A Lattice and Random Intermediate Point (LARI) Sampling Design for Animal Movement

bit.ly/liz-westat

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PhD Co-advisors: Ephraim Hanks & Matthew Beckman

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Ph.D. Research

1

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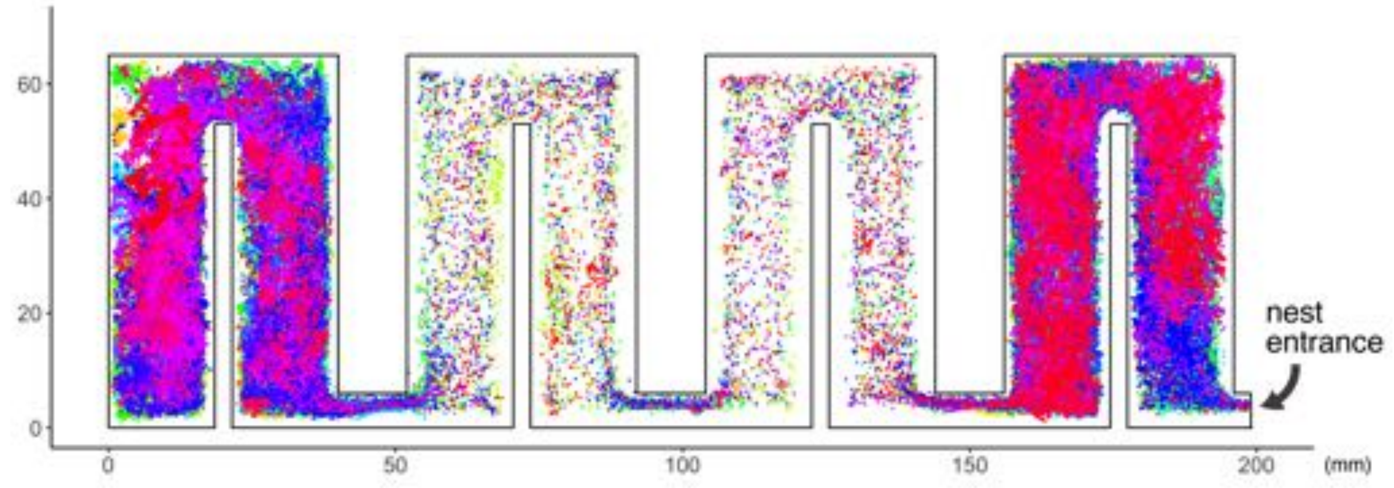

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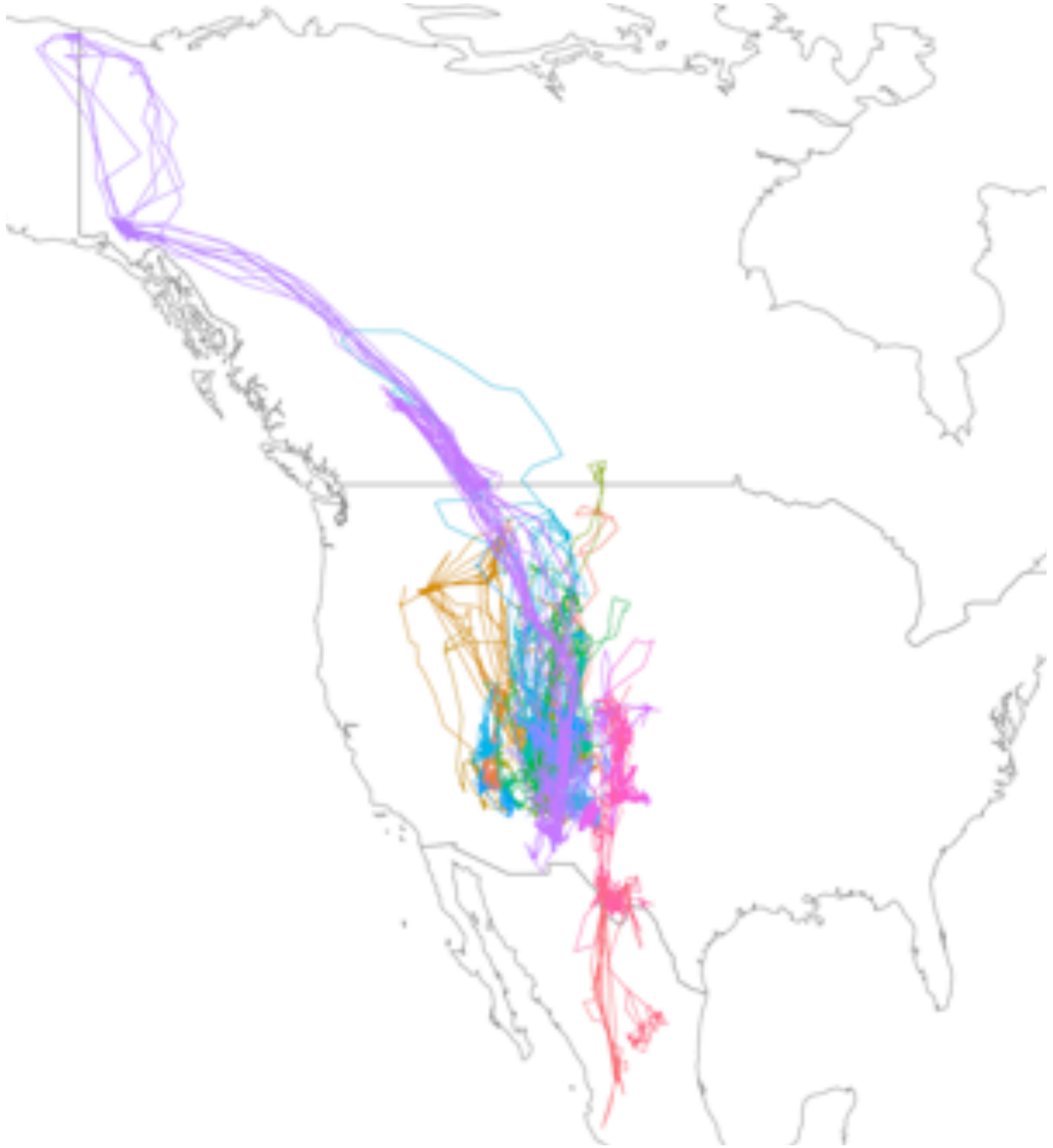
Modeling Yearly Patterns in Golden Eagle Movement



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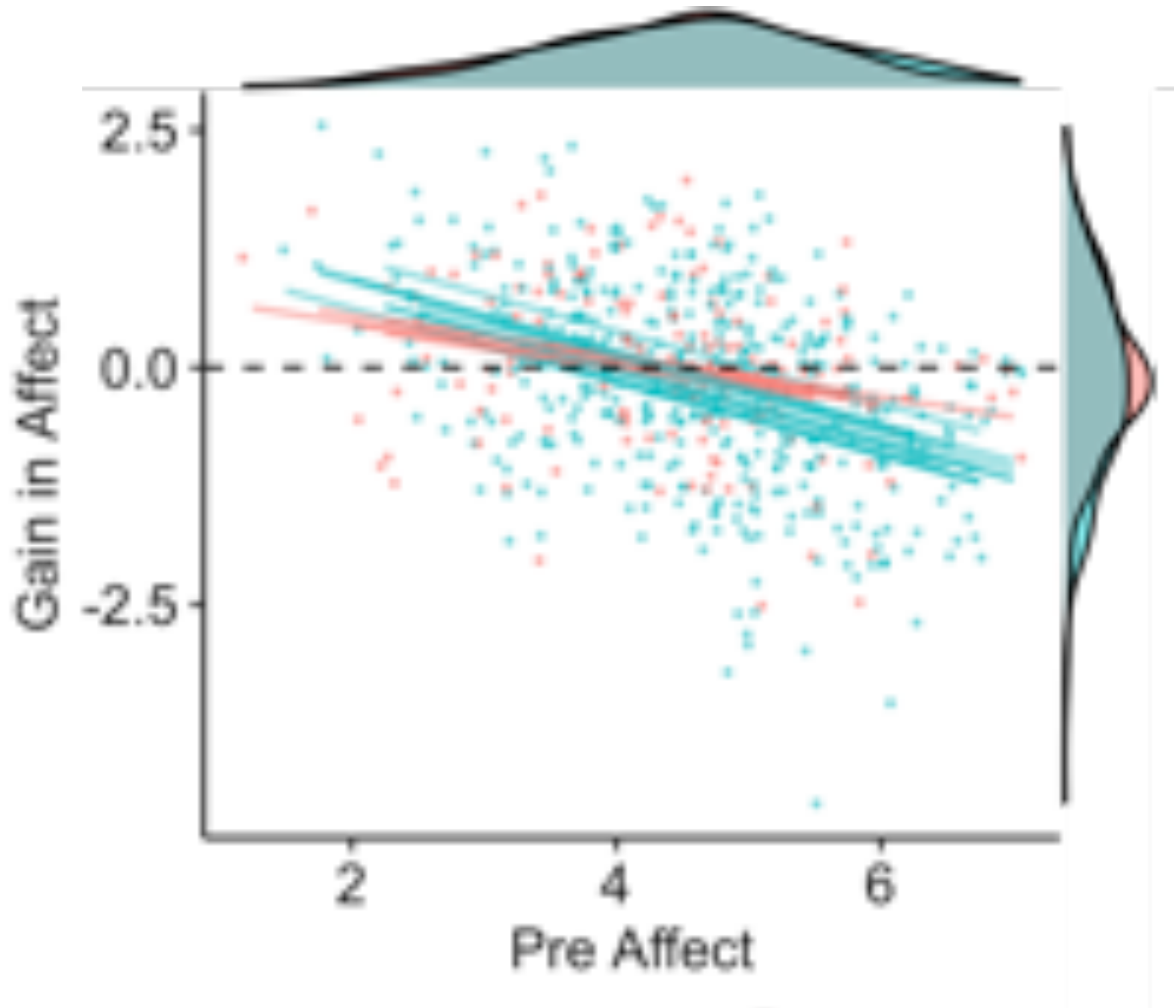
3

Survey of Probability Attitudes



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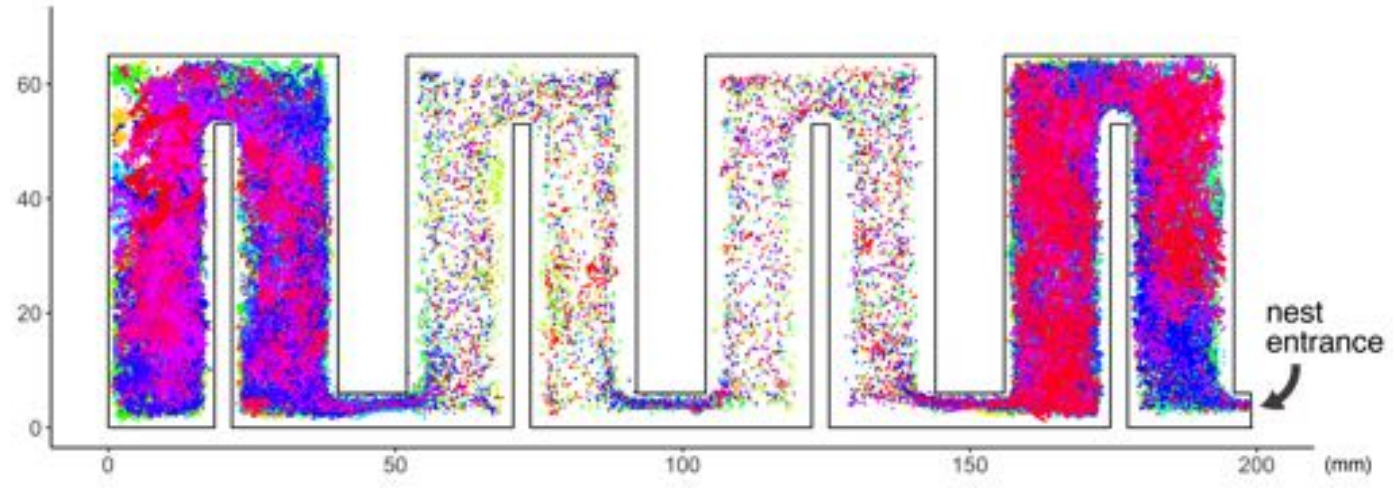


- **Background**
- LARI sampling design
- A model for animal movement
- Ant example
- Conclusion & Implications

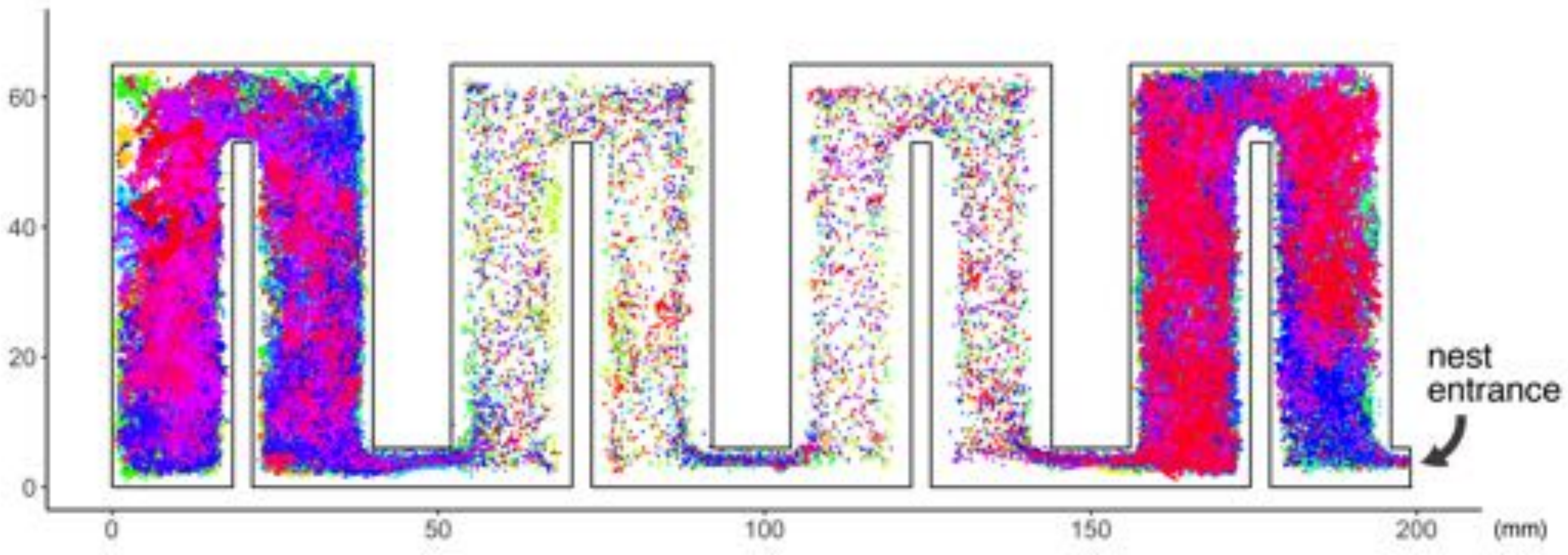
Researchers study animal movement to **understand behavior** and inform **management efforts**.

We use statistical equations to represent and quantify movement.

Hughes lab at Penn State collected **high resolution ant data,** but data collection was **time-consuming** (1000s of student-hours).

4 hours of movement data
78 ants
1 second intervals

The resulting dataset consists of **4 hours** of movement data for **78 ants** at 1 second intervals (14,401 observations per ant).



We were approached by the researchers with the **scenario**:

Next time, we will collect **lower resolution** data.

How should we do this to **minimize the loss of information** about movement behavior?

This question is **relevant to many researchers** collecting animal movement data.

1

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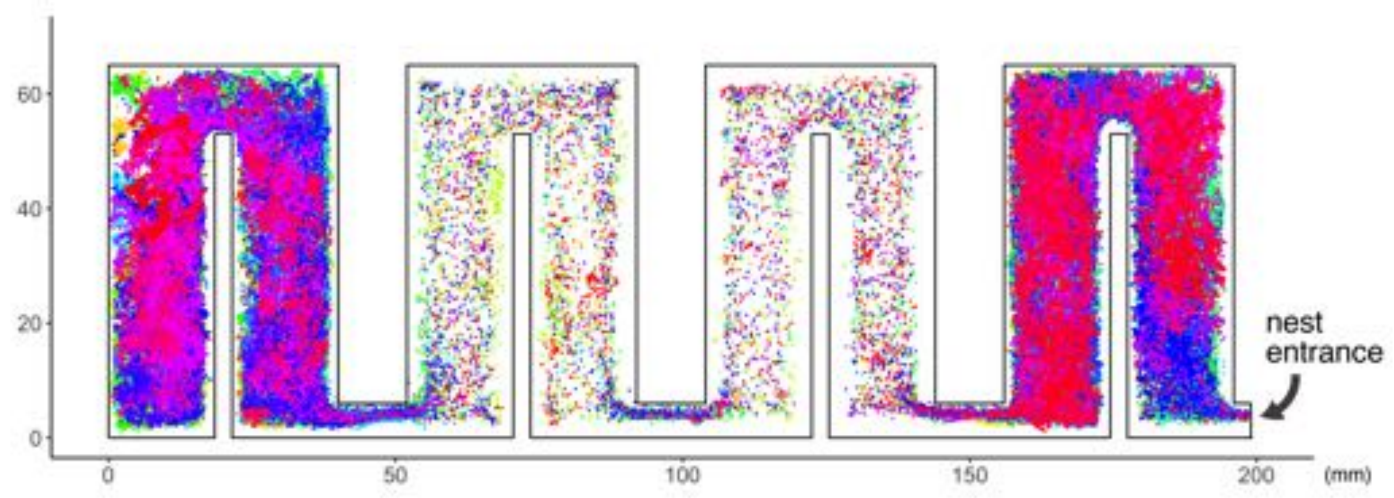

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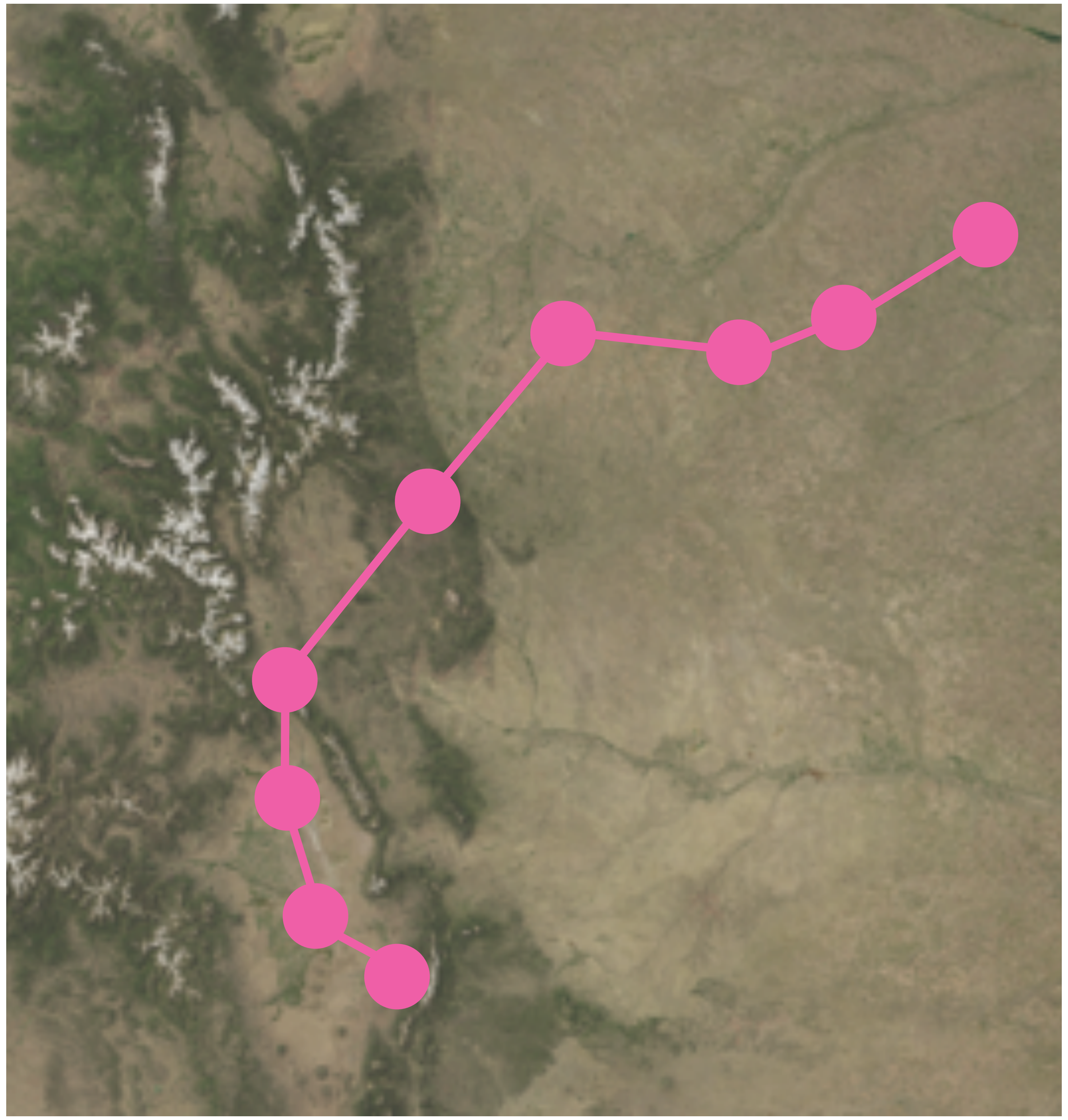
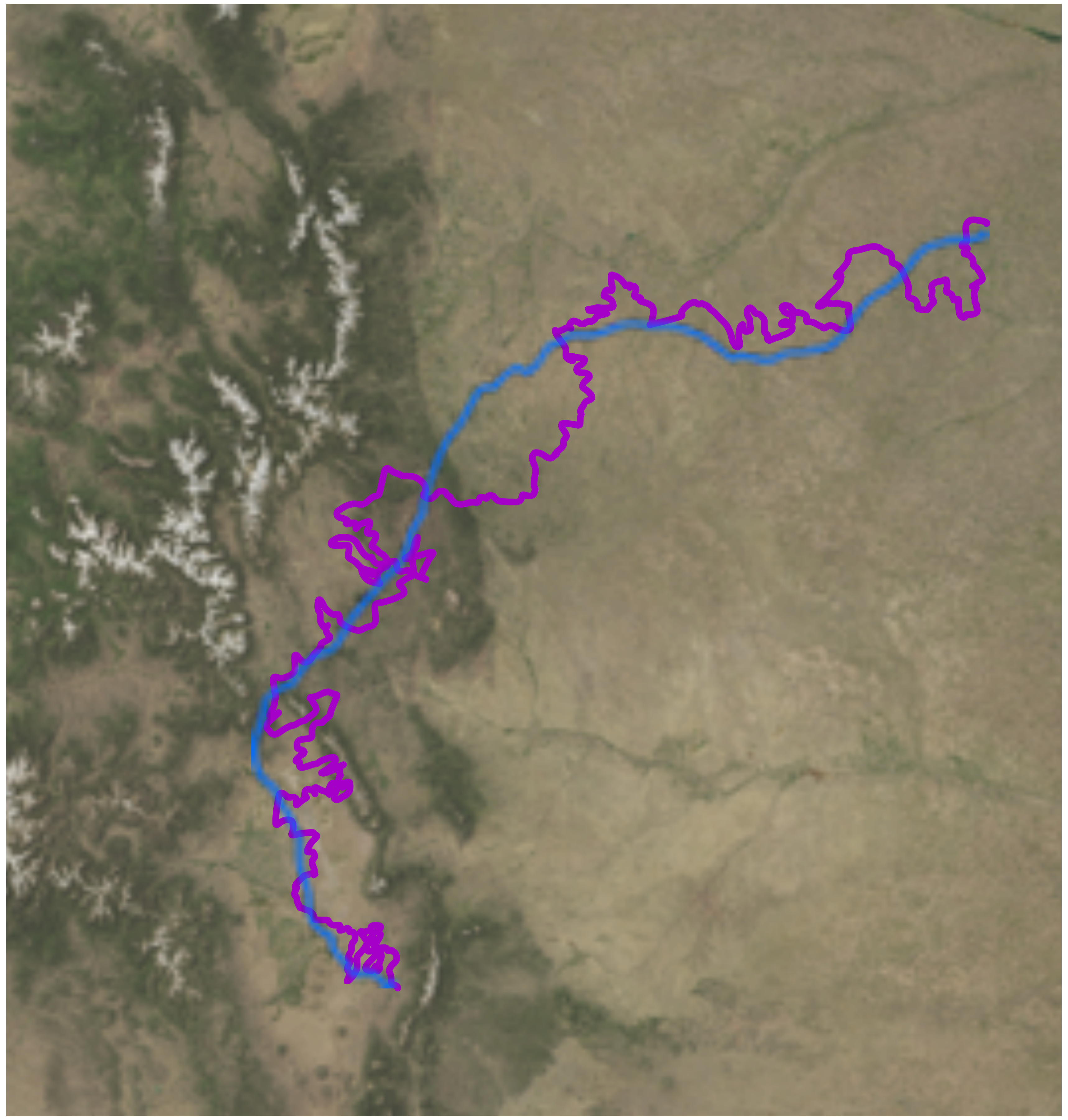
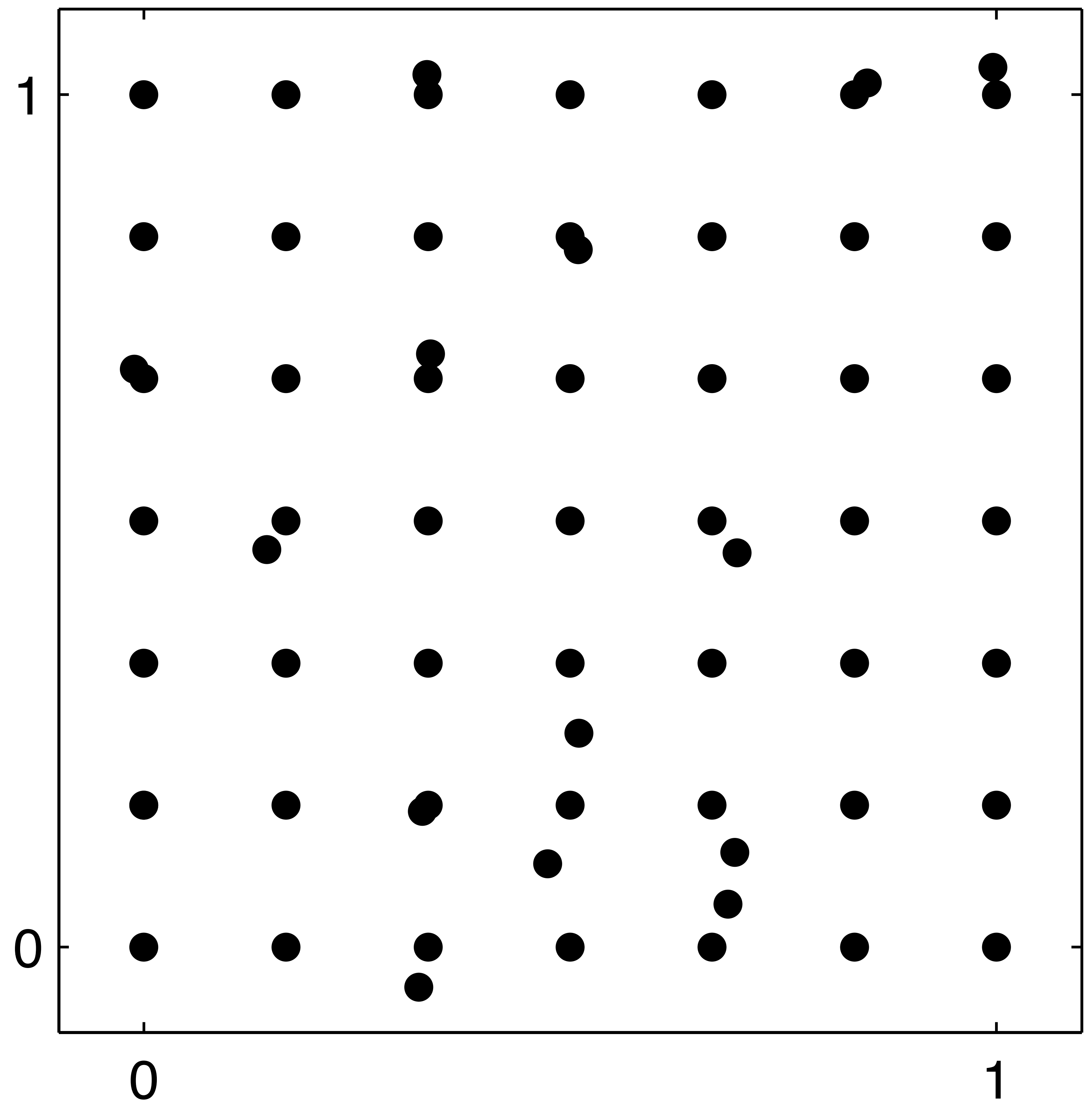
Sampling at **regular time intervals can hide important information** about the speed and tortuosity of the path.





In geostatistics, researchers often adopt a **lattice plus close pairs** design over a lattice alone or a lattice and infill approach.

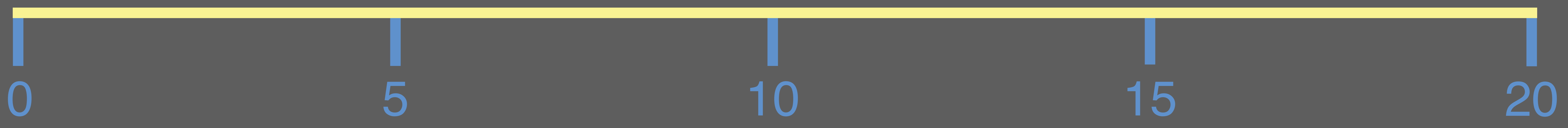


(Diggle and Lophaven, 2006)

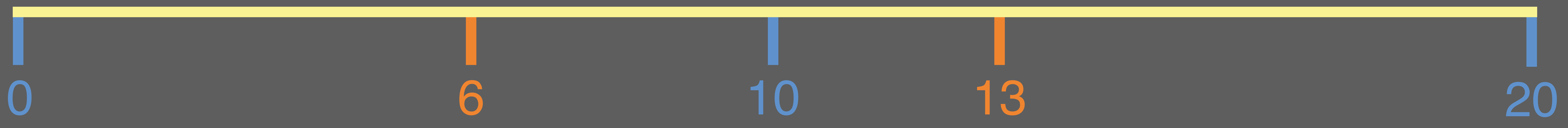
We **propose a sampling scheme** for animal telemetry data inspired by the lattice plus close pairs geostatistical design.

2 sampling designs:

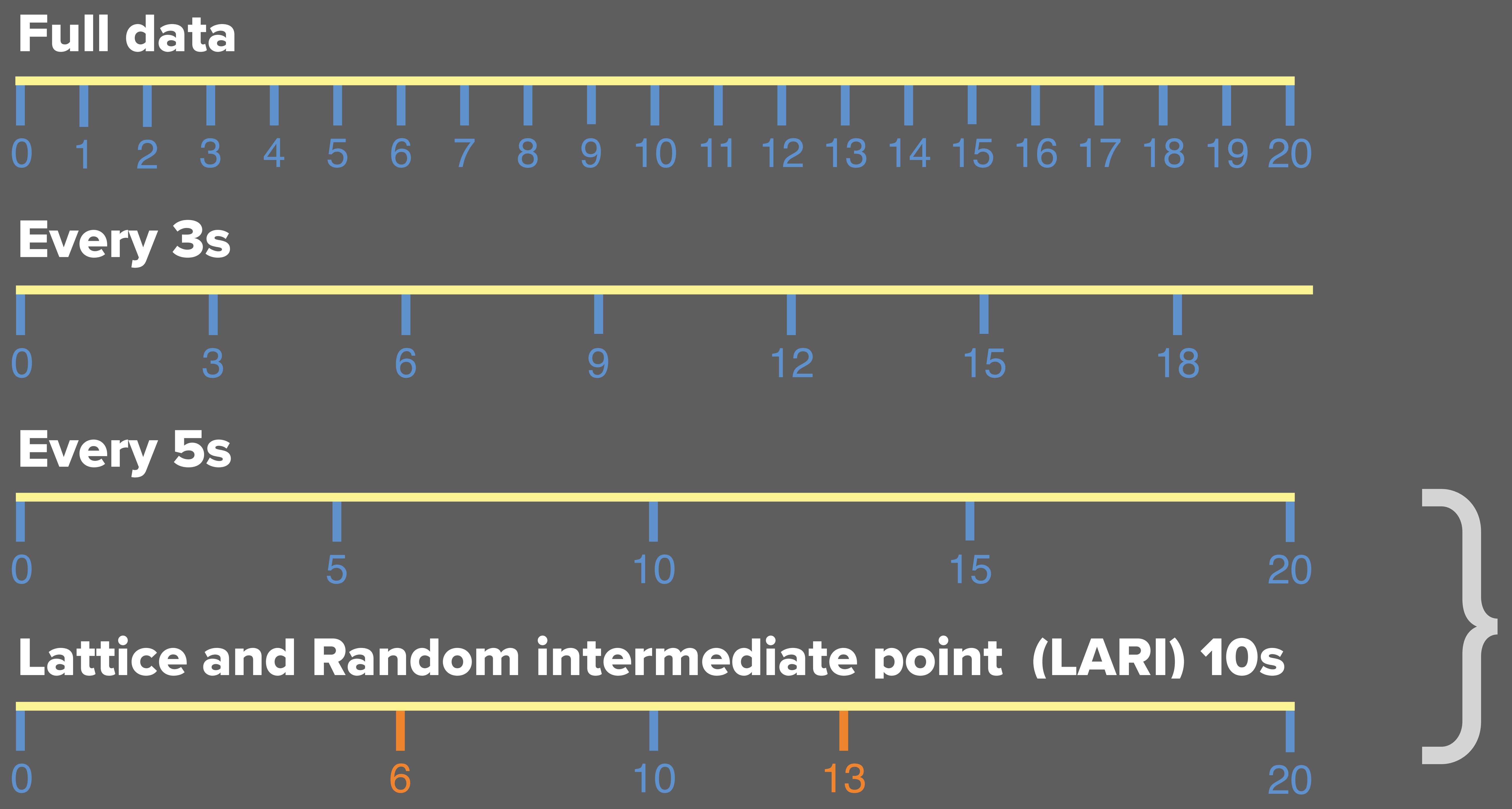
REGULAR



LATTICE AND RANDOM INTERMEDIATE POINT (LARI)



To compare regular and LARI sampling designs, we look at **4 subsamples** of the ant data.



Every 5s and LARI 10s have the same number of data points

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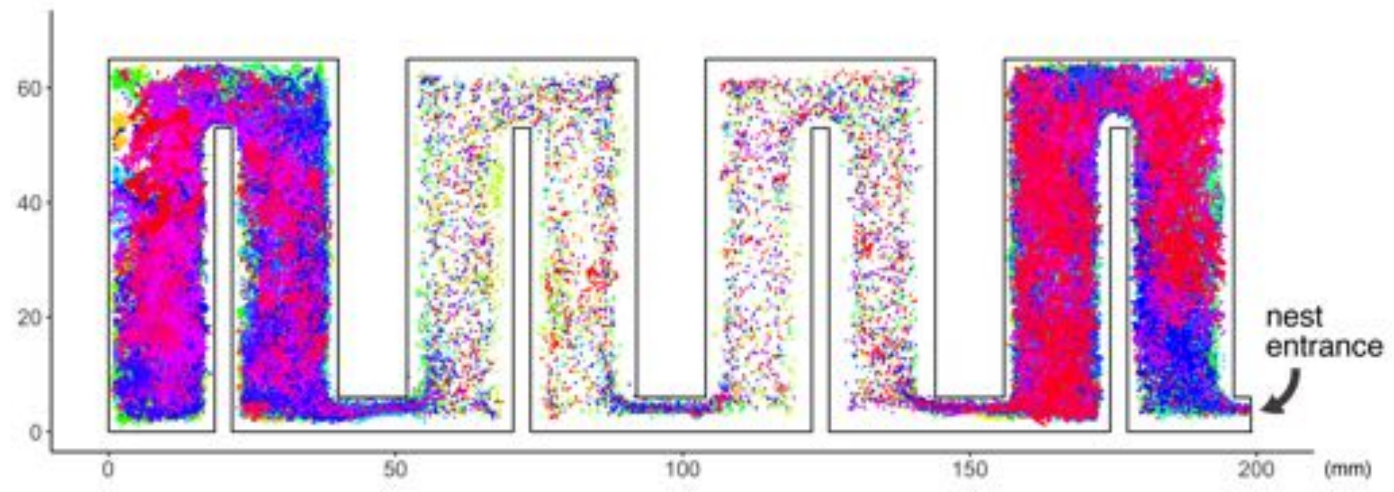

- Background
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- **A model for animal movement**
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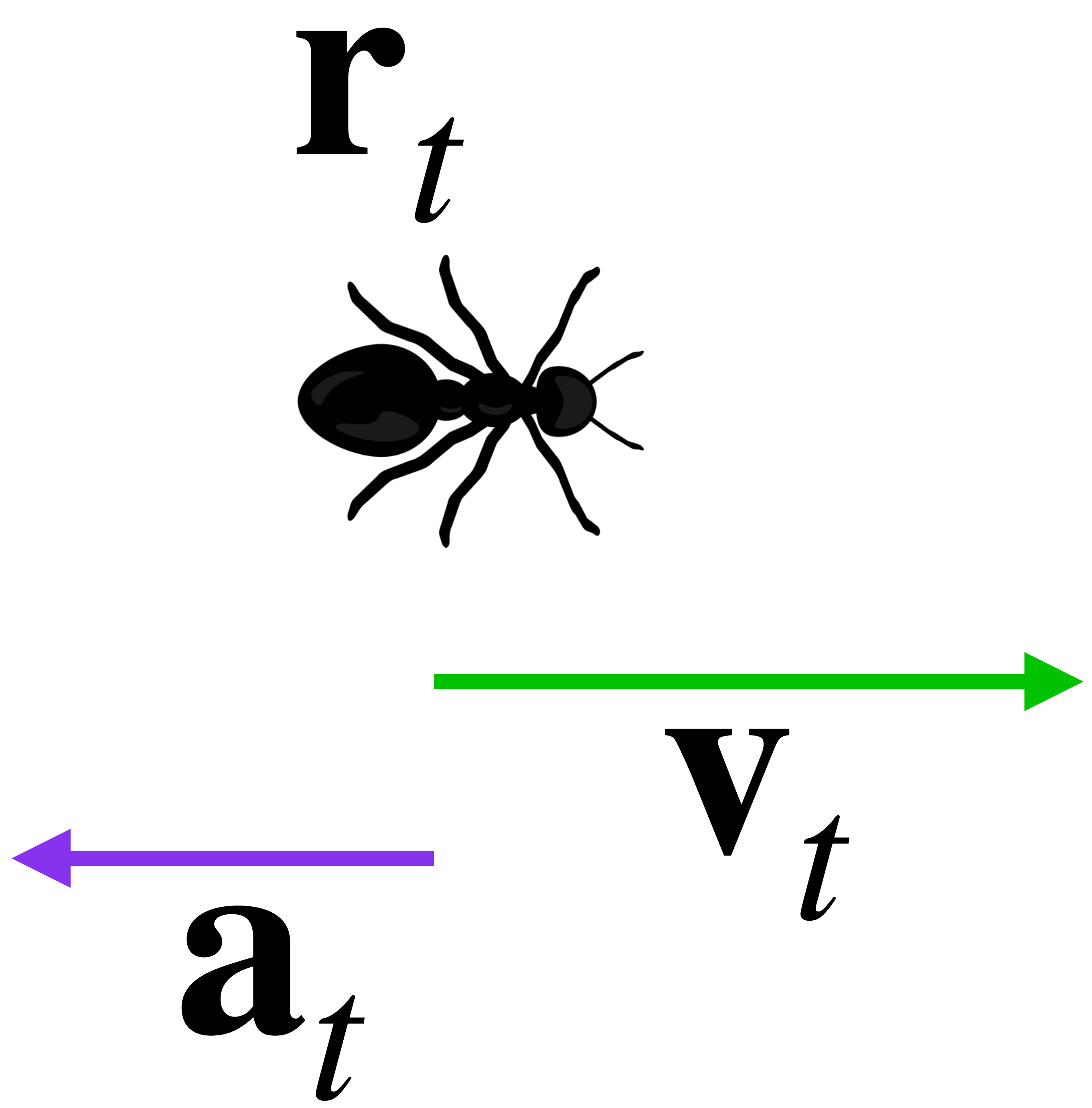
To **model movement at an individual level**, we use basic concepts from physics.

$\mathbf{r}_t =$ position

$\mathbf{v}_t =$ velocity

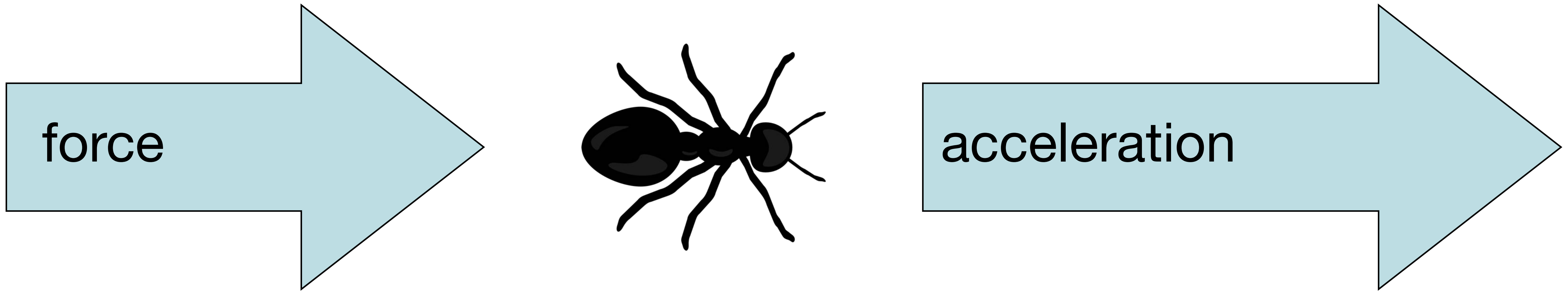
$\mathbf{a}_t =$ acceleration

This ant is slowing down



$$\mathbf{F}_t = m\mathbf{a}_t$$

So modeling acceleration is the same as **modeling "force"** acting on an animal.



The **2 main equations** for this model

The derivative of position with respect to time is velocity.

$$\boxed{\frac{d\mathbf{r}_t}{dt} = \mathbf{v}_t} \quad \longleftrightarrow \quad \boxed{d\mathbf{r}_t = \mathbf{v}_t dt}$$

The derivative of velocity with respect to time is acceleration.

$$\boxed{\frac{d\mathbf{v}_t}{dt} = \mathbf{a}_t} \quad \longleftrightarrow \quad \boxed{d\mathbf{v}_t = \mathbf{a}_t dt}$$

The **2 main equations** for this model

To model animal movement, we use

$$\boxed{d\mathbf{r}_t = \mathbf{v}_t \, dt}$$

and rewrite acceleration as a sum of forces

$$d\mathbf{v}_t = \underbrace{\boxed{\beta \, (\boldsymbol{\mu}(\mathbf{r}_t) - \mathbf{v}_t) \, dt}}_{\text{mean-reverting force}} + \underbrace{\boxed{c(\mathbf{r}_t) \, \mathbf{I} d\mathbf{w}_t}}_{\text{random force}}$$

Stochastic differential equation (SDE) model for animal movement

Data: $\mathbf{r}_t,\ t = 1, 2, \ldots, 14401$ for each ant

SDE model framework:

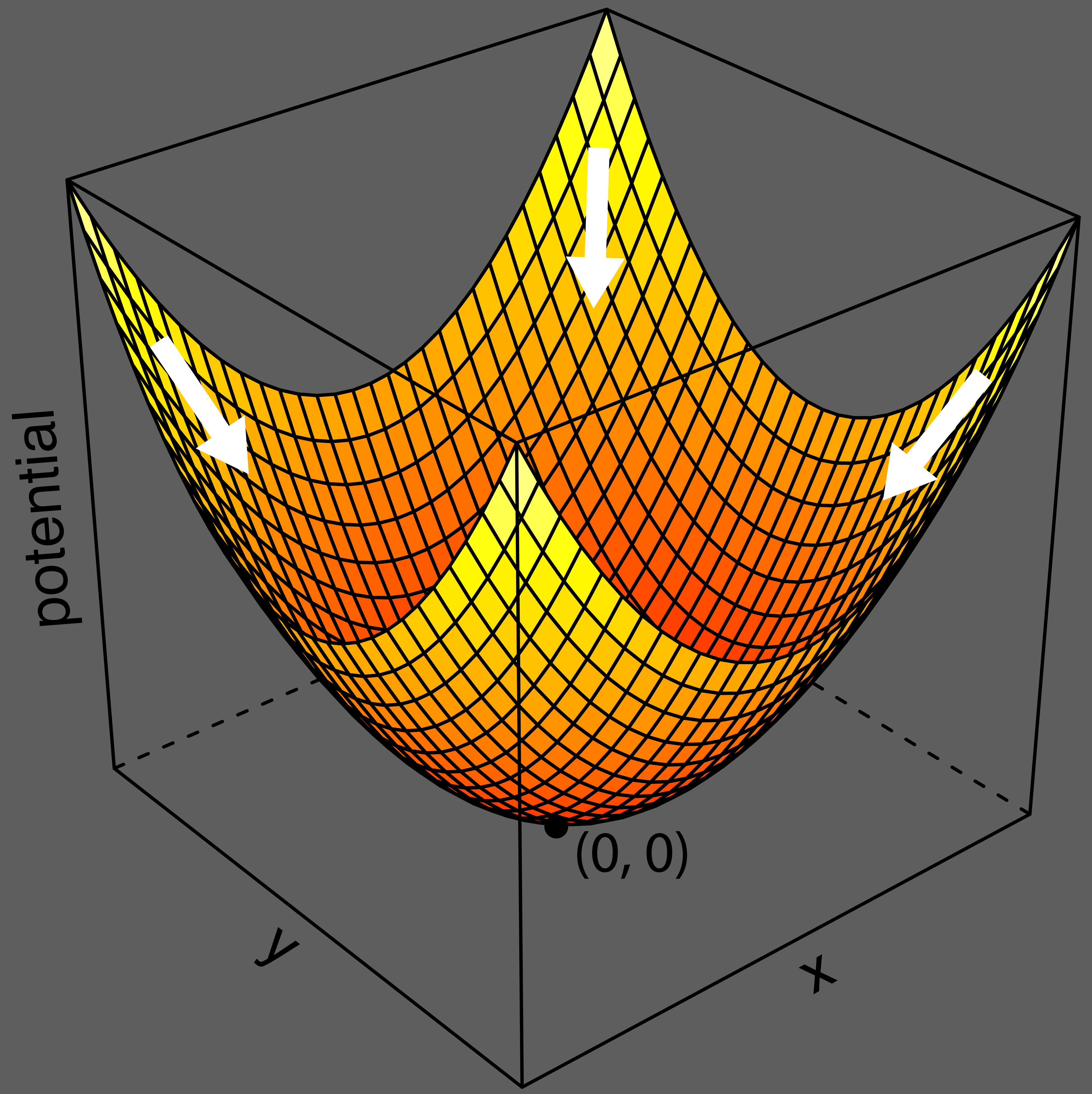
$$d\mathbf{r}_t = \mathbf{v}_t\ dt$$
$$d\mathbf{v}_t = \beta\ (\boldsymbol{\mu}(\mathbf{r}_t) - \mathbf{v}_t)\ dt + c(\mathbf{r}_t)\ \mathbf{I}d\mathbf{w}_t$$

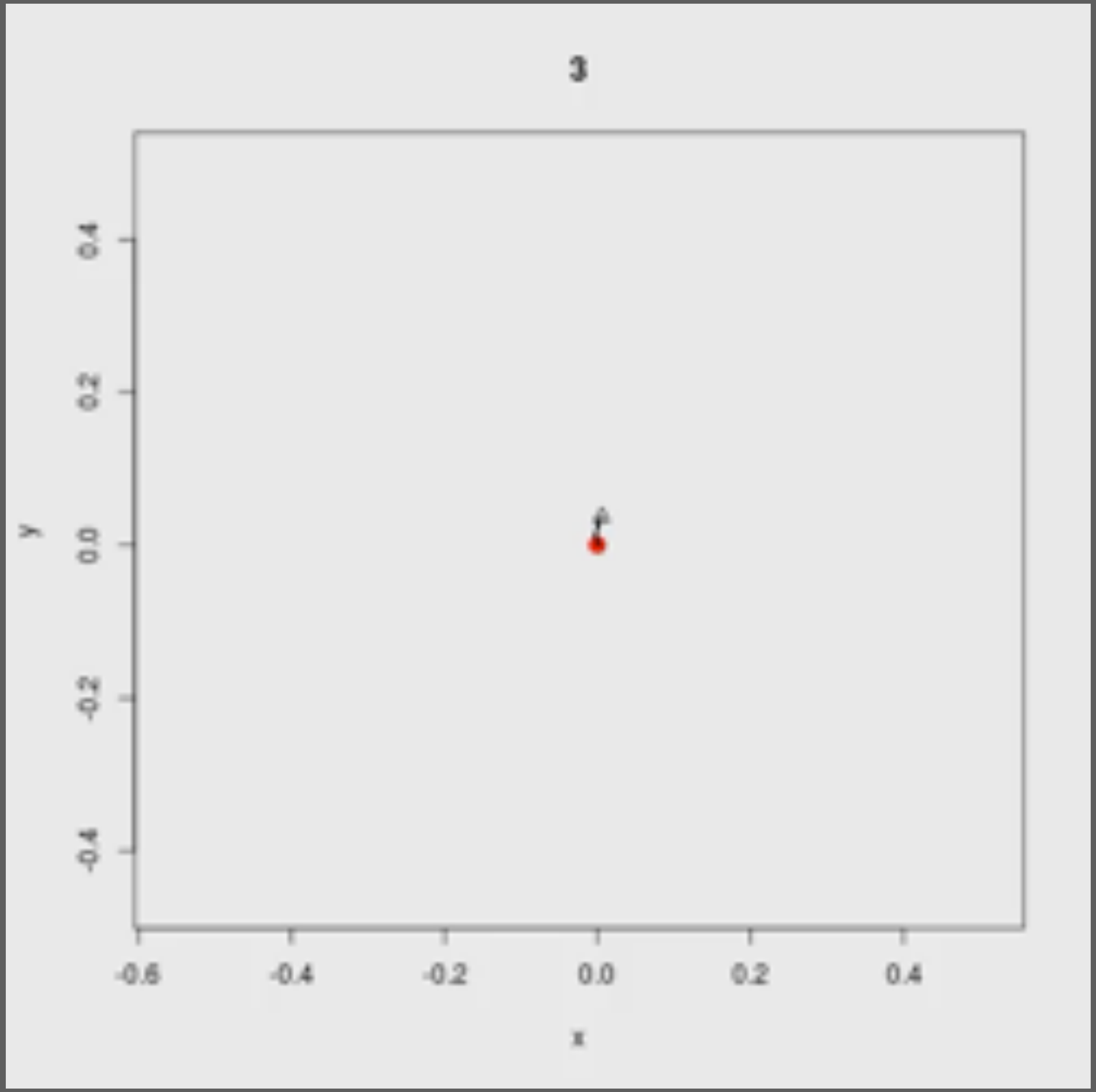
Utilizing motility and potential surfaces, define:

$$\boldsymbol{\mu}(\mathbf{r}_t) = m(\mathbf{r}_t)\ [-\nabla p(\mathbf{r}_t)] \qquad \text{(mean drift)}$$
$$c(\mathbf{r}_t) = \sigma\ m(\mathbf{r}_t) \qquad \text{(magnitude of stochasticity)}$$

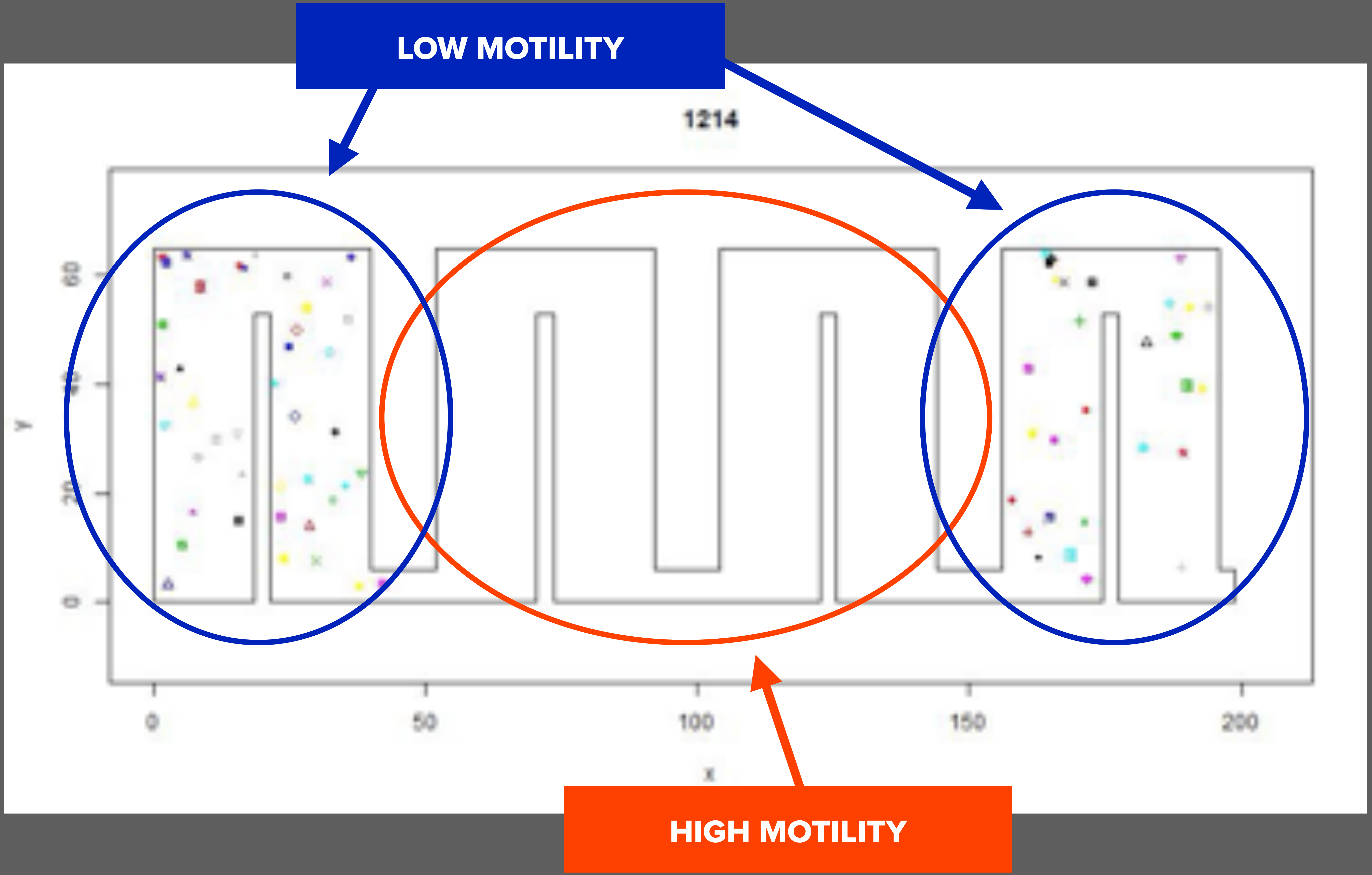
(James Russell et al., 2018)

We describe animal movement using a stochastic differential equation model with 2 parameters: **potential** and motility





We describe animal movement using a stochastic differential equation model with 2 parameters: potential and **motility**



Where did this model come from?

A similar set of equations was first developed in 1943 to model movement of stars.

In 2001, David Brillinger adapted the equations to model elk and mule deer movement.

The framework I use was proposed in 2018 by Jim Russell and applied to ant movement data.

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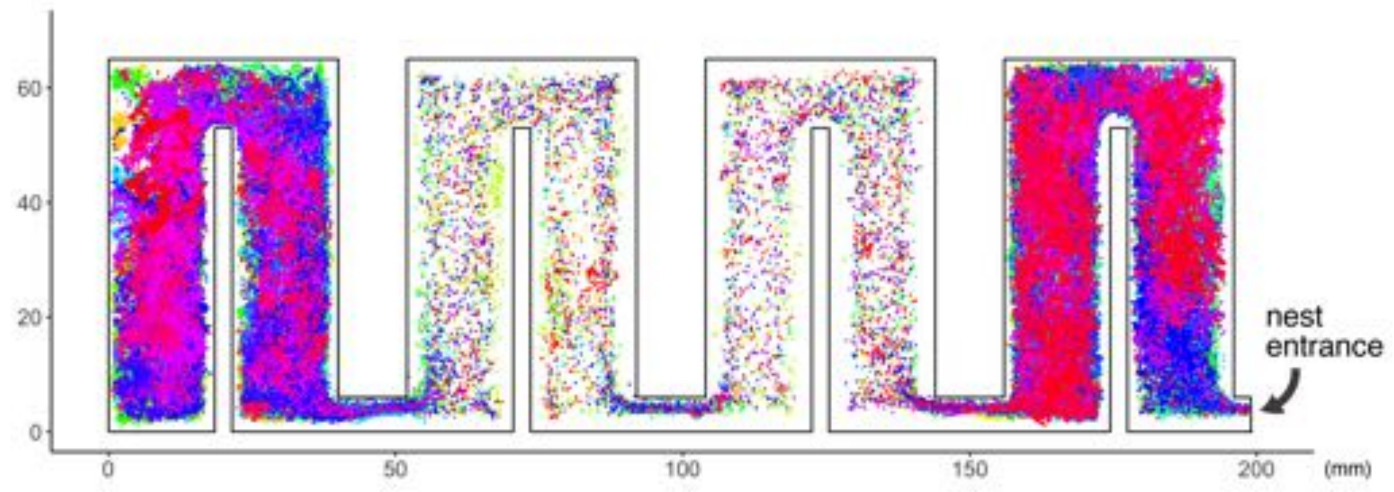

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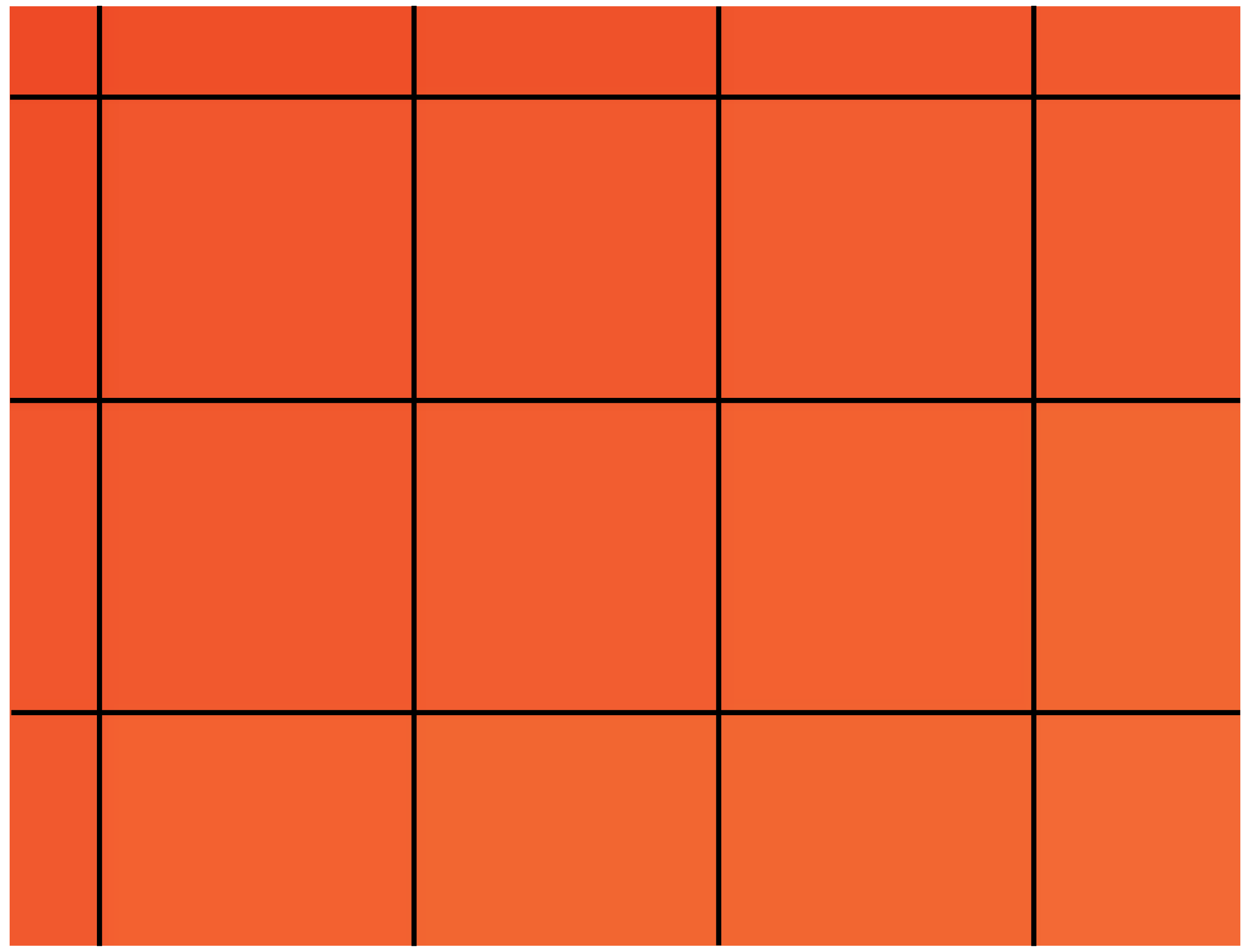
Spline expansion (degree 0, piecewise constant) of the motility and potential surfaces

$$m(\mathbf{r}_t) = \sum_{j=1}^{J} m_j s_j(\mathbf{r}_\tau)$$

$$p(\mathbf{r}_t) = \sum_{j=1}^{J} p_j s_j(\mathbf{r}_\tau)$$

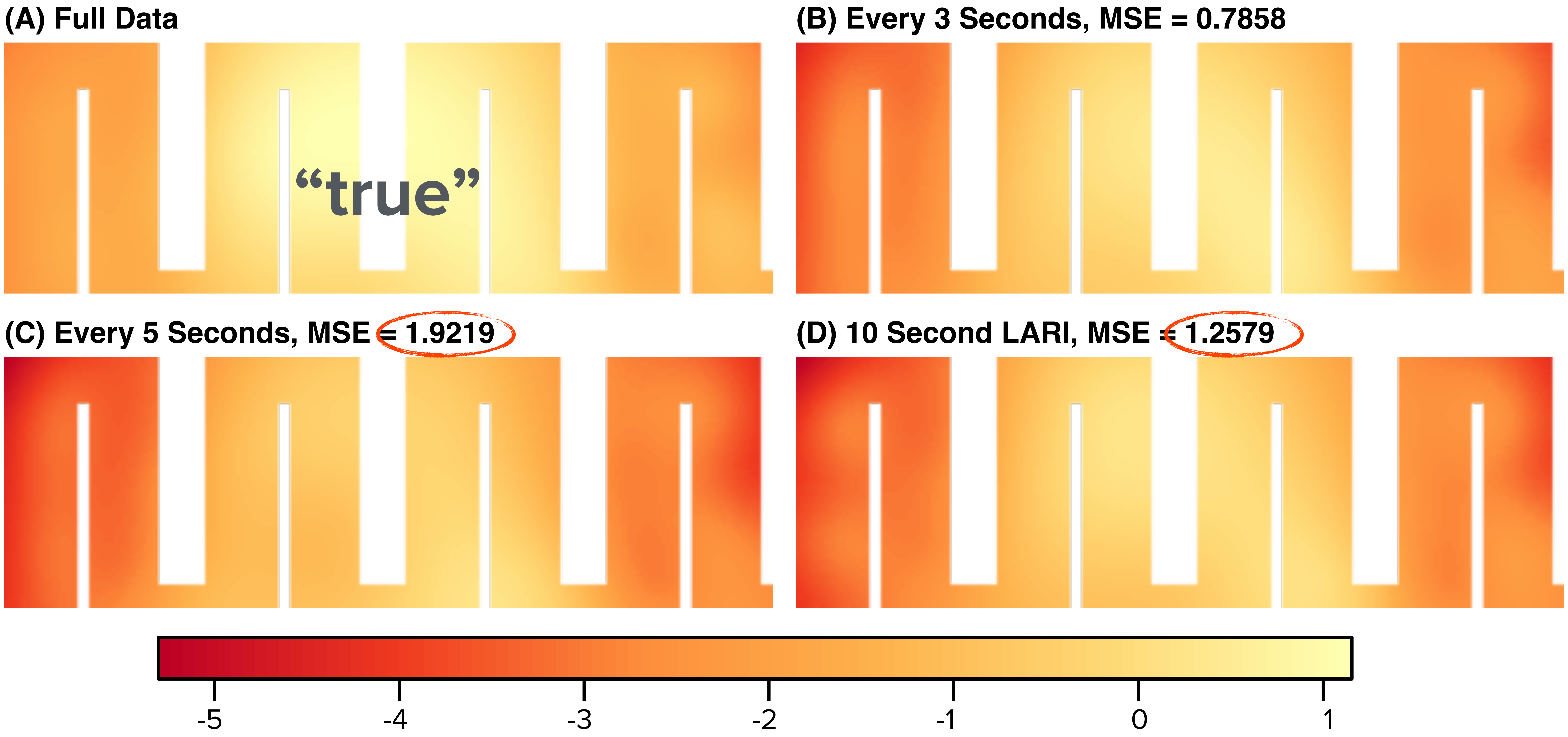
$$s_j(\mathbf{r}_\tau) \equiv \begin{cases} 1, & \mathbf{r}_\tau \textbf{ in } j^{th} \textbf{ grid cell} \\ 0, & \textbf{otherwise} \end{cases}$$



Penalize the roughness of ***m*** and ***p***

Smoothness parameters are chosen with a holdout set.

We **compare motility and potential** surfaces estimated with the 4 subsamples using multiple metrics.



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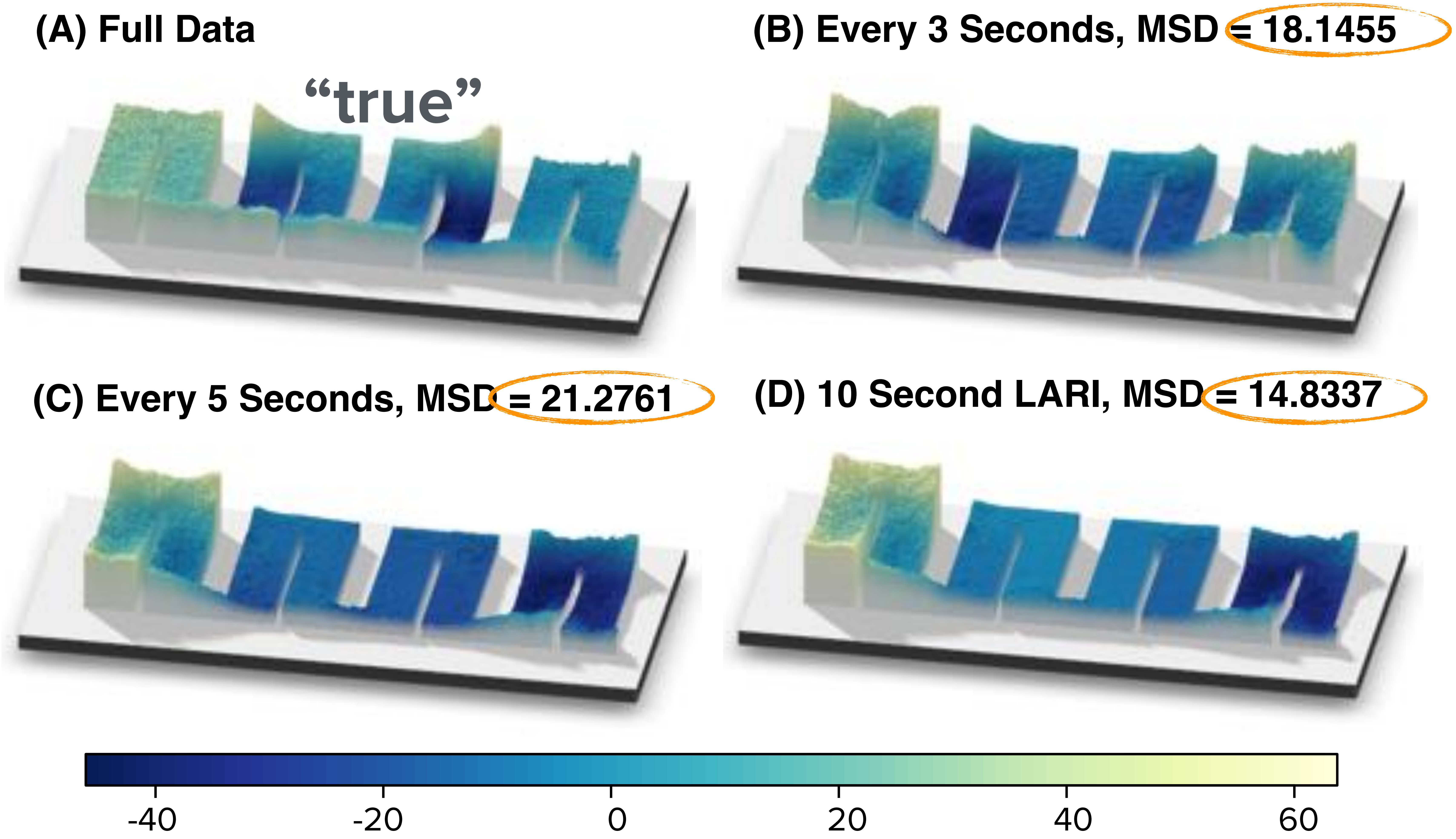
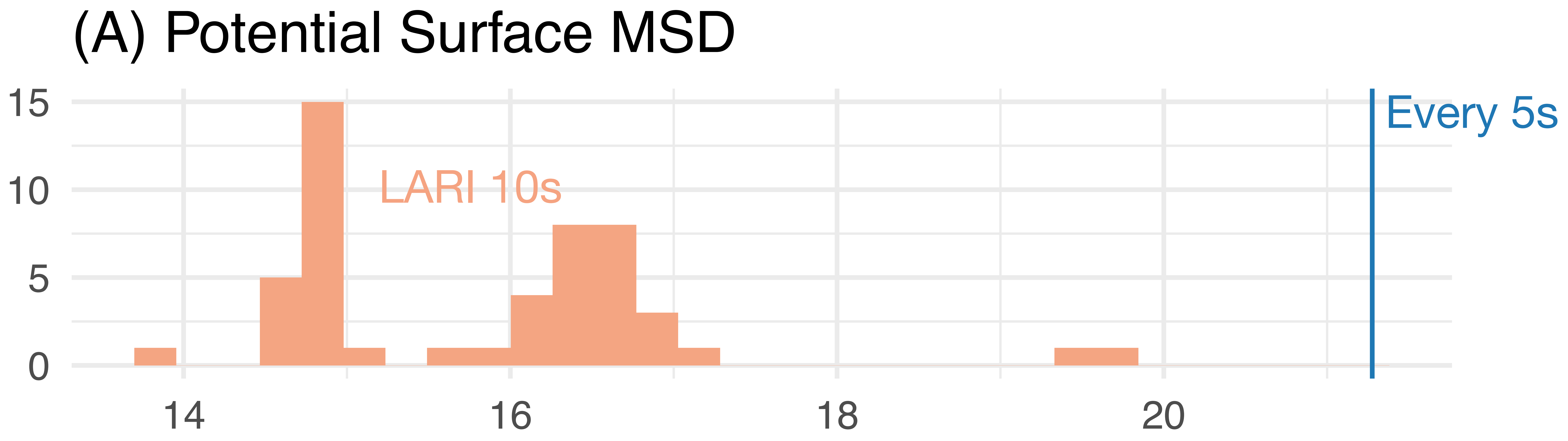
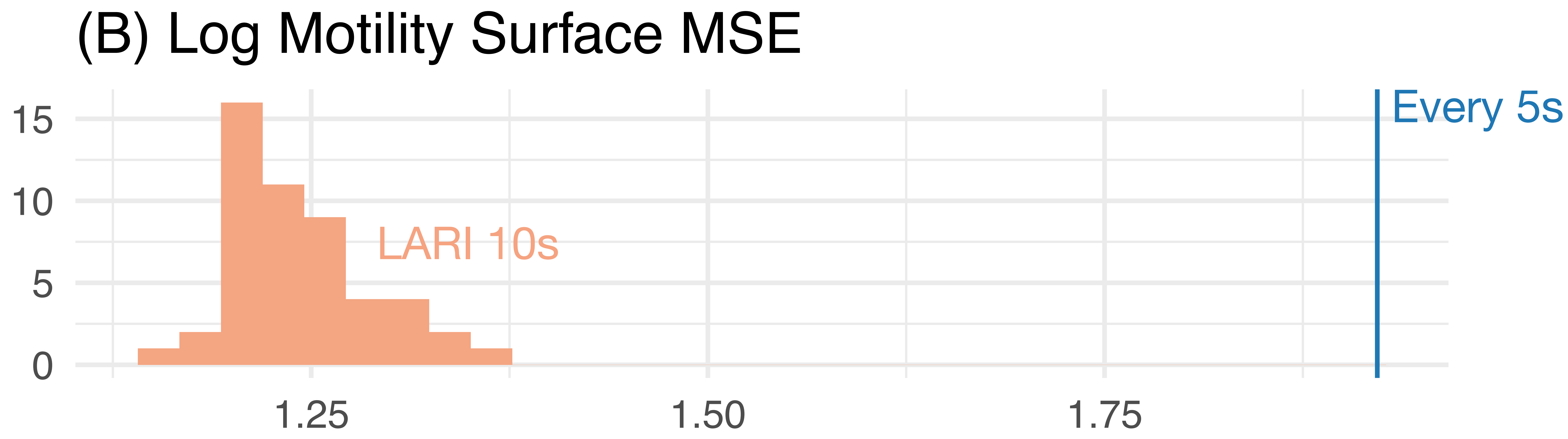
POTENTIAL SURFACE



We fit 50 different LARI subsamples to understand random variation.





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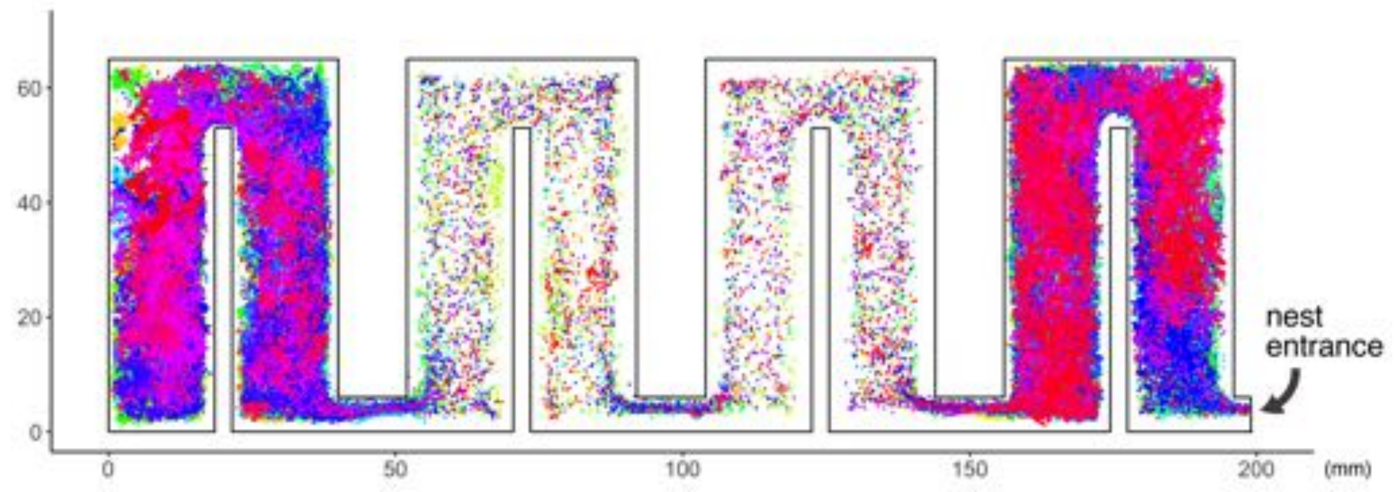

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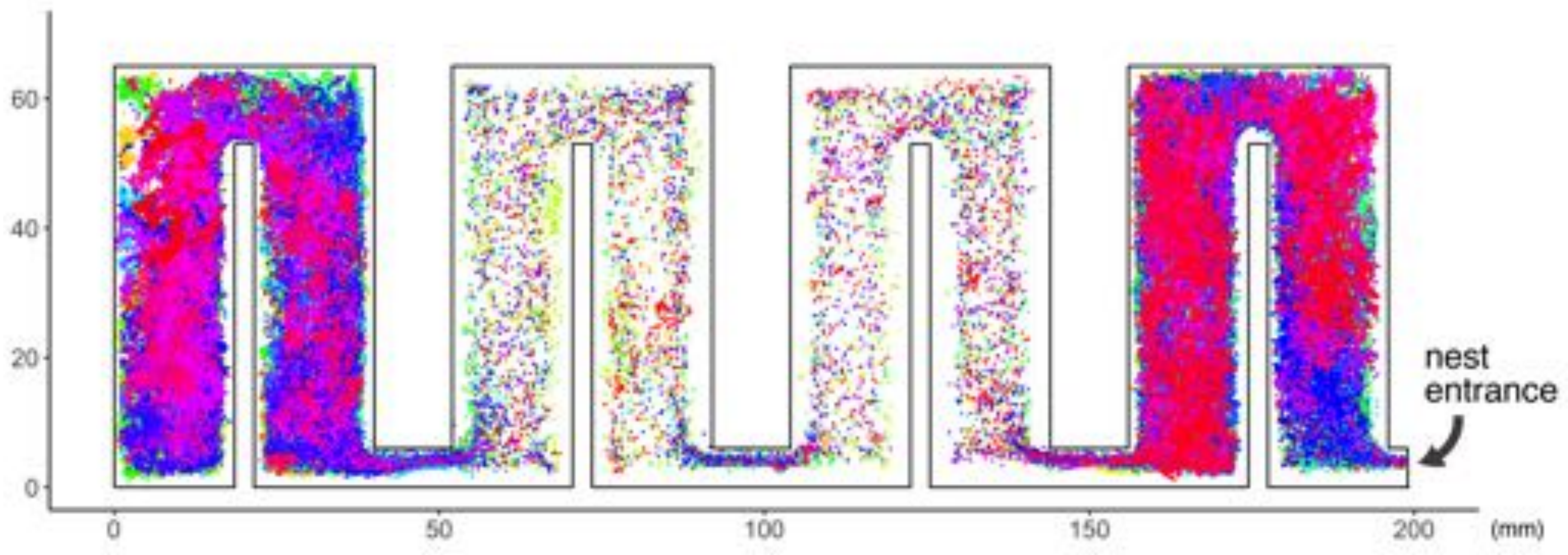
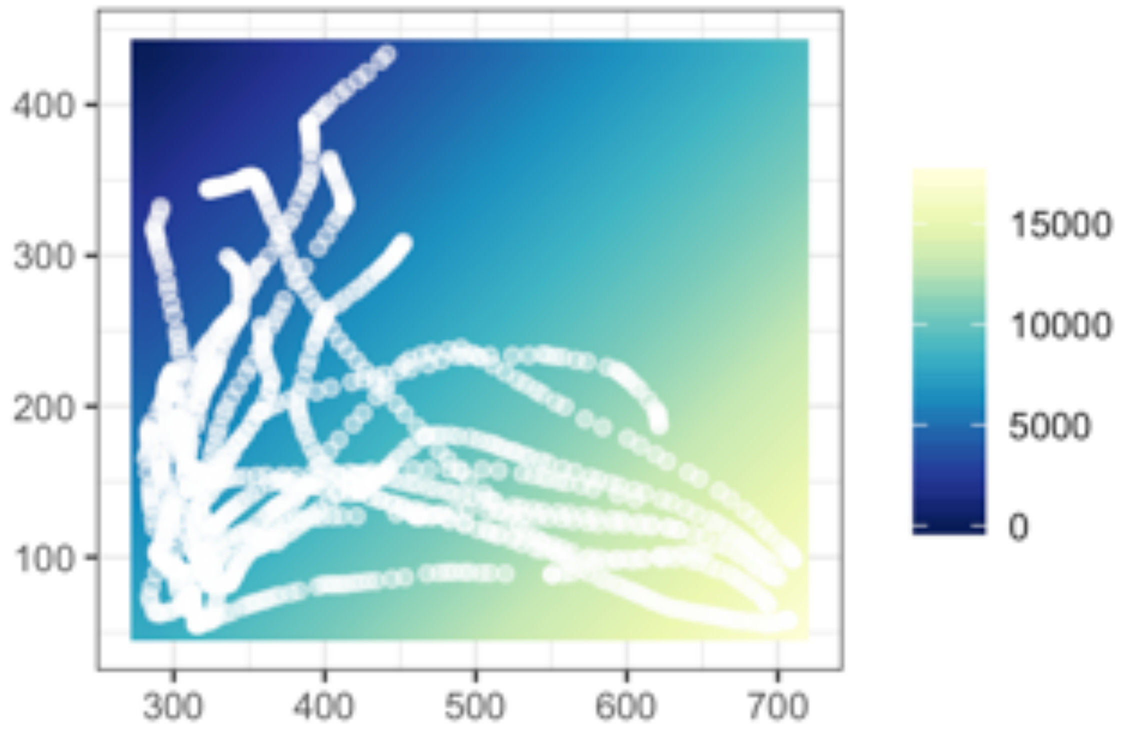
Result: **LARI sampling was better** than regular sampling overall for understanding movement behavior. A simulation study and additional data example support this conclusion. It may also be better for estimating missing data.

Conclusion: Regular sampling may not always be the best choice.

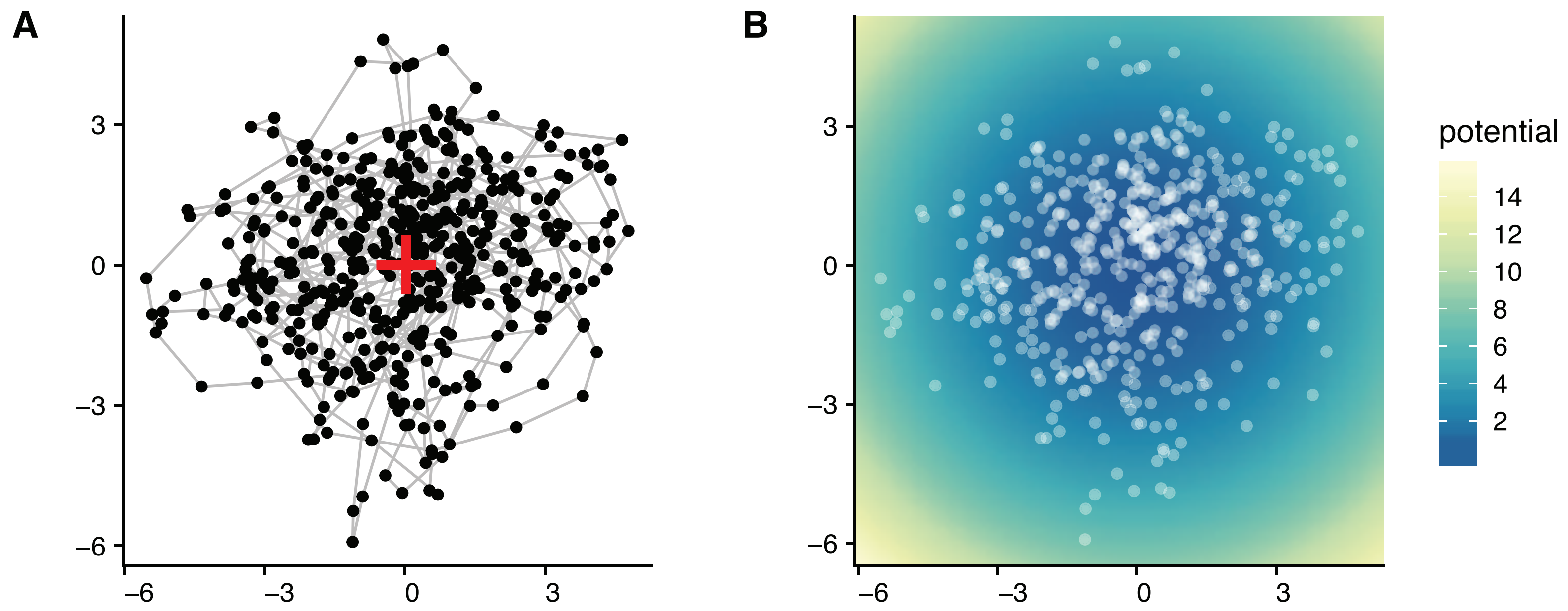
Ant data



Guppy data



Simulated data



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Implications:

1. Not all tracking units can be programmed to collect data at irregular time intervals, but we recommended using LARI for future ant studies using **videos**.

2. For **subsampling of high resolution telemetry data**, irregular subsampling such as LARI may preserve more information than regular subsampling.

Ph.D. Research

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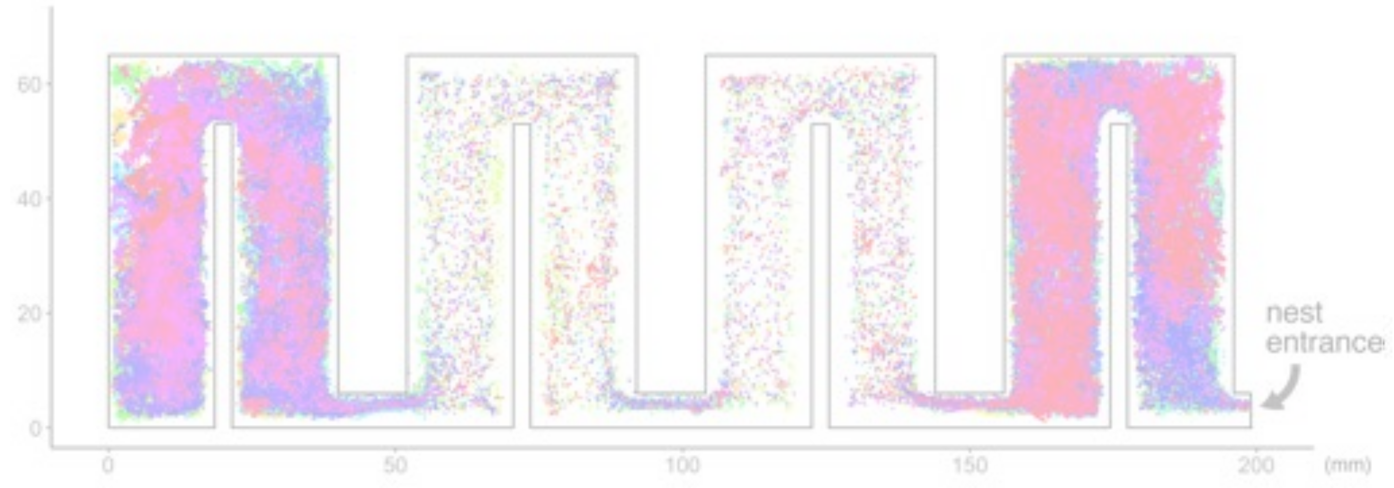

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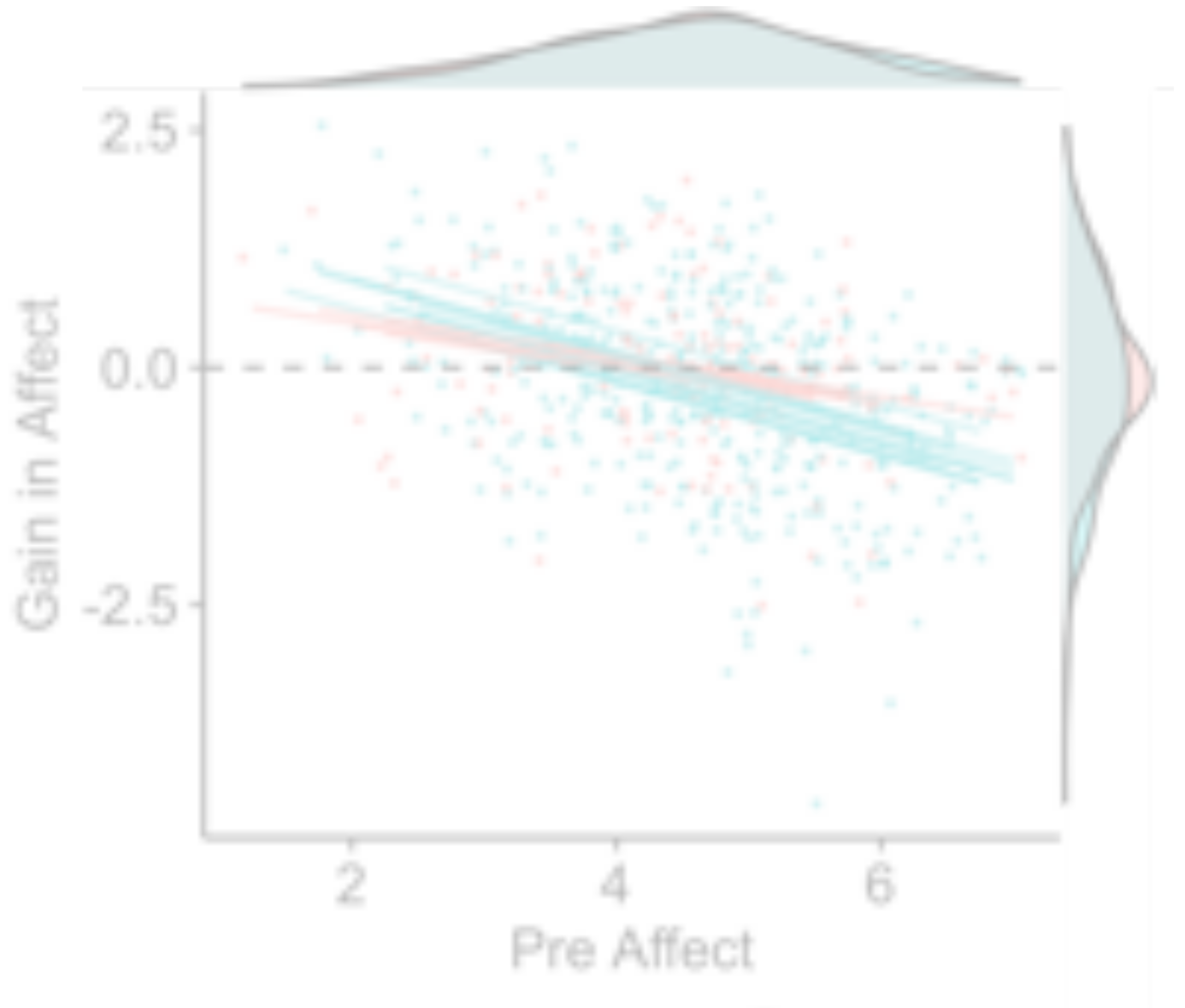
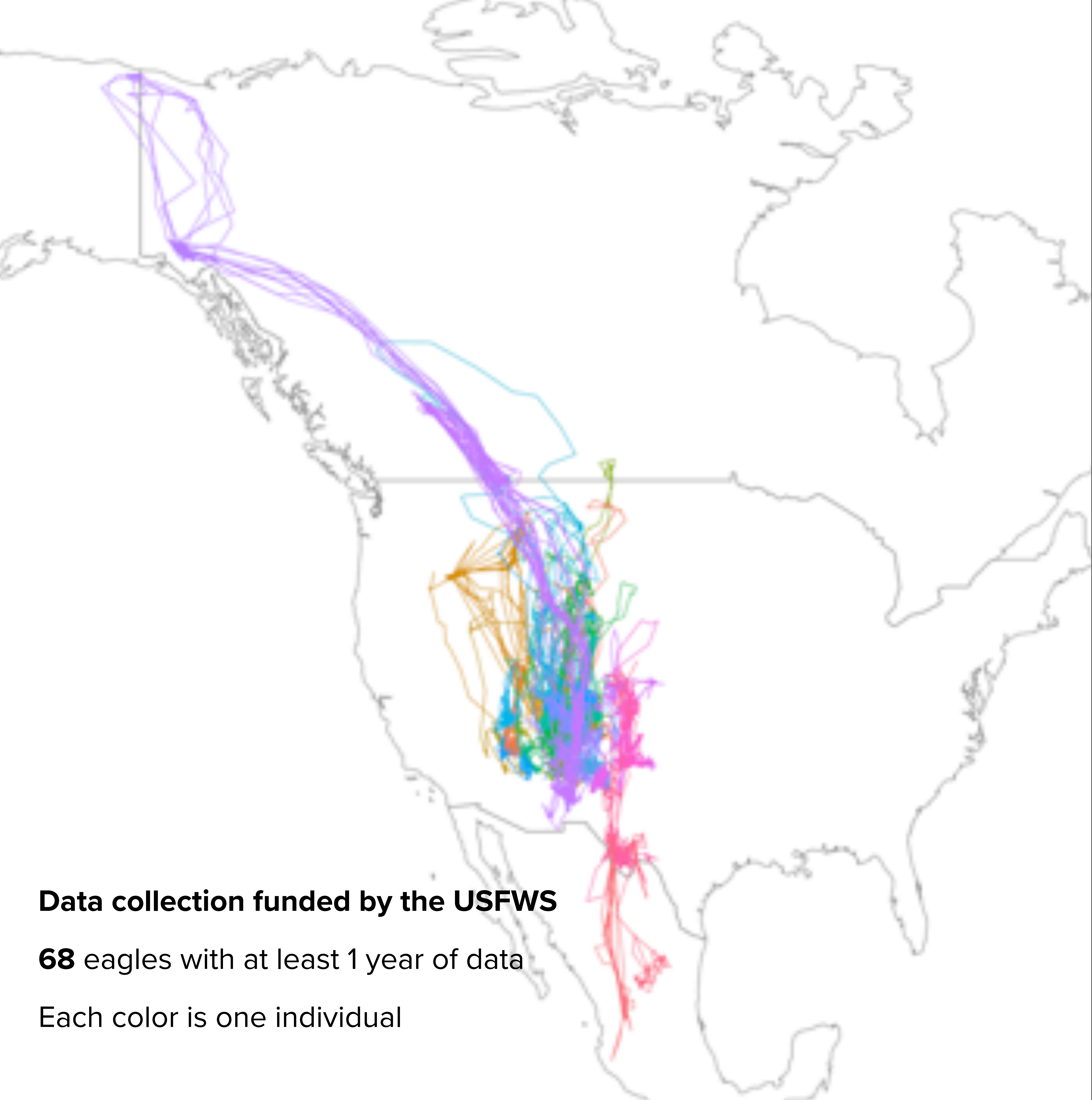
Survey of Probability Attitudes





Data collection funded by the USFWS

68 eagles with at least 1 year of data

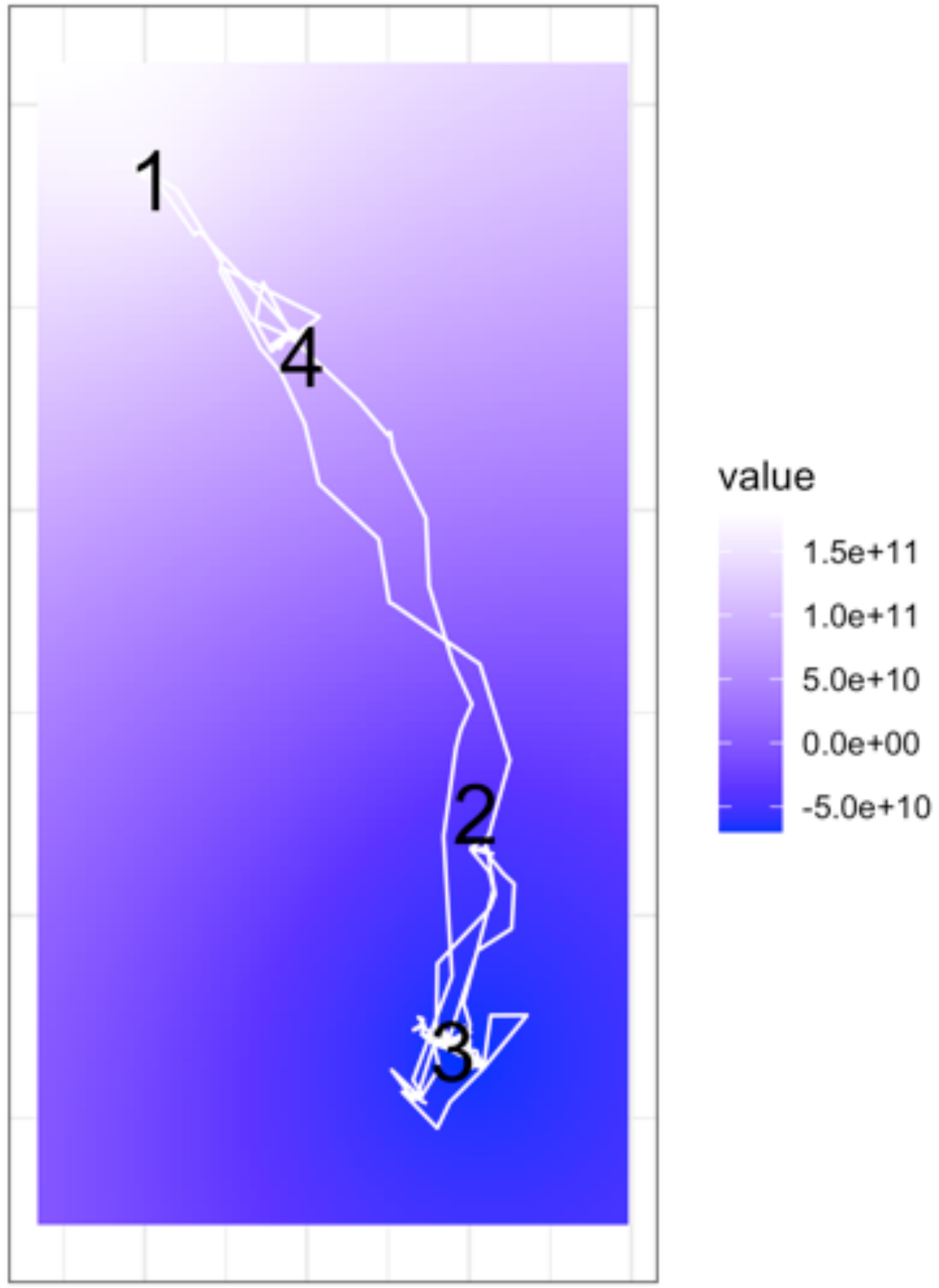
Each color is one individual

Large **variability** in individual golden eagle movement behaviors.

Goals:

1. **Simple** but **flexible** model
2. Capture the **full range of yearly movement behavior**, even if it isn't well understood

We **proposed a flexible model** using varying coefficients to control strength of attraction to individual-specific attractors.



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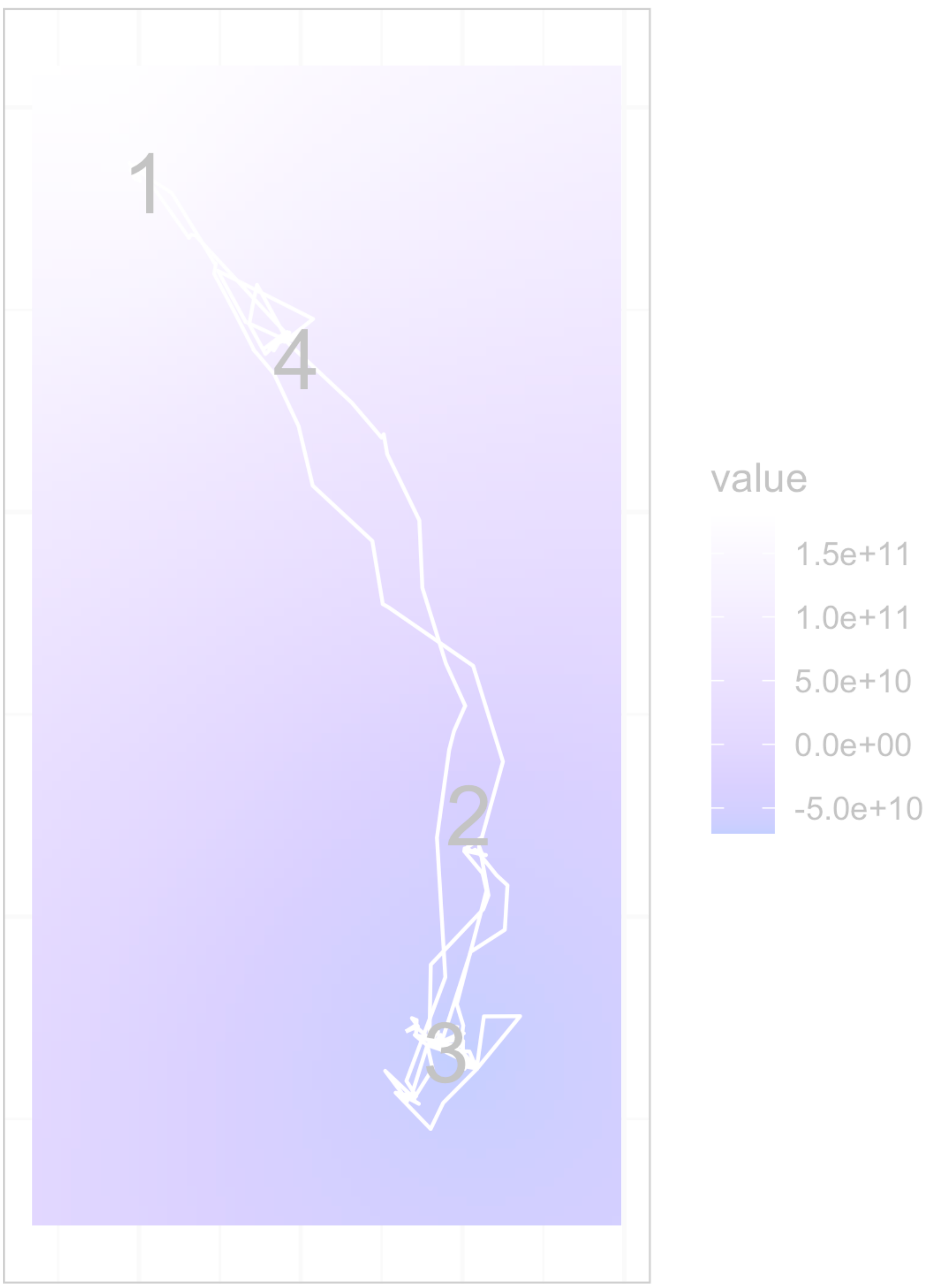
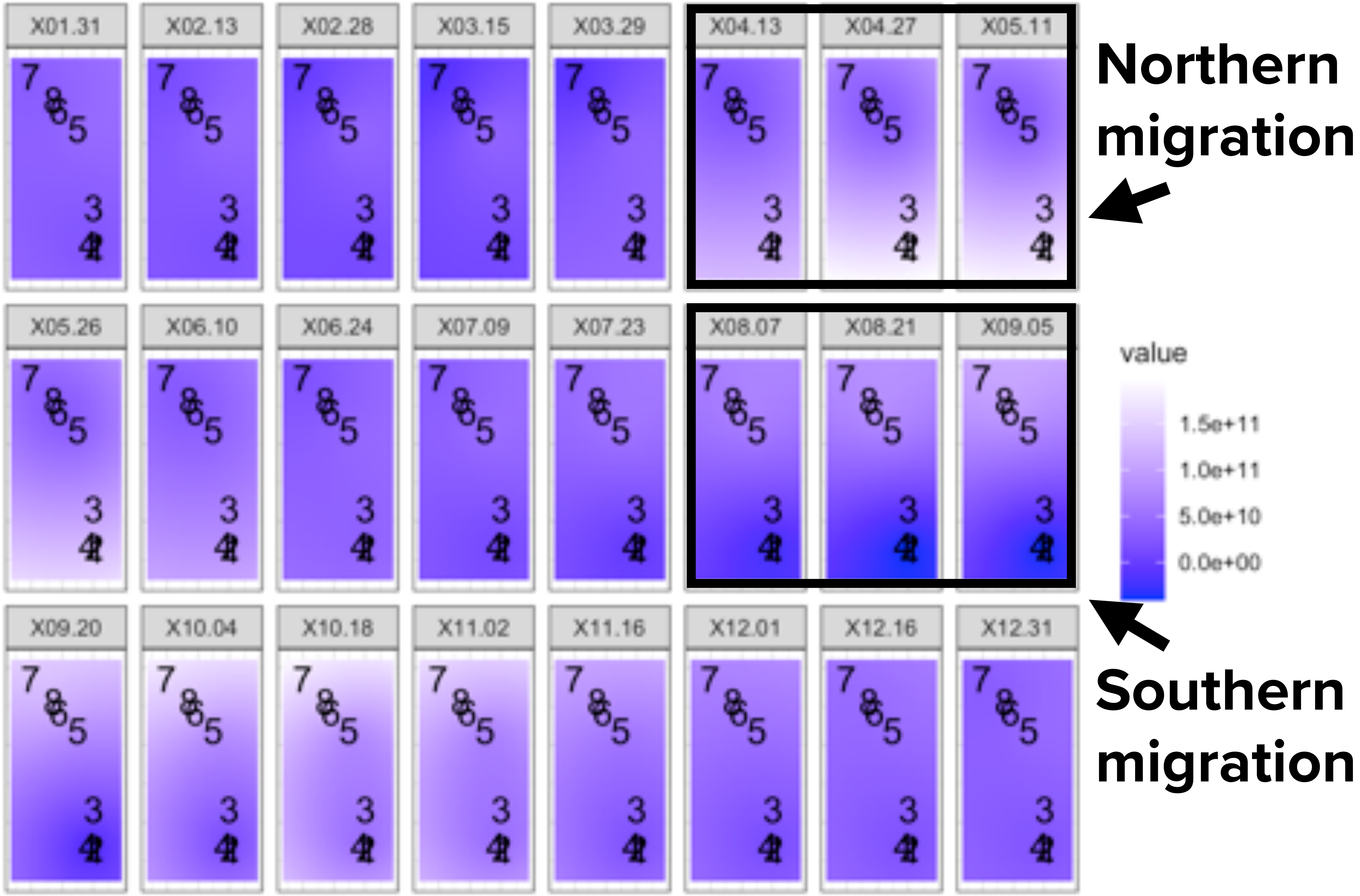
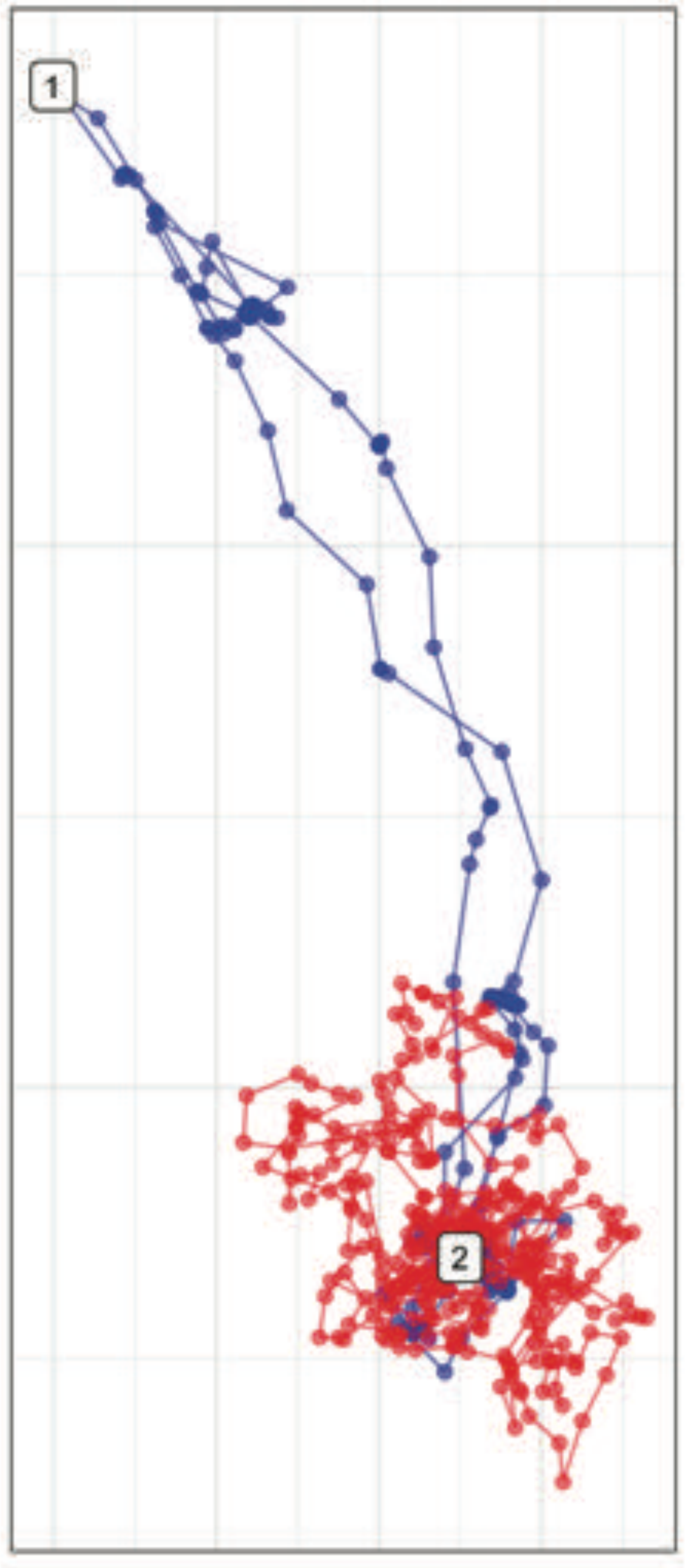


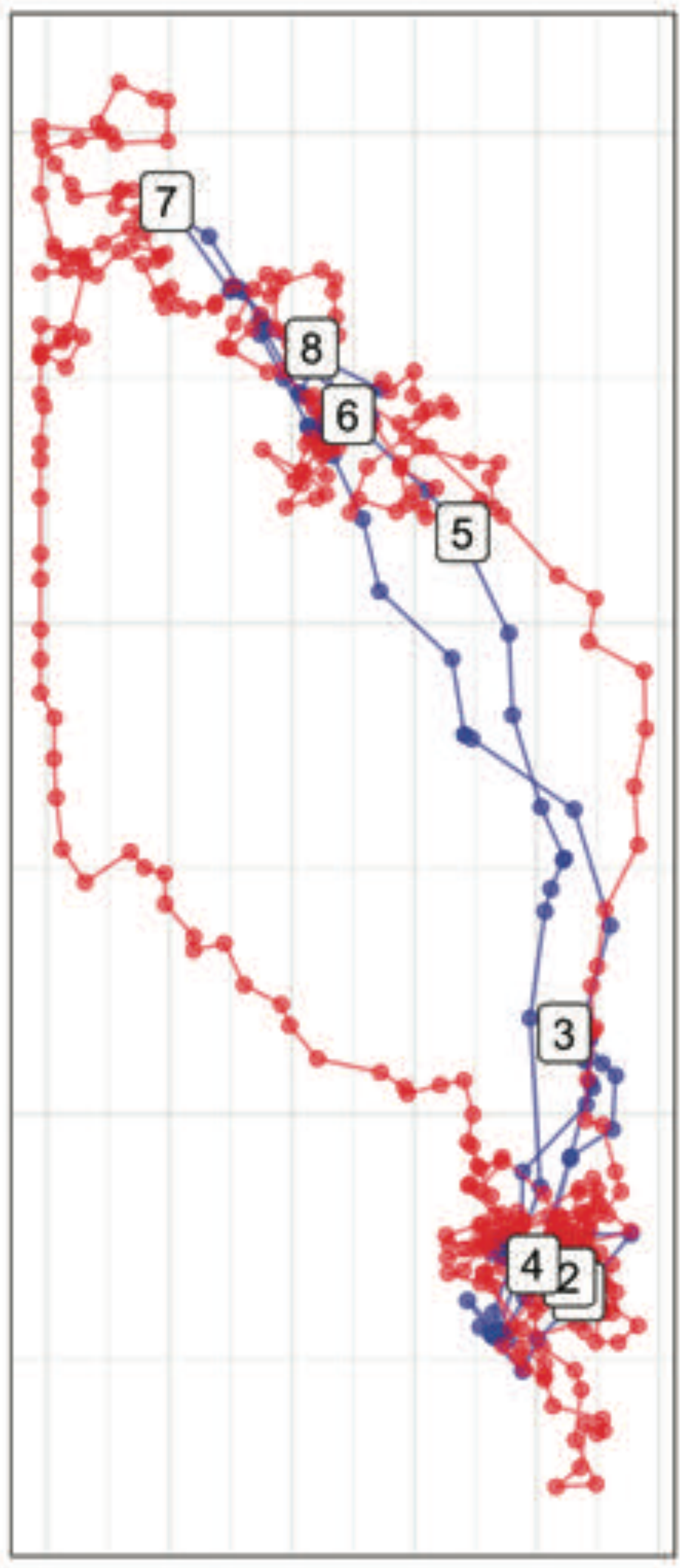


We **compared** our approach **to Hidden Markov Models**, defined differently for **migration**, dispersal, or residence.

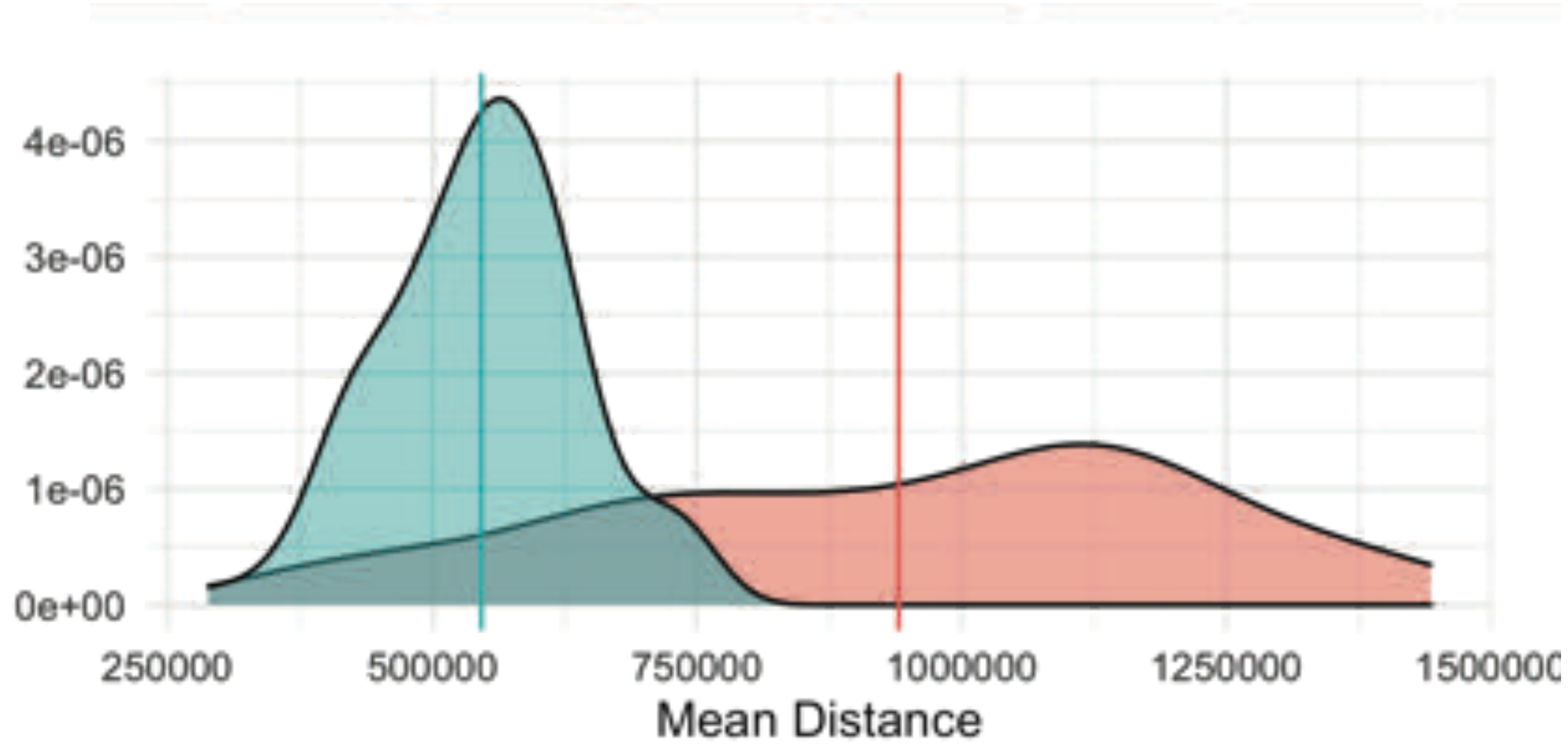
HMM



Varying coefficient model



Mean distances from simulated locations to true locations

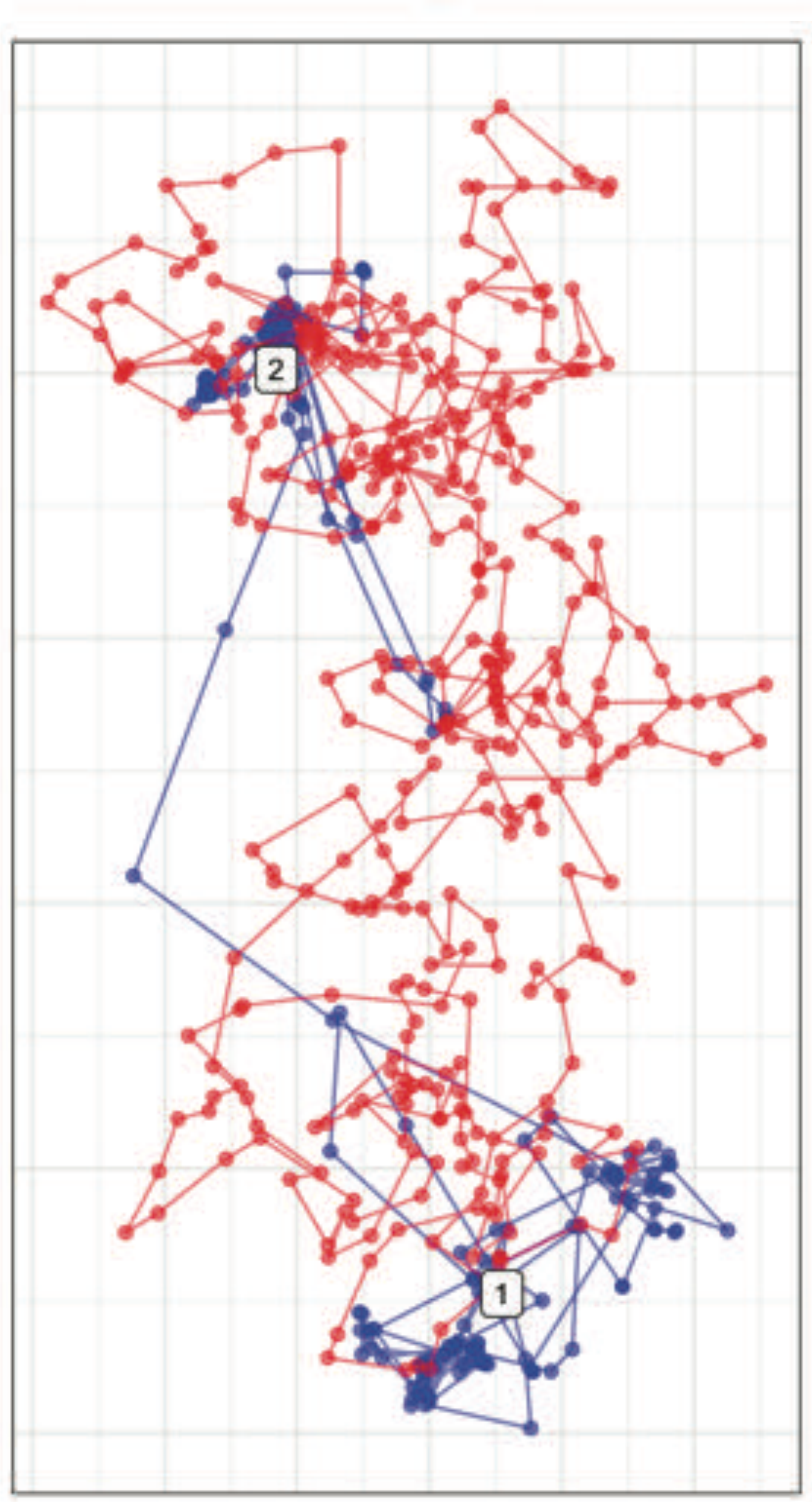


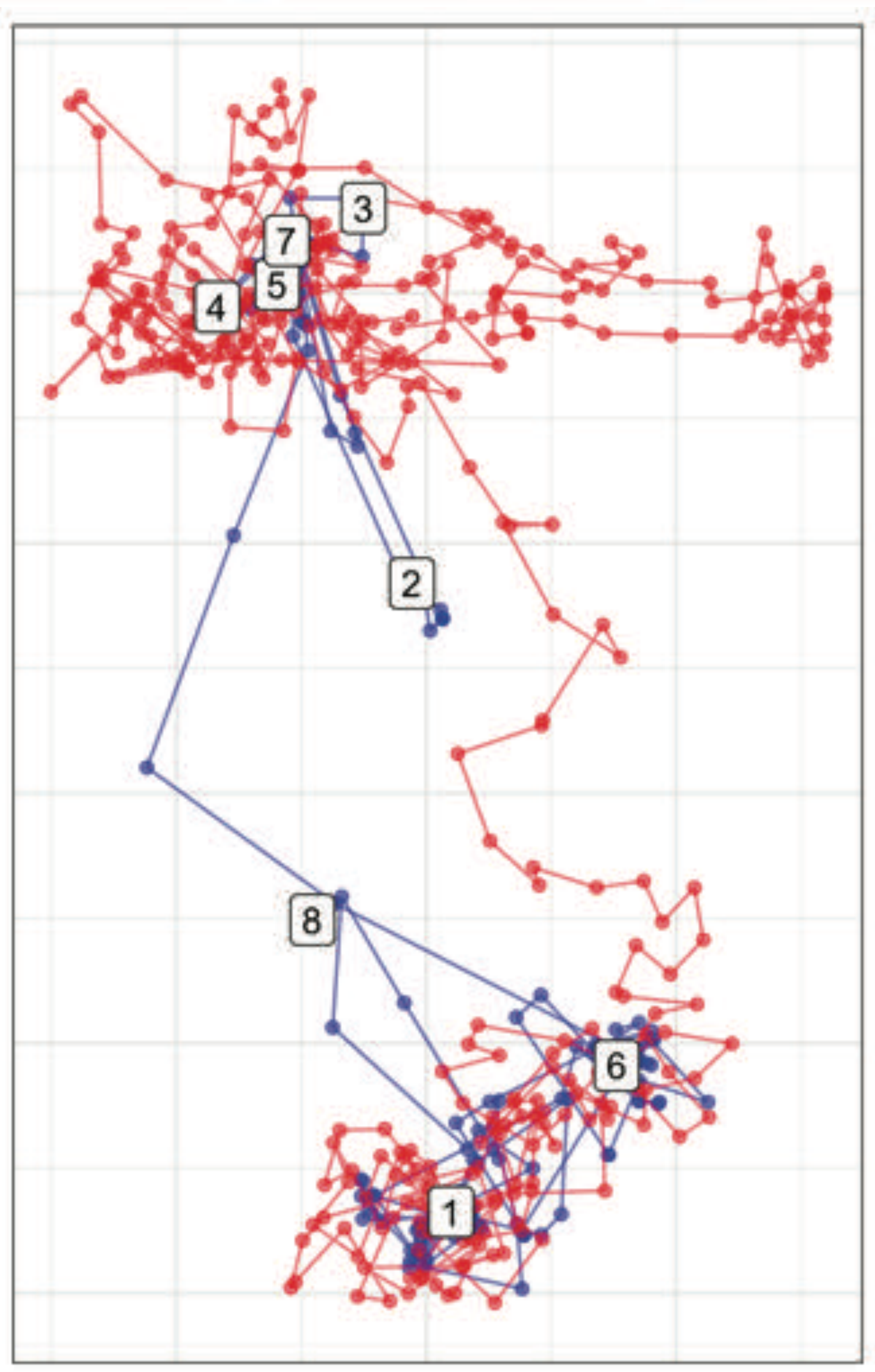
True path in blue & simulation in red

We **compared** our approach **to Hidden Markov Models**, defined differently for migration, **dispersal**, or residence.

HMM

Varying coefficient model





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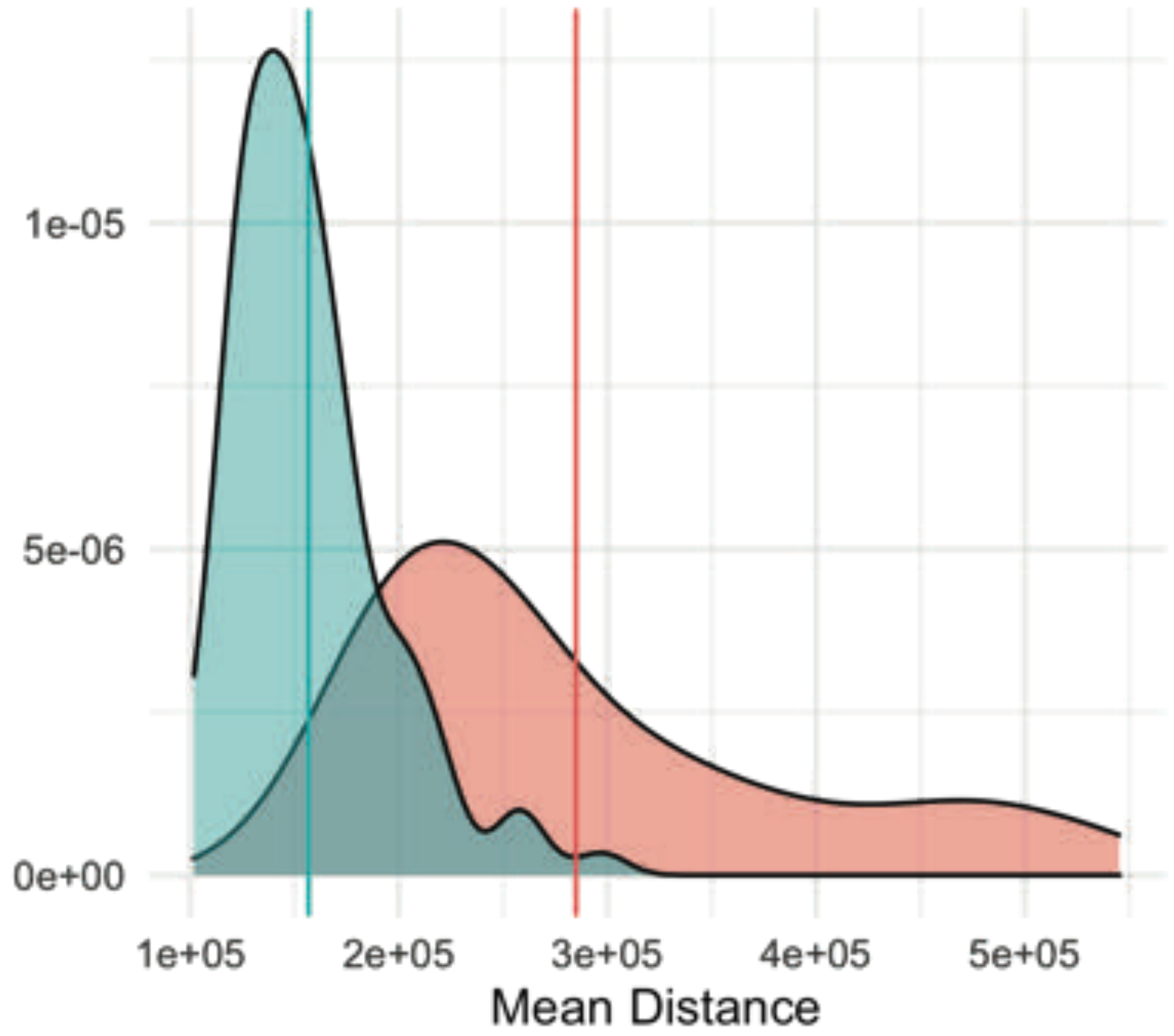

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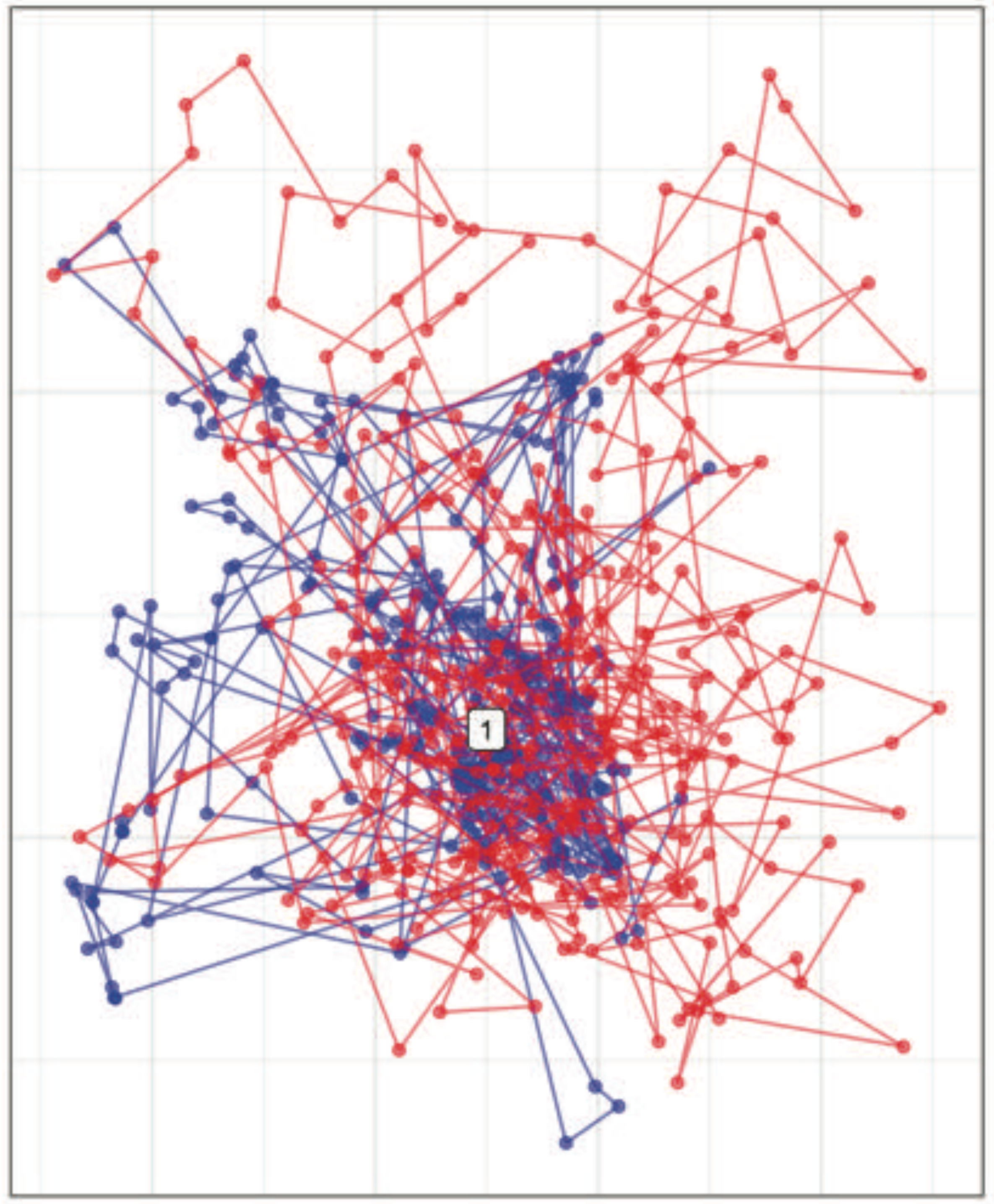
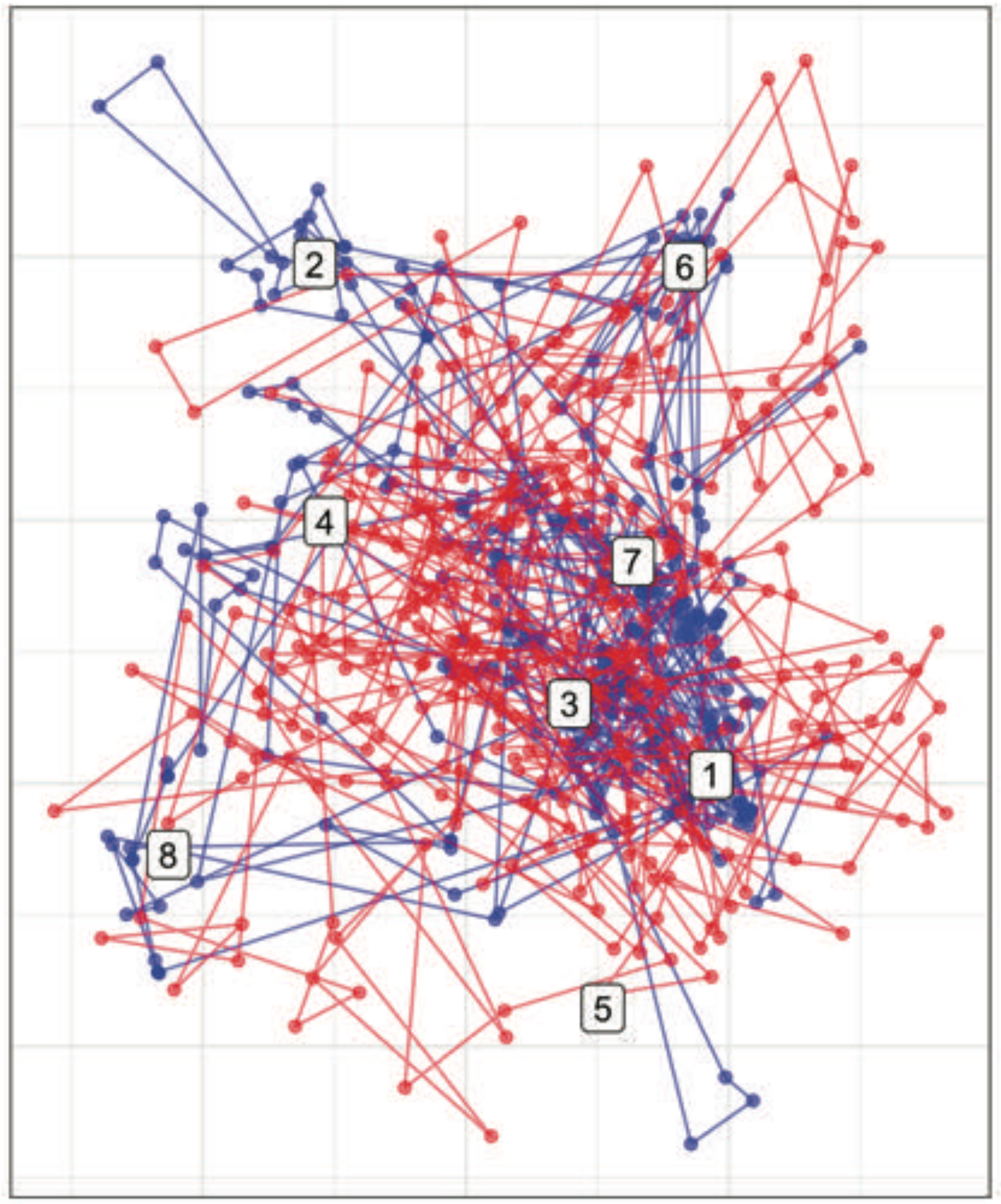
We **compared** our approach **to Hidden Markov Models**, defined differently for migration, dispersal, or **residence**.

HMM



Varying coefficient model



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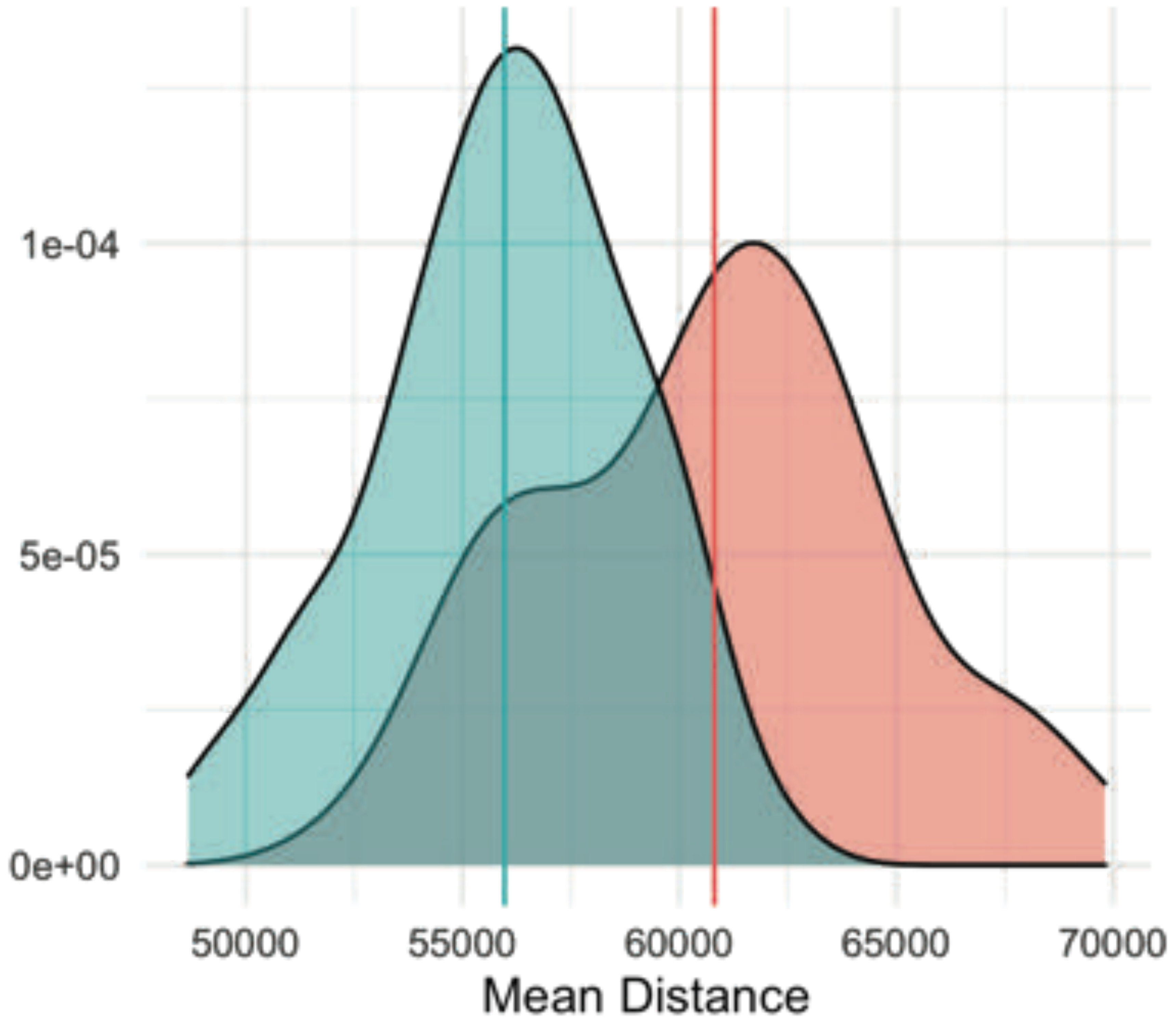
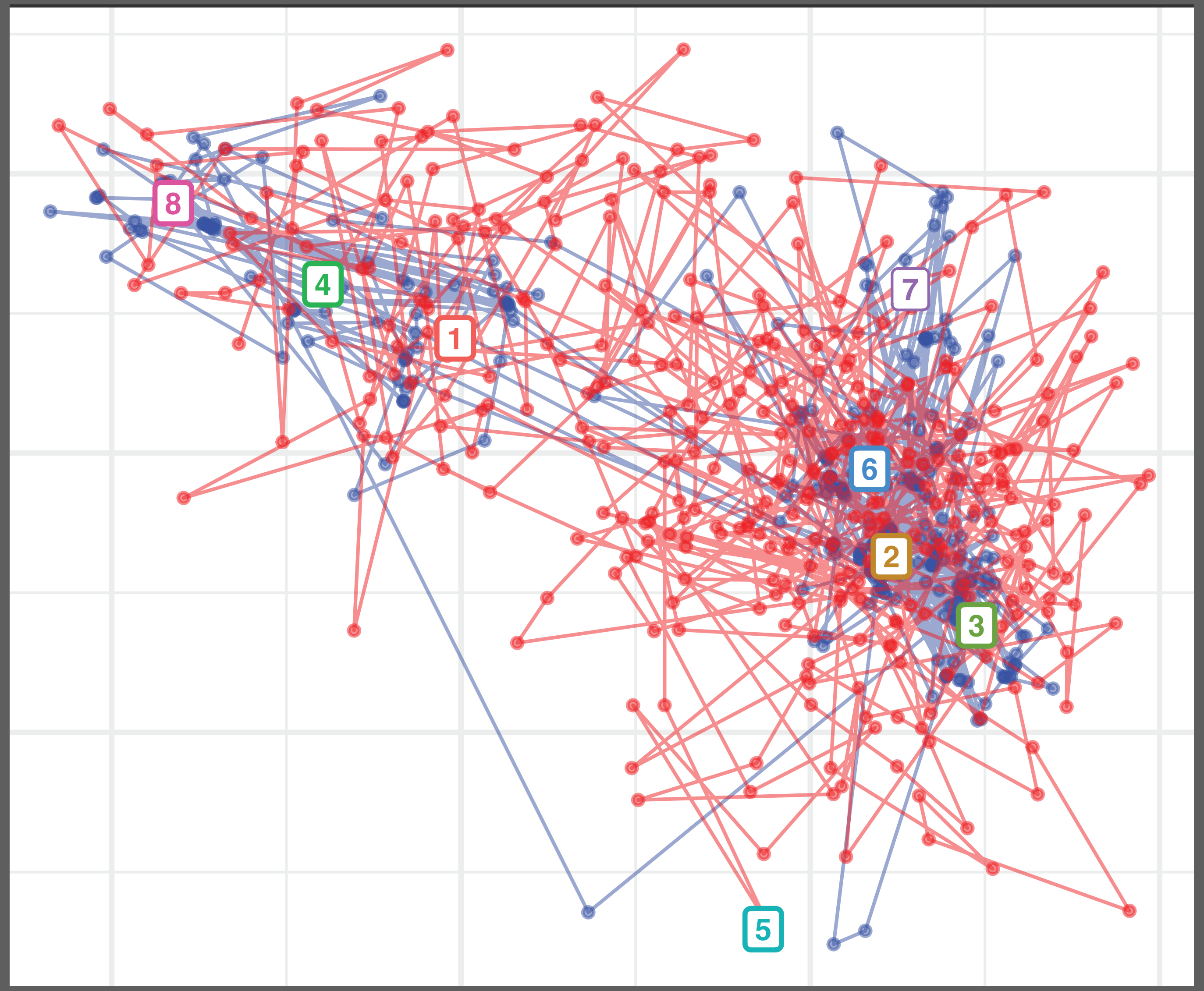
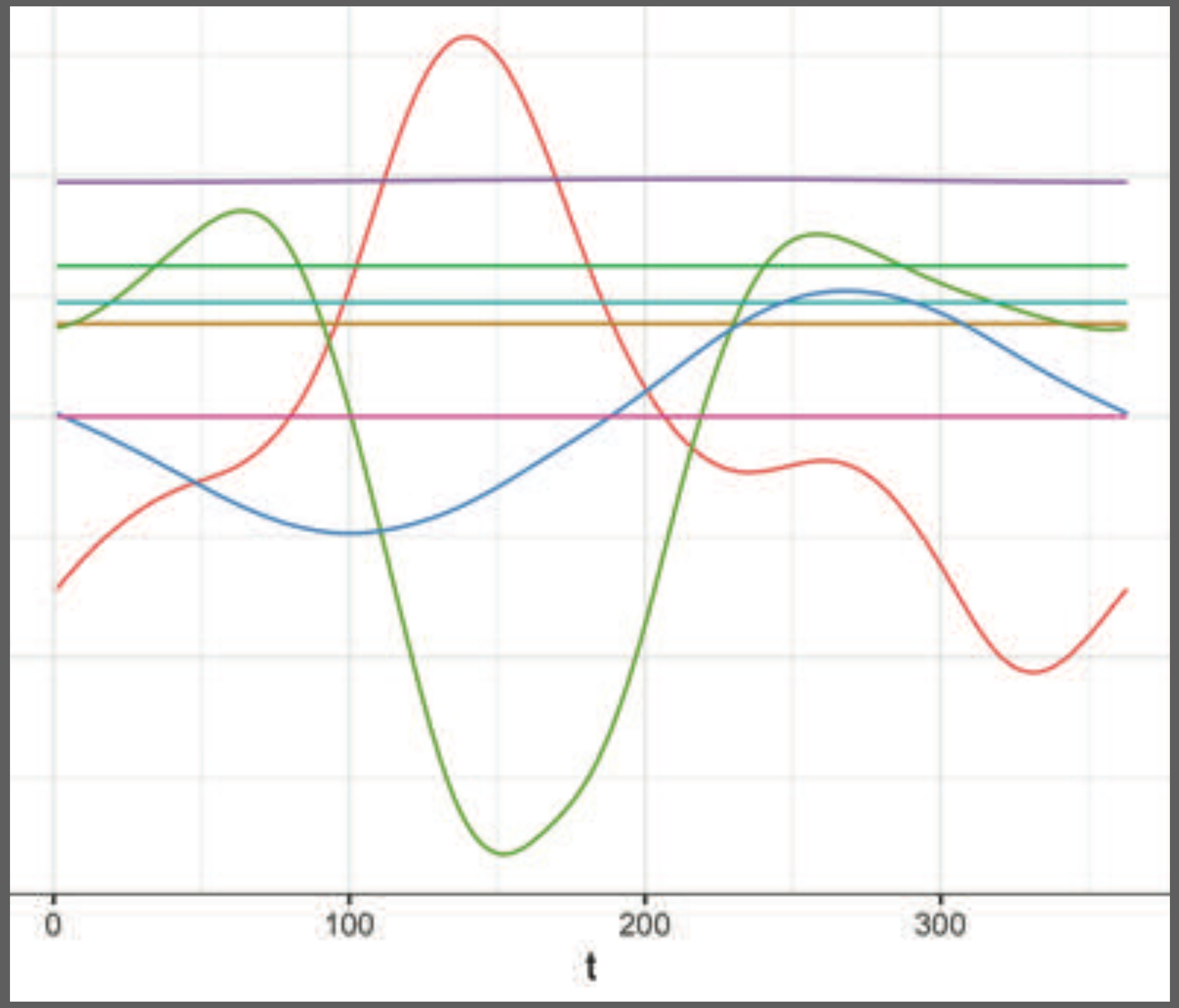


True path in blue & simulation in red

Conclusions:

1. For three example individuals displaying **migration, residence, and dispersal**, simulations from our varying coefficient model **more closely resembled the true paths**.
2. Our approach is flexible enough to model **less-stereotyped individuals** as well.





Future work: Structured population-level model

Ph.D. Research

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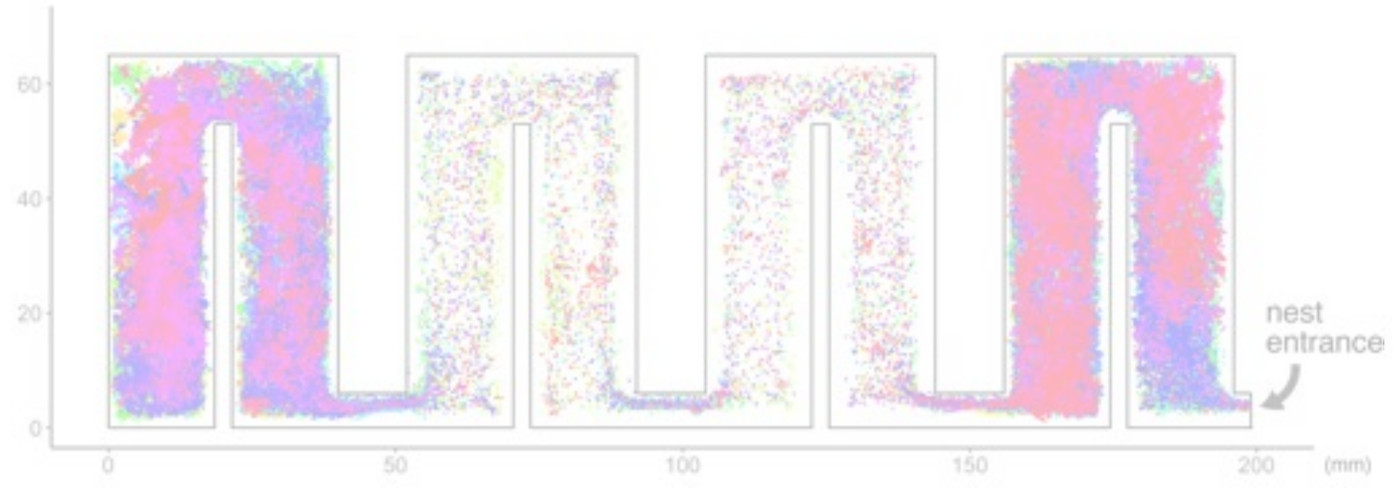

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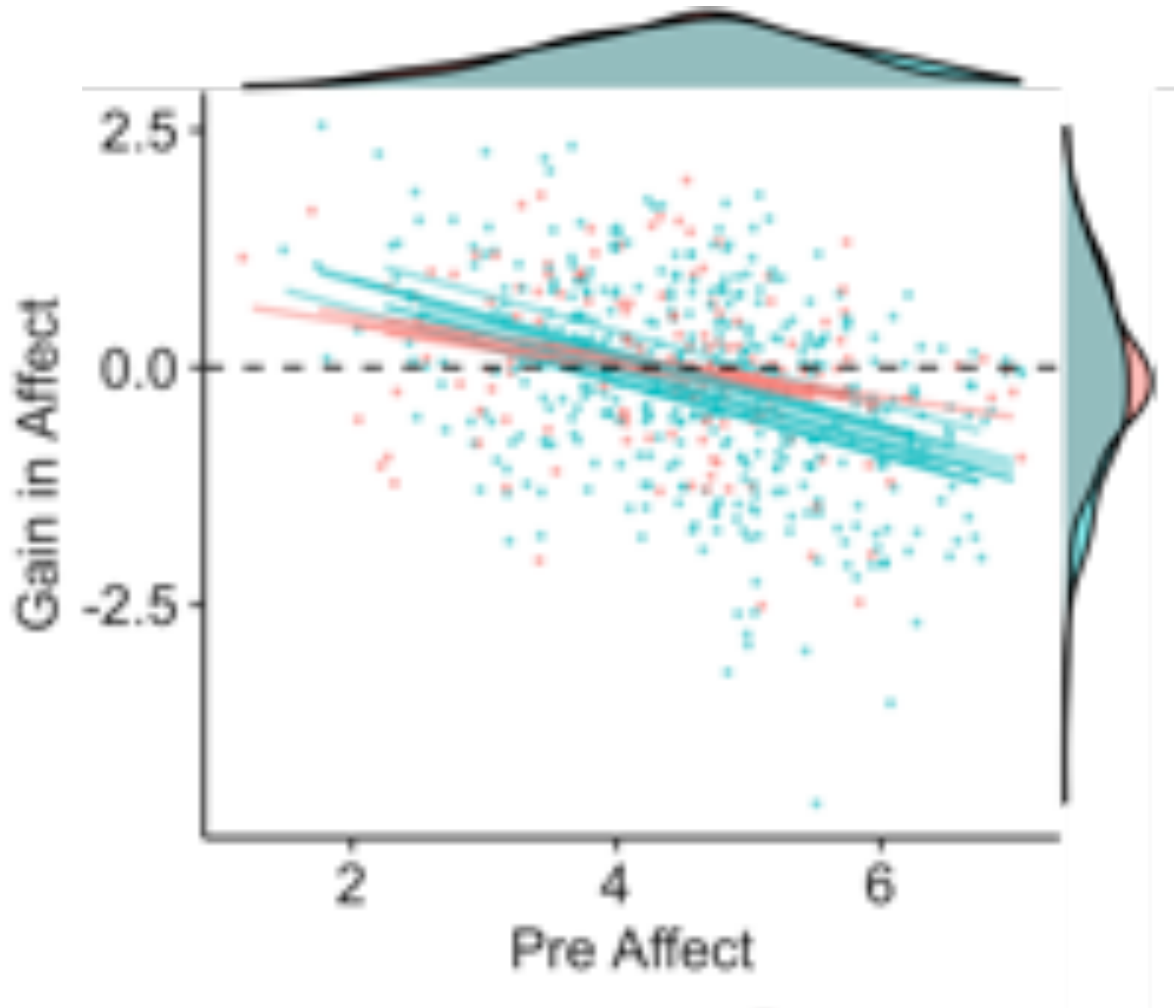
Survey of Probability Attitudes



Goal: assess students' attitudes toward probability

Why? Probability plays a strong role within statistics curricula, and some students take probability before taking statistics.

How?

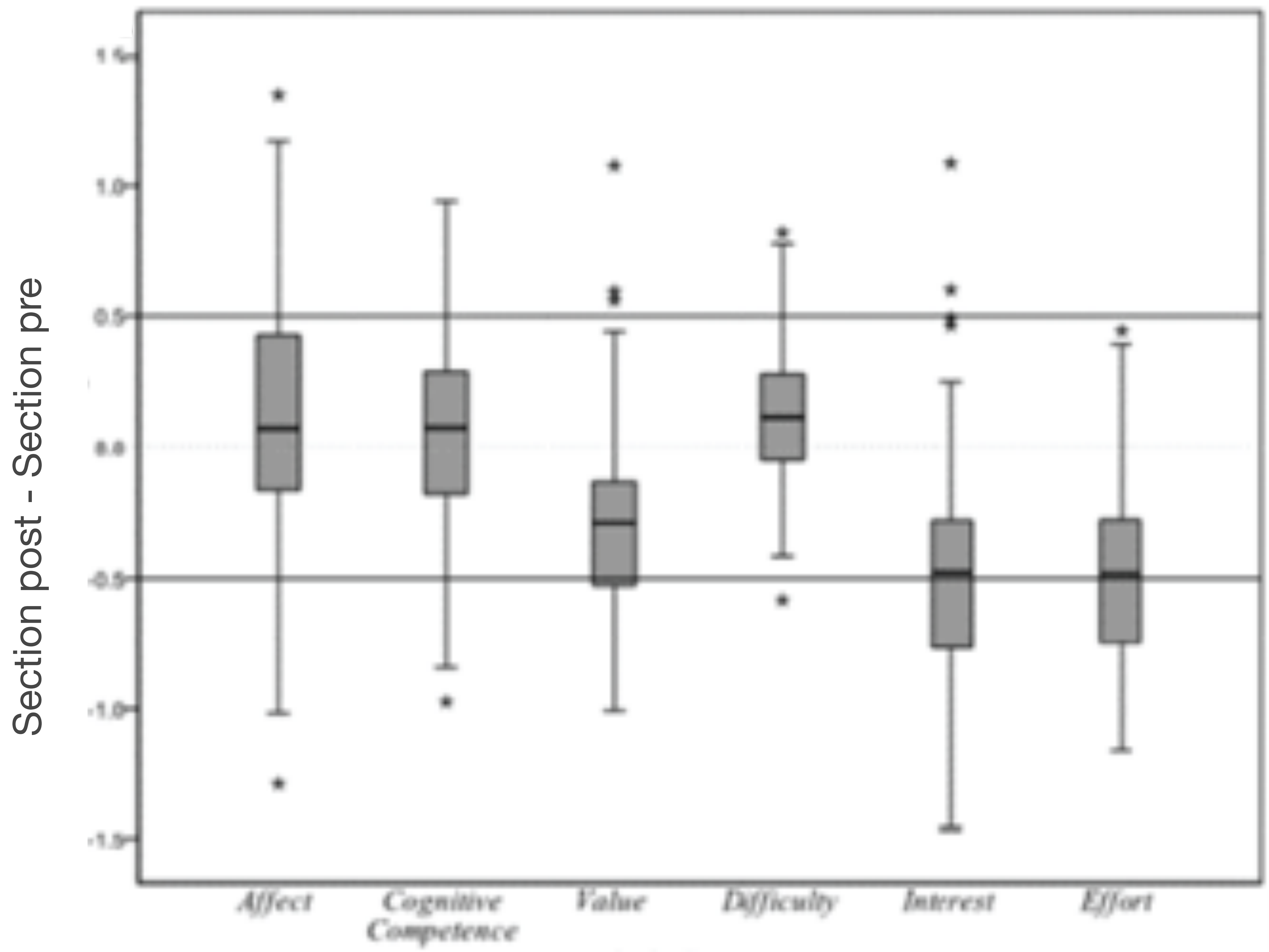
1. Adapt the existing **SATS-36** to assess probability attitudes.
2. Obtain IRB approval to use Survey of Probability Attitudes (**SPA**).
3. Administer pre & post to 586 Penn State students.
4. Validity evidence, including in development, CFA, EFA, Cronbach's alpha, correlations with another instrument.
5. Analyze results with t-tests and mixed effects models.

Attitude components:

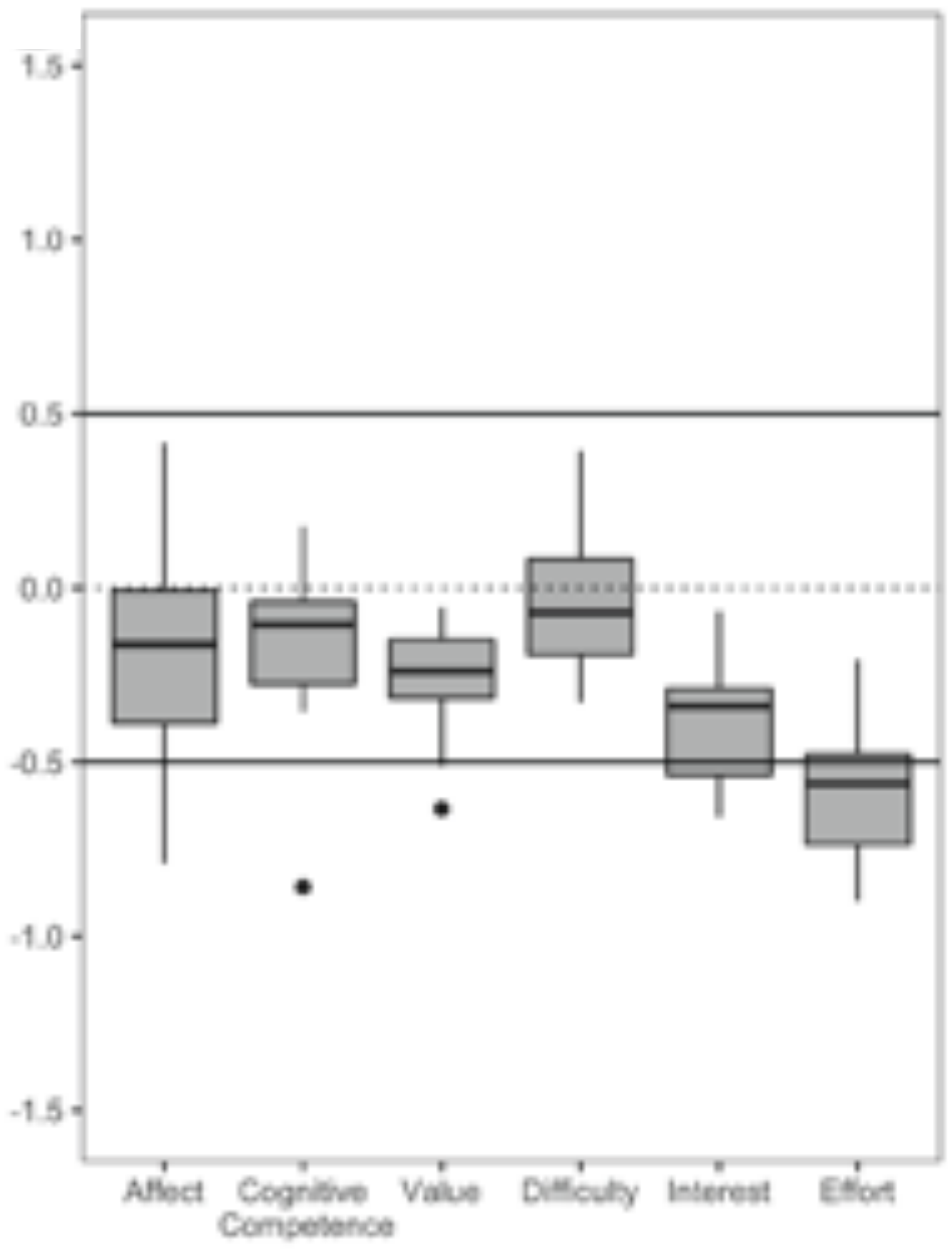
- **Affect** – students' feelings concerning probability
- **Cognitive Competence** – students' attitudes about their intellectual knowledge and skills when applied to probability
- **Value** – students' attitudes about the usefulness, relevance, and worth of probability in personal and professional life
- **Difficulty** – students' attitudes about the difficulty of probability as a subject
- **Interest** – students' level of individual interest in probability
- **Effort** – amount of work the student expends to learn probability

Median change scores are in a similar range of 0 for both the SATS-36 and SPA.

SATS-36

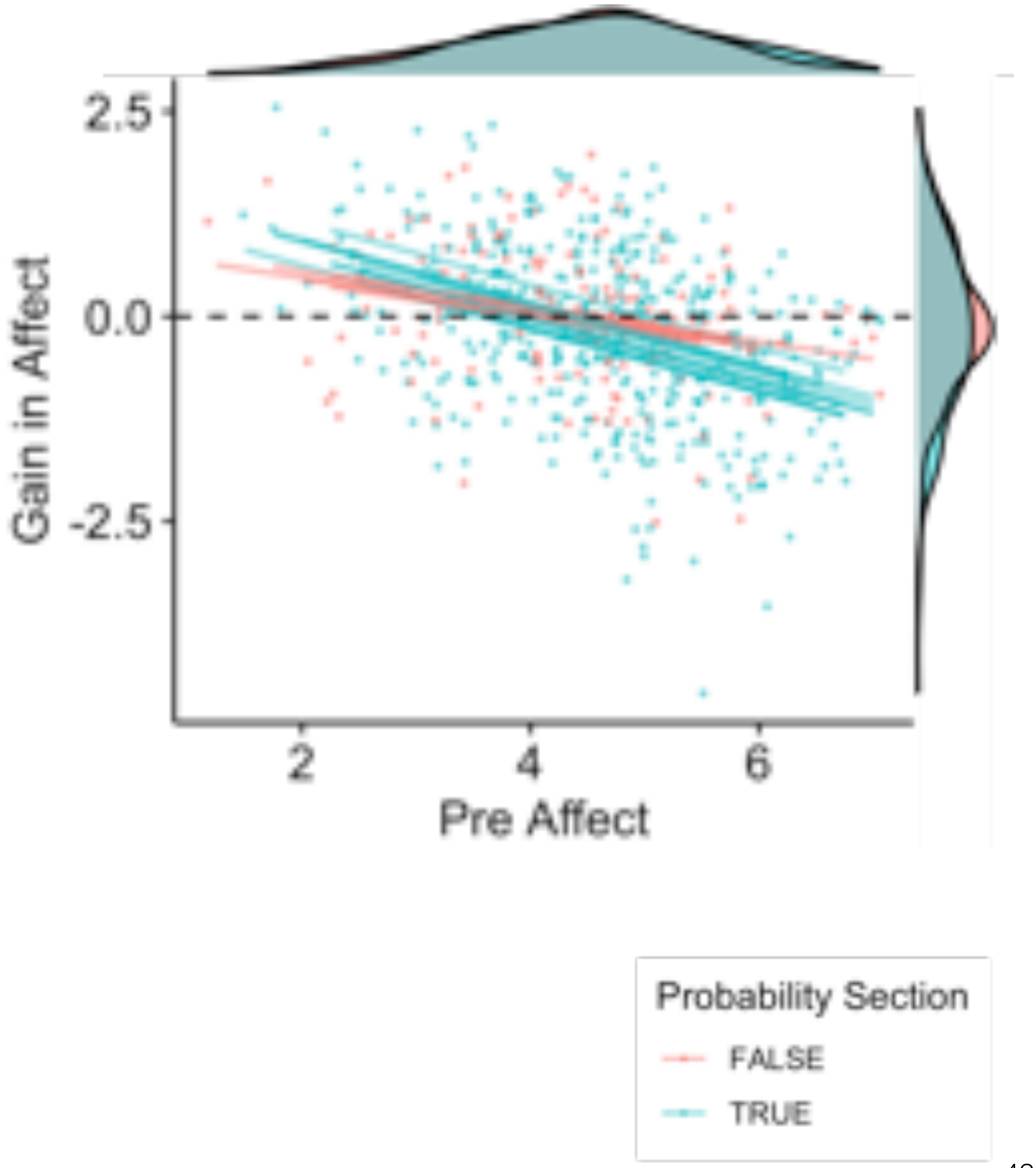


SPA

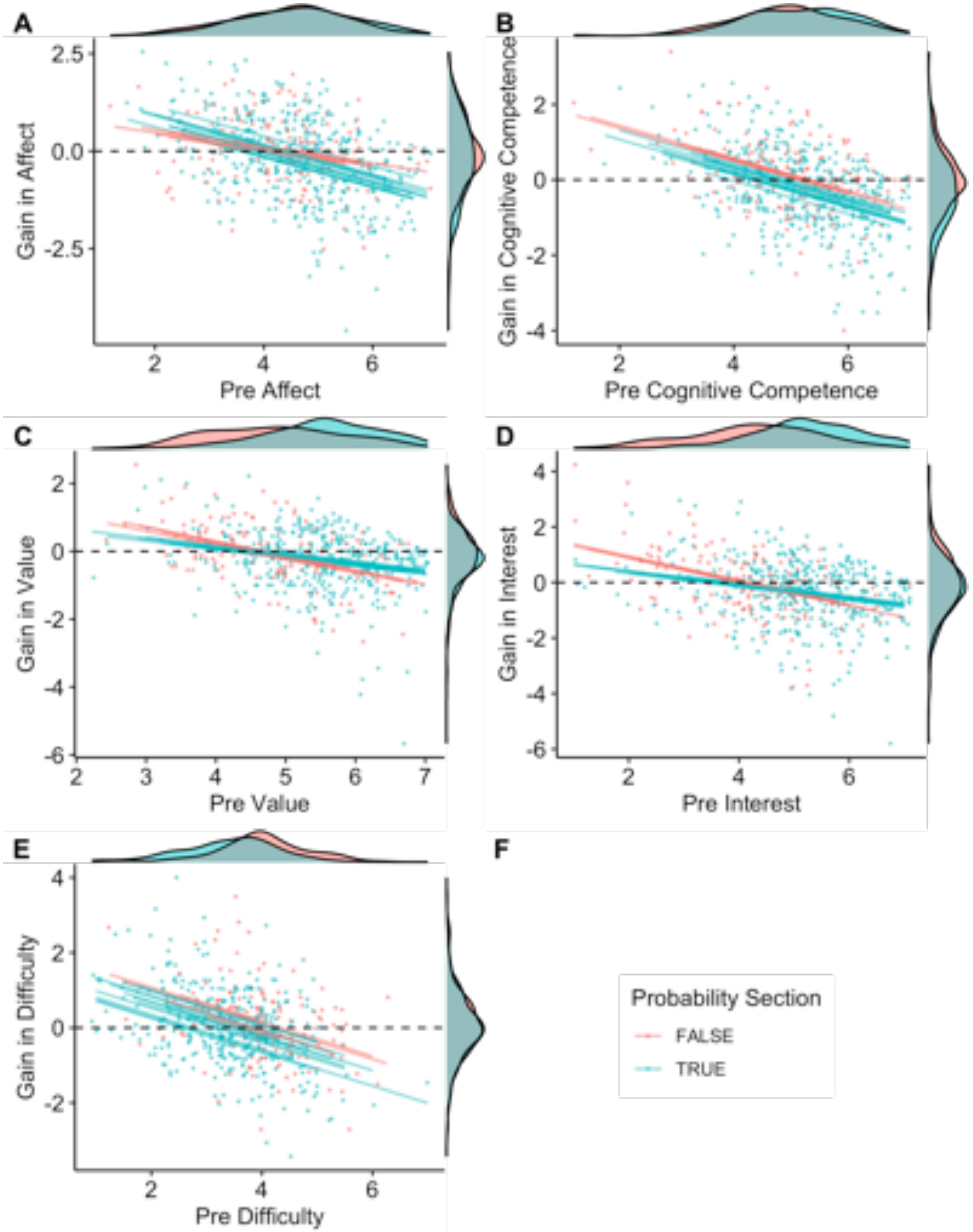


(used with permission from Schau and Emmioğlu, 2012)

Administered pre and post Survey of Probability Attitudes (SPA) to 427 **probability** students and 159 **non-probabilility** students.



1. Strong evidence of the **validity** of the SPA.
2. **No evidence of change in students' attitudes toward probability** on average from the beginning to the end of the probability courses in our study.



Implications:

Lack of differences between probability and non-probability students' attitudes toward probability suggest:

- the import of using a **control group** for attitude studies
- future survey iterations should be **more sensitive** to small attitude changes
- desired attitudes toward probability should **inform teaching methods**

Thank you.

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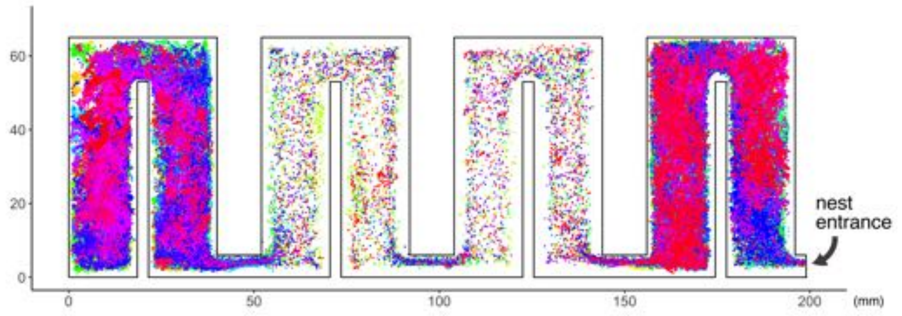
1

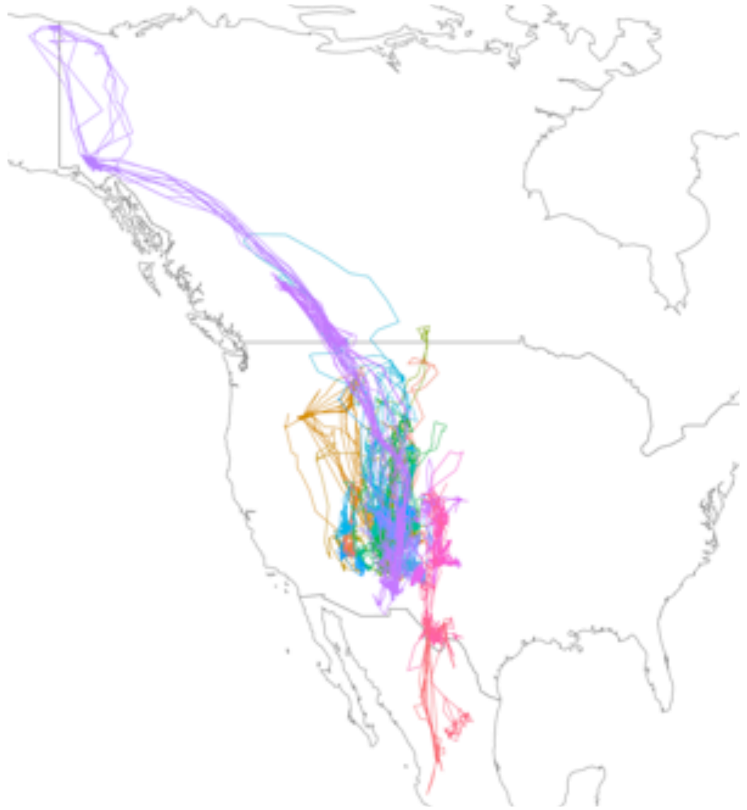
A Lattice and Random Intermediate Point Sampling Design for Animal Movement



Eisenhauer, Elizabeth, and Ephraim **Hanks**. "A lattice and random intermediate point sampling design for animal movement." *Environmetrics* (2020): e2618.

2

Modeling Yearly Patterns in Golden Eagle Movement



Eisenhauer, Elizabeth, Ephraim **Hanks**, Matthew **Beckman**, Robert **Murphy**, Tricia **Miller**, and Todd **Katzner**. "A Flexible Movement Model for Partially Migrating Species. " *Spatial Statistics* (2022): 100637.

3

Survey of Probability Attitudes