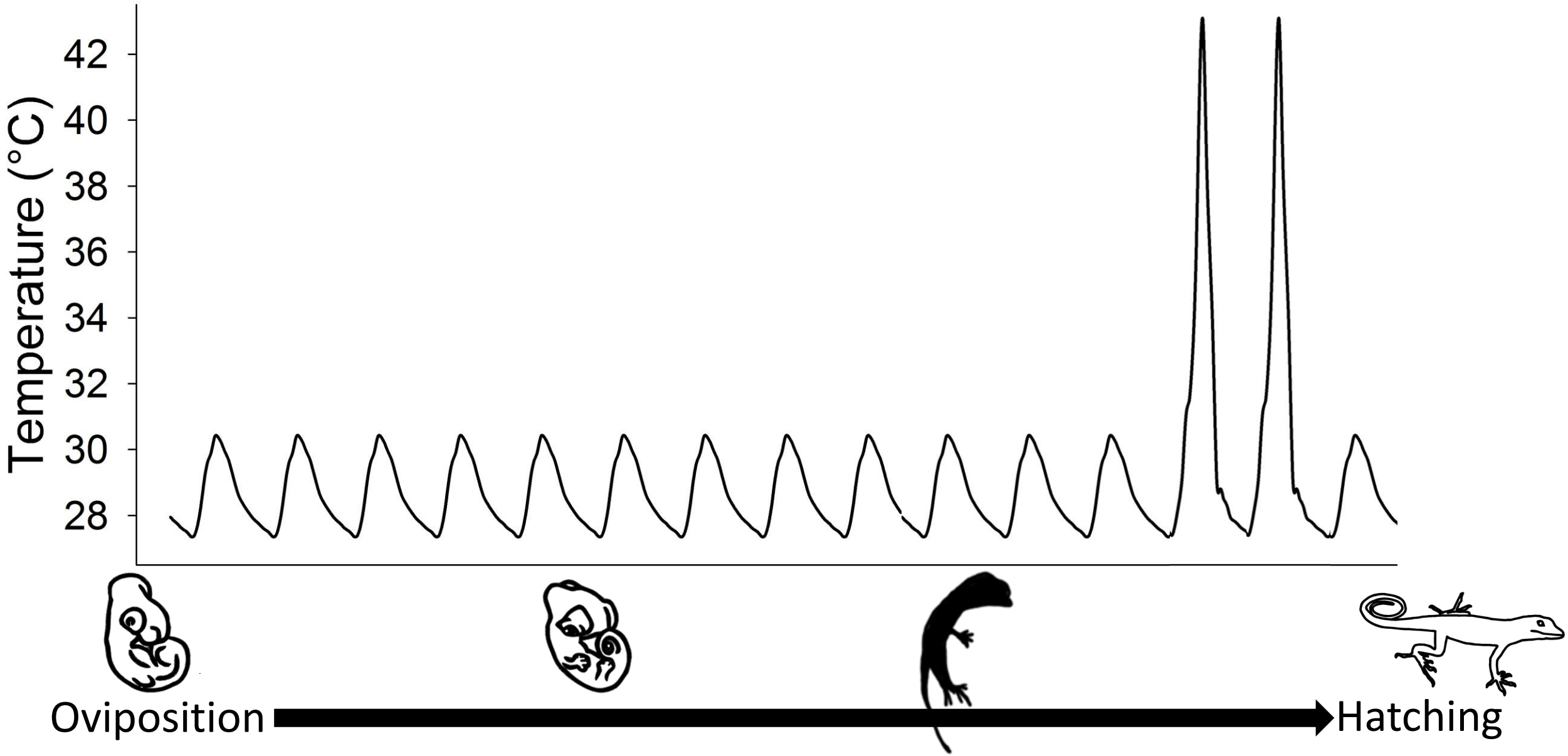
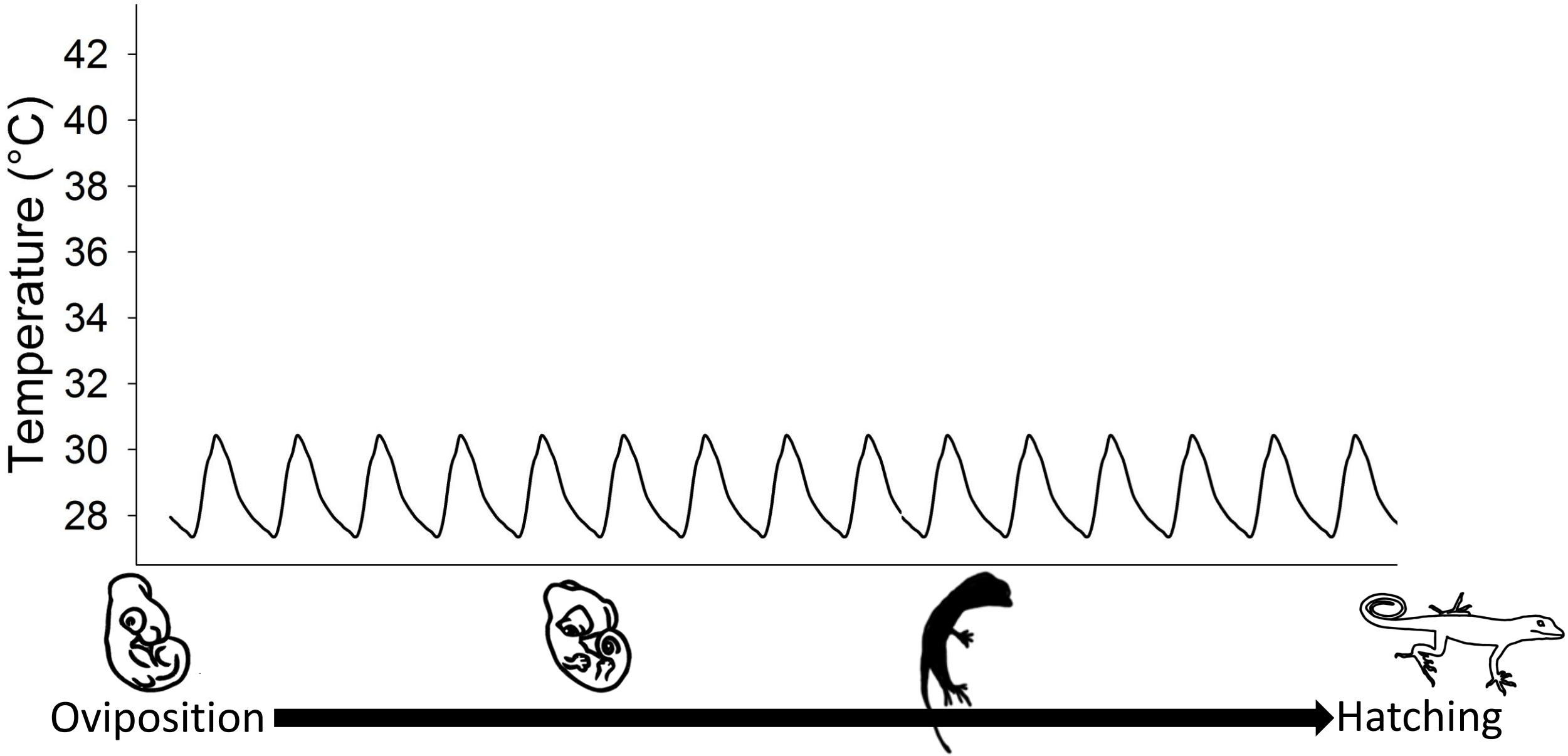
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching


Temperature (°C)
42
40
38
36
34
32
30
28
Oviposition
Hatching

Embryo Survival

- Survival ~

Embryo Survival

- Survival ~ Mag + Freq + Age

Embryo Survival

- Survival ~ Mag + Freq + Age + Interactions

Embryo Survival

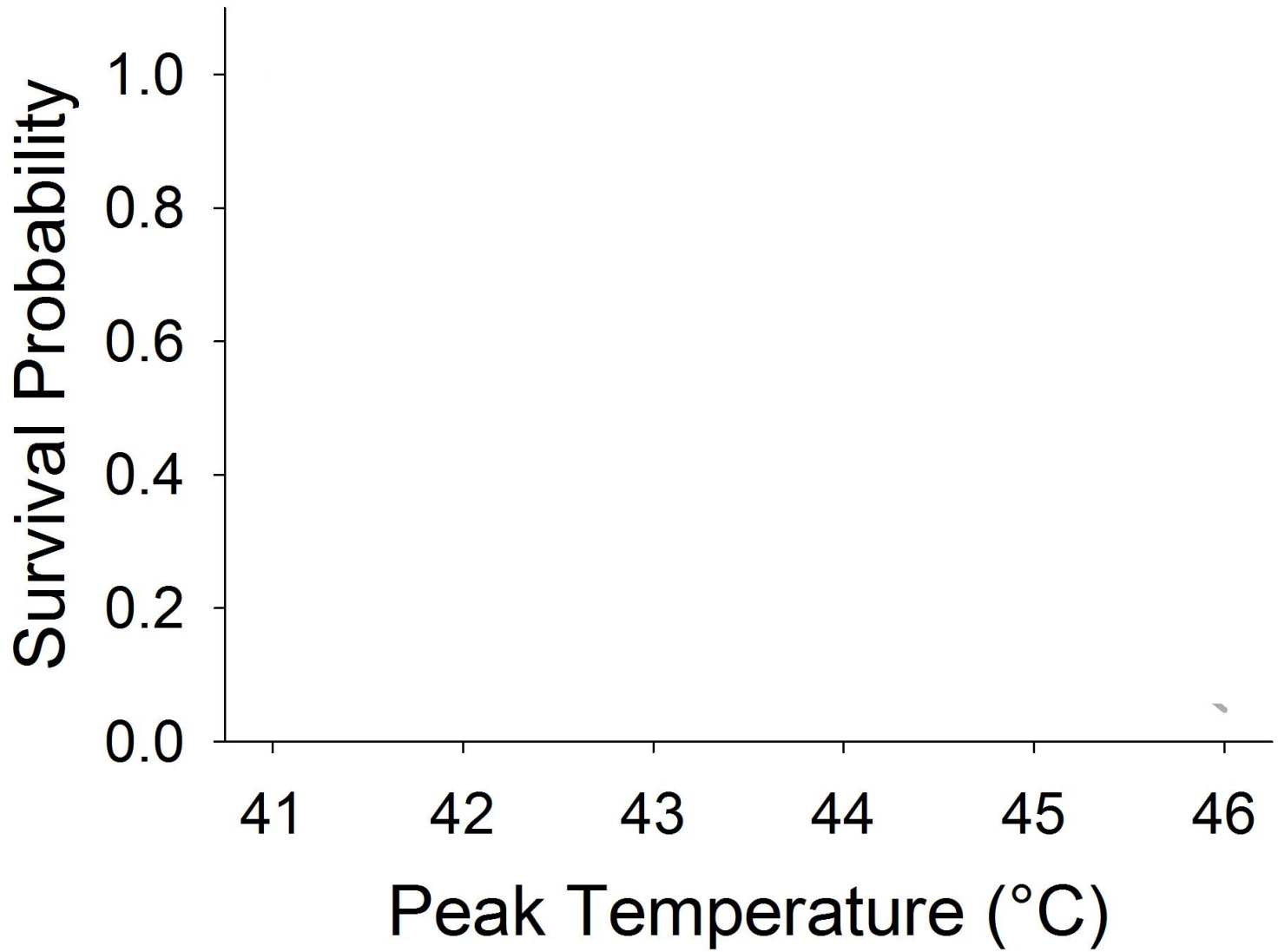
- Survival ~ Mag + Freq + Age + Interactions

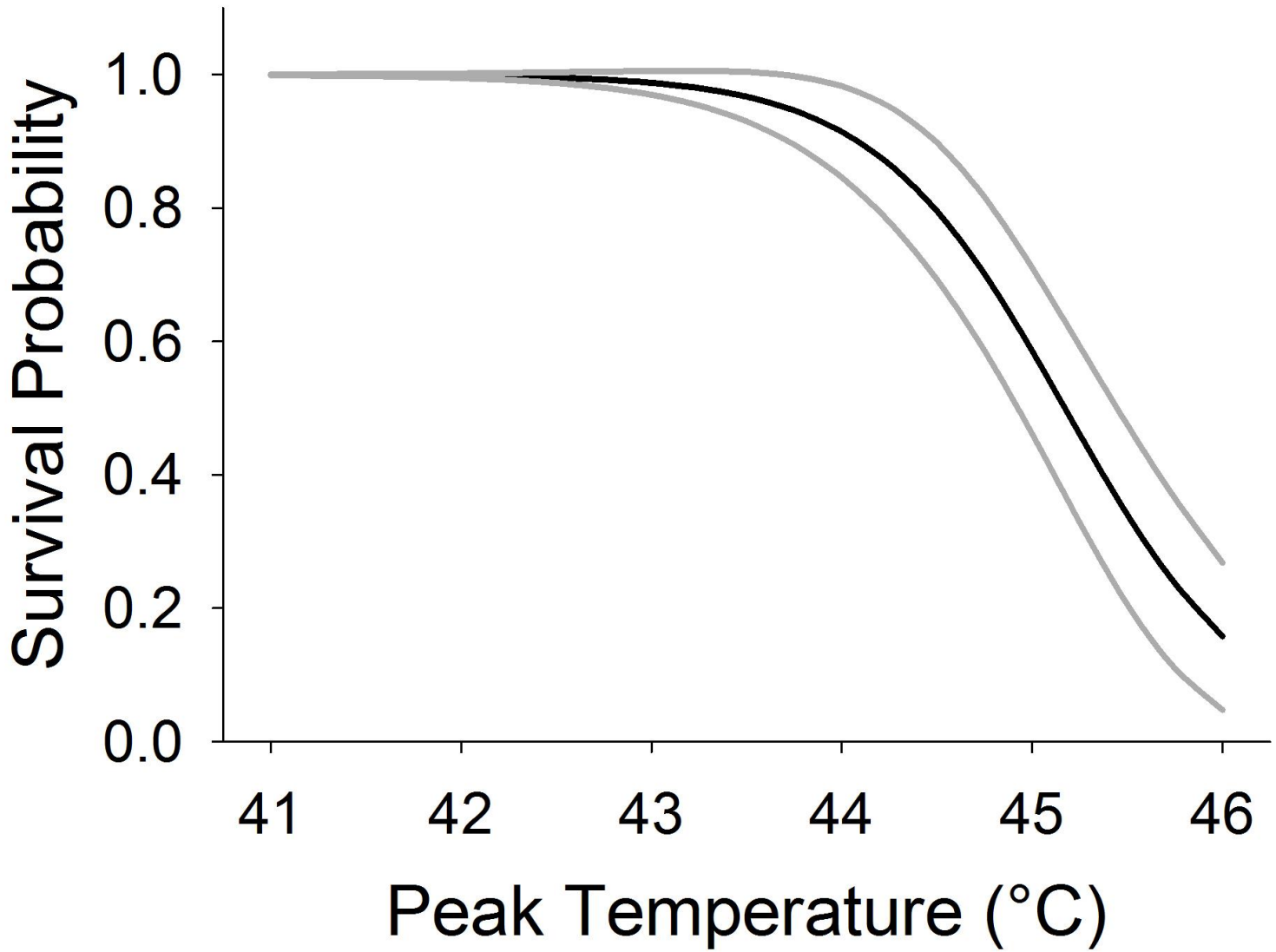
Independent	DF	χ^2	P
Magnitude	**1**	**5.79**	**0.02**
Frequency	1	0.001	0.99
Age	1	0.44	0.51

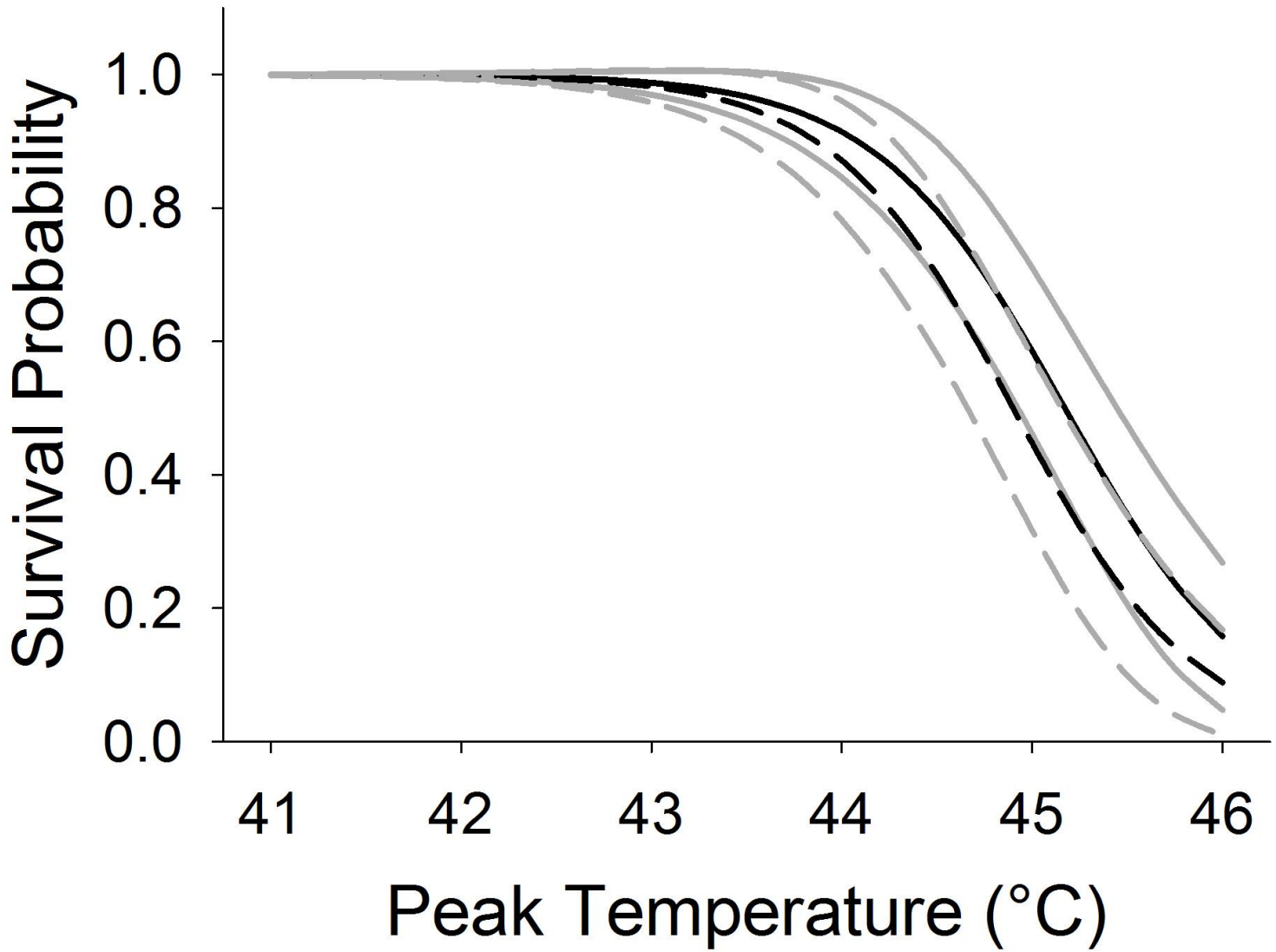
Embryo Survival

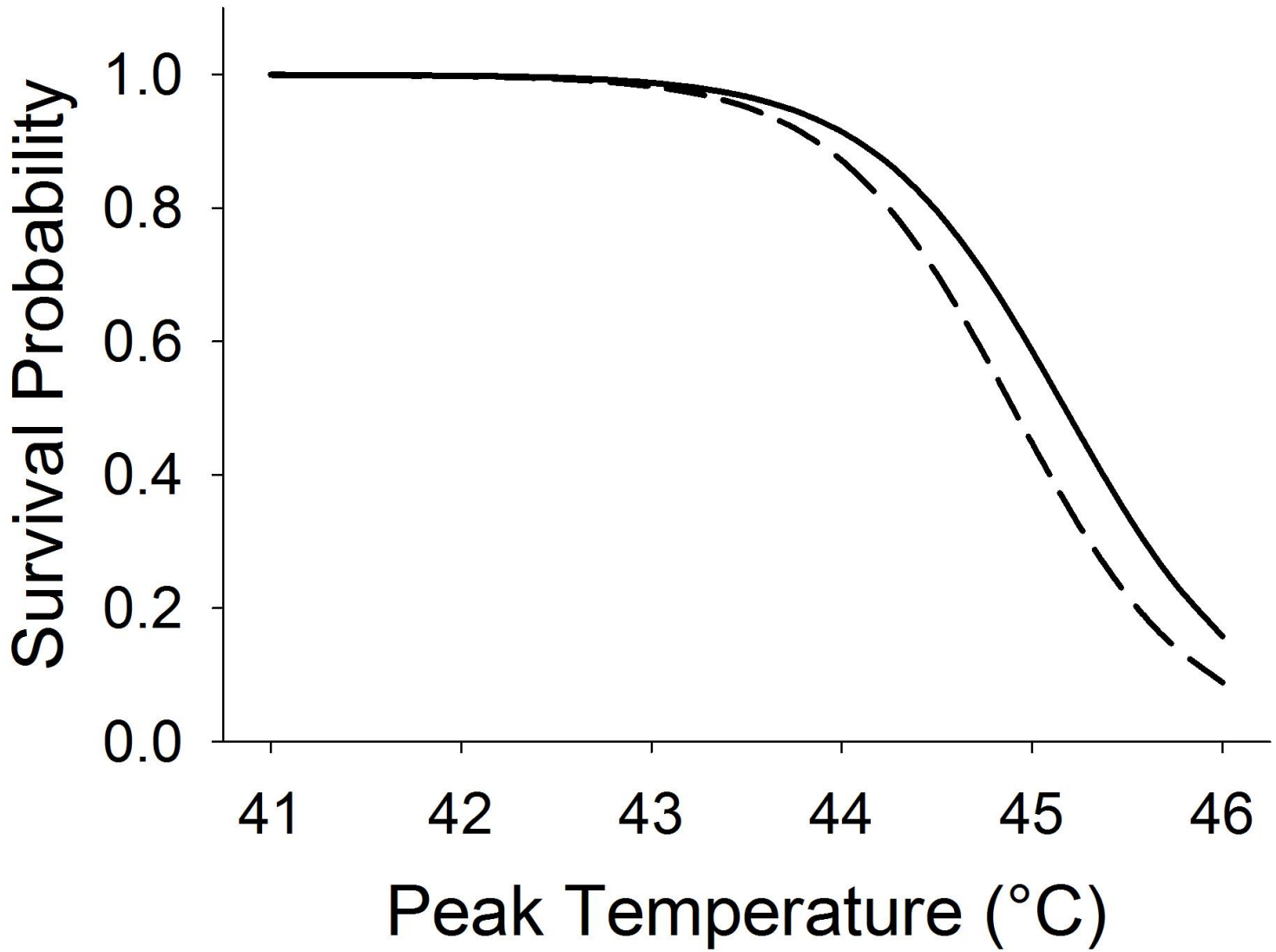
- Survival ~ Mag + Freq + Age + Interactions

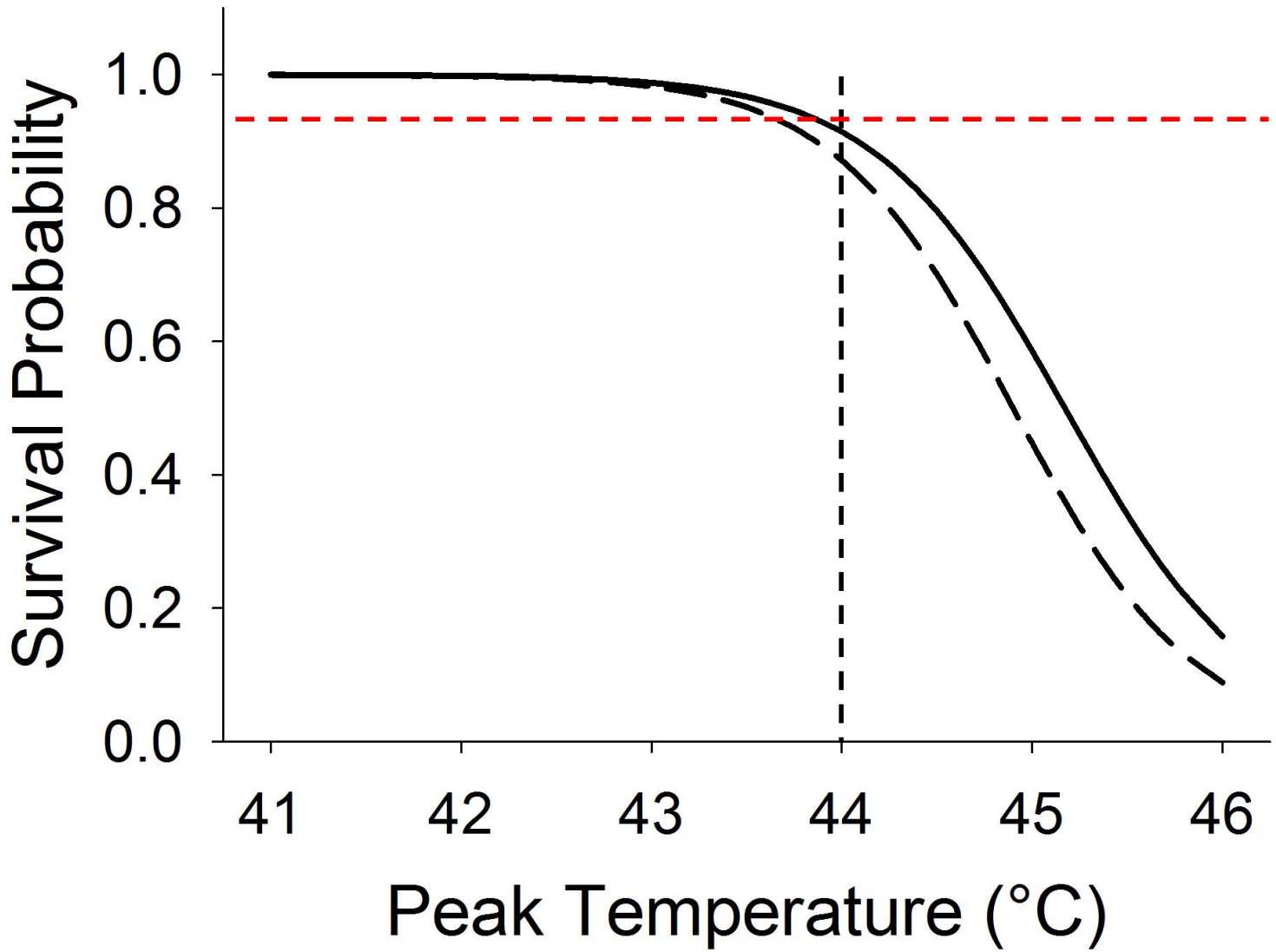
Independent	DF	χ^2	P
Magnitude	**1**	**5.79**	**0.02**
Frequency	1	0.001	0.99
Age	1	0.44	0.51
Mag:Freq	1	0.05	0.82
Mag:Age	1	0.23	0.66
Freq:Age	1	1.35	0.24

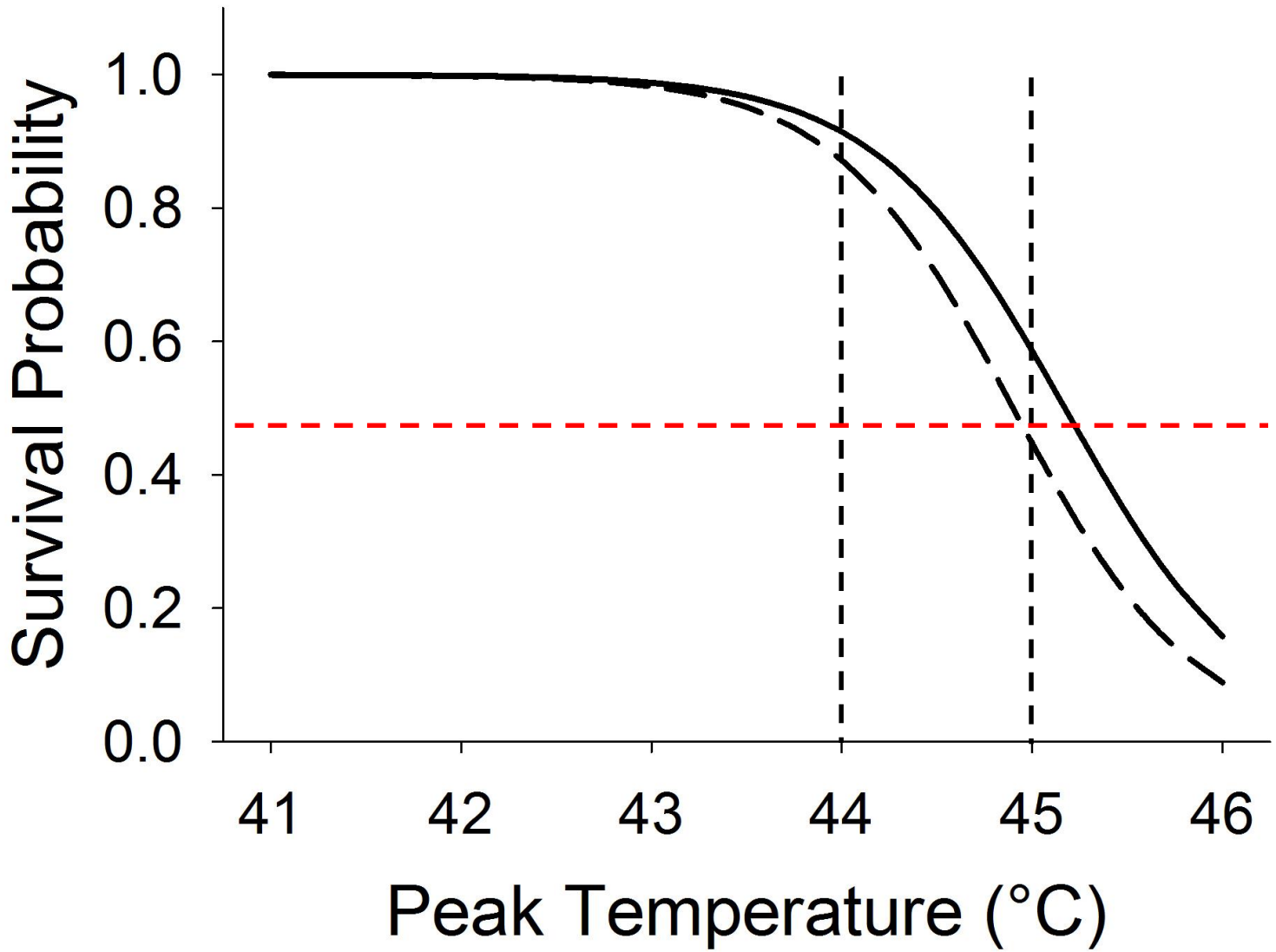

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

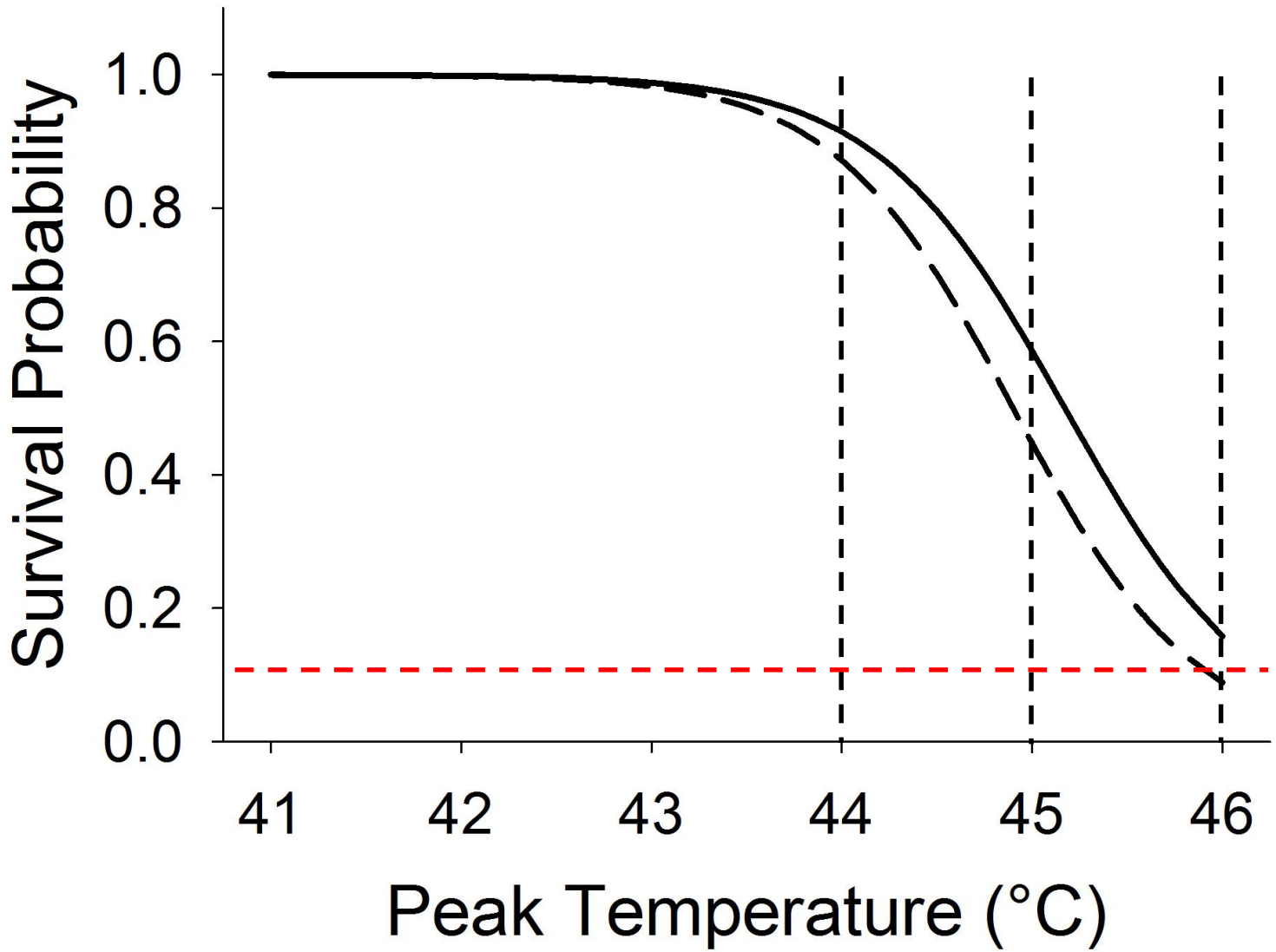

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

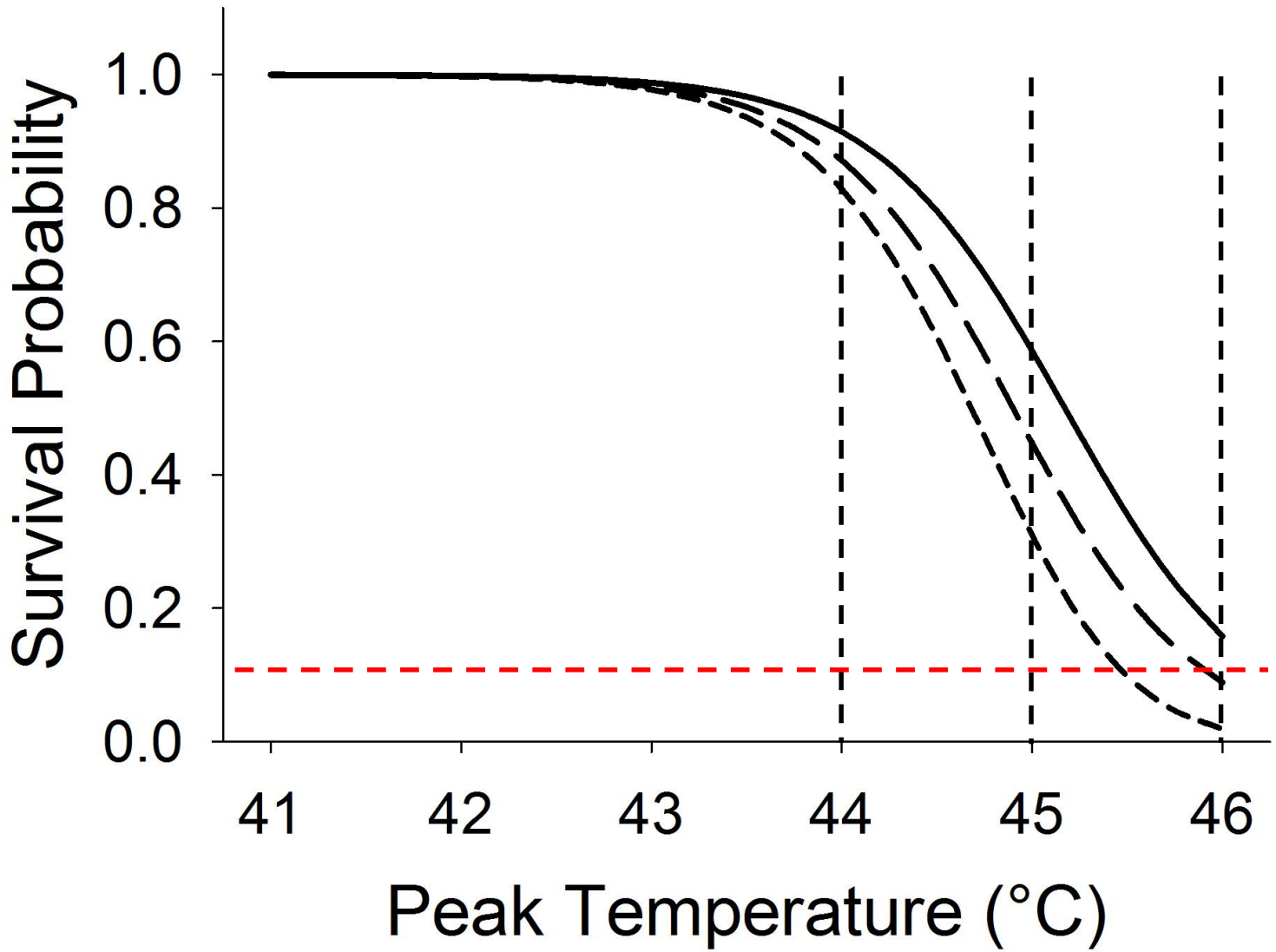

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

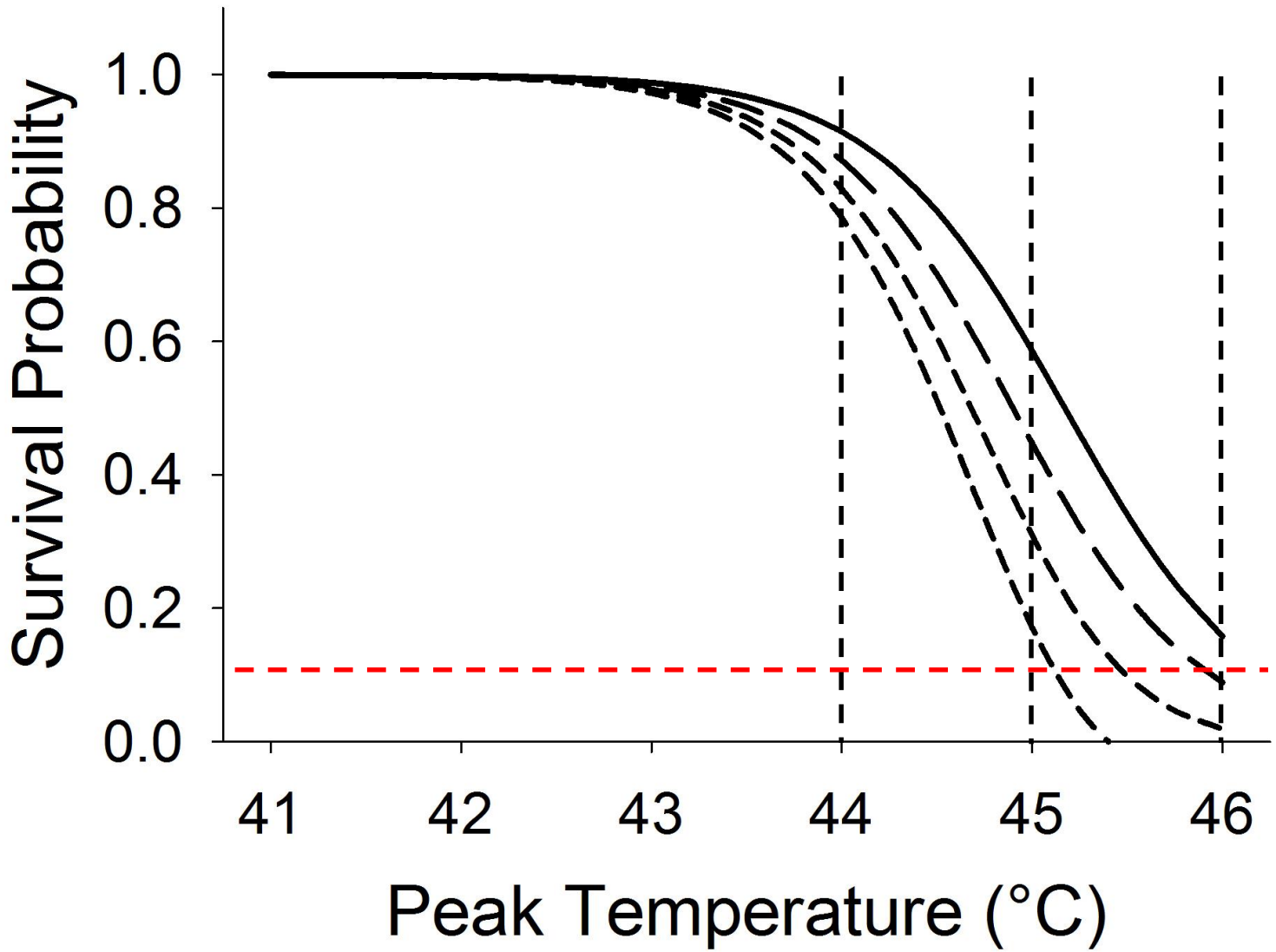

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

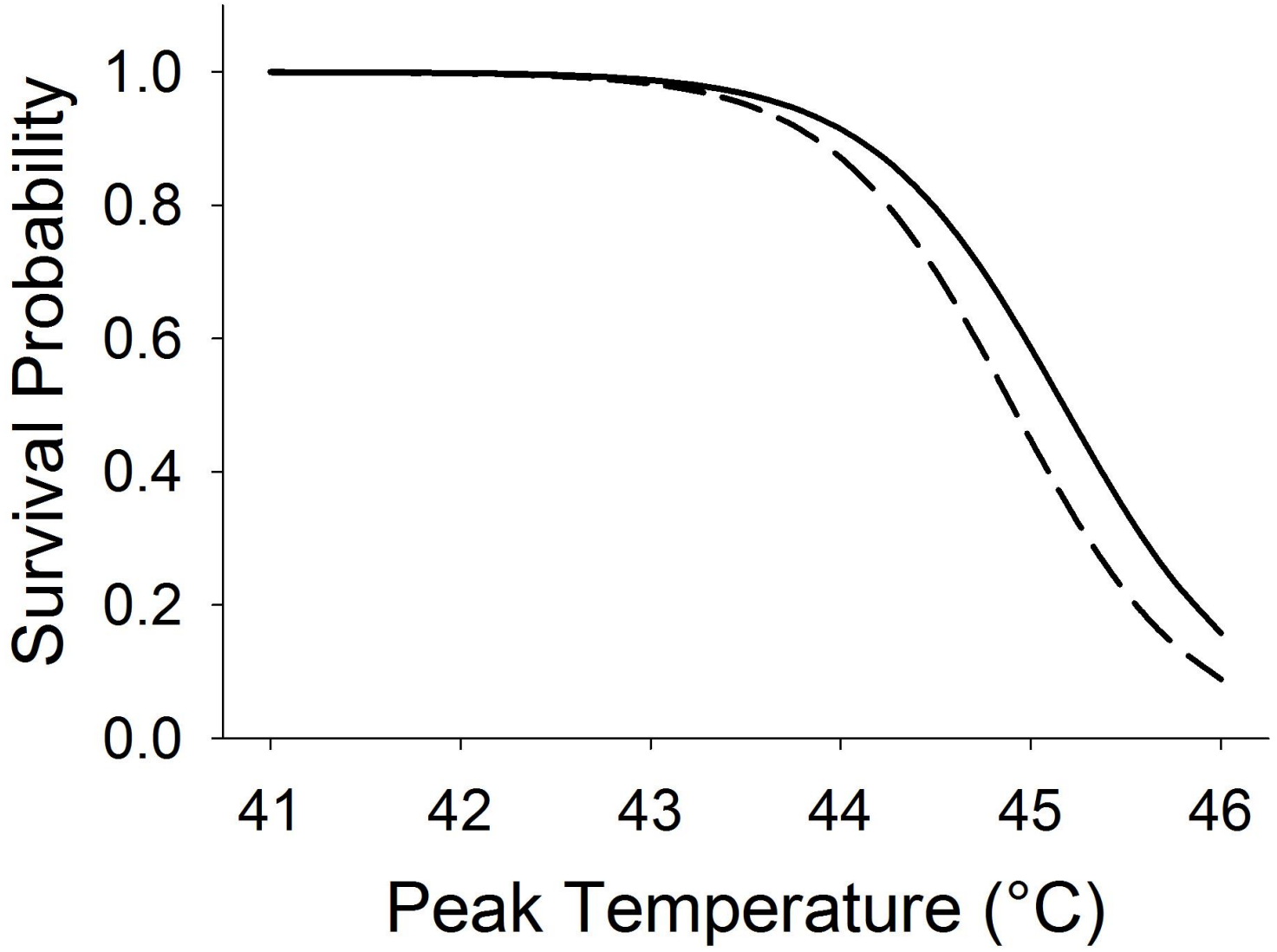

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

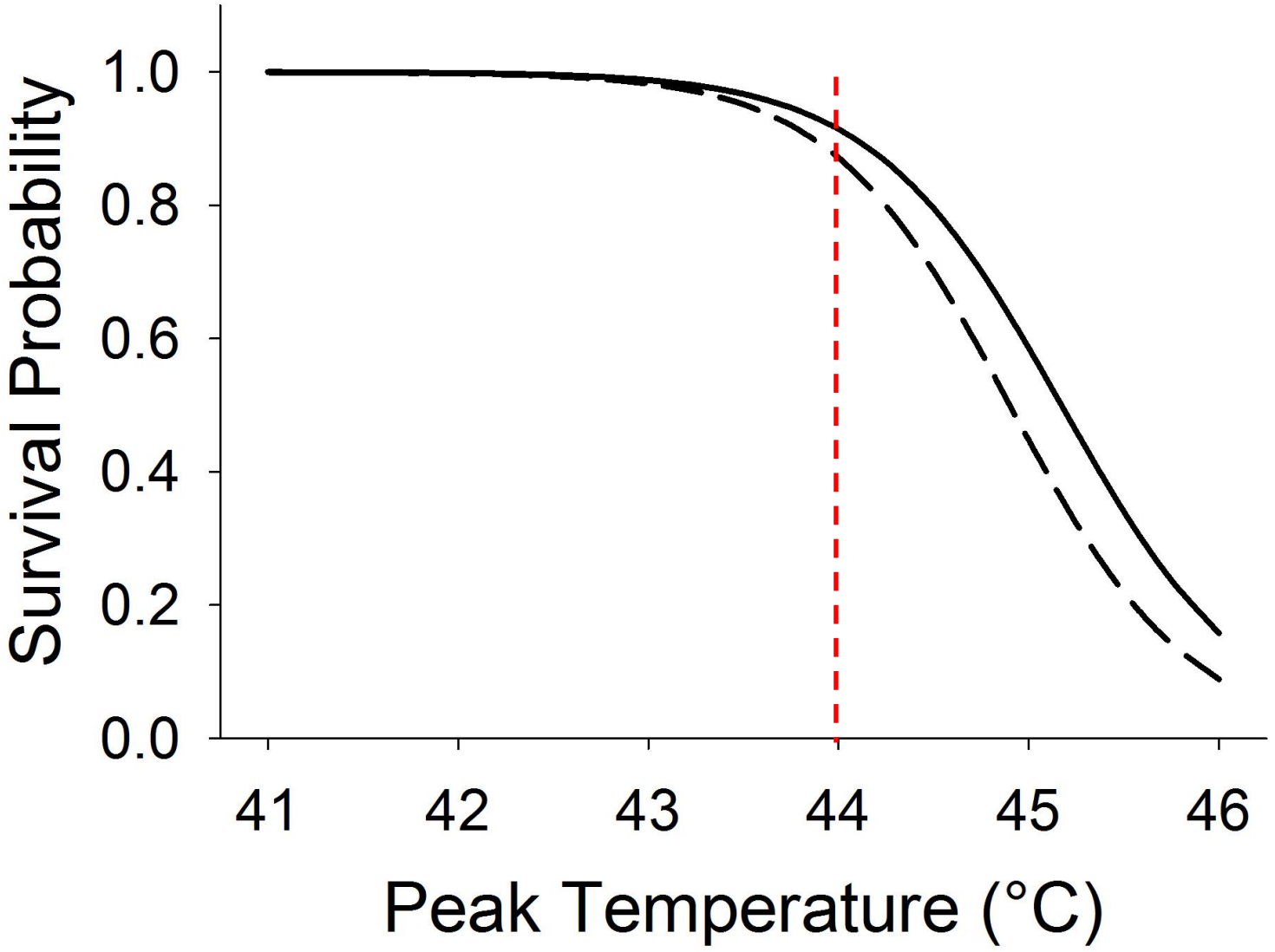

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)

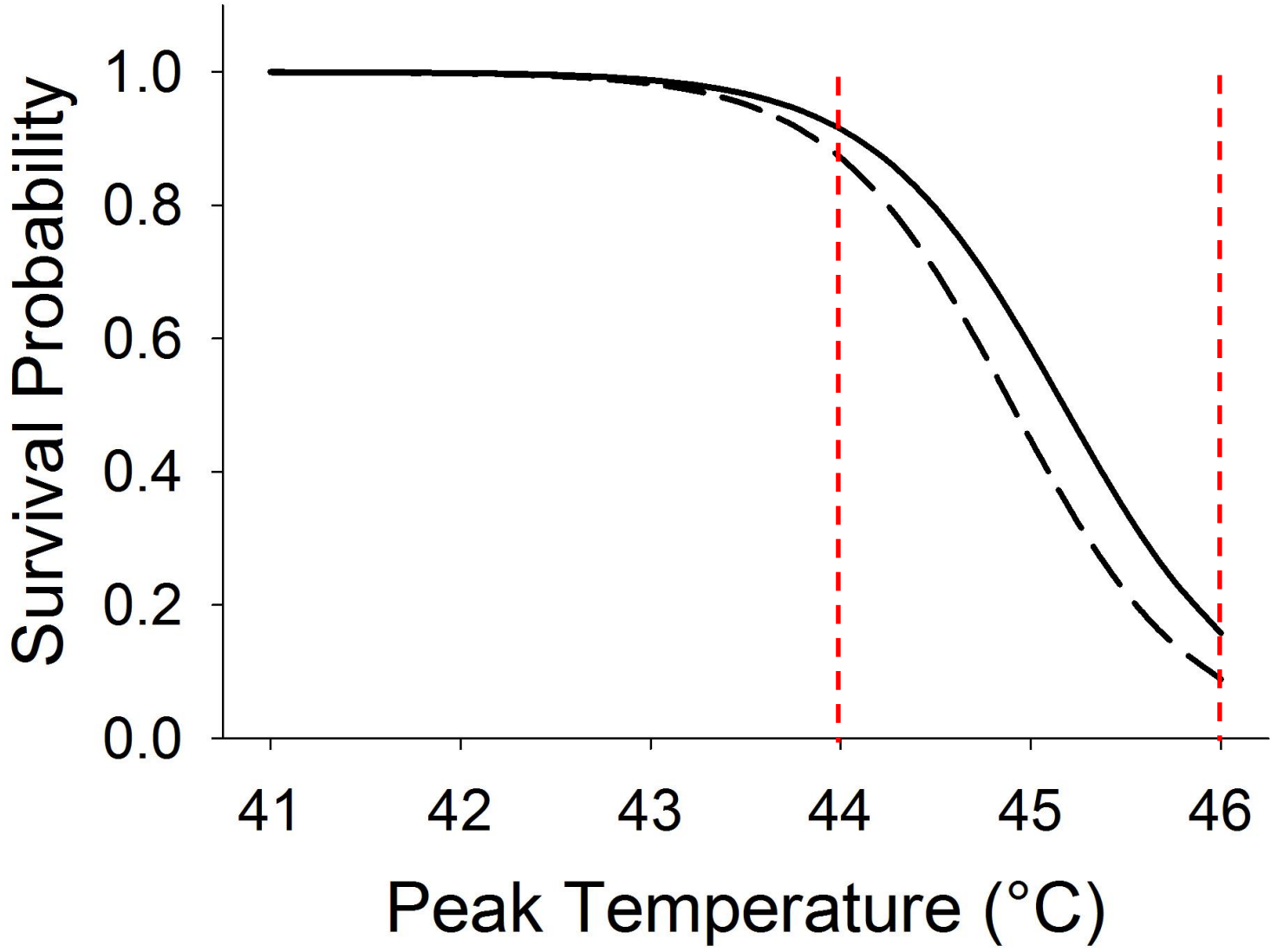
Survival vs Age?



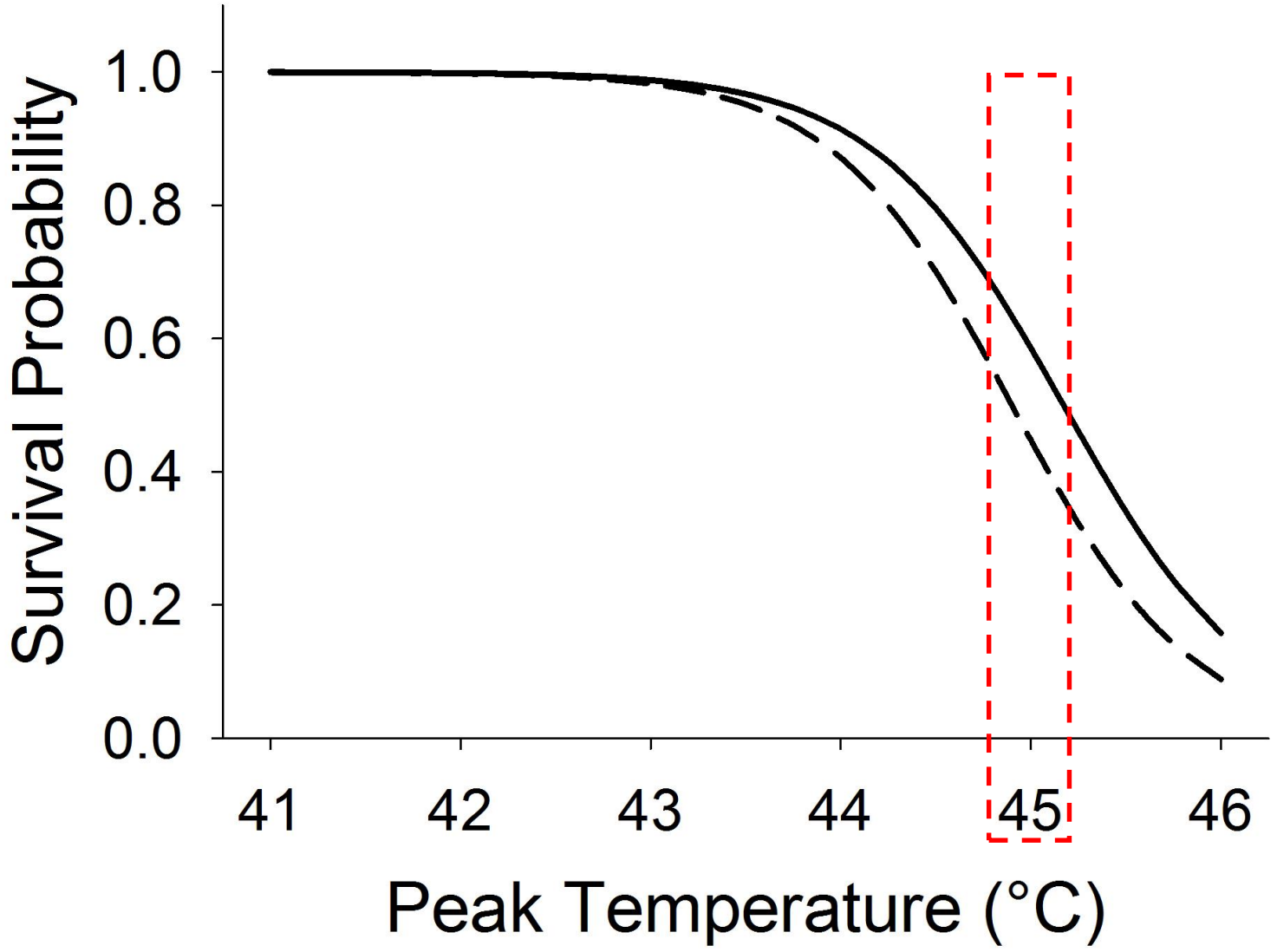
Survival vs Age?



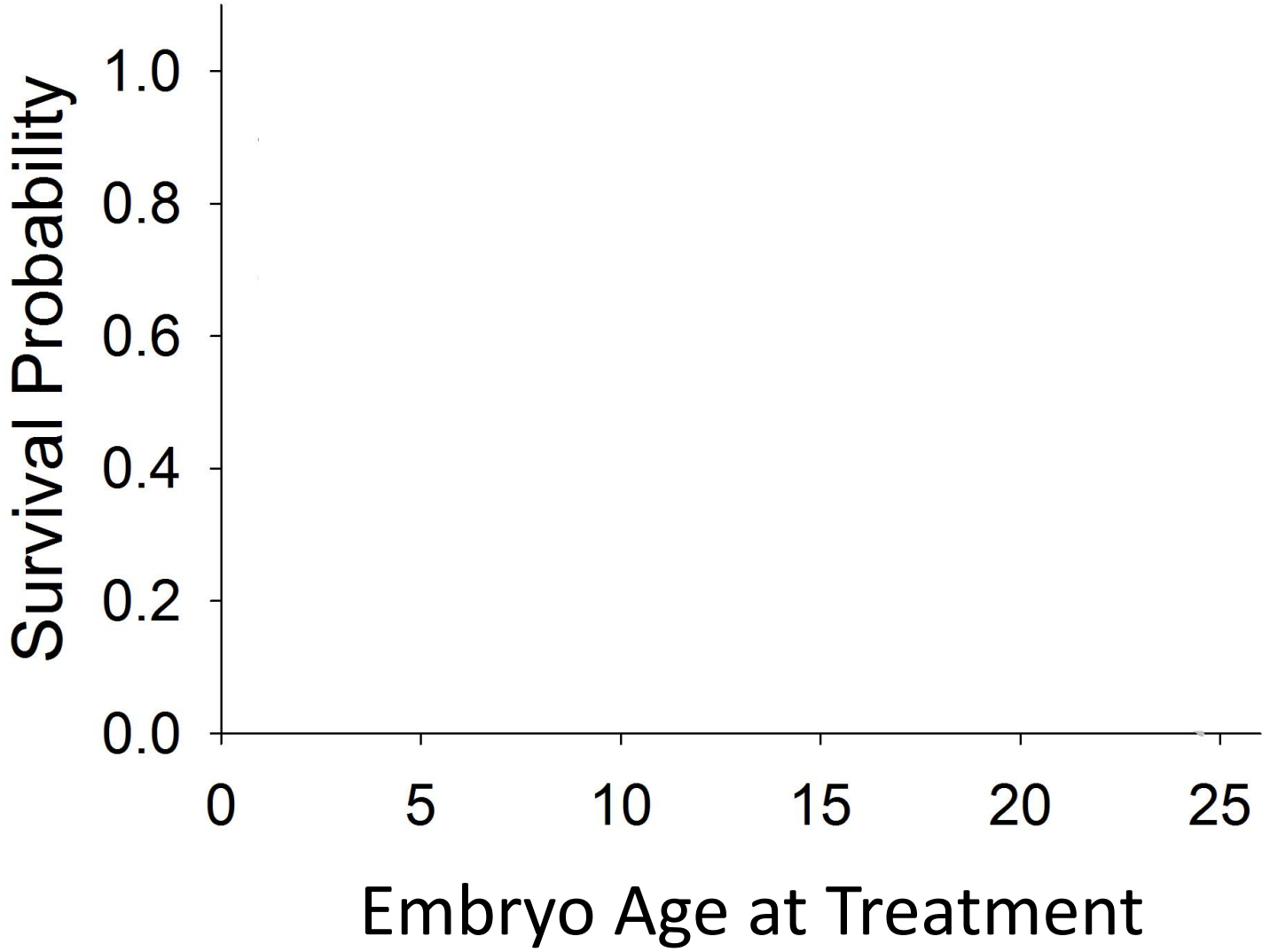
Survival vs Age?



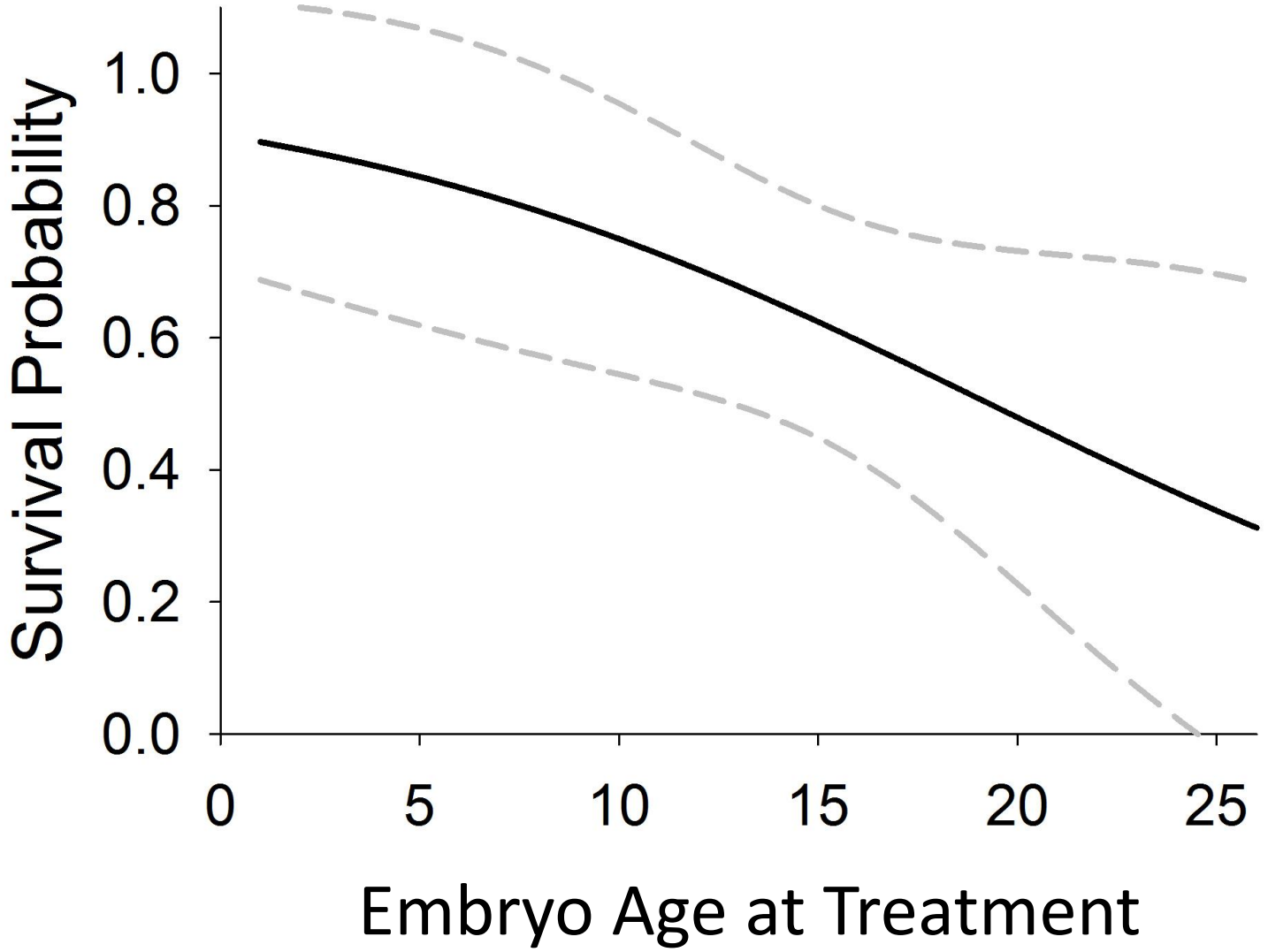
Survival vs Age?



Survival vs Age?

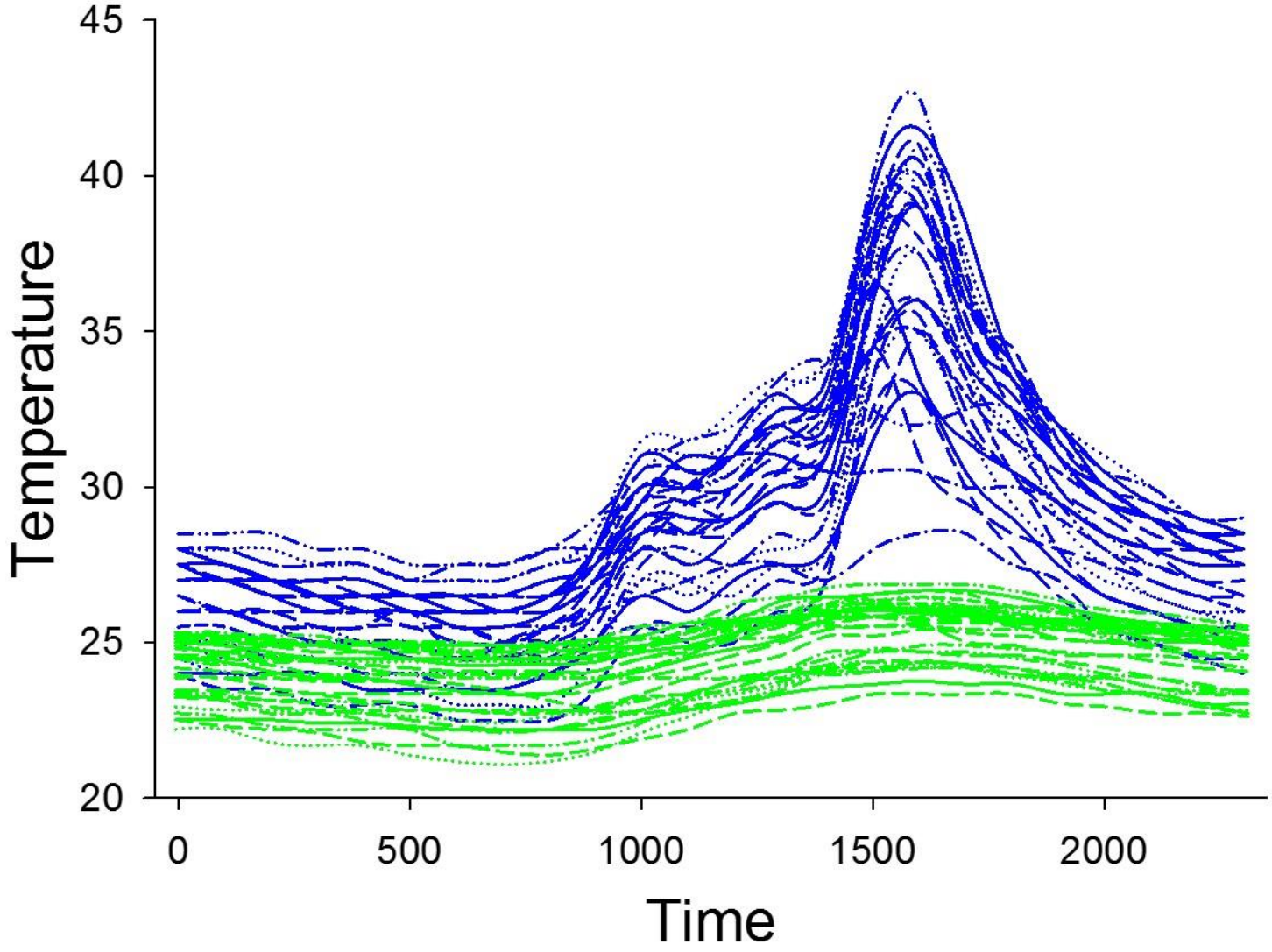


Survival vs Age?



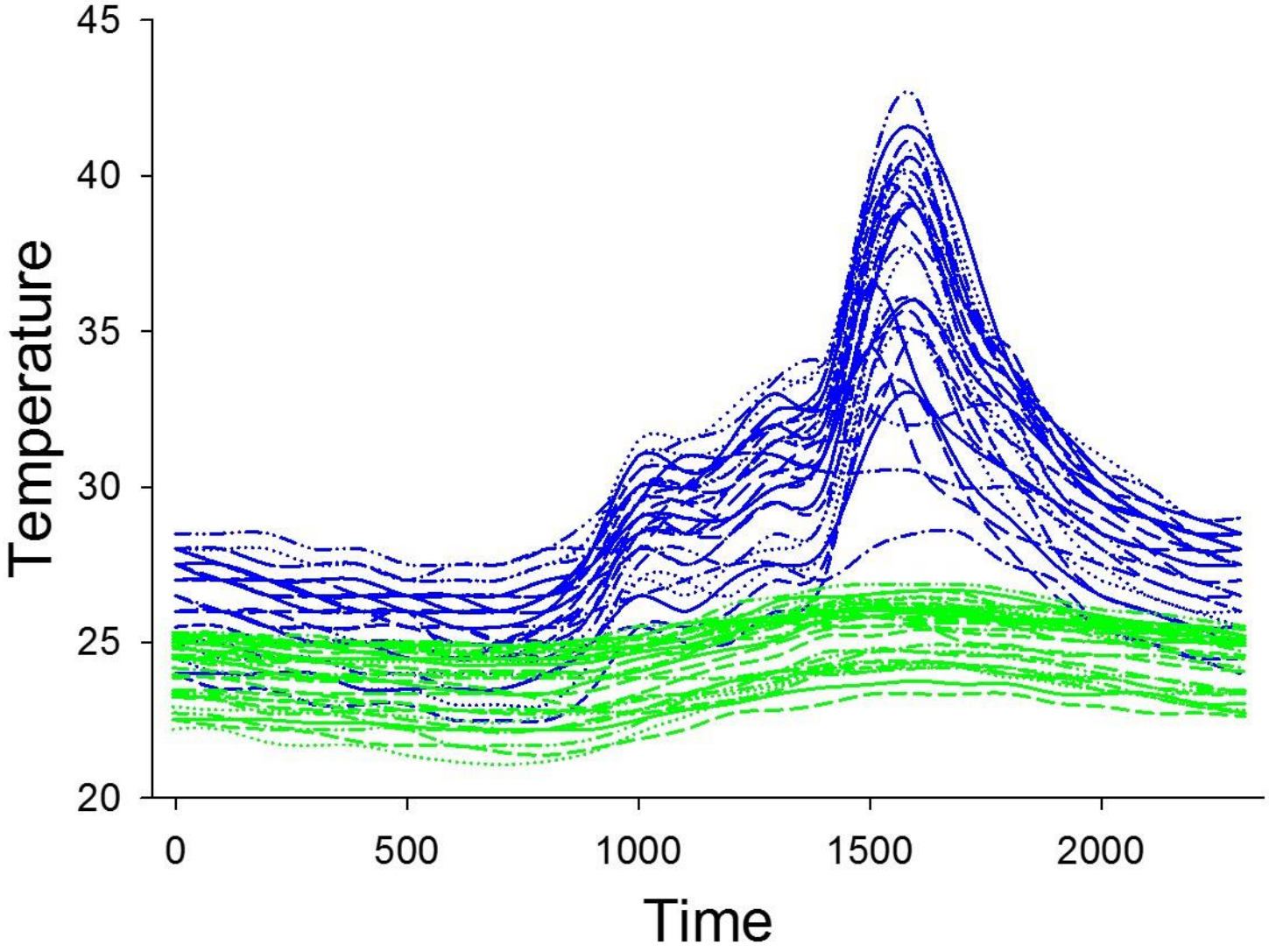
Thermal Extremes

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

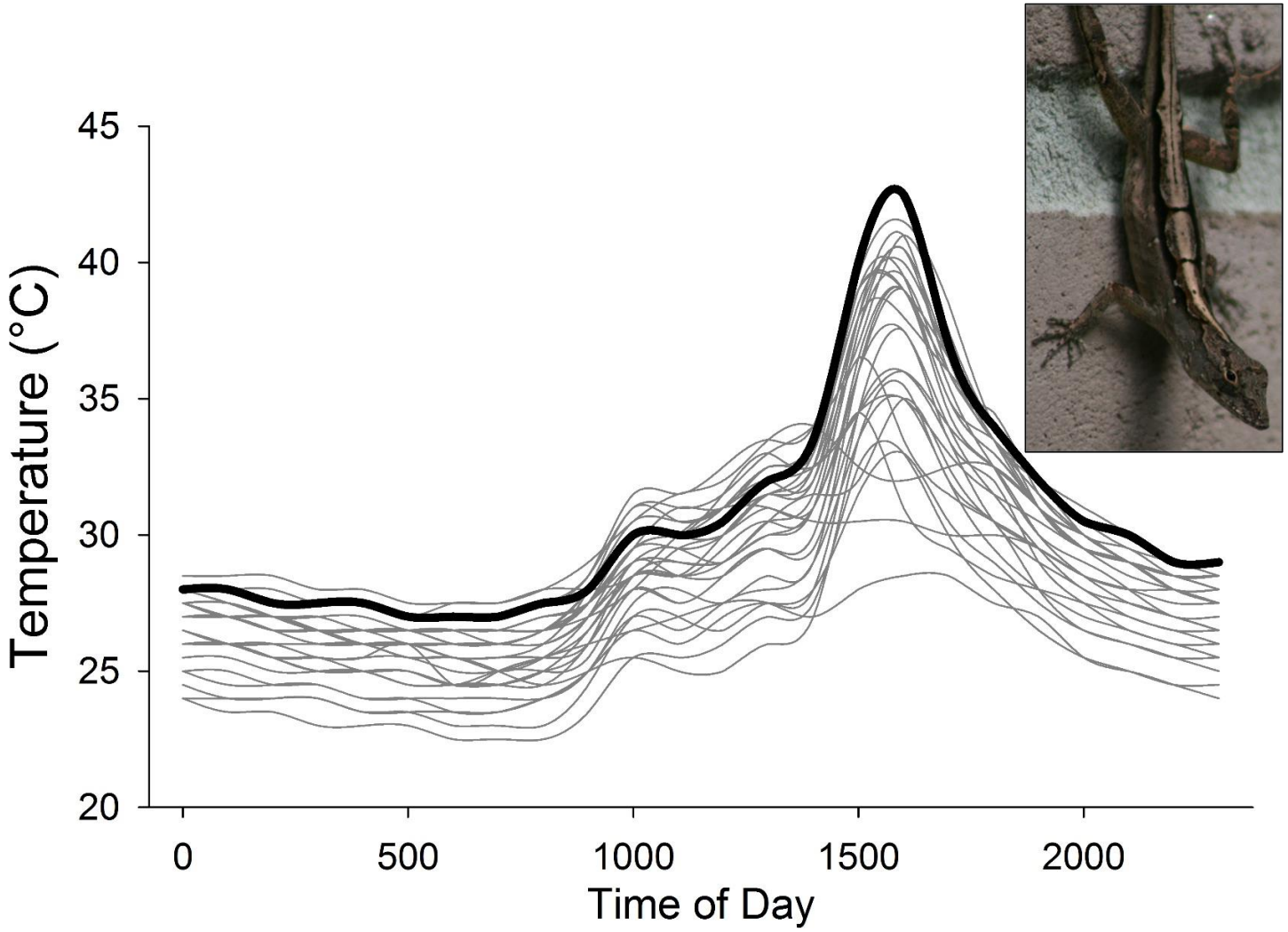


Thermal Extremes

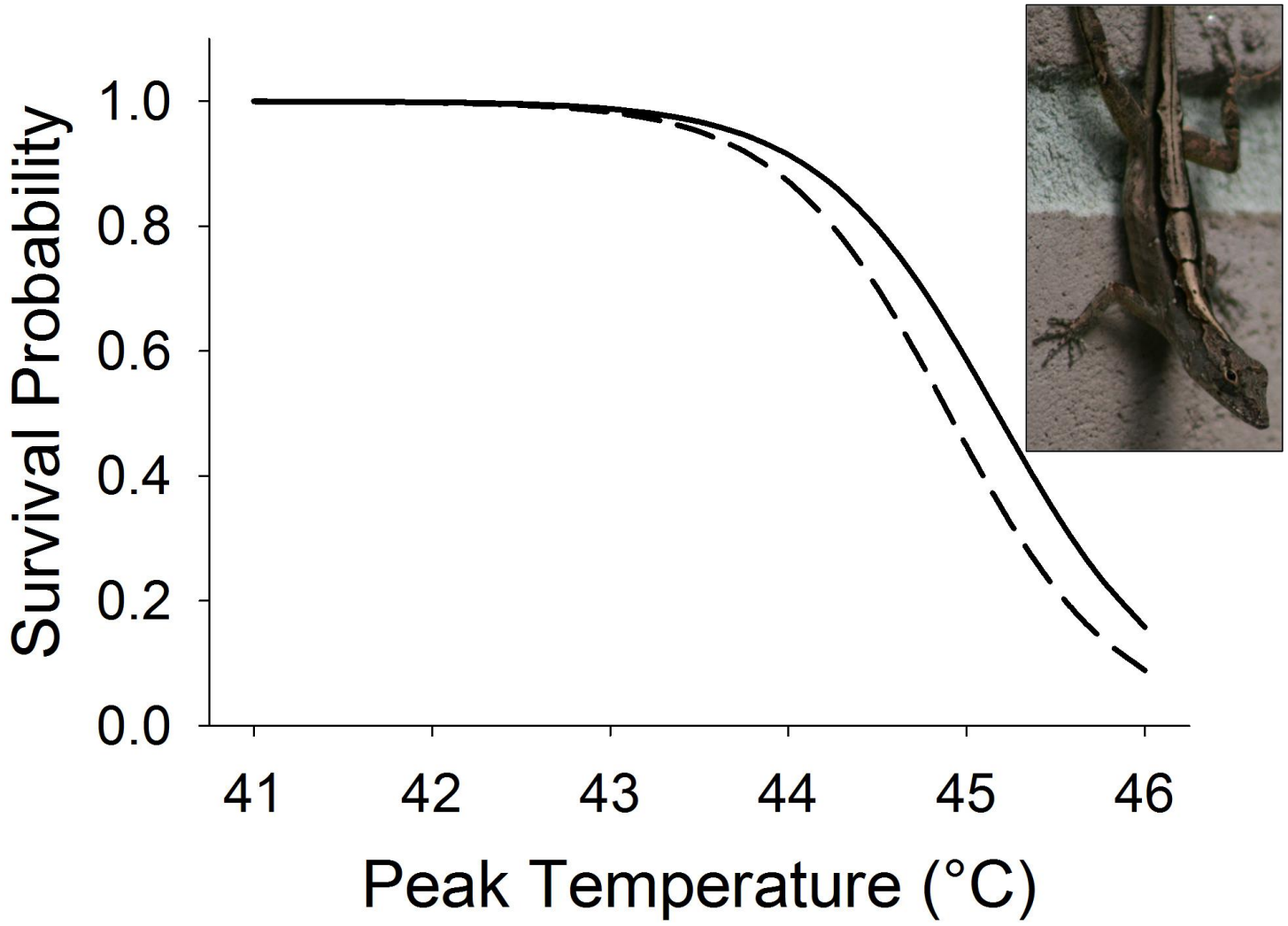
- Magnitude (how hot?)
- Frequency (how often?)
- Timing (how old?)
- Species (how general?)



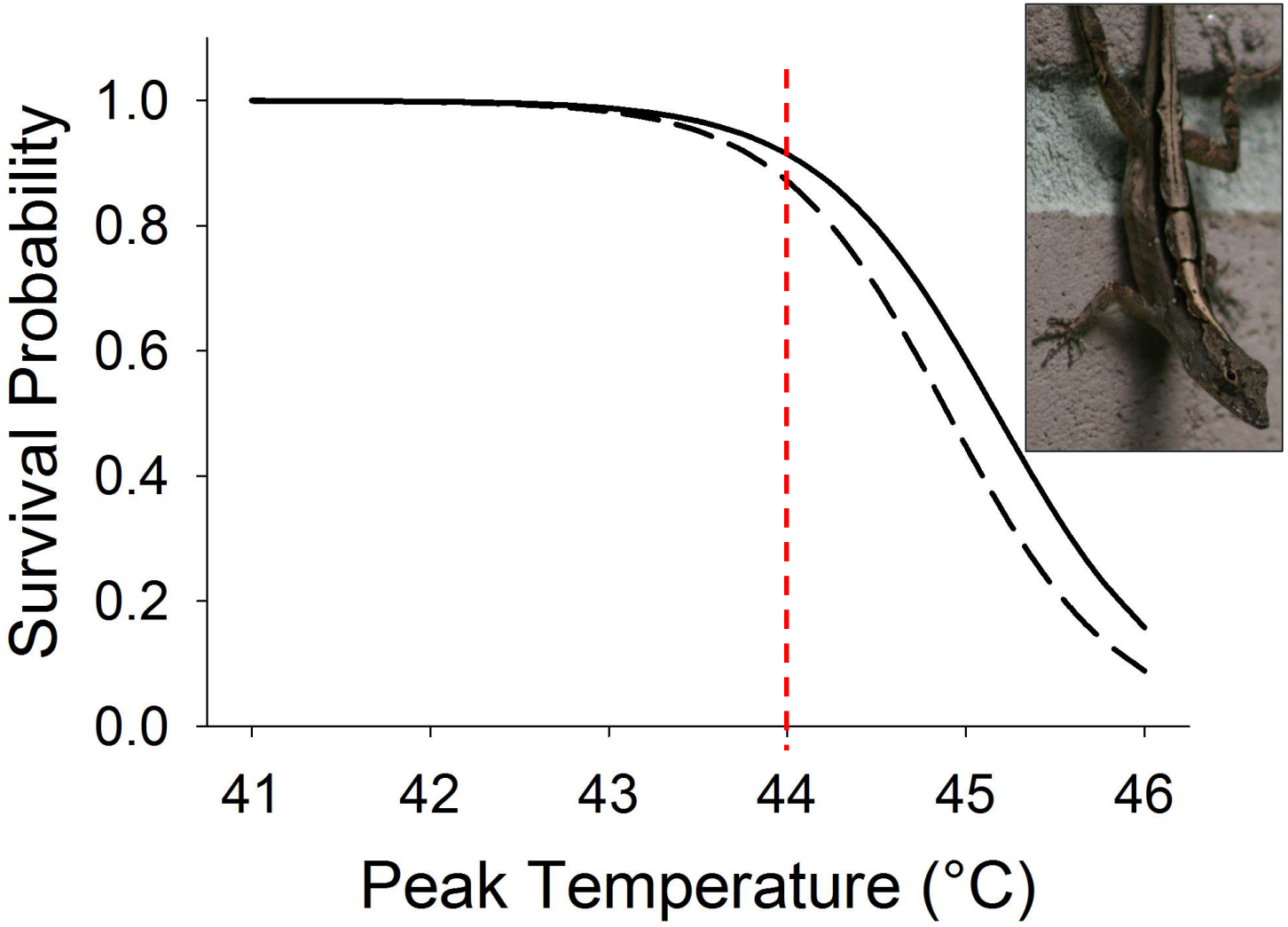
Experimental Design – Frequency and Age



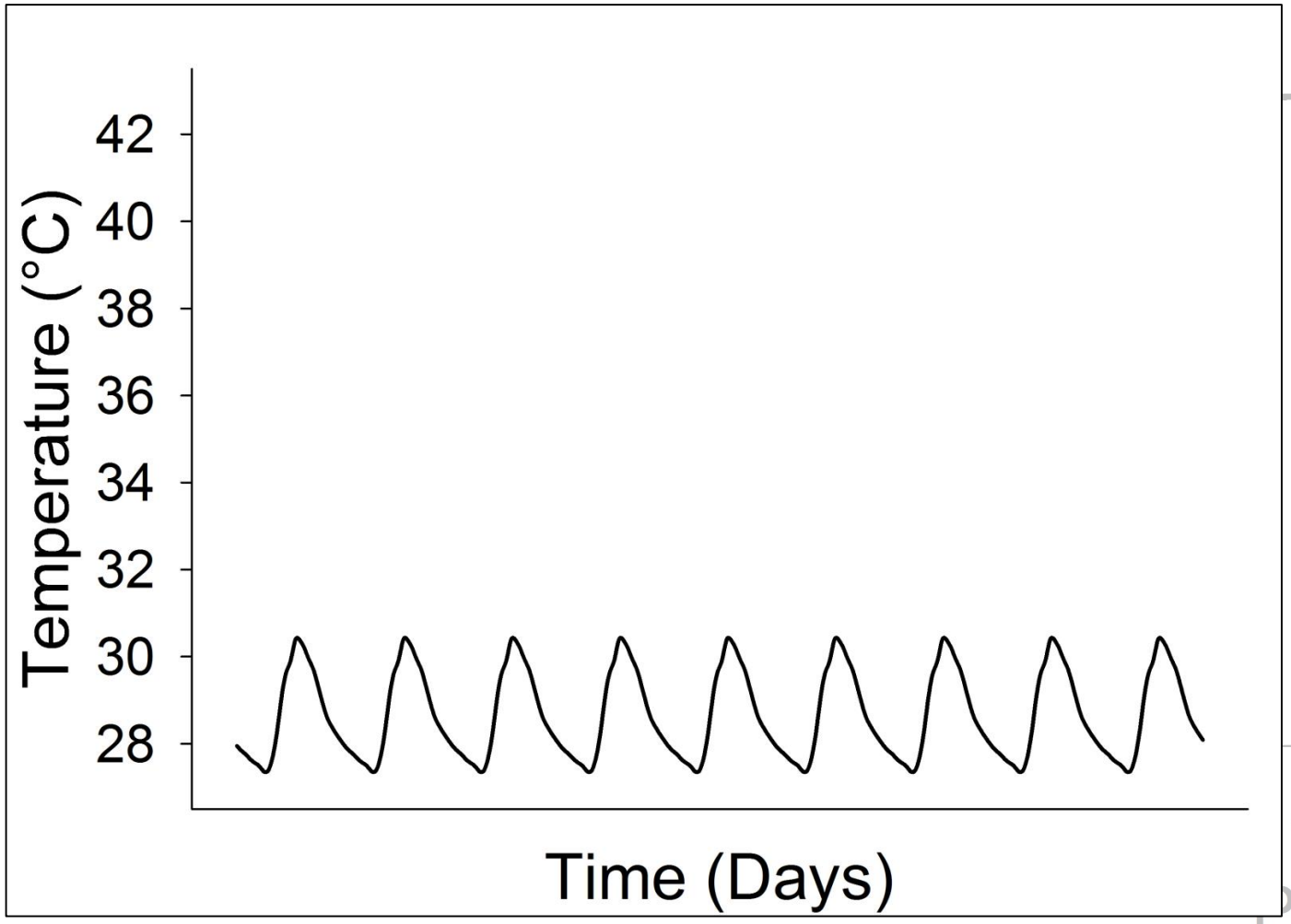
Experimental Design – Frequency and Age

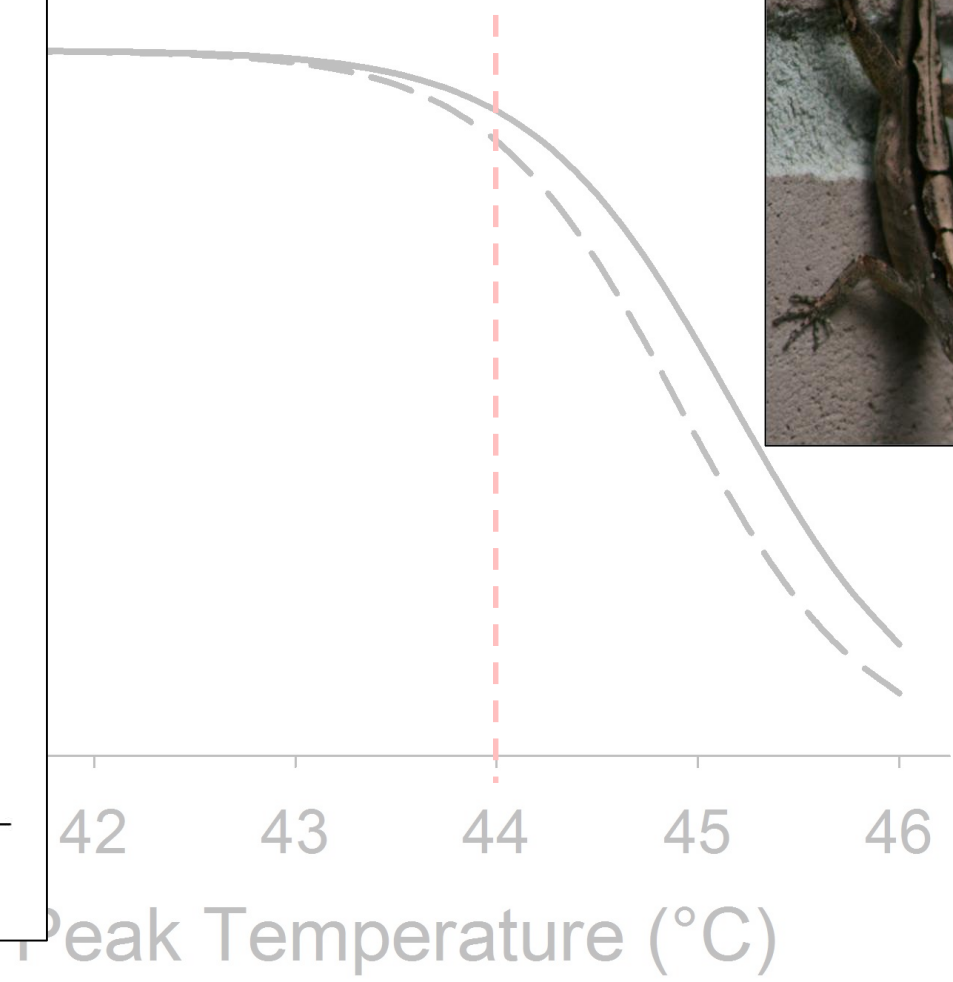


Experimental Design – Frequency and Age

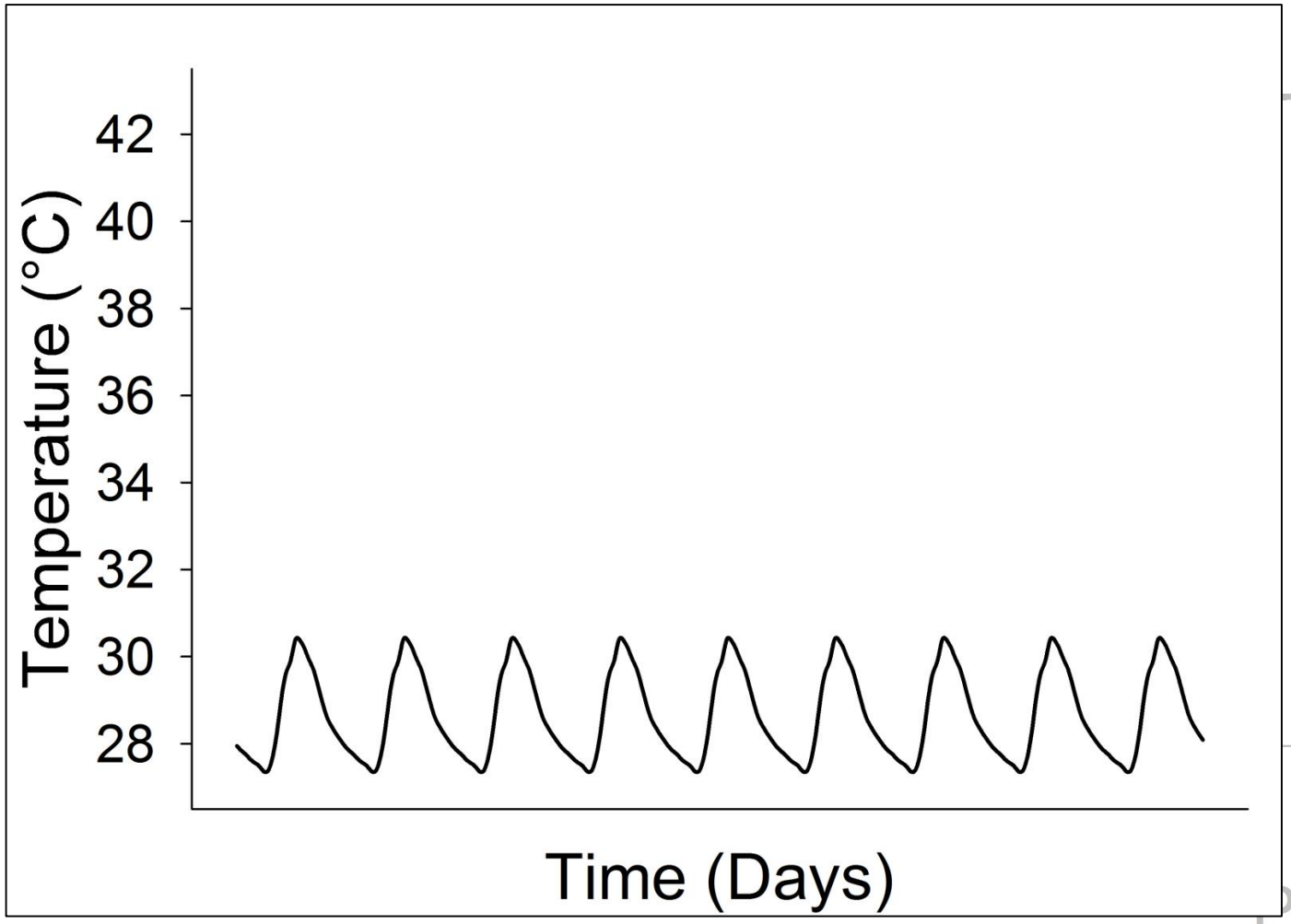


Experimental Design – Frequency and Age





Experimental Design – Frequency and Age

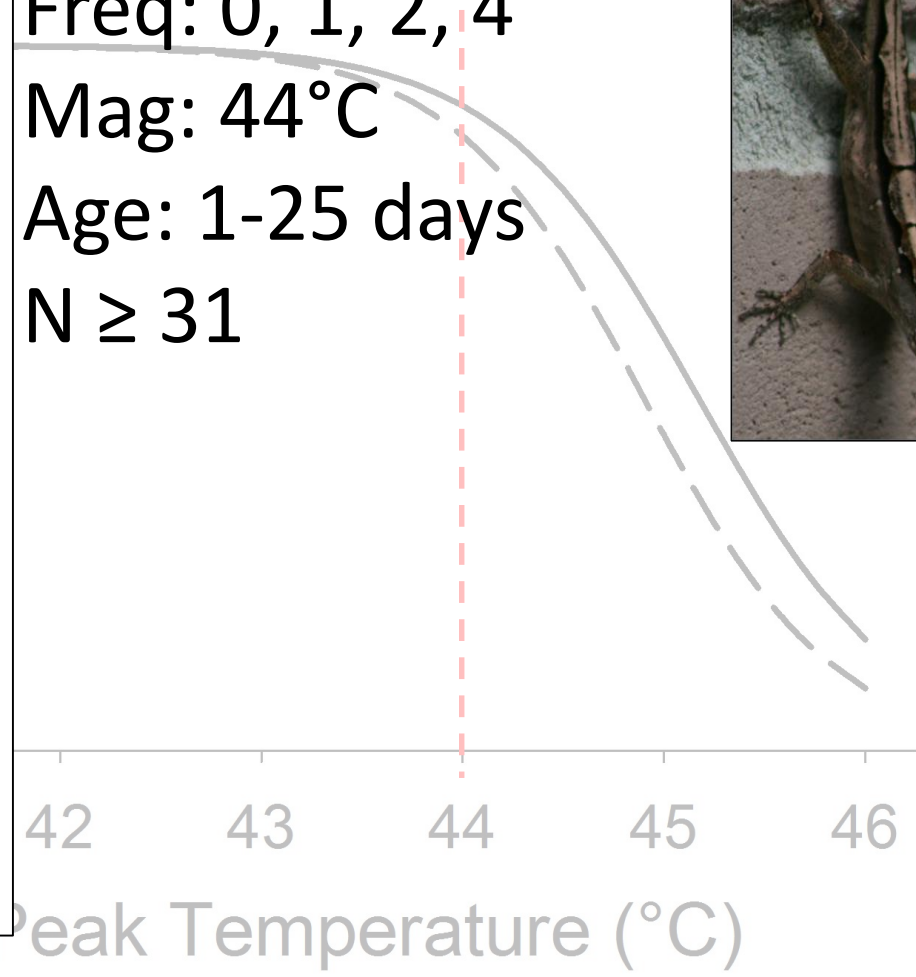


Freq: 0, 1, 2, 4

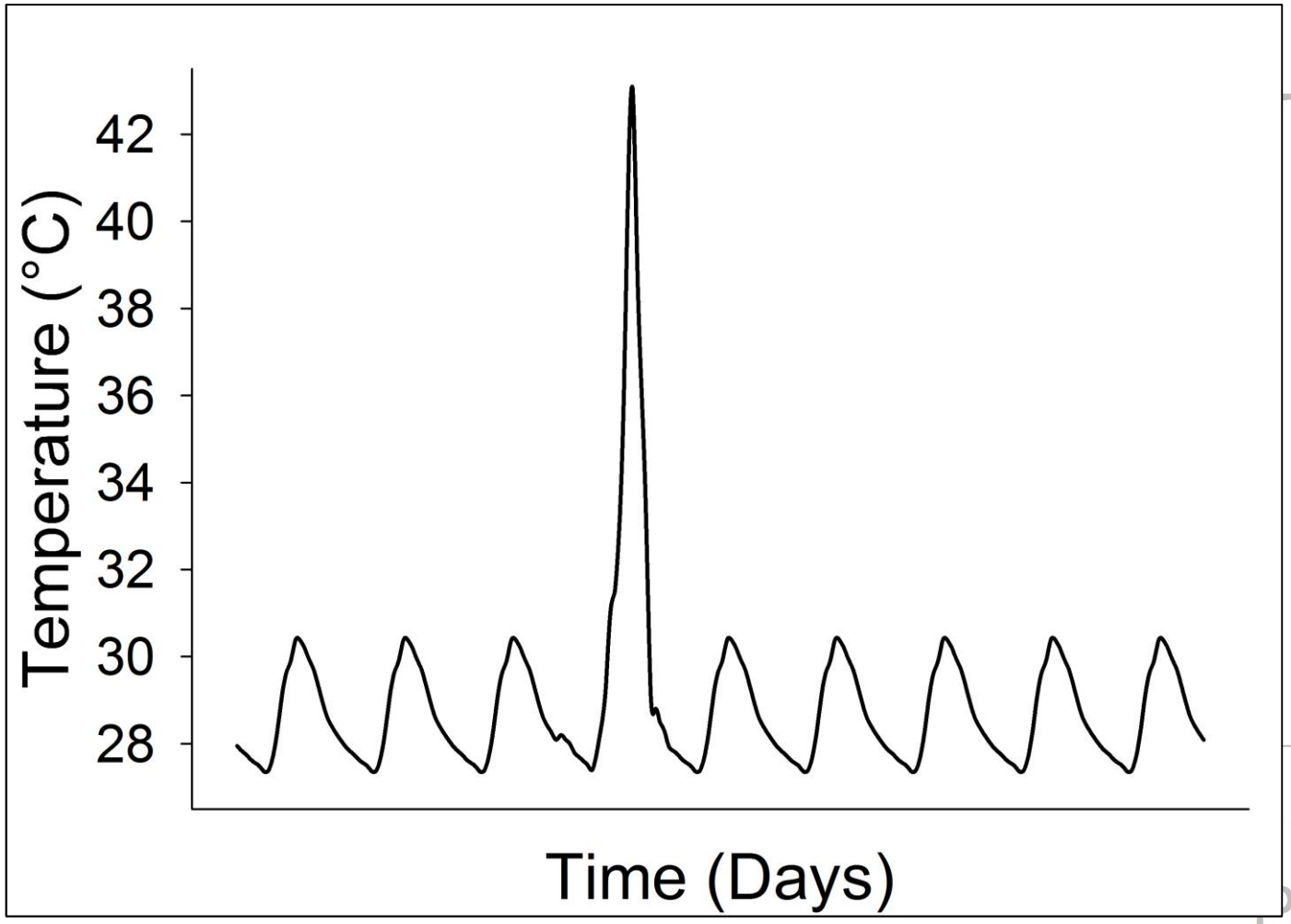
Mag: 44°C

Age: 1-25 days

N ≥ 31



Experimental Design – Frequency and Age

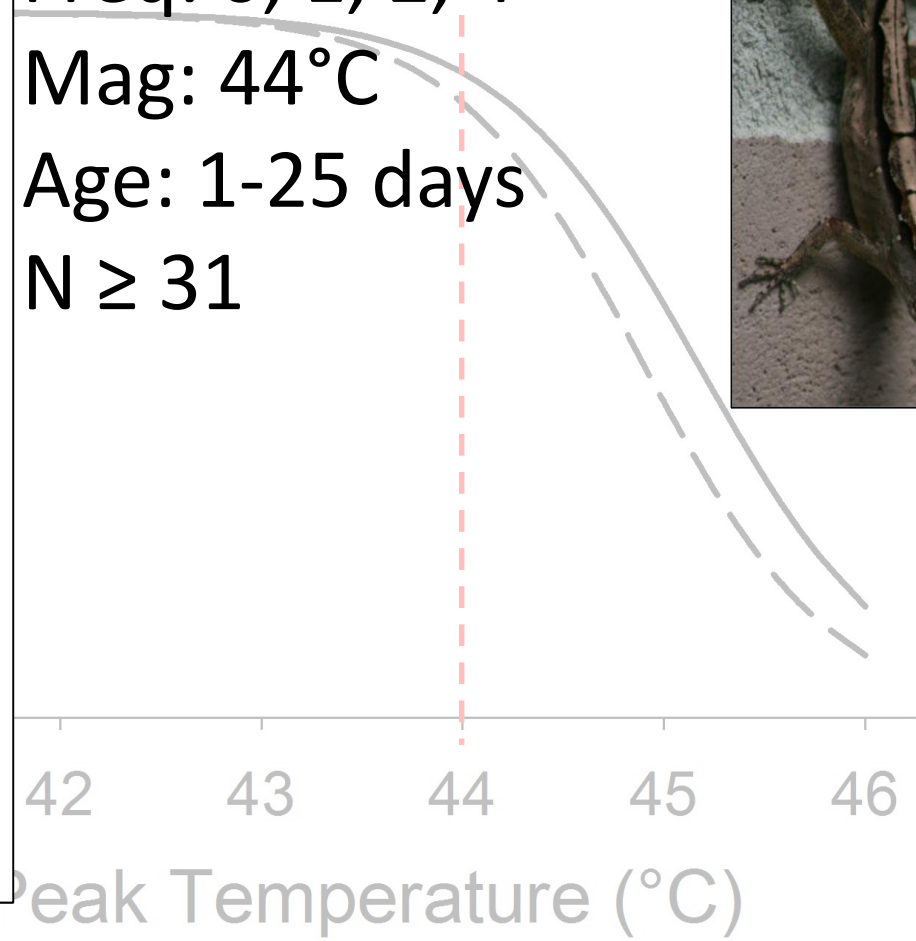


Freq: 0, 1, 2, 4

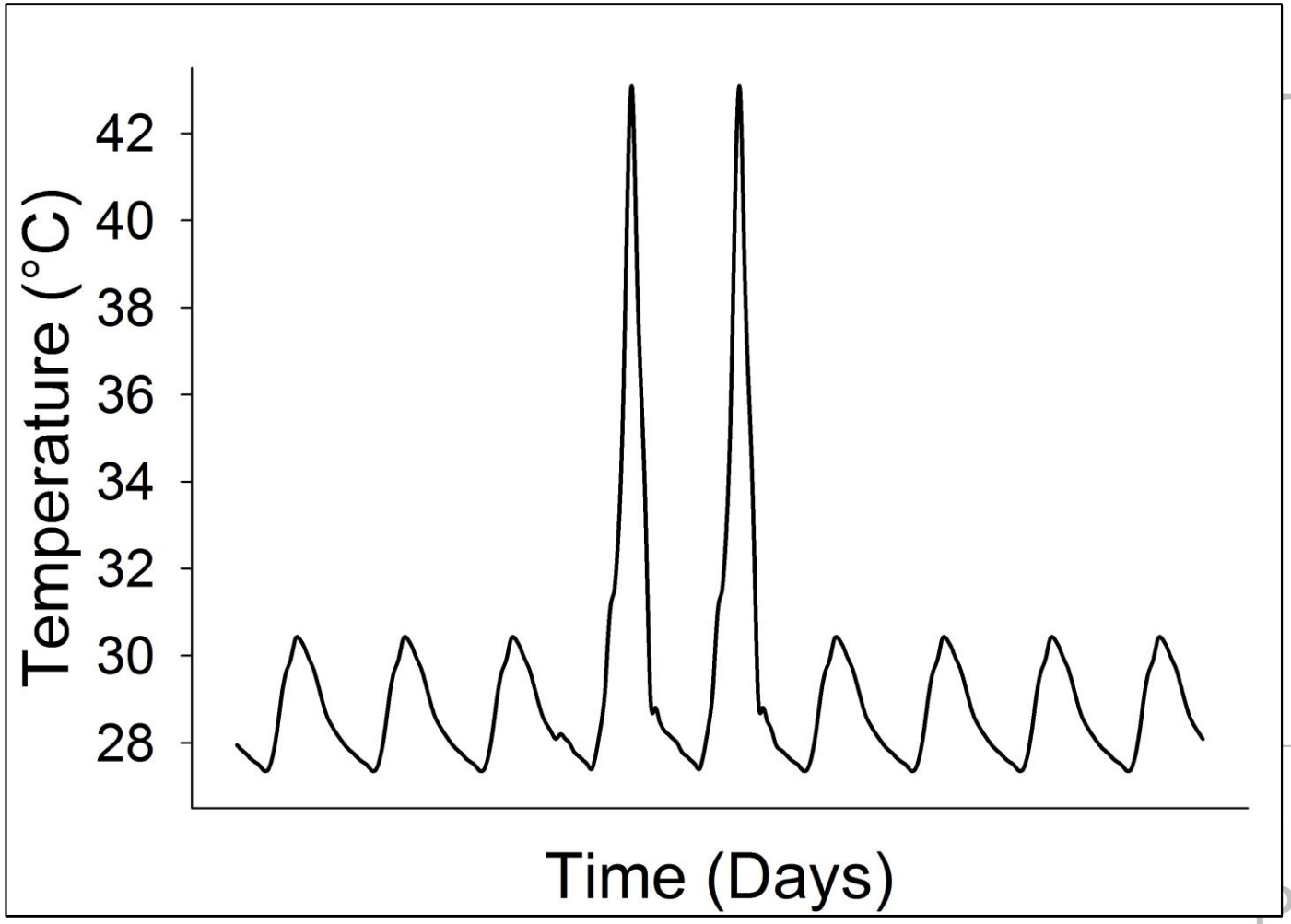
Mag: 44°C

Age: 1-25 days

N ≥ 31



Experimental Design – Frequency and Age

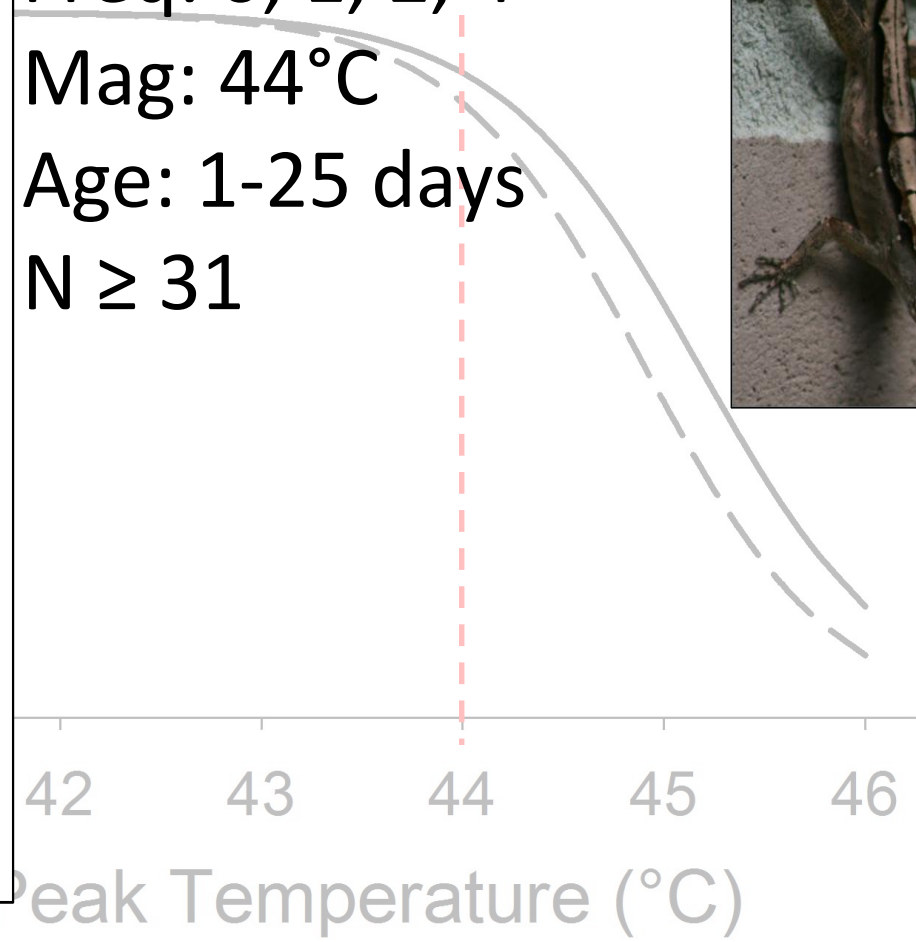


Freq: 0, 1, 2, 4

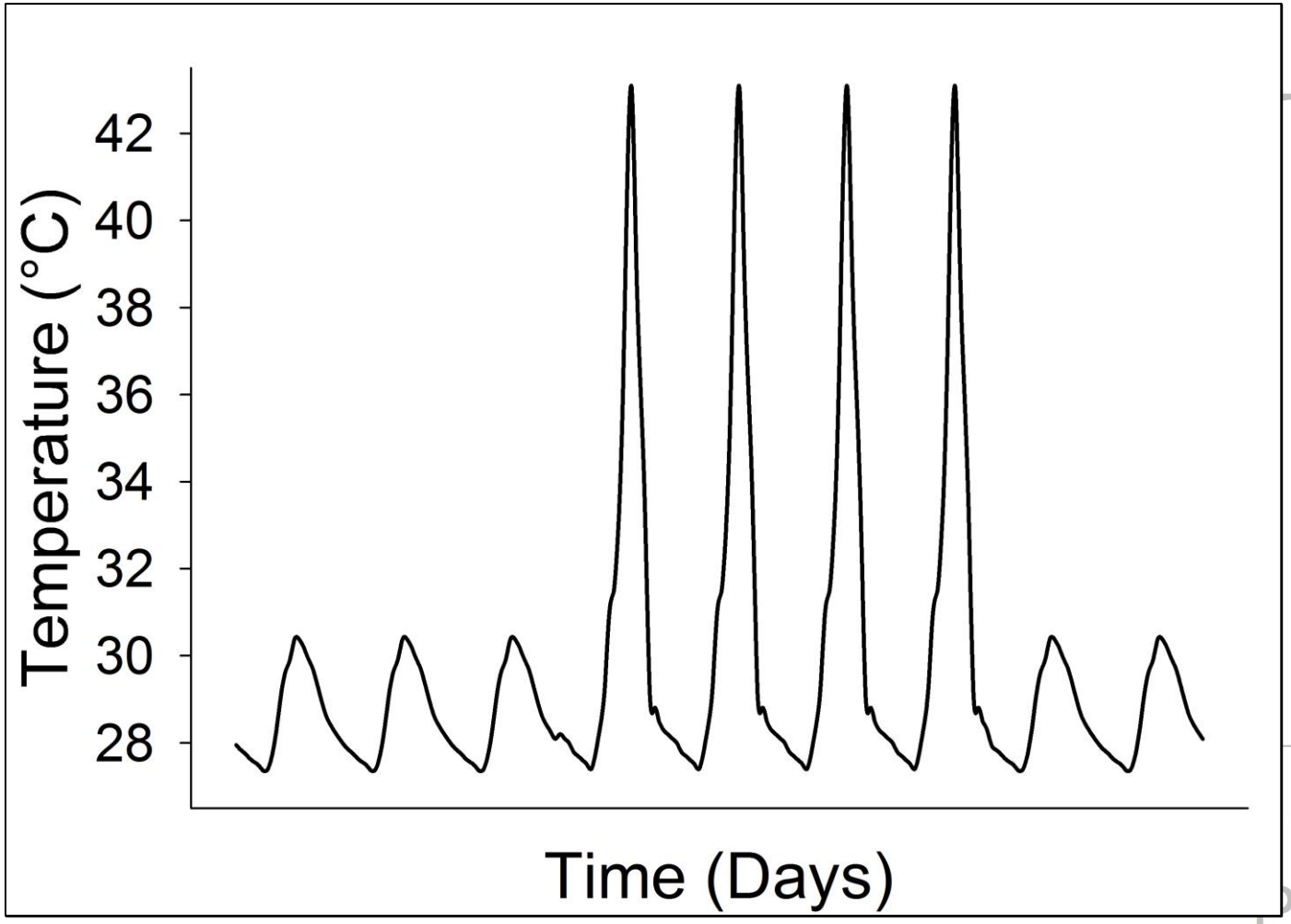
Mag: 44°C

Age: 1-25 days

N ≥ 31



Experimental Design – Frequency and Age

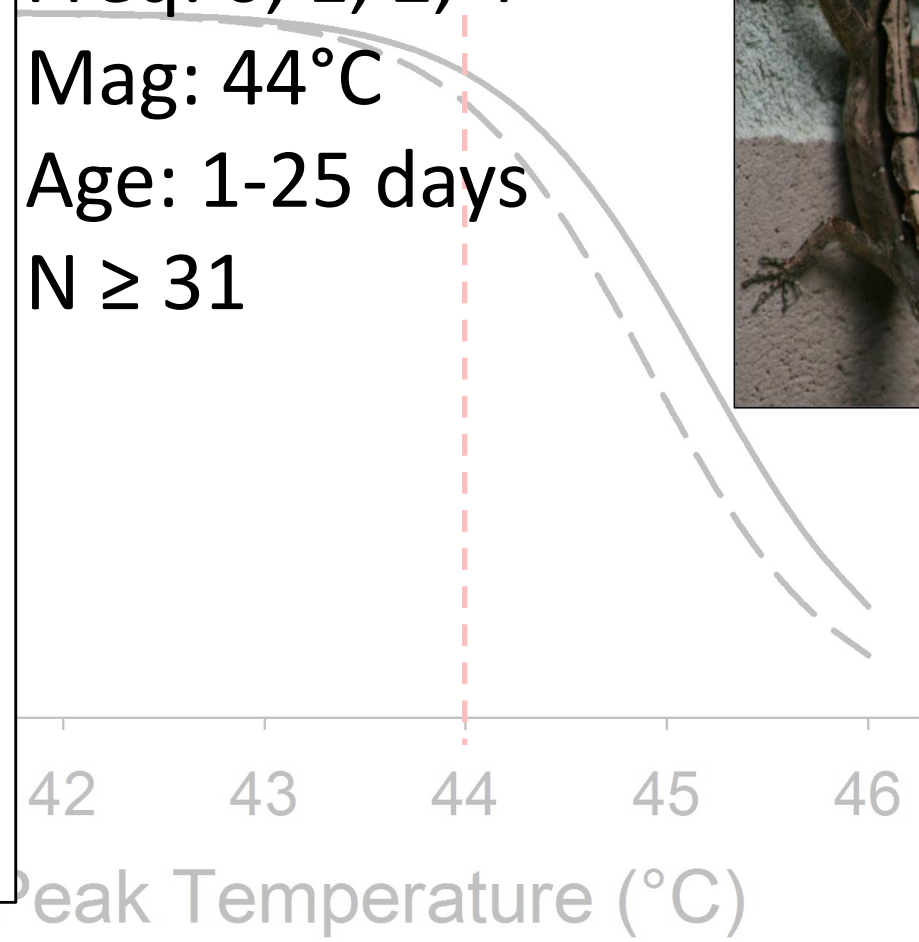


Freq: 0, 1, 2, 4

Mag: 44°C

Age: 1-25 days

N ≥ 31



Embryo Survival

- Survival ~

Embryo Survival

- Survival ~ Frequency

Embryo Survival

- Survival ~ Frequency + Age

Embryo Survival

- Survival ~ Frequency + Age + Frequency:Age

Embryo Survival

- Survival ~ Frequency + Age + Frequency:Age

Independent	DF	χ^2	P
Frequency	1	0.46	0.50

Embryo Survival

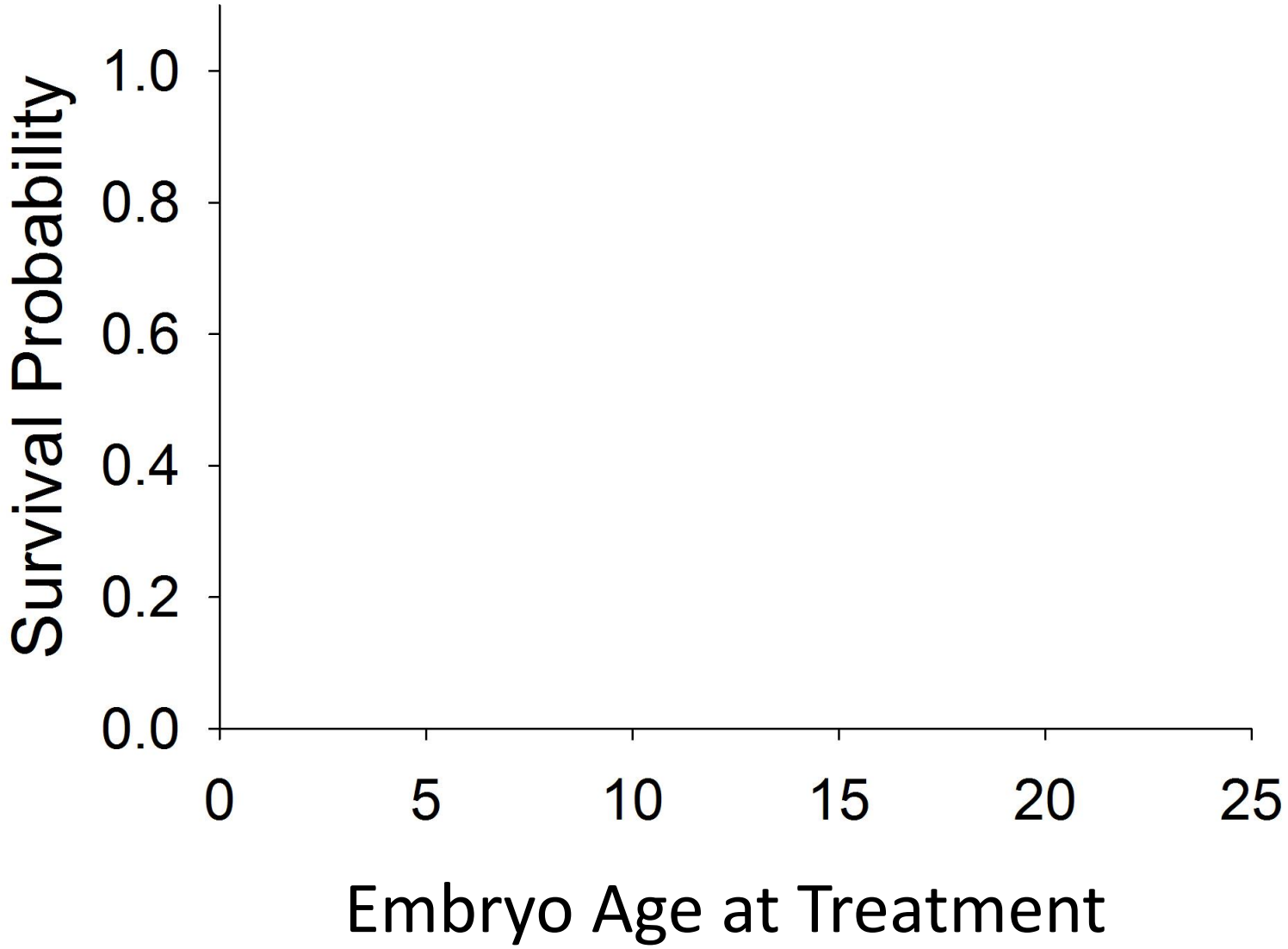
- Survival ~ Frequency + Age + Frequency:Age

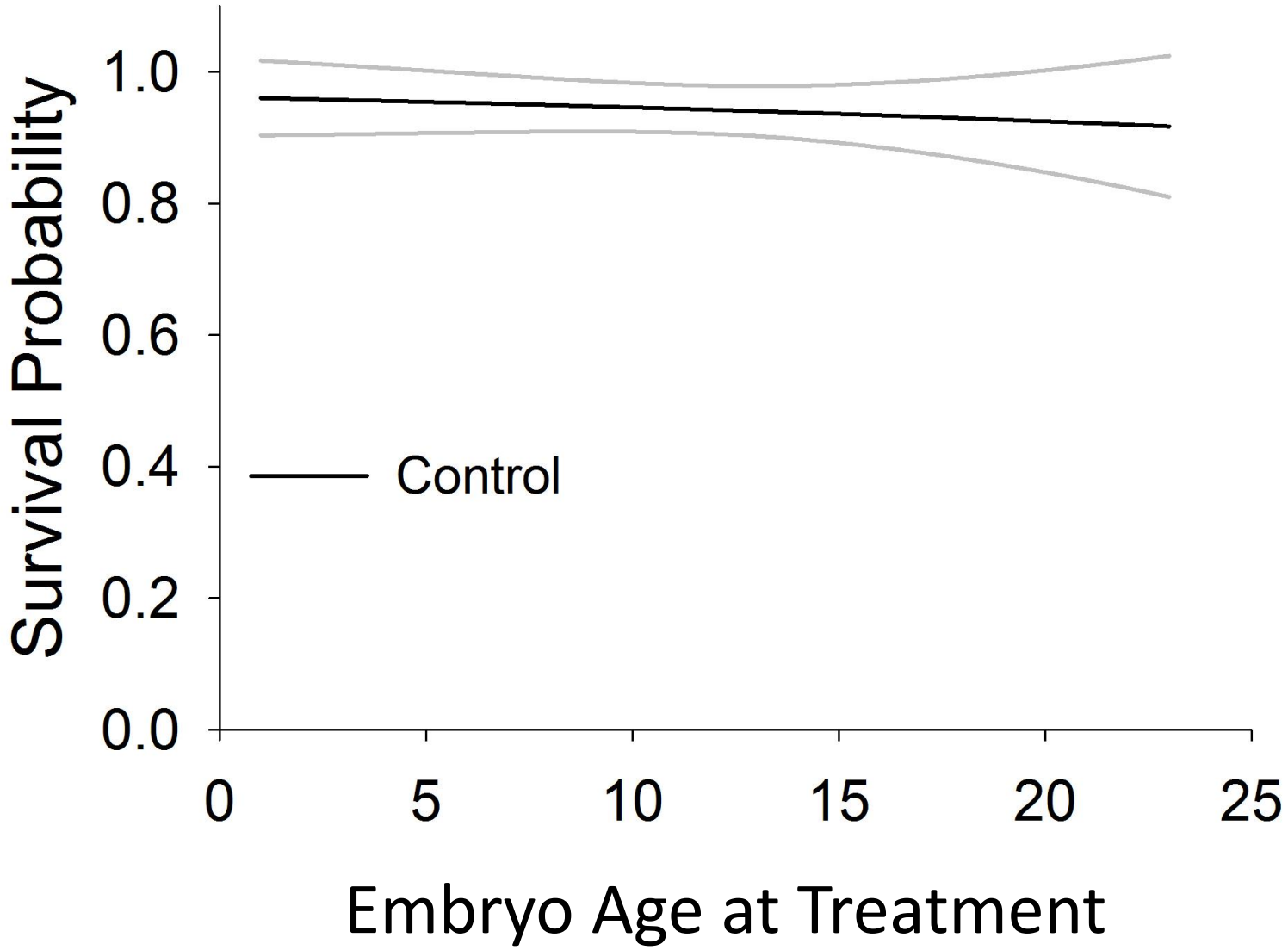
Independent	DF	χ^2	P
Frequency	1	0.46	0.50
Age	1	0.41	0.52

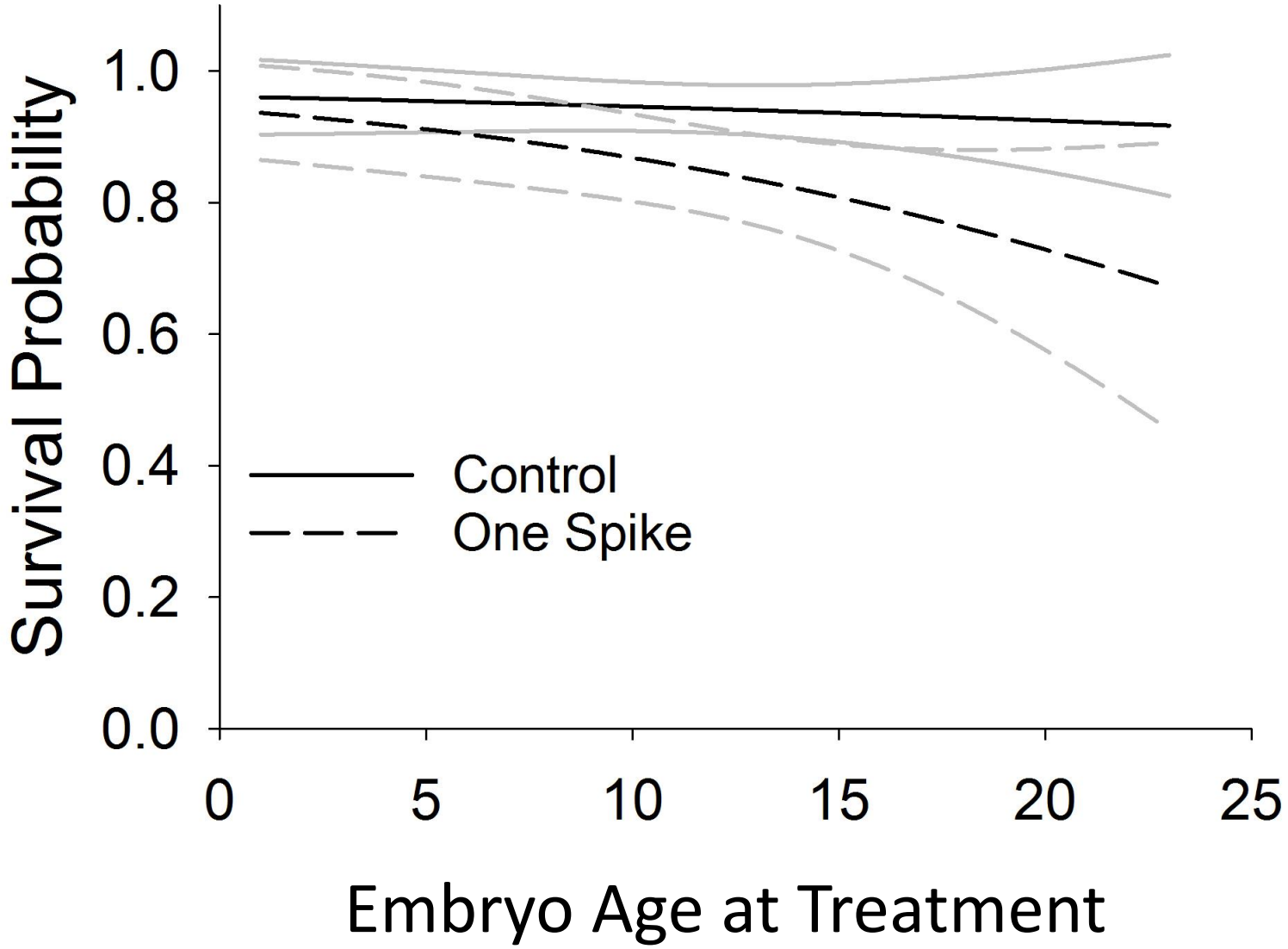
Embryo Survival

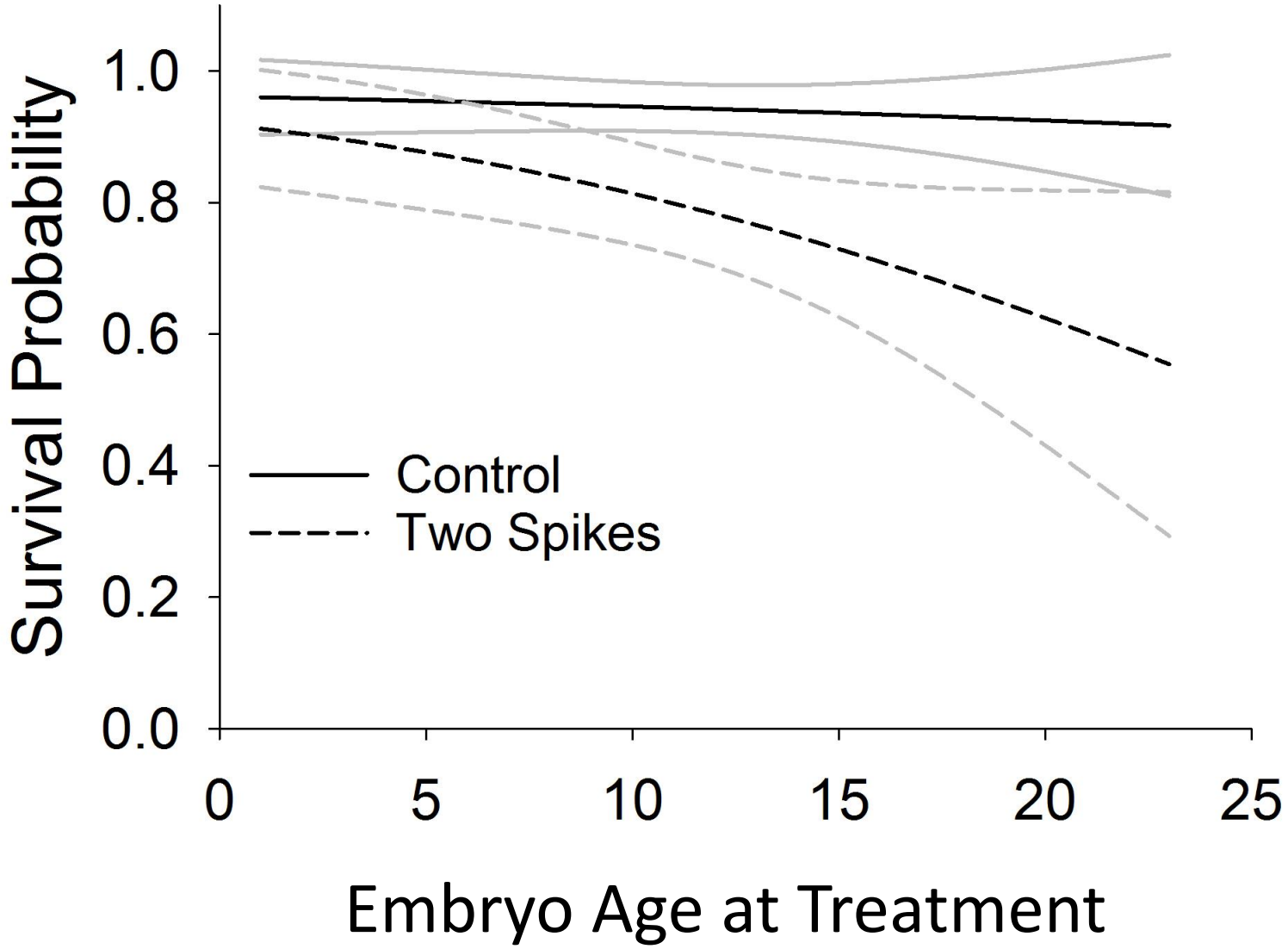
- Survival ~ Frequency + Age + Frequency:Age

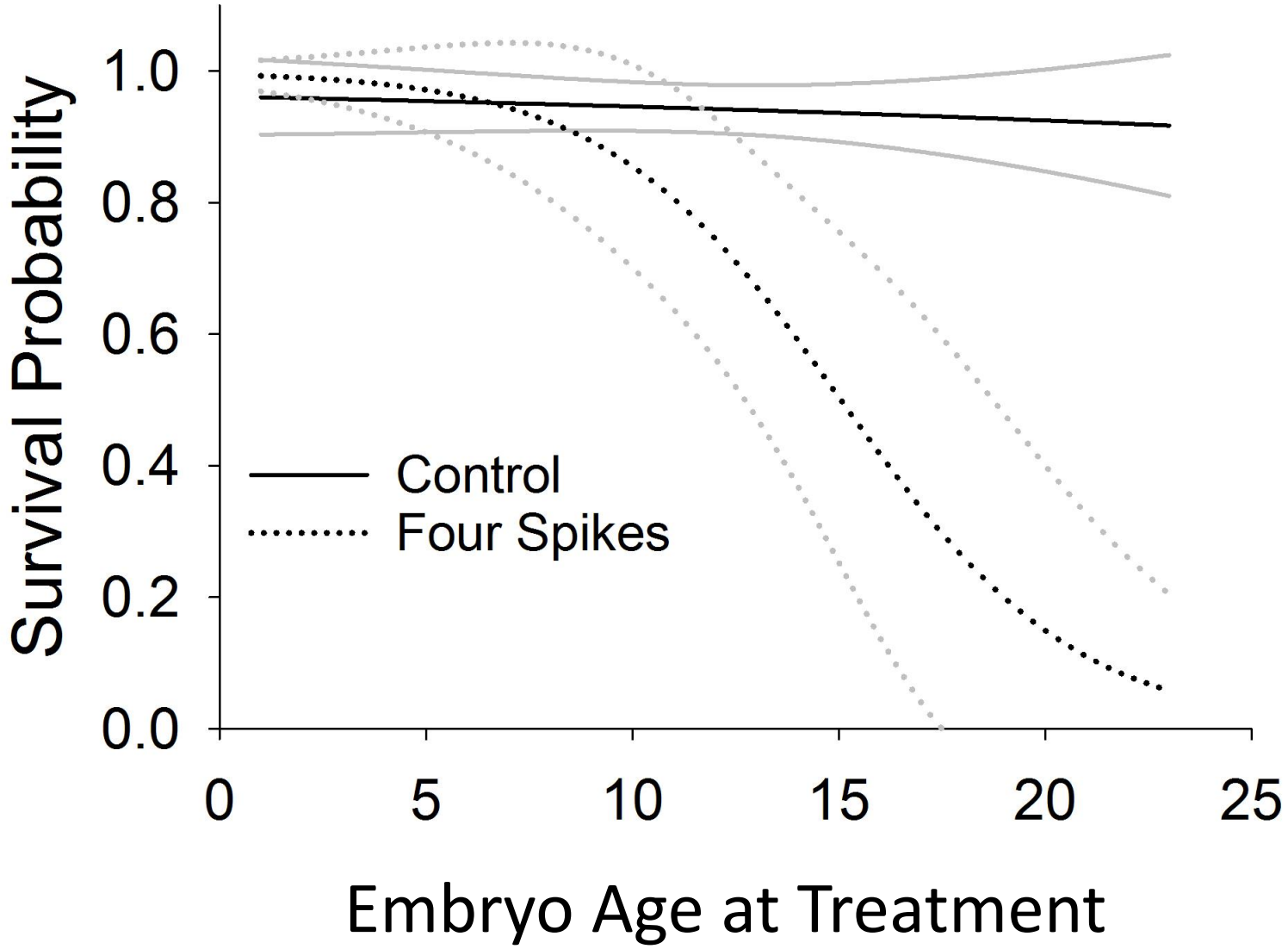
Independent	DF	χ^2	P
Frequency	1	0.46	0.50
Age	1	0.41	0.52
Frequency:Age	**1**	**5.14**	**0.023**

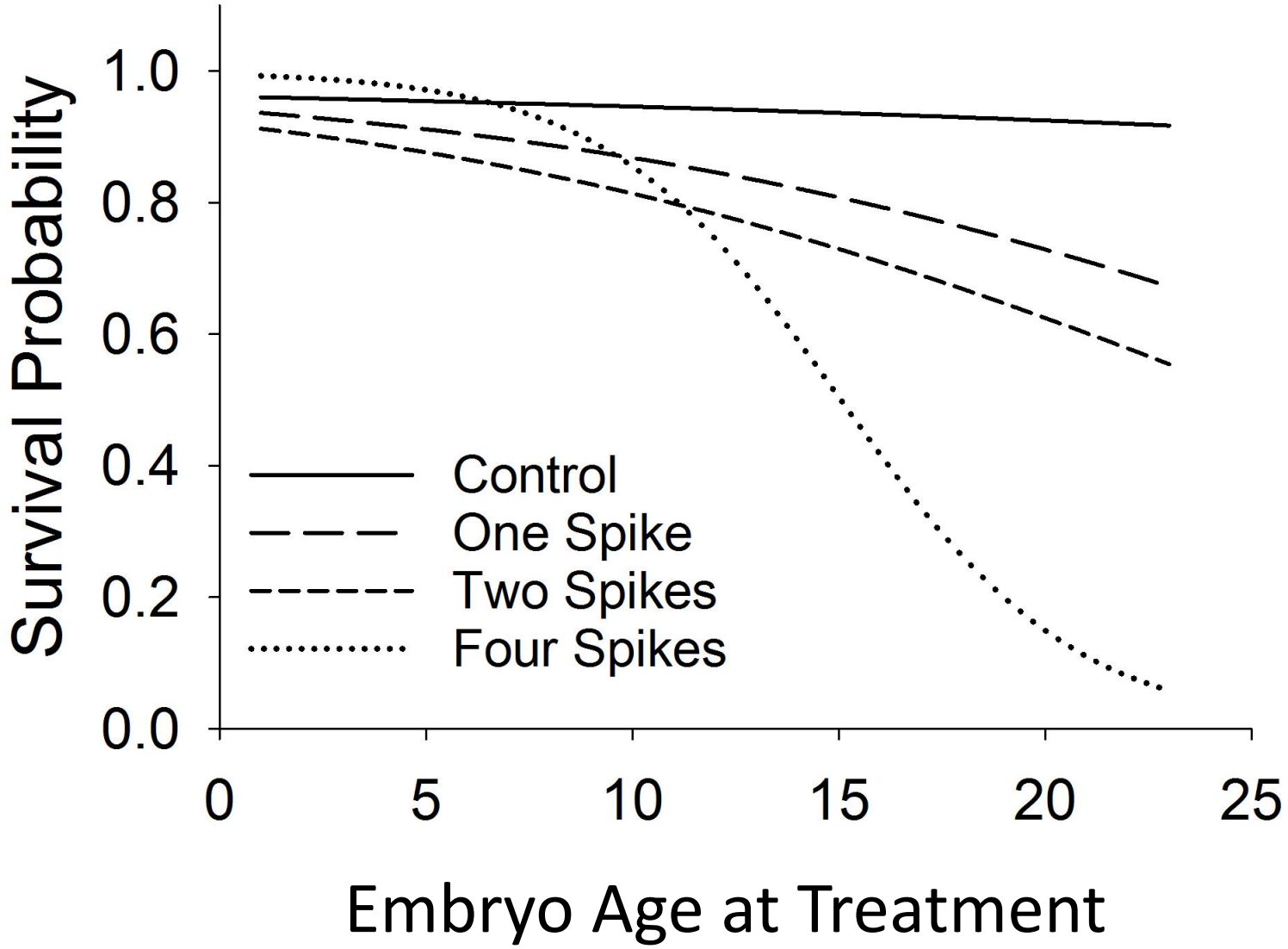

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Embryo Age at Treatment

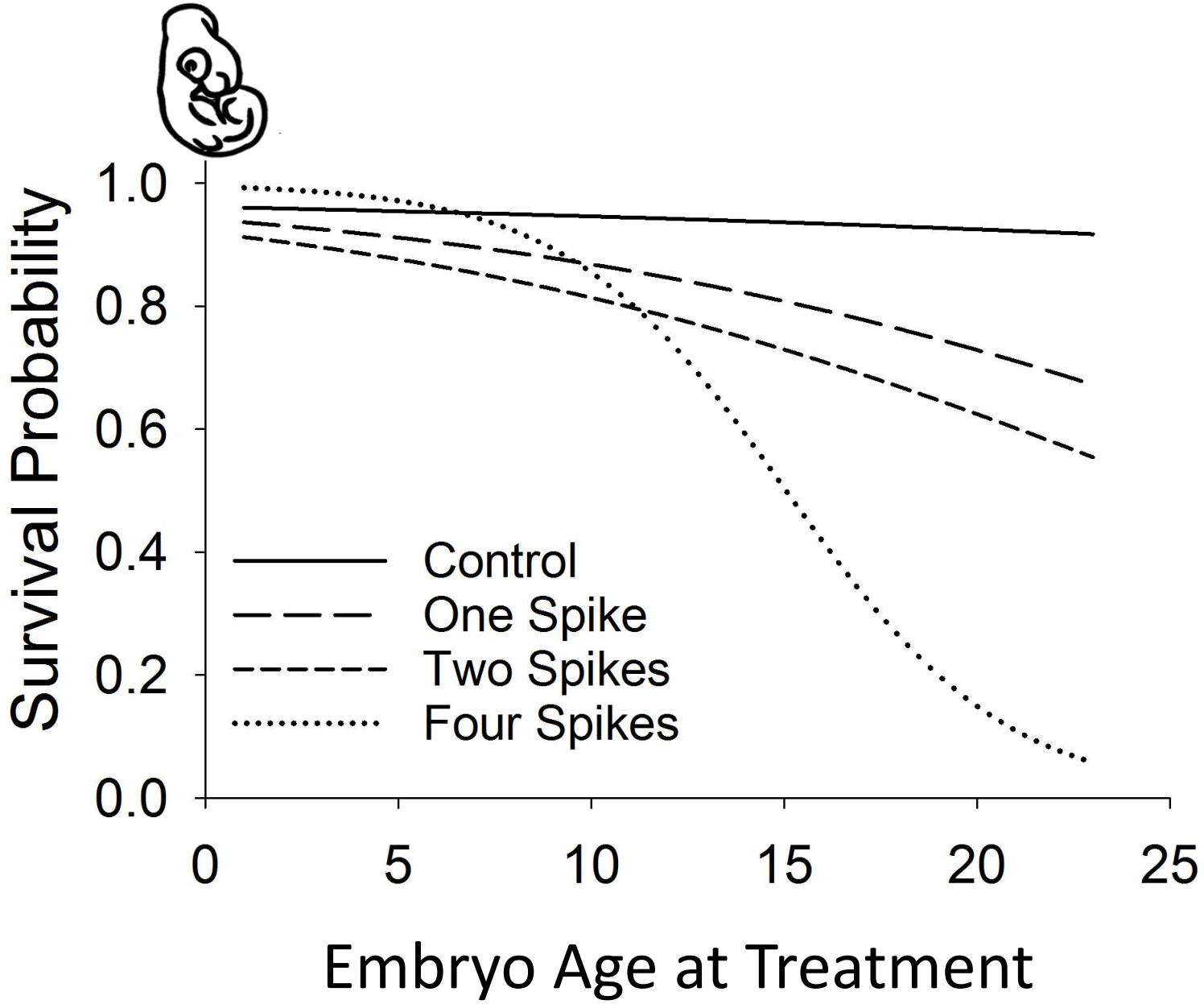

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
Control
0
5
10
15
20
25
Embryo Age at Treatment

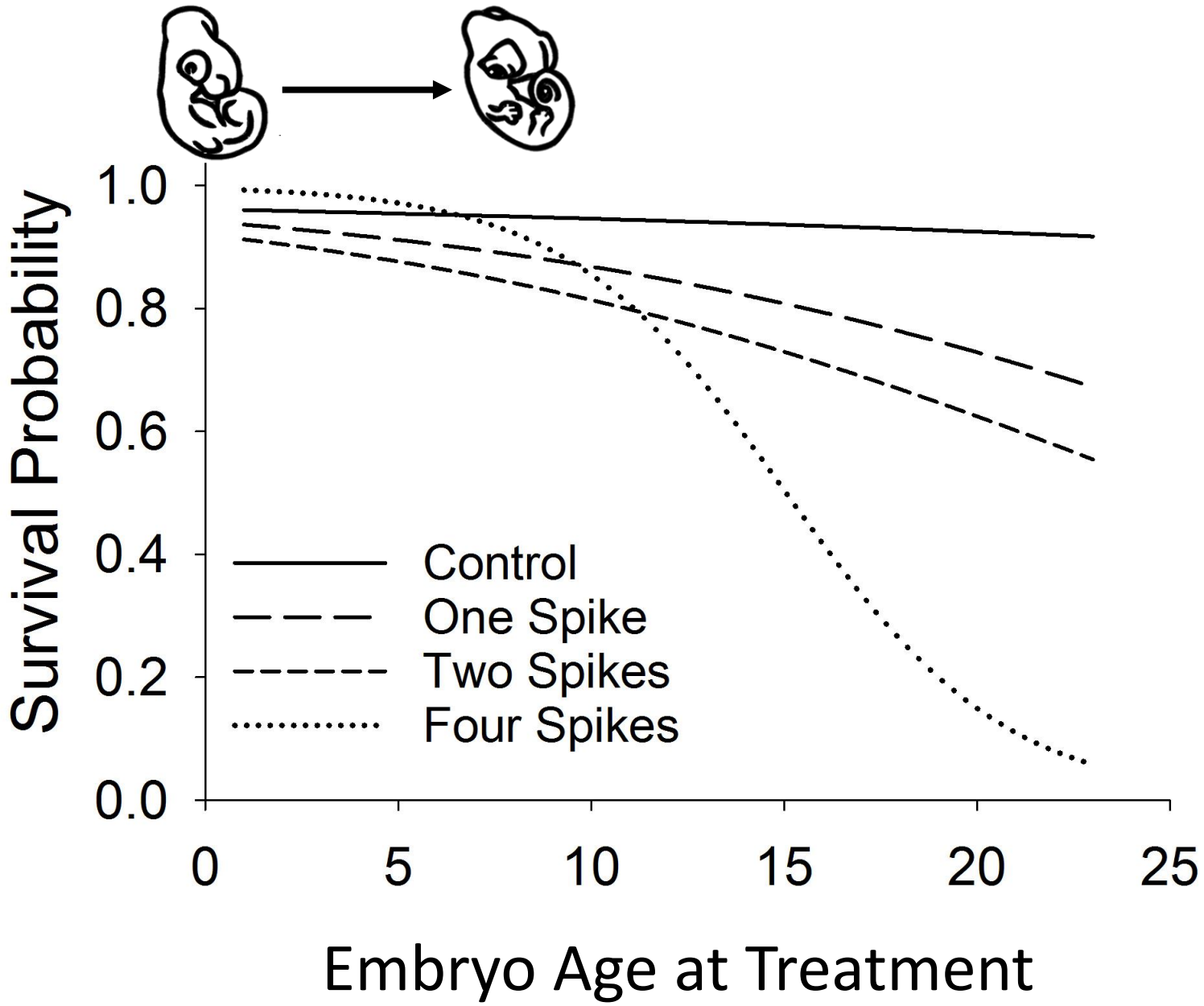

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
Control
One Spike
0
5
10
15
20
25
Embryo Age at Treatment

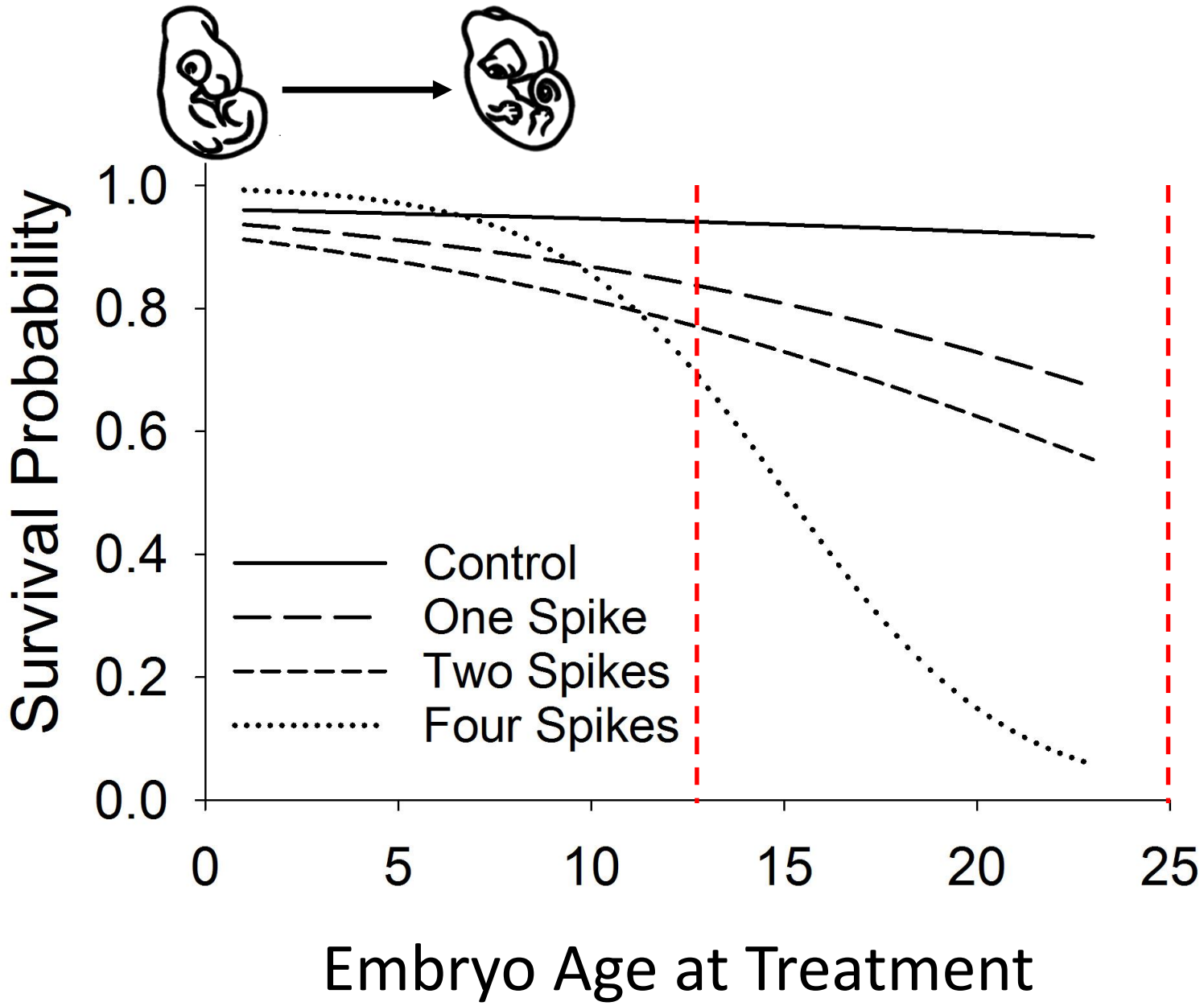

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
Control
Two Spikes
0
5
10
15
20
25
Embryo Age at Treatment


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
Control
Four Spikes
0
5
10
15
20
25
Embryo Age at Treatment


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
Control
One Spike
Two Spikes
Four Spikes
0
5
10
15
20
25
Embryo Age at Treatment


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Control
One Spike
Two Spikes
Four Spikes
Embryo Age at Treatment


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
Control
One Spike
Two Spikes
Four Spikes
Embryo Age at Treatment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1.0
0.8
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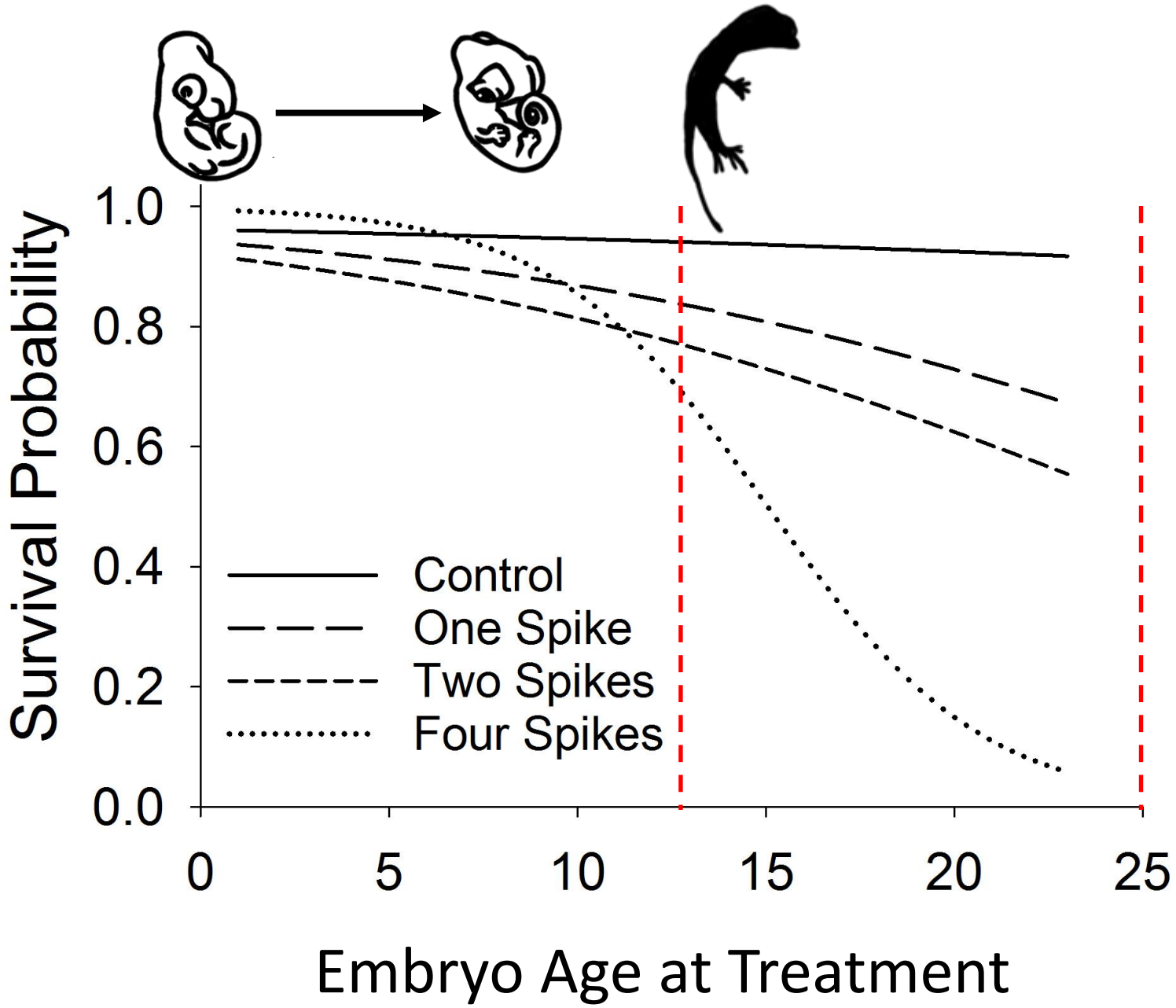
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0.6
0.4
0.2
0.0
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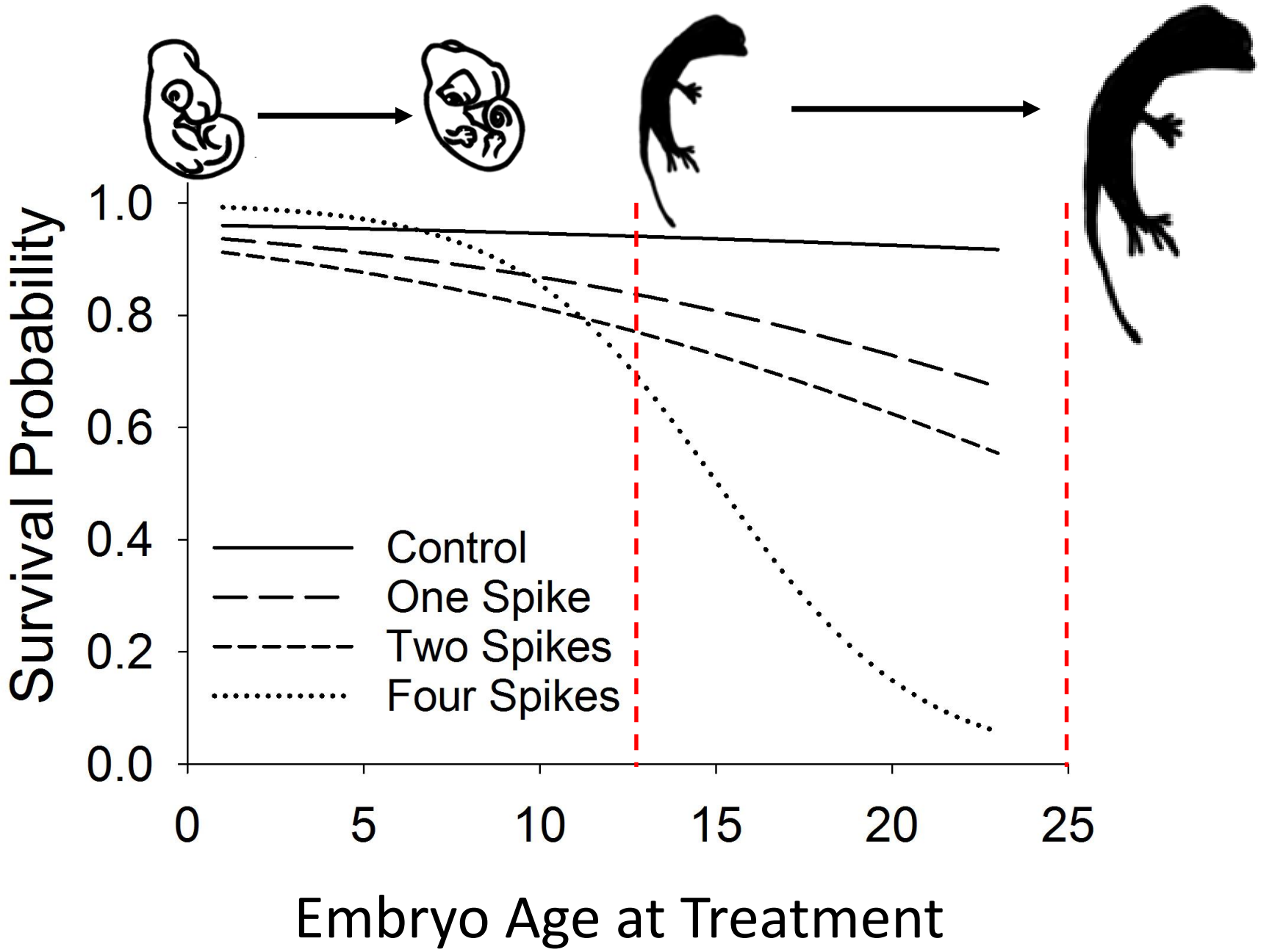
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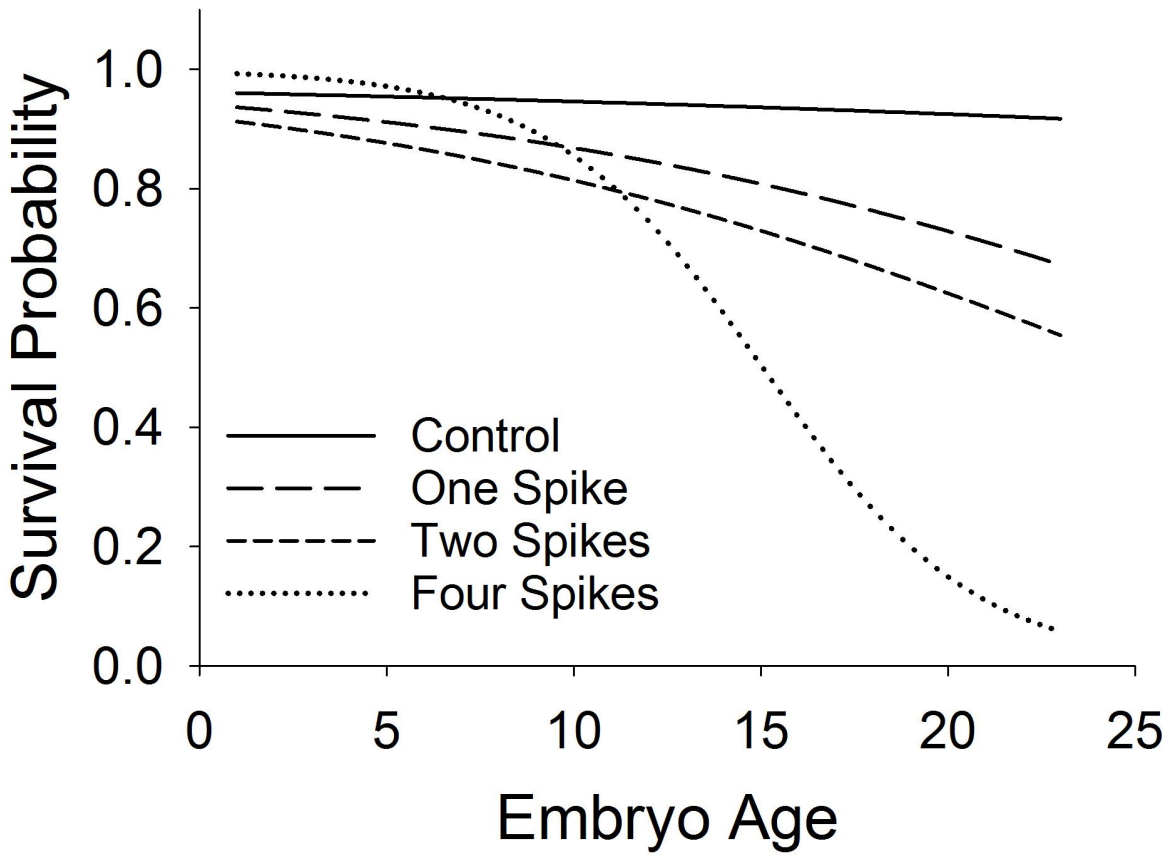
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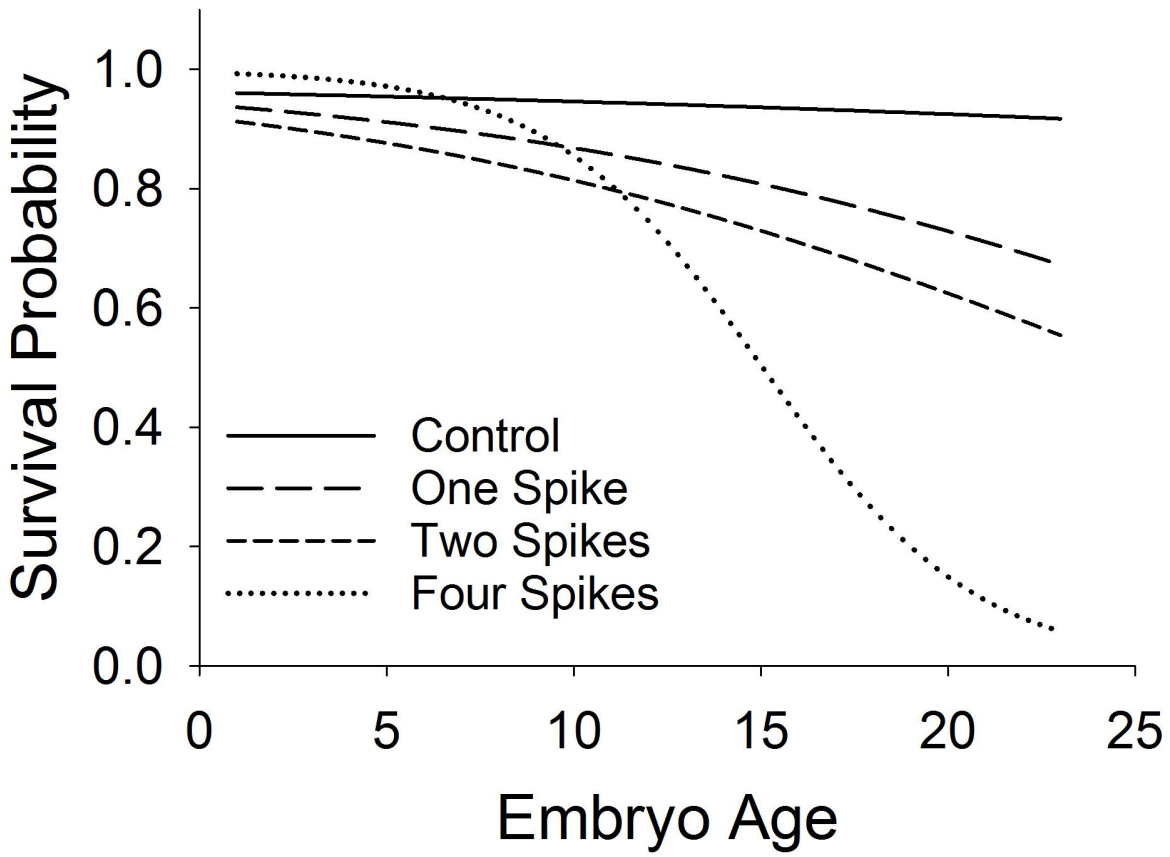
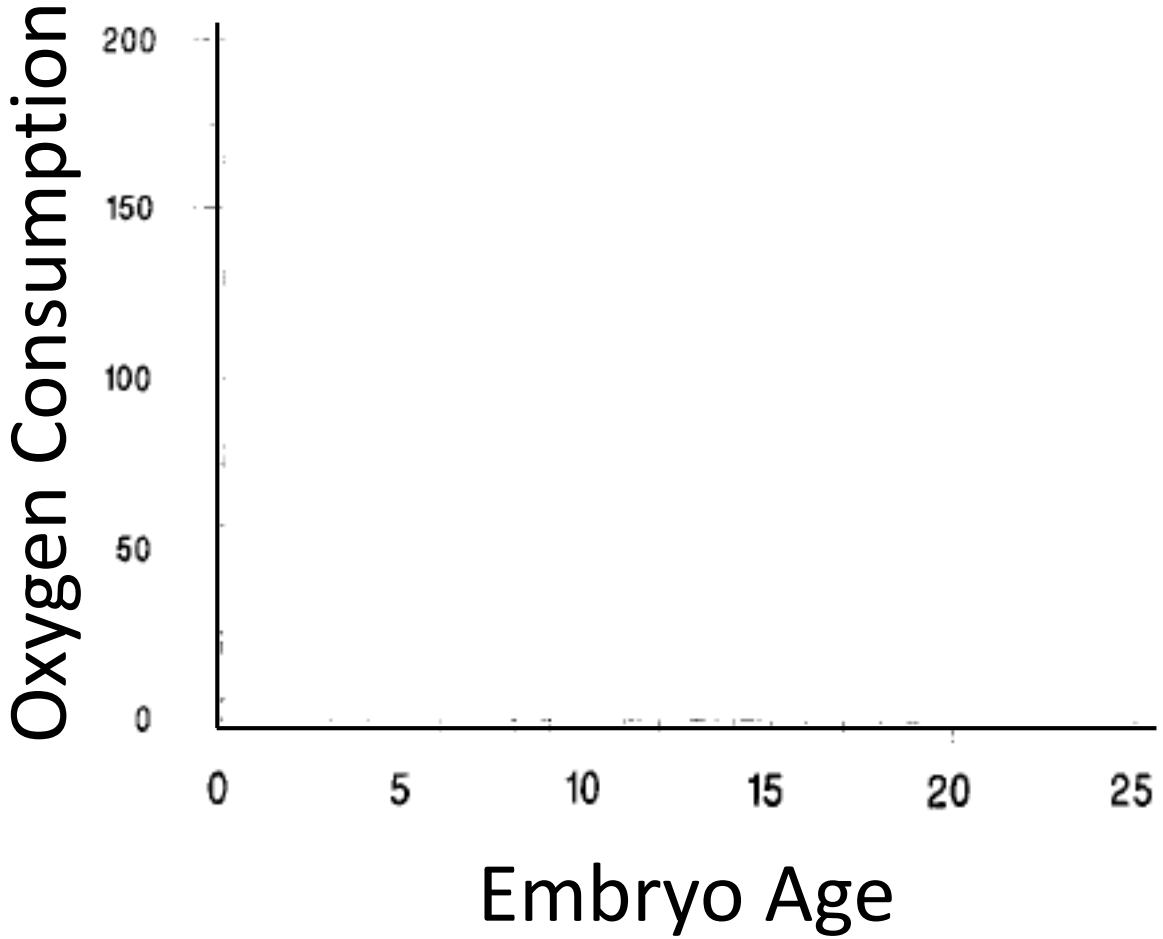
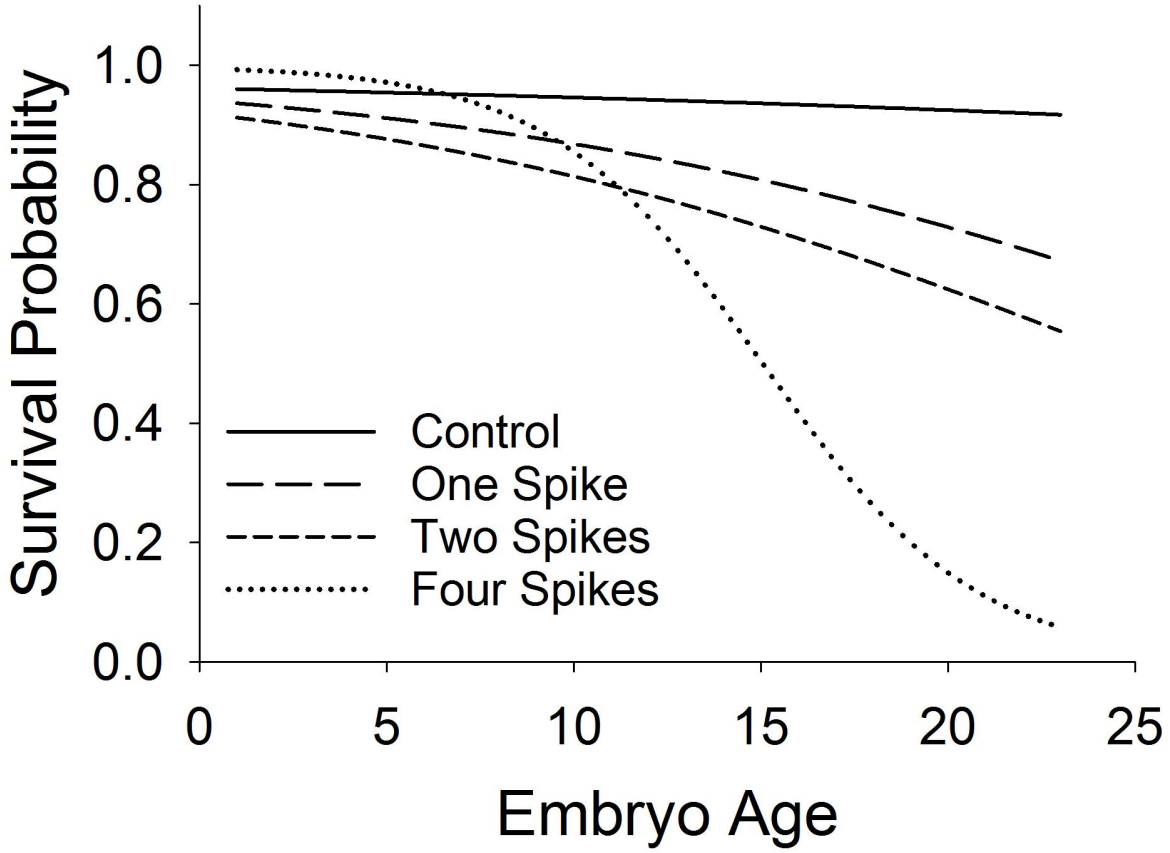
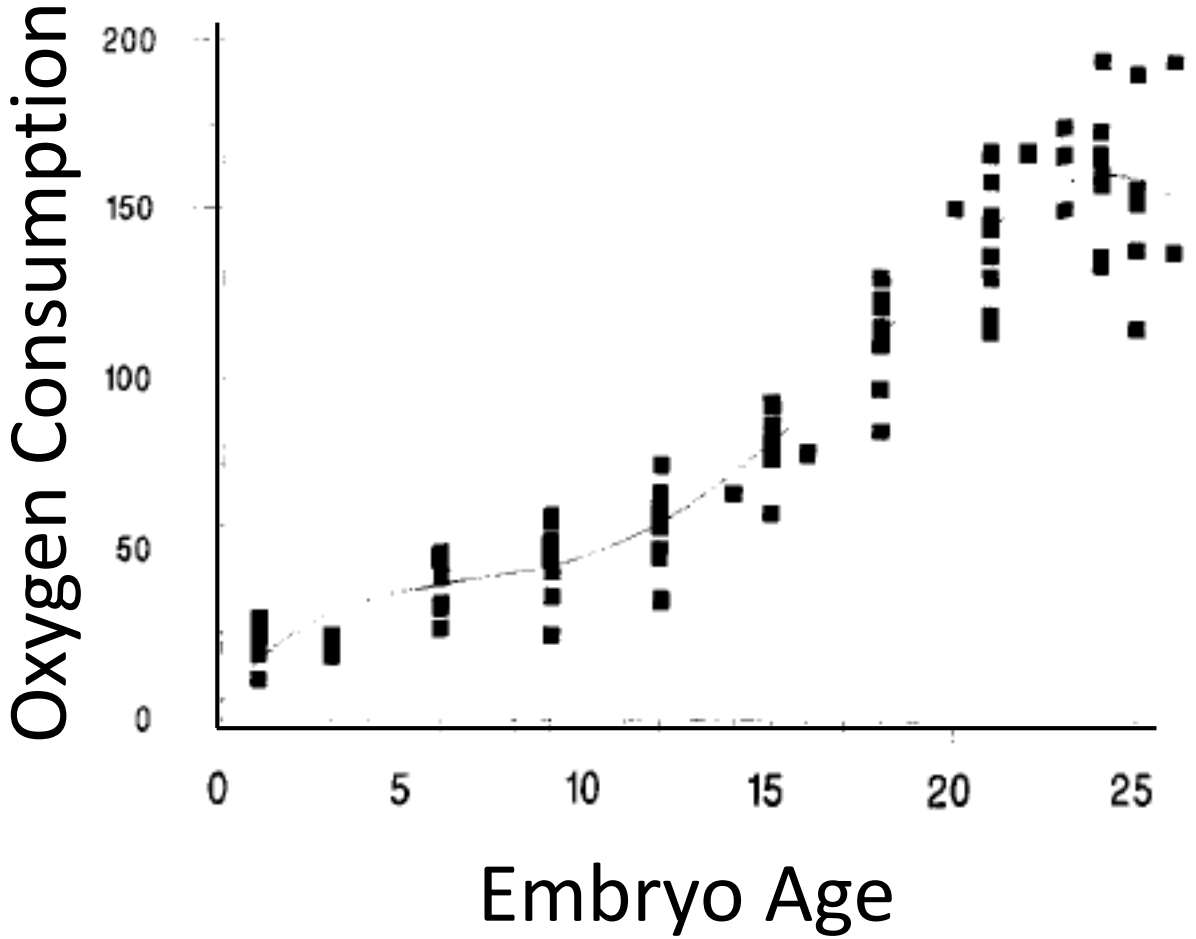




Thompson & Stewart; CBP 1997

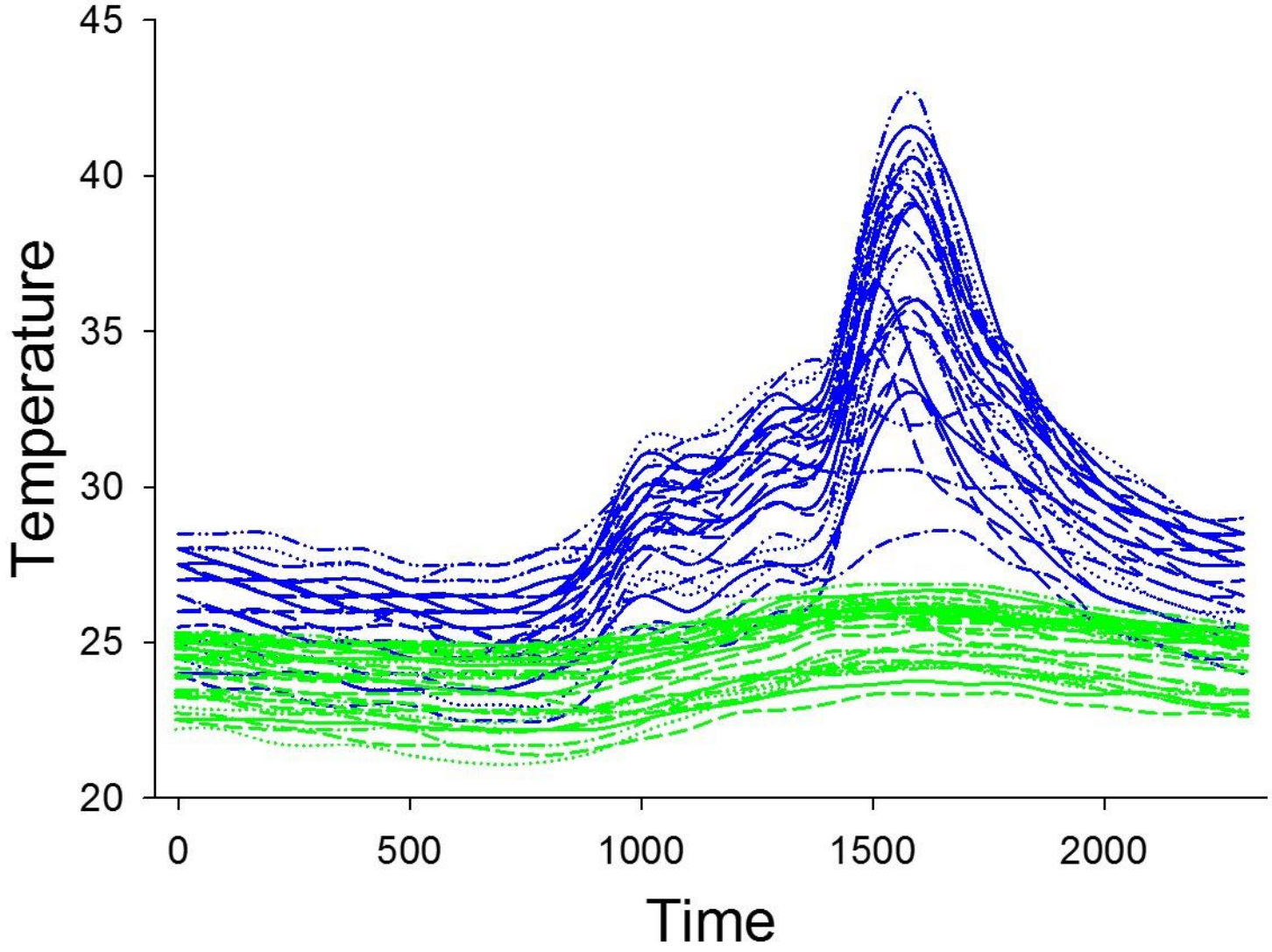




Thompson & Stewart; CBP 1997

Thermal Extremes

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



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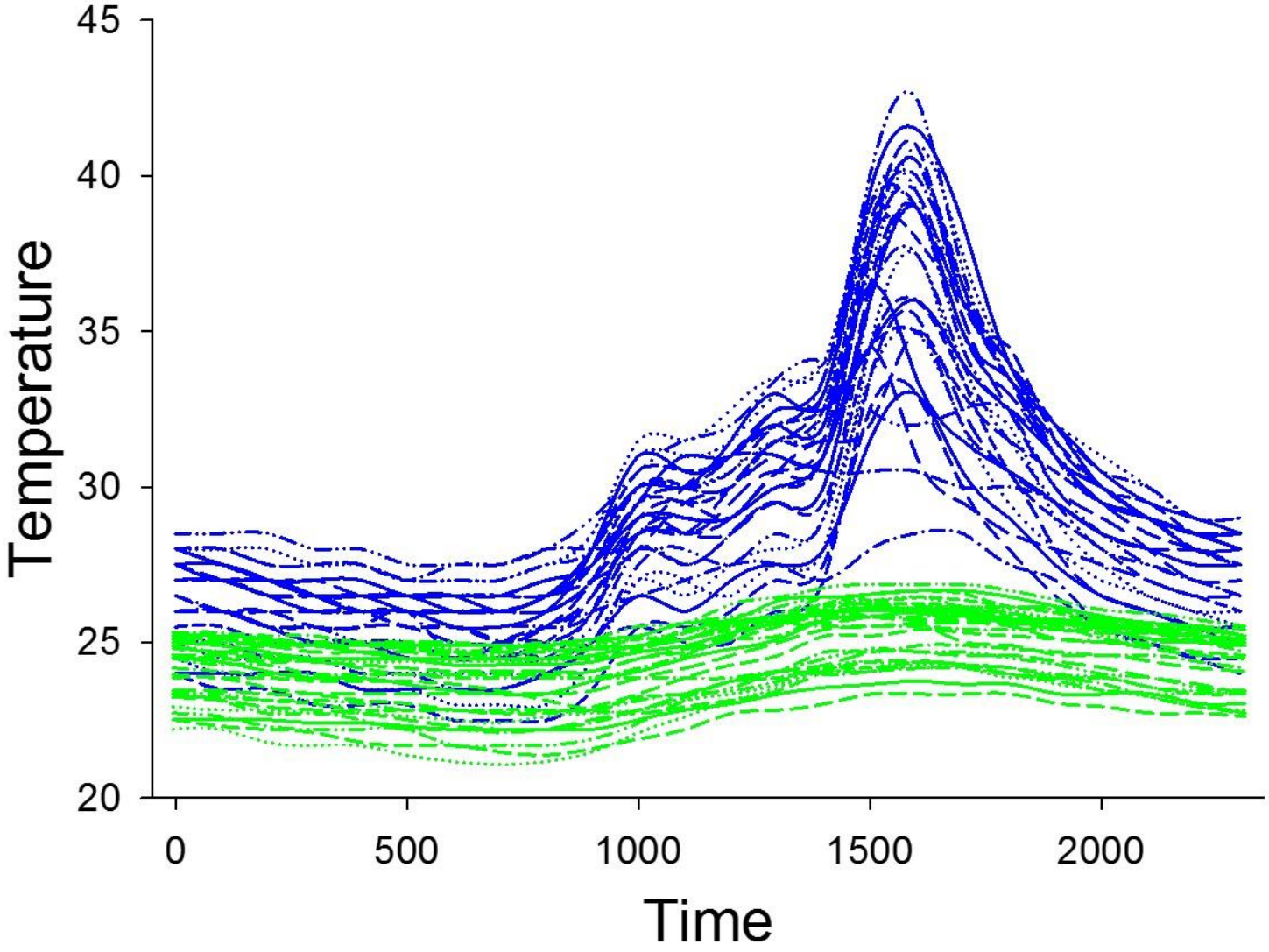
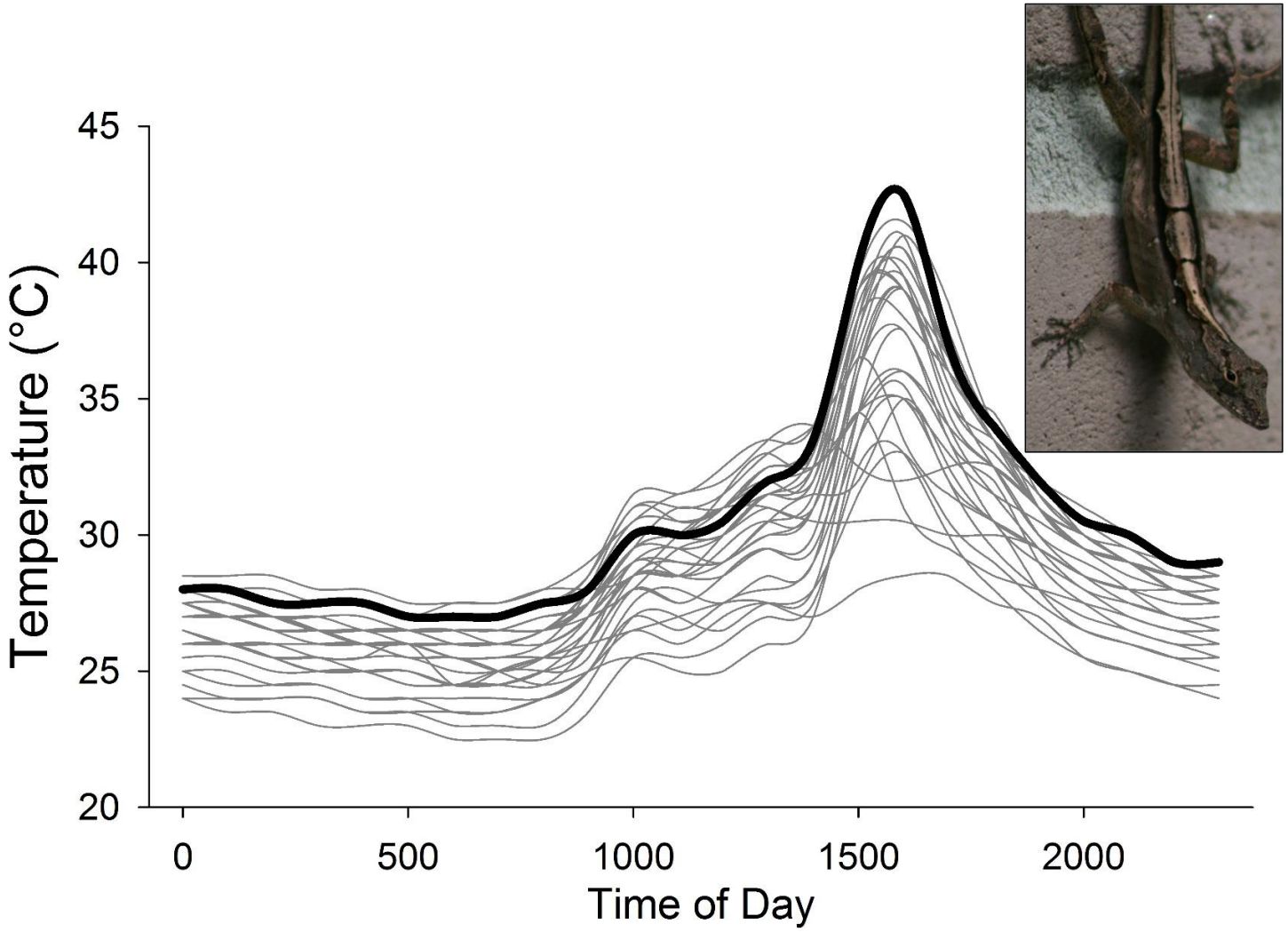
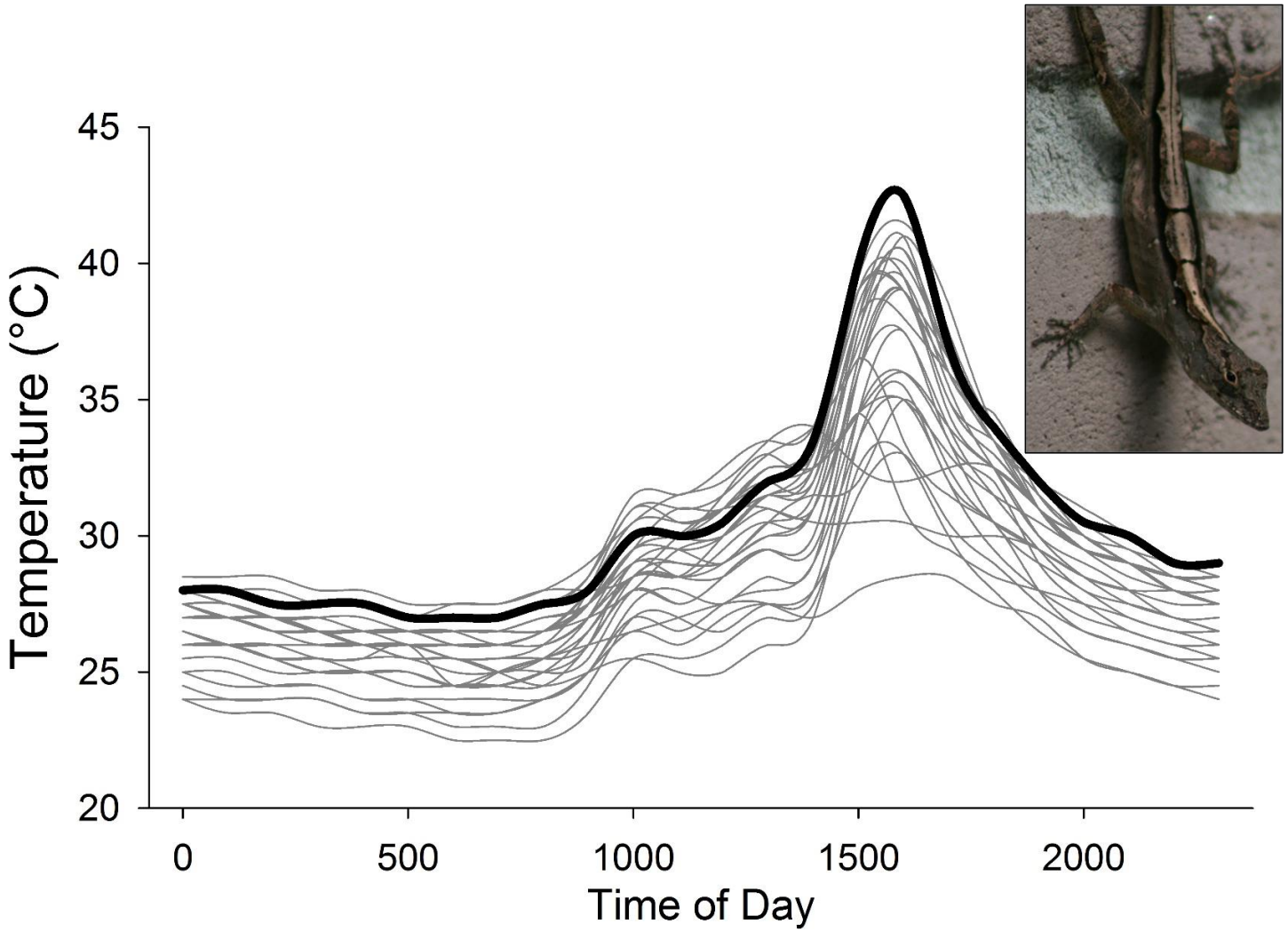


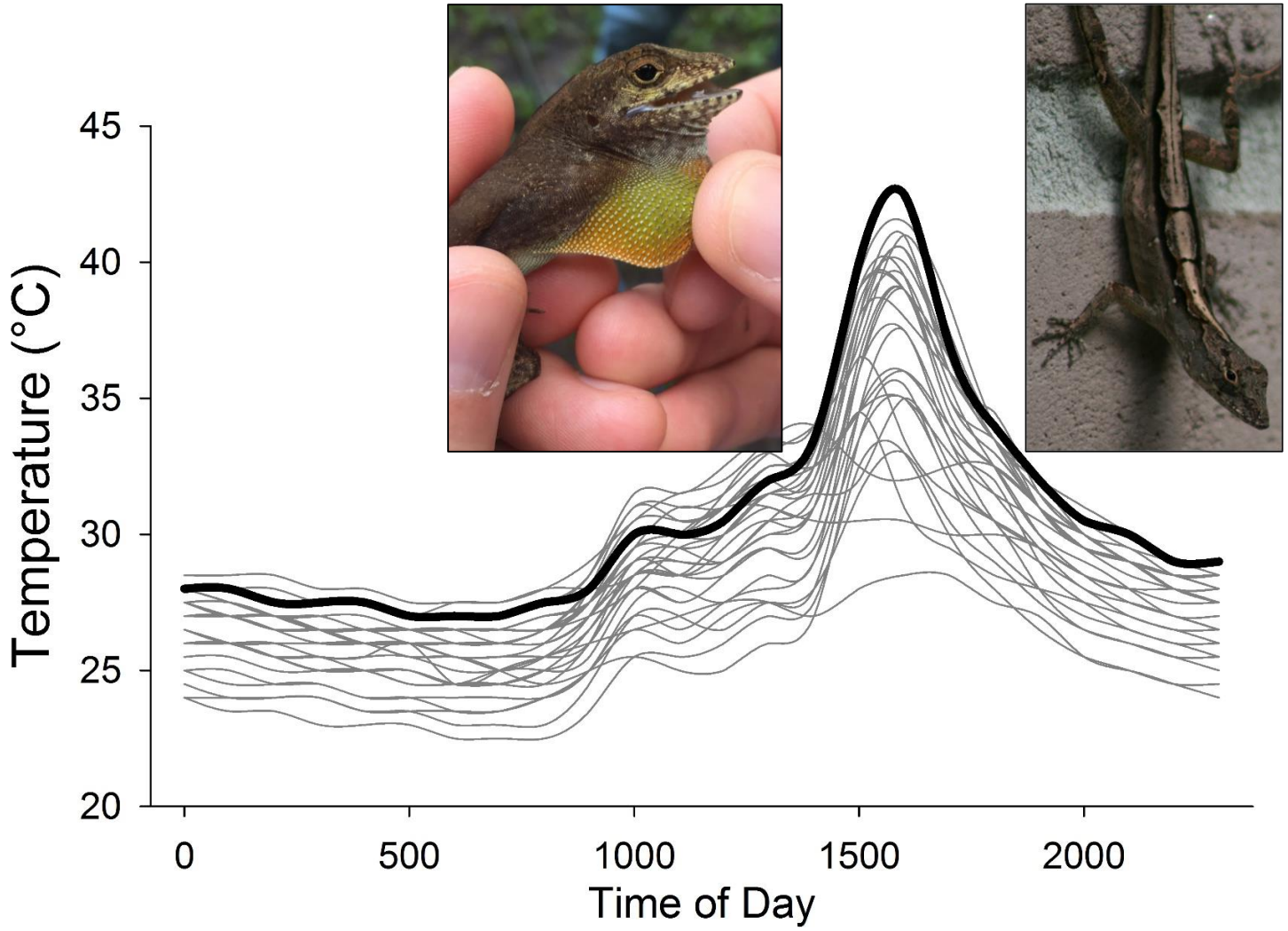
Experimental Design – Species



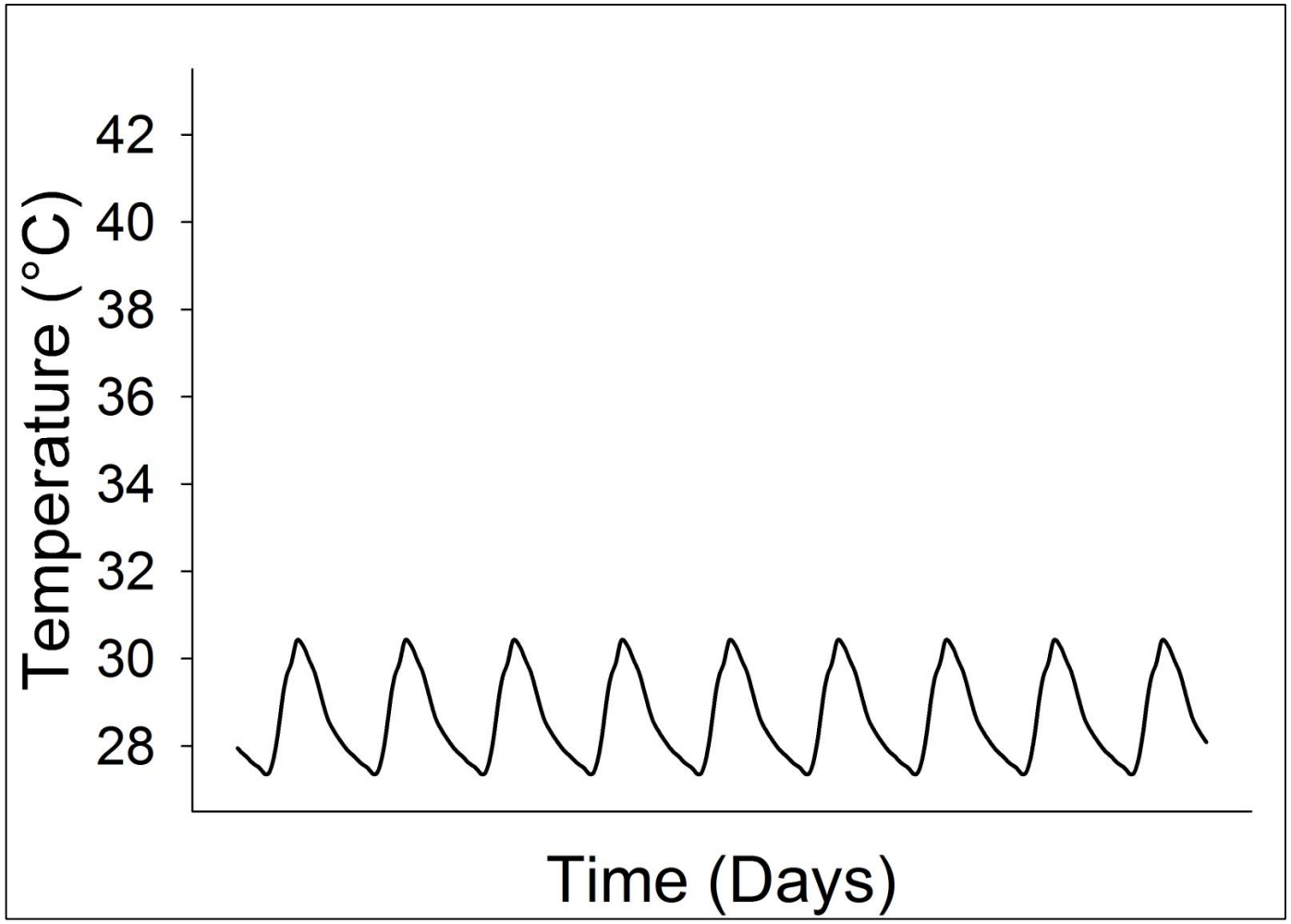
Experimental Design – Species



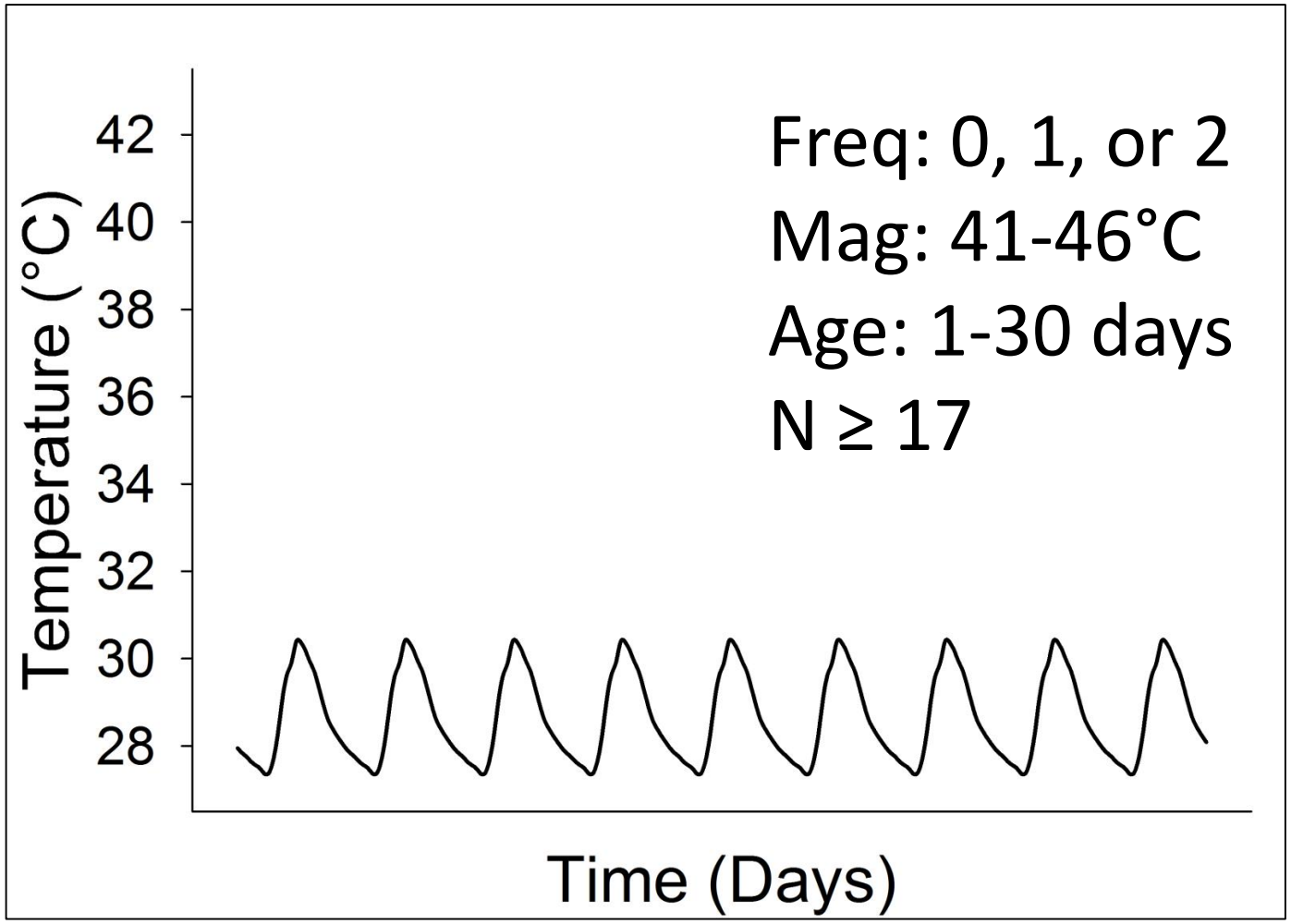
Experimental Design – Species



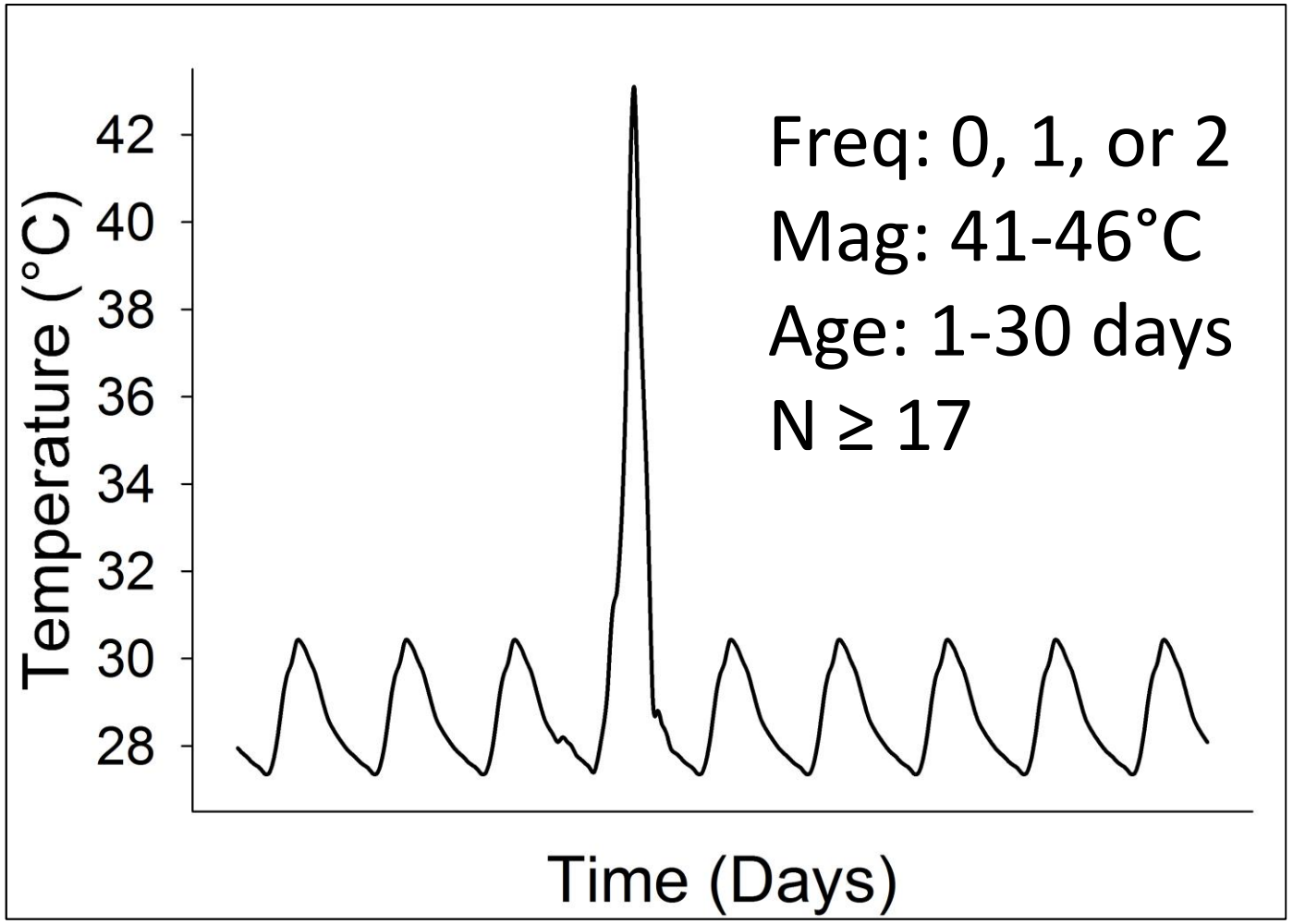
Experimental Design – Species



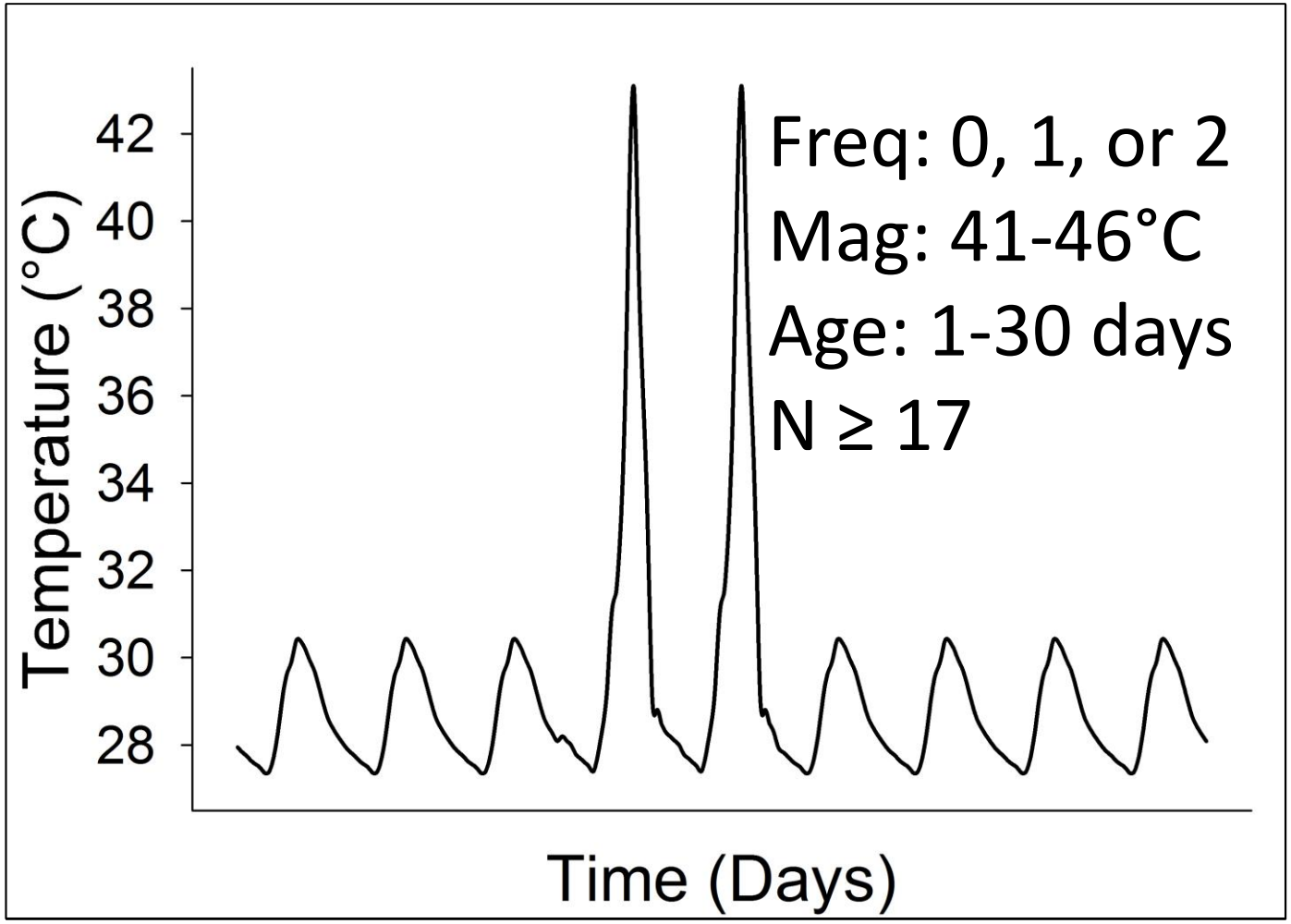
Experimental Design – Species

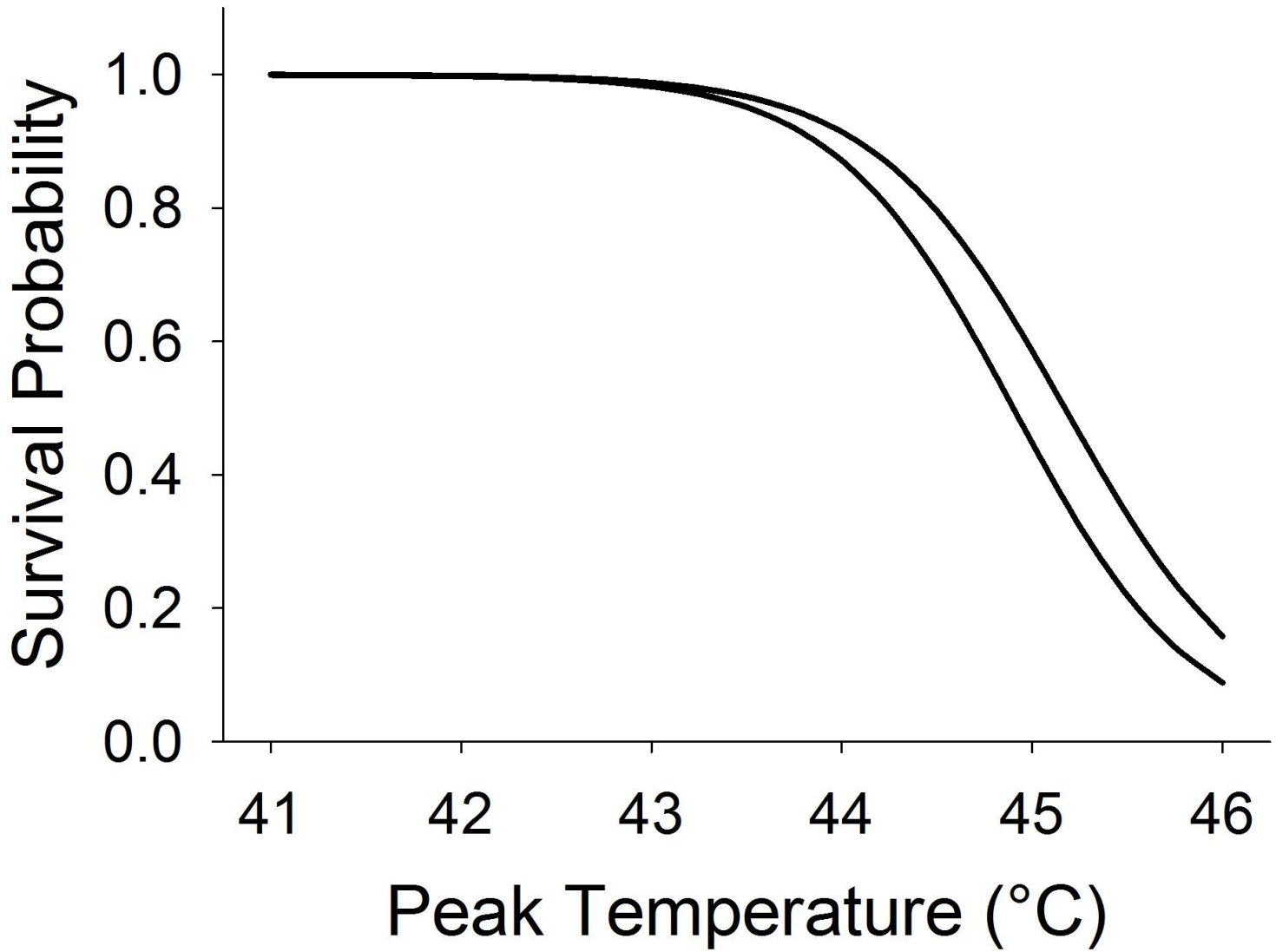


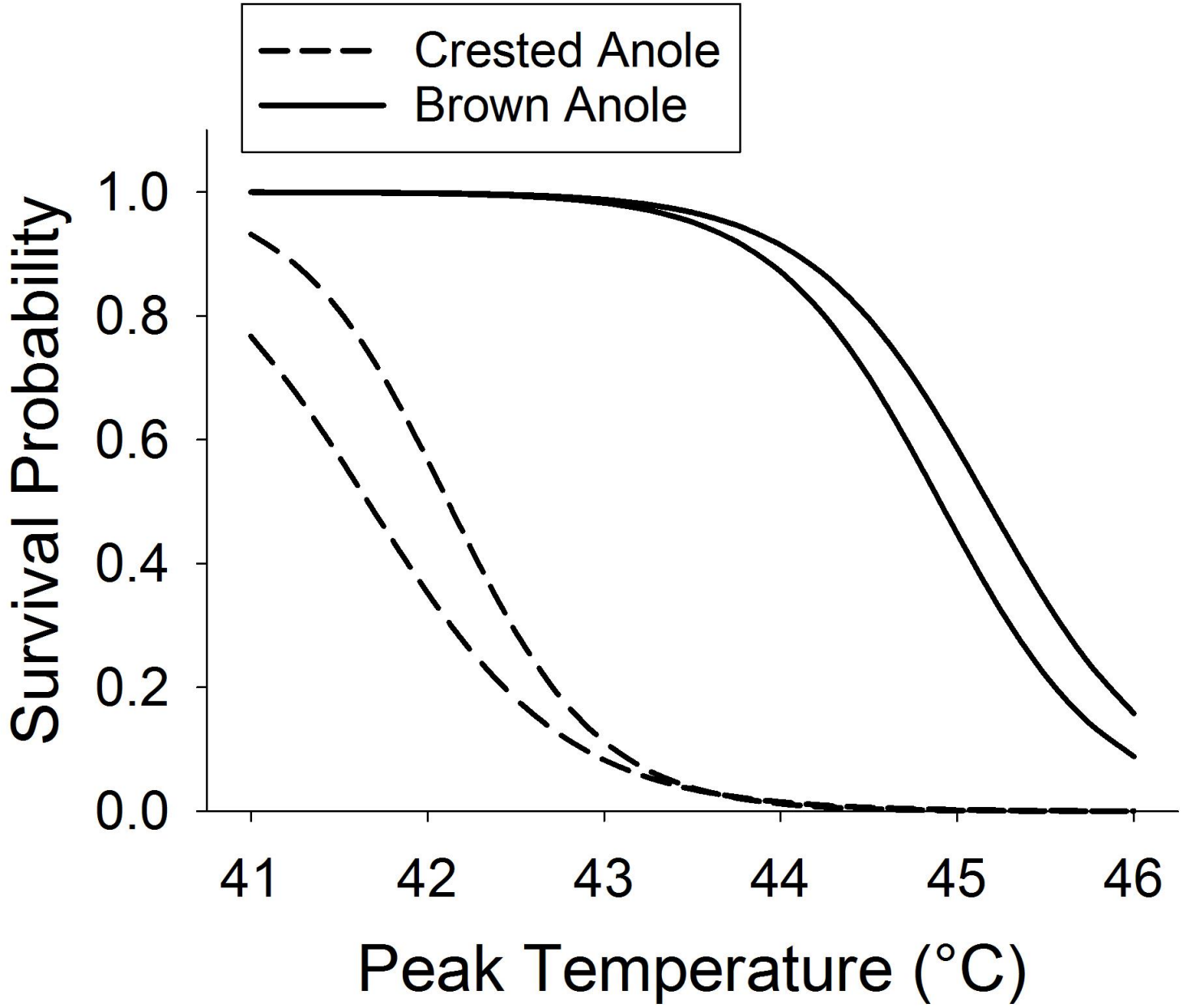
Experimental Design – Species

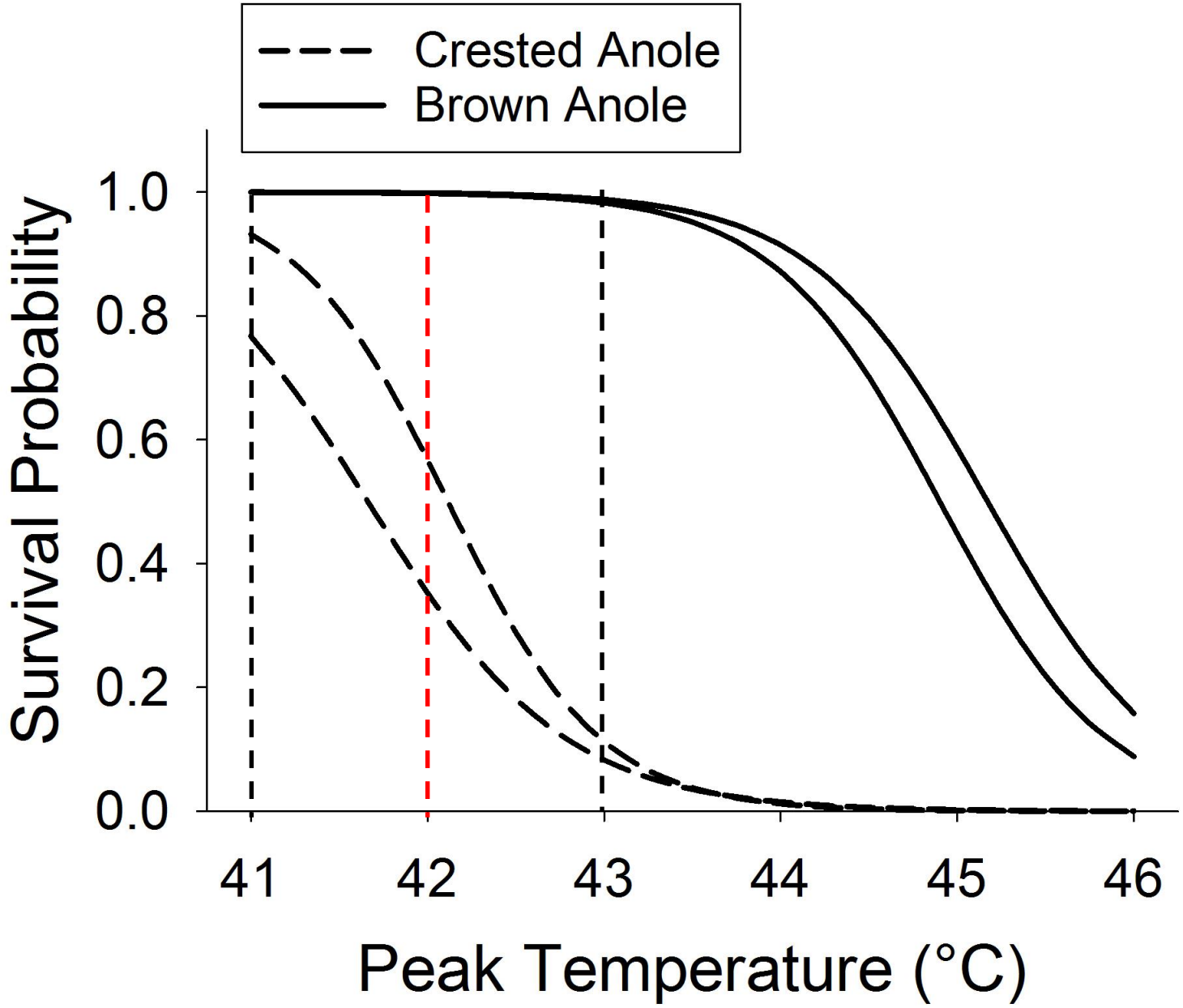


Experimental Design – Species




Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)


Crested Anole
Brown Anole
Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
41
42
43
44
45
46
Peak Temperature (°C)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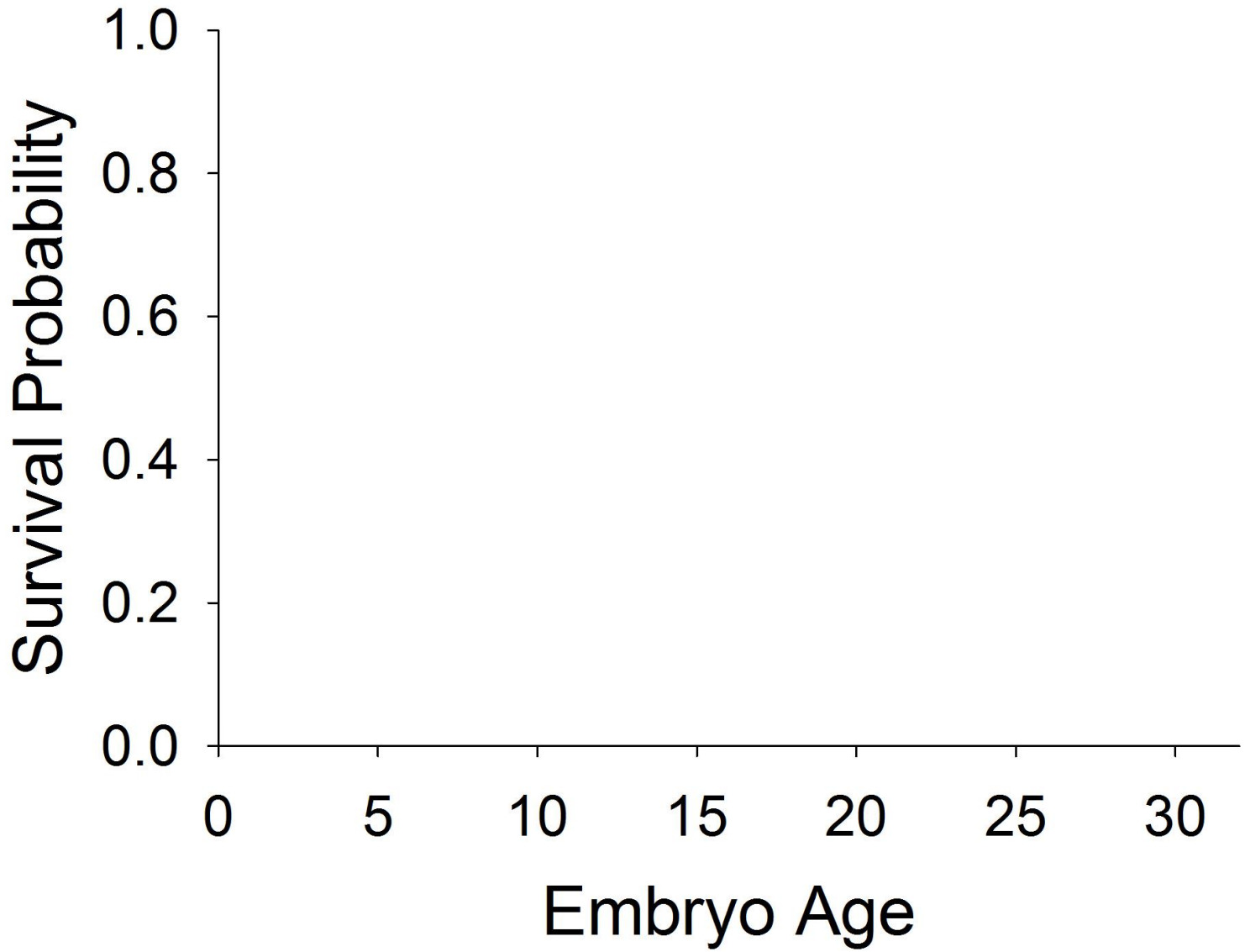
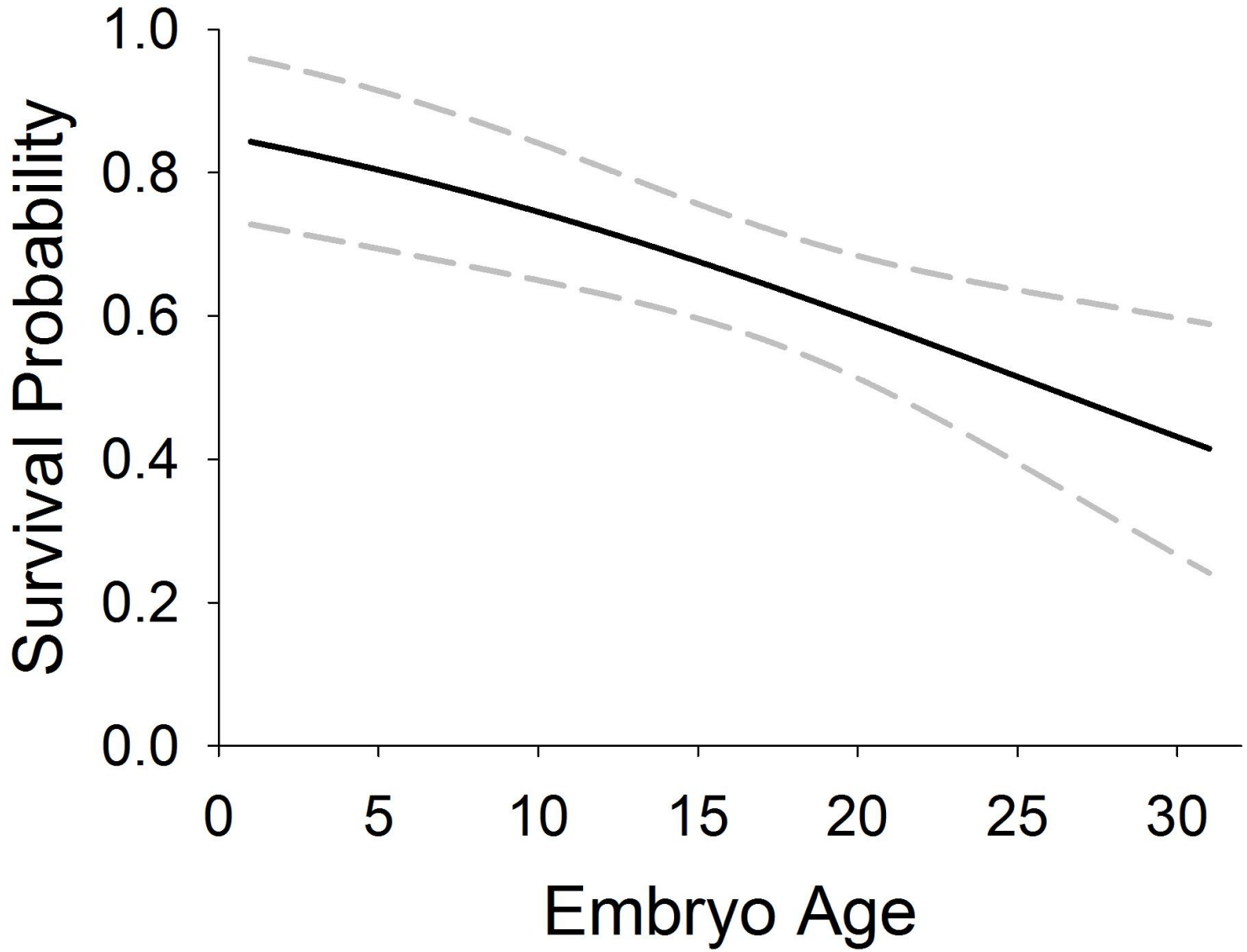

Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
Embryo Age


Survival Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
Embryo Age

Thermal Extremes

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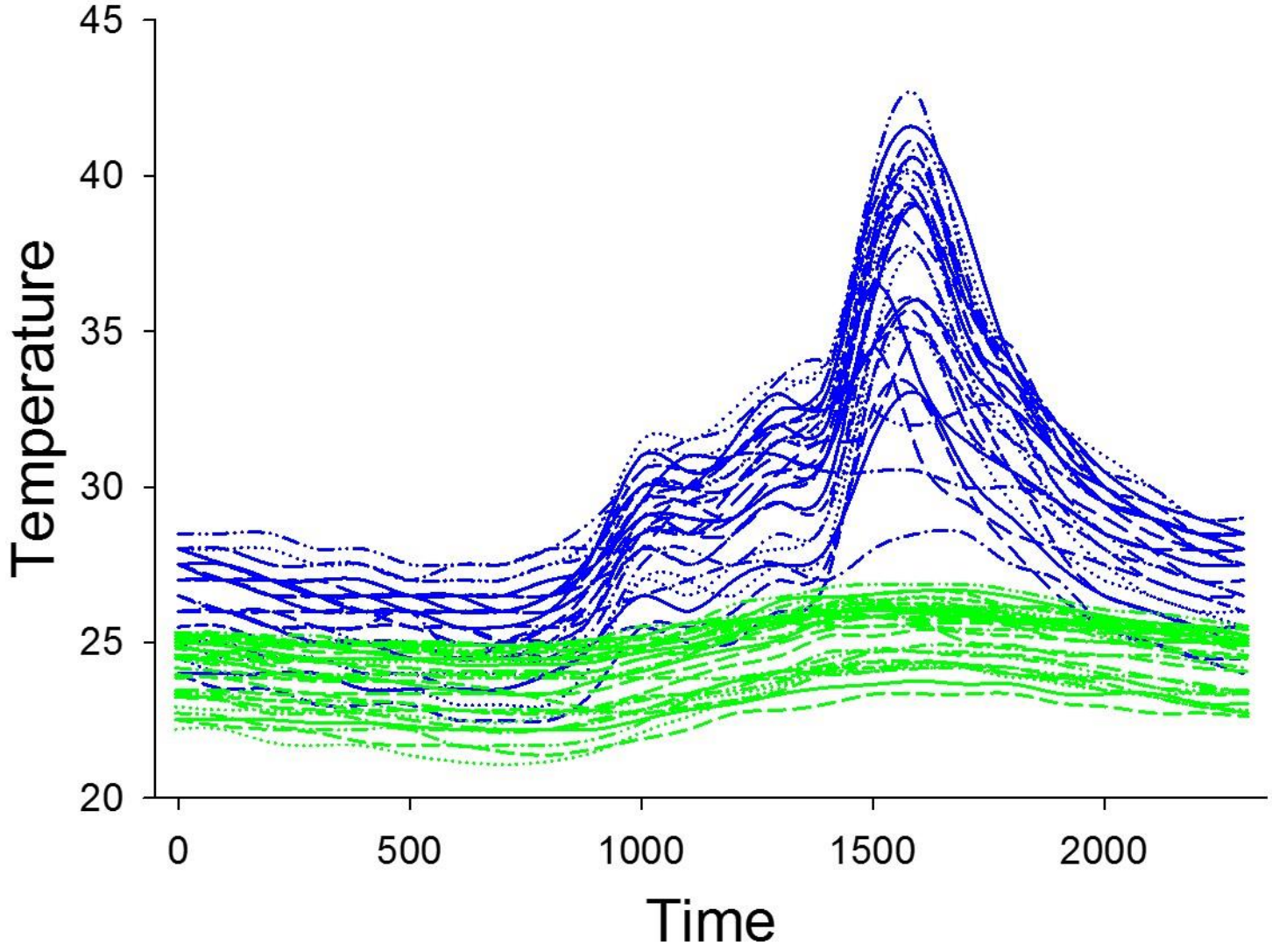

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Thermal Extremes

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- ~2°C window
- 2°C increase due to climate change is reasonable

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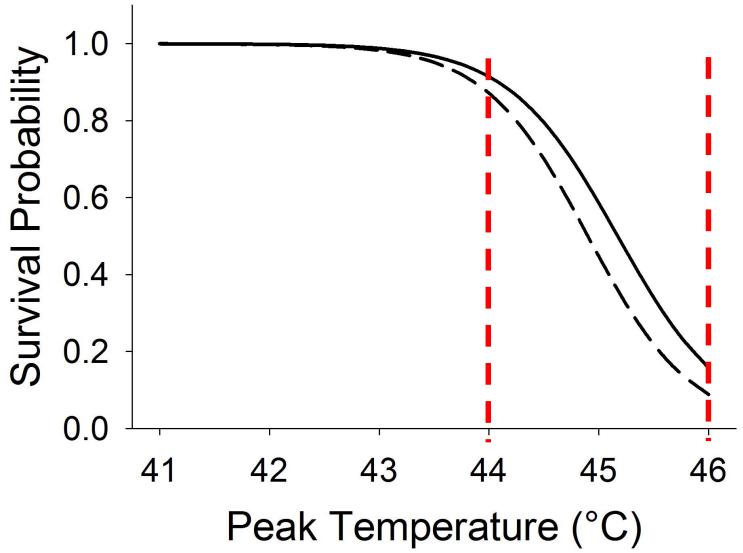
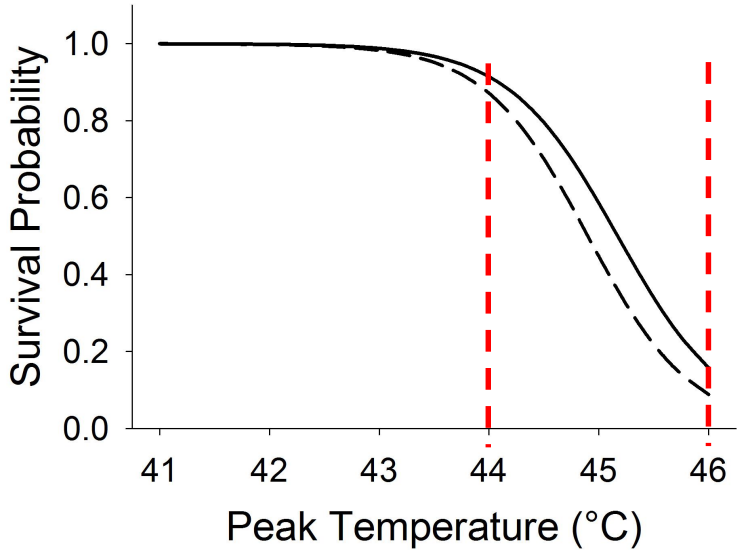


Thermal Extremes

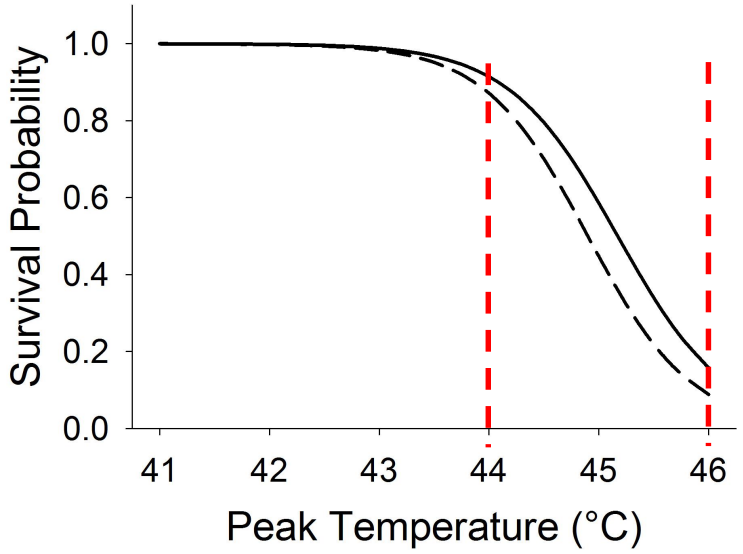
- Magnitude (how hot?)
- **Frequency (how often?)**
- Timing (how old?)
- Species (how general?)



Thermal Extremes

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

- Lowers survival
- Increased frequency closes the ‘survival window’



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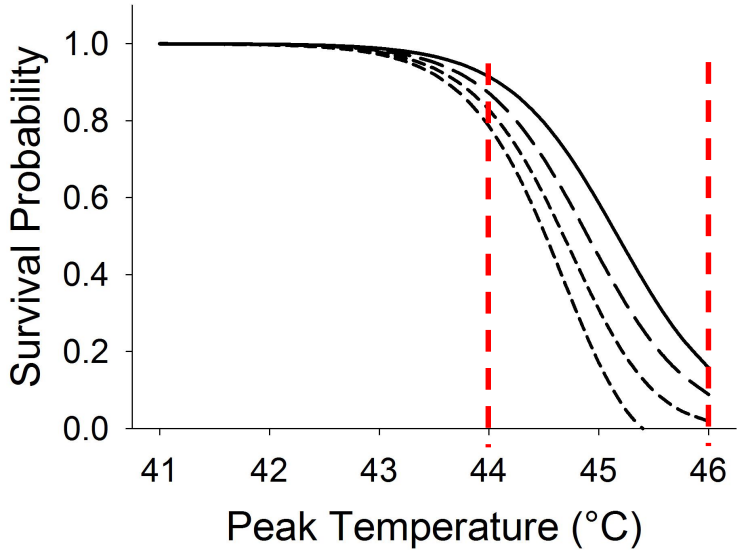

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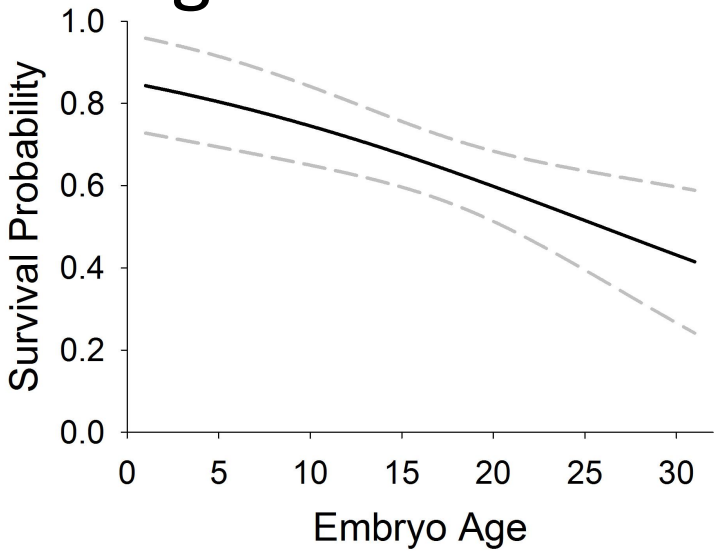
- Older embryos less robust (oxygen demand)
- Age likely interacts with magnitude and frequency



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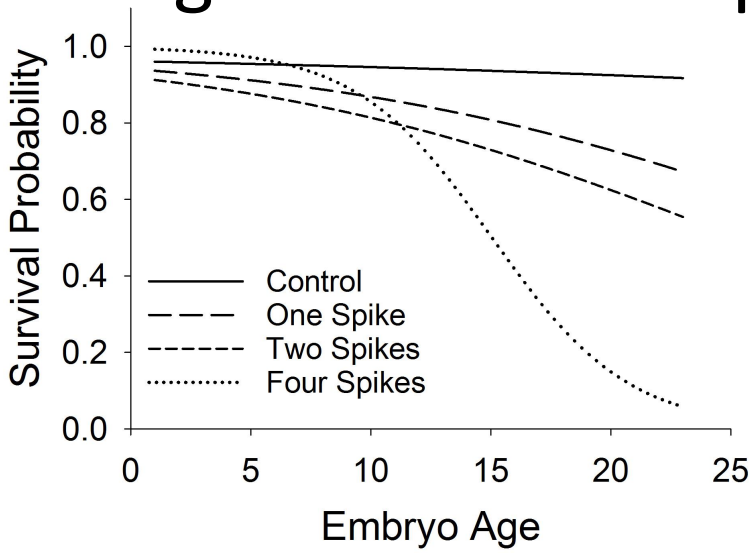

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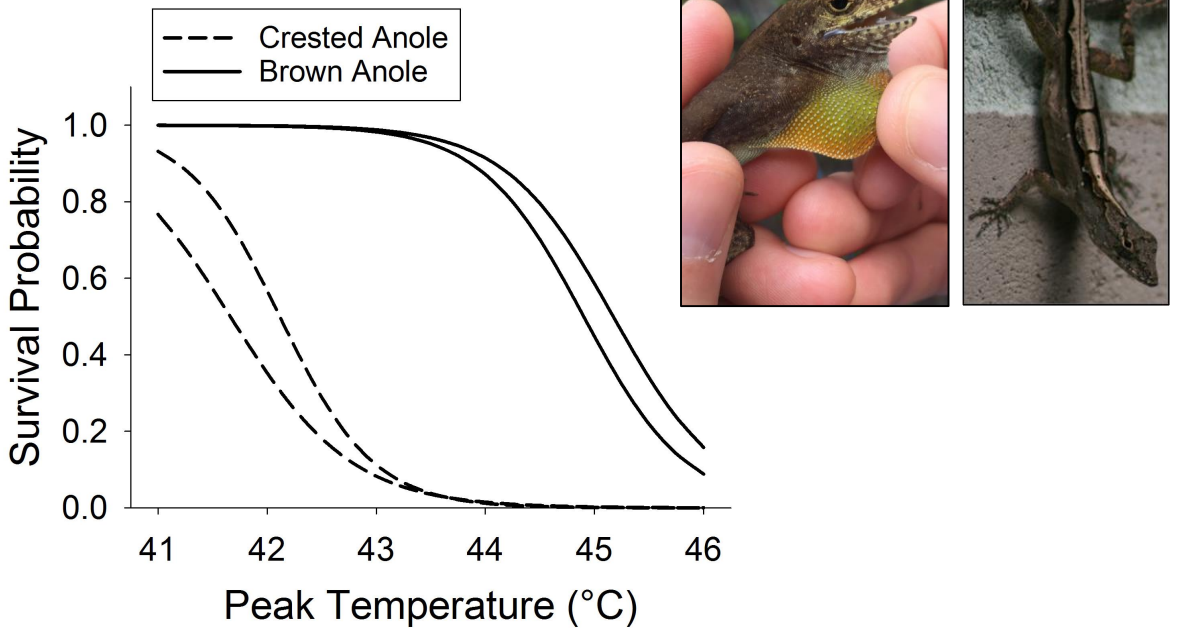
Thermal Extremes

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

- Results not necessarily generalizable



Acknowledgements

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