

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

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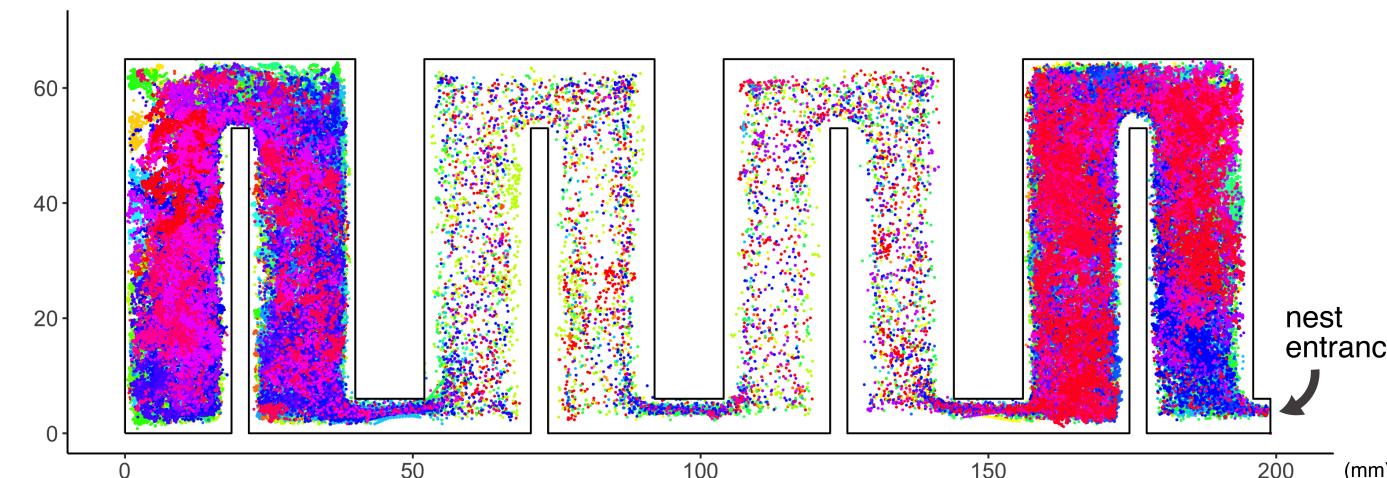
Elizabeth Eisenhauer

Pennsylvania State University Department of Statistics
PhD Co-advisors: Ephraim Hanks & Matthew Beckman

Ph.D. Research

1

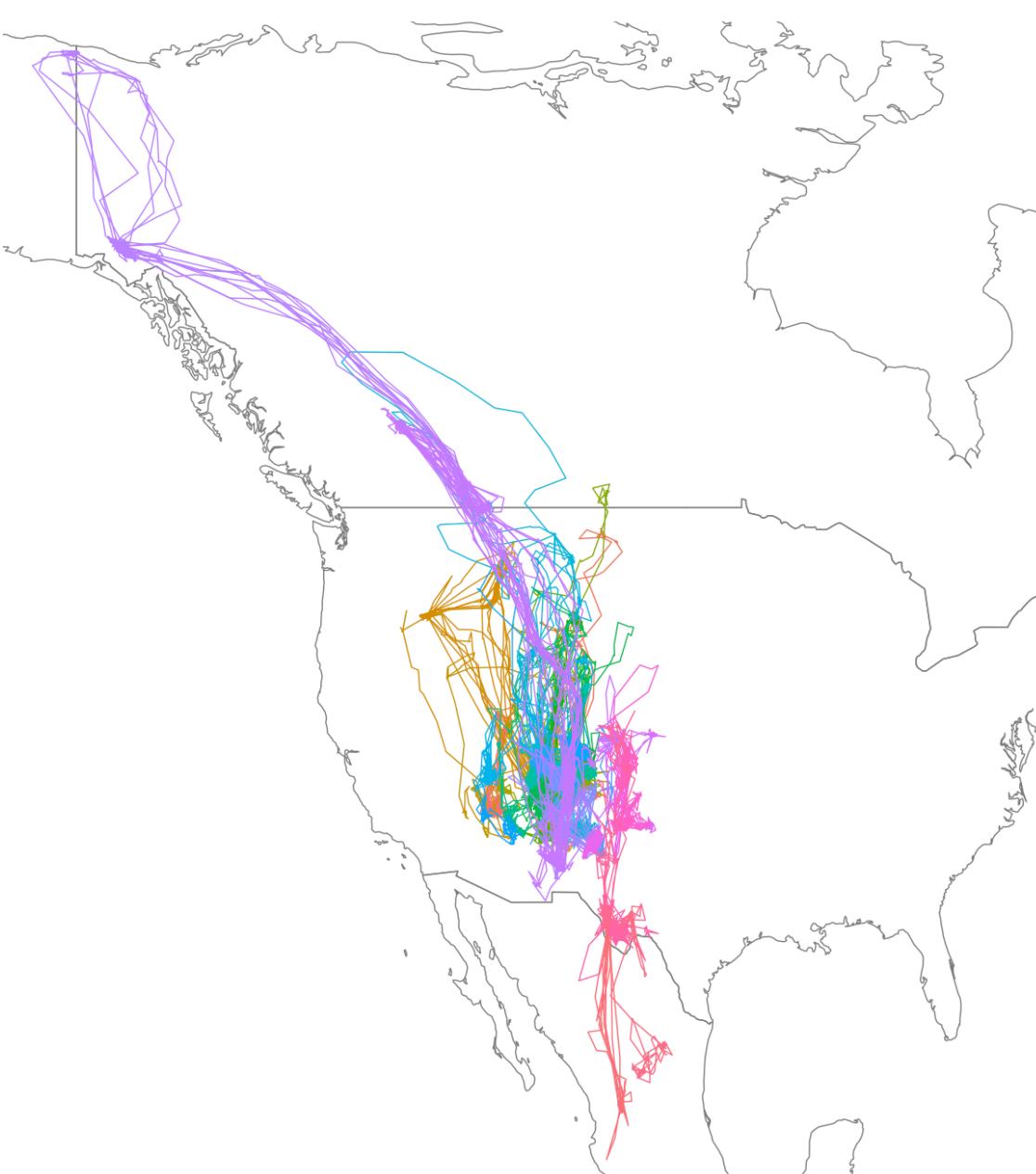
A Lattice and Random Intermediate Point Sampling Design for Animal Movement



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

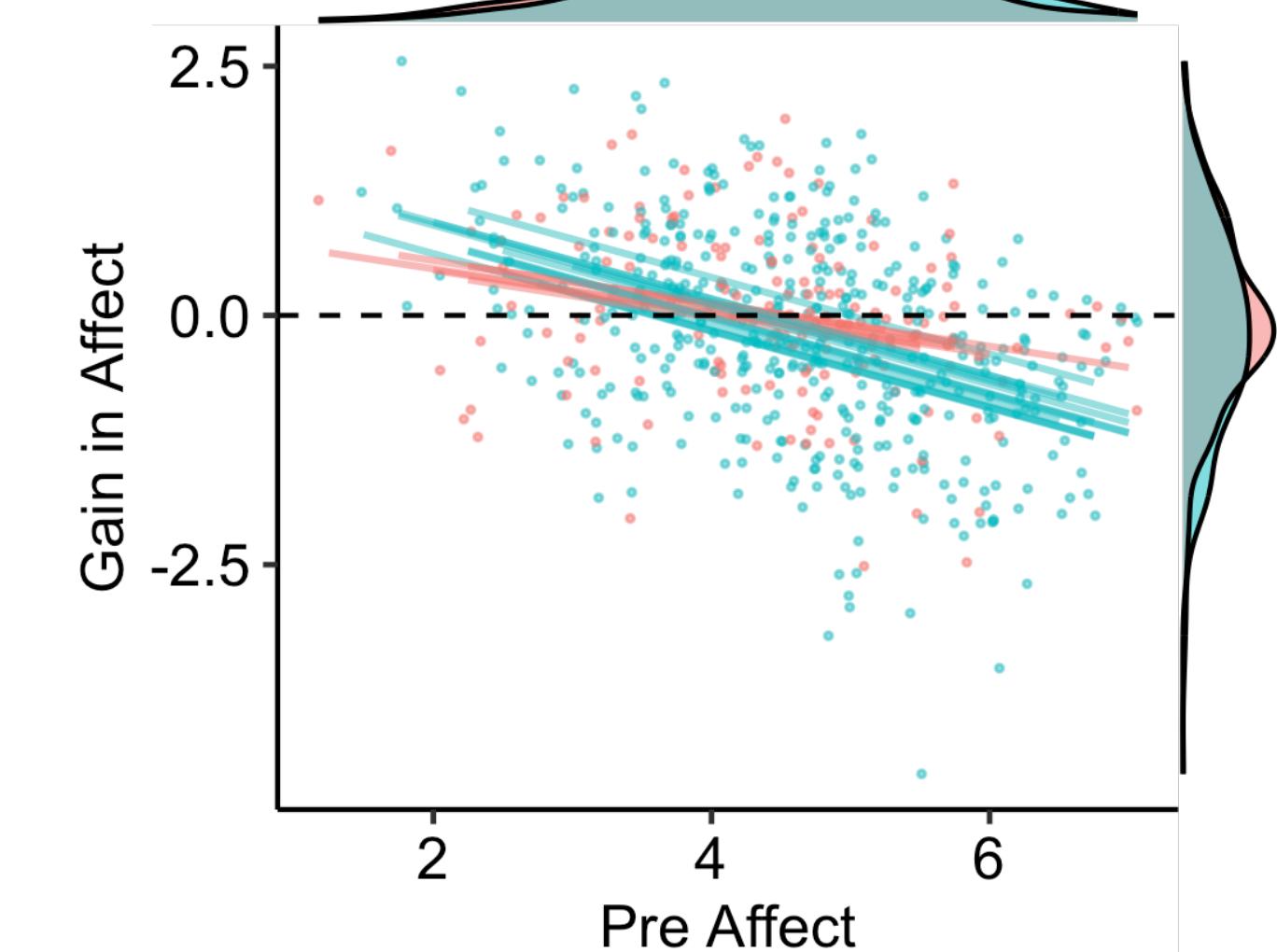
2

Modeling Yearly Patterns in Golden Eagle Movement



3

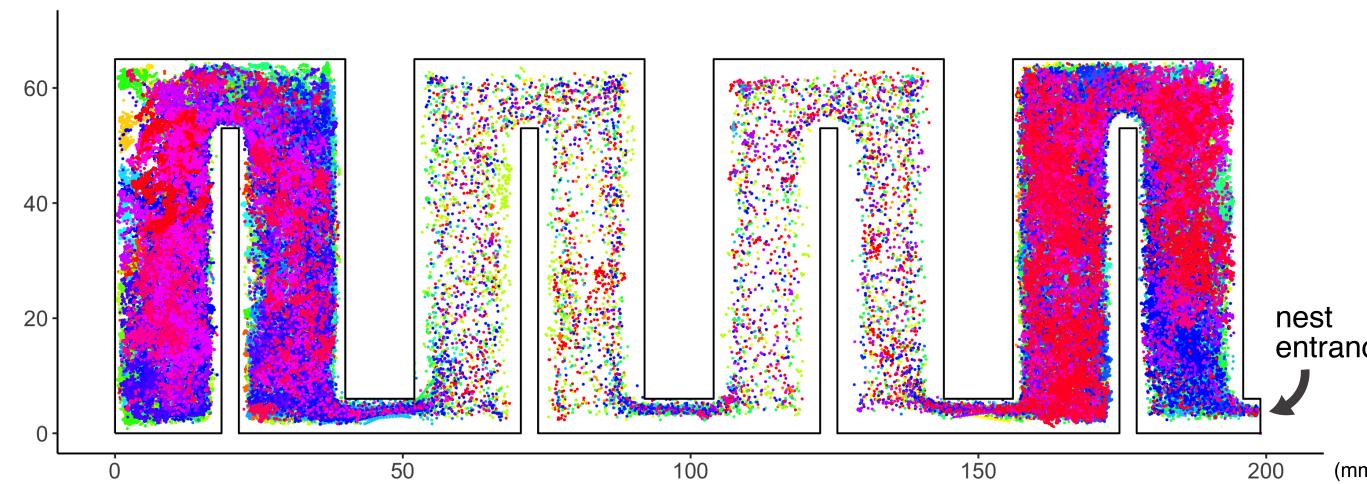
Survey of Probability Attitudes



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.

1

A Lattice and Random Intermediate Point Sampling Design for Animal Movement



* Background

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

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



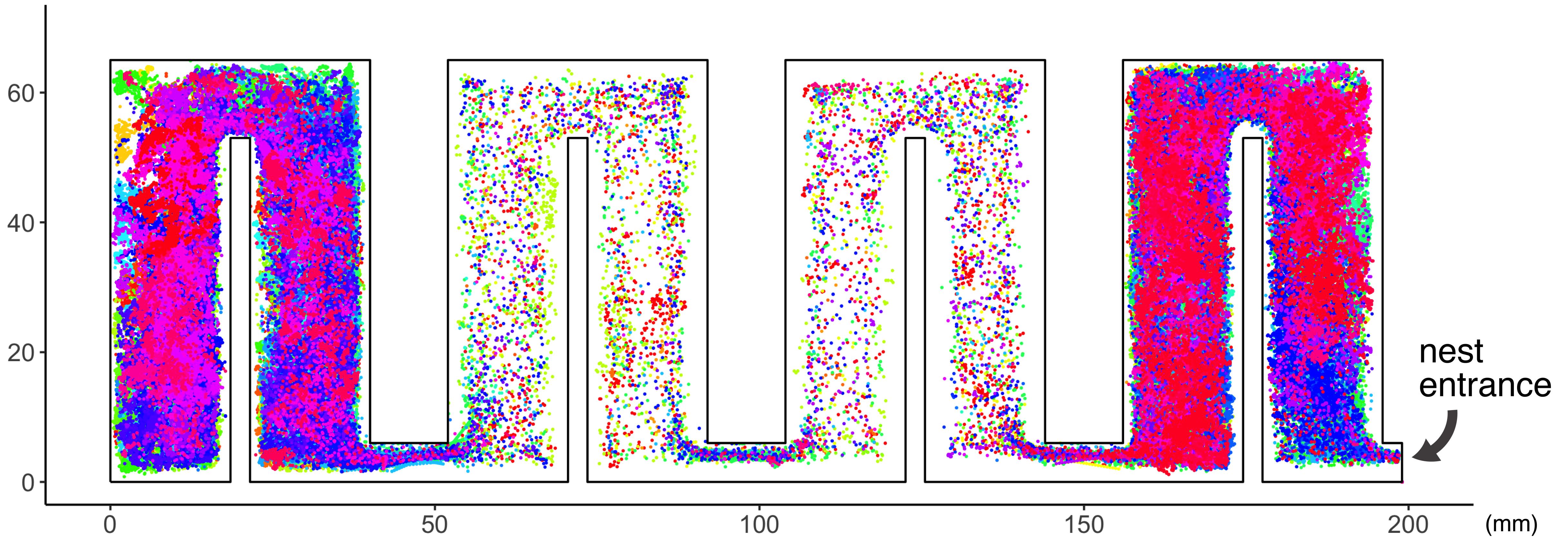
We use statistical equations to represent and quantify movement.

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**:

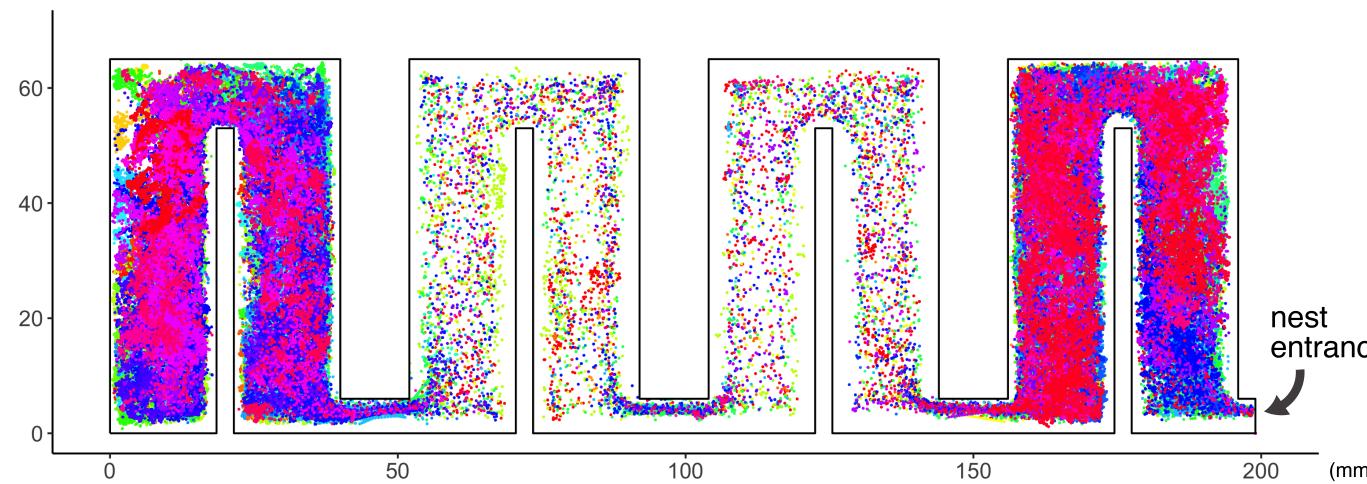
Next time, we will collect **lower resolution** data.

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.

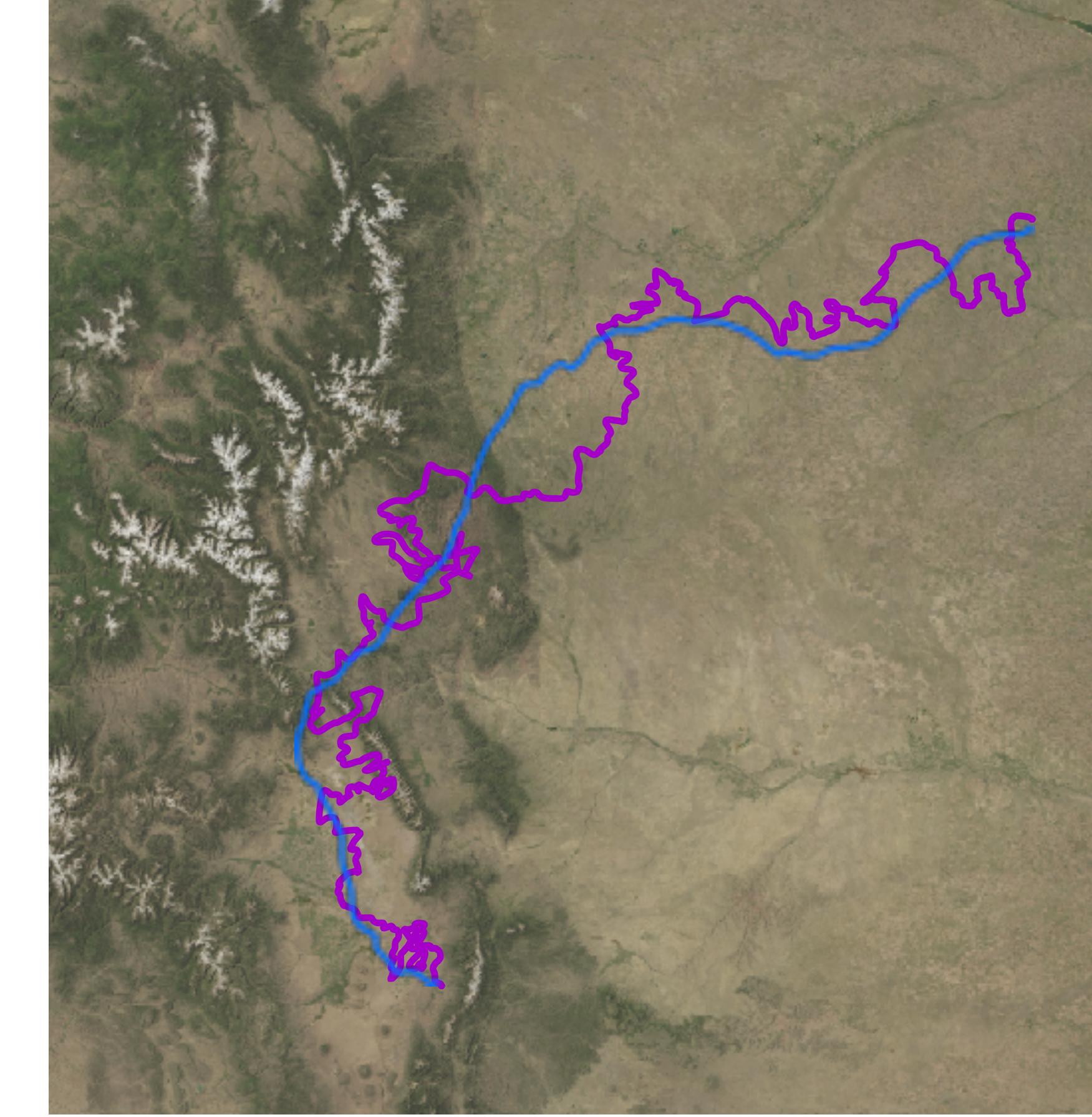
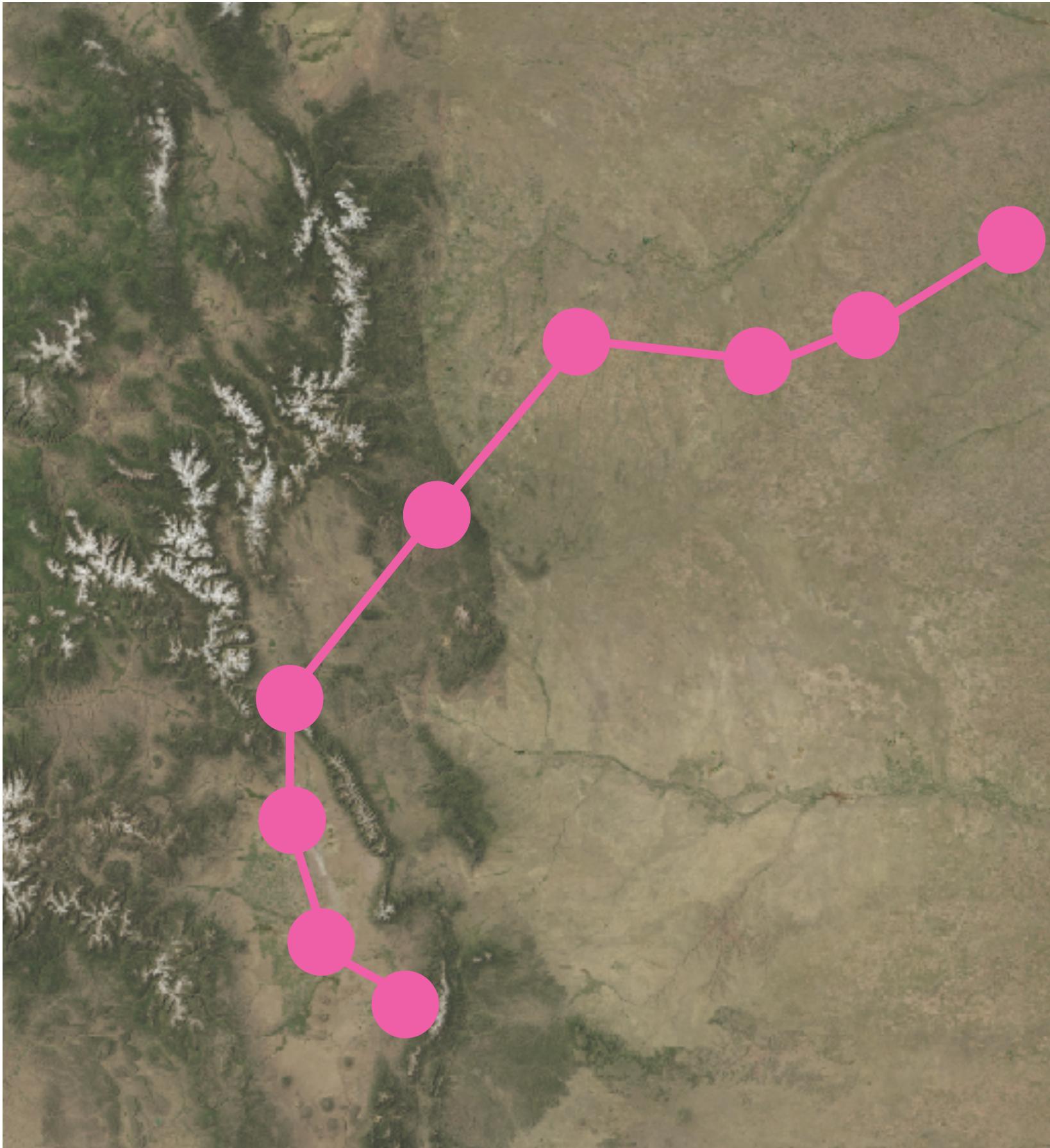
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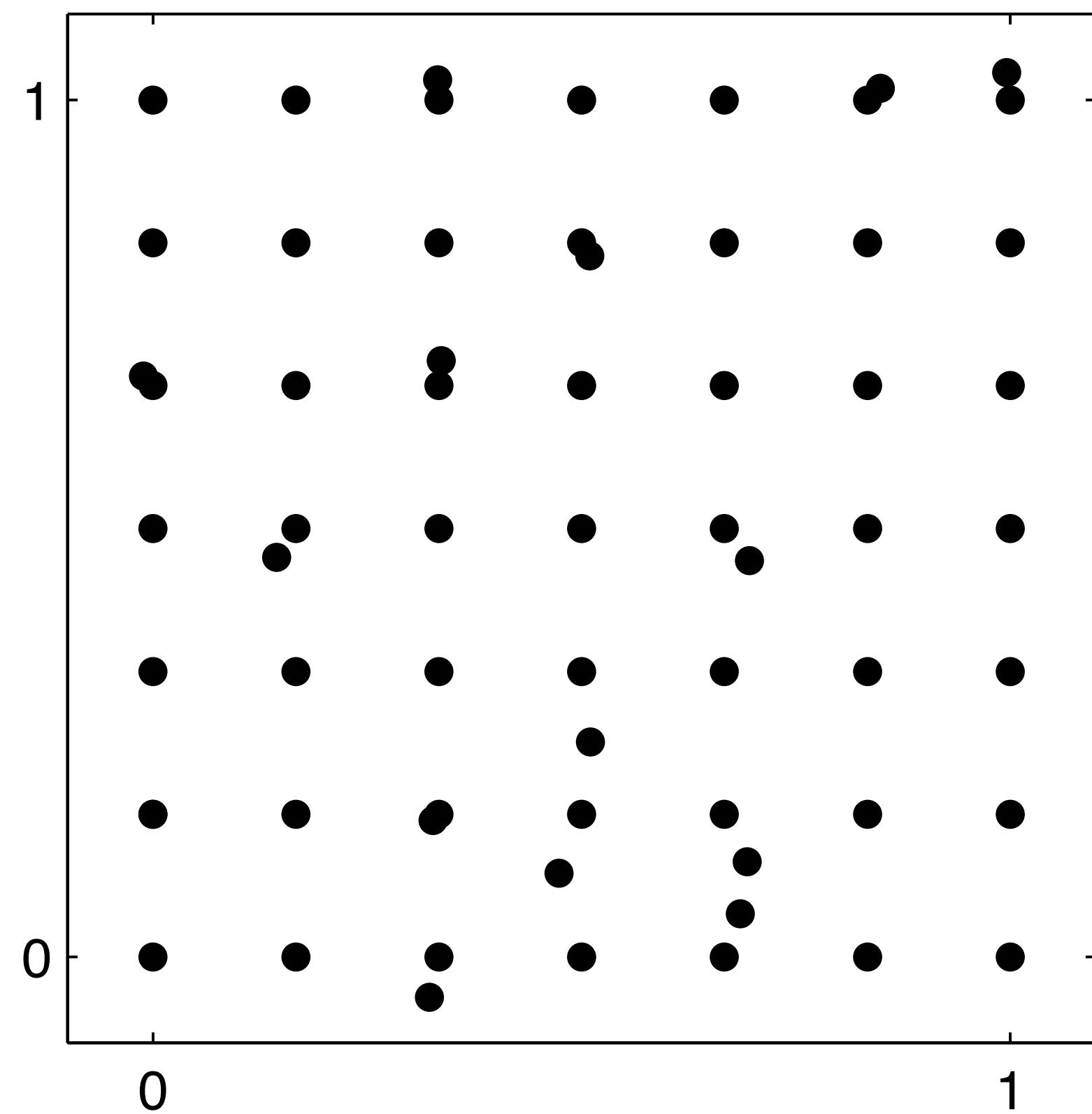


- * Background
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Sampling at **regular time intervals** can hide important information about the speed and tortuosity of the path.



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)

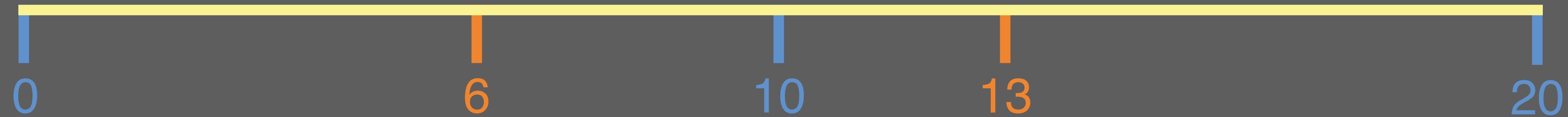
We **propose a sampling scheme** for animal telemetry data inspired by the lattice plus close pairs geostatistical design.

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.

Full data



Every 3s



Every 5s



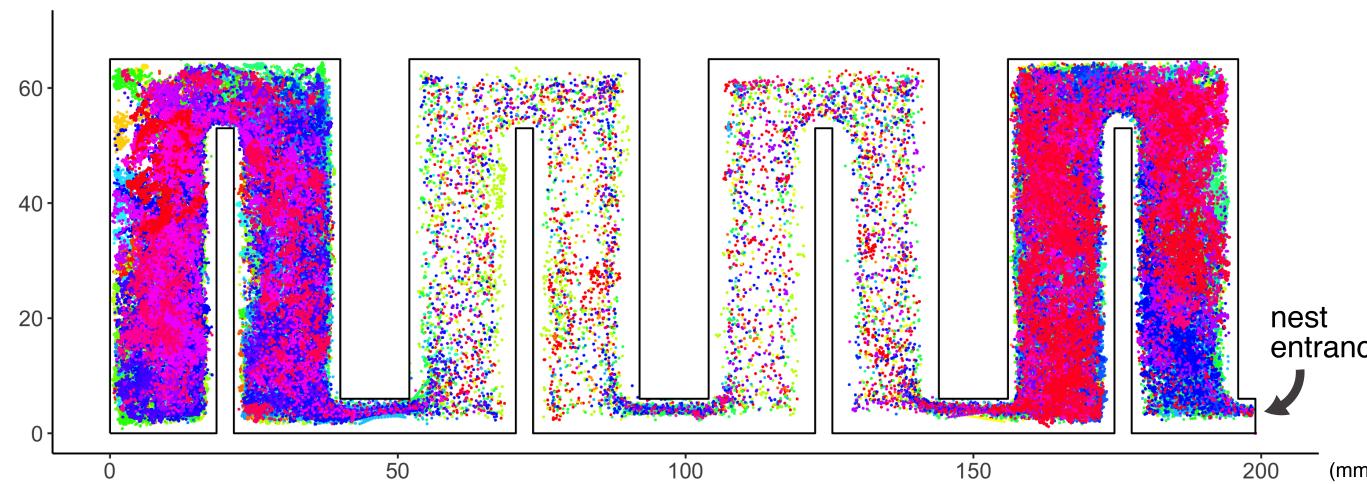
Lattice and Random intermediate point (LARI) 10s



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

1

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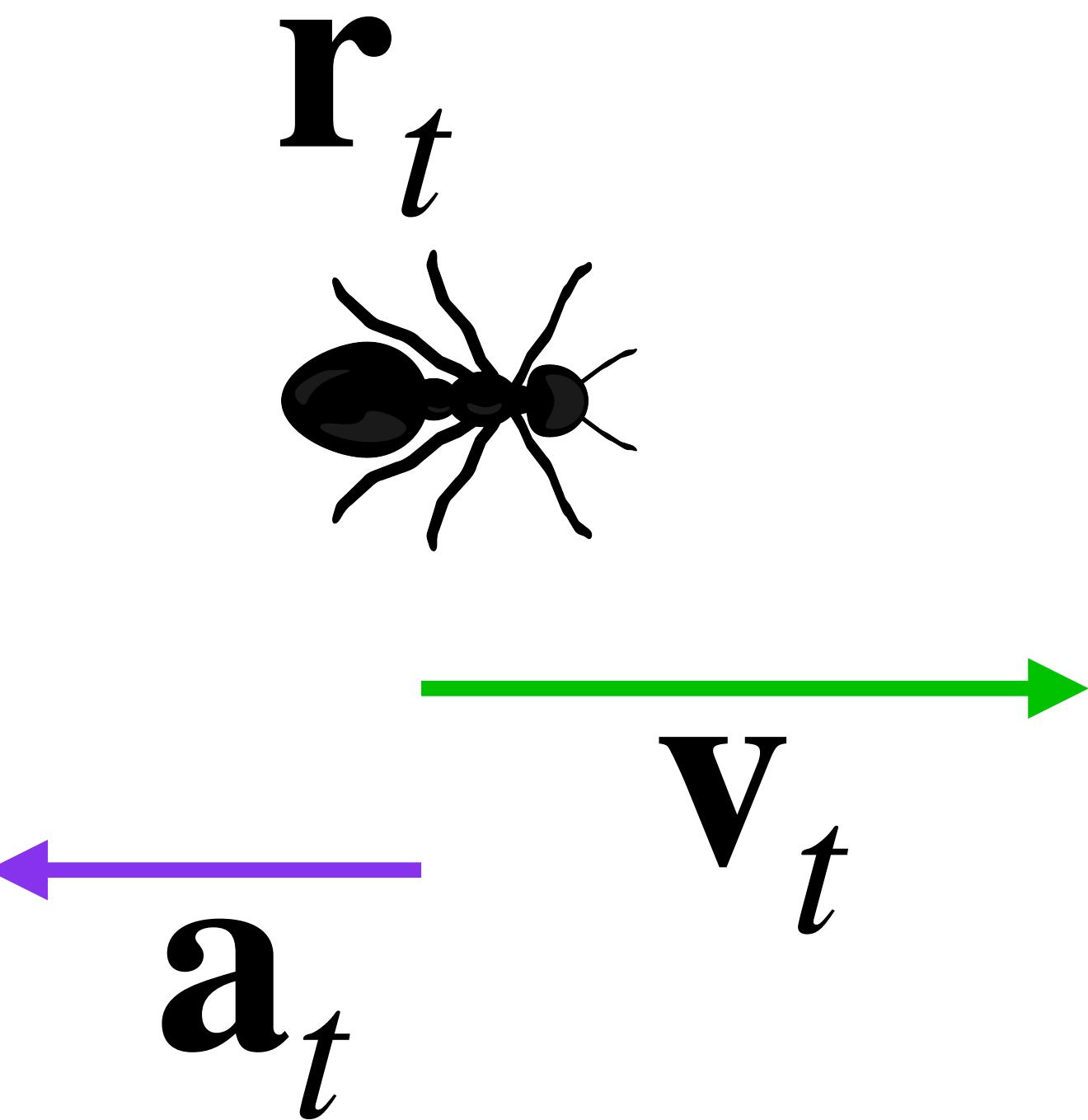
To **model movement at an individual level**, we use basic concepts from physics.

\mathbf{r}_t = position

\mathbf{v}_t = velocity

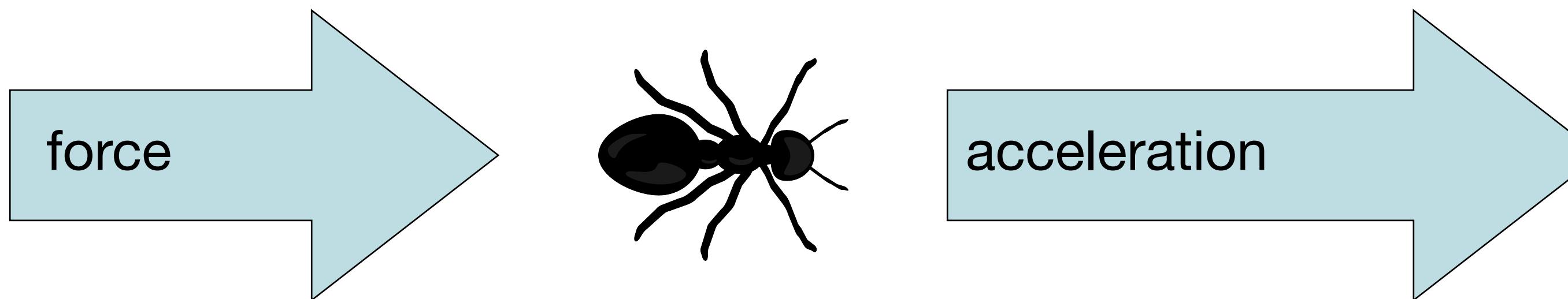
\mathbf{a}_t = acceleration

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.

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

The derivative of velocity with respect to time is acceleration.

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

The **2** main equations for this model

To model animal movement, we use

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

and rewrite acceleration as a sum of forces

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

mean-reverting force

random force

Stochastic differential equation (SDE) model for animal movement

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

SDE model framework:

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

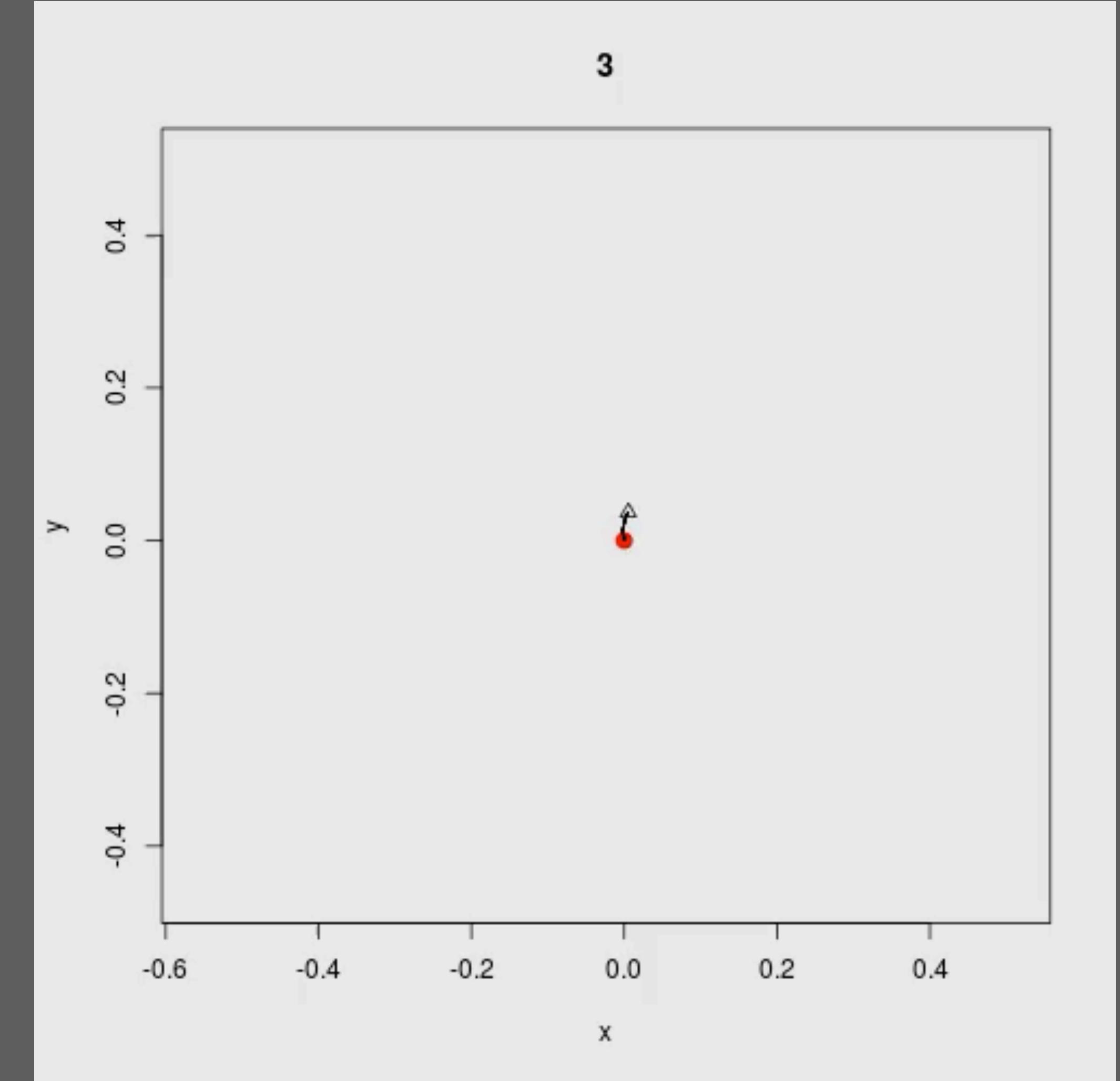
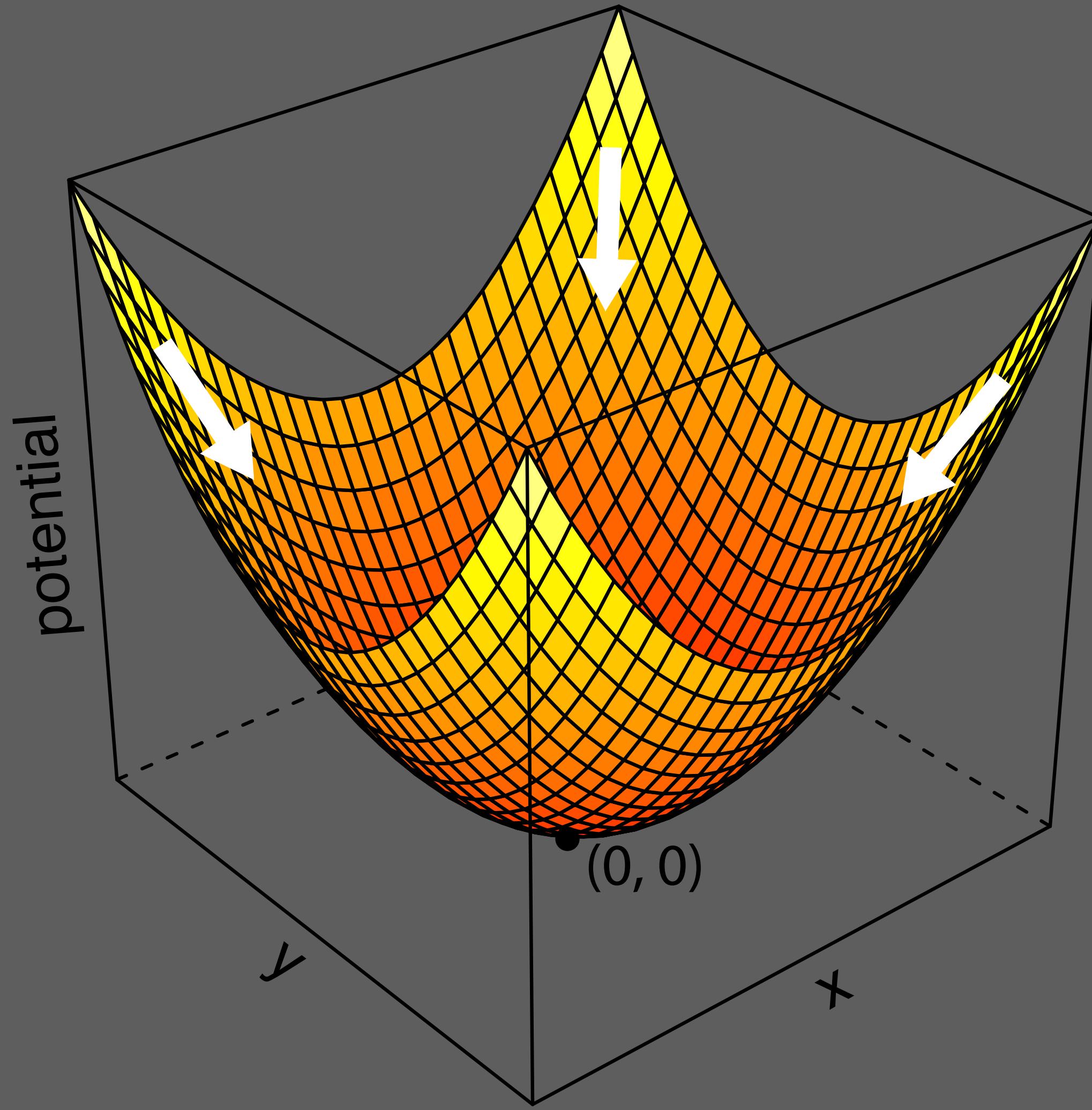
$$d\mathbf{v}_t = \beta (\mu(\mathbf{r}_t) - \mathbf{v}_t) dt + c(\mathbf{r}_t) \mathbf{I} d\mathbf{w}_t$$

Utilizing motility and potential surfaces, define:

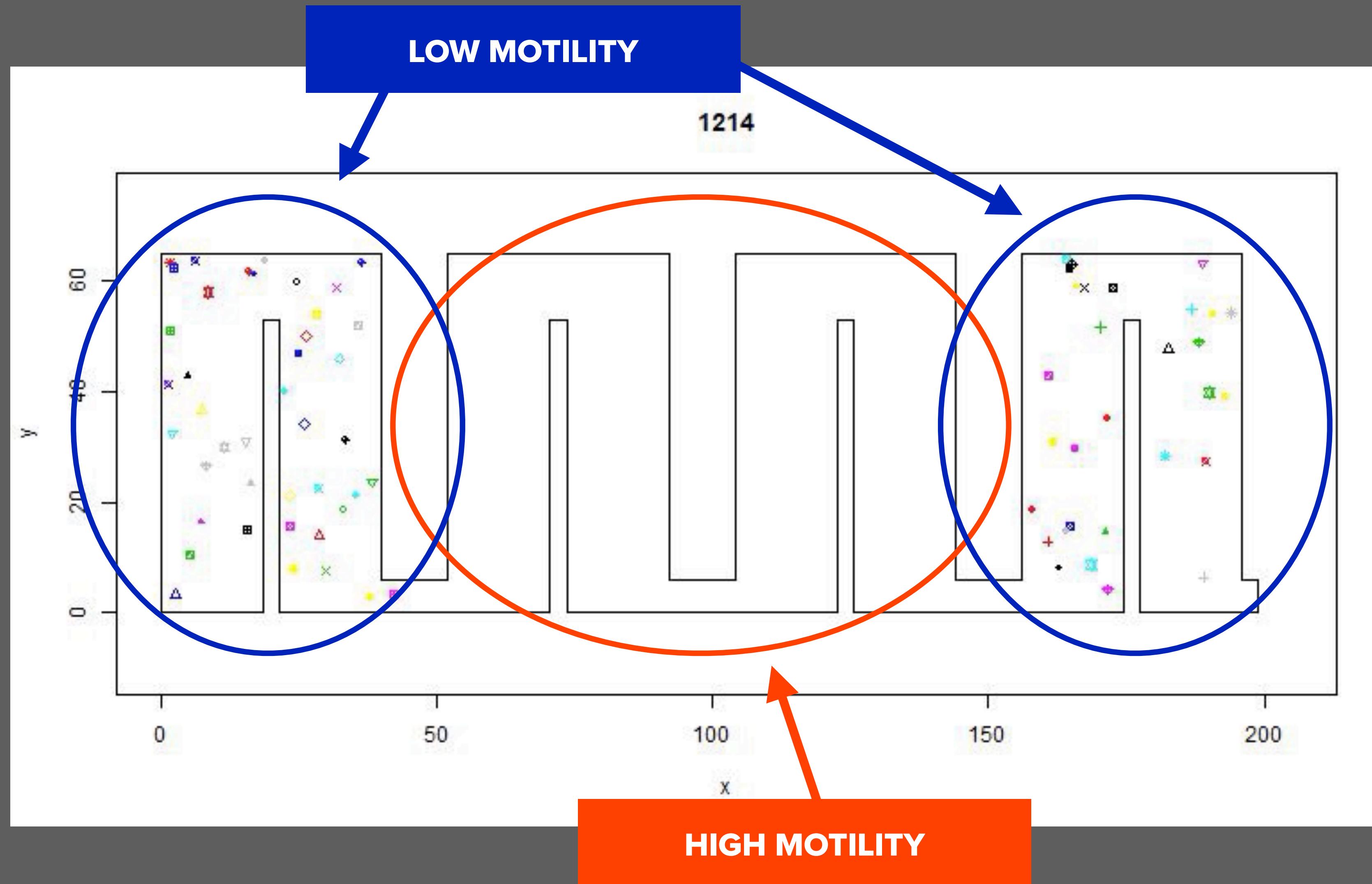
$$\mu(\mathbf{r}_t) = \textcolor{brown}{m}(\mathbf{r}_t) [- \nabla p(\mathbf{r}_t)] \quad (\text{mean drift})$$

$$c(\mathbf{r}_t) = \sigma \textcolor{brown}{m}(\mathbf{r}_t) \quad (\text{magnitude of stochasticity})$$

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.

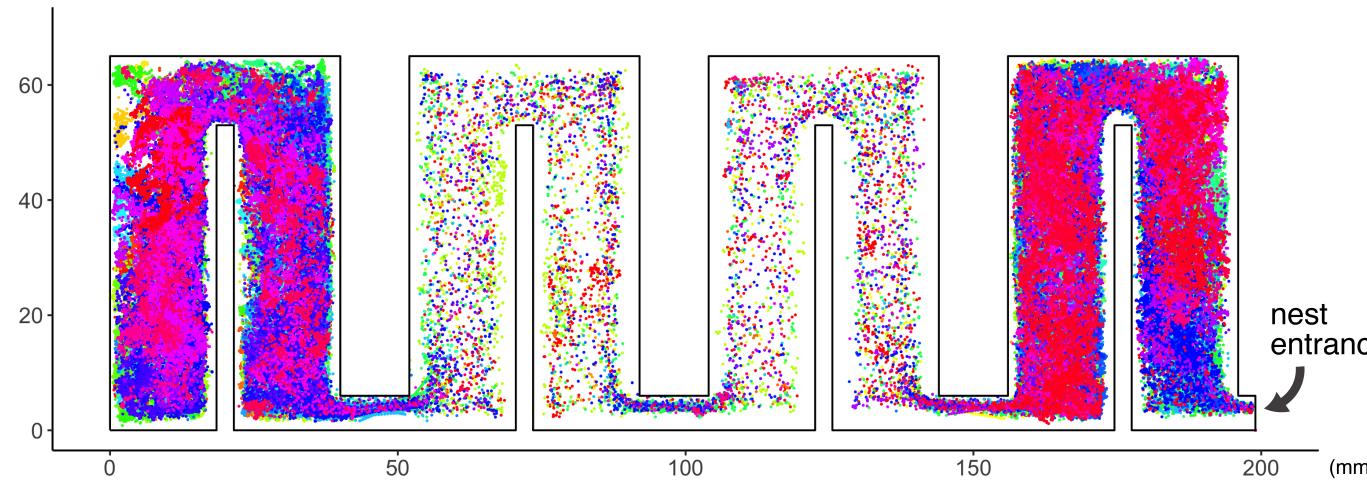


The framework I use was proposed in 2018 by Jim Russell and applied to ant movement data.



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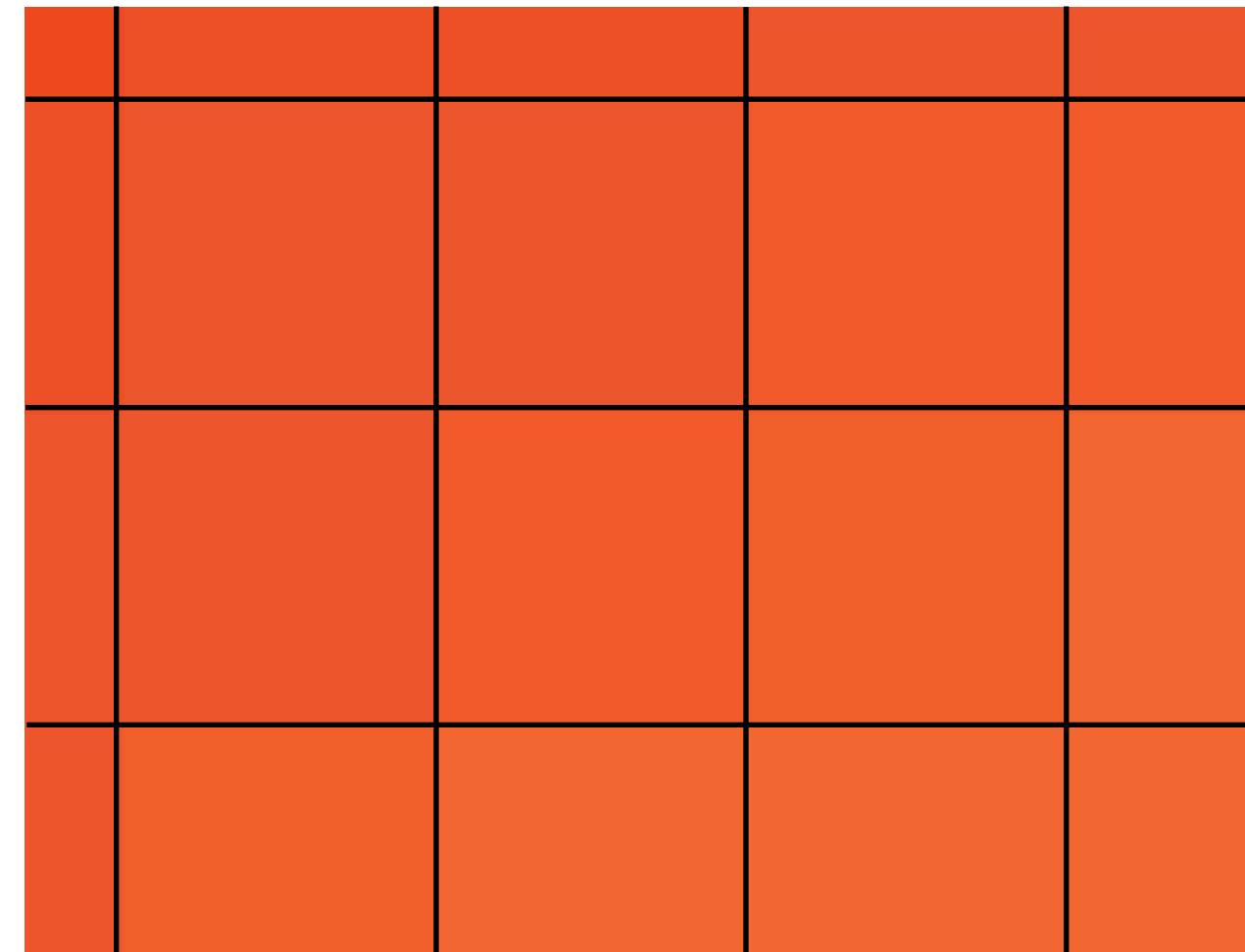
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Spline expansion (degree 0, piecewise constant) of the motility and potential surfaces

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

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

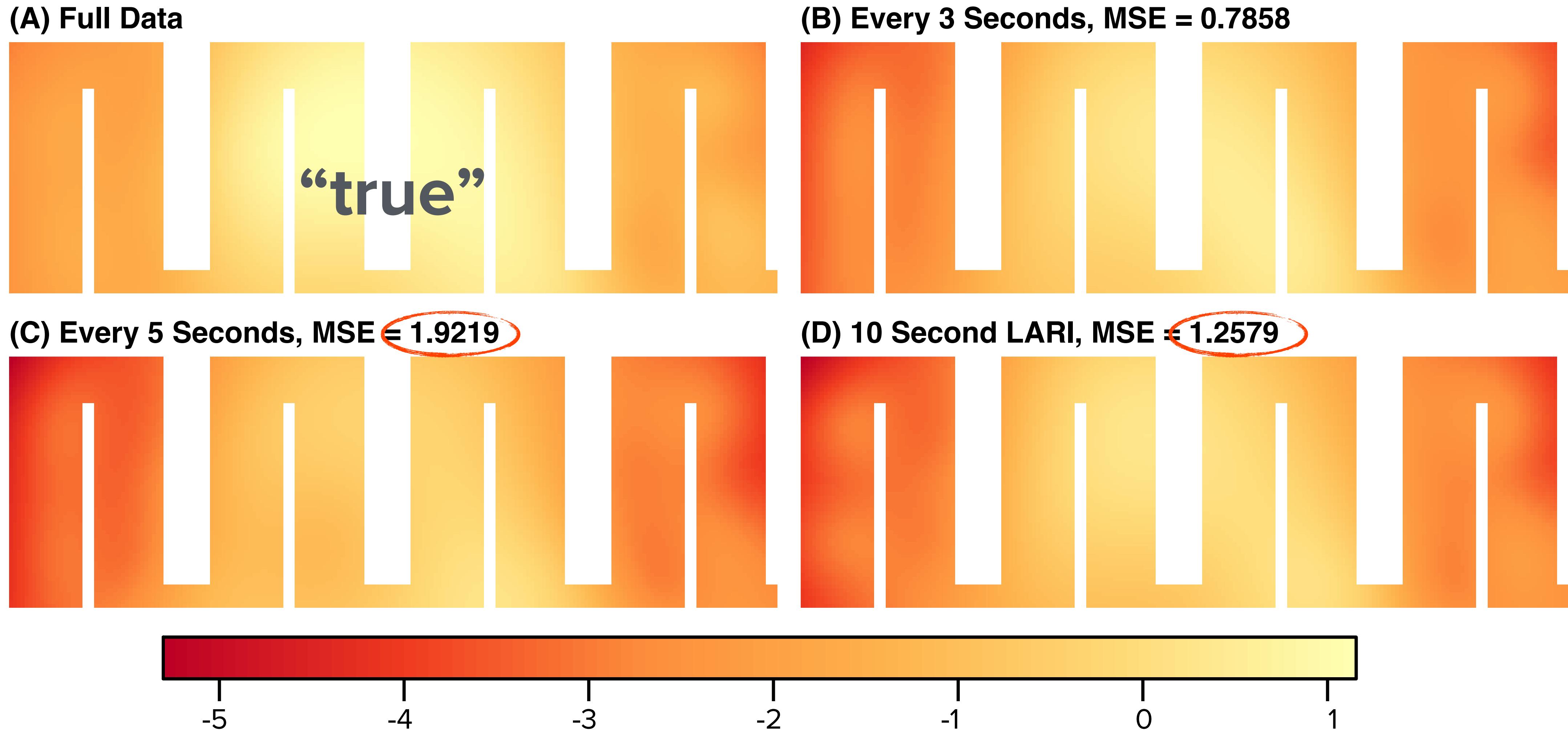
$$s_j(\mathbf{r}_\tau) \equiv \begin{cases} 1, & \mathbf{r}_\tau \text{ in } j^{\text{th}} \text{ grid cell} \\ 0, & \text{otherwise} \end{cases}$$



Penalize the roughness of m and p

Smoothness parameters are chosen with a holdout set.

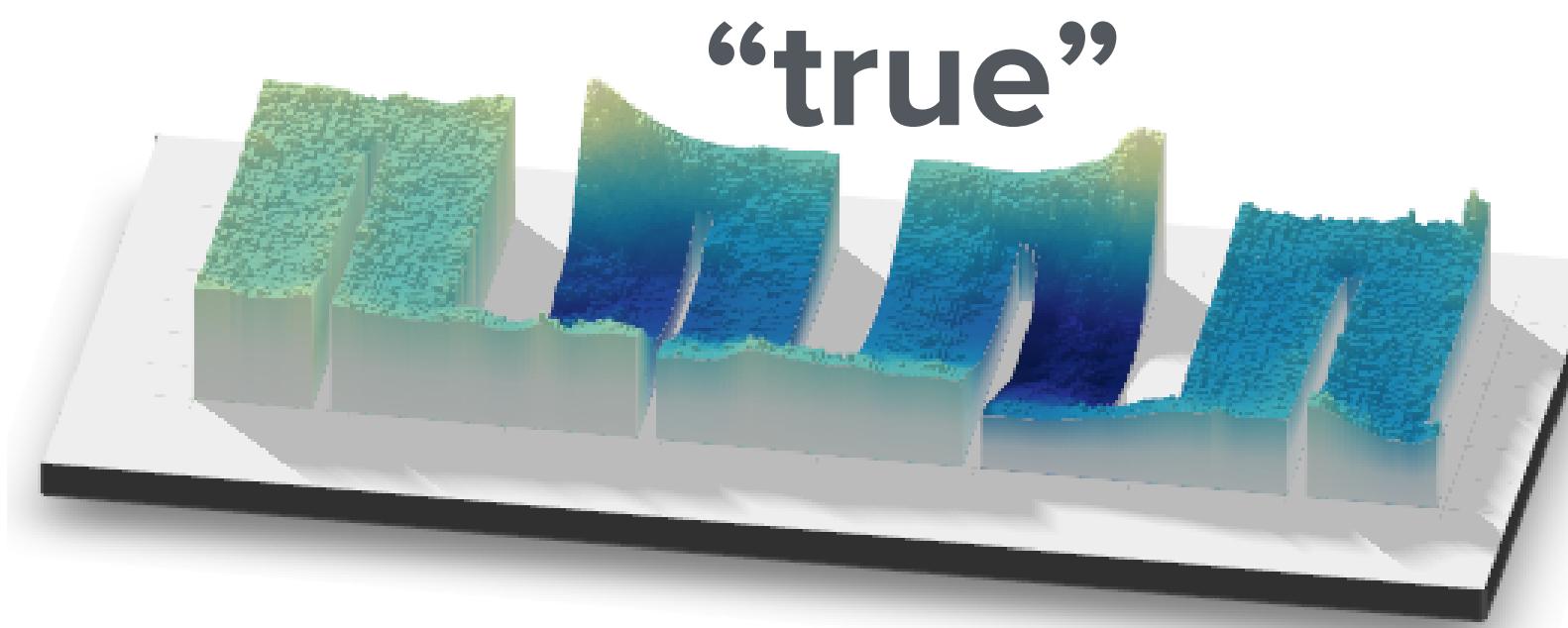
We compare motility and potential surfaces estimated with the 4 subsamples using multiple metrics.



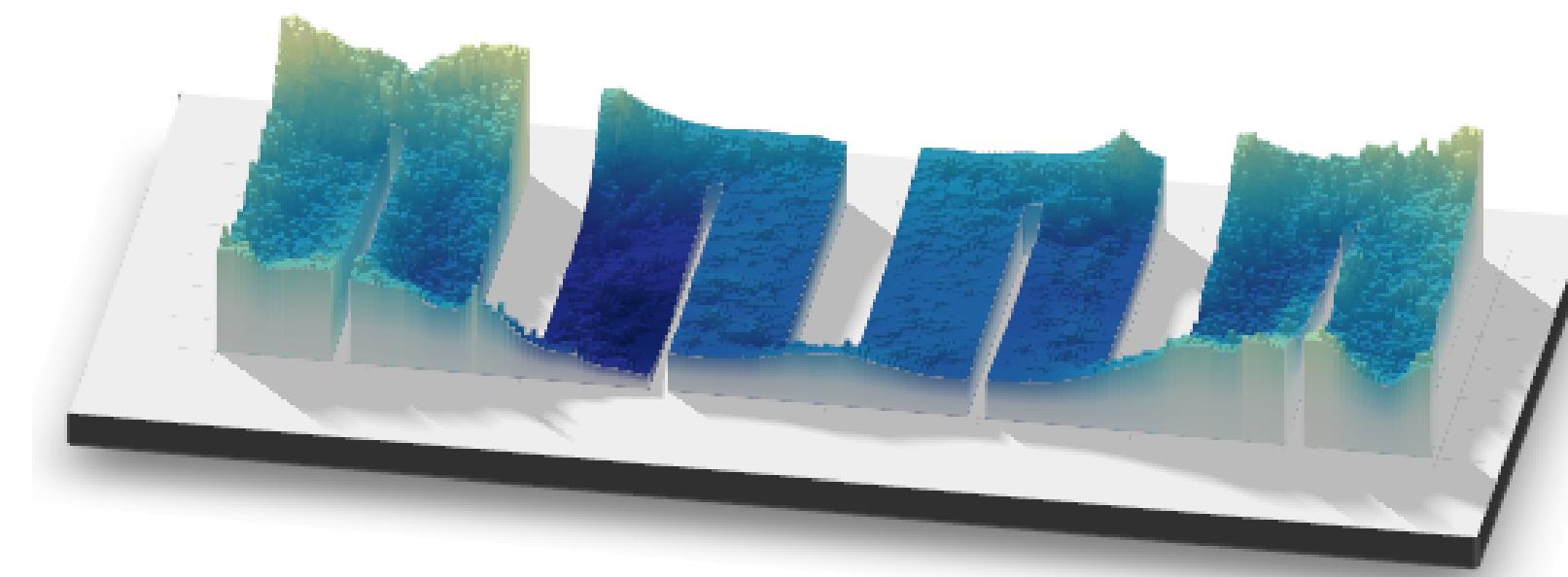
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POTENTIAL SURFACE

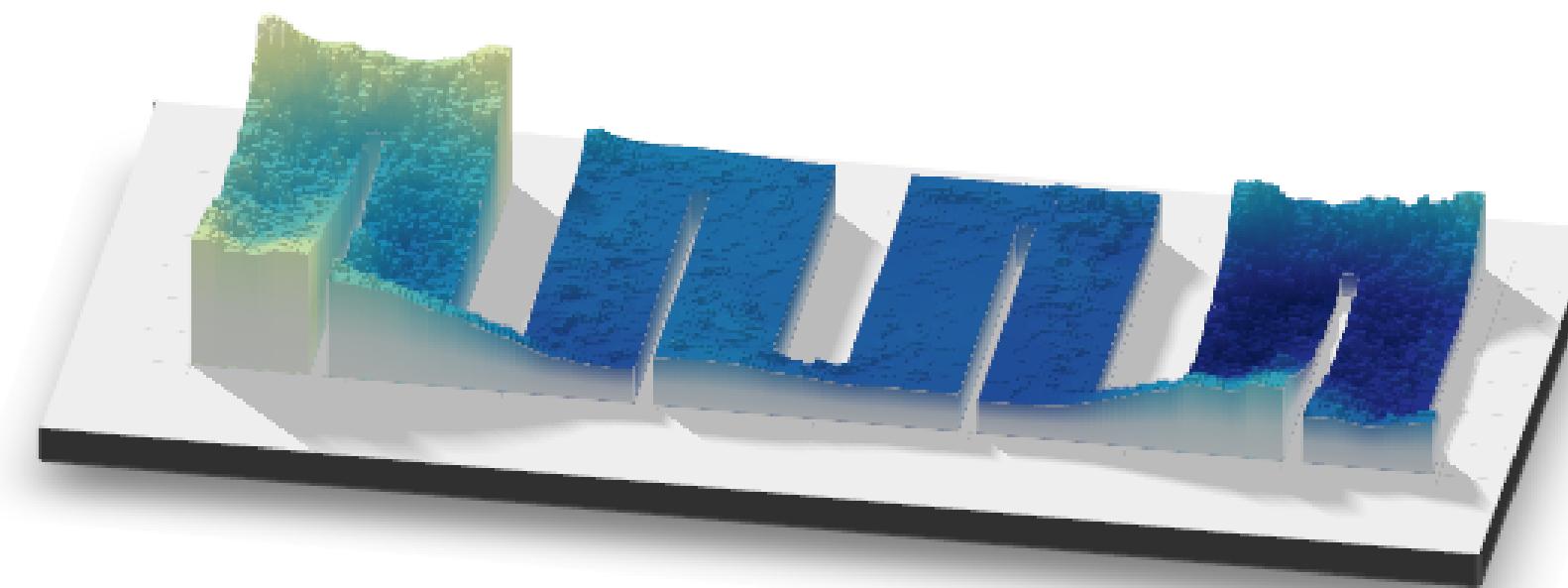
(A) Full Data



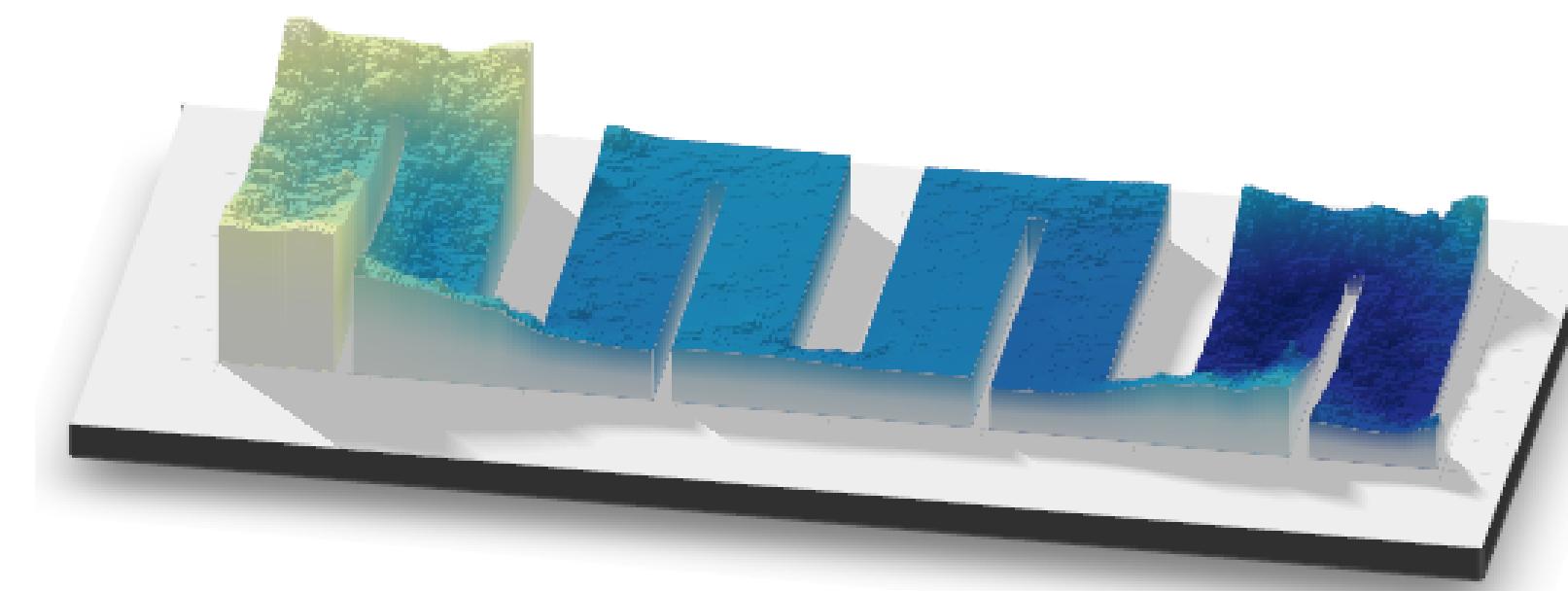
(B) Every 3 Seconds, $\text{MSD} = 18.1455$



(C) Every 5 Seconds, $\text{MSD} = 21.2761$

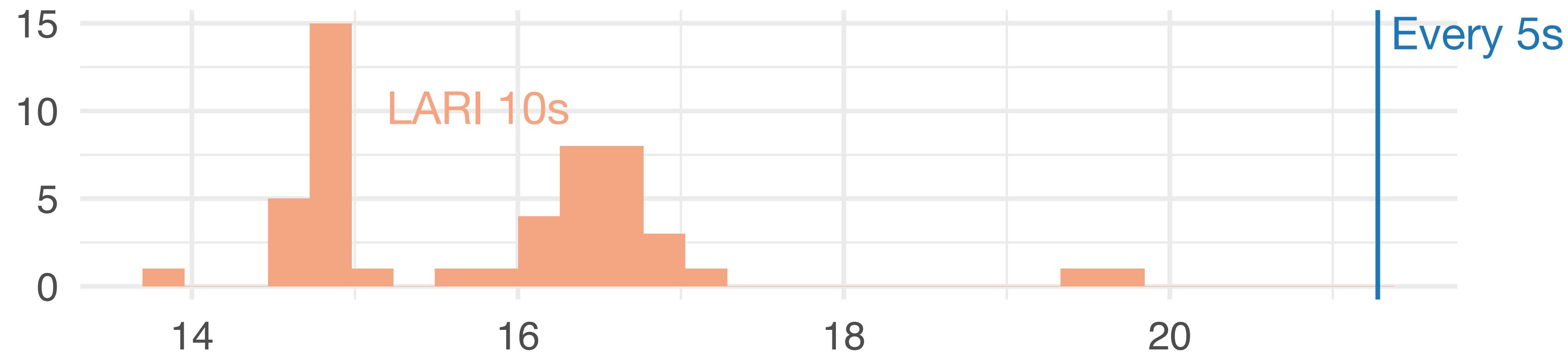


(D) 10 Second LARI, $\text{MSD} = 14.8337$

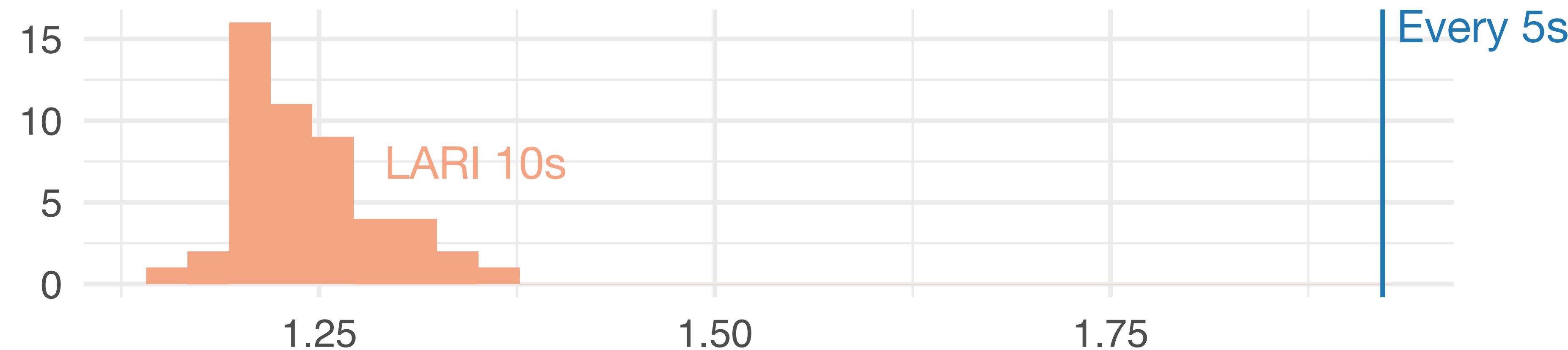


We fit 50 different LARI subsamples to understand random variation.

(A) Potential Surface MSD

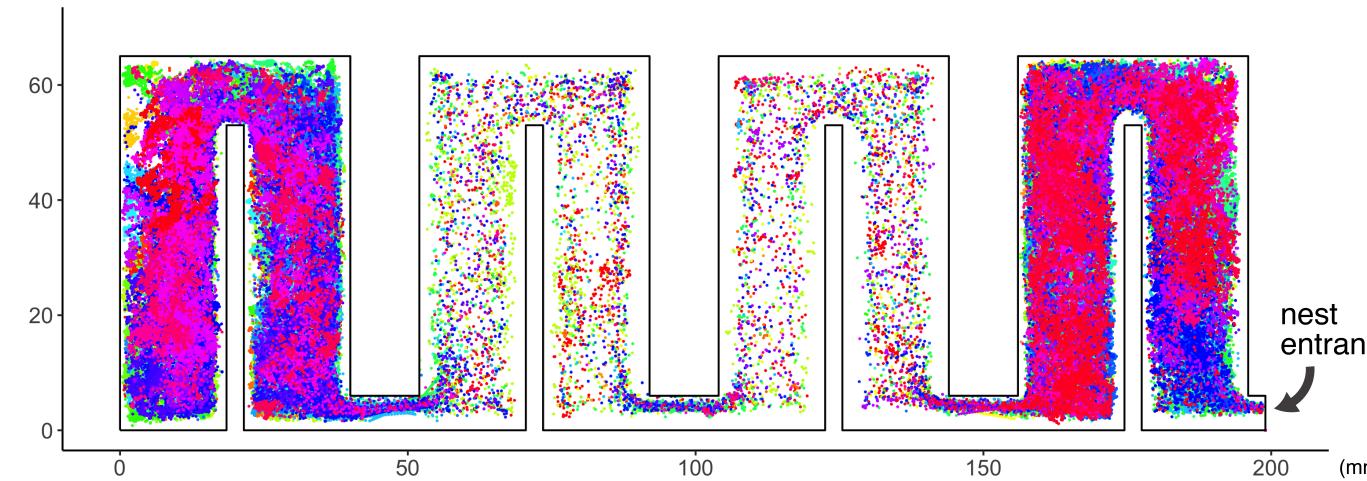


(B) Log Motility Surface MSE



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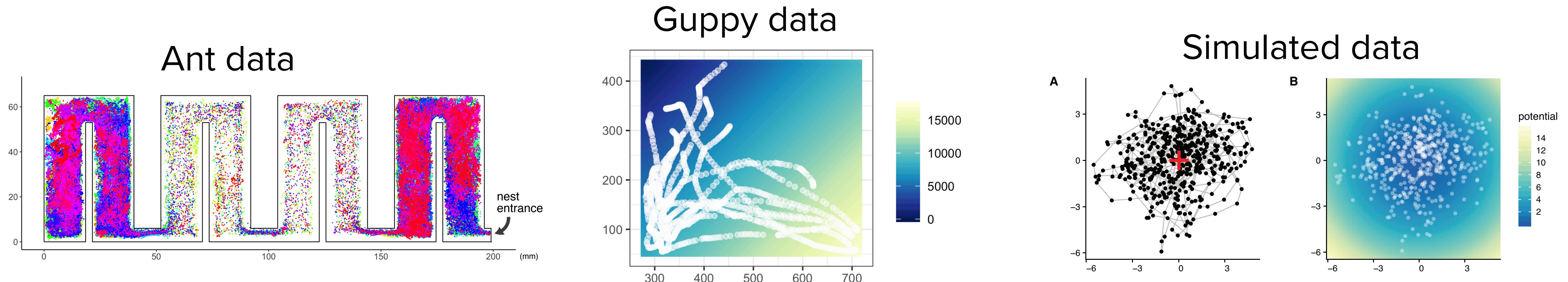
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Result: **LARI sampling was better** than regular sampling overall for understanding movement behavior. A simulation study and additional data example support this conclusion. It may also be better for estimating missing data.

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



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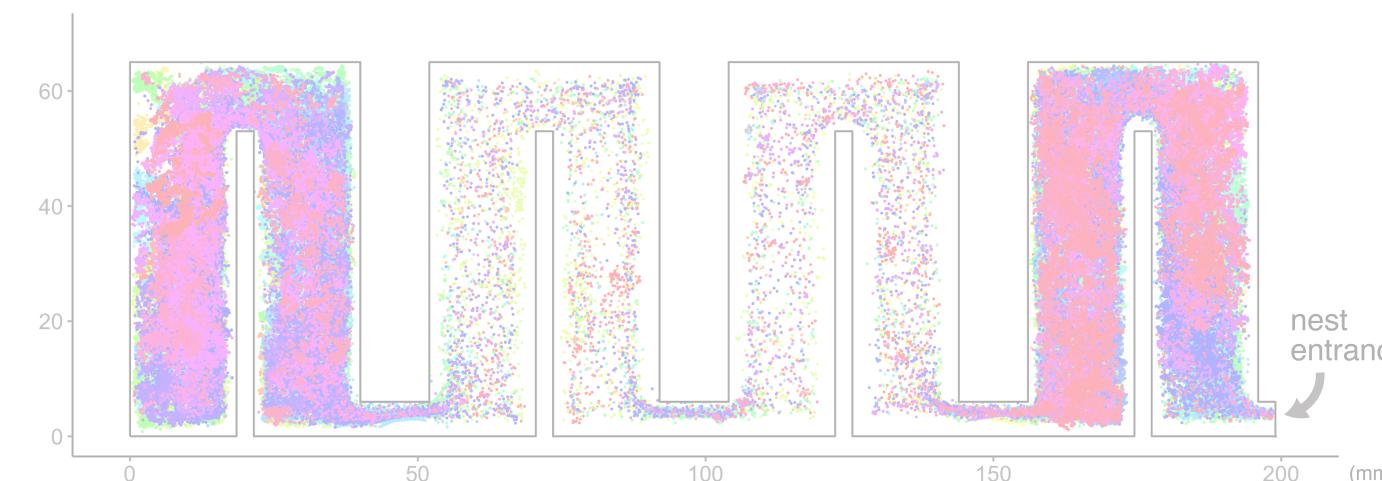
Implications:

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

1

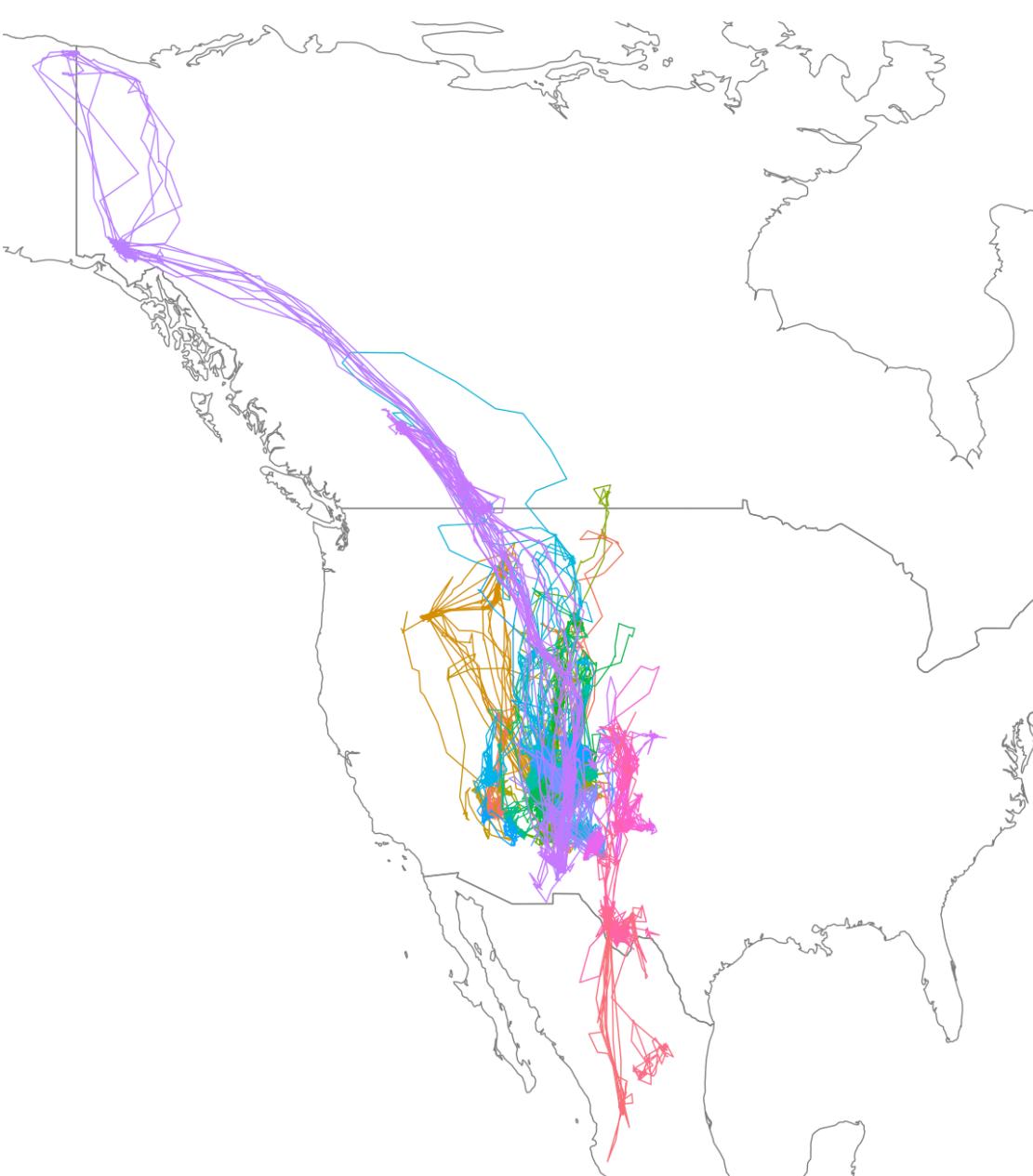
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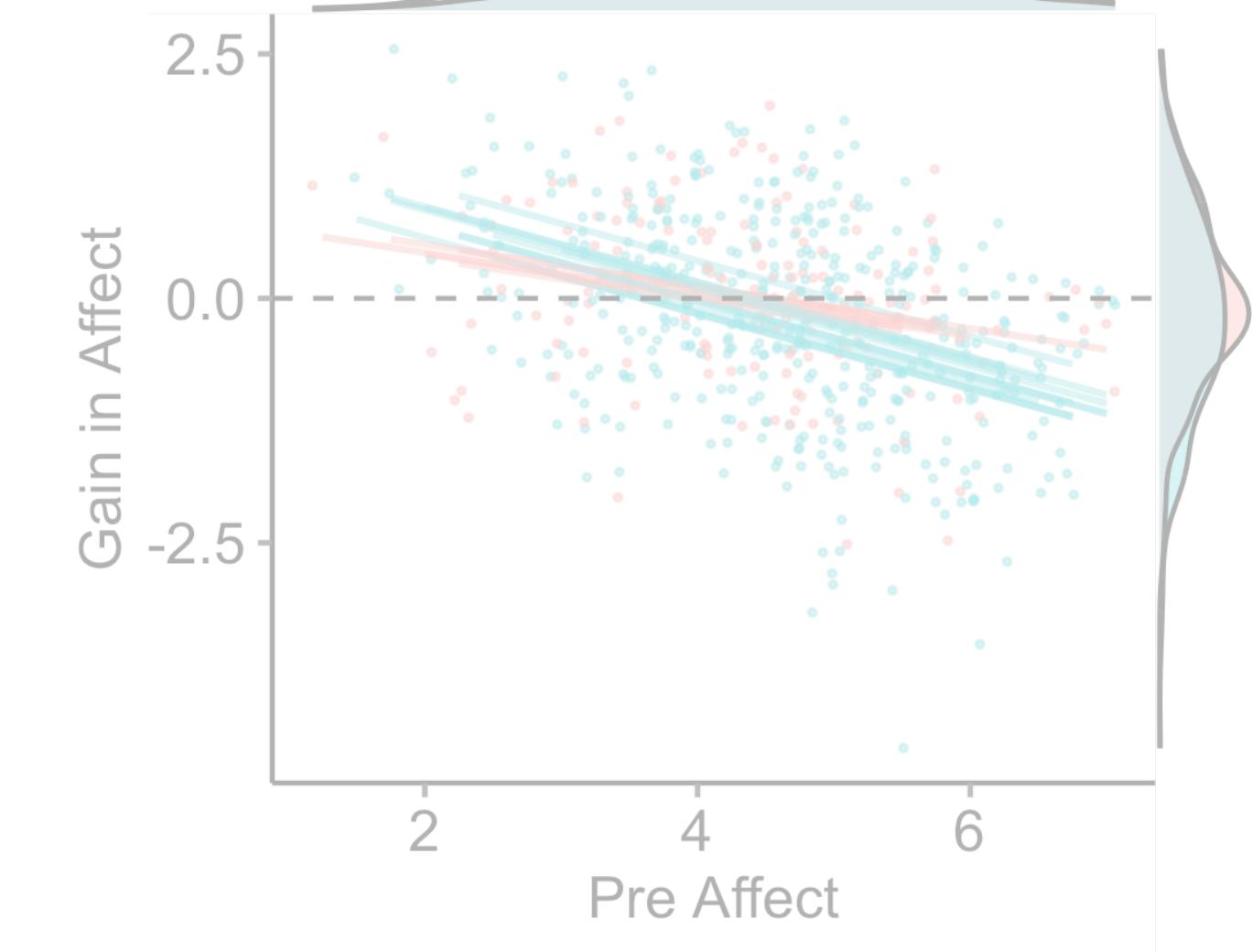
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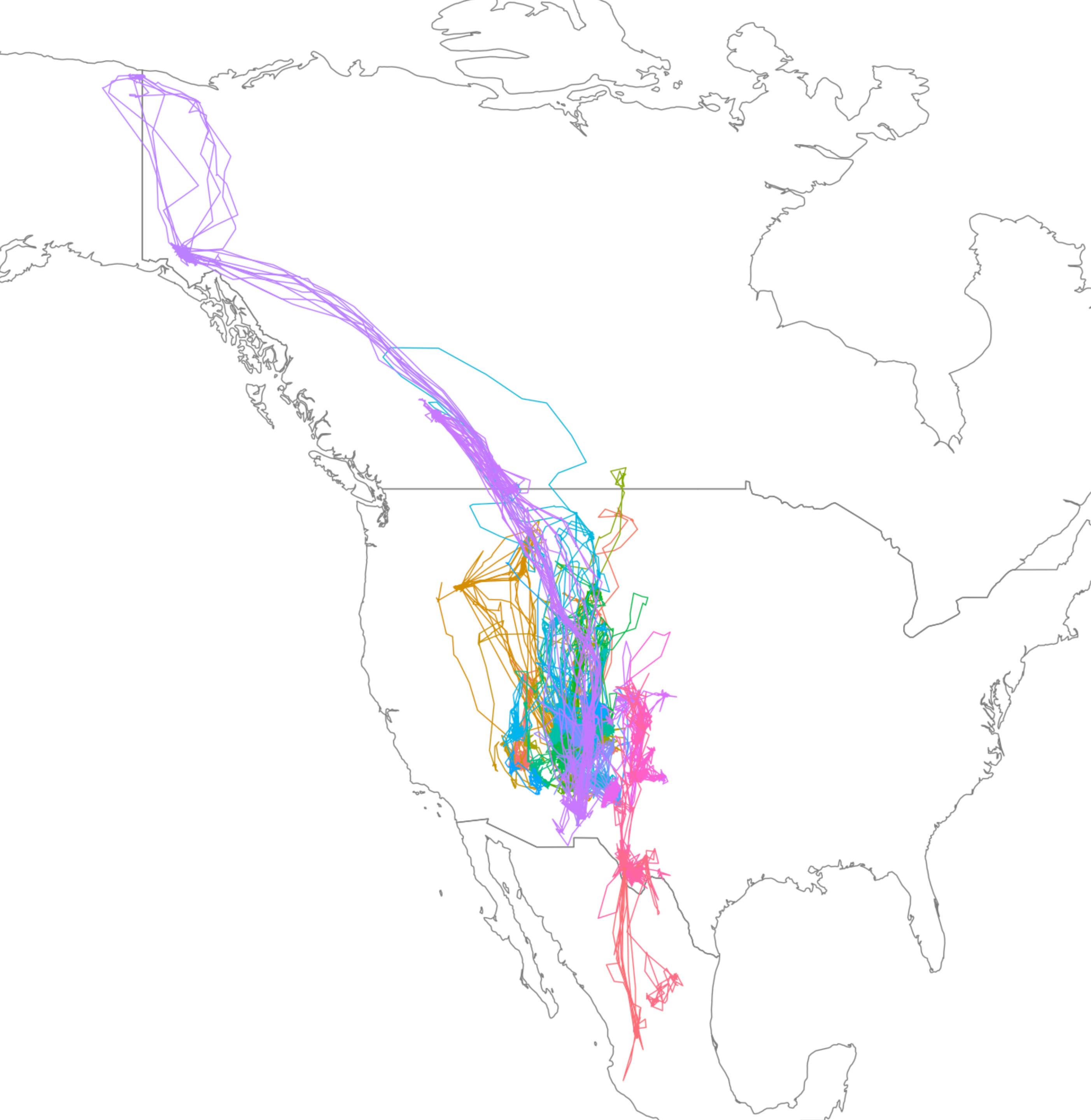


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3

Survey of Probability Attitudes



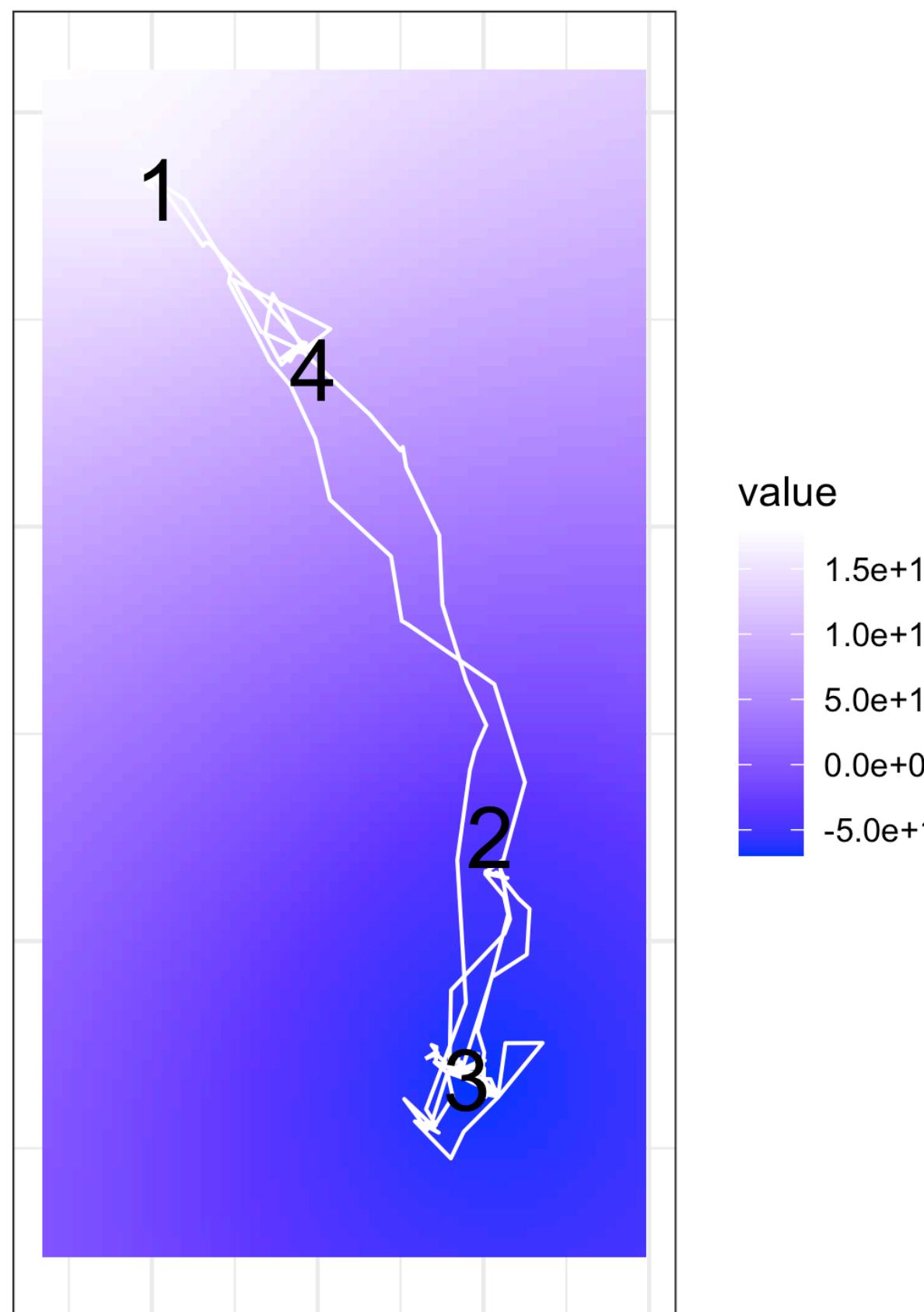


Large **variability** in individual golden eagle movement behaviors.

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.

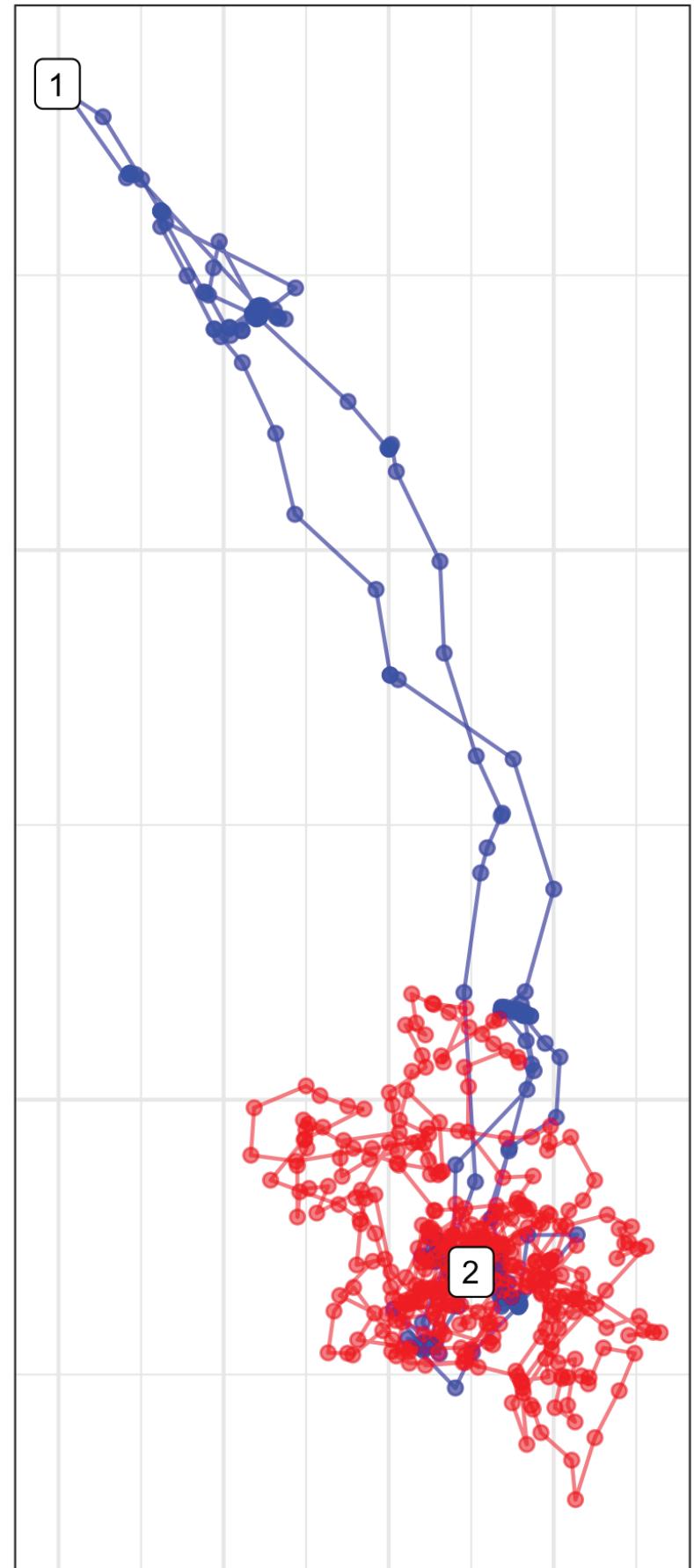


We proposed a **flexible model** using varying coefficients to control strength of attraction to individual-specific attractors.

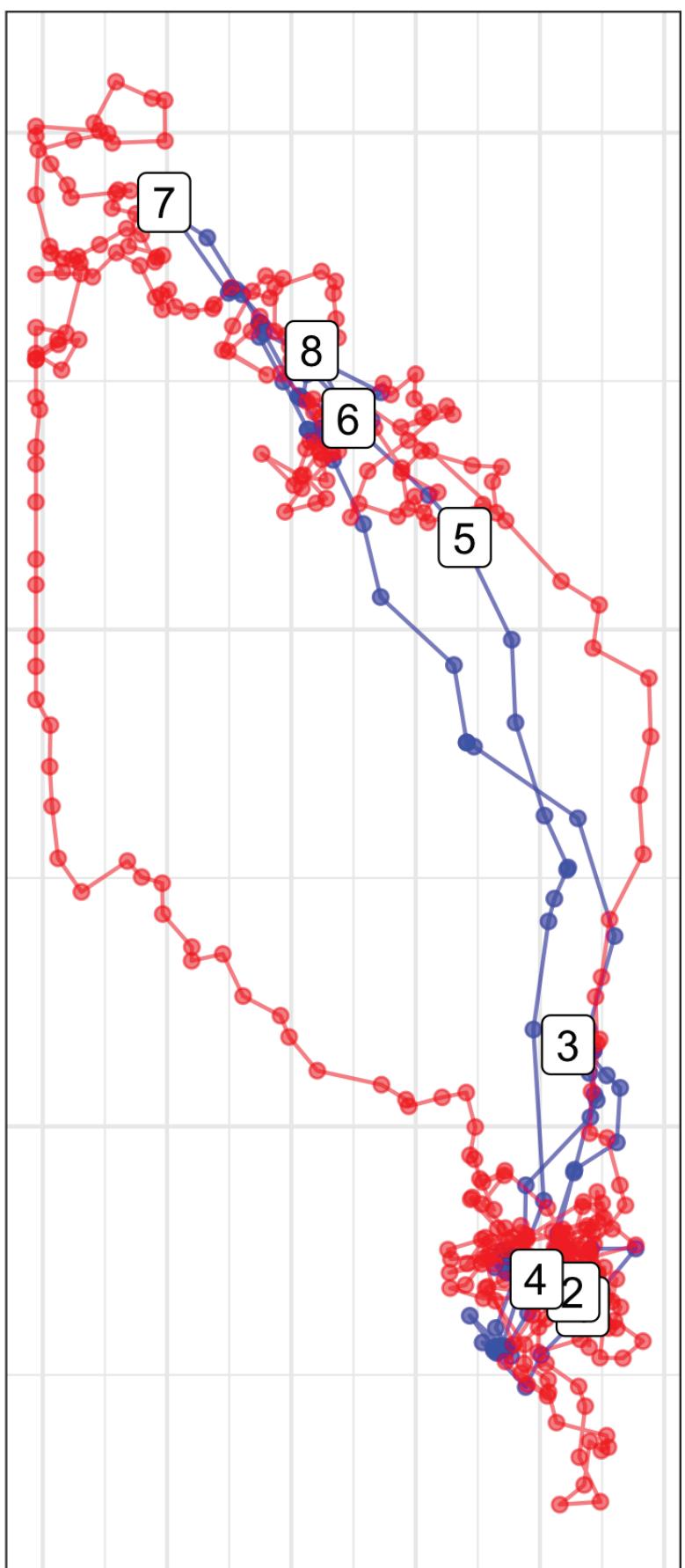


We compared our approach to **Hidden Markov Models**, defined differently for **migration**, dispersal, or residence.

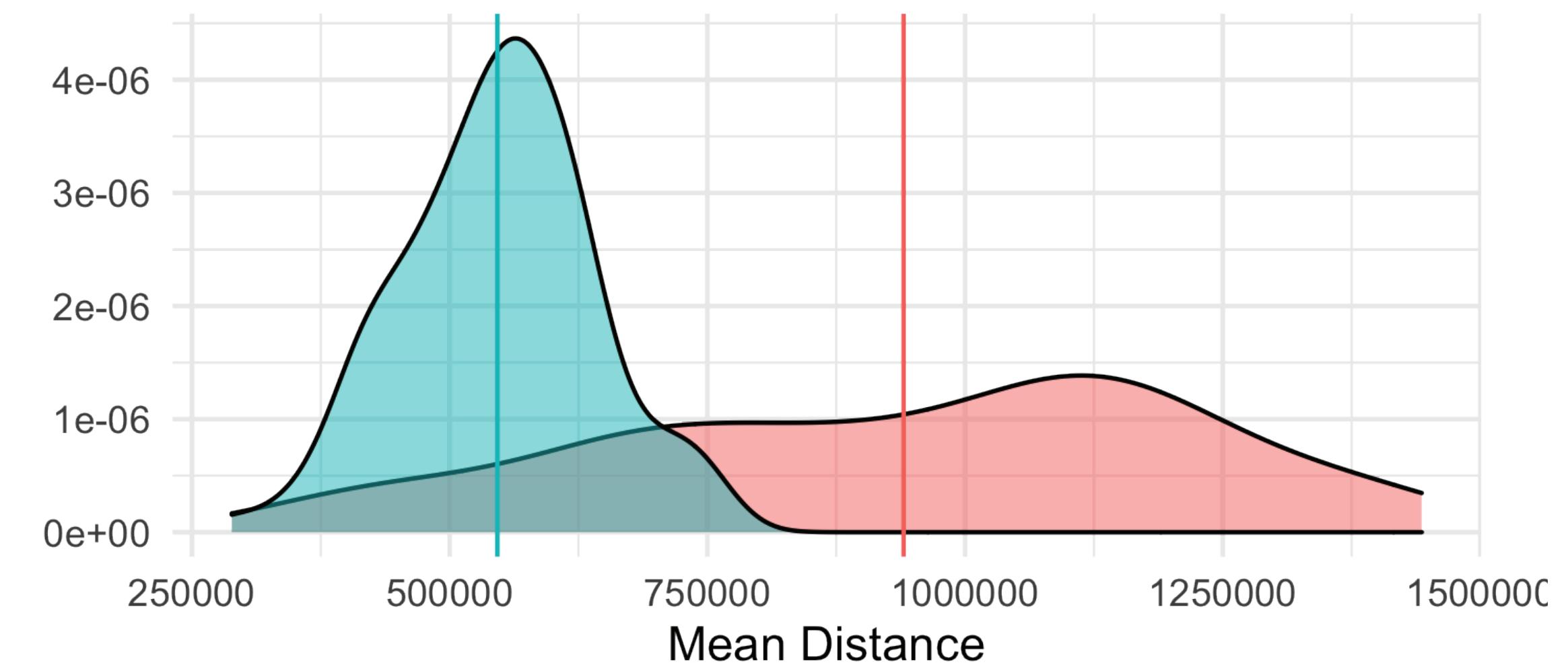
HMM



Varying coefficient model



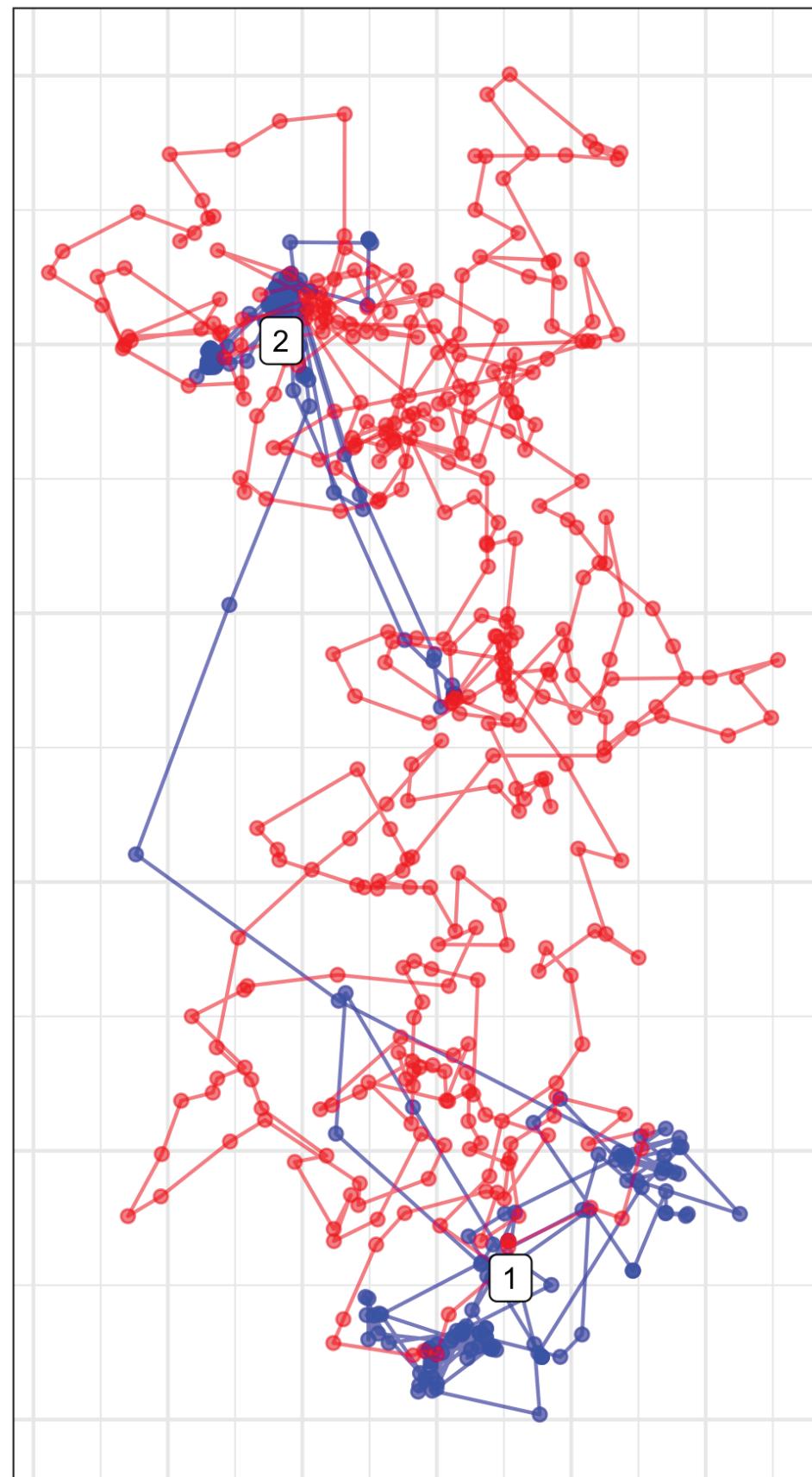
Mean distances from simulated locations to true locations



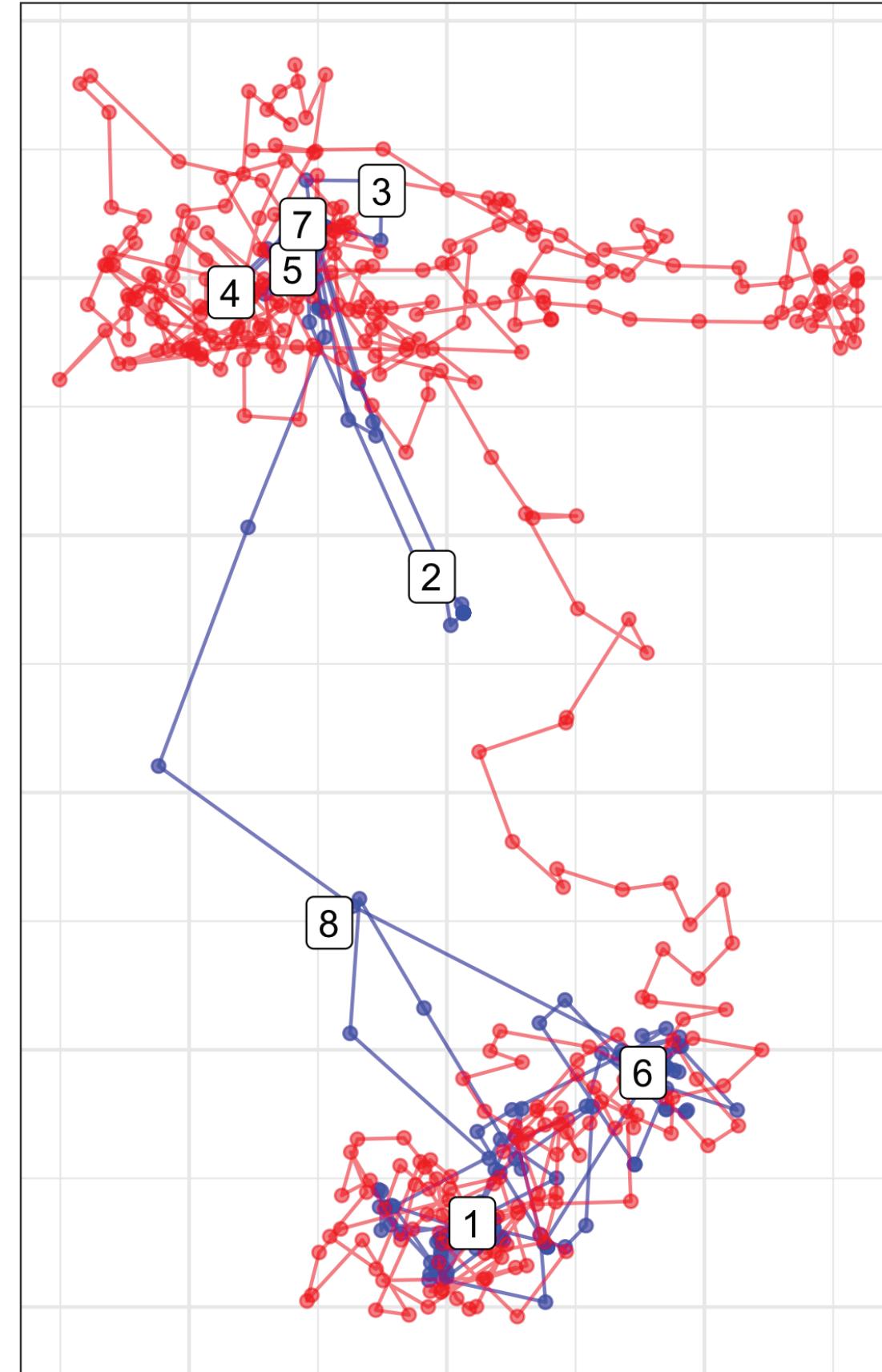
True path in blue & simulation in red

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

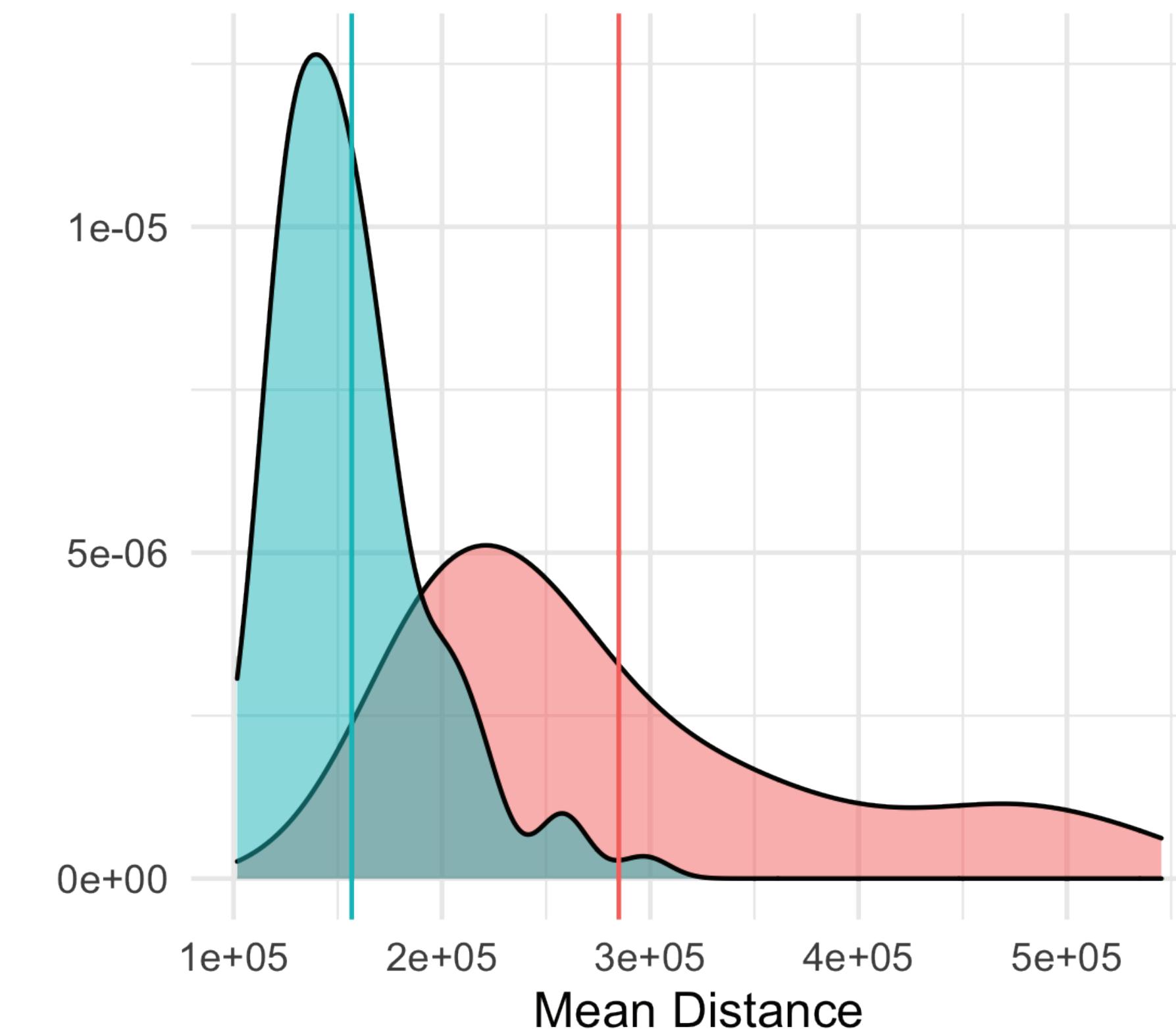
HMM



Varying coefficient model



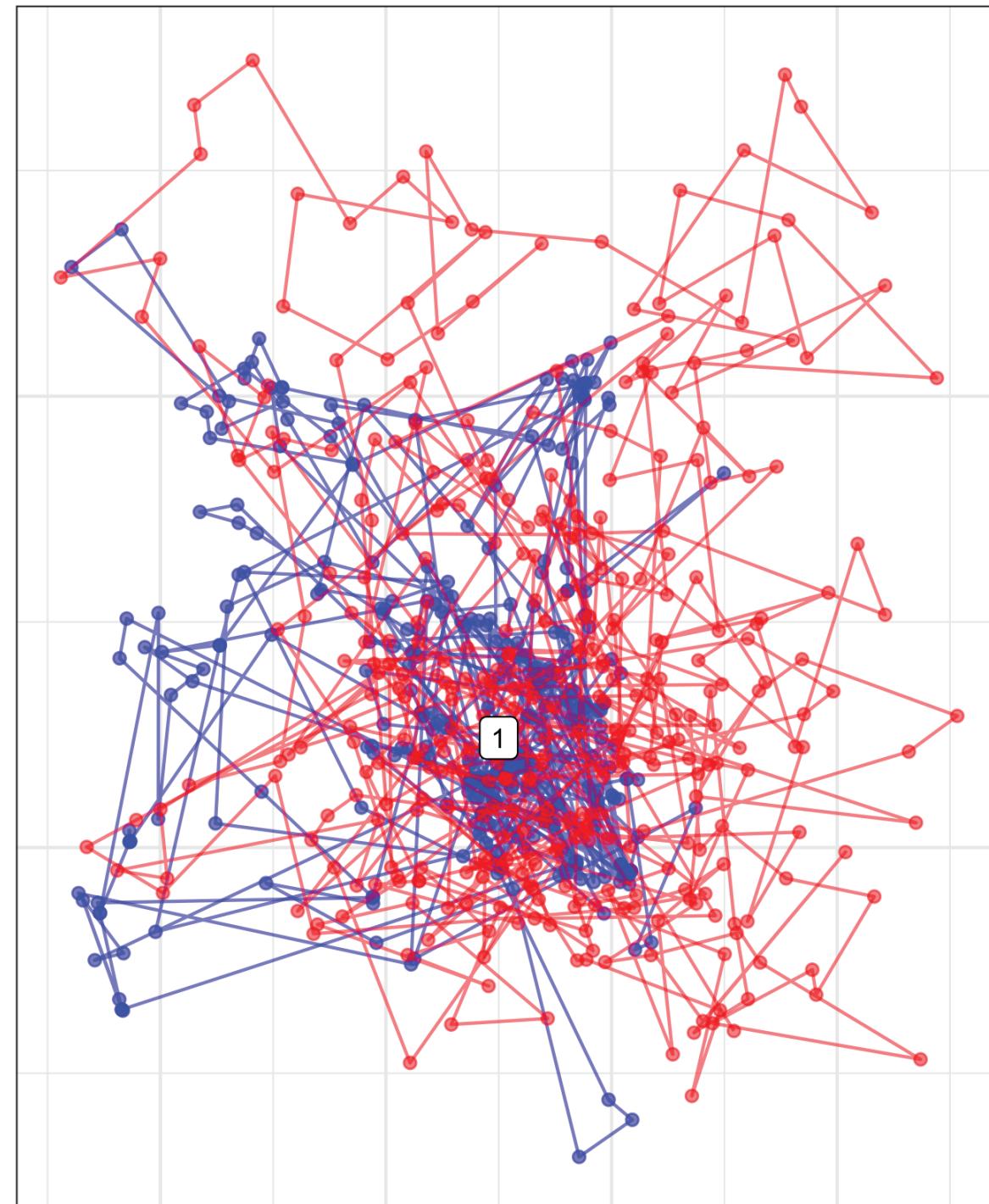
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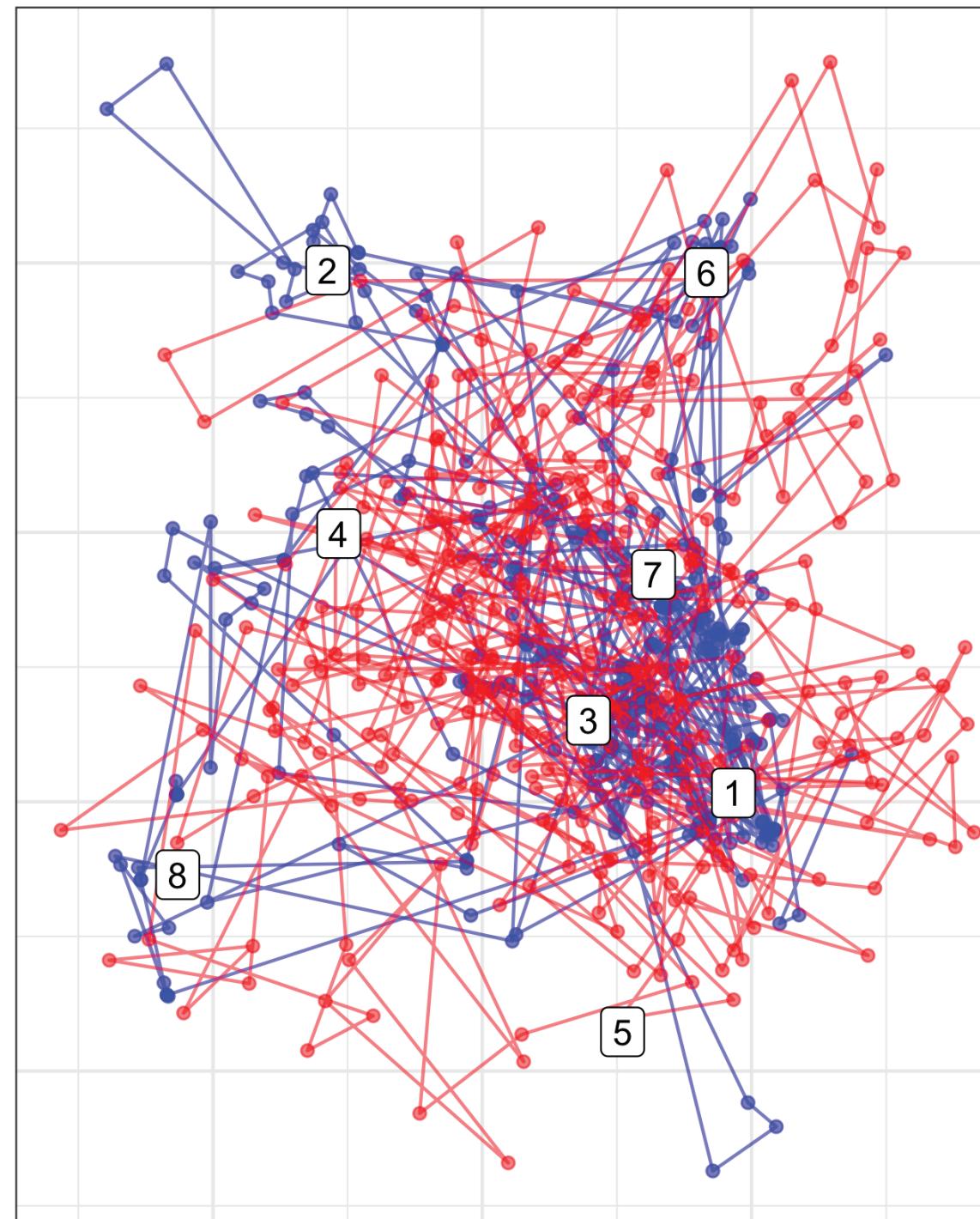
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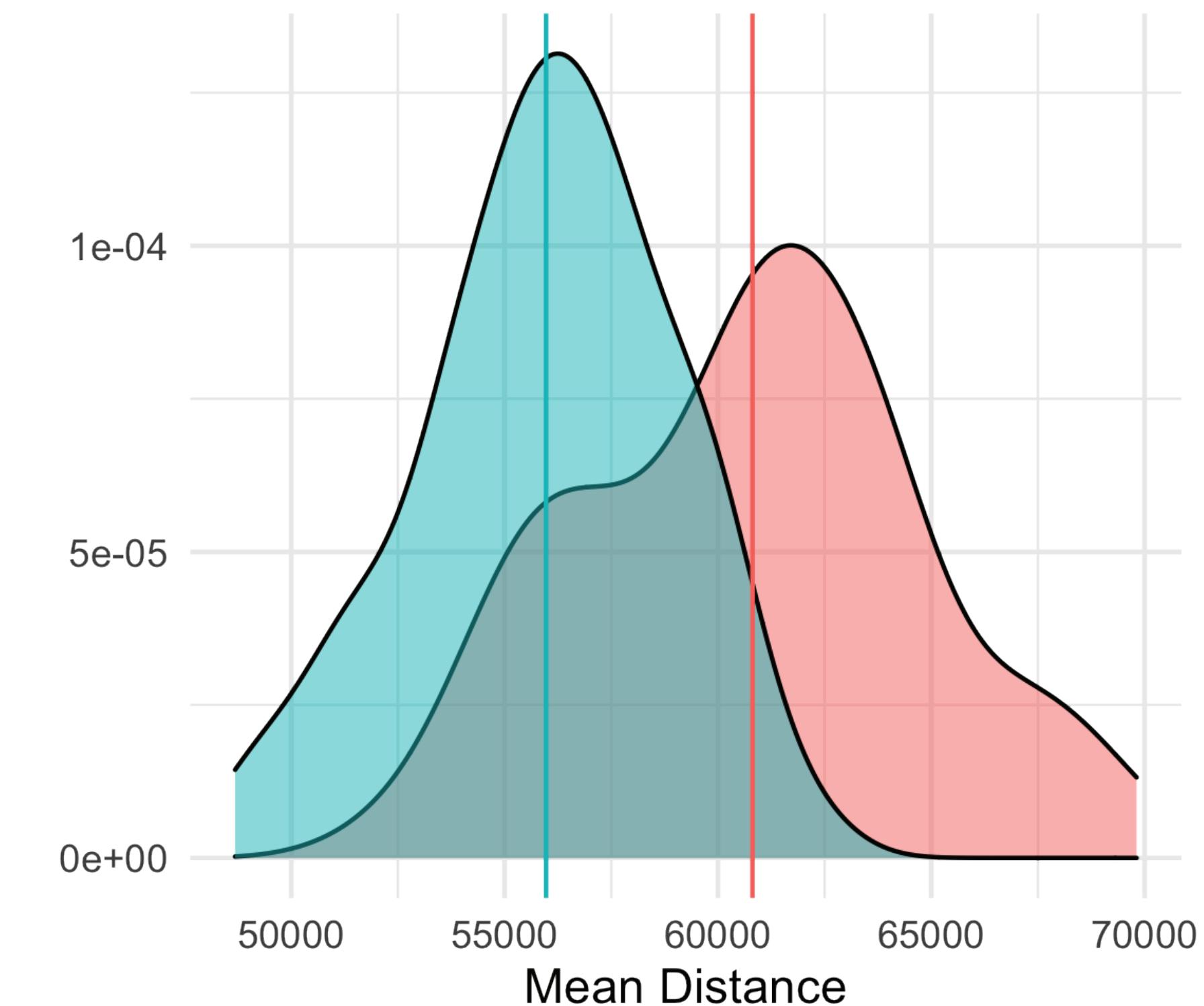
HMM



Varying coefficient model



Mean distances from simulated locations to true locations

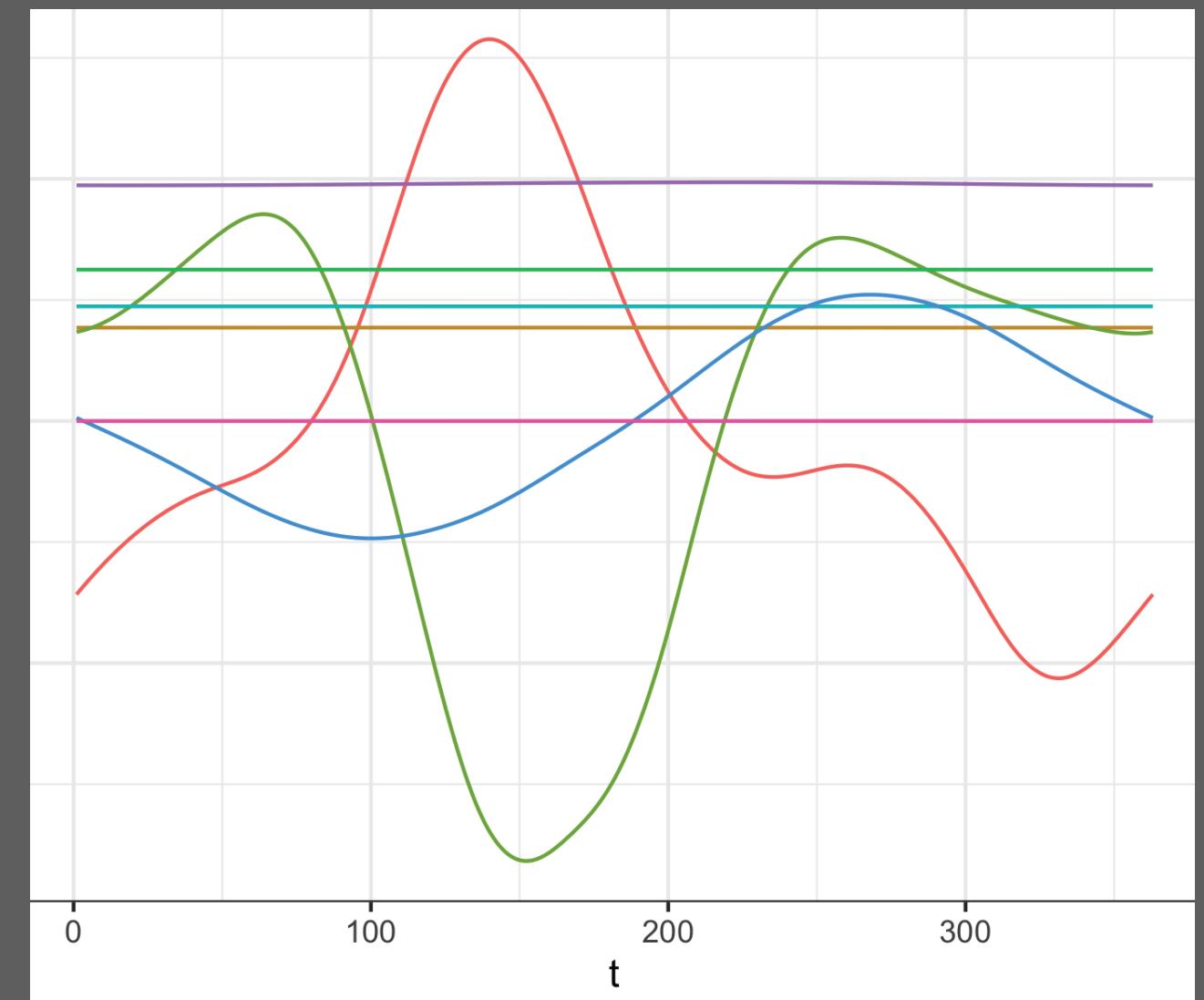
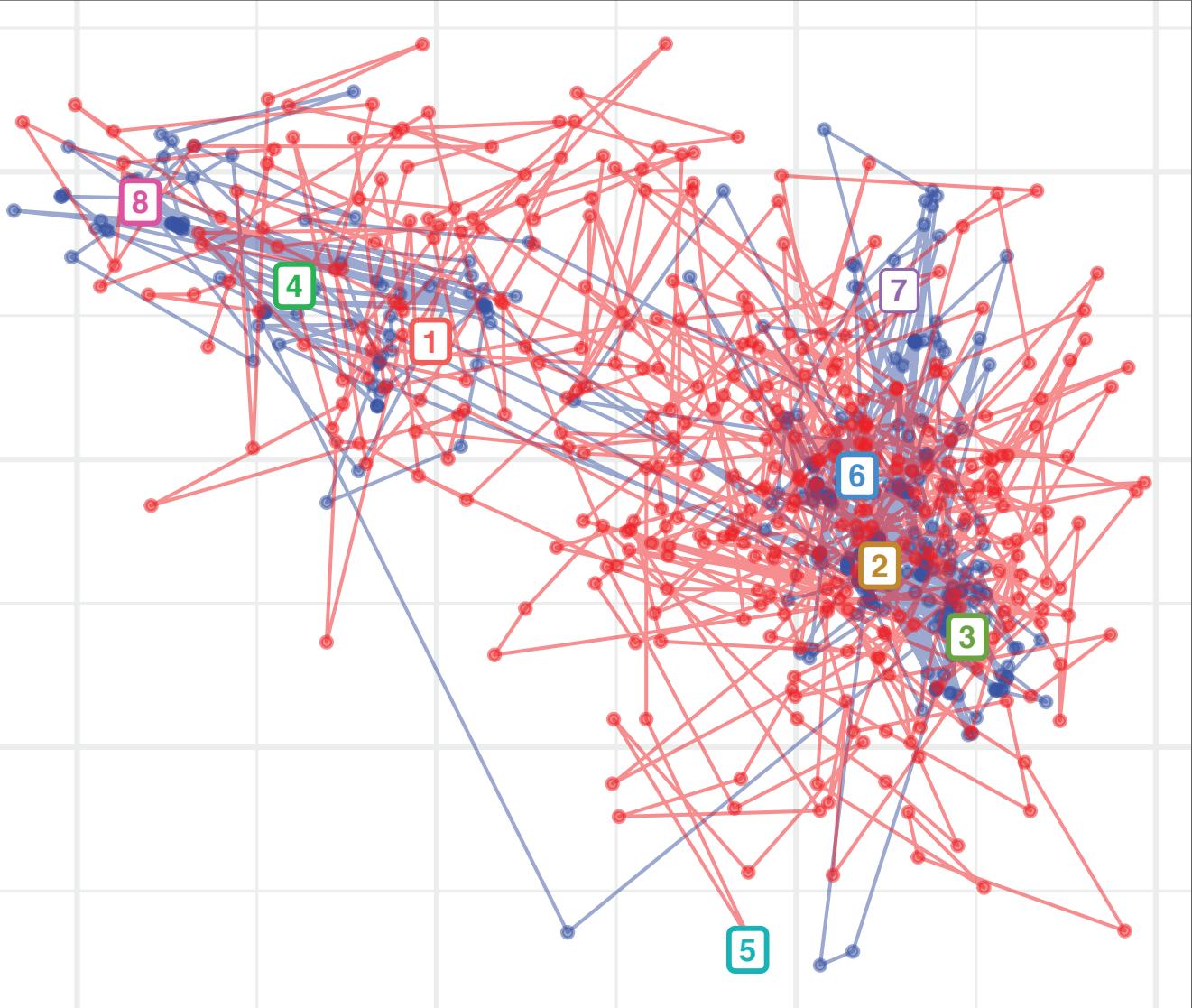


True path in blue & simulation in red

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.

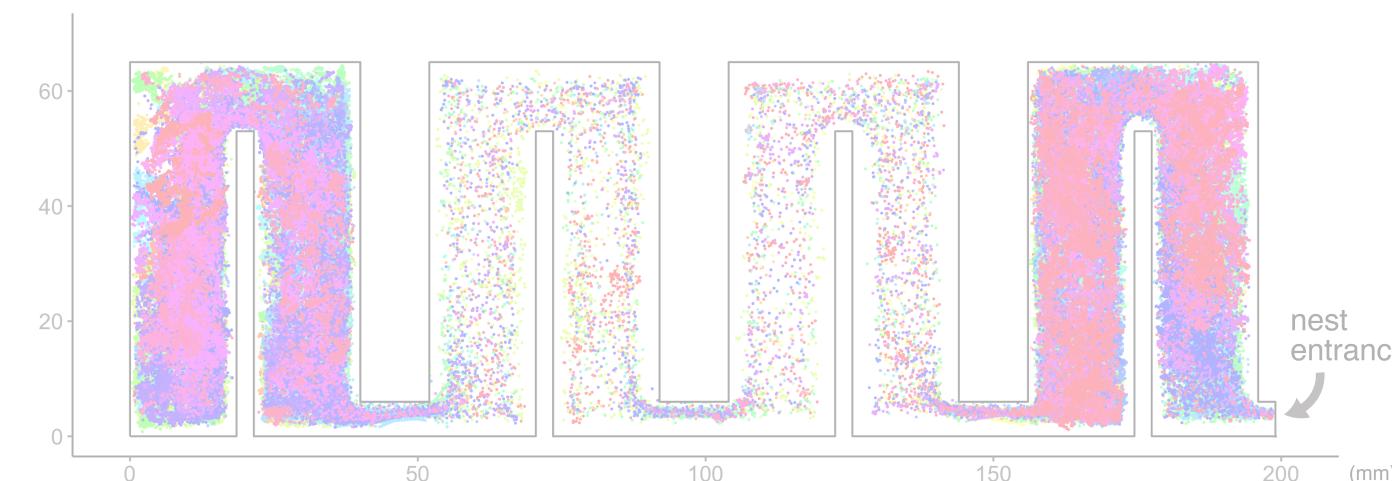
Future work: Structured population-level model



Ph.D. Research

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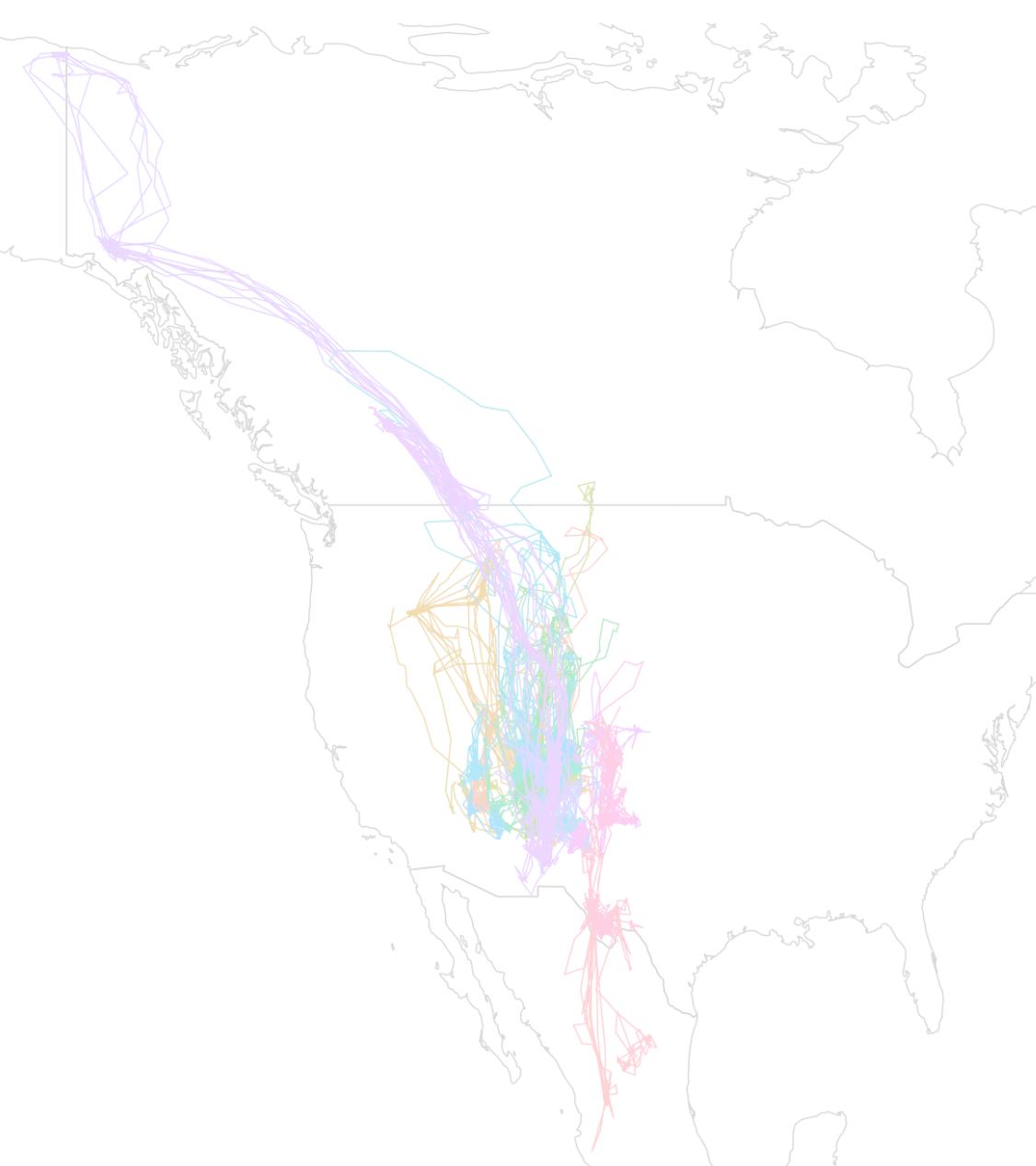
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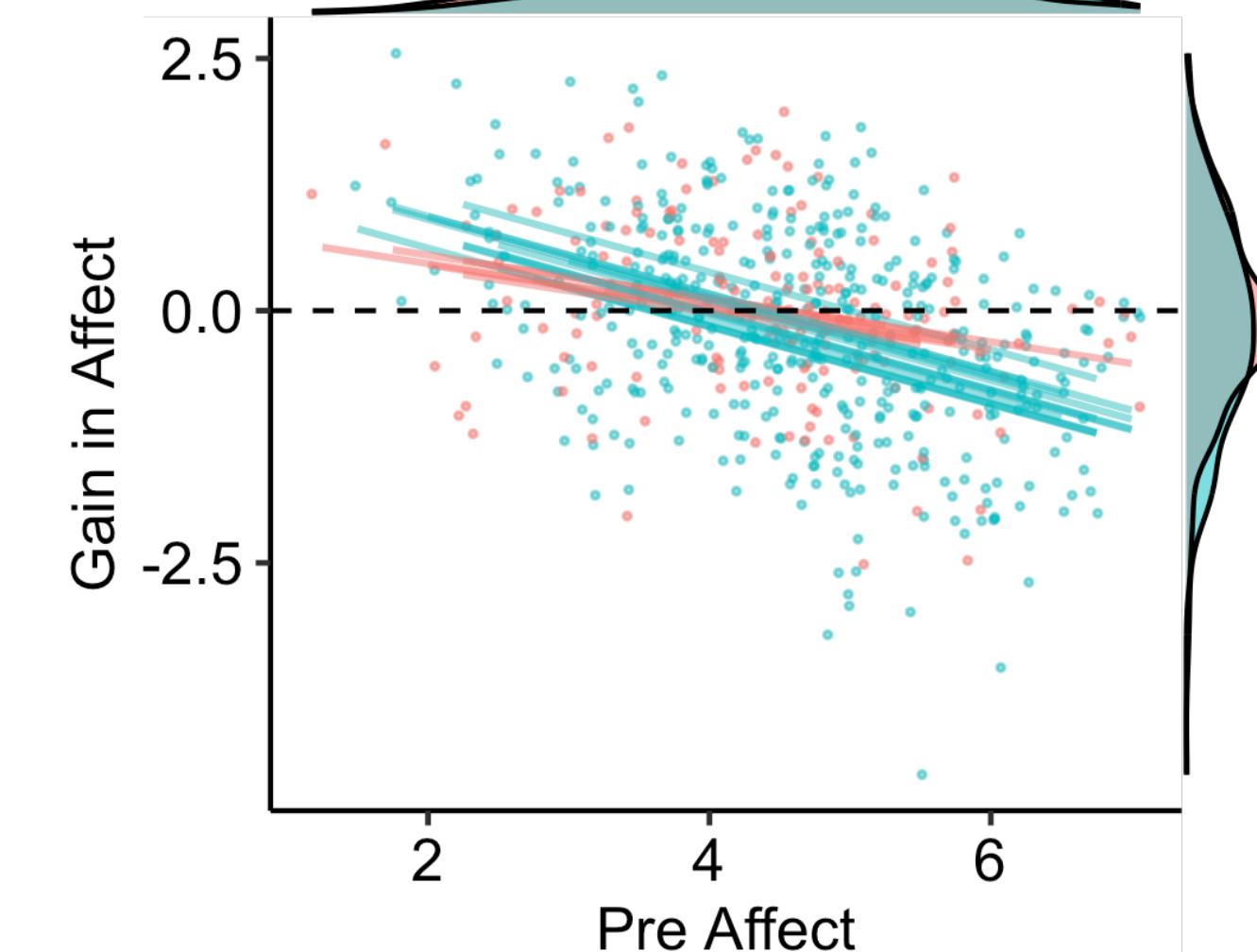
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Modeling Yearly Patterns in Golden Eagle Movement



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Survey of Probability Attitudes



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Goal: assess students' attitudes toward probability

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

How?

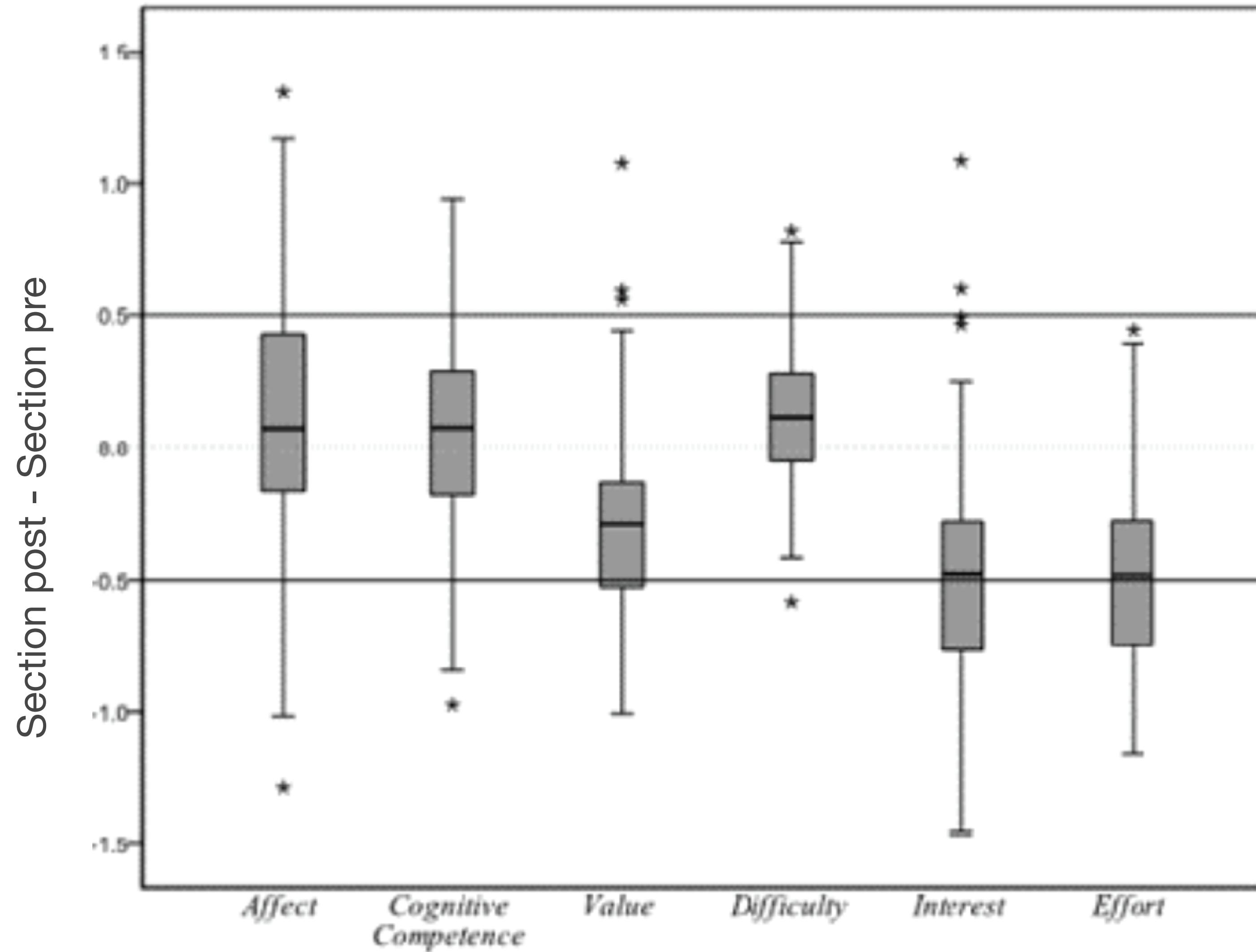
1. Adapt the existing **SATS-36** to assess probability attitudes.
2. Obtain IRB approval for the Survey of Probability Attitudes (**SPA**).
3. Administer pre & post to >586 Penn State students.
4. Validity evidence & analysis of results.

Attitude components:

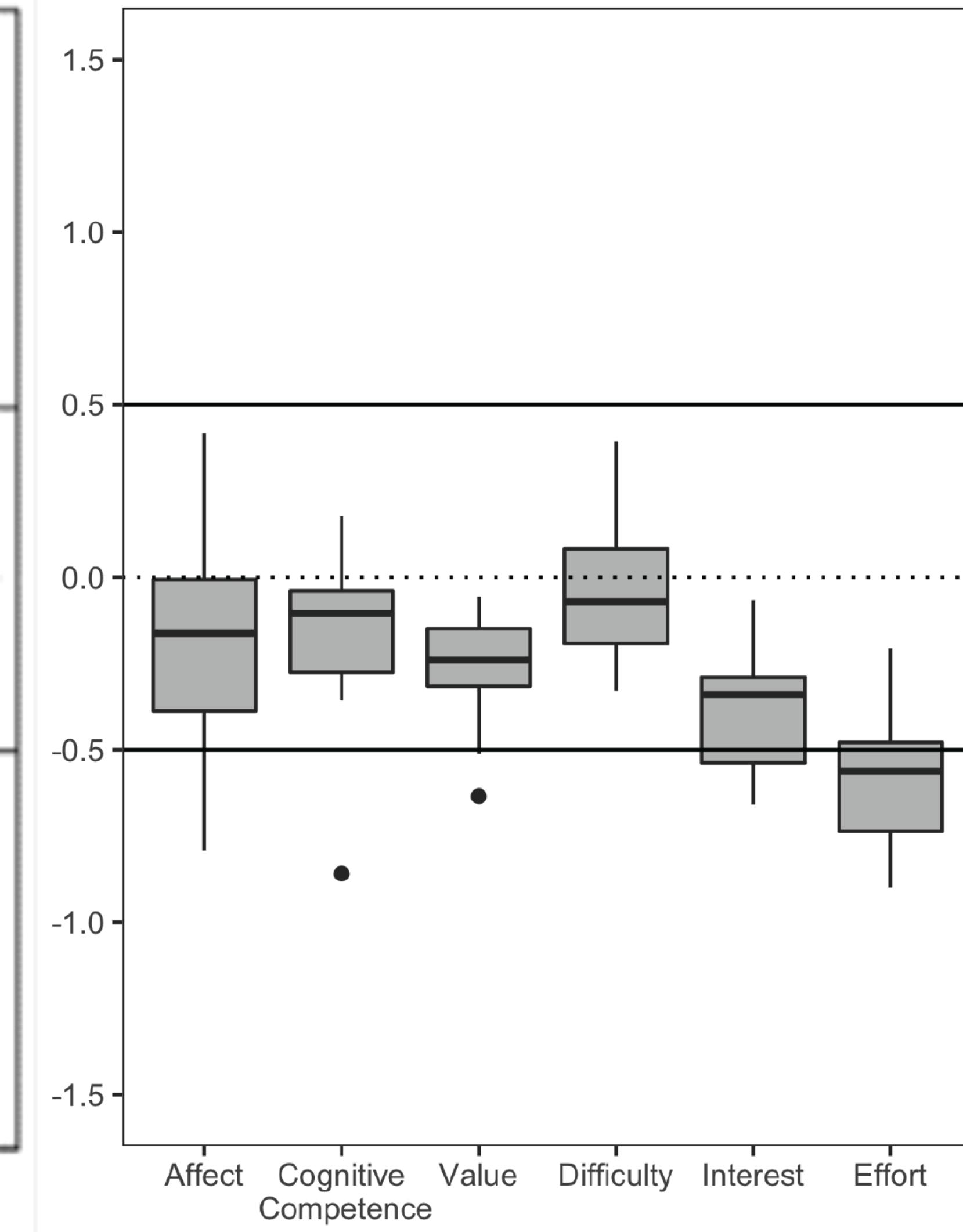
- **Affect** – students' feelings concerning probability
- **Cognitive Competence** – students' attitudes about their intellectual knowledge and skills when applied to probability
- **Value** – students' attitudes about the usefulness, relevance, and worth of probability in personal and professional 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

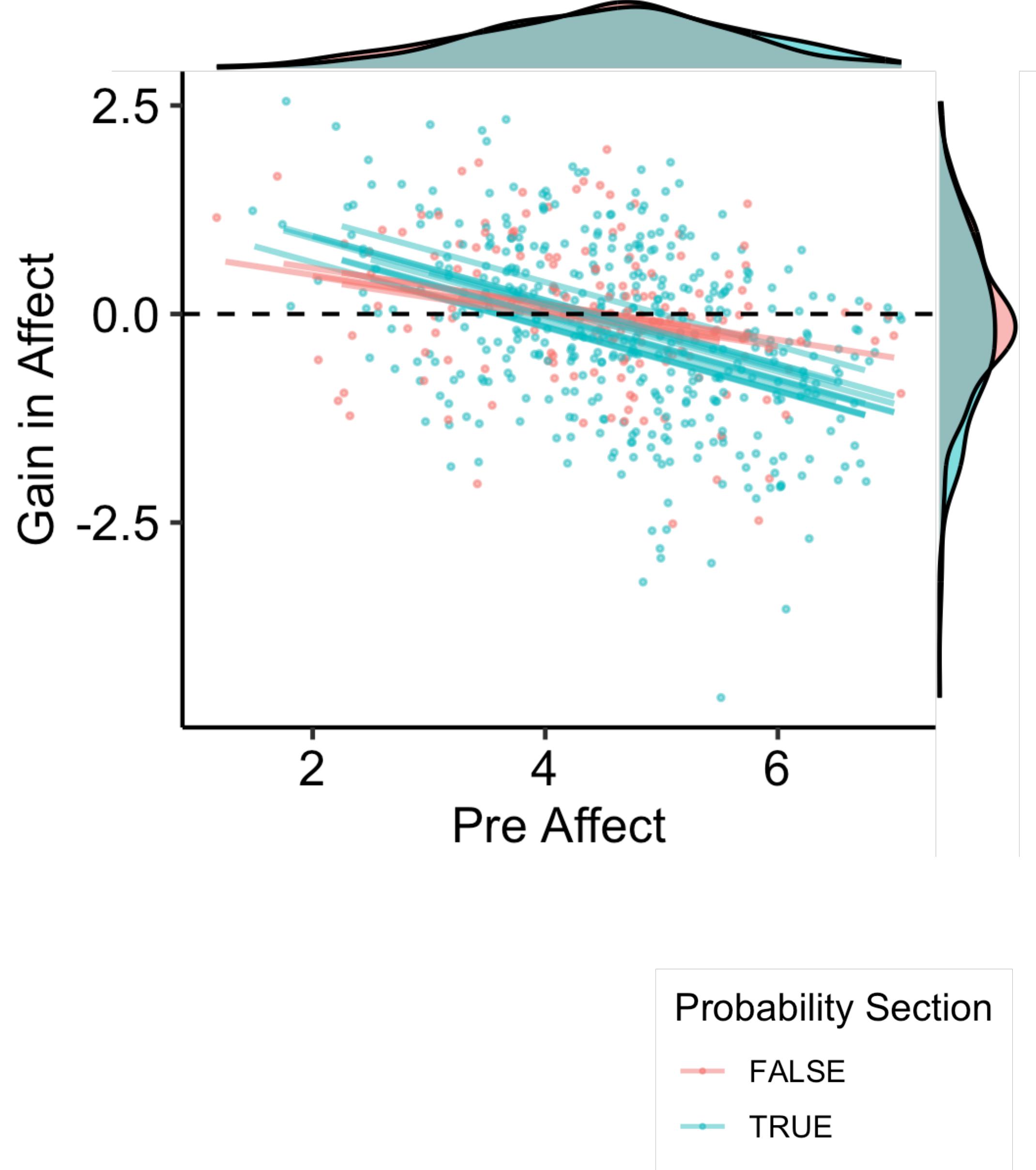


SPA

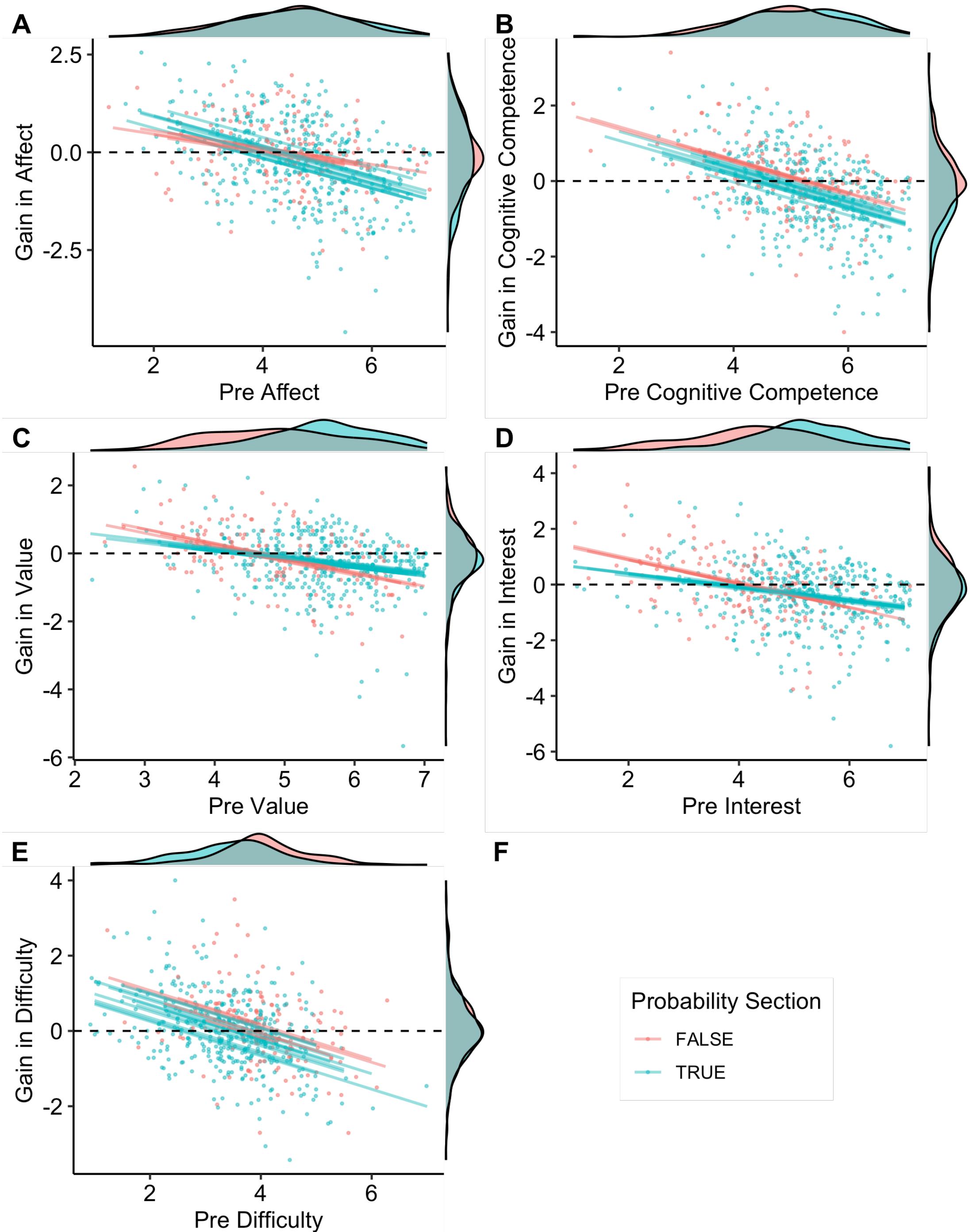


(used with permission from Schau and Emmioğlu, 2012)

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



1. Strong evidence of the **validity** of the SPA for the intended use.
2. **No evidence of improvement 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:

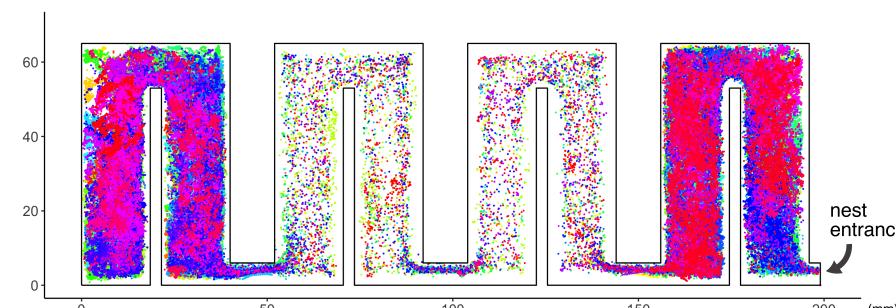
- the import of using a **control group** for attitude studies
- future survey iterations should be **more sensitive** to small attitude changes
- desired attitudes toward probability should **inform teaching methods**

Thank you.

Elizabeth Eisenhauer
eisenhauer@psu.edu

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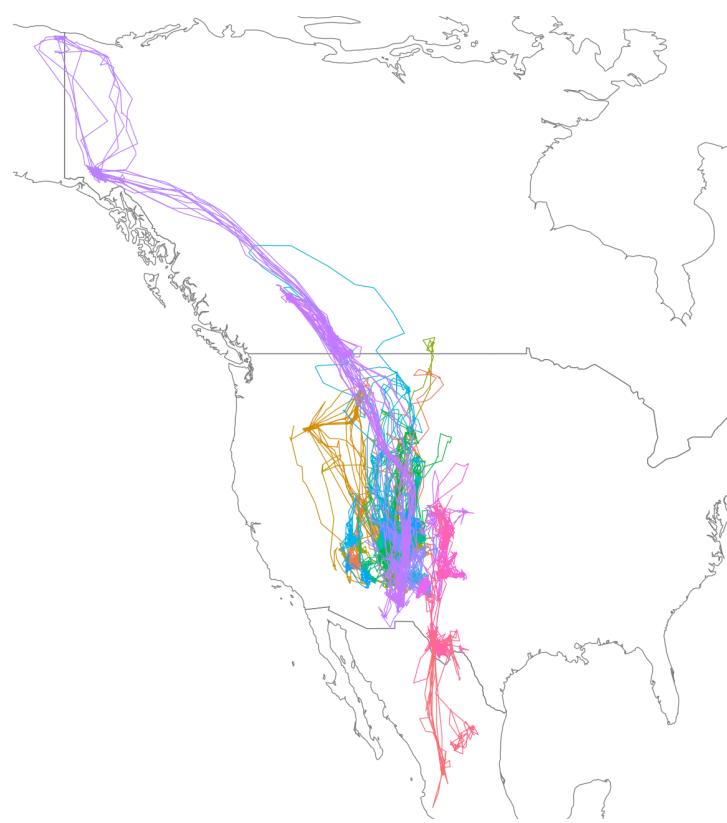
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