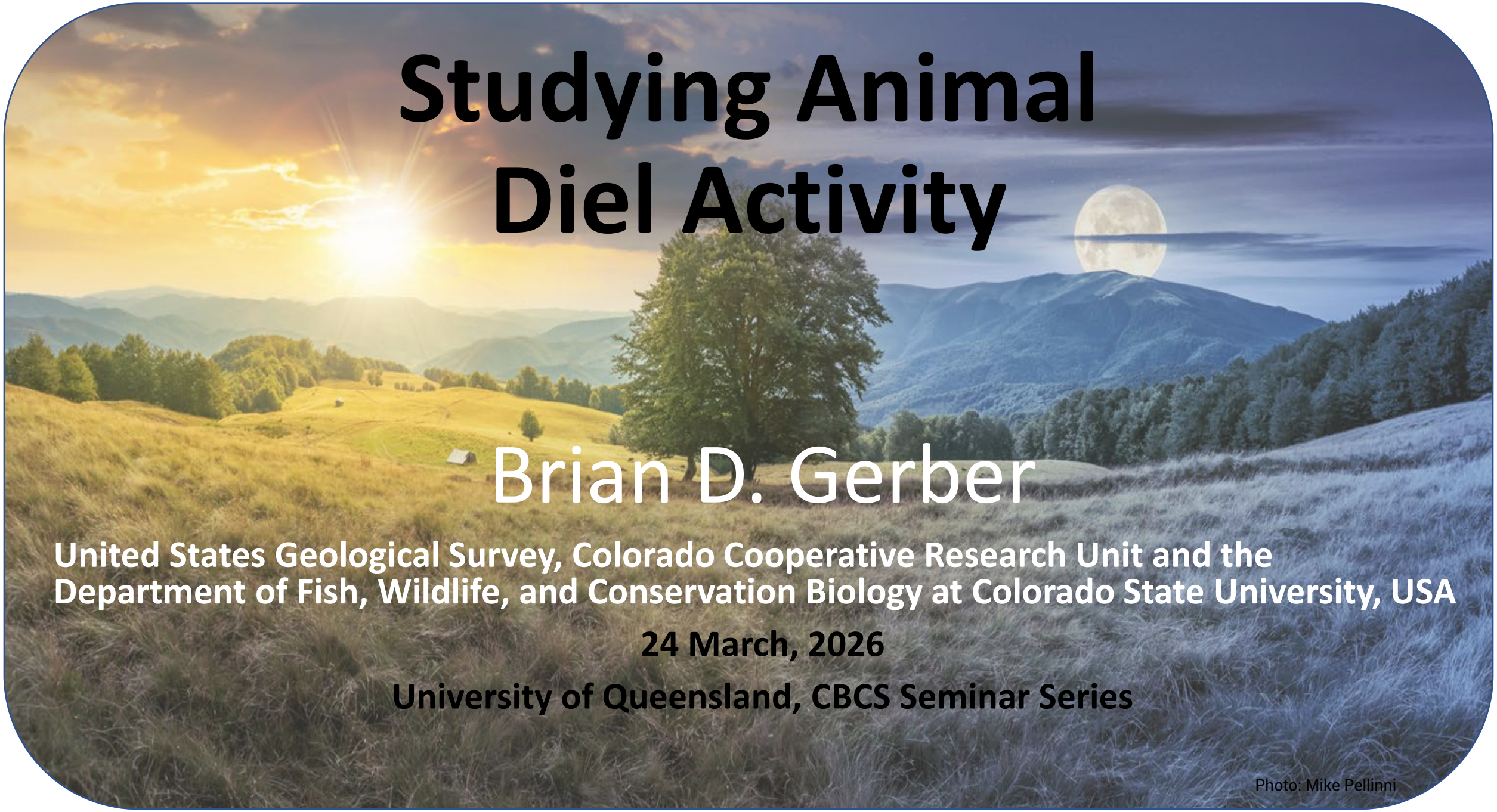
Studying Animal Diel Activity



Brian D. Gerber

United States Geological Survey, Colorado Cooperative Research Unit and the Department of Fish, Wildlife, and Conservation Biology at Colorado State University, USA

24 March, 2026

University of Queensland, CBCS Seminar Series

Photo: Mike Pellinni

Outline

1) Context

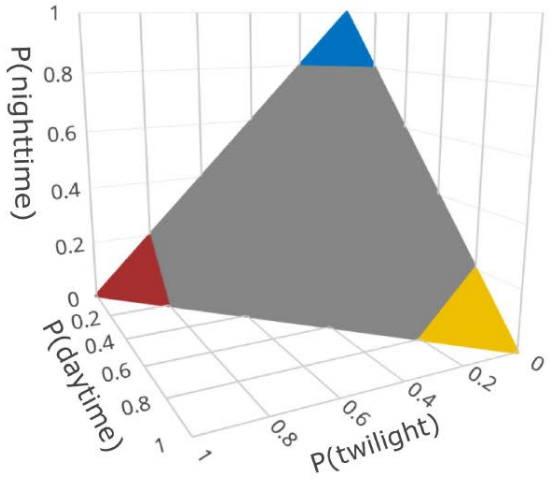


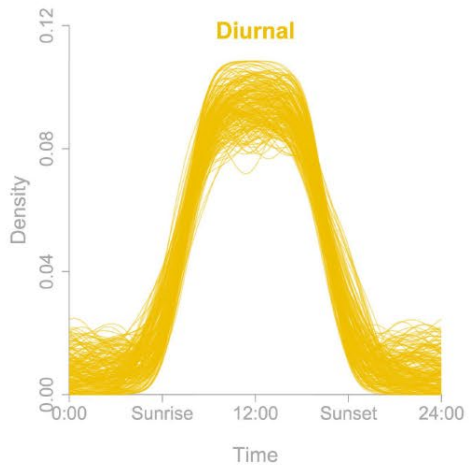
‘Diel’ - denoting or involving a period of 24 hours

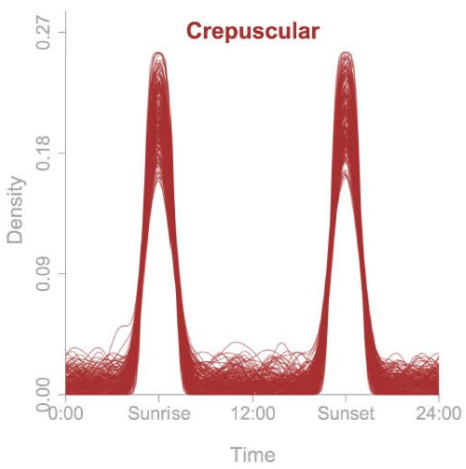
Outline

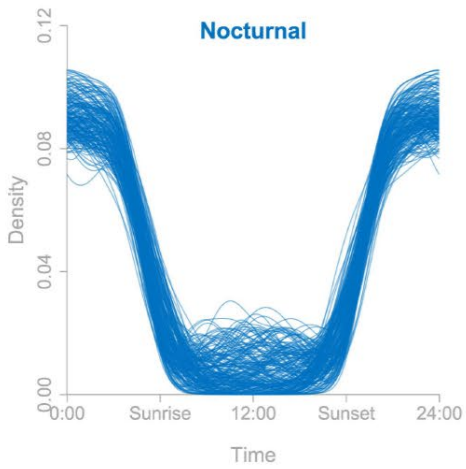
1) Context

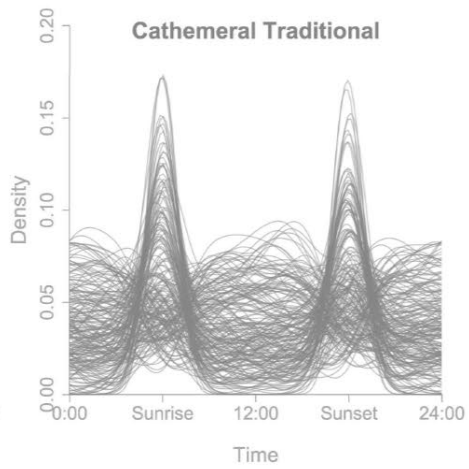
2) A framework









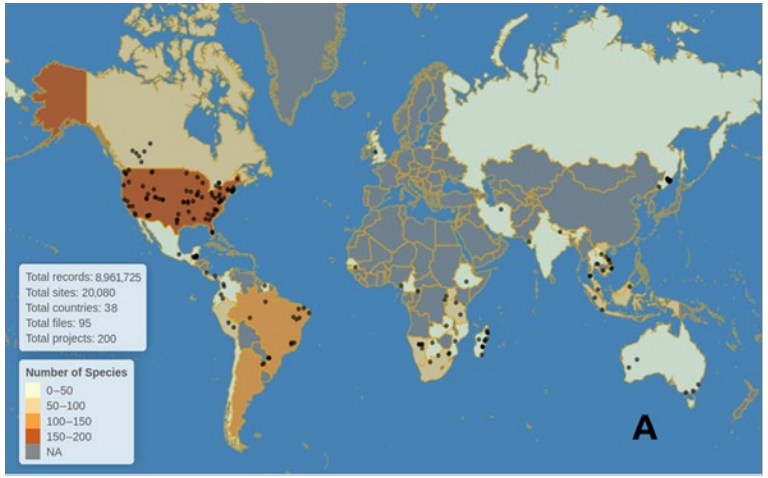


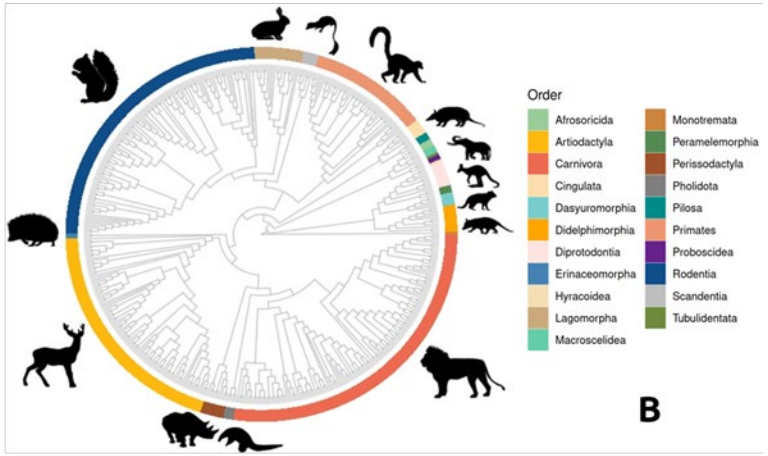
Outline

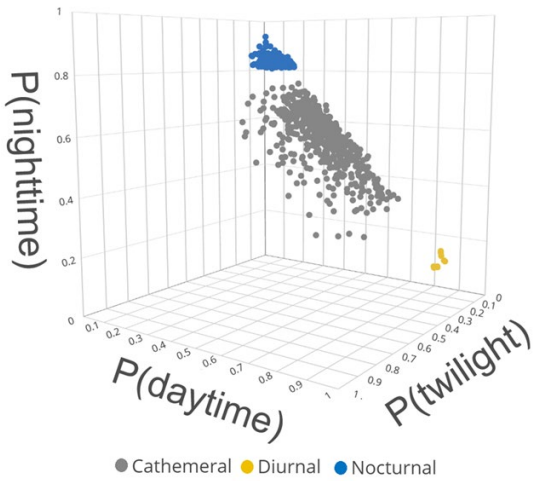
1) Context

2) A framework

3) An application







1) Context



Mark Gee

Animal Diel Activity



Variation in intensity of animal movement through the diel period (Hut et al., 2012).



Hut, R. A et al.. (2012). In search of a temporal niche: Environmental factors. Progress in Brain Research, 199, 281–304.

Habitat

- Fundamental to the field of ecology
- Combination of resources, risks, and conditions
- Thought of spatially and colloquially tied to landcover



Habitat

"the place where an organism lives, or place where one would go to find it."

Odum & Barrett (1971)

"a place where an animal lives"

Morrison et al. 1998



Odum, E. P., & Barrett, G. W. (1971). Fundamentals of ecology. Philadelphia: Saunders.
Morrison, M. L., Marcot, B. G. and Mannan, R. W. 1998. Wildlife-habitat relationships: concepts and applications. Univ. of Wisconsin Press.

Habitat



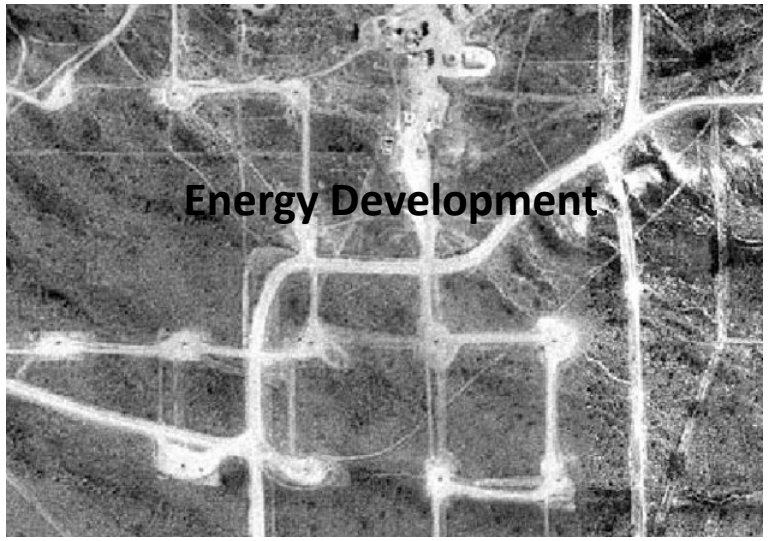










Photo Credits
Miguel Lurgi
Civil Eats
Getty Images
Pew
Flcikr

Spatial resources can be taken away; habitat can be lost

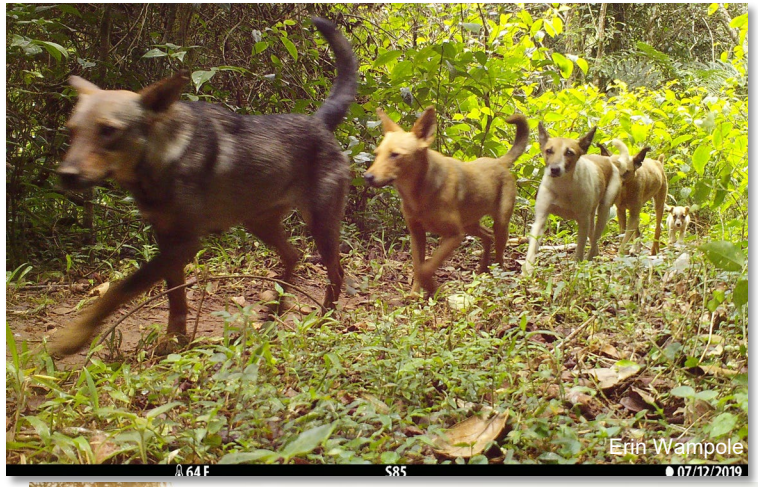
Habitat

For that ‘place’ to be habitat and allow for realized/potential species occurrence, requires the necessary resources/conditions to be spatially present, but also accessible.



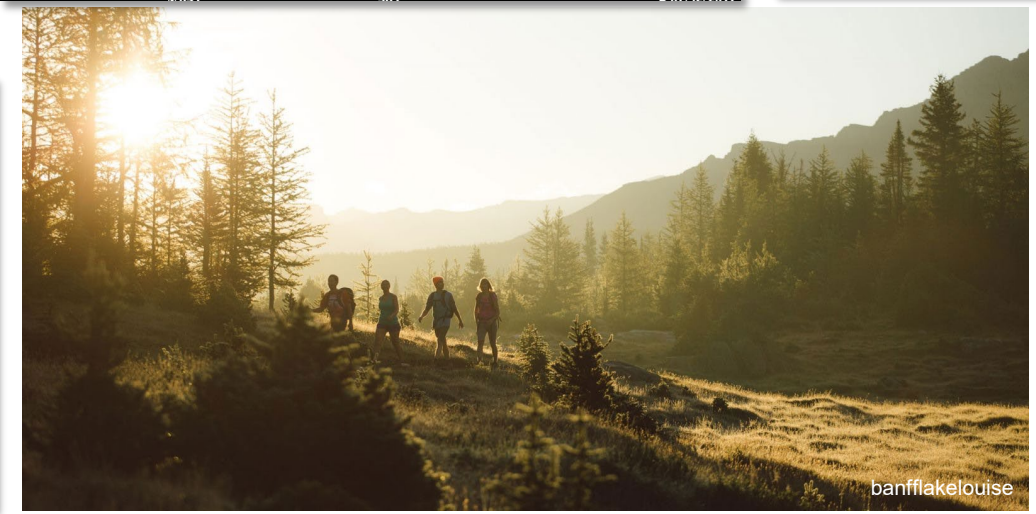
Habitat







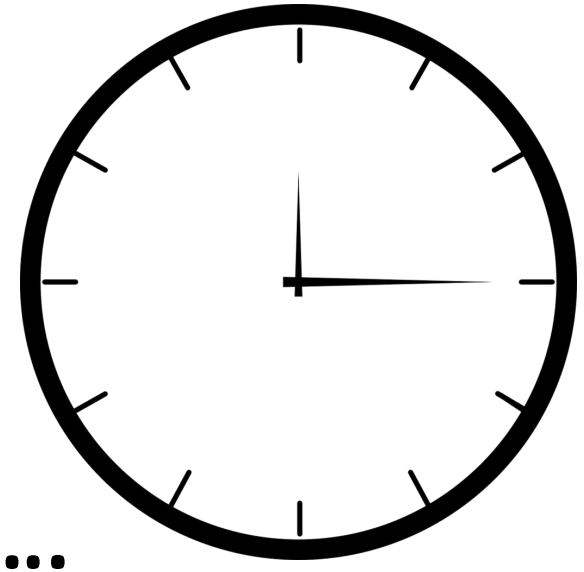






Resource can be temporally unavailable through indirect and direct species interactions

Habitat



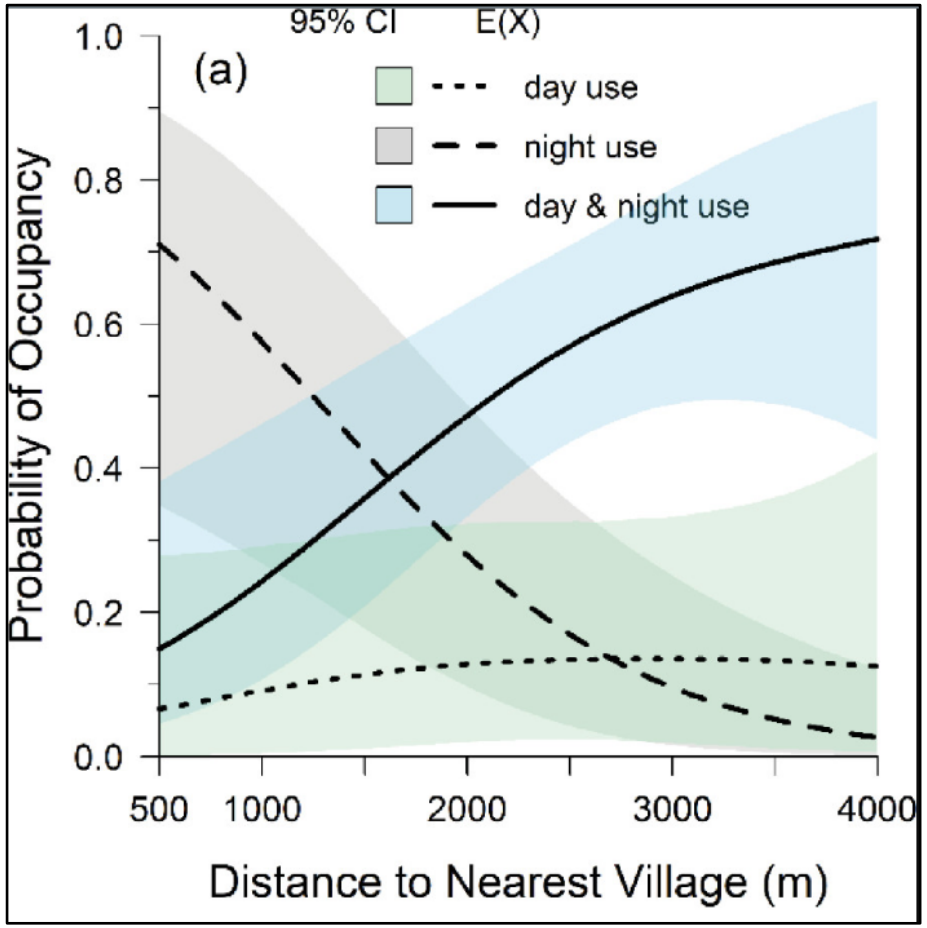
Time is a resource – it can be “taken away”….

...or at least time periods can become too risky and its use may diminish and costs could incur.

Fosa (*Cryptoprocta ferox*)





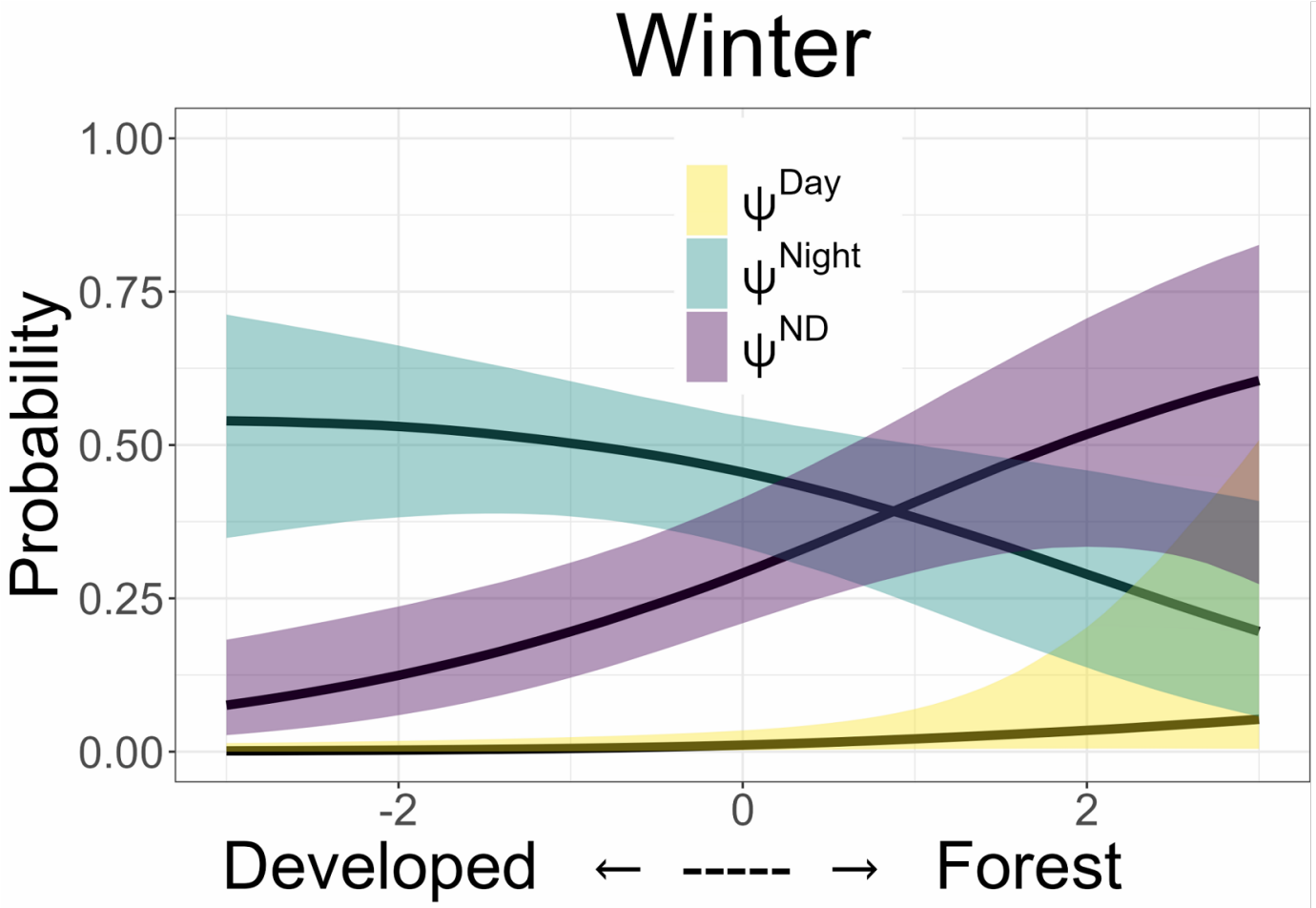


Rivera, K., Fidino, M., Farris, Z. J., Magle, S. B., Murphy, A., & Gerber, B. D. (2022). Rethinking habitat occupancy modeling and the role of diel activity in an anthropogenic world. *The American Naturalist*, *200*, 556-570.

Fisher (*Pekania pennanti*)





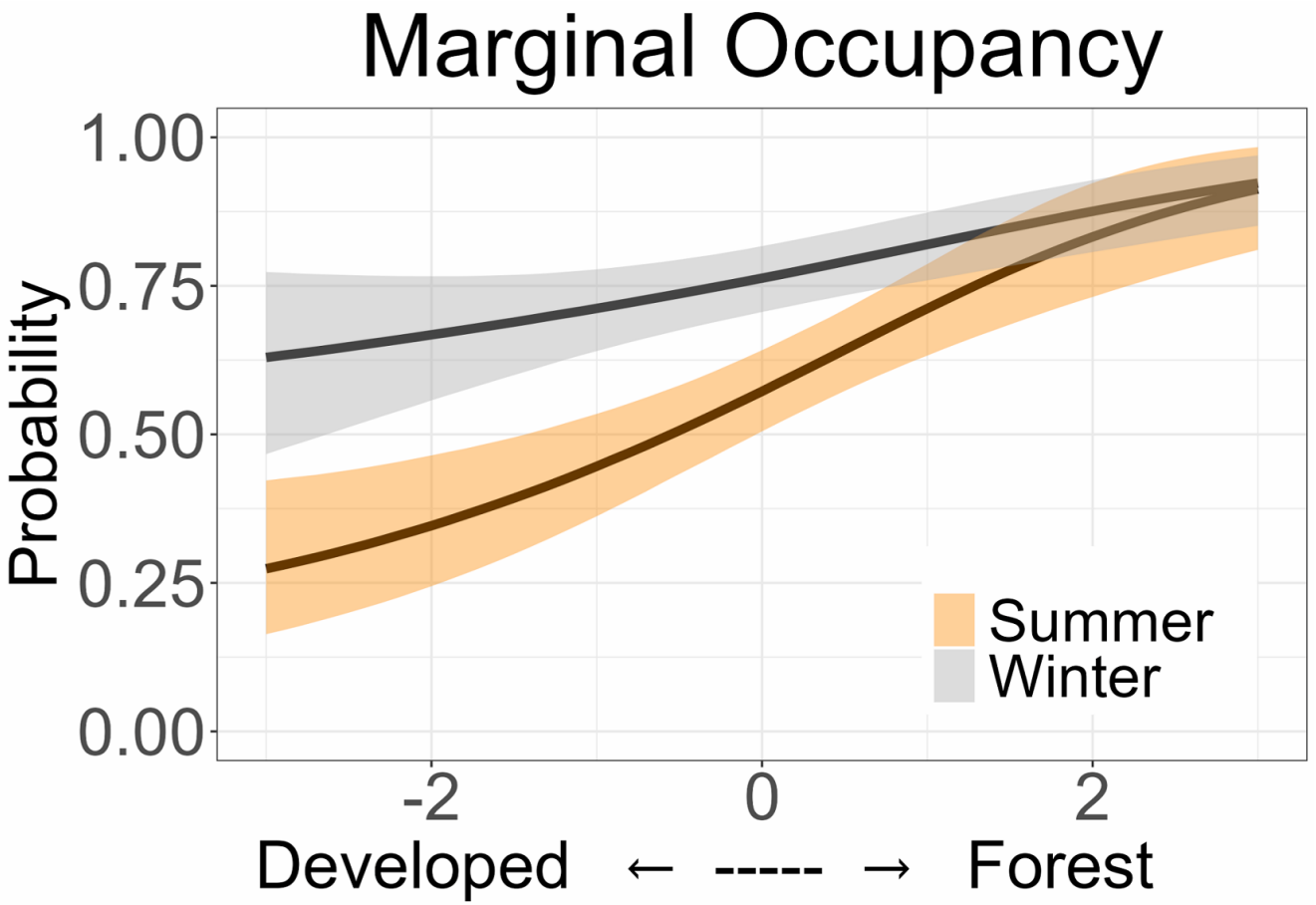


Mayer, A. E., Ganoe, L. S., Brown, C., & Gerber, B. D. (2023). Diel activity structures the occurrence of a mammal community in a human-dominated landscape. *Ecology and Evolution*, *13*, e10684.

Fisher (*Pekania pennanti*)







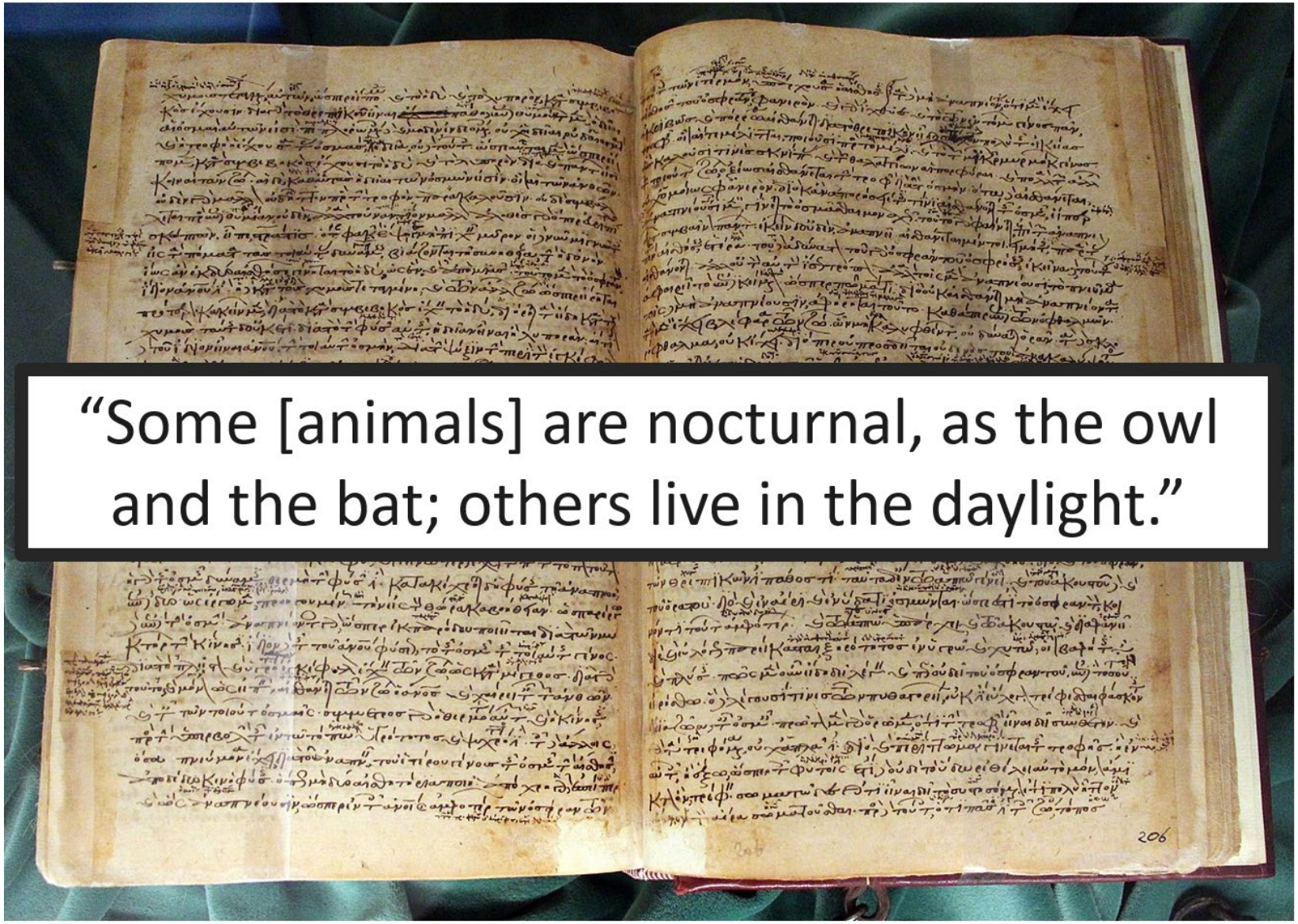
Mayer, A. E., Ganoe, L. S., Brown, C., & Gerber, B. D. (2023). Diel activity structures the occurrence of a mammal community in a human-dominated landscape. *Ecology and Evolution*, *13*, e10684.

"No description of where an animal lives and what it does can be complete without considering when the activity takes place".

Enright, JT. 1970.

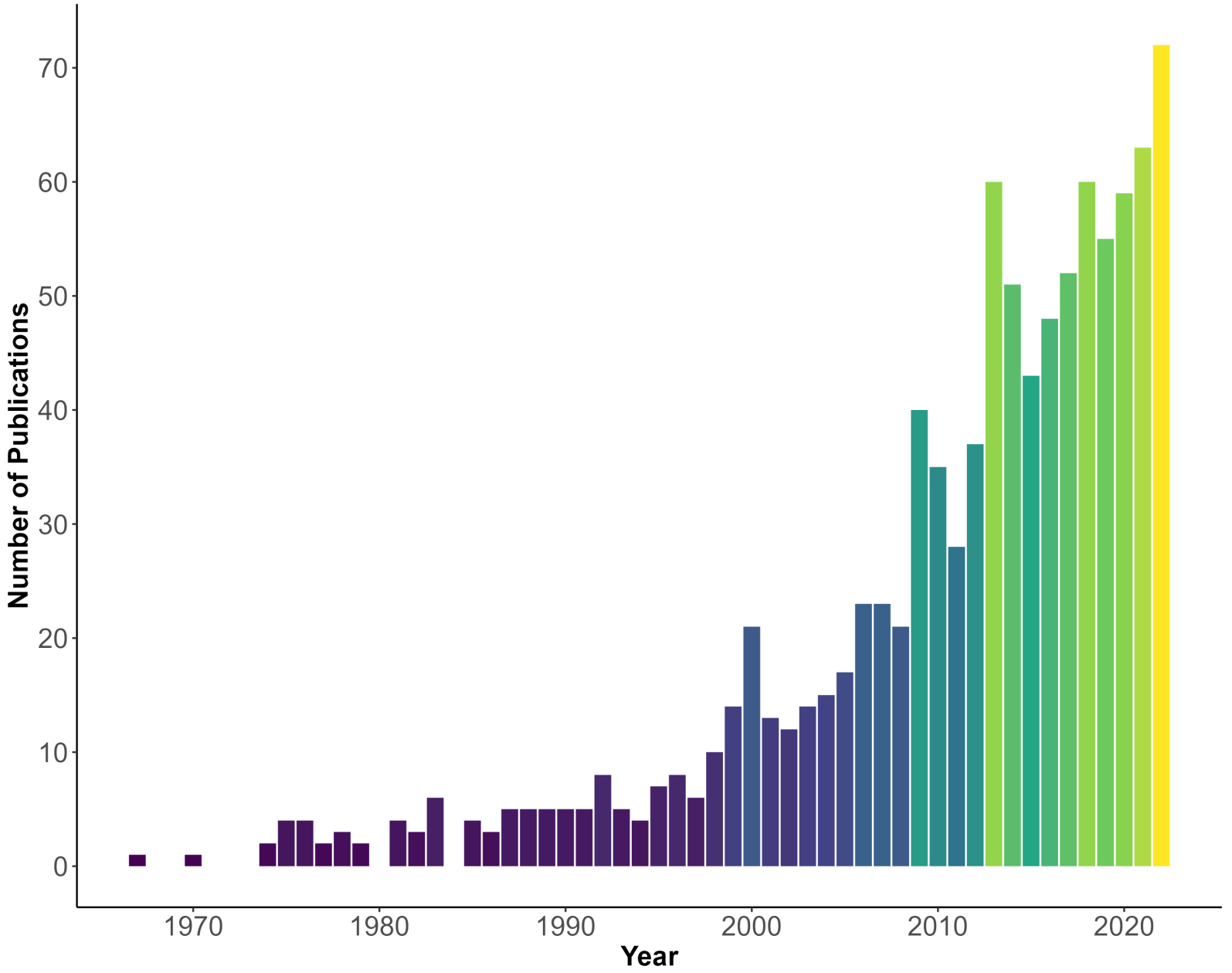
Enright, J. T. (1970). Ecological aspects of endogenous rhythmicity. *Annual review of ecology and systematics*, *1*:221-238.

History



"Some [animals] are nocturnal, as the owl and the bat; others live in the daylight."

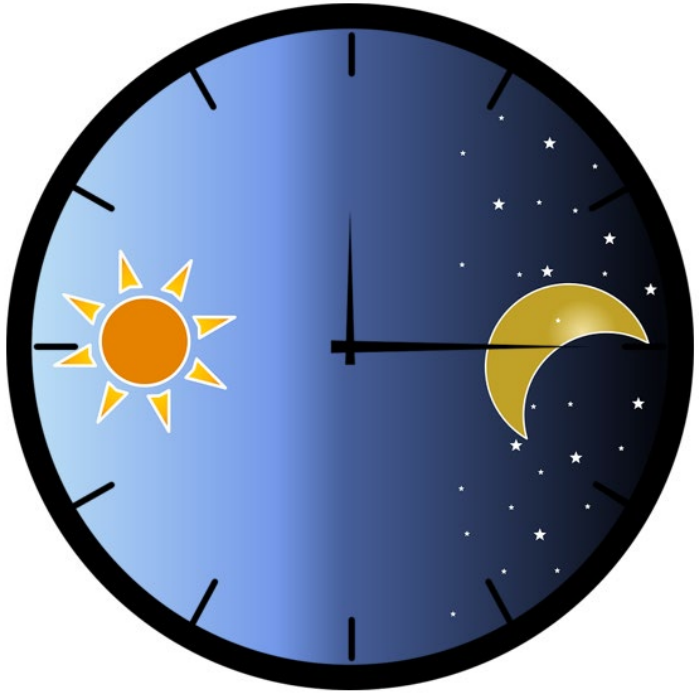
Aristotle's *History of Animals*



Scopus: ‘diel AND activity OR patterns AND animal’

2) A conceptual and statistical framework for defining activity into diel phenotypes







Is my study species diurnal/nocturnal/etc?

What does it mean to be diurnal/nocturnal/etc?

Diel Phenotypes

- Diurnal: active during the daylight
- Nocturnal: active during the nighttime
- Crepuscular: active during twilight (i.e., dawn and dusk)
- Cathemeral: active throughout the 24-hr day

Often viewed as a fixed trait for a species

Schoener, T. W. (1974). Science, 185, 27-39.
Schoener, T. W. (1974). Proceedings of the National Academy of Sciences, 71, 4169-4172.
Kronfeld-Schor, N., & Dayan, T. (2003). Annual review of ecology, evolution, and systematics, 34, 153-181.
Anderson & Wiens. (2017). Evolution, 71, 1944-1959.
Levy et al. (2019). Ecological Monographs, 89, e01334.
Tattersall, I. (2006). Folia primatologica, 77, 7-14.

Eco-Evo studies using reference literature diel classifications as data

Article | Open access | Published: 19 March 2021

Diel niche variation in mammals associated with expanded trait space

D. T. C. Cox, A. S. Gardner & K. J. Gaston

Nature Communications **12**, Article number: 1753 (2021) | Cite this article

JOURNAL ARTICLE

Out of the dark: 350 million years of conservatism and evolution in diel activity patterns in vertebrates

Get access

Samantha R. Anderson, John J. Wiens

Evolution, Volume 71, Issue 8, 1 August 2017, Pages 1944–1959,
https://doi.org/10.1111/evo.13284

RESEARCH ARTICLE | 24 OCT 2012

Eye shape and the nocturnal bottleneck of mammals

Margaret I. Hall; Jason M. Kamilar; E. Christopher Kirk

+ Author & article information

Proc Biol Sci (2012) 279 (1749): 4962–4968 .

https://doi.org/10.1098/rspb.2012.2258 **Article history**

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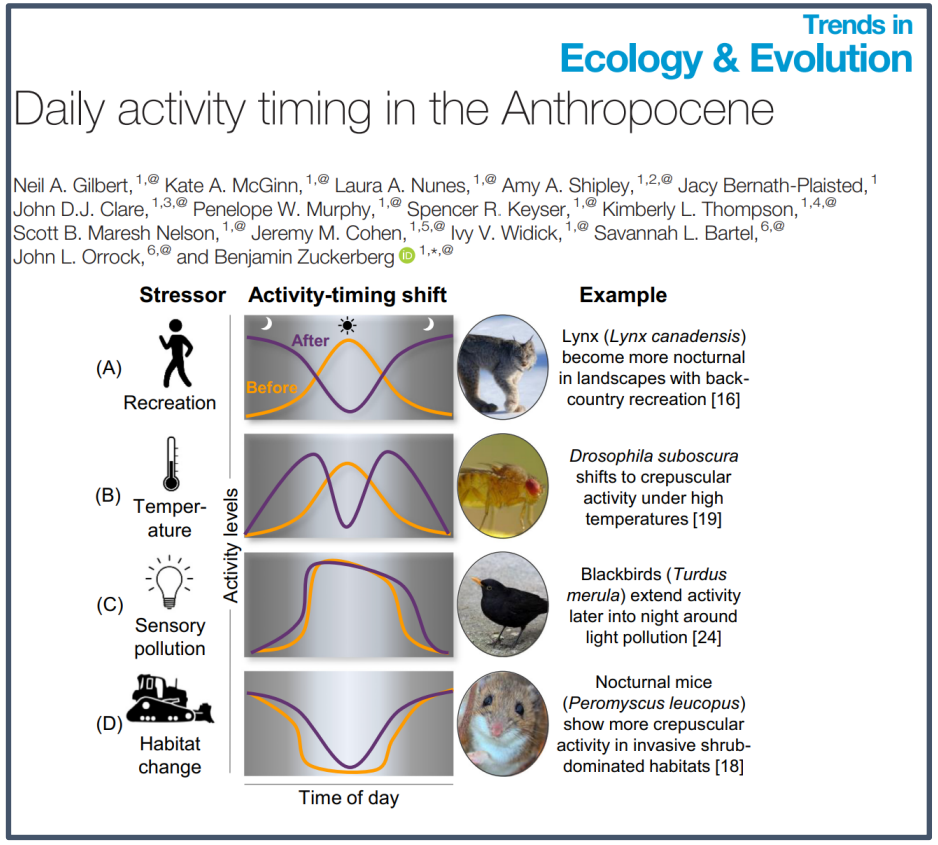
Vision Research

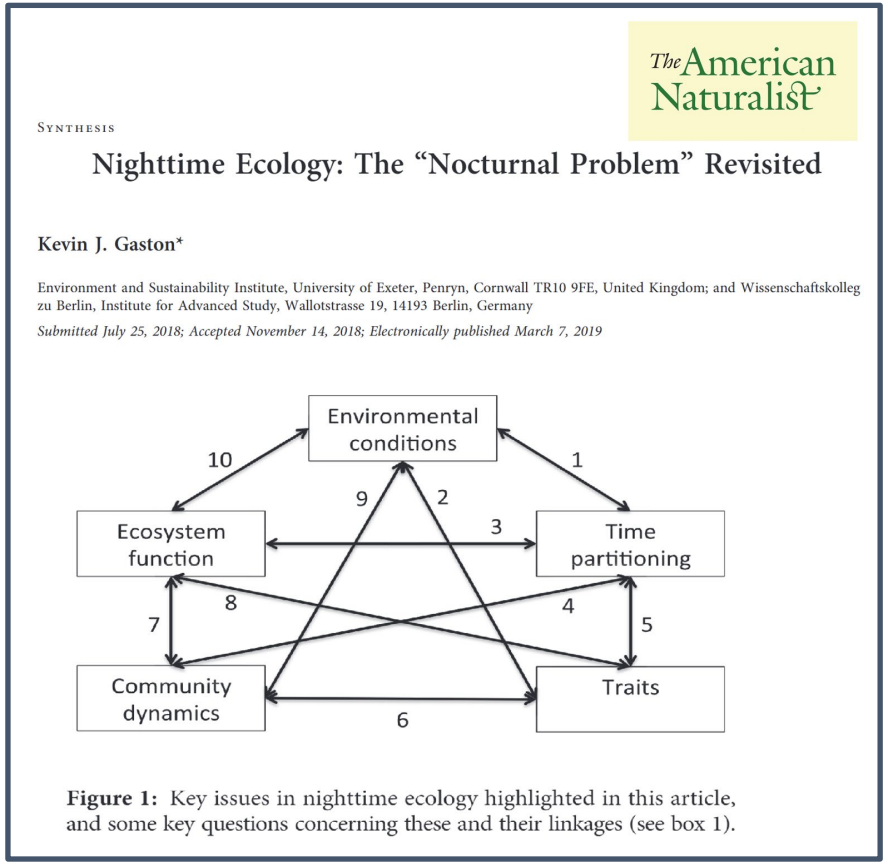
Volume 50, Issue 10, 12 May 2010, Pages 936-946

Morphological differences between the eyeballs of nocturnal and diurnal amniotes revisited from optical perspectives of visual environments

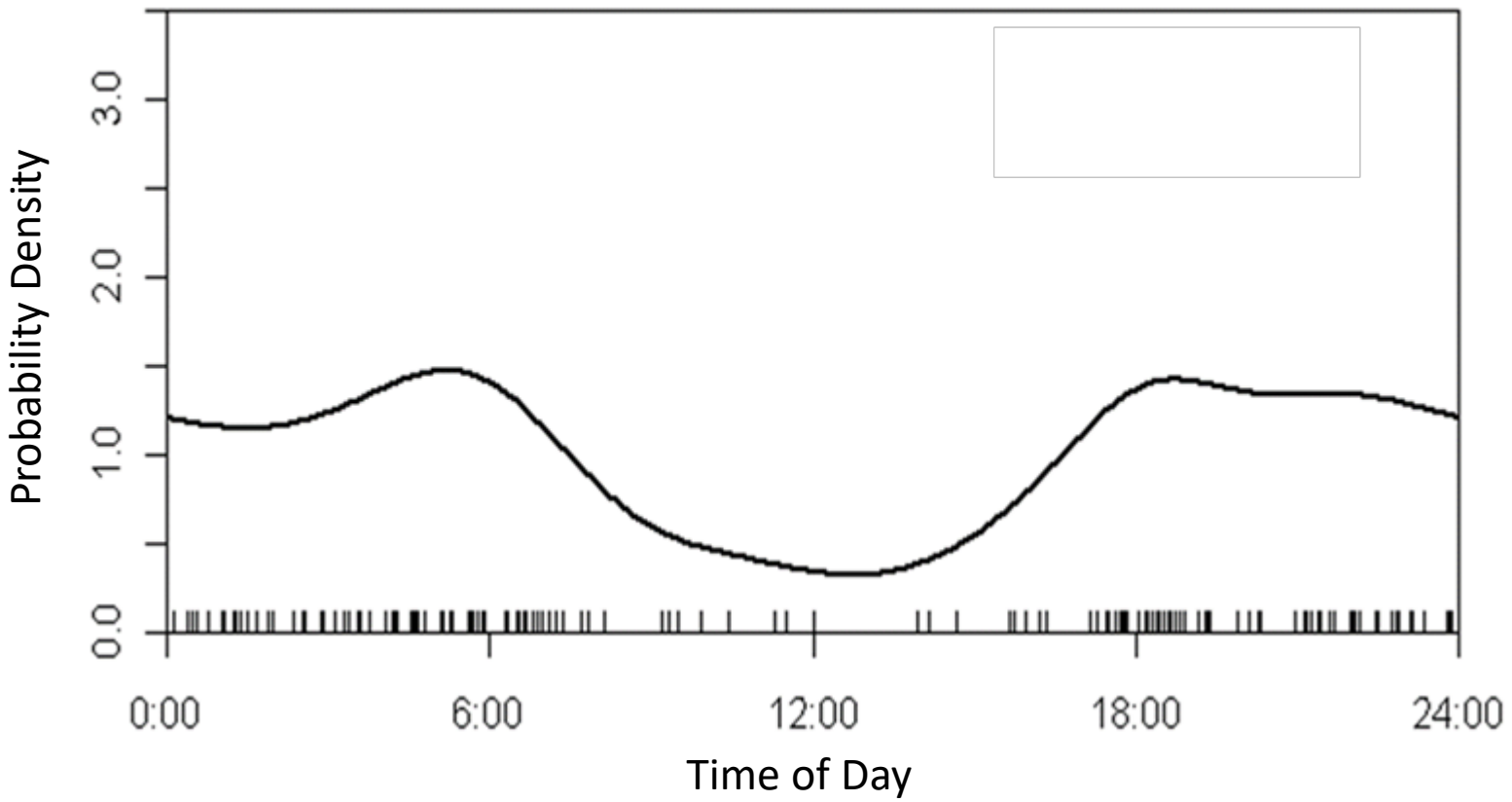
Lars Schmitz [a b], Ryosuke Motani [a]

Diel Ecology Frameworks





My real motivation









© Daniel Branch

Concerns

Diel Phenotypes

- Studies rely on reference literature classifications
- descriptive and no standard
- difficult evaluating plasticity (e.g., diurnal→ nocturnal)
- may be too general

No clear way to evaluate the support for a phenotype

P(diurnal|data) vs.

P(nocturnal|data) vs.

….

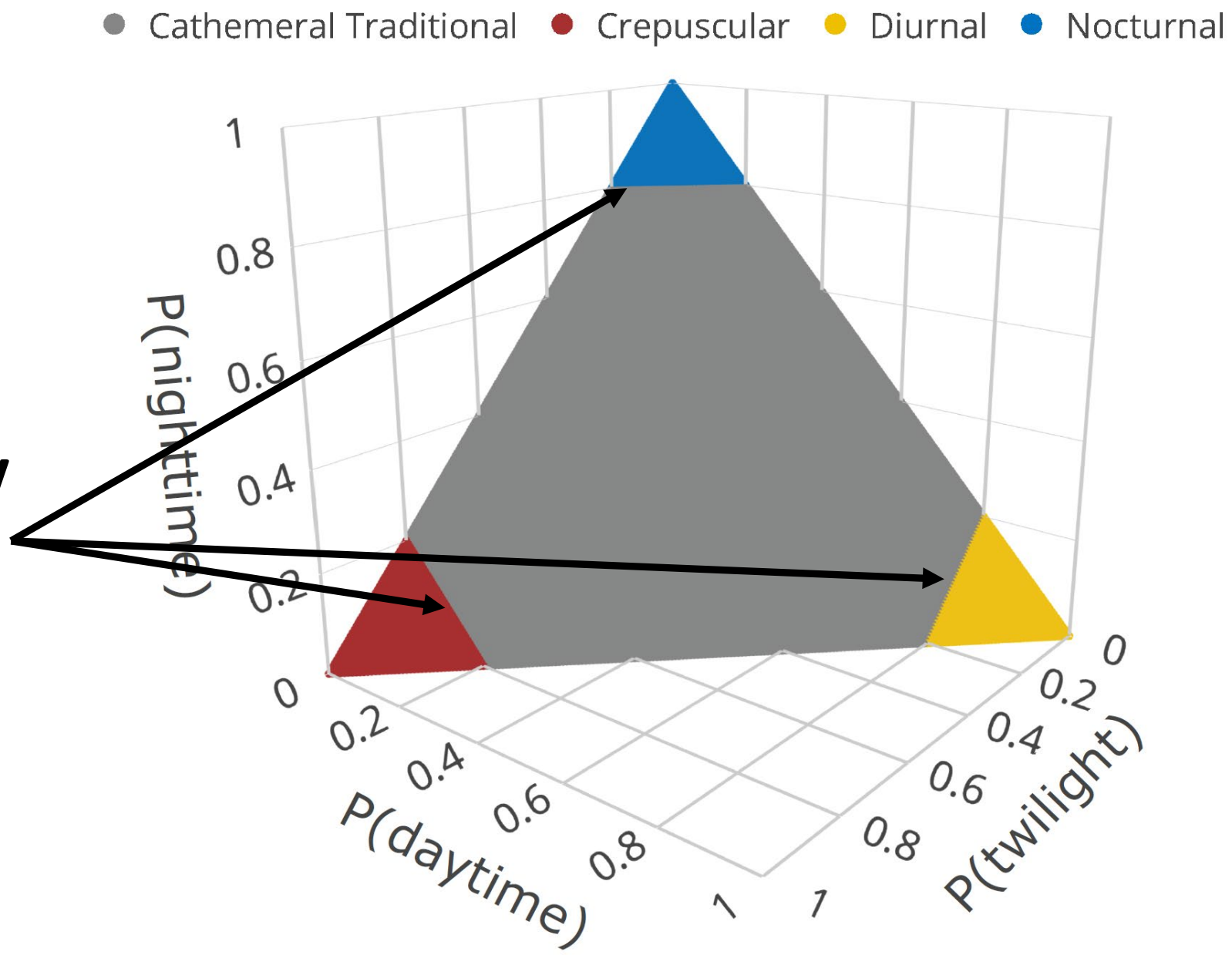
Objectives

1. Outline a conceptual framework to define diel phenotypes consistently and thus comparably

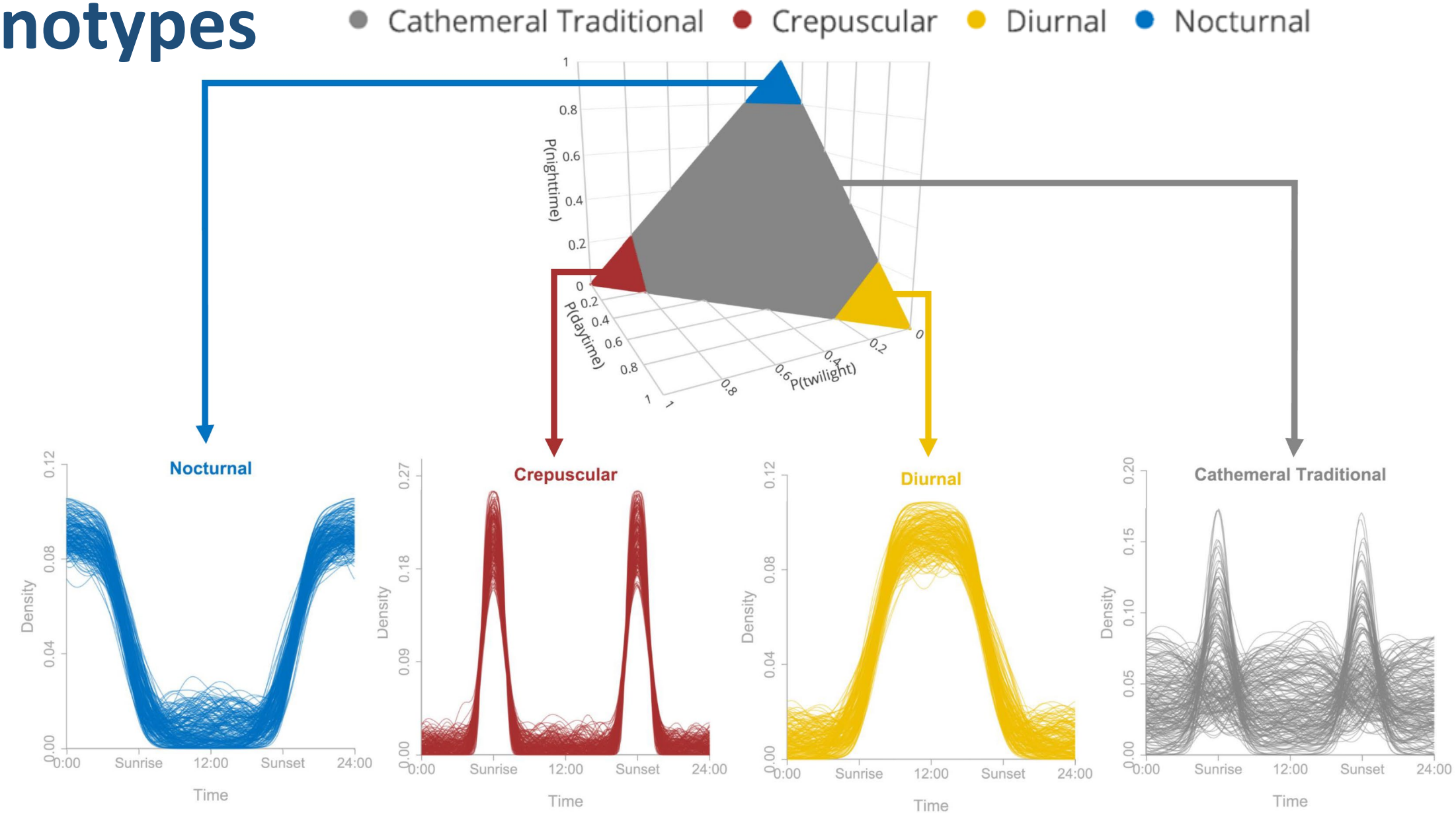
2. Implement a model-based evaluation of phenotypes as hypotheses and estimate parameters with empirical data

Define Diel Phenotypes

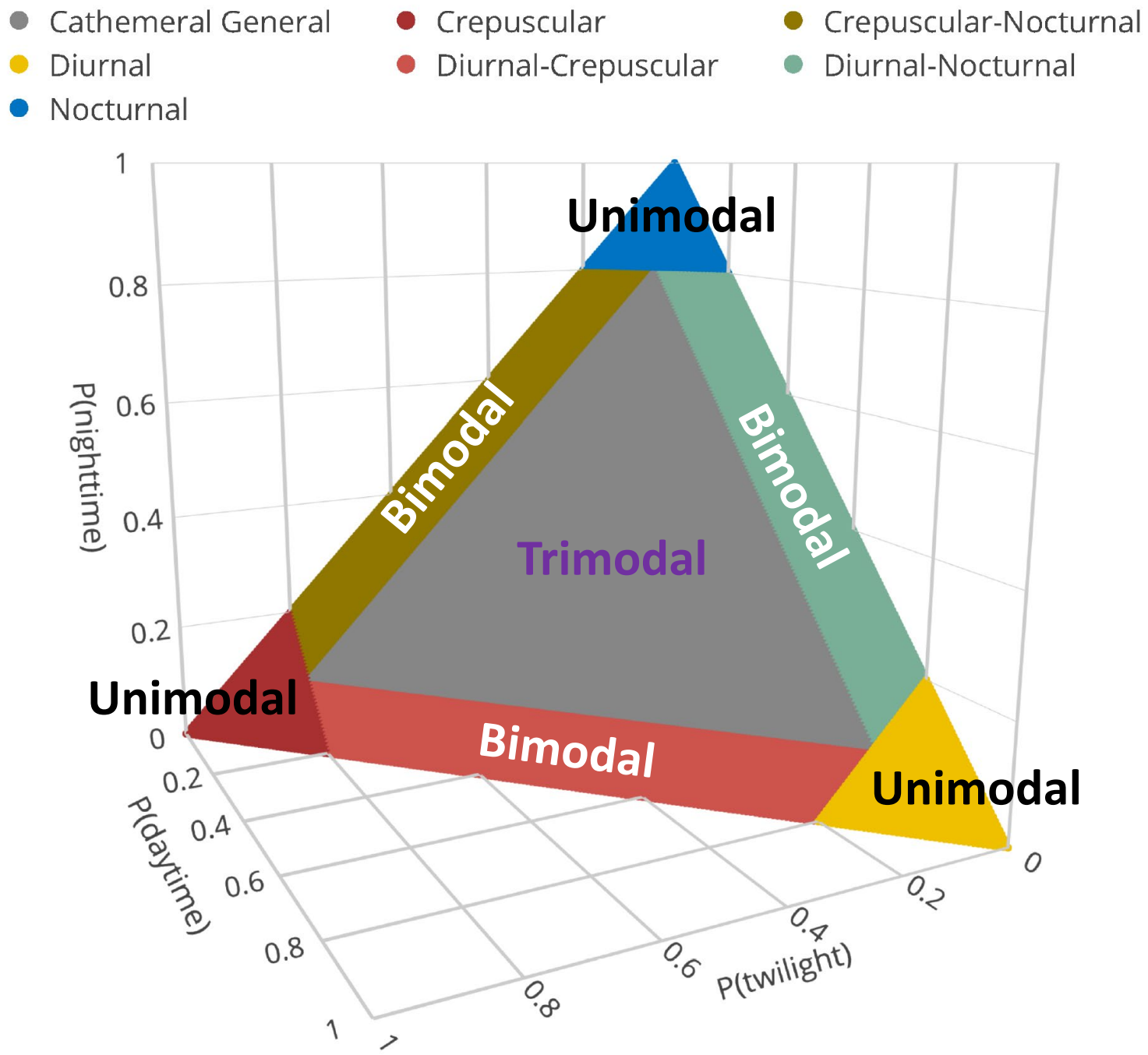
Probability Threshold of 0.80



Define Diel Phenotypes



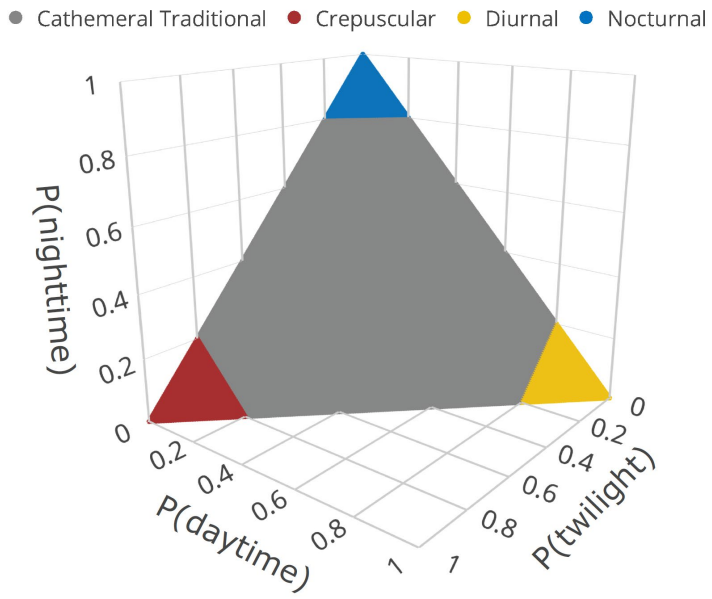
More General Diel Phenotypes



Modeling

$\mathbf{y} = [y_{twilight}\ y_{day}\ y_{night}]$, e.g. = [3 10 5]

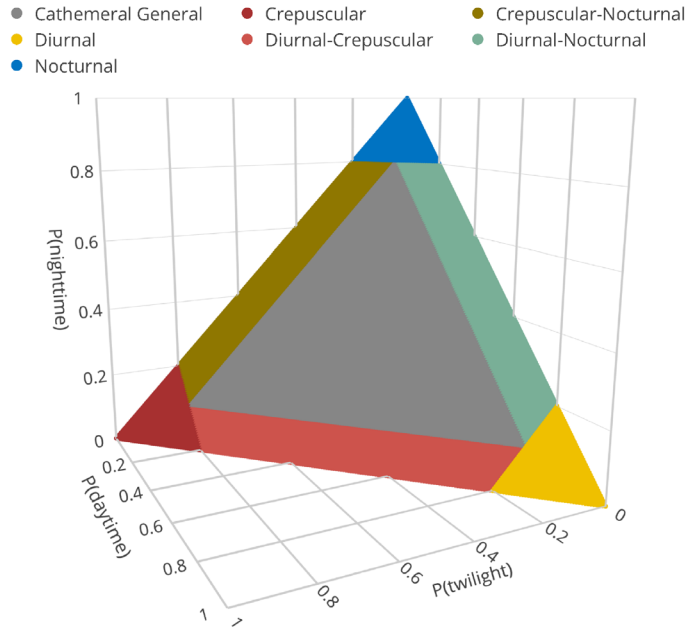
$\boldsymbol{\theta} = [p_{twilight}\ p_{day}]$



Multinomial with Inequality Constraints

$$A\theta \leq b$$

Model Comparison via Bayes Factors to get P(phenotype|y)



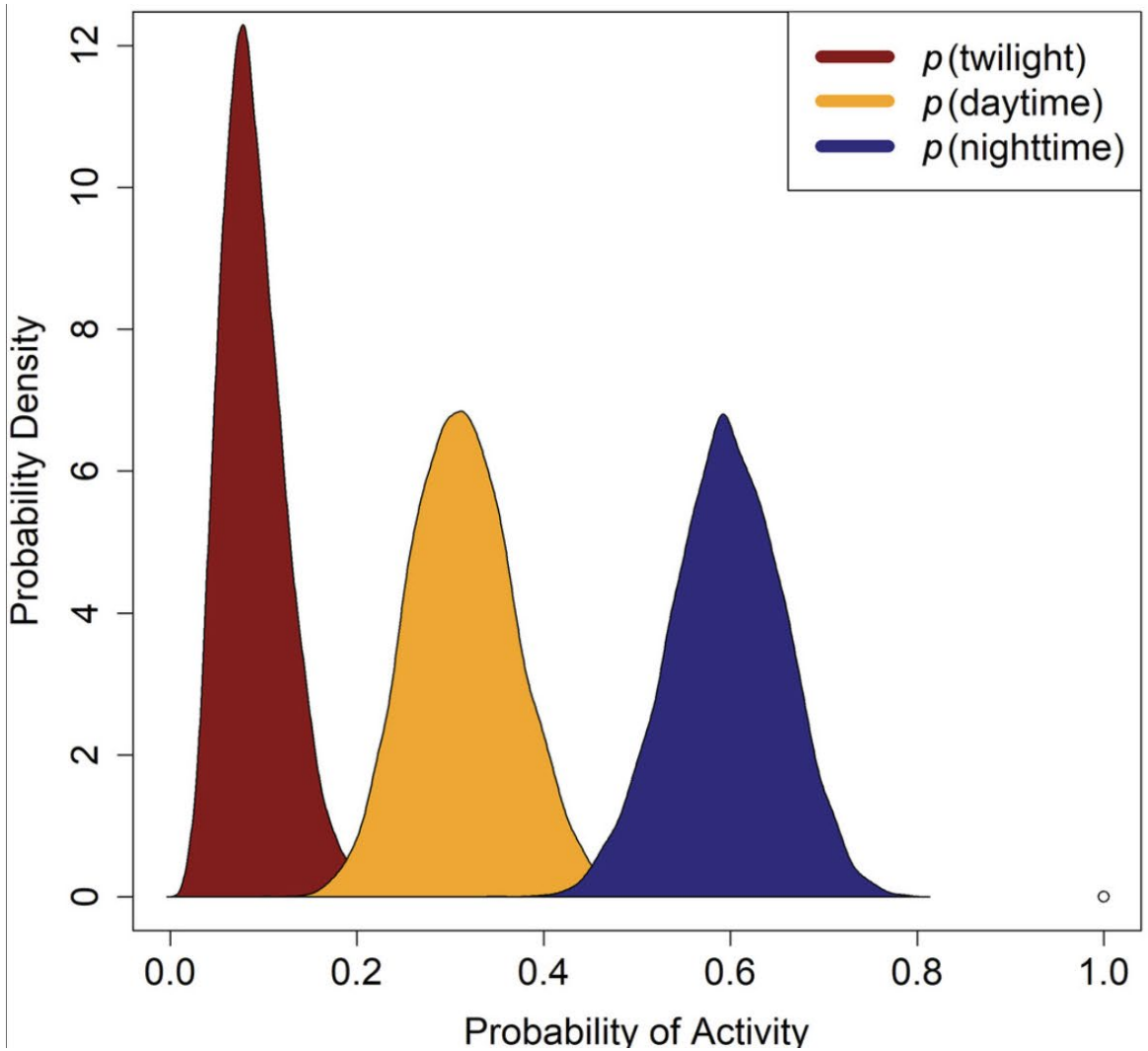
Heck and Davis-Stober. (2019). J Math Psychol. 91, 70-87.

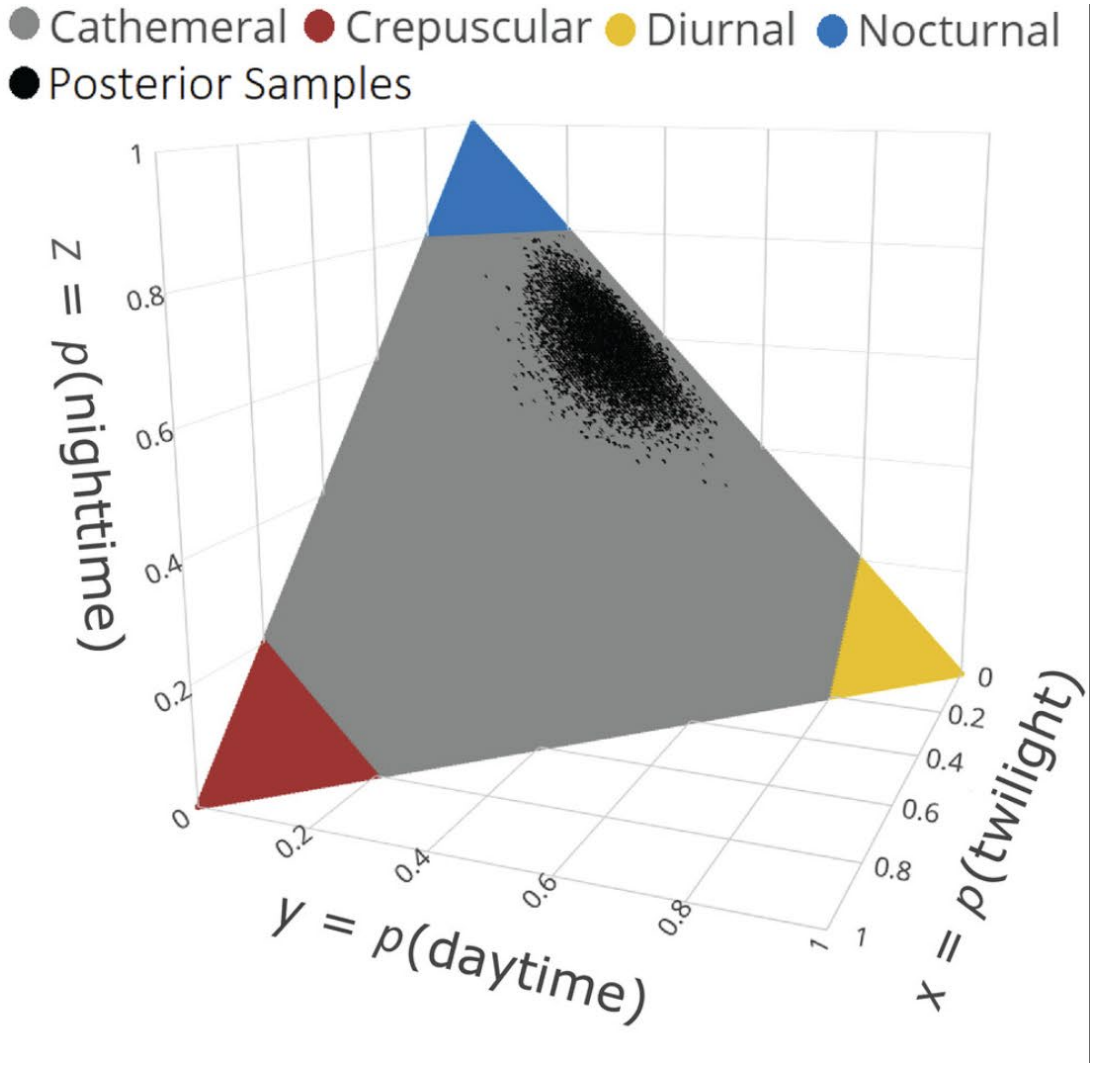
Output

Model Support for data, y = [3 10 4]

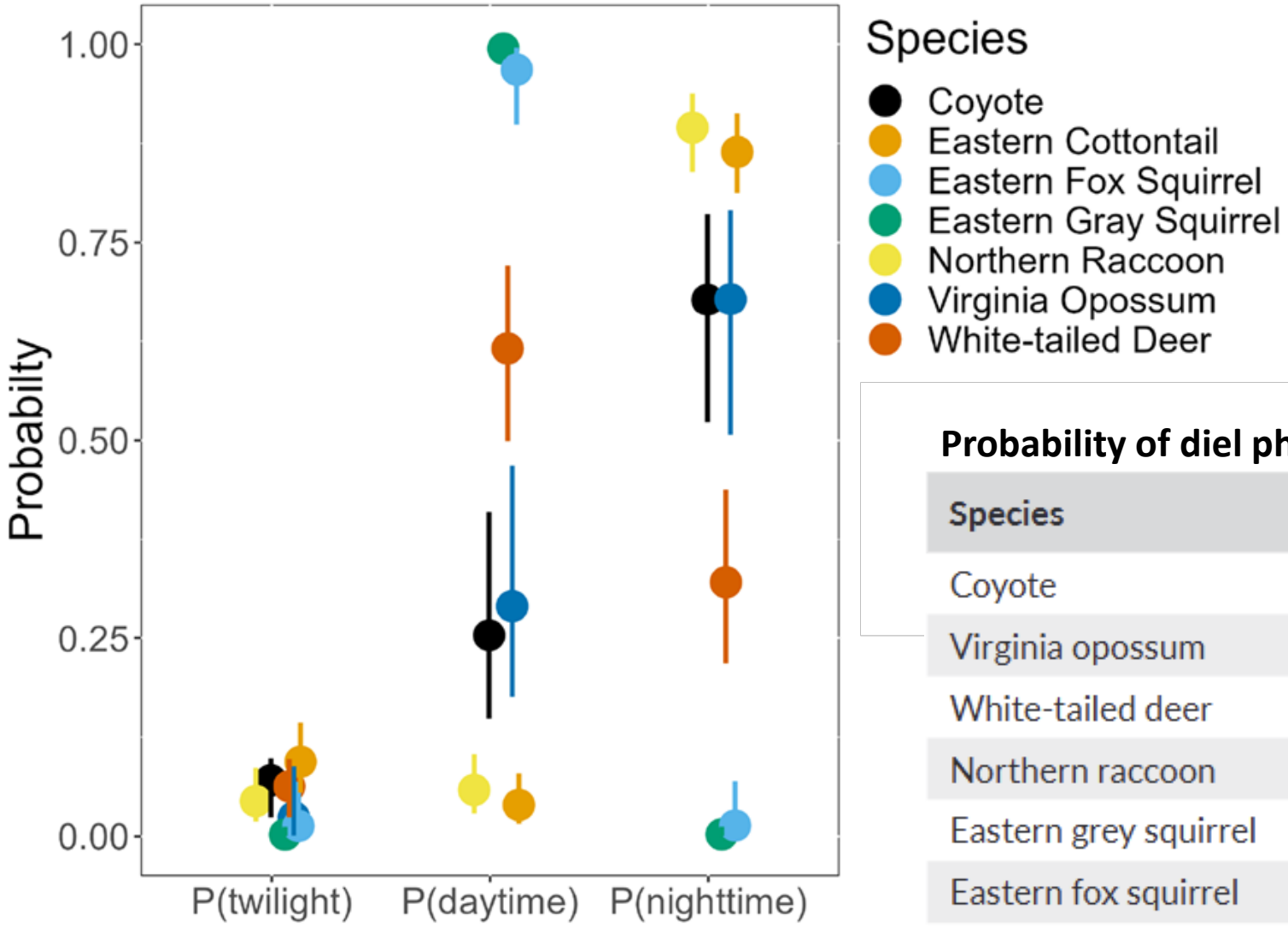
Phenotype/Hypothesis	**Probability of Support**
Diurnal	0.0353
Nocturnal	0.0000
Crepuscular	0.0000
Cathemeral	0.9646

Output


p(twilight)
p(daytime)
p(nighttime)
Probability Density
0
2
4
6
8
10
12
0.0
0.2
0.4
0.6
0.8
1.0
Probability of Activity


Cathemeral
Crepuscular
Diurnal
Nocturnal
Posterior Samples
z = p(nighttime)
y = p(daytime)
x = p(twilight)
0
0.2
0.4
0.6
0.8
1

Multiple species



Probability of diel phenotype support

Species	Diurnal	Nocturnal	Cathemeral	Diur-Noct
Coyote	0.00	0.07	0.17	0.75
Virginia opossum	0.00	0.21	0.02	0.77
White-tailed deer	0.00	0.00	0.07	0.93
Northern raccoon	0.00	1.00	0.00	0.00
Eastern grey squirrel	1.00	0.00	0.00	0.00
Eastern fox squirrel	1.00	0.00	0.00	0.00
Eastern Cottontail	0.00	0.99	0.00	0.00

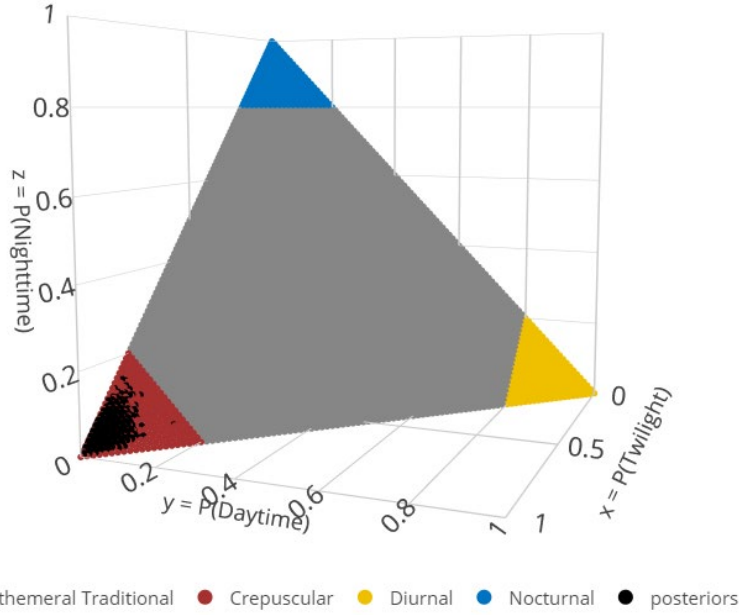
Implementation: Defining and Estimating

Diel.Niche R package

https://github.com/diel-project/Diel-Niche-Modeling

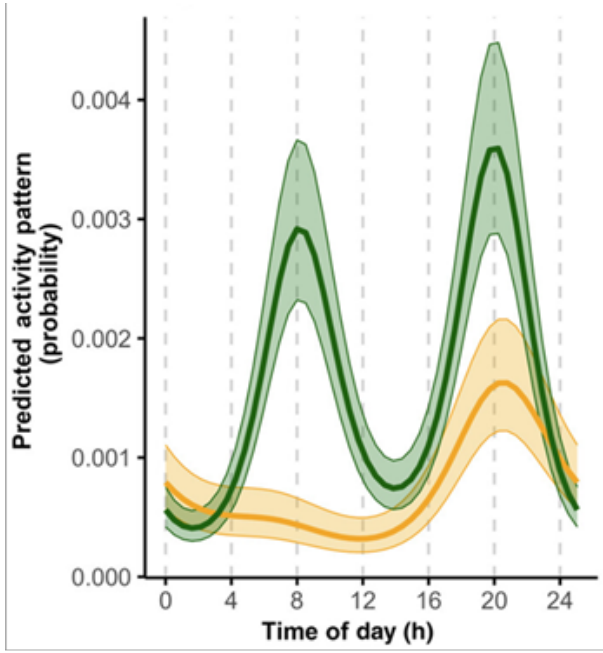
Features

- 9 Code walk throughs (Vignettes)
- Multiple hypothesis sets
- User-defined phenotype hypotheses
- Fast estimation, model comparison, and 3D plotting
- Derive phenotypes from other outputs

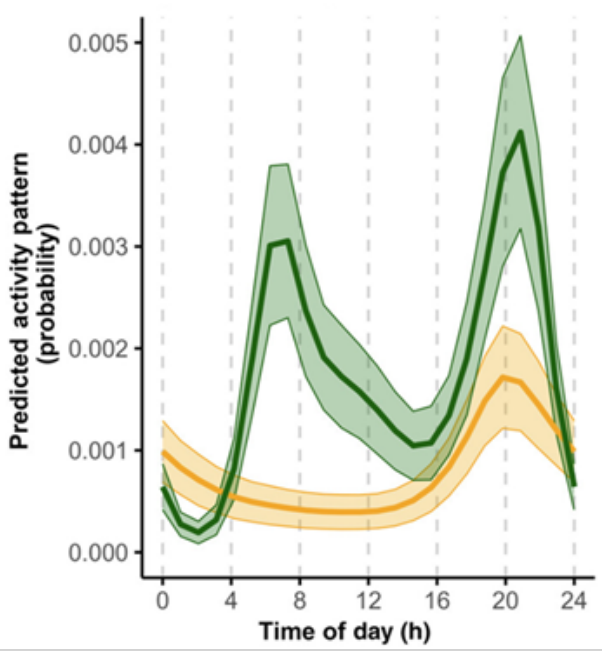


More complex models

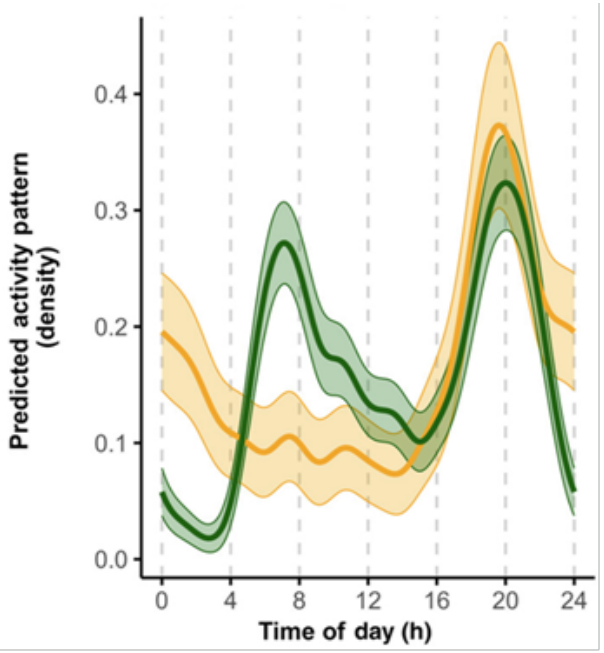
Hierarchical trigonometric model



Hierarchical GAM

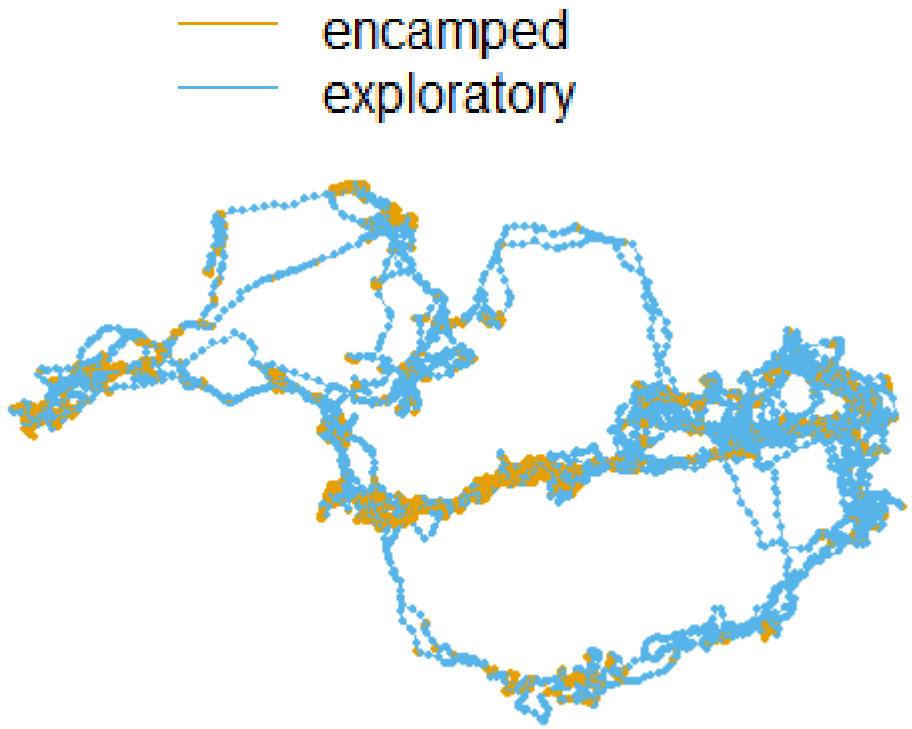


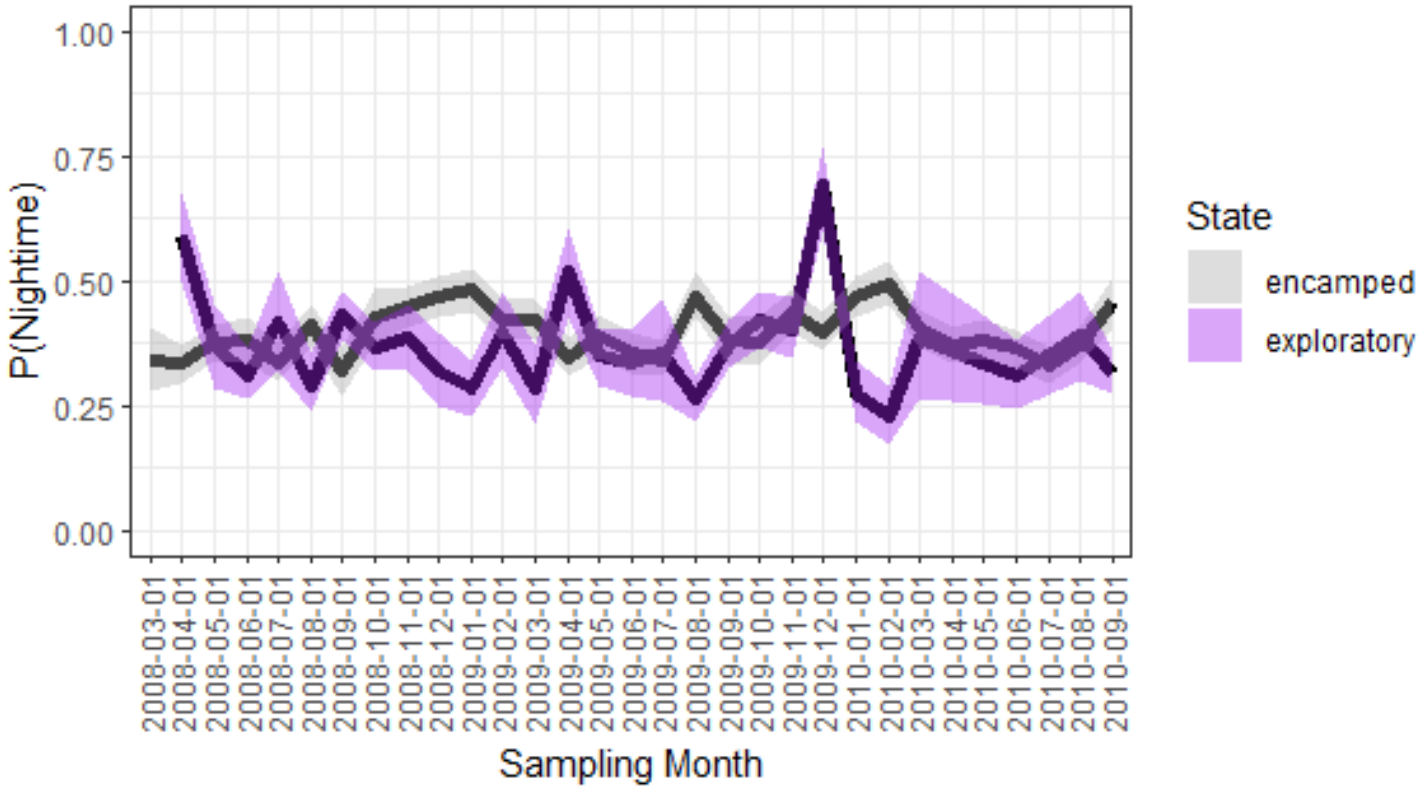
Circular Kernel Density Estimator



Iannarilli, F., Gerber, B. D., Erb, J., & Fieberg, J. R. (2025). A ‘how-to’guide for estimating animal diel activity using hierarchical models. *Journal of Animal Ecology*, *94*(2), 182-194.

State-based diel animal movement modeling





Summarize probability of activity and Diel.Niche can be used to define the supported diel phenotype

Resources

Journal of Animal Ecology

BRITISH ECOLOGICAL SOCIETY

RESEARCH METHODS GUIDE | Open Access

A model-based hypothesis framework to define and estimate the diel niche via the 'Diel.Niche' R package

Brian D. Gerber, Kadambari Devarajan, Zach J. Farris, Mason Fidino

Diel.Niche R package

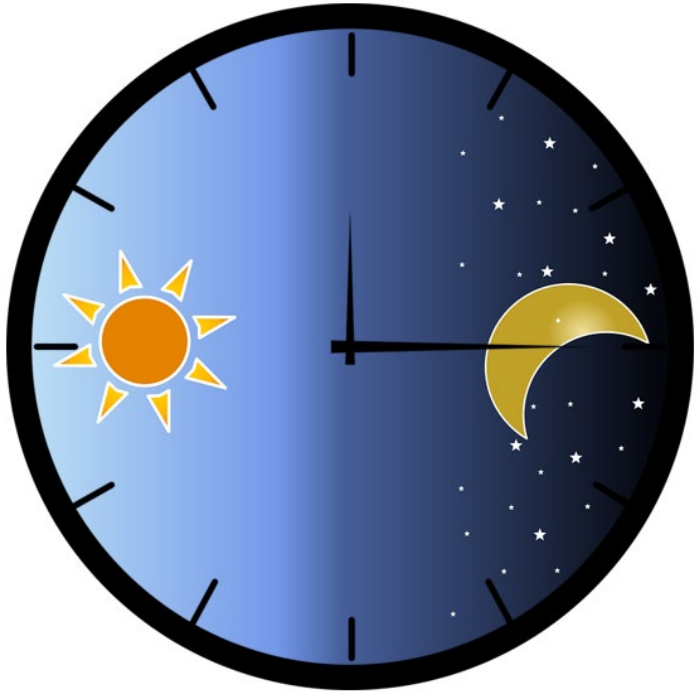
https://github.com/diel-project/Diel-Niche-Modeling

Online Shiny Implementation

https://shiny.uri.edu/bgerber/DielNiche/

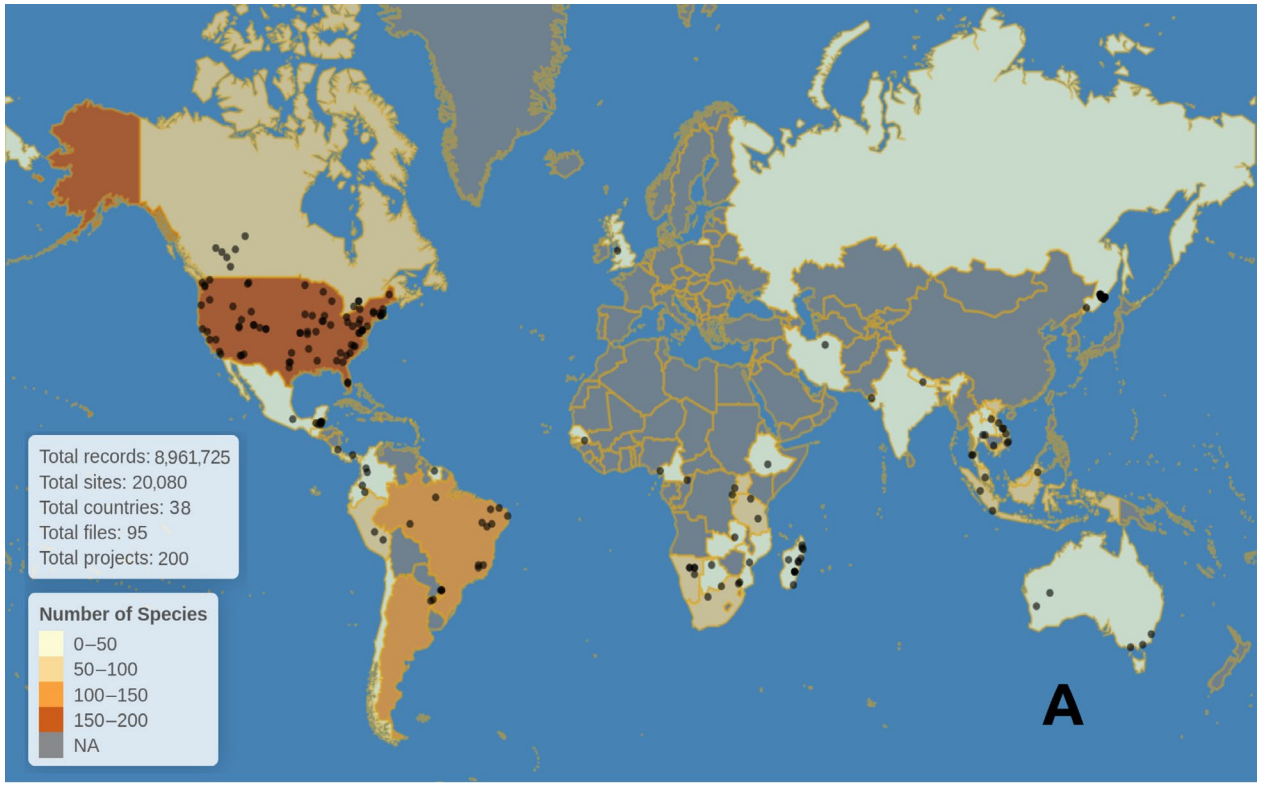


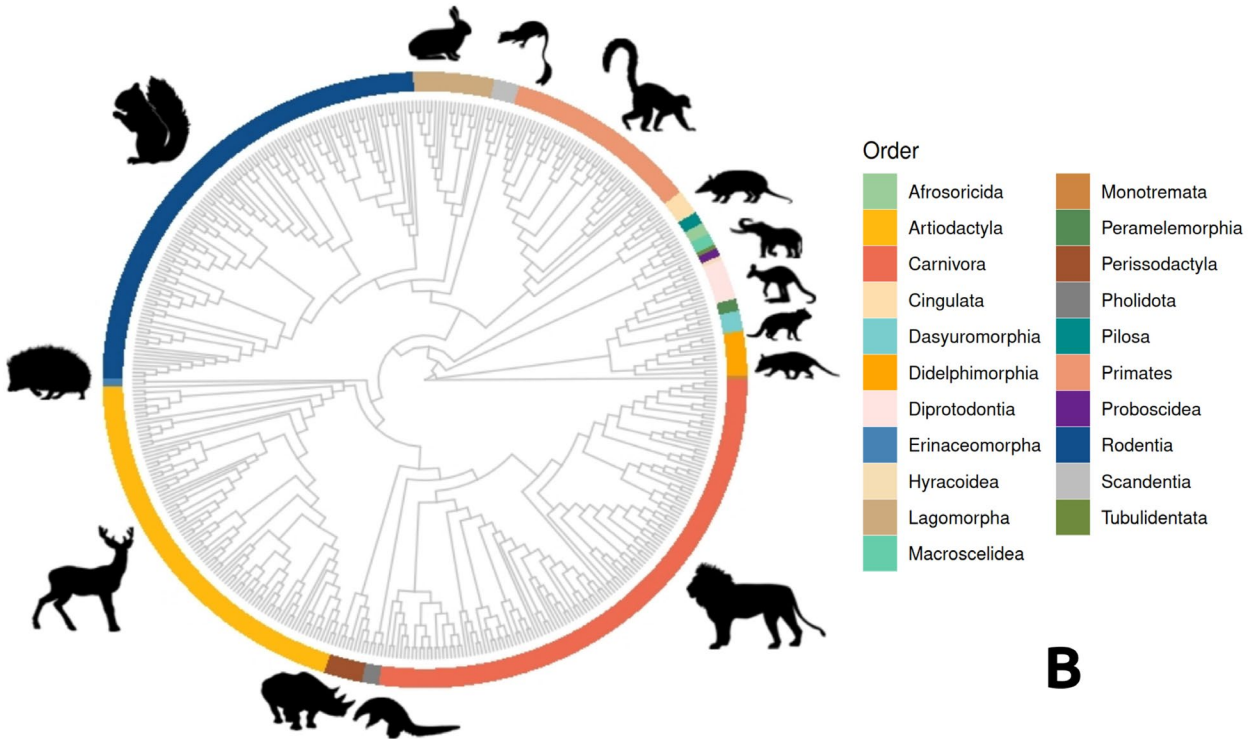
3) An application of the framework to a global camera trap dataset



1) Do empirical results agree with reference literature diel phenotypes?
2) How variable are diel phenotypes for different species?

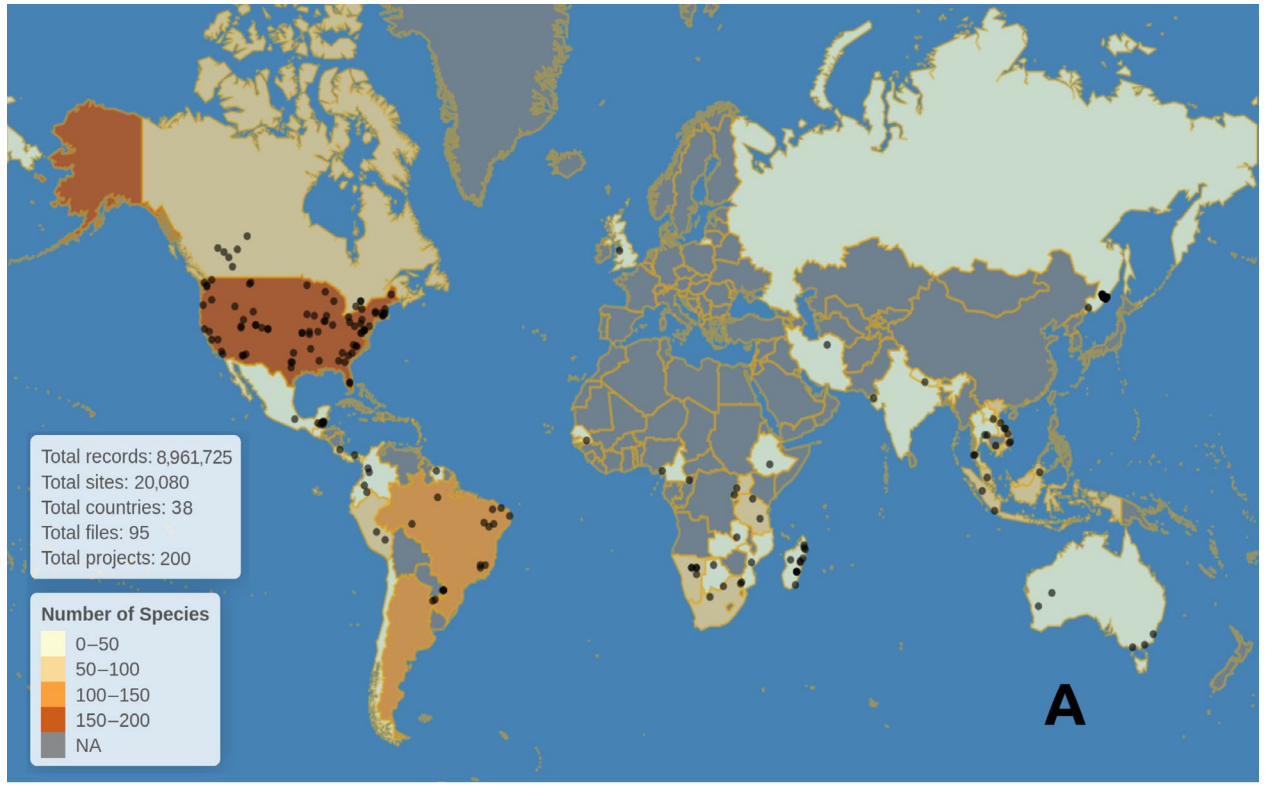
Data Curation





Kadambari Devarajan *et al.,* When the wild things are: Defining mammalian diel activity and plasticity. *Scence Advances.***11**,eado3843(2025).DOI:10.1126/sciadv.ado3843

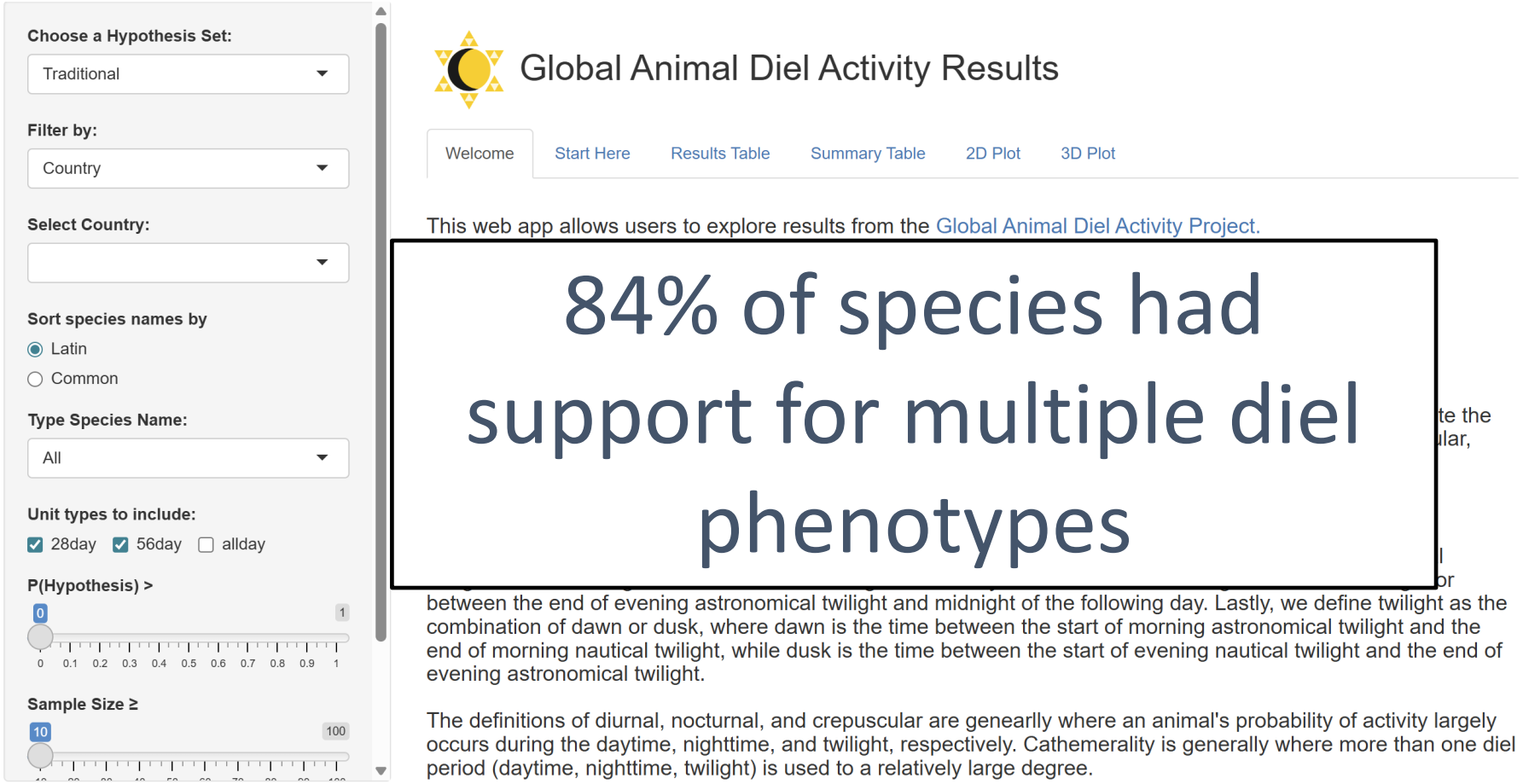
Data Curation



- 8.9 million photos
- 1.7 million independent events
- 445 species
- 67 families
- 14,587 data analysis units

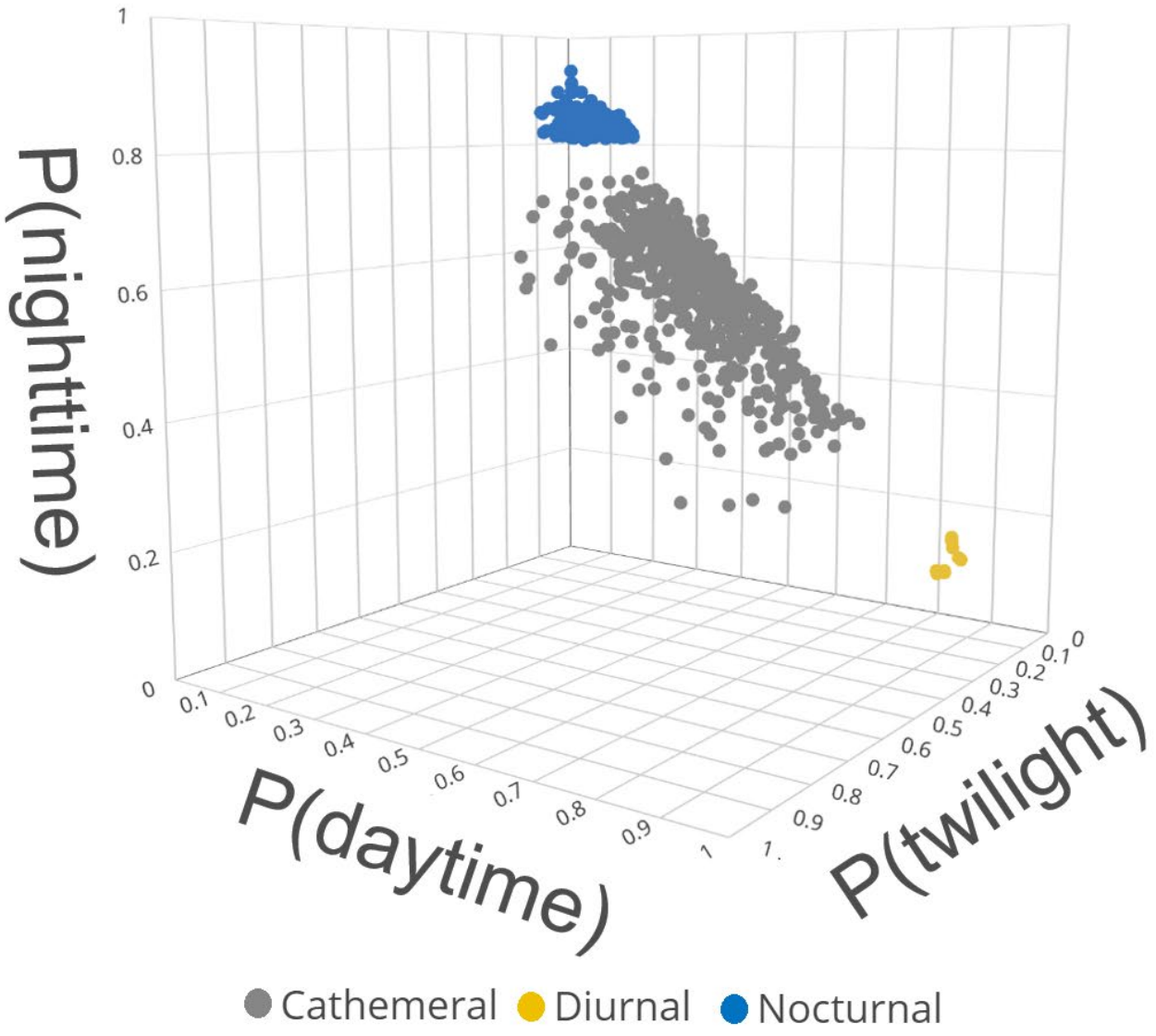
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Results: https://shiny.uri.edu/bgerber/GlobalDiel/



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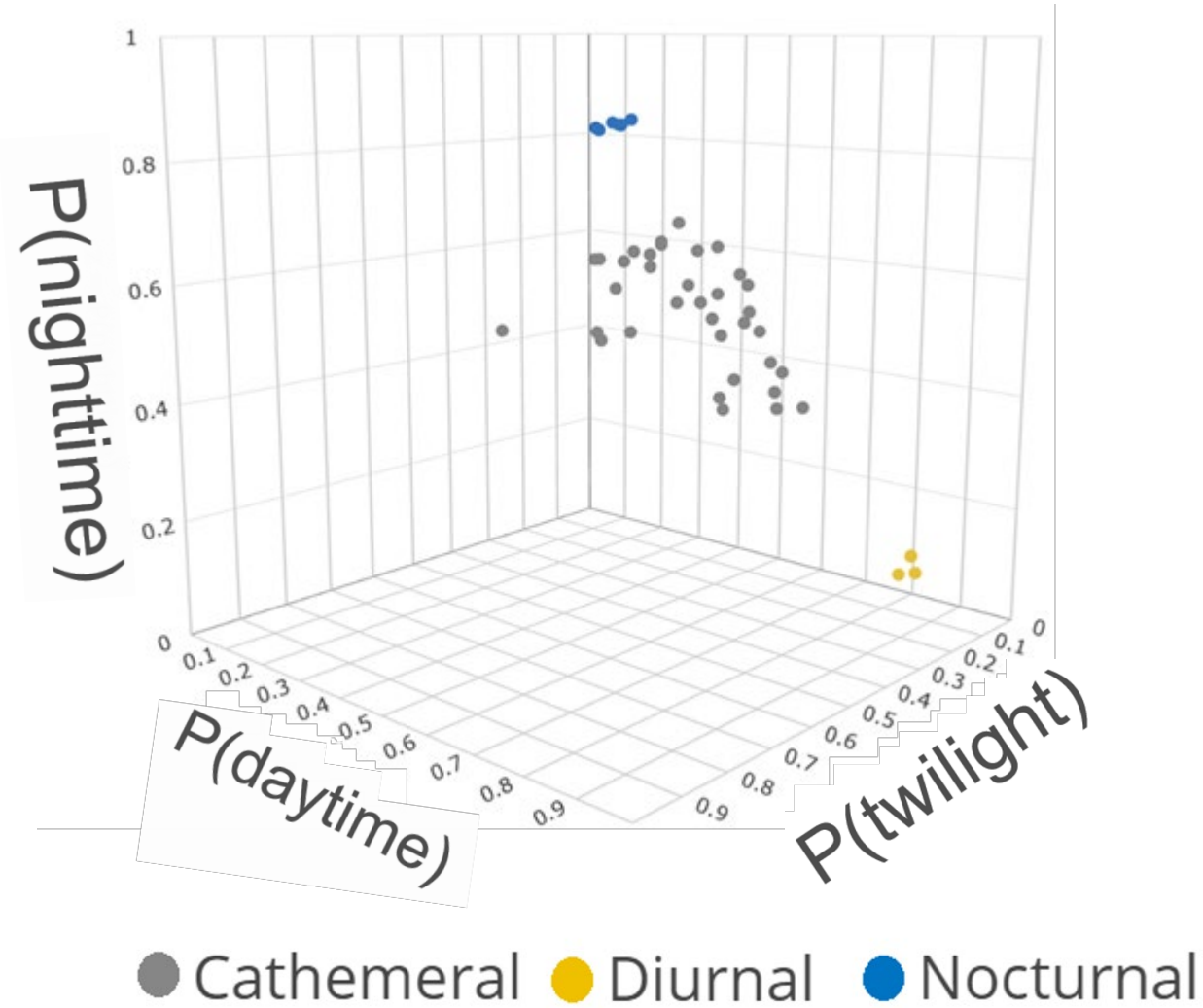
Species Results



Species	Coyote
Reference	Cathemeral
Units	707



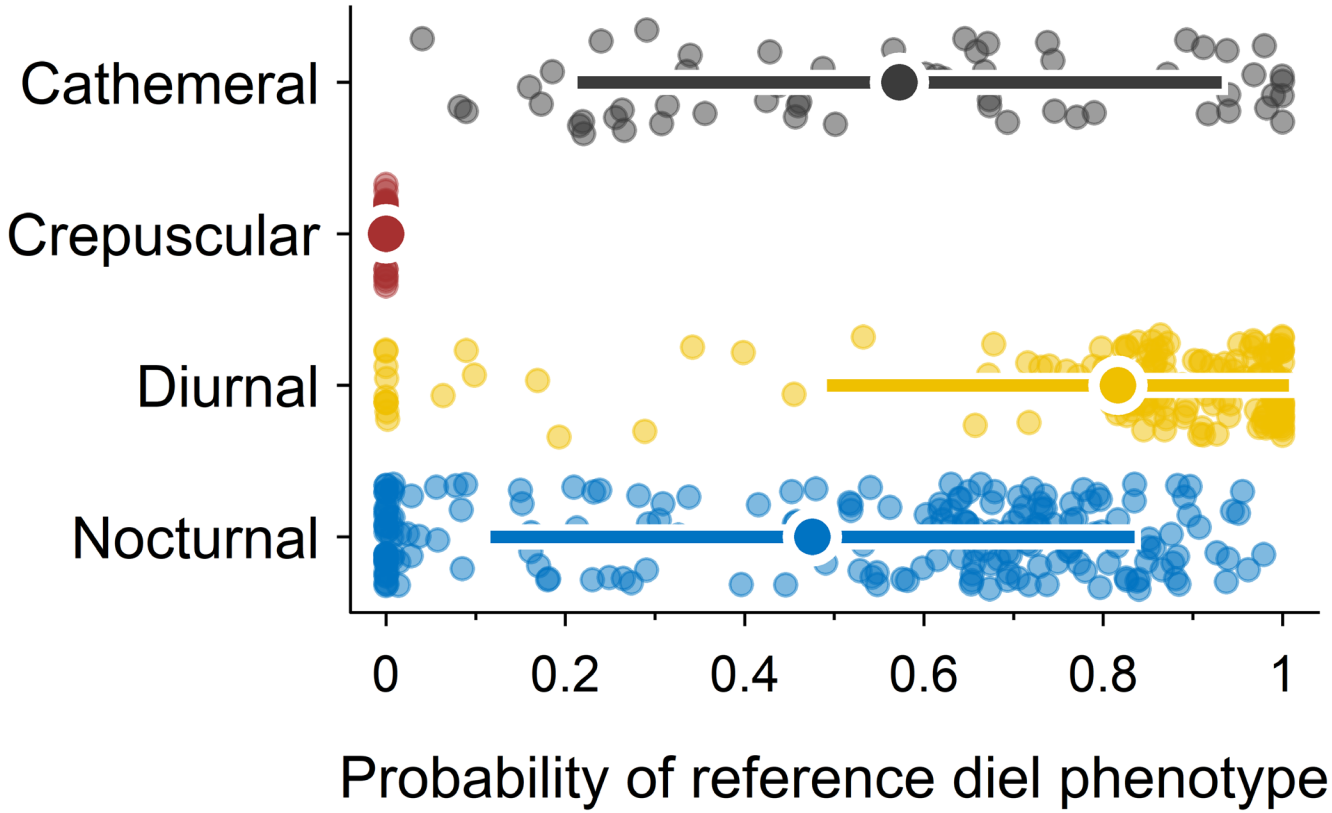
Species Results

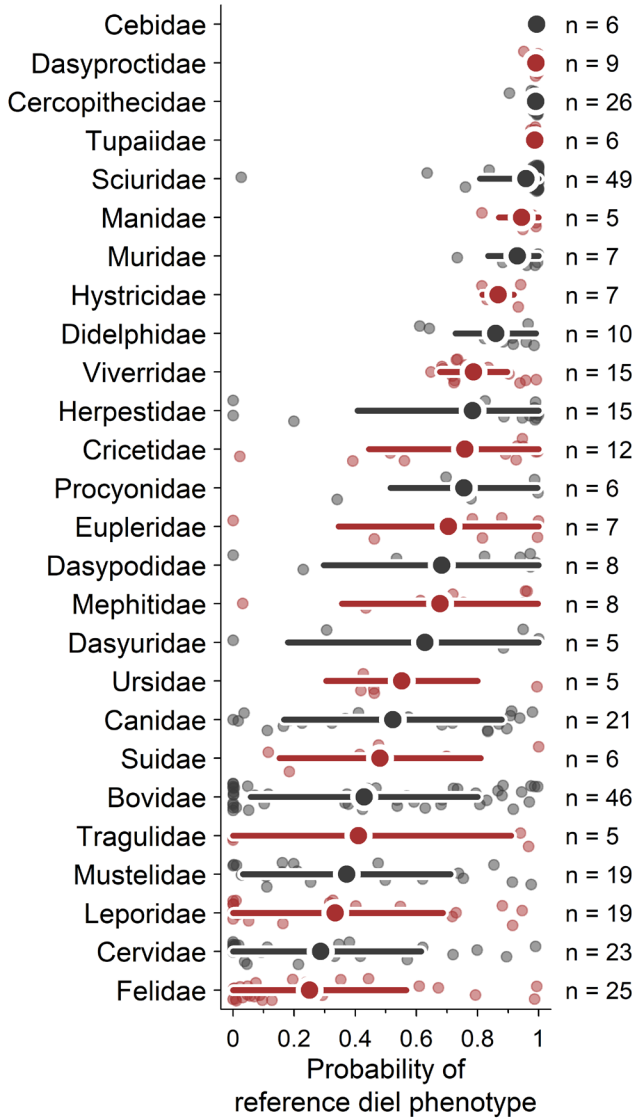


Species	Fosa
Reference	Cathemeral
Units	45



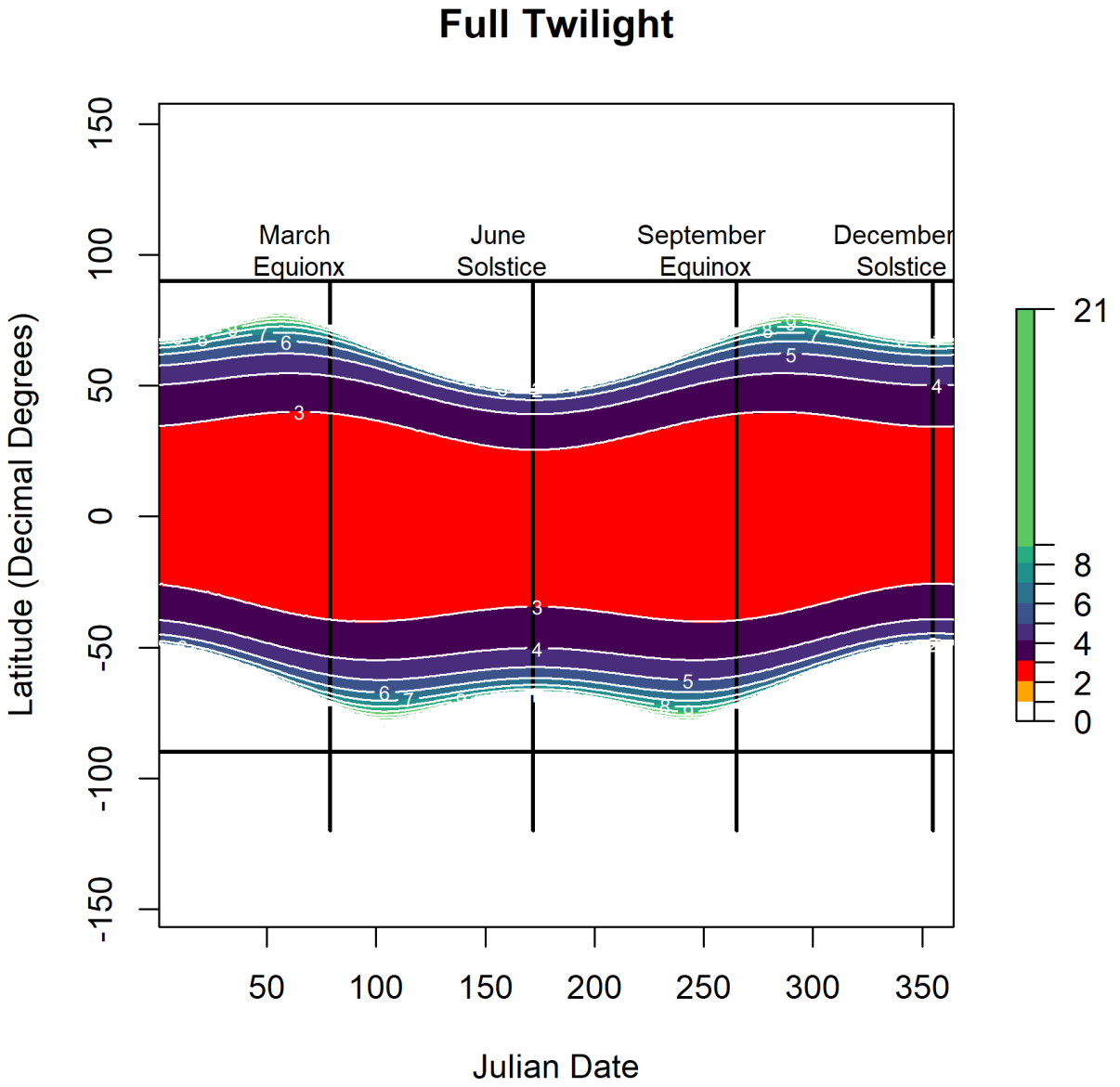
Reference Literature - Empirical comparison

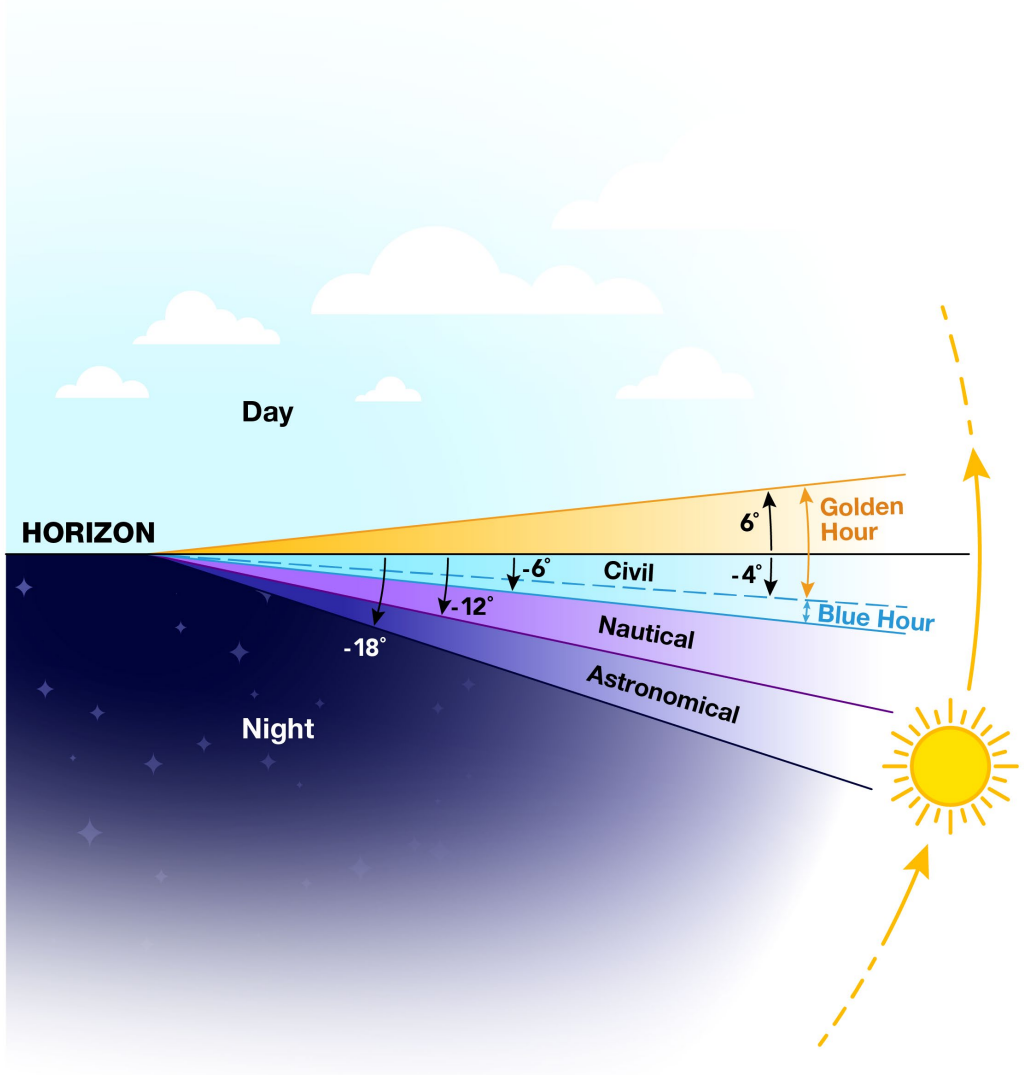




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Are there crepuscular mammals?





Some take aways

1) To understand habitat may require understanding diel behavior

2) Hopefully a useful framework for producing comparable empirical results of diel phenotypes

3) Diel phenotype variation is common among terrestrial vertebrates; a crepuscular animal is maybe not what we think

A huge thanks to ….

Kadambari Devarajan

Amy Mayer

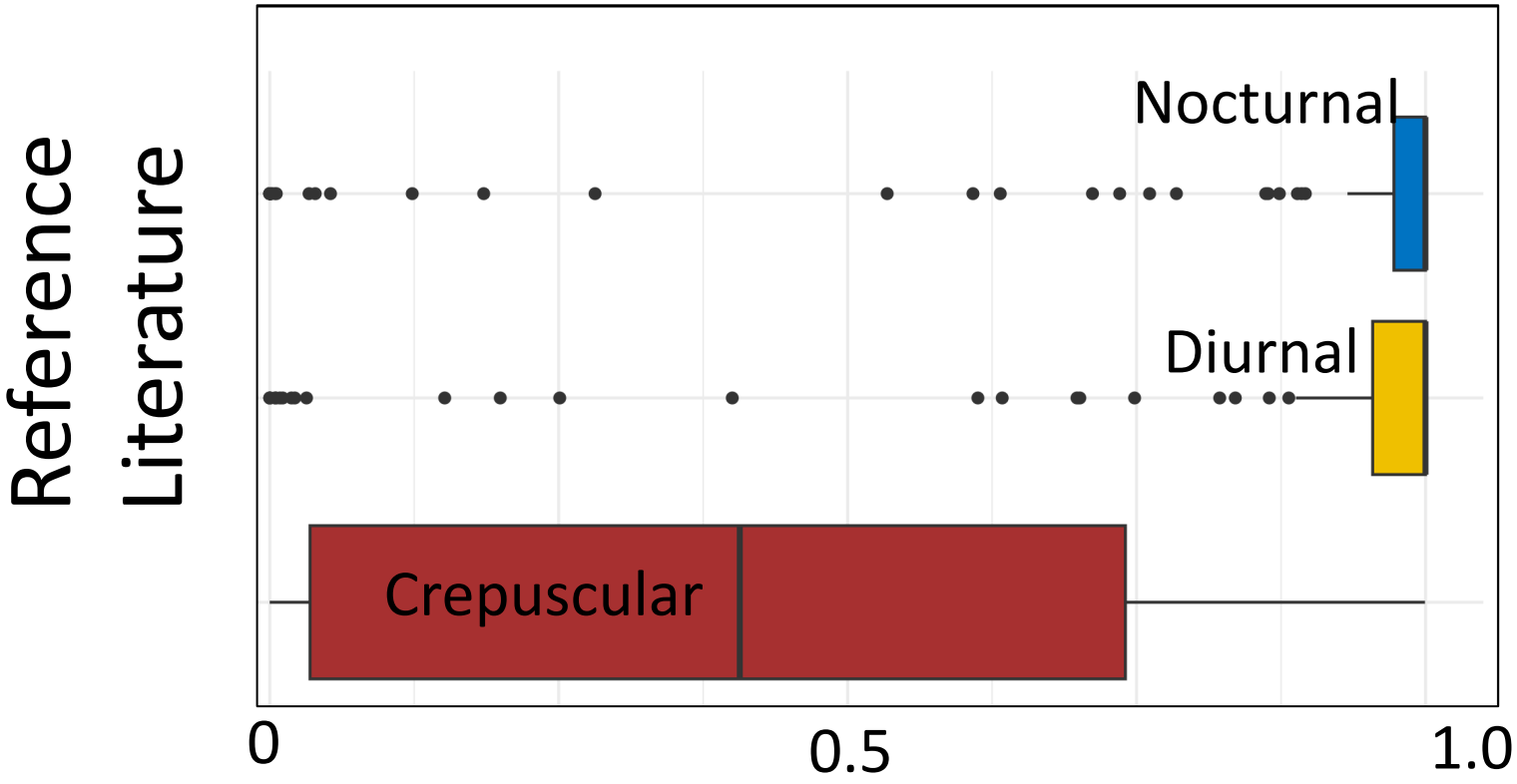
Mason Fidino

Zach Farris

Thank you to 219 collaborators….

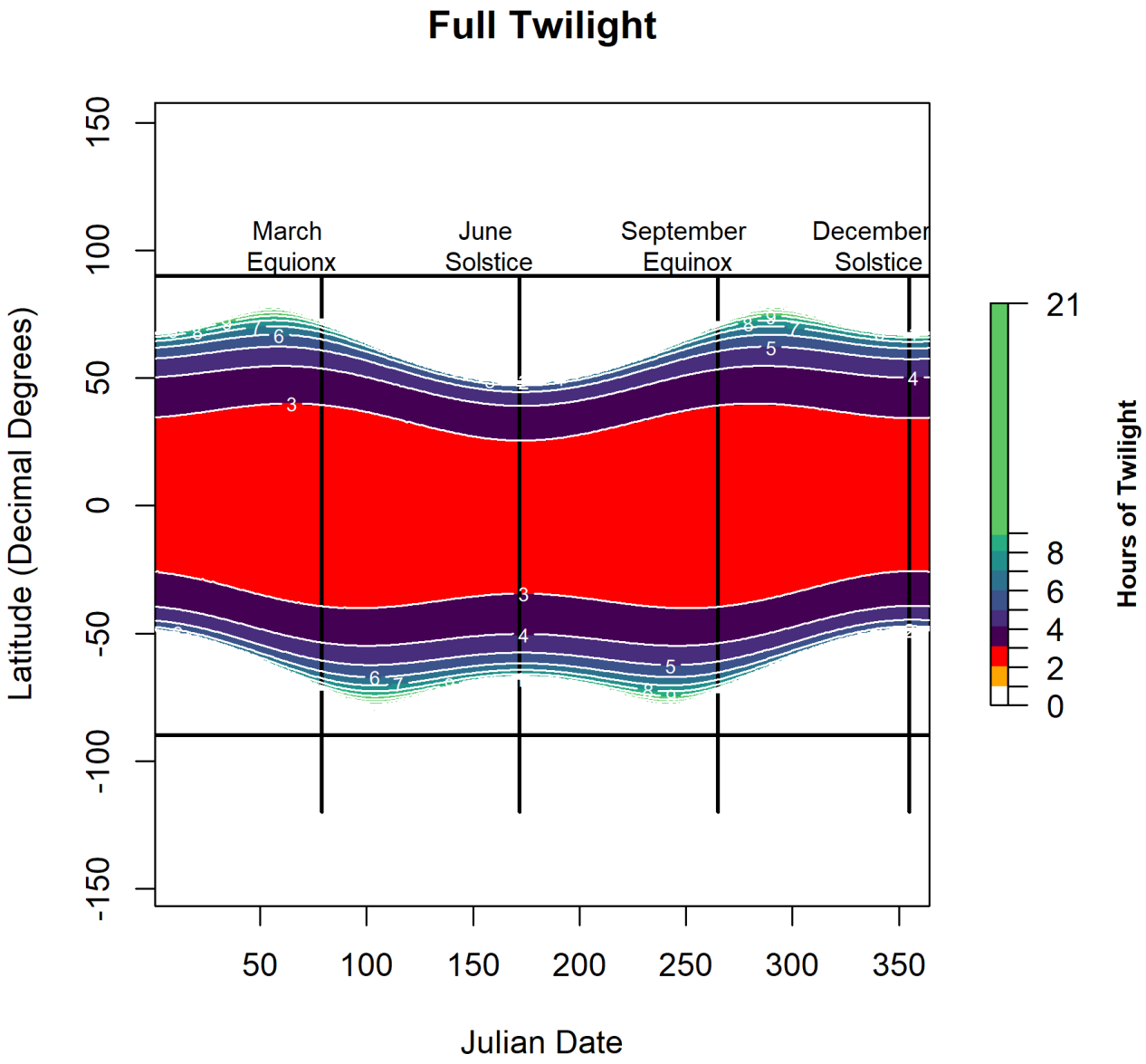
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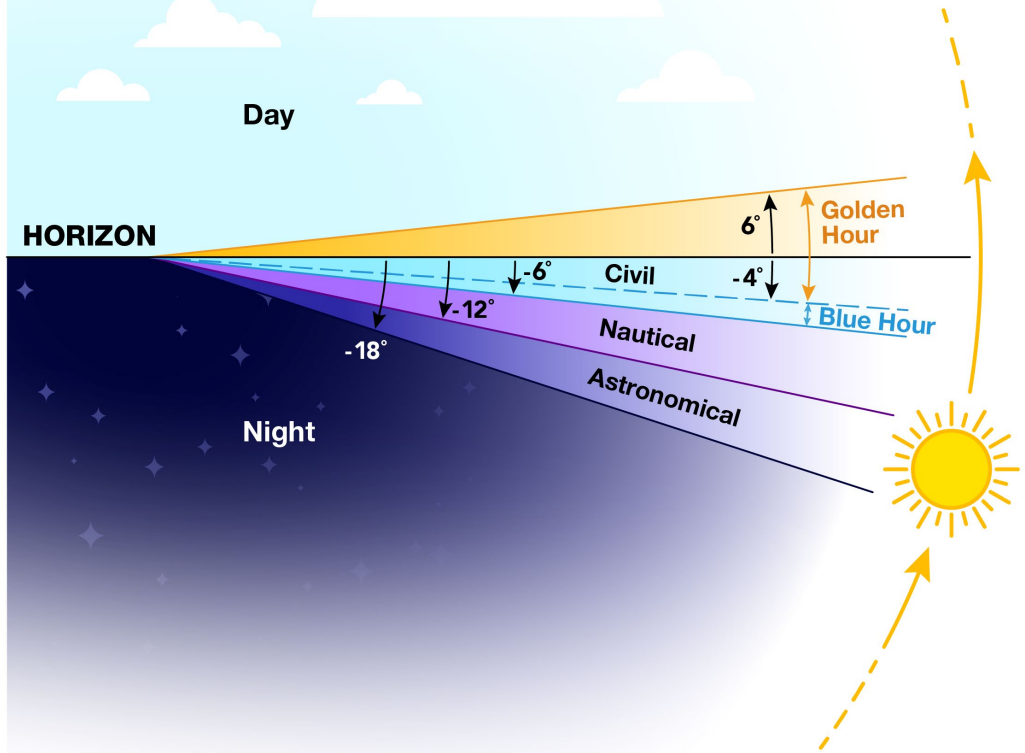
Preliminary – probability of selection (not use)



Probability of species selection (use>availability) of the diel period

Are there crepuscular animals?





Simulation Results

