

MARE-Madeira 2025



# *Habitat-informed home ranges*

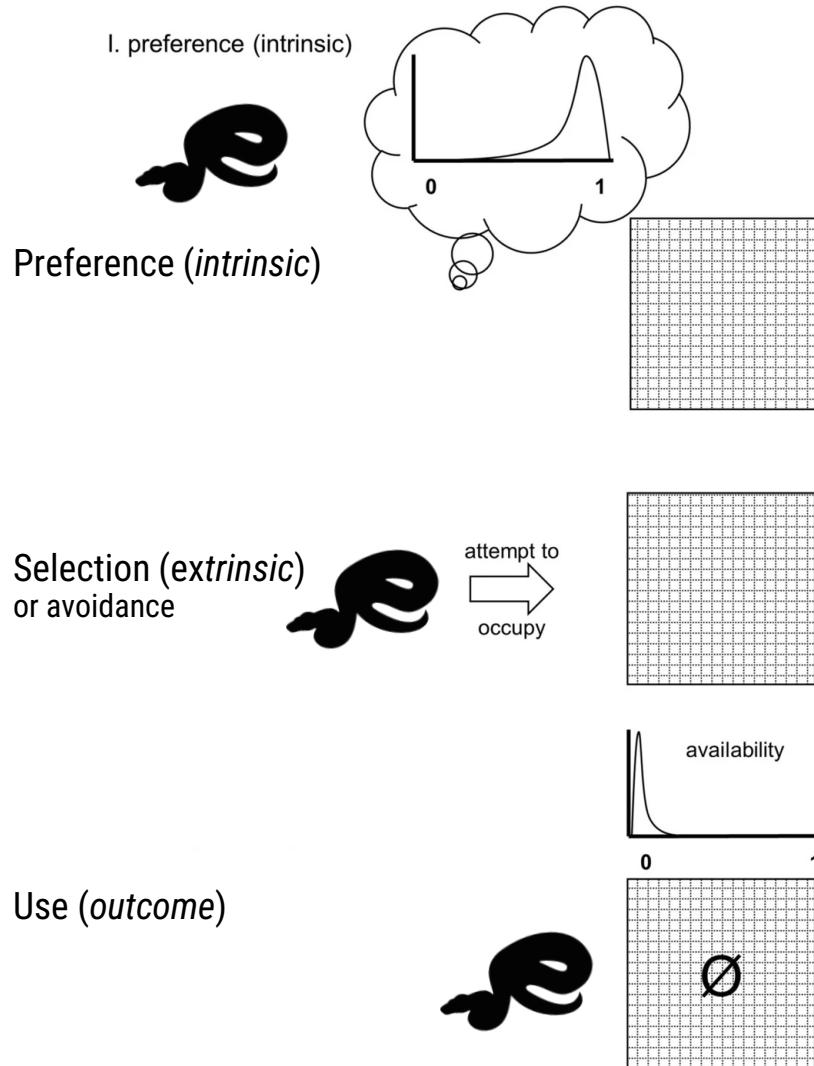
Using the '`ctmm`' R package

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# Introduction



## Hypotheses

### King Cobra (*Ophiophagus hannah*)

~ select for semi-natural habitat.

~ select for forest habitat.

### Burmese Python (*Python bivittatus*)

~ select for areas near water.

### Malayan Krait (*Bungarus candidus*)

~ select for buildings and natural areas.

### Banded Krait (*Bungarus fasciatus*)

~ select for waterways and field edges.

 Marshall et al. (in prep)

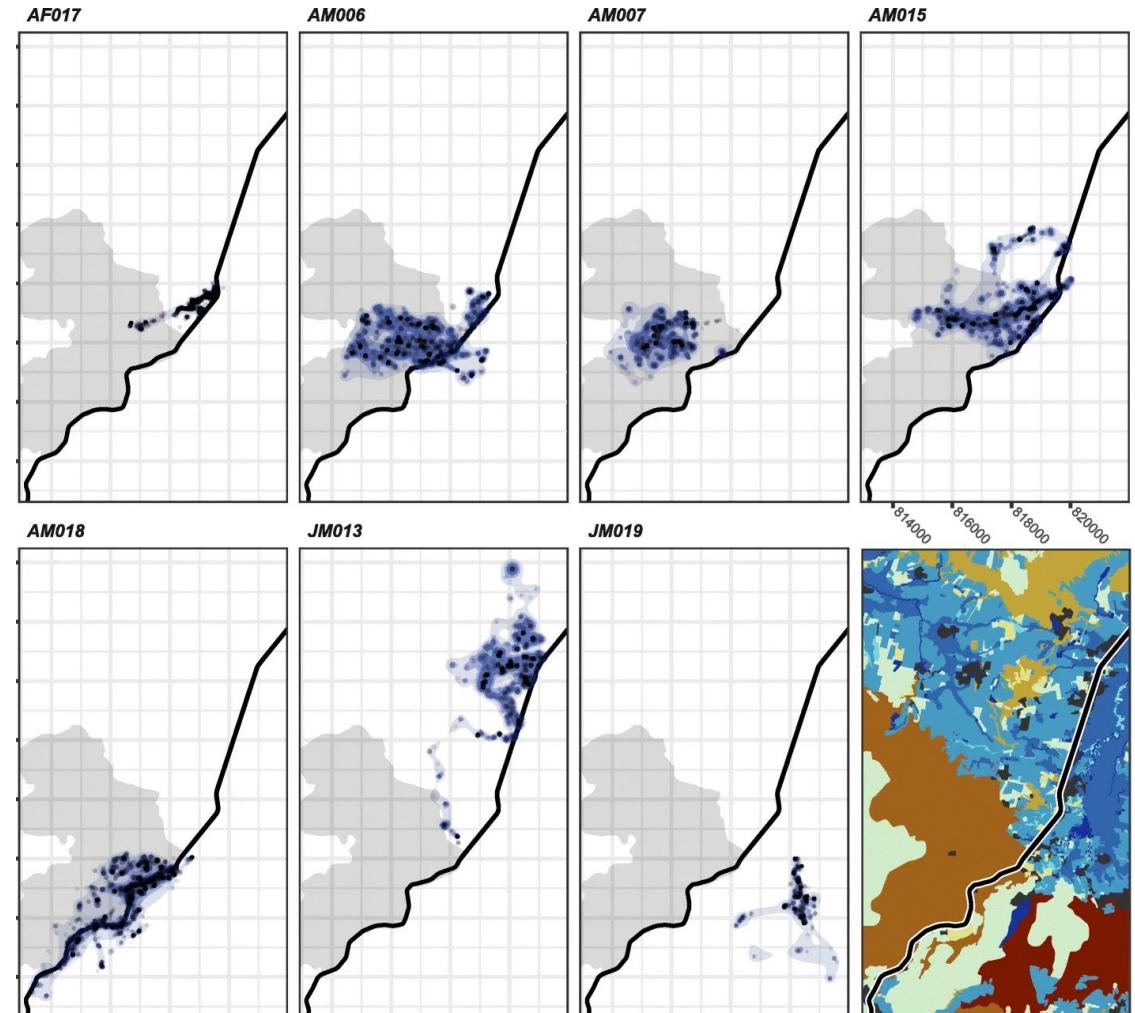


# Introduction



“What **landscape features** do animals seek or avoid?”

“In which areas of the landscape are animals at **risk**? ”

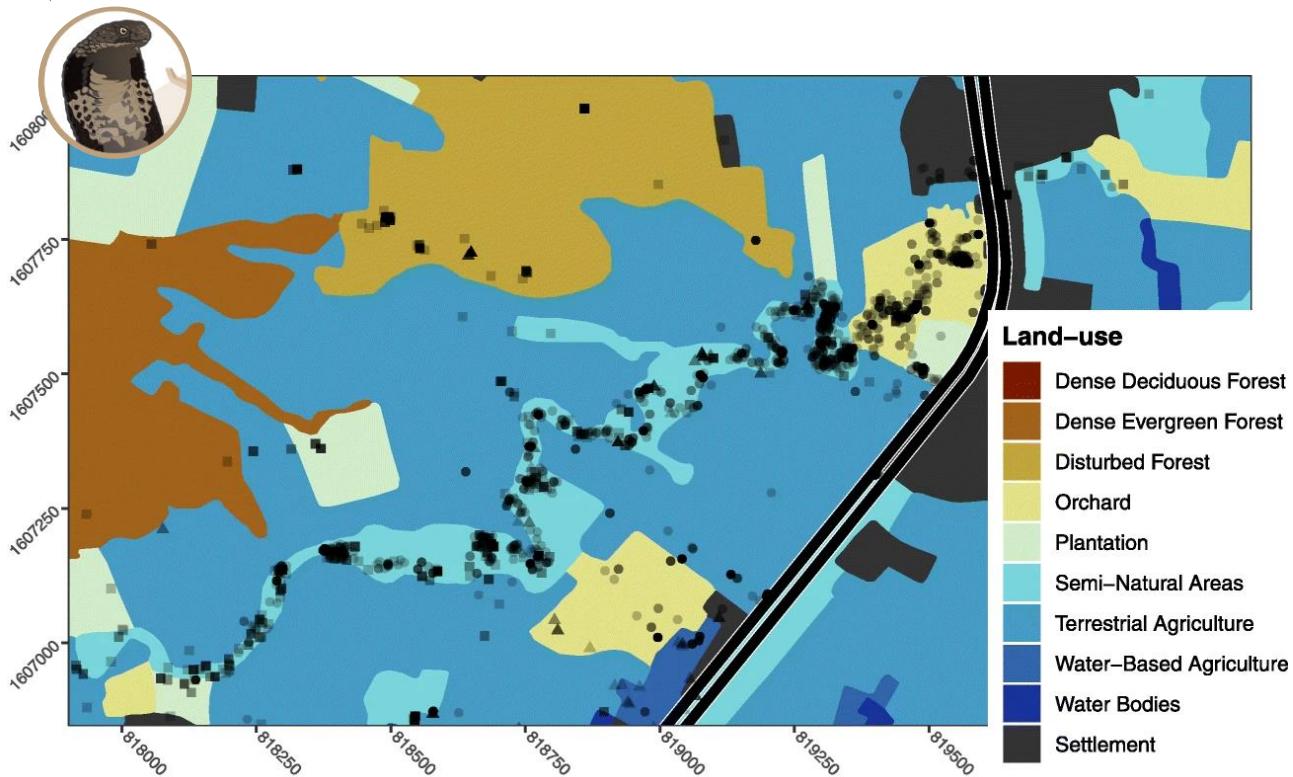


Marshall et al. (2020)

DOI: 10.1186/s40462-020-00219-5



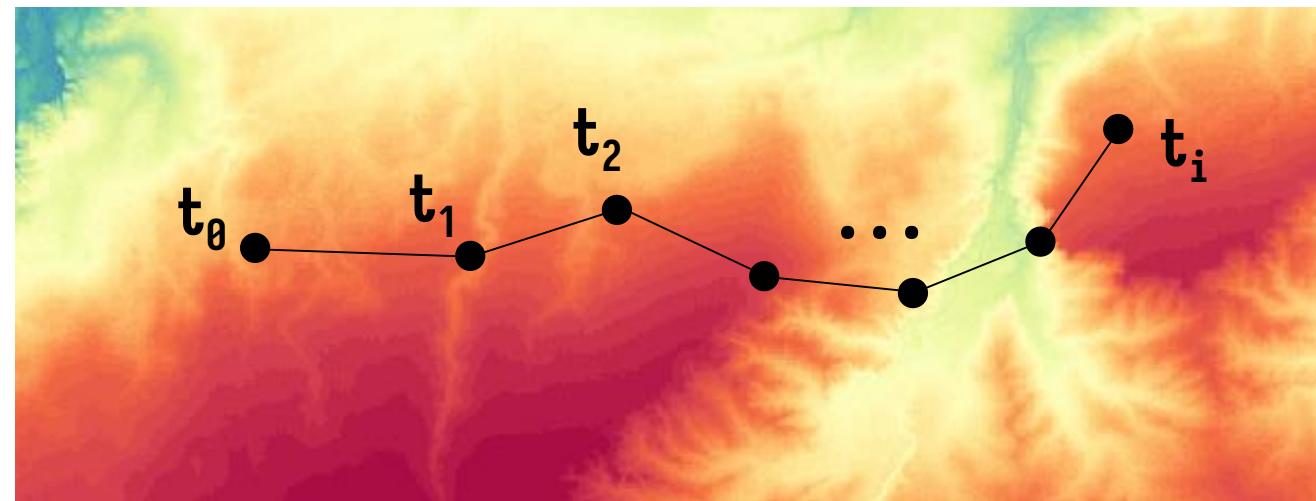
Reliance on **semi-natural areas**,  
compared to the surrounding **matrix of agricultural fields**.



**Marshall et al. (2020)**  
DOI: 10.1186/s40462-020-00219-5

≈ acting as movement corridors through the fragmented landscape.

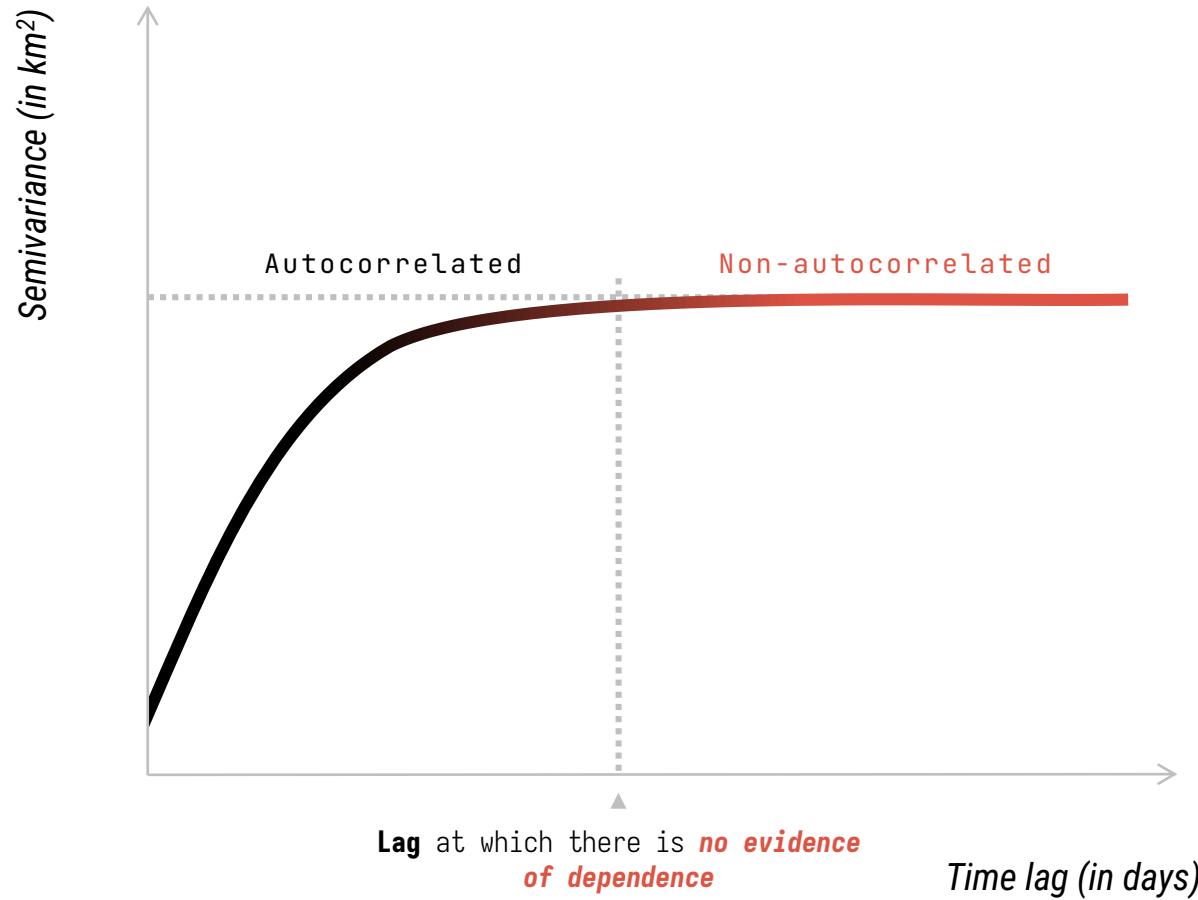
Assumes that successive positions are **independent**. However, ...



An animal's location at time  $t_i$  is a function of both resource selection and its location at time  $t_{i-1}$ .

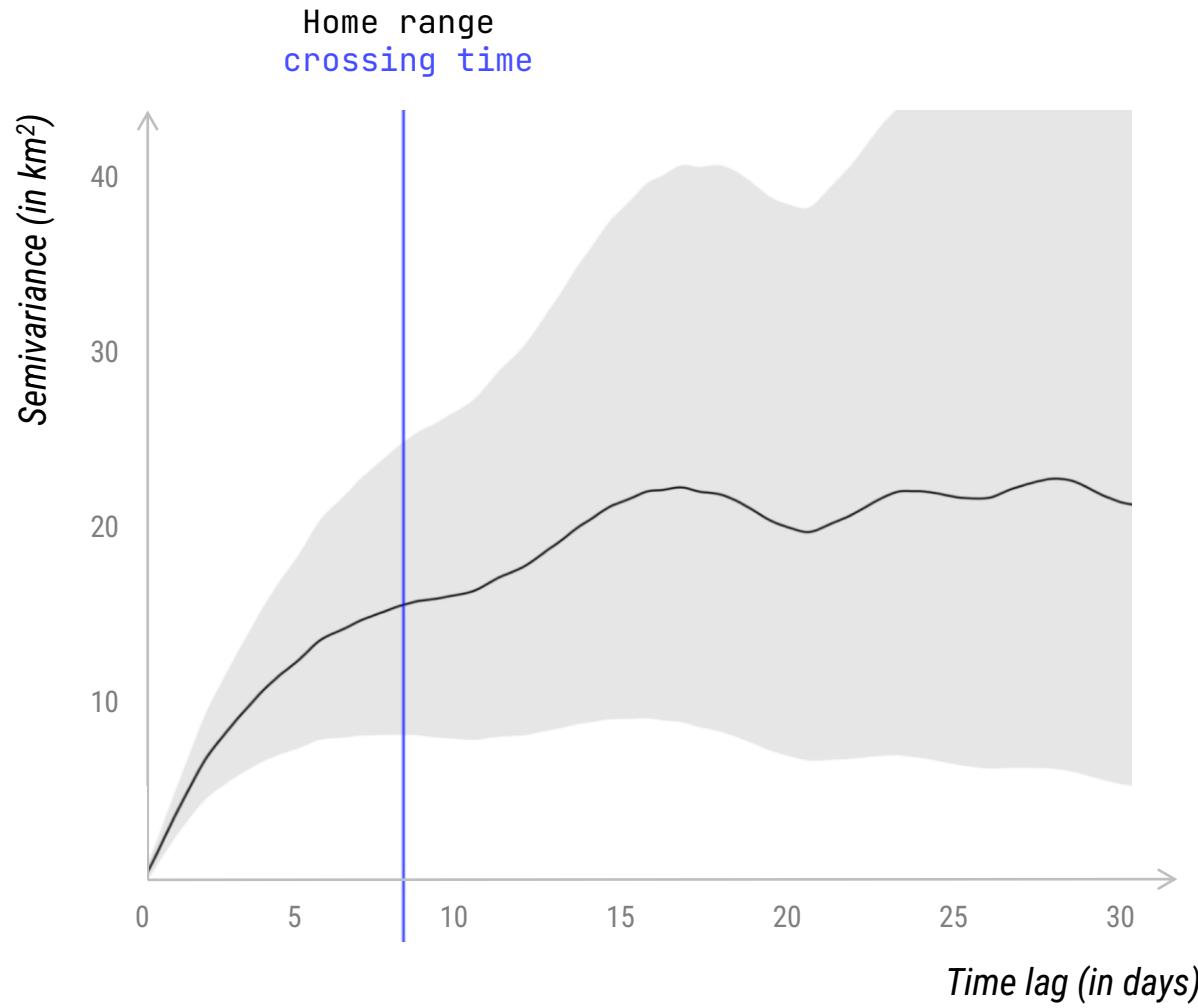


## Resource selection functions





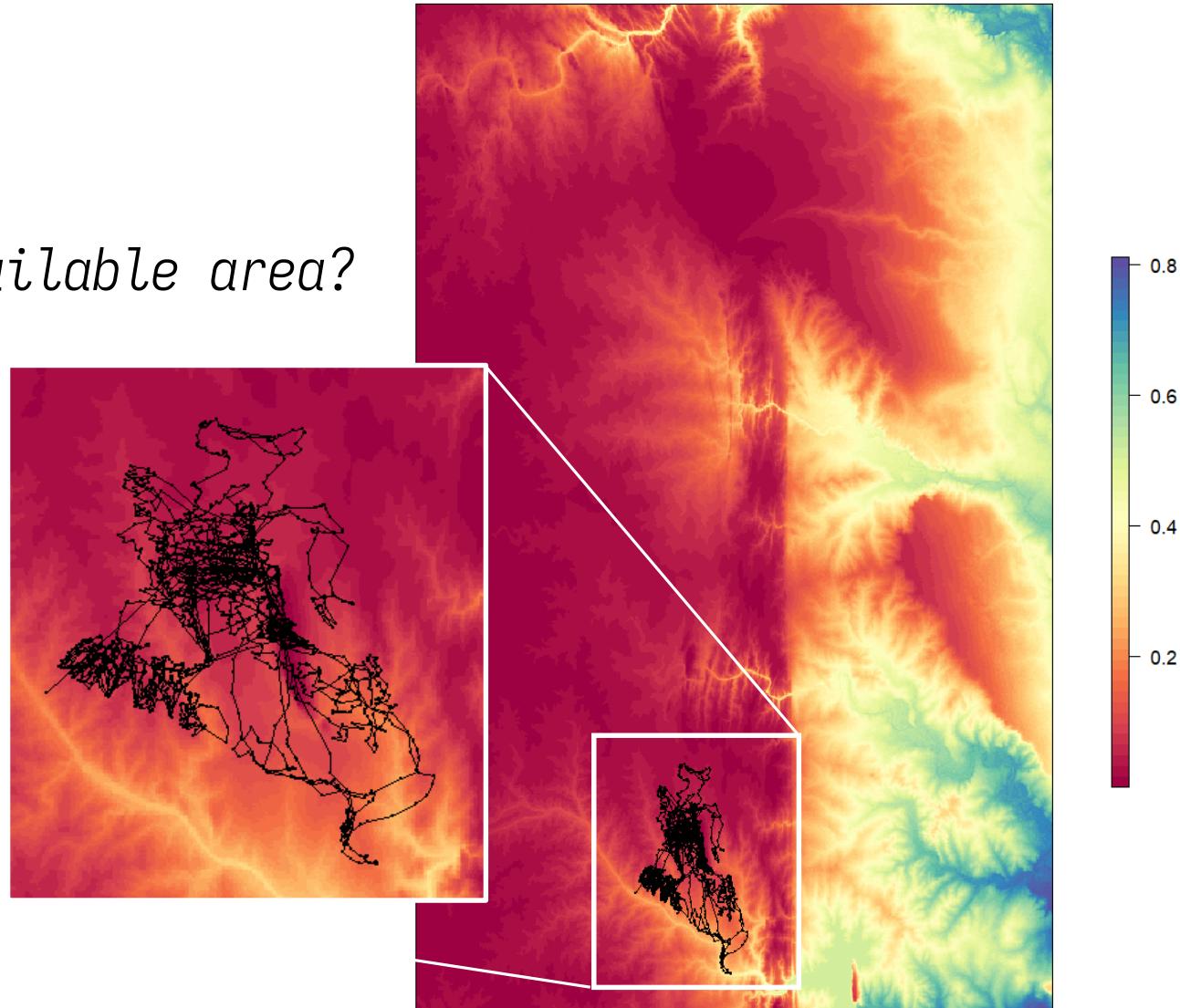
## Resource selection functions



Lag > **blue**, we are fulfilling the assumptions of RSF.

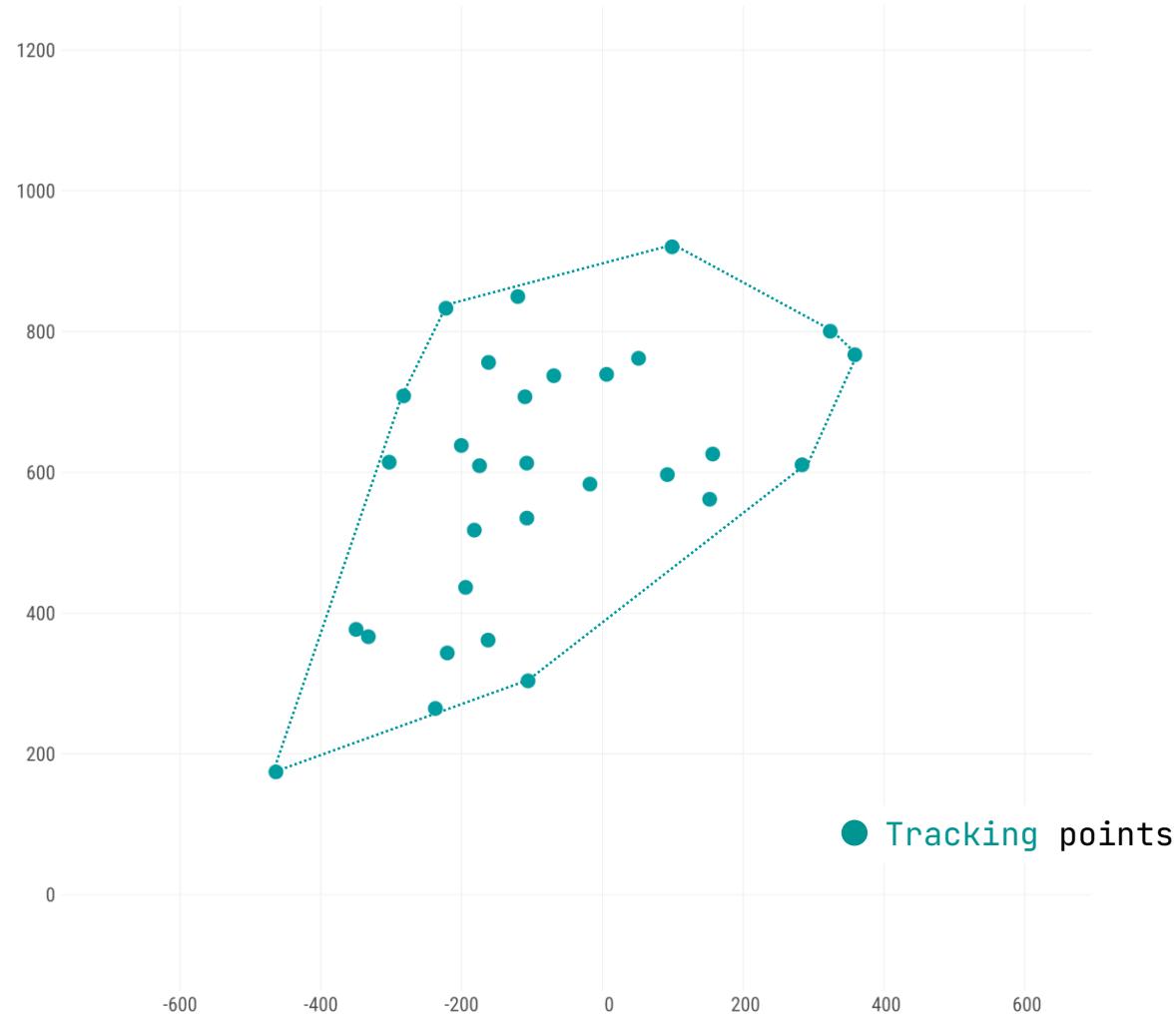


What is the available area?



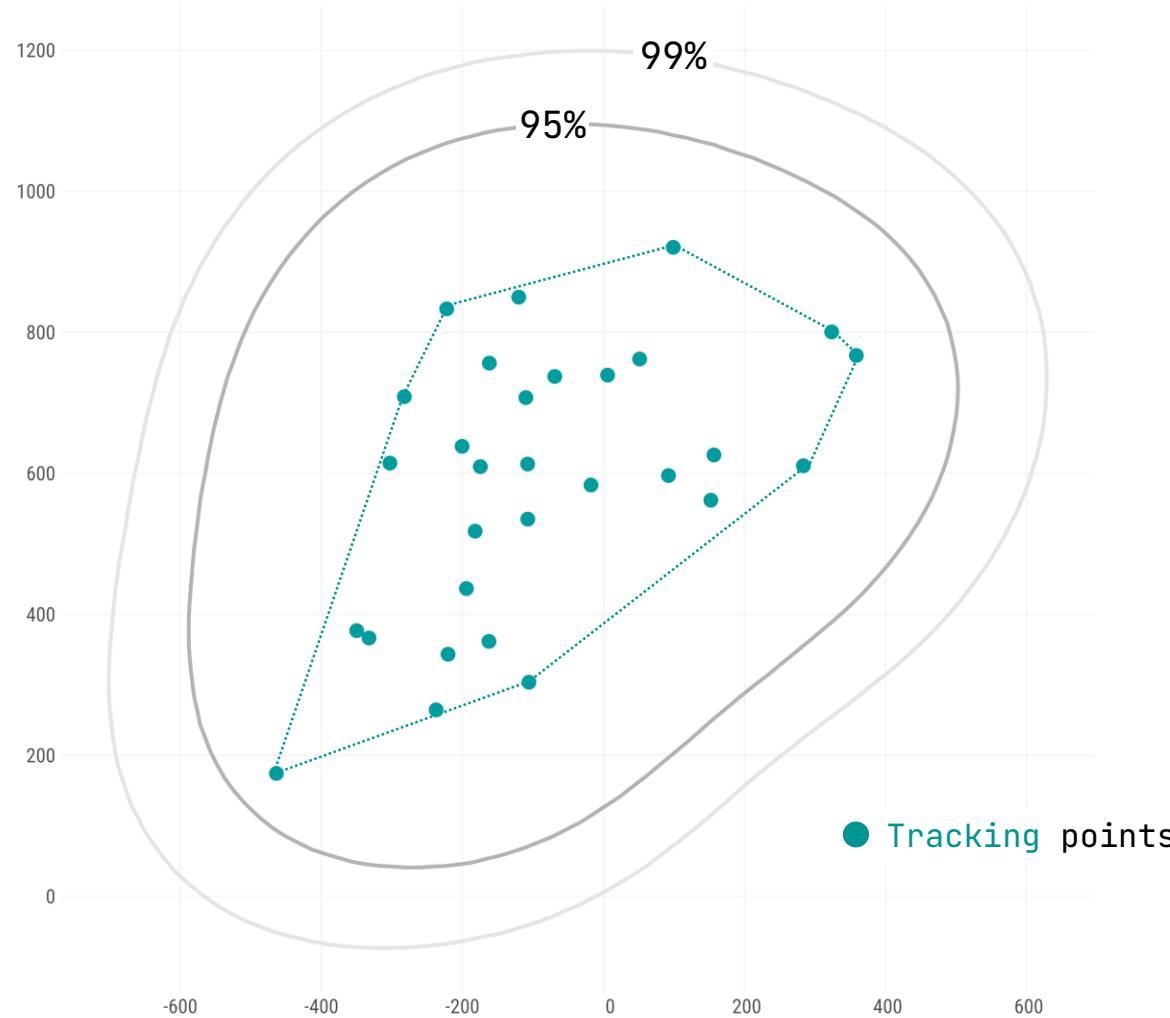


## Resource selection functions



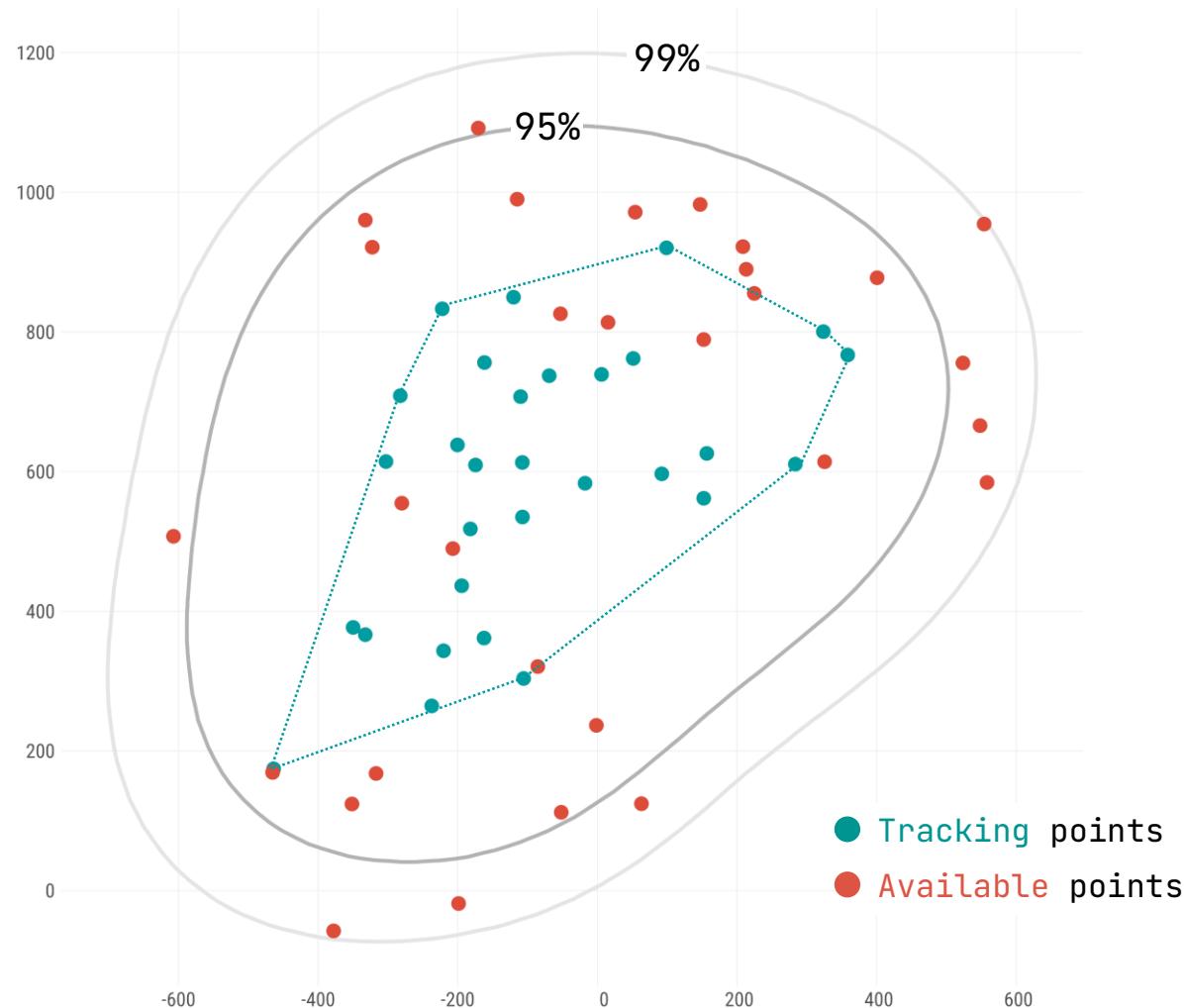


## Resource selection functions





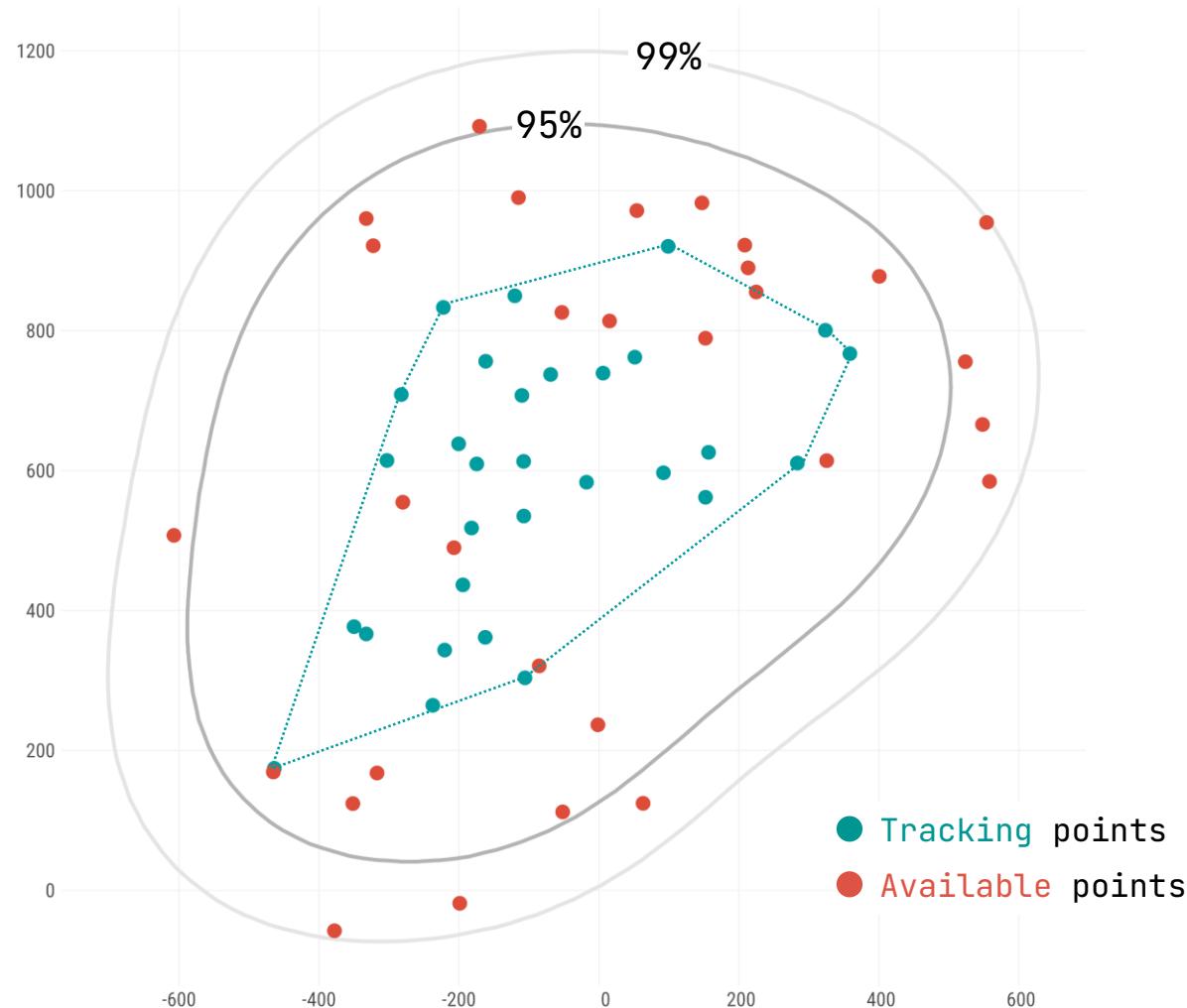
## Resource selection functions



Framed as comparing data to  
*random available* points.



## Resource selection functions



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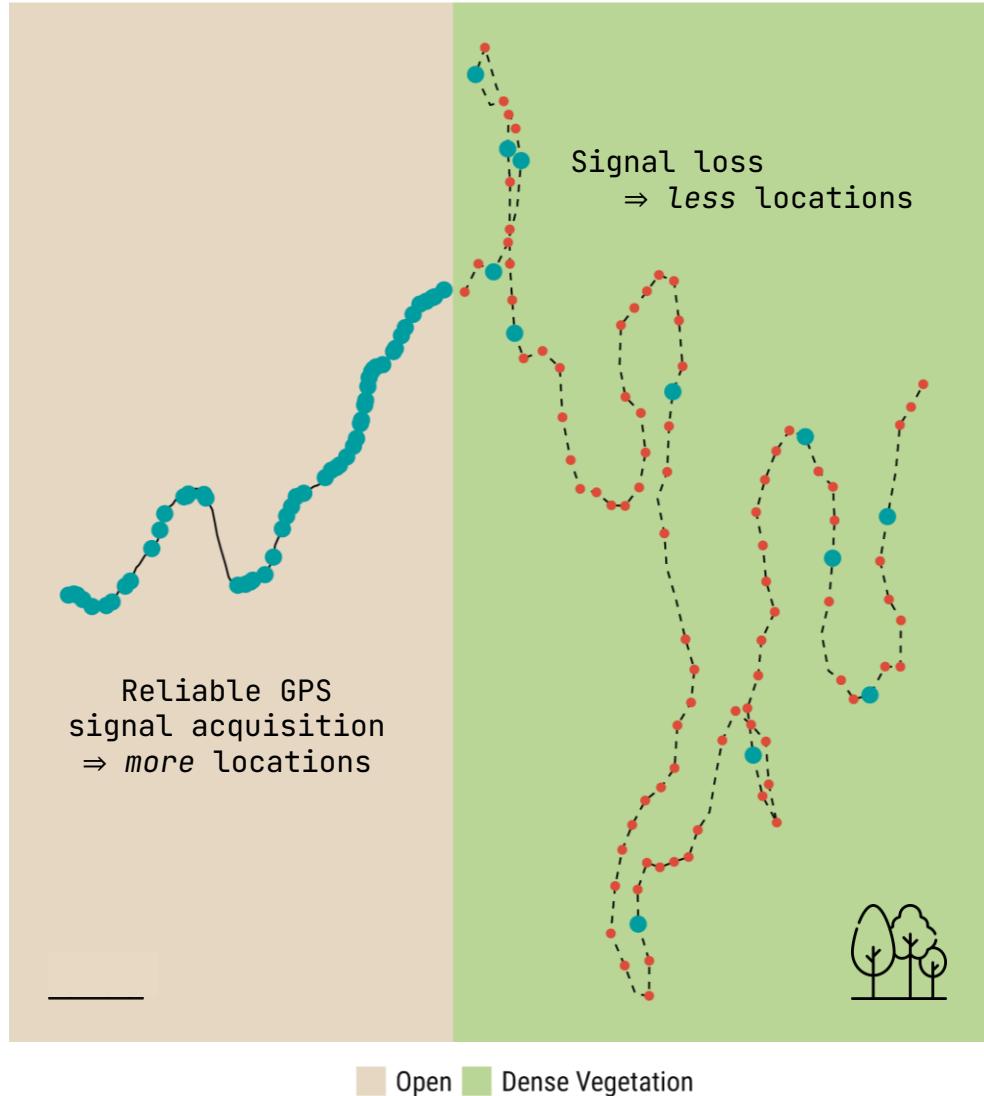
However,

Available locations are *not* directly estimated, and depend on arbitrary choices (e.g., MCP, 99% home range area).

RSF results can be *sensitive* to how availability is defined.

*Uncertainty* in the available area is not propagated into the RSF models.

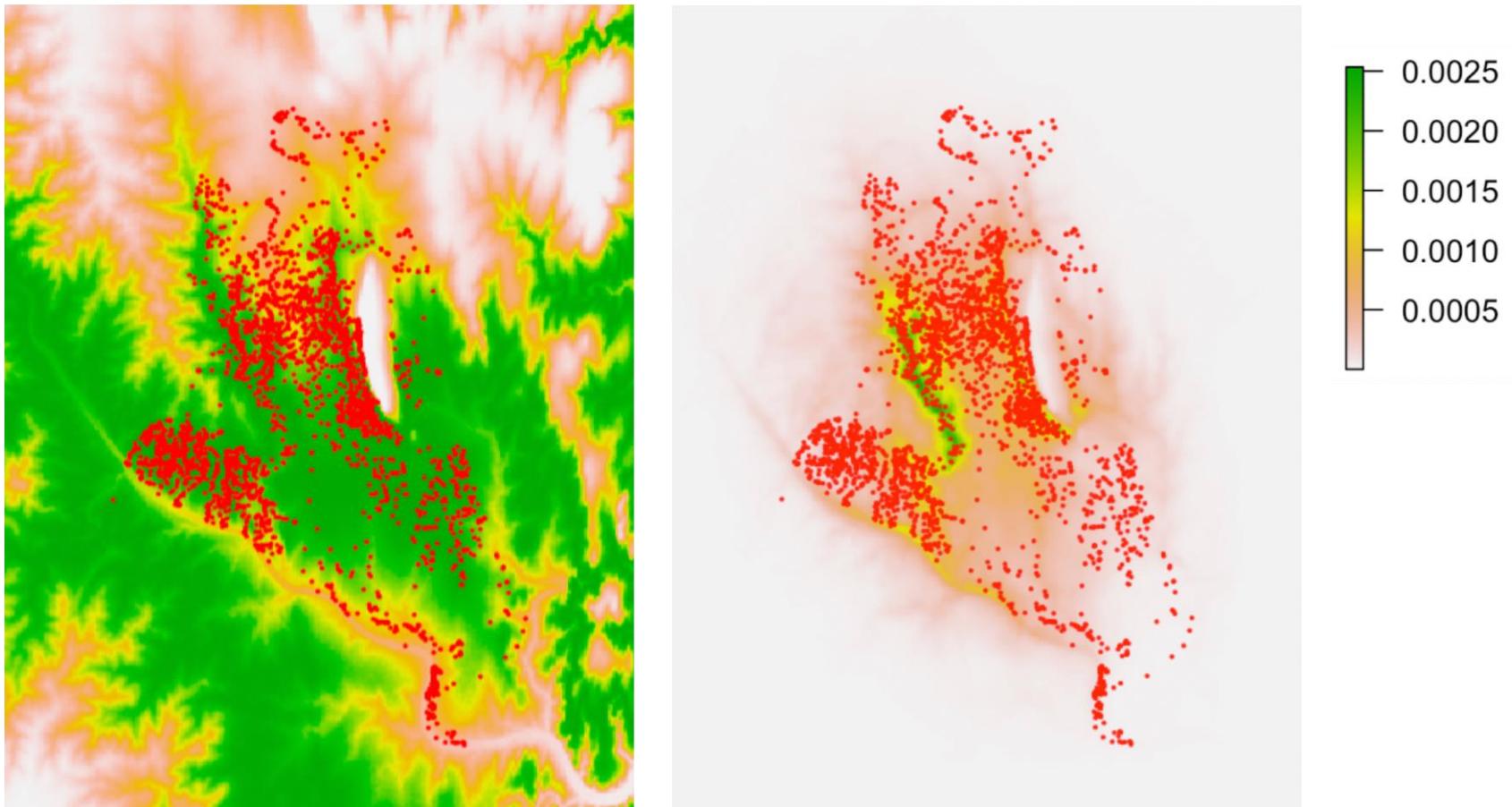




Failing to account for autocorrelation is more problematic if environmental covariates (e.g., **dense vegetation**) cause non-random data gaps.

*What is the available area?*

We estimate the available area in a **Poisson Point Process model**.



## Conventional RSFs

Statistical issues:

1. No checks for numerical convergence  
*inconsistent parameter estimates*
2. Assume IID data  
*spurious “significant” results*
3. Assume uniformly weighted data  
*can result in spurious results for,  
e.g., habitat-dependent triangulation failure*
4. Assign a uniform distribution to available points  
*disregards movement process*

## Integrated RSFs

Solutions:

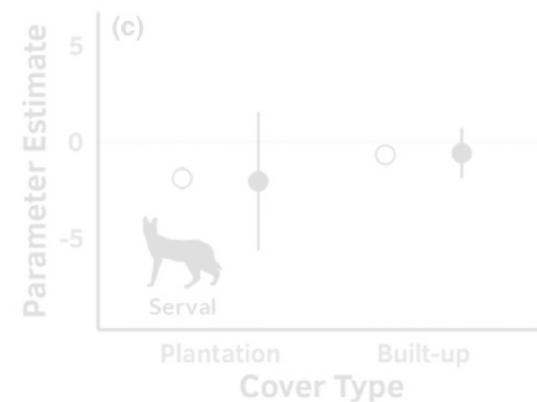
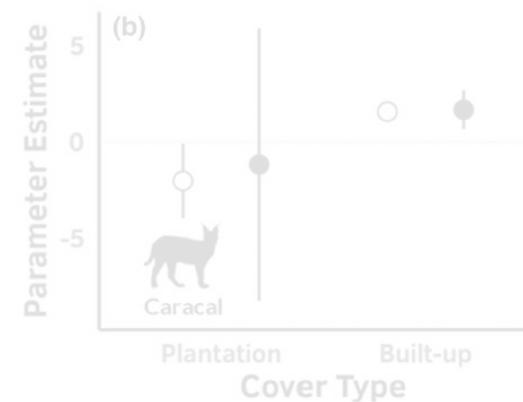
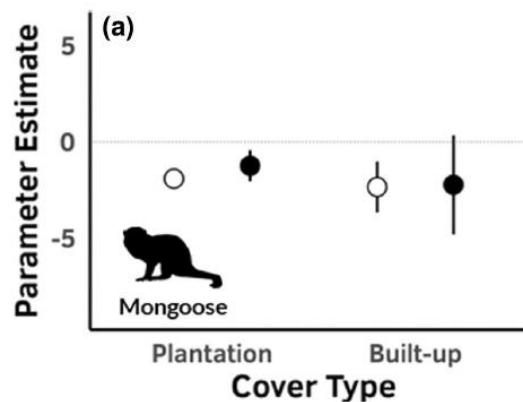
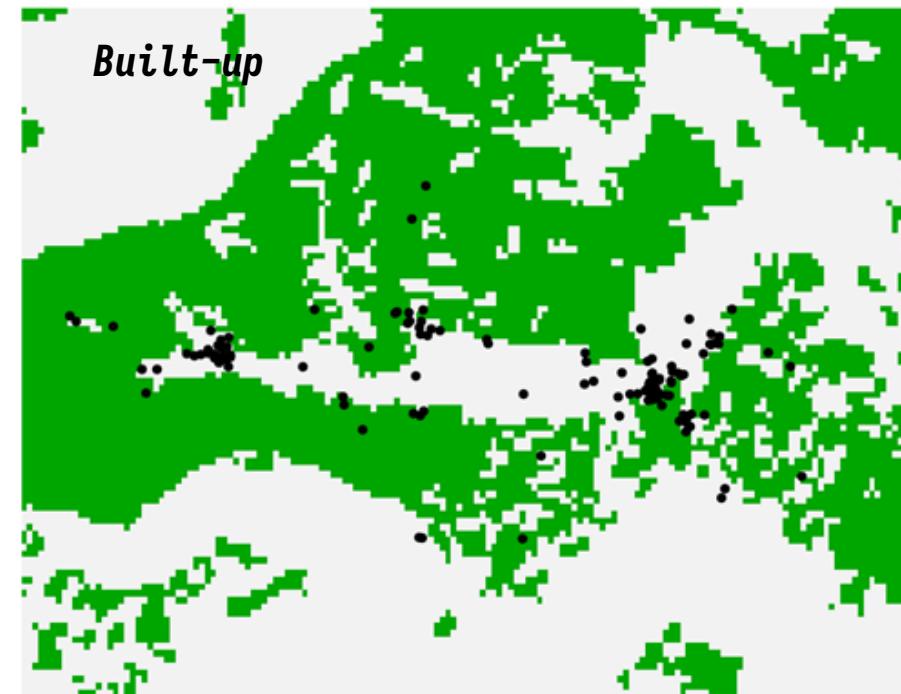
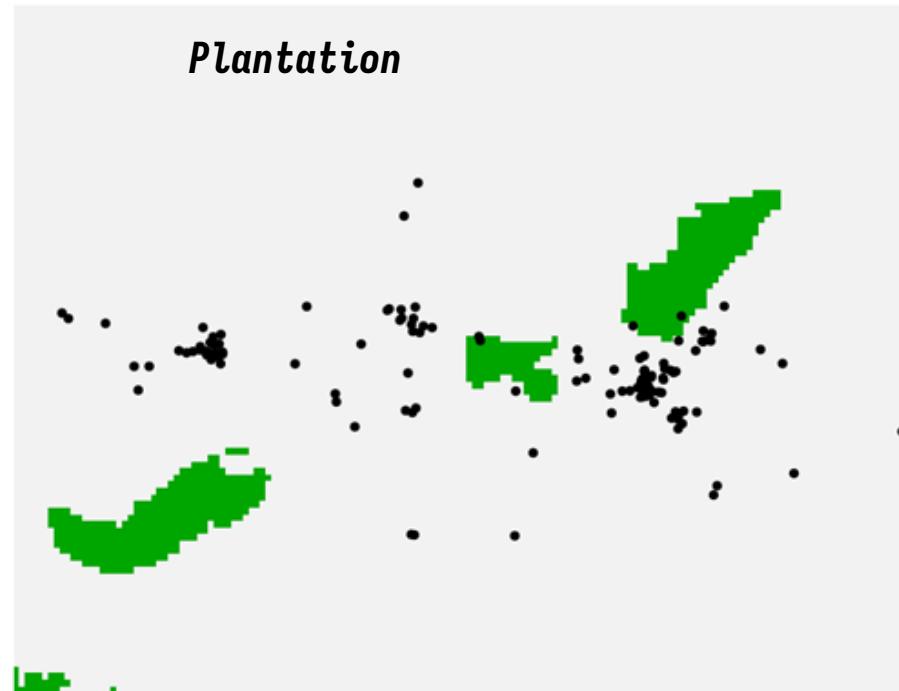
1. Automatically checks for numerical convergence
2. Down-weights data to reduce pseudoreplication
3. Re-weights data to mitigate differential autocorrelation
4. Samples availability according to null movement process



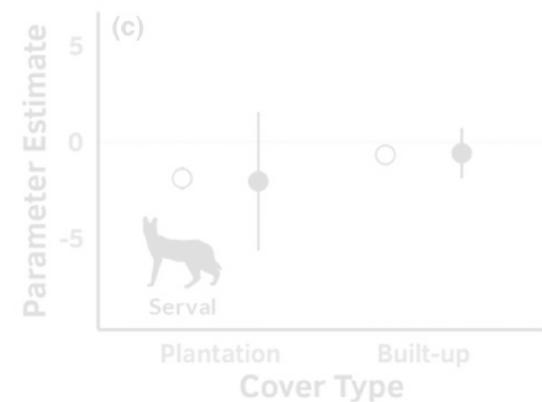
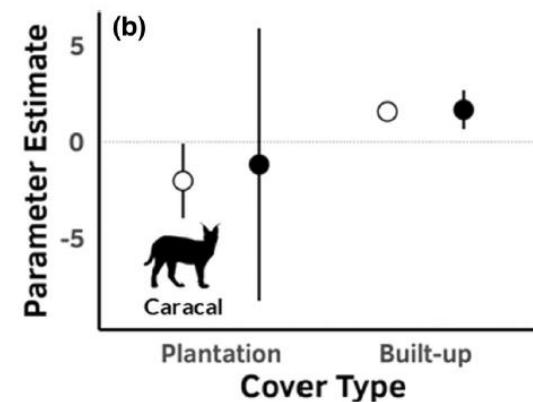
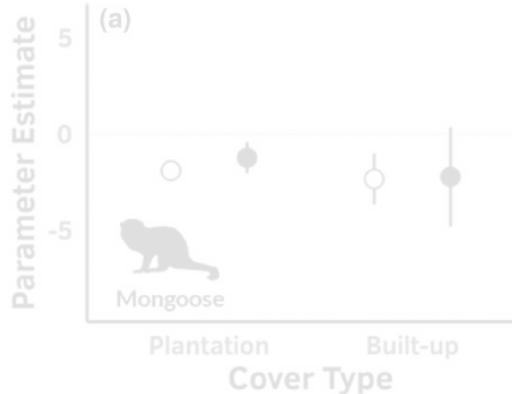
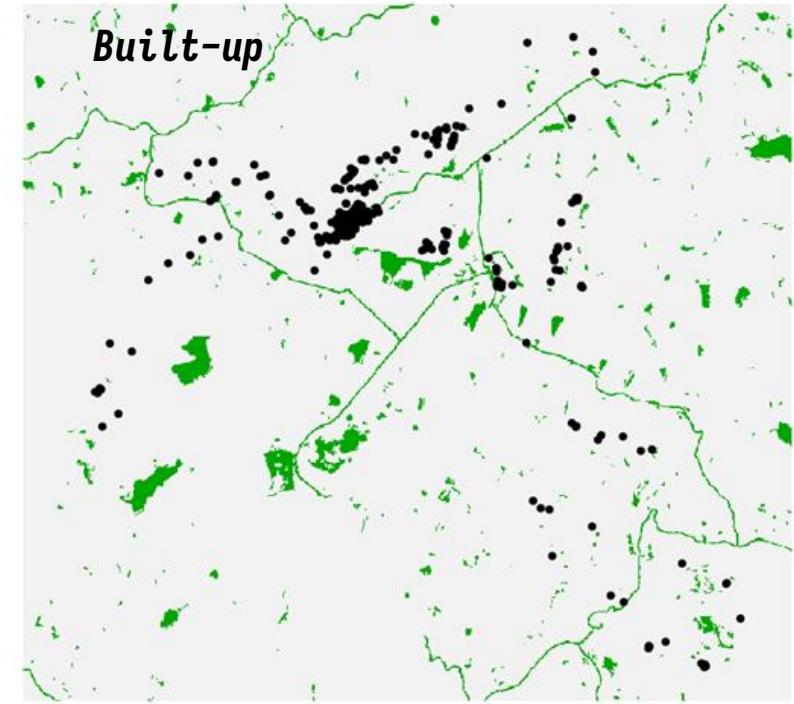
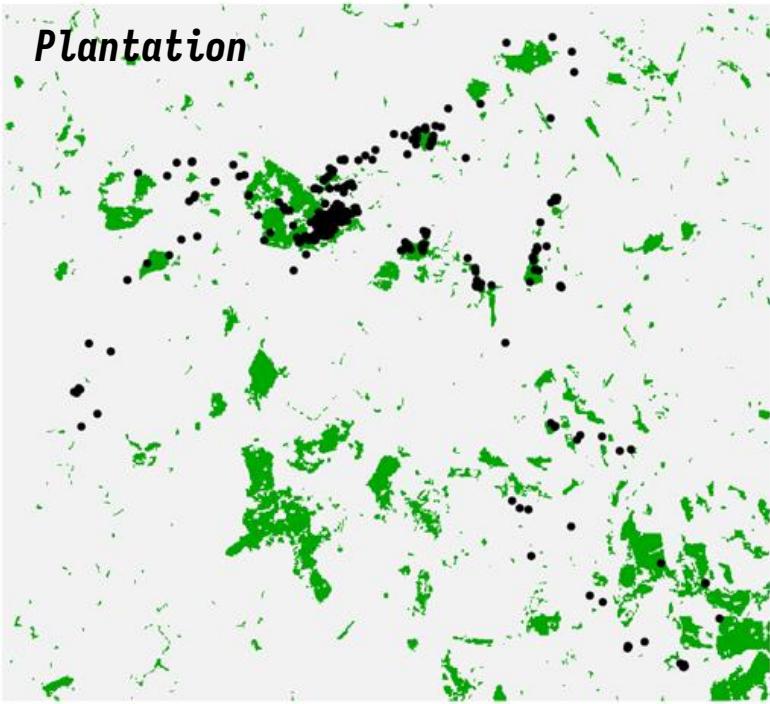
144 locations over 58 days



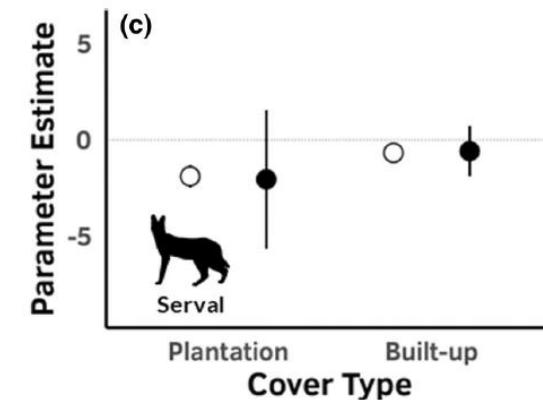
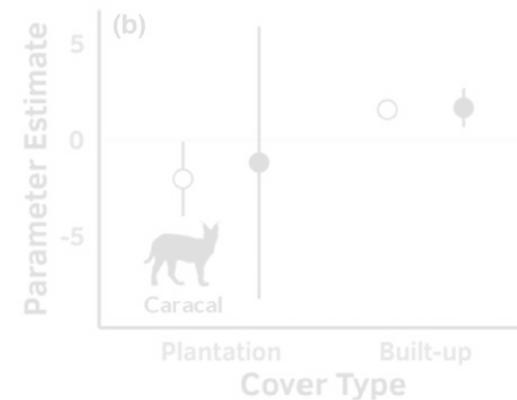
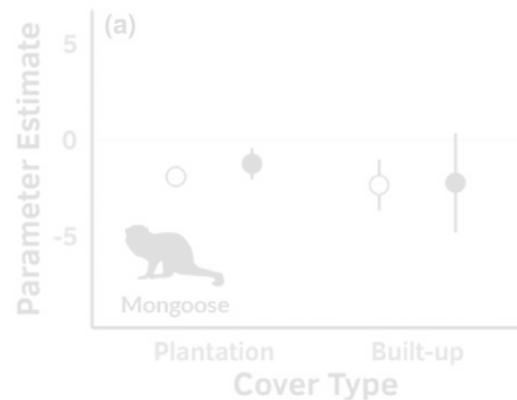
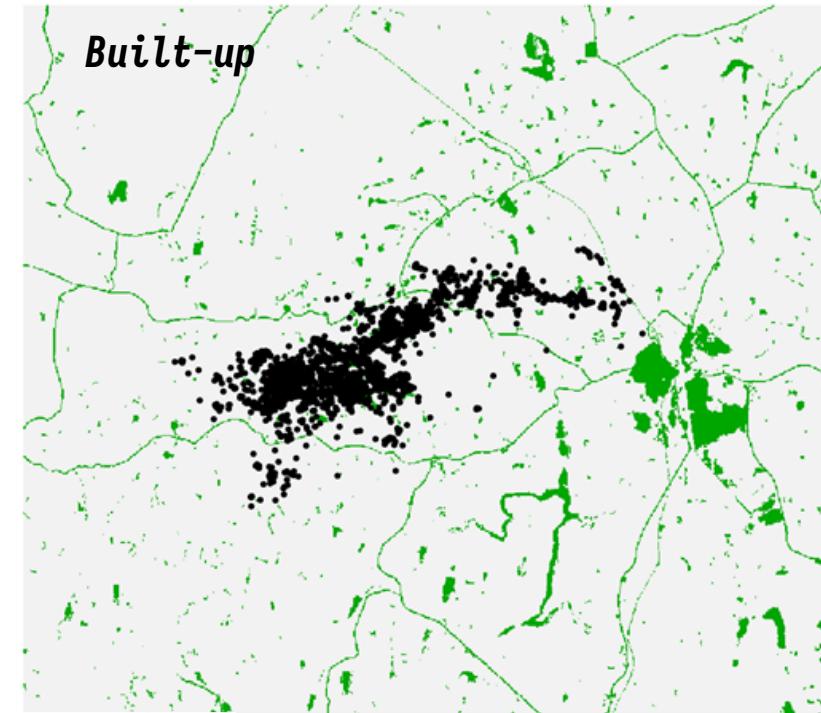
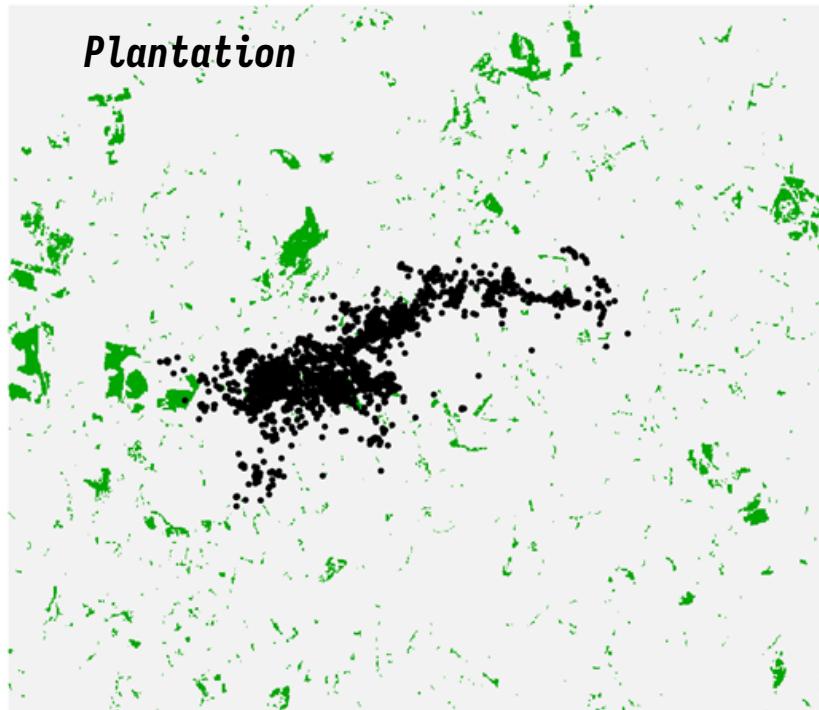
Mongoose



504 locations over 85 days



3603 locations over 321 days





## Integrated RSF

Implemented in ctmm via `rsf.fit()` and `rsf.select()`,

### Advantages:

- ..... Log-likelihood is downweighted to account for *autocorrelation* and *irregular sampling*,
- ..... Available points are randomly sampled until numerical convergence,
- ..... Available area is estimated (along with the parameters) so *uncertainty* is propagated.



Alston et al. (2023)

DOI: 10.1111/2041-210X.14025

### Warnings:

- ..... Will take **longer** to run than conventional RSF,
- ..... Requires **range-resident animals** (no migration or dispersal).



### KDE

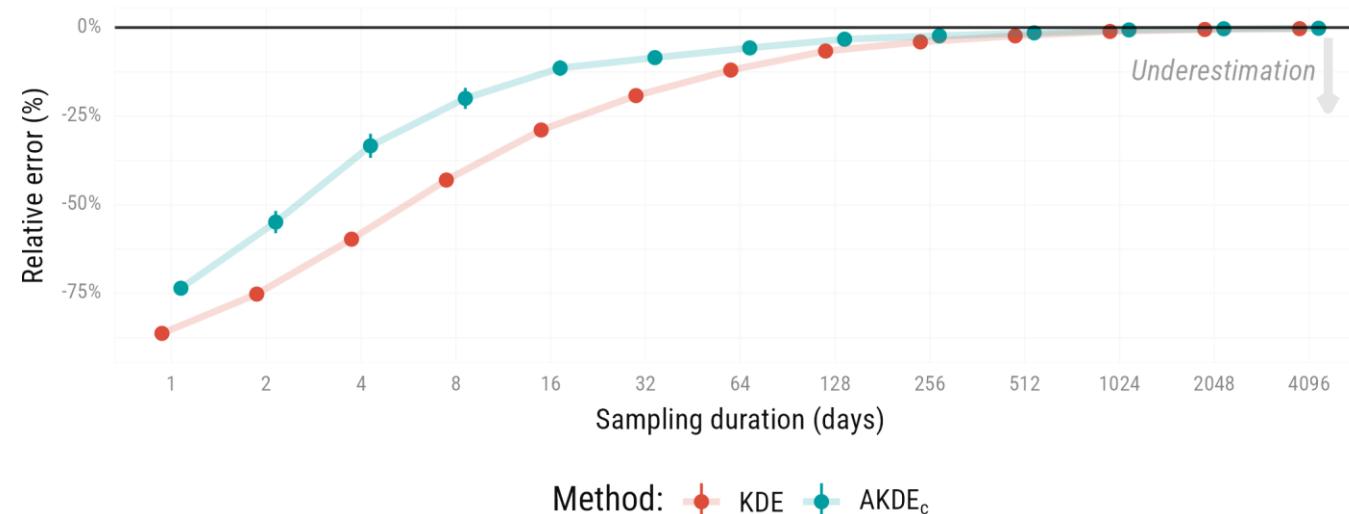
For IID data

- Non-parametric
- Optimal and asymptotically consistent
- Sensitive to autocorrelation (→ biased area)

### AKDE

For autocorrelated data

- Non-parametric
- Optimal and asymptotically consistent
- Accounts for autocorrelation





### KDE

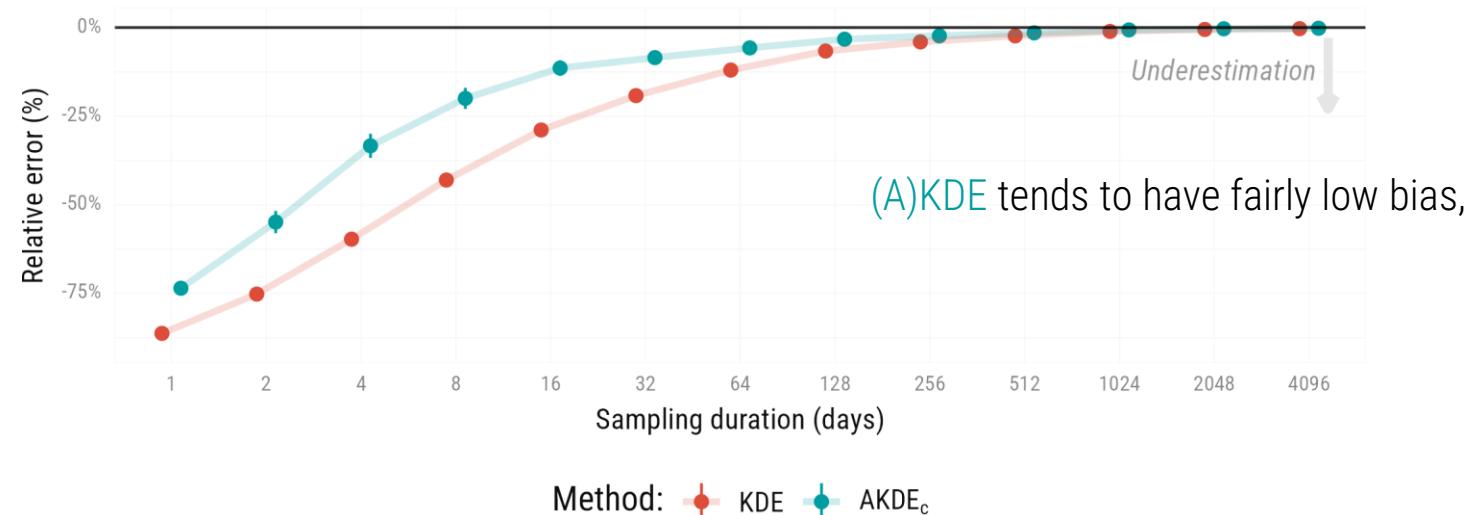
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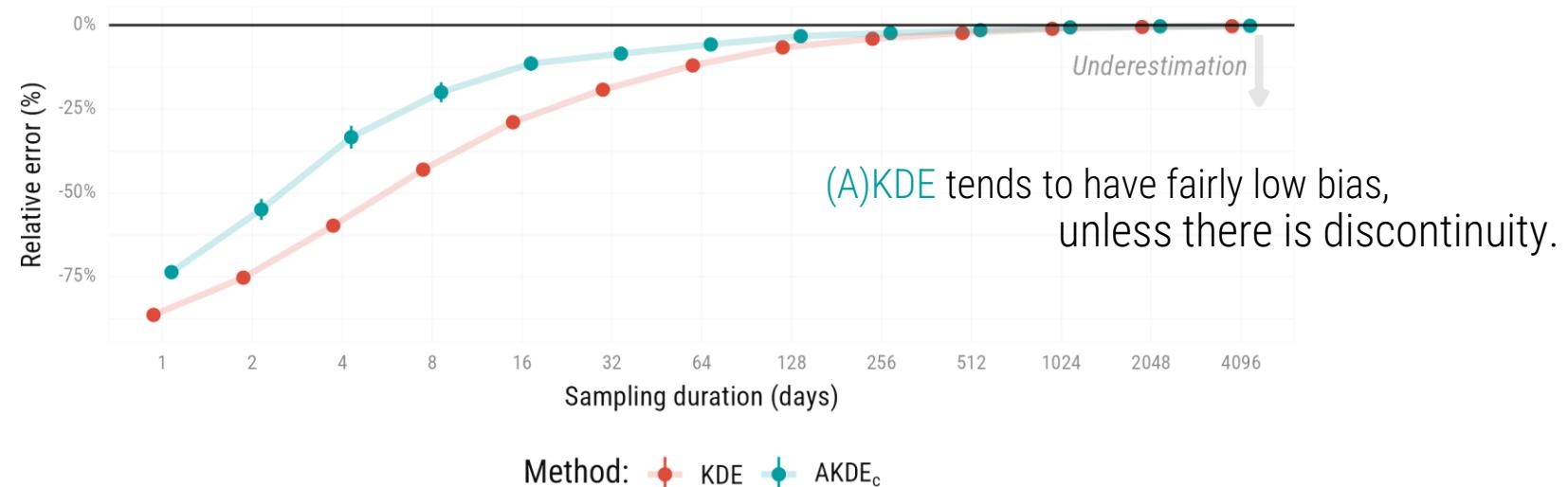
For IID data

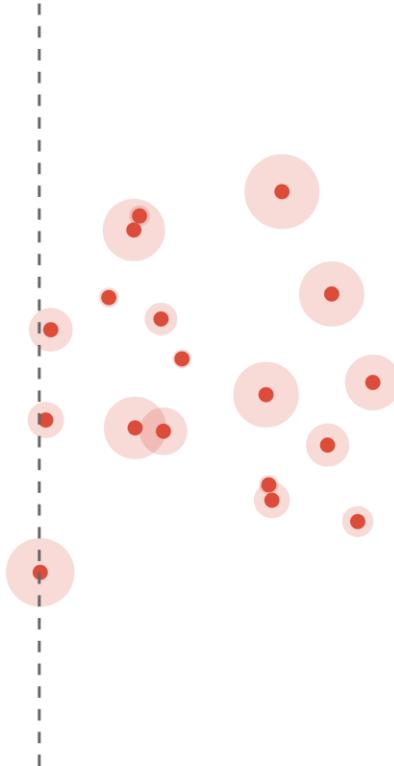
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For autocorrelated data

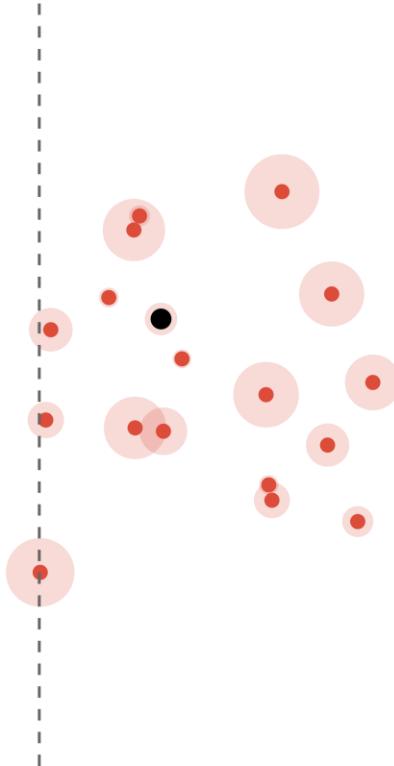
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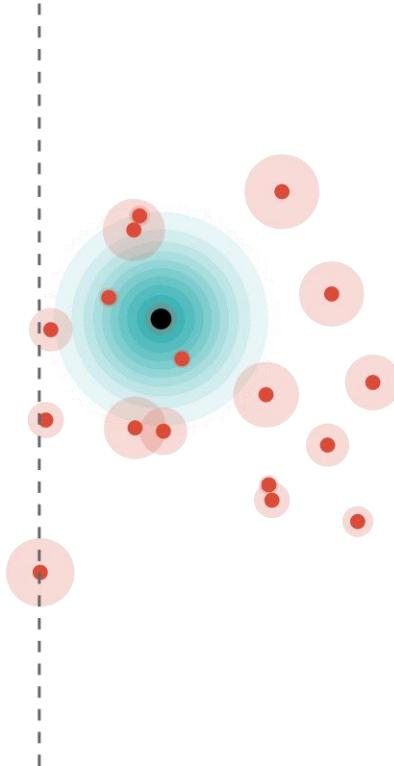
## *“Spillover bias”*

in which home range estimates do not respect impassable movement boundaries (e.g., shorelines, fences), and occurs in all forms of kernel density estimation.



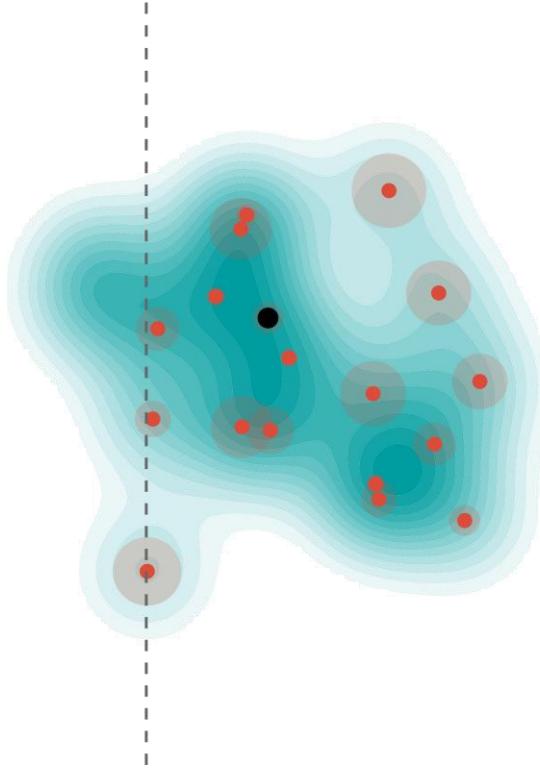
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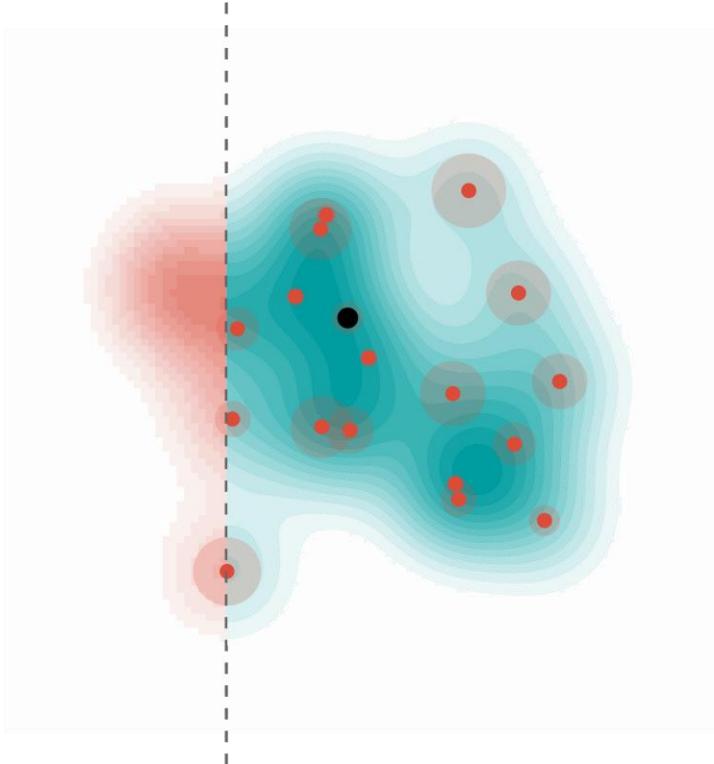
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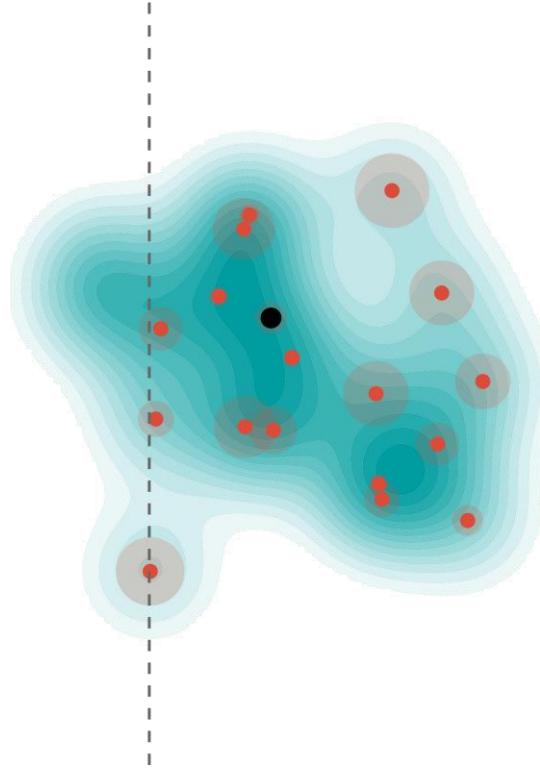
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## *“Spillover bias”*

in which home range estimates do not respect impassable movement boundaries (e.g., shorelines, fences), and occurs in all forms of kernel density estimation.

i.e., assigning non-zero probability density to space the animal cannot reach.



## *“Discontinuity bias”*

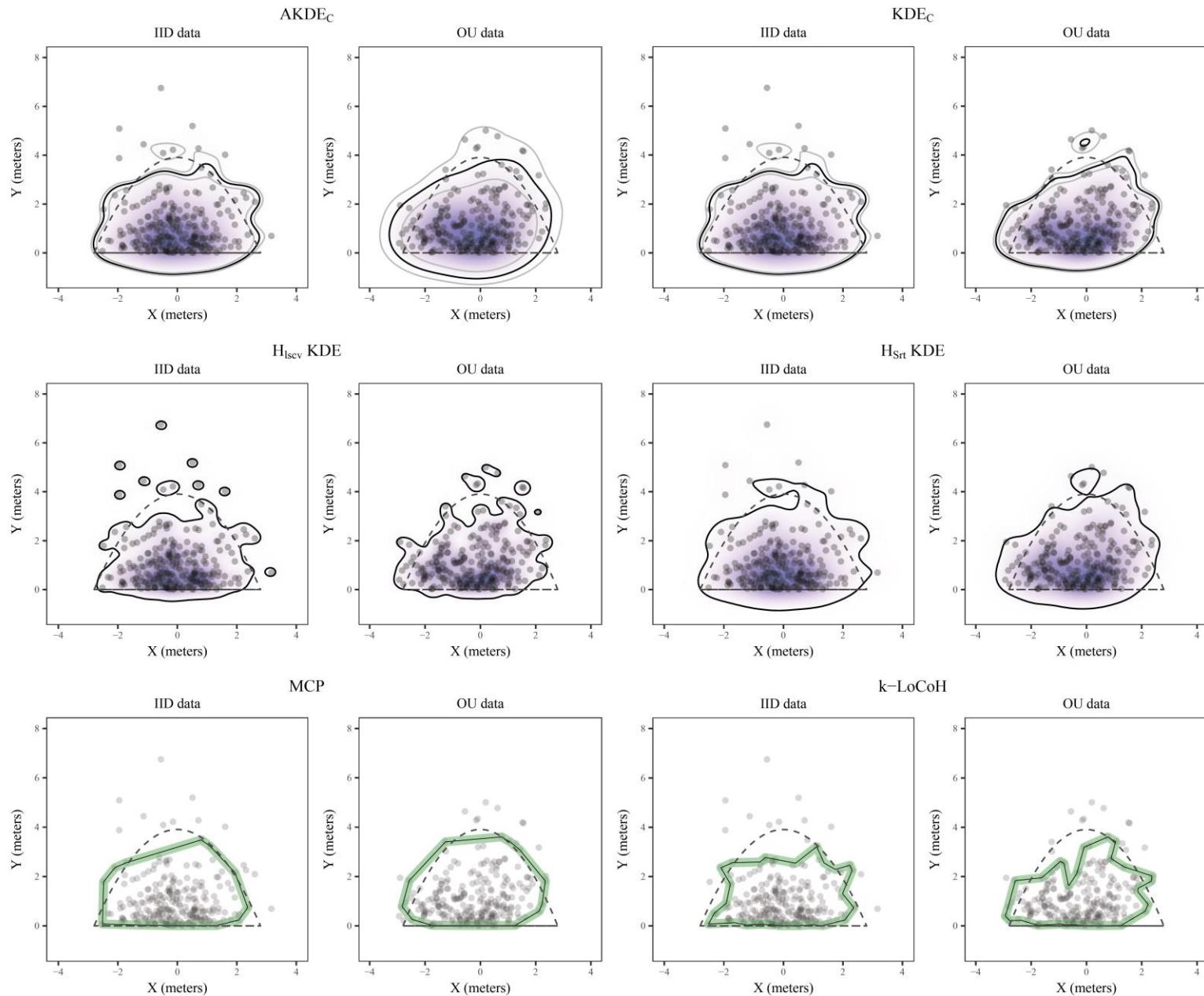
when animals show strong preferences for specific habitat types, constituent kernels may encompass areas which **are available, but unused**, by the tracked animal.



This bias will be exacerbated with shorter tracking durations, or when movement is *tightly constrained* by environmental characteristics.



## Method comparison

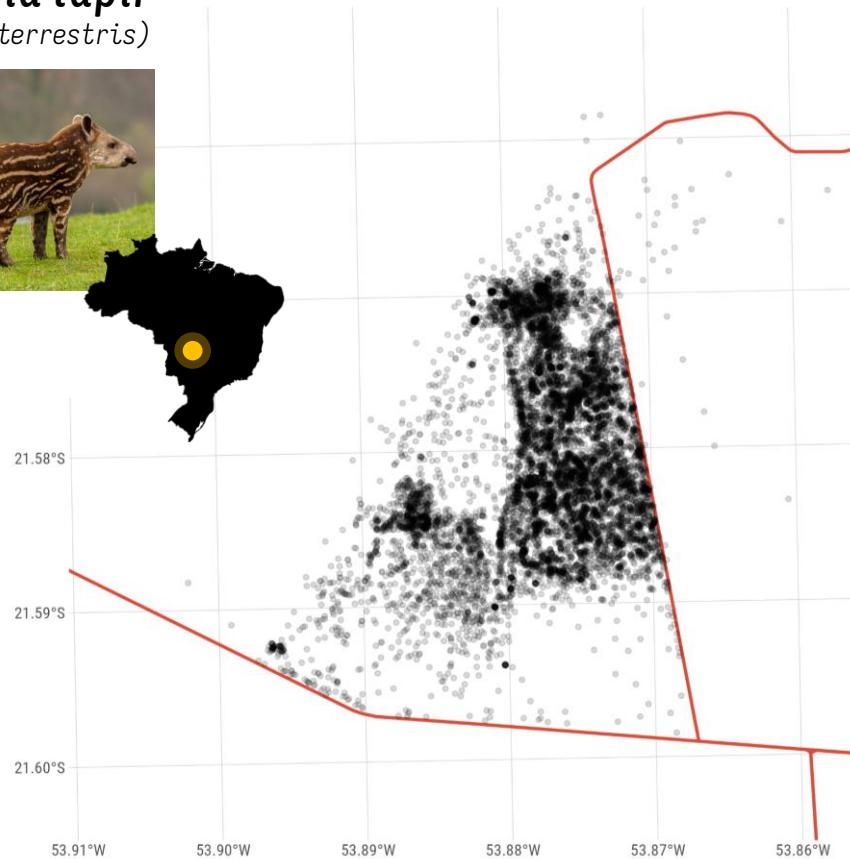


## Lowland tapir

(*Tapirus terrestris*)



VU

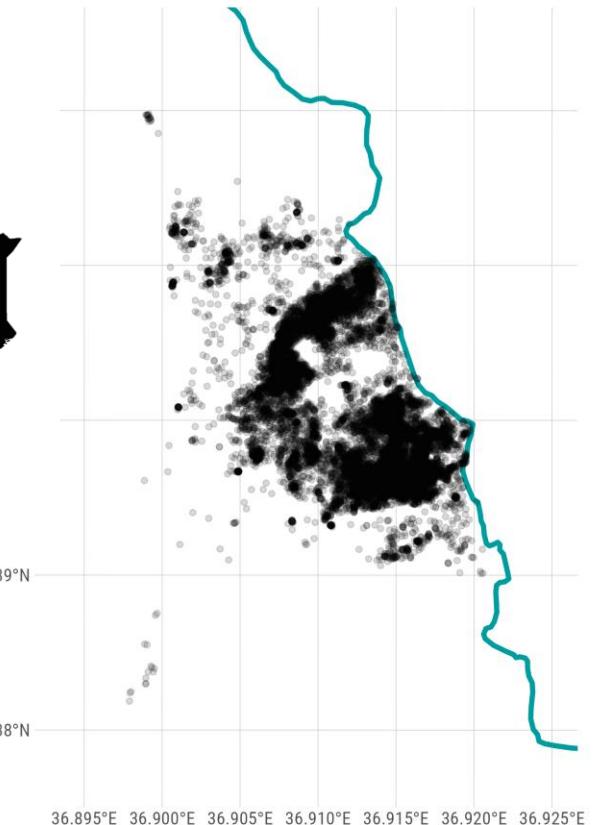
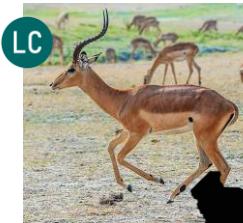


## Impala

(*Aepyceros melampus*)



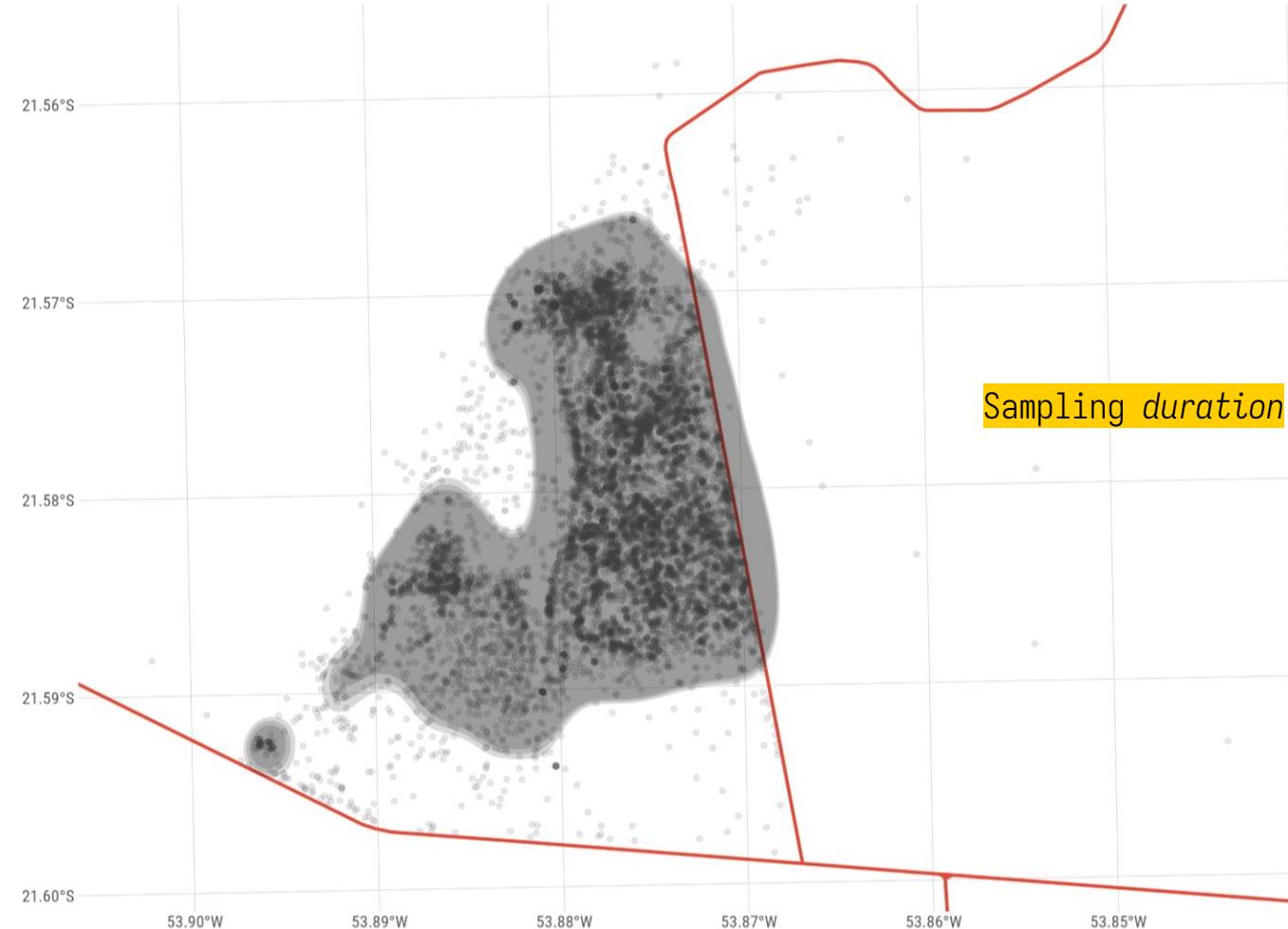
LC



## Lowland tapir (*Tapirus terrestris*)



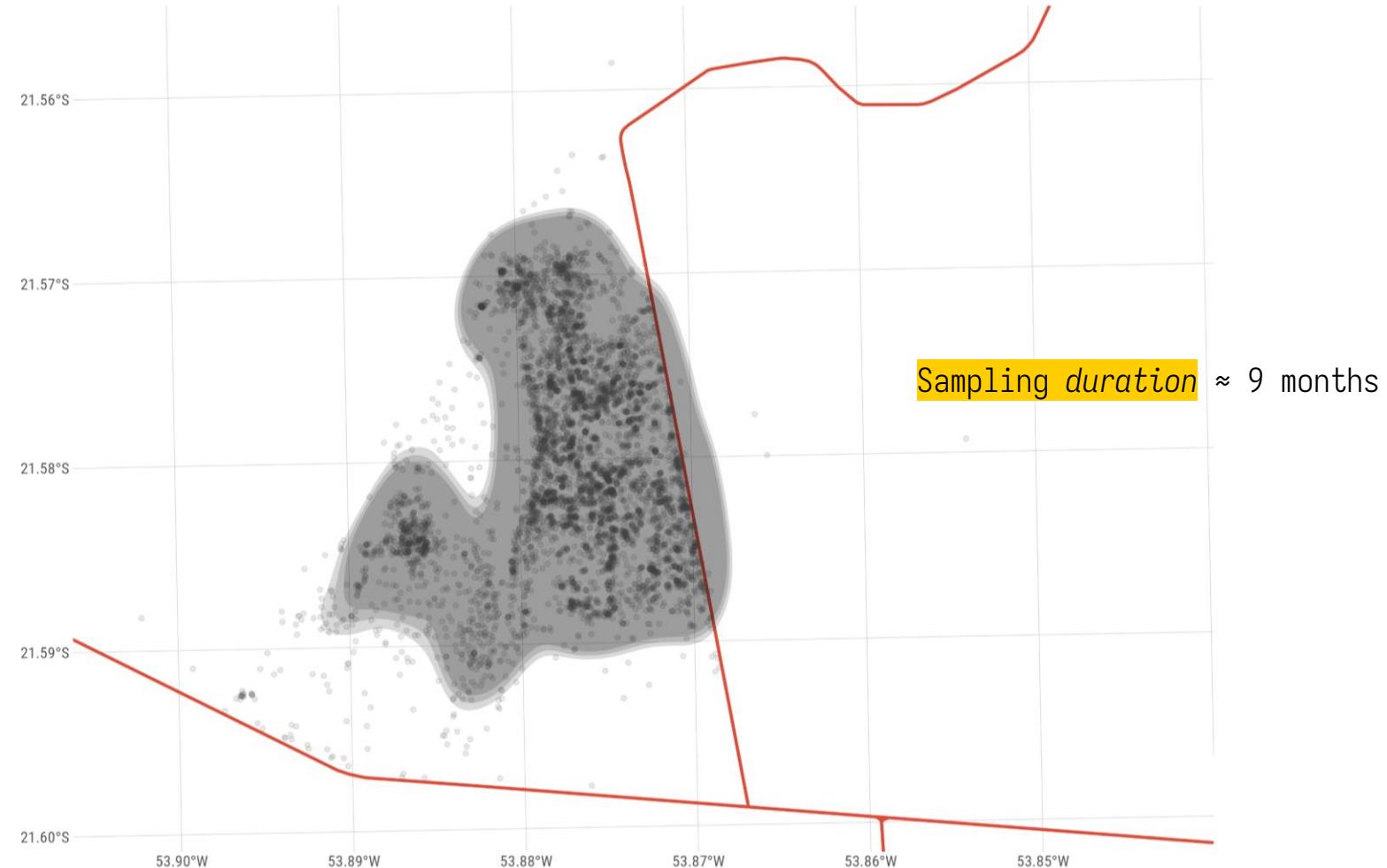
VU



## Lowland tapir (*Tapirus terrestris*)



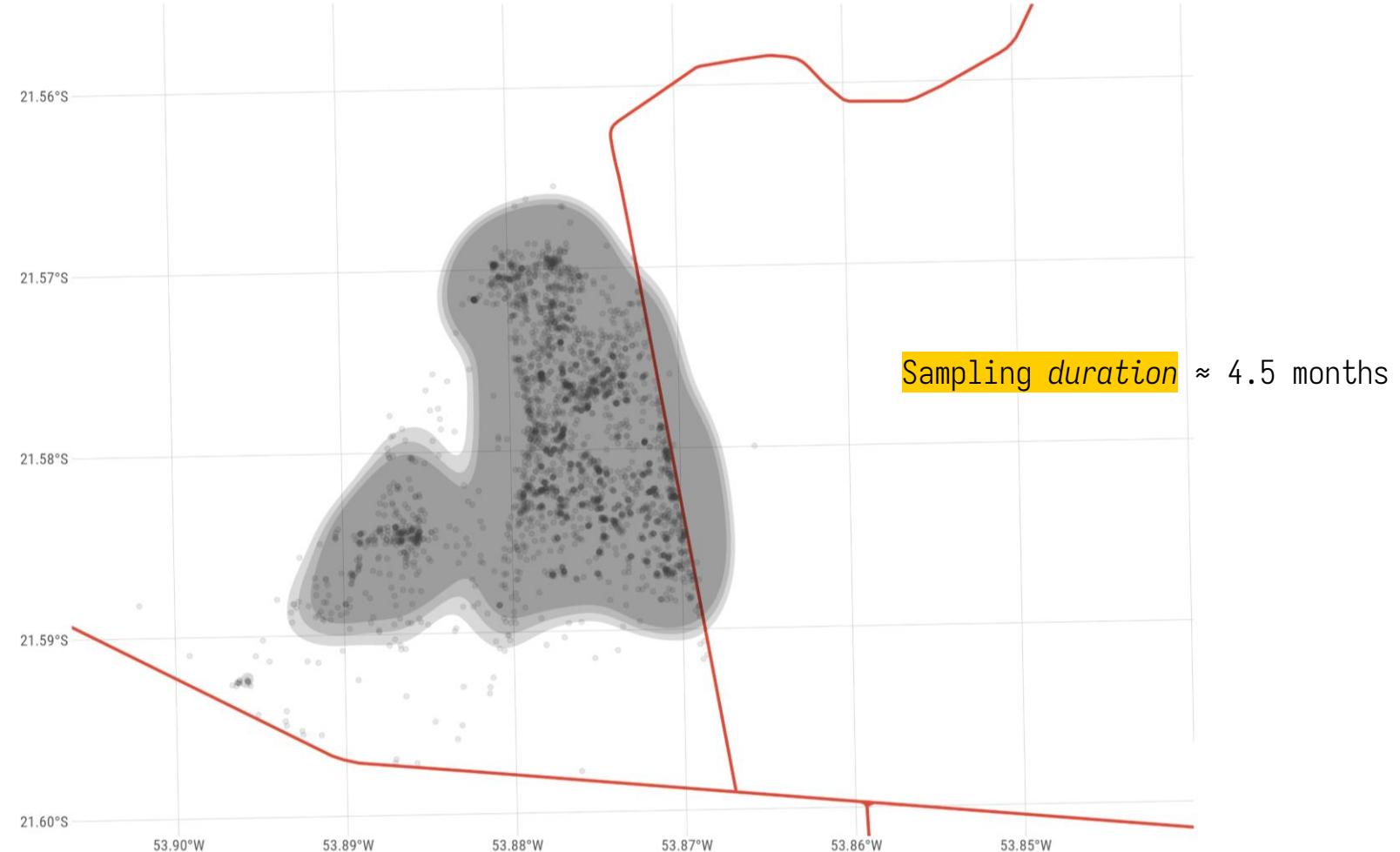
VU



## Lowland tapir (*Tapirus terrestris*)



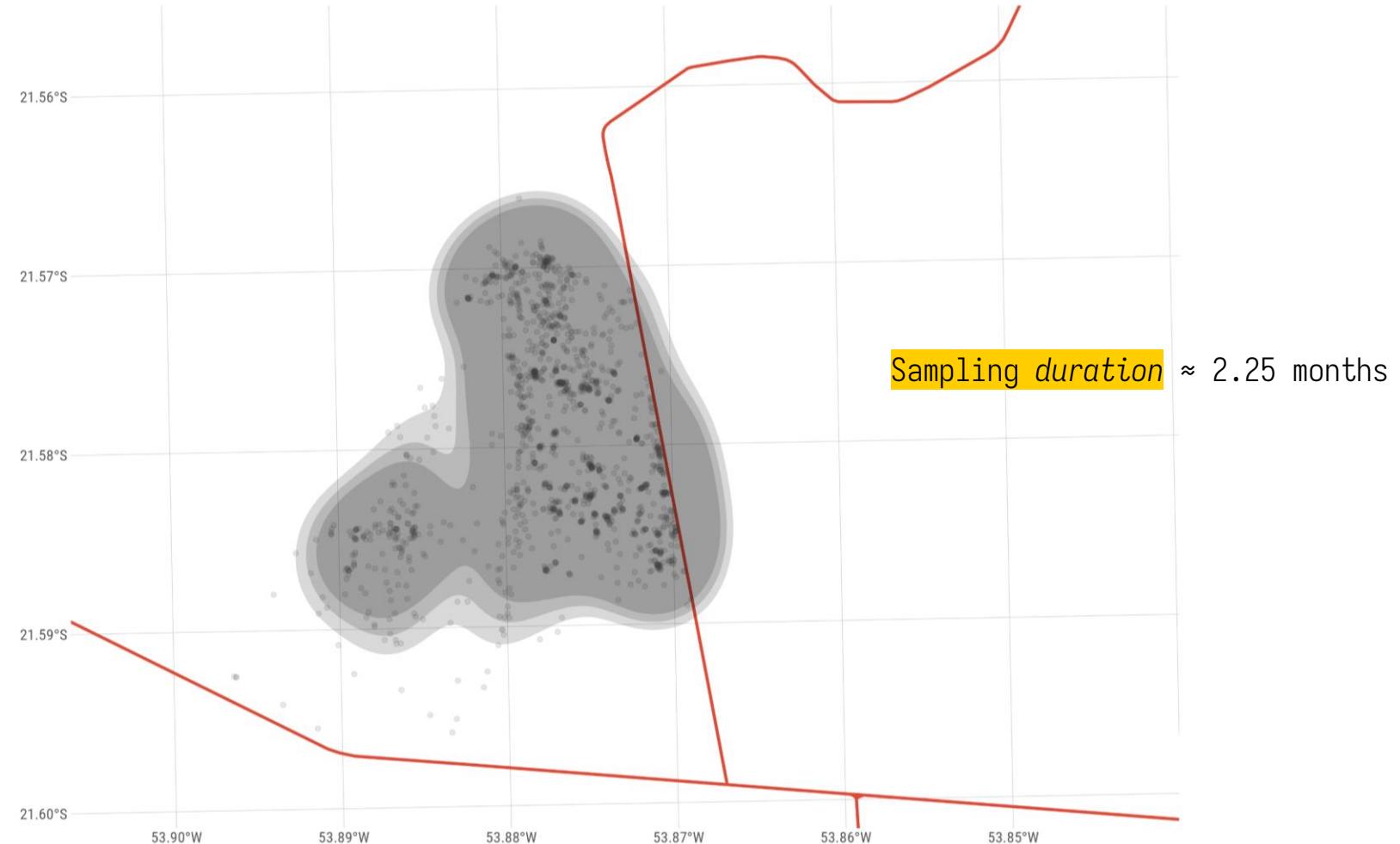
VU



## Lowland tapir (*Tapirus terrestris*)



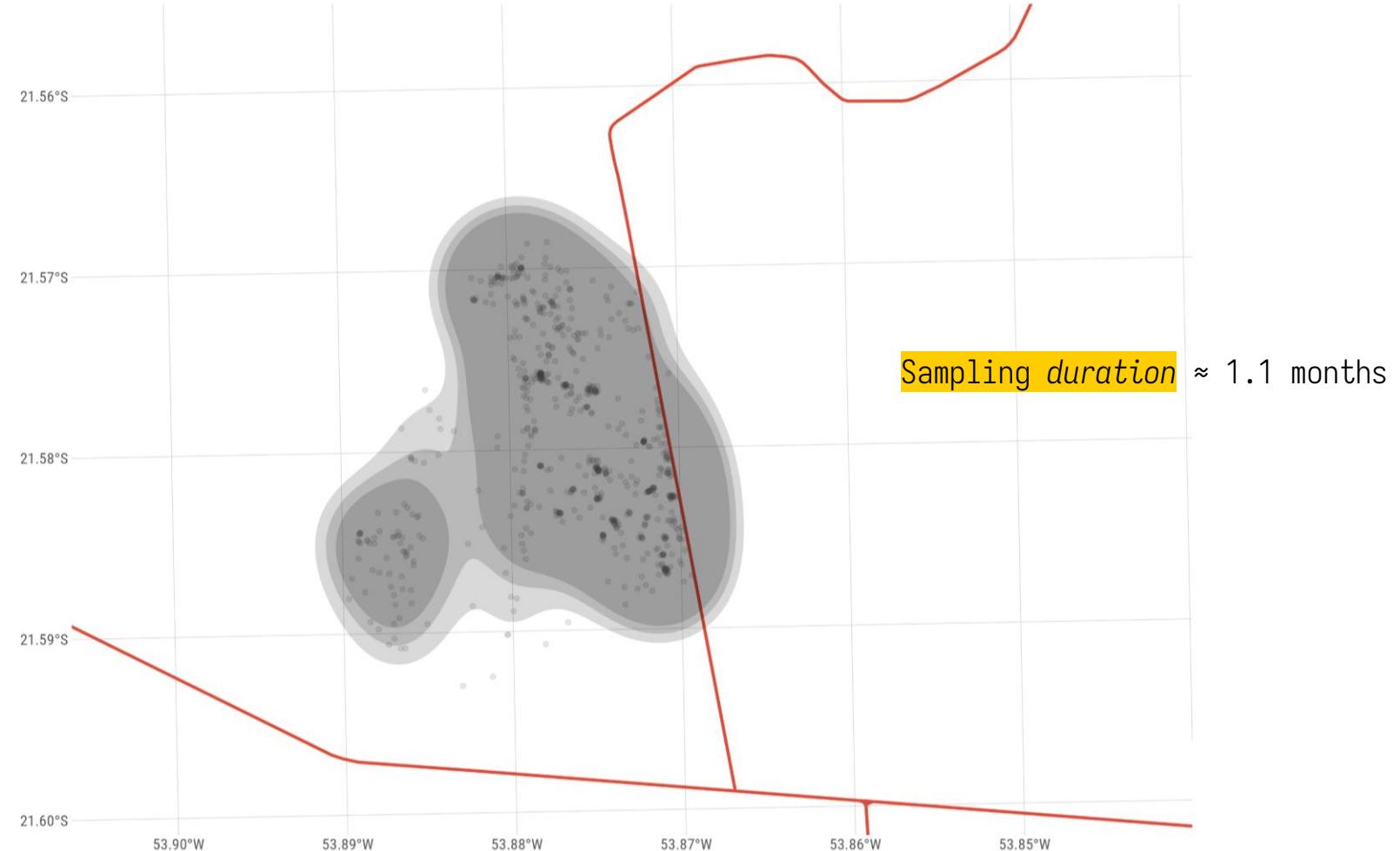
VU



## Lowland tapir (*Tapirus terrestris*)



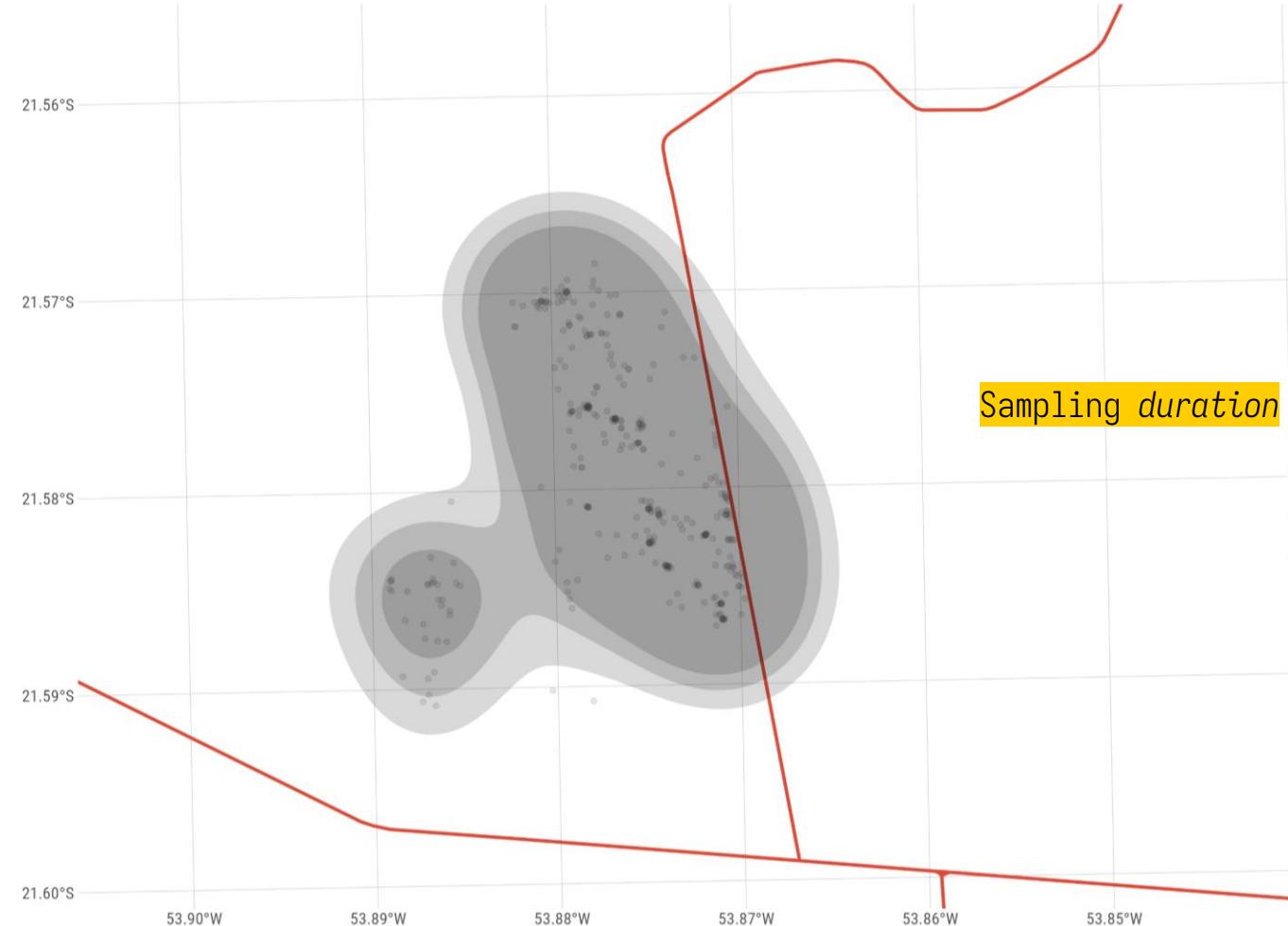
VU



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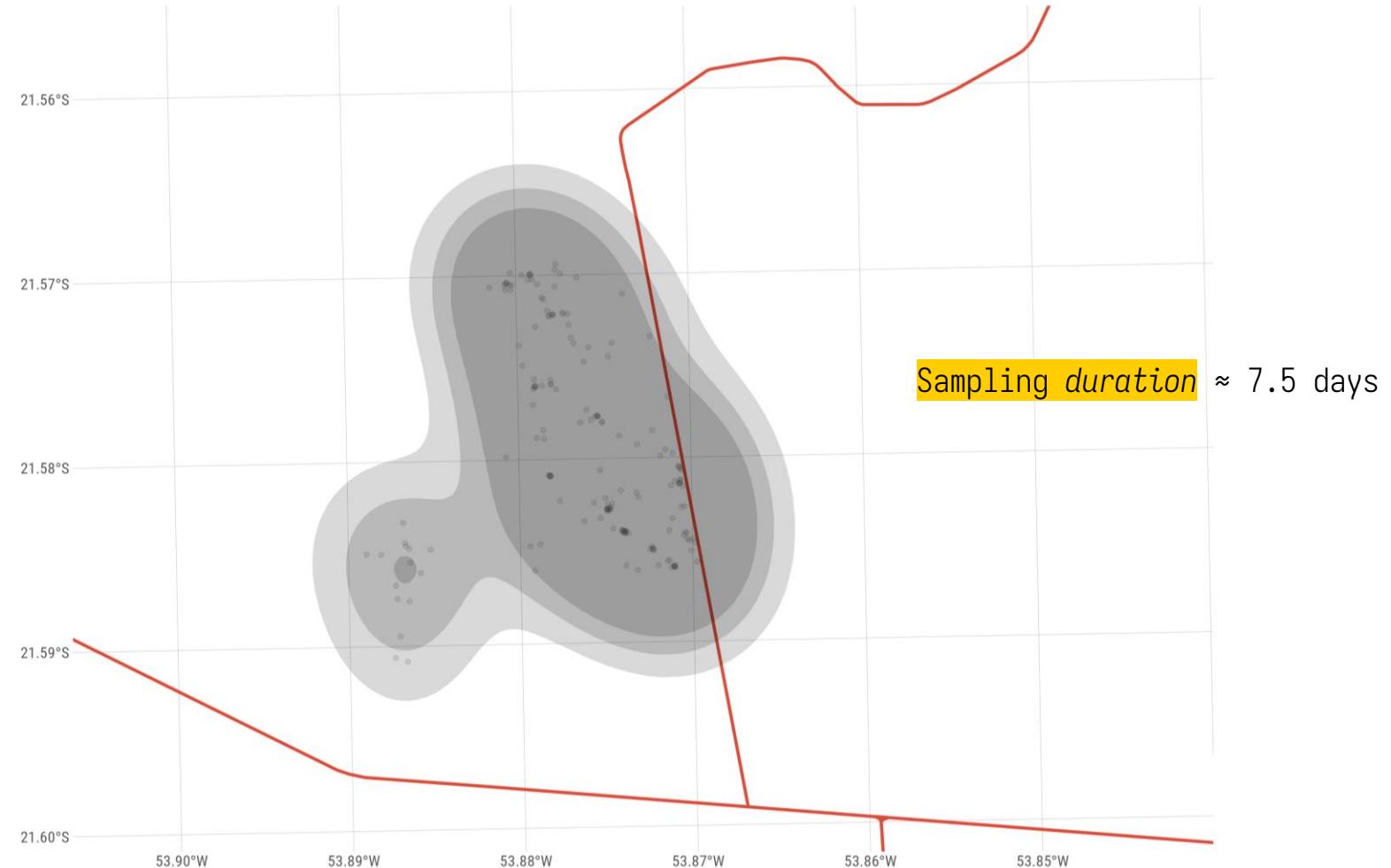
VU



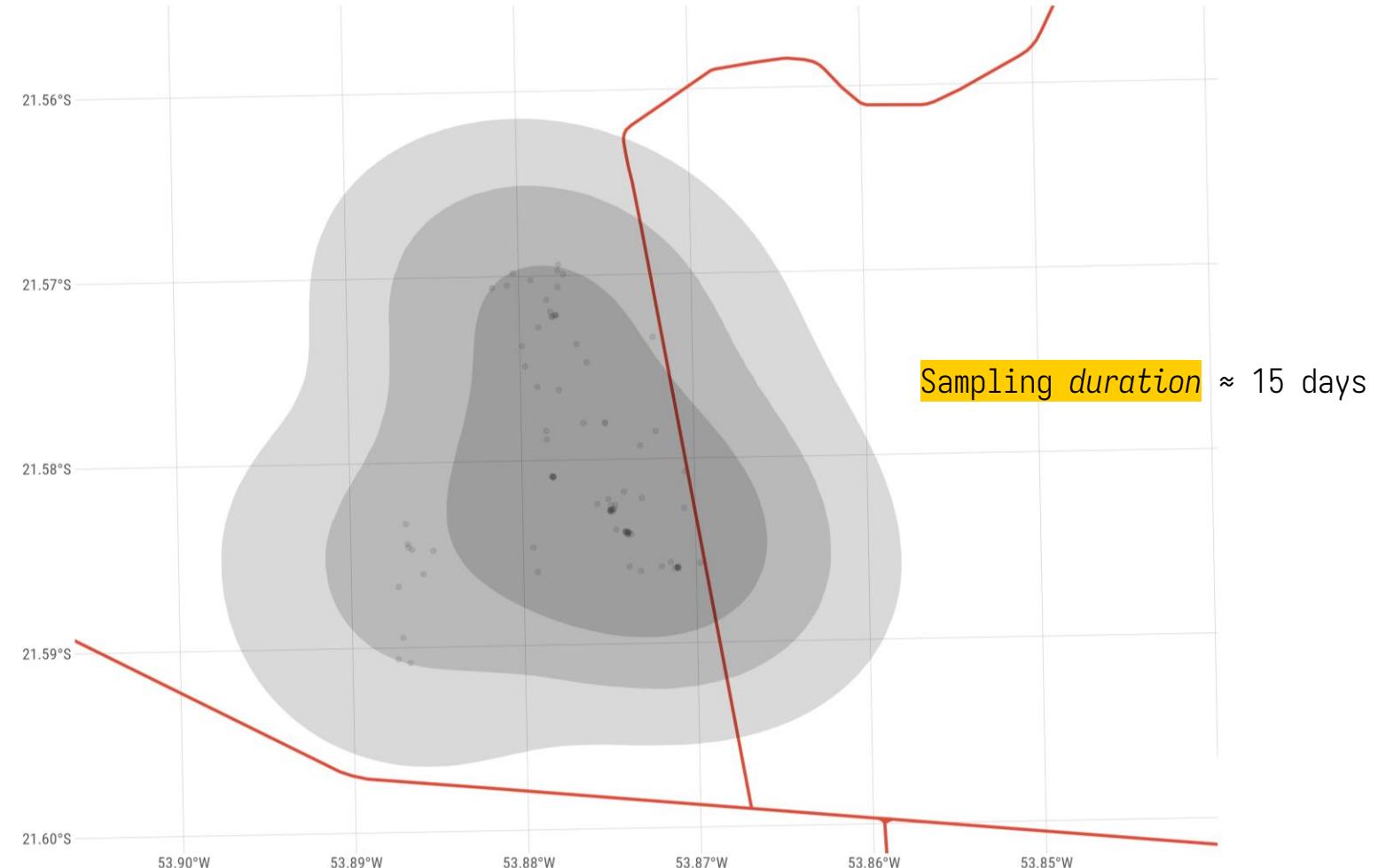
## Lowland tapir (*Tapirus terrestris*)



VU



## Lowland tapir (*Tapirus terrestris*)





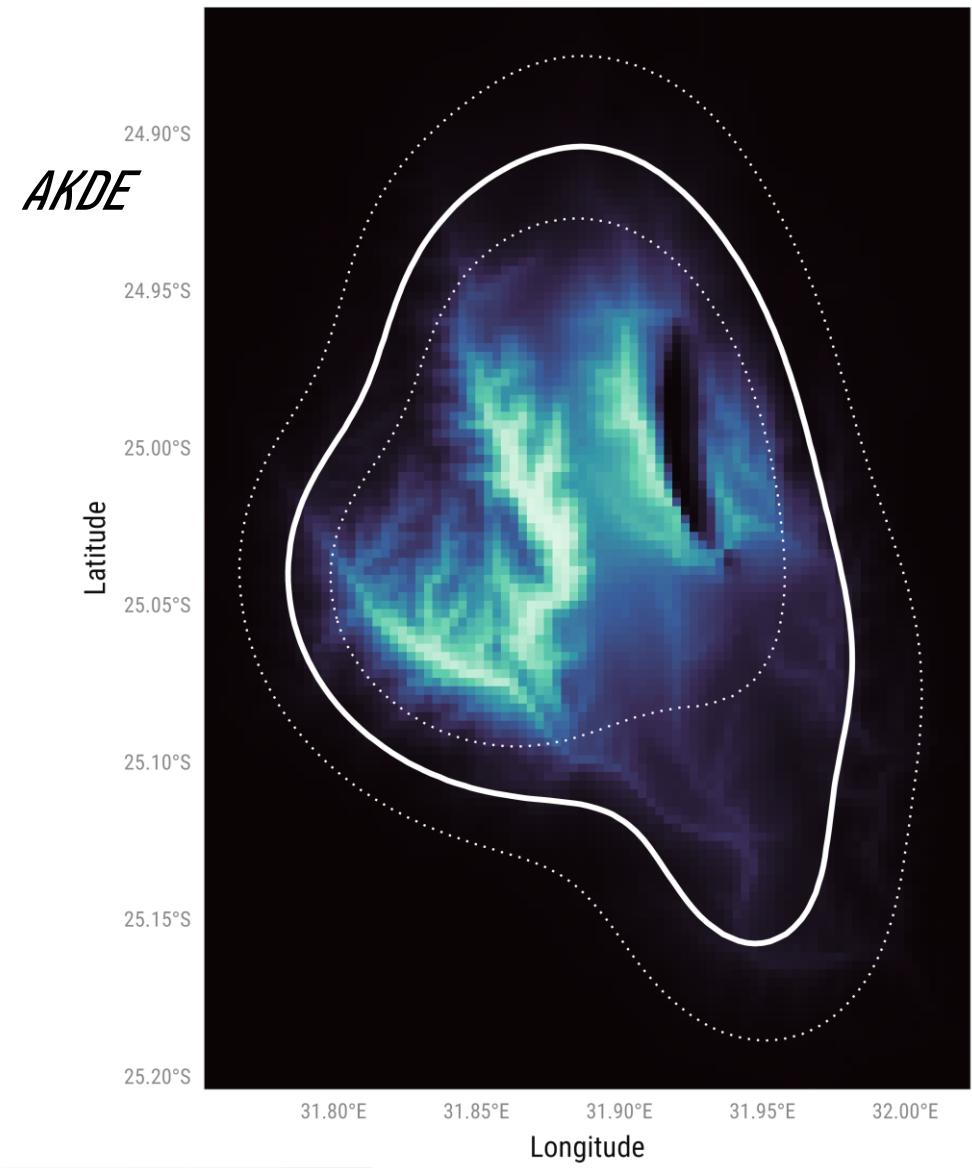
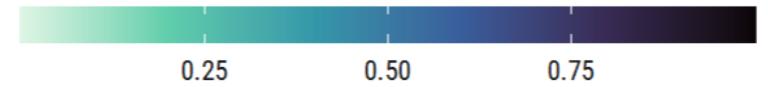
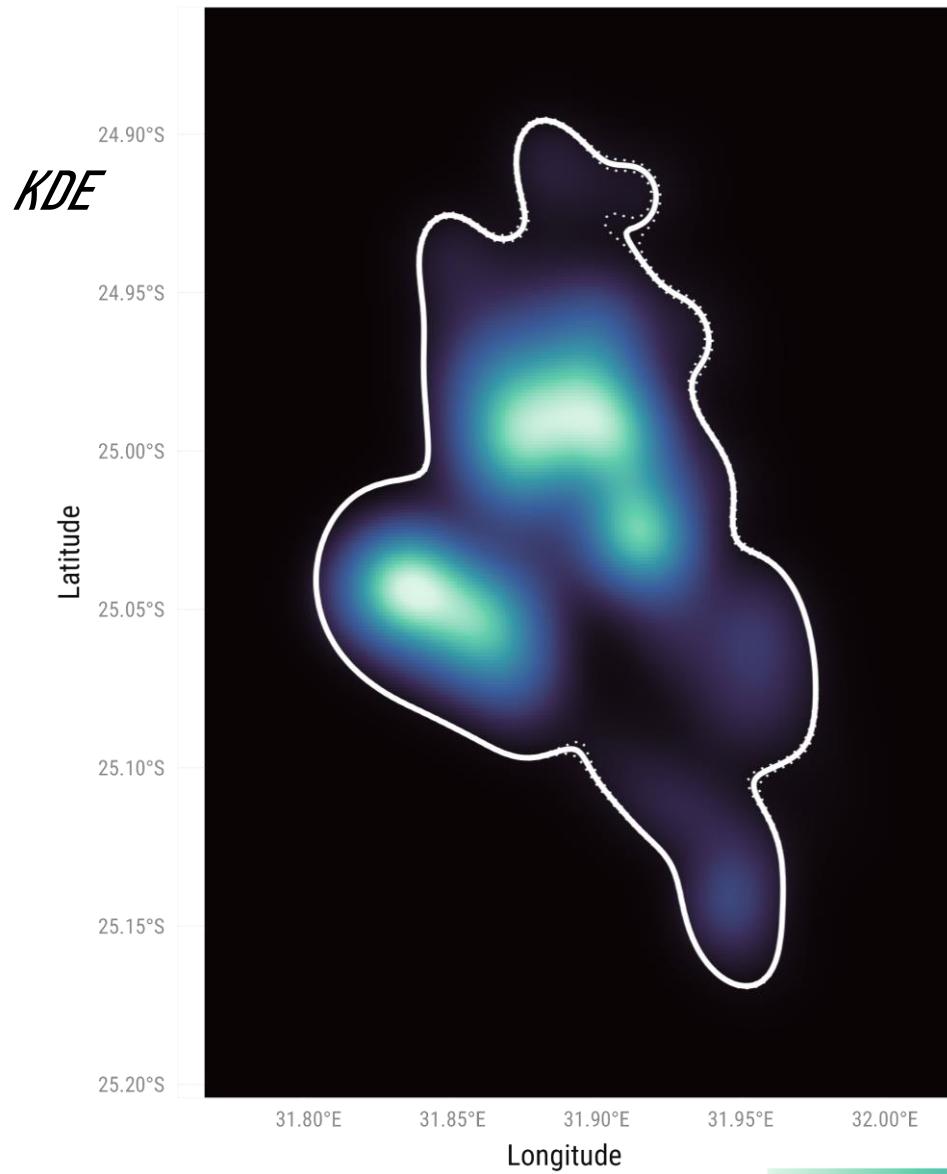
**RSF models** can provide **good habitat suitability estimates**, but usually provide poor home-range estimates. **(A)KDE** can provide **good home-range estimates**, when there is no discontinuity.

**RSF + (A)KDE** works better, respecting habitat preferences and barriers!

Incorporated into the `ctmm::akde()` function.



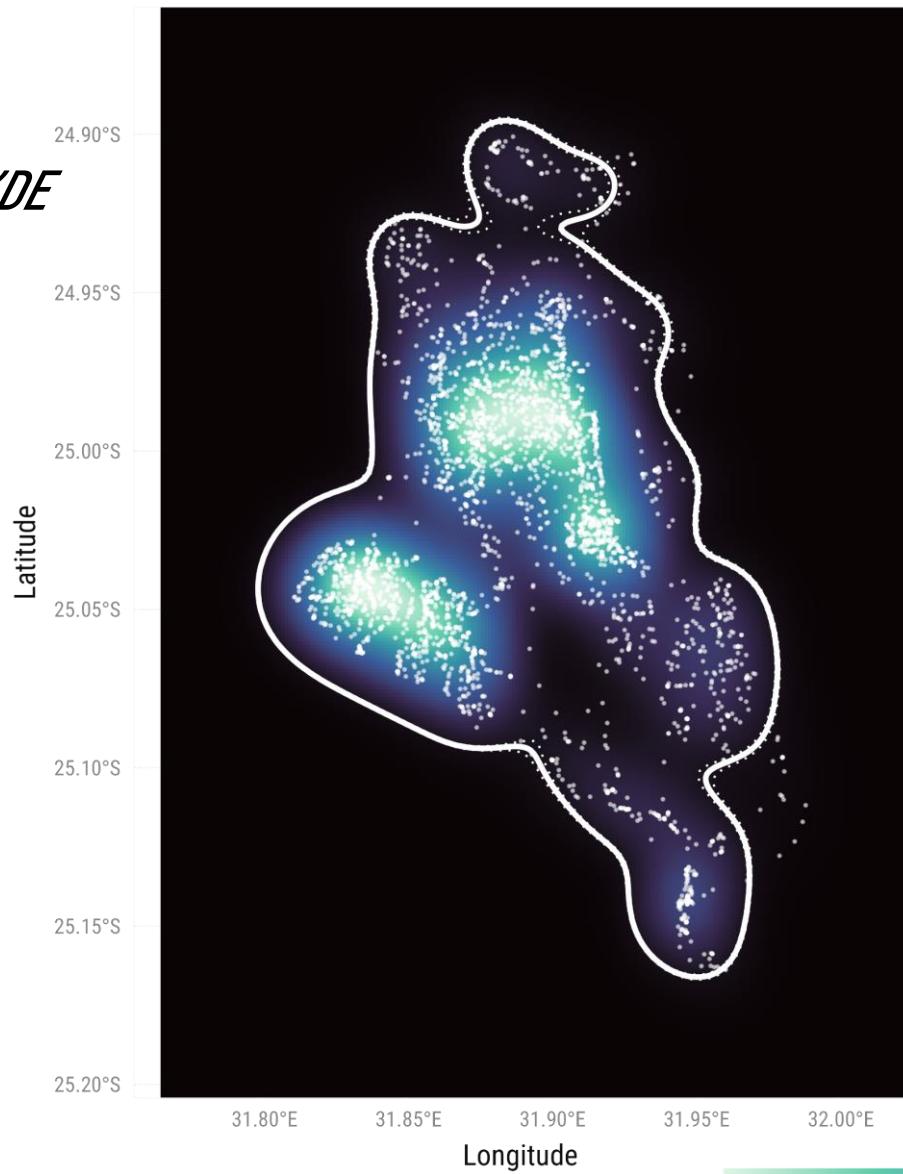
## Example



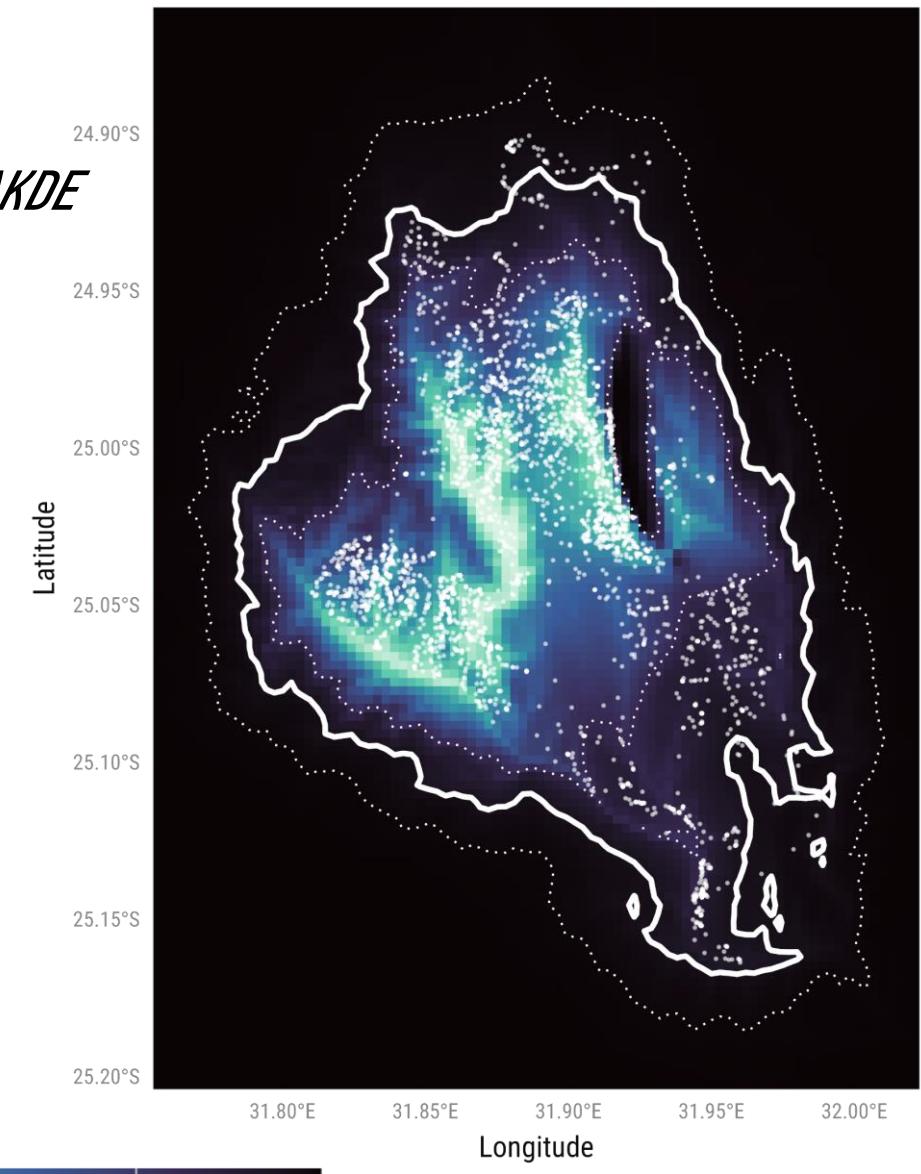


## Example

*RSF-KDE*

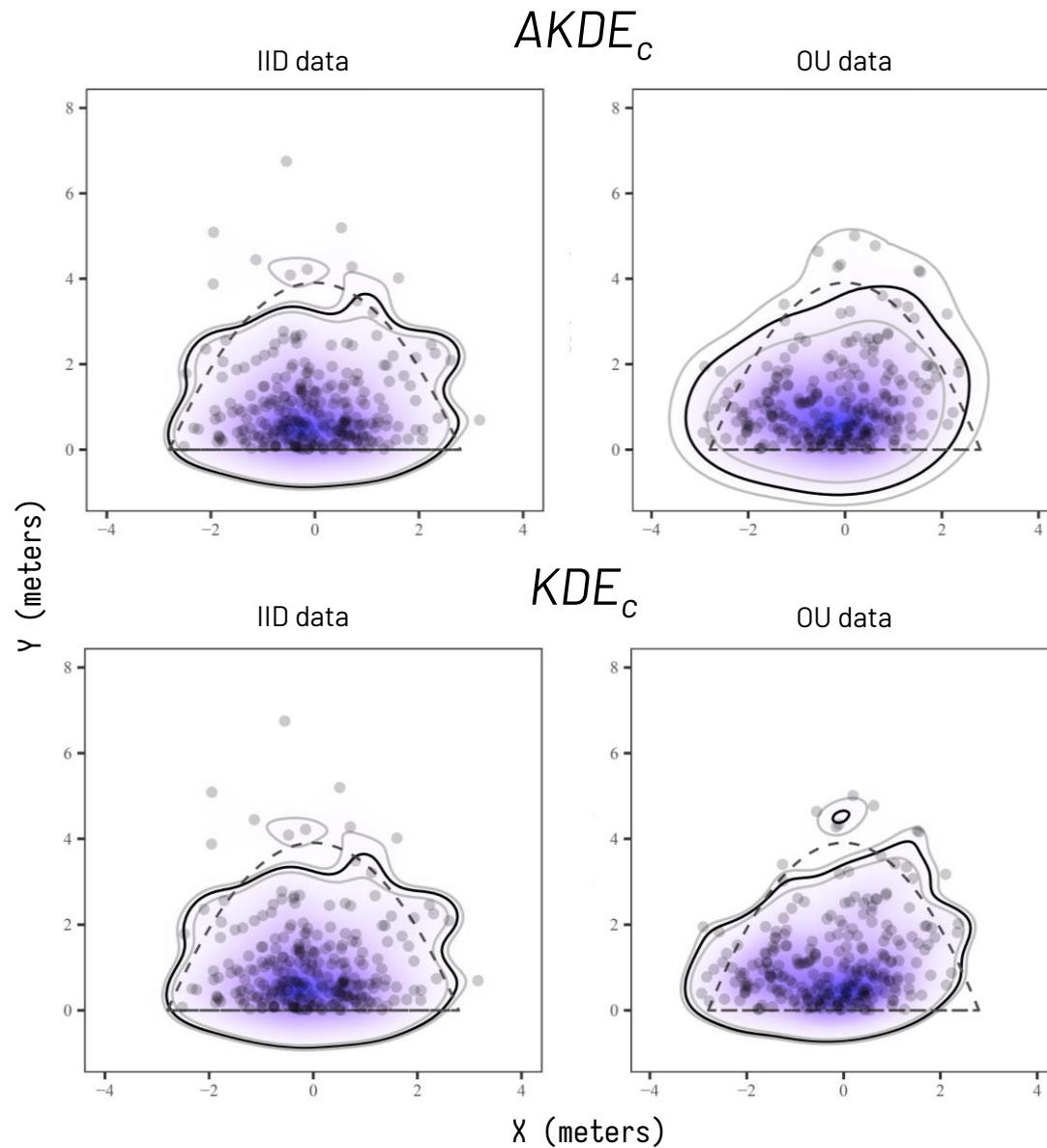


*RSF-AKDE*





## Dealing with **hard boundaries**



### *“Spillover bias”*

can lead to **overestimation** of home range areas, especially in (A)KDE.

This bias arises when animal movement is constrained by **impassable boundaries**, and is **proportional** to:

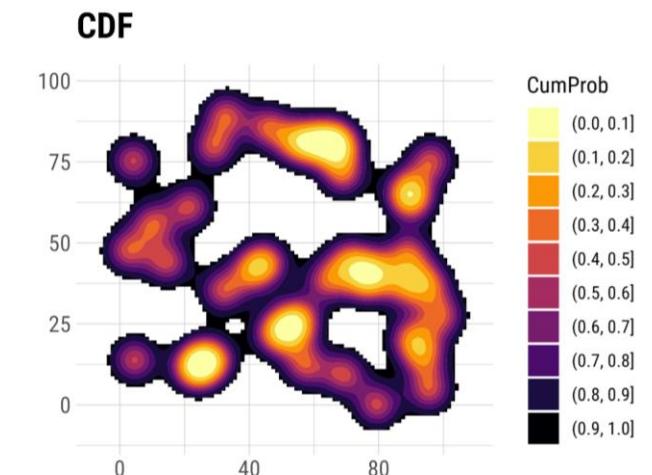
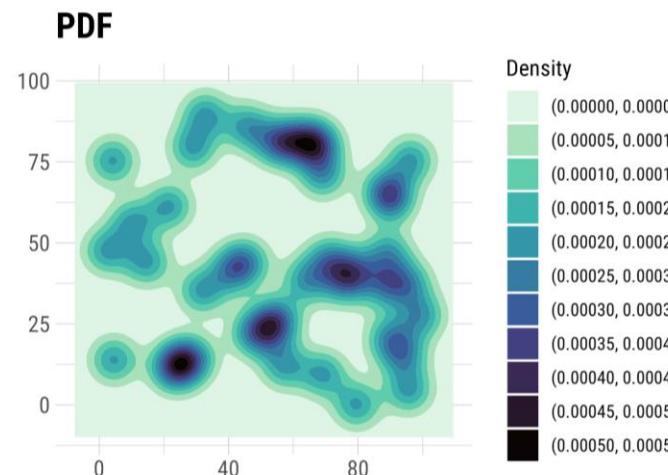
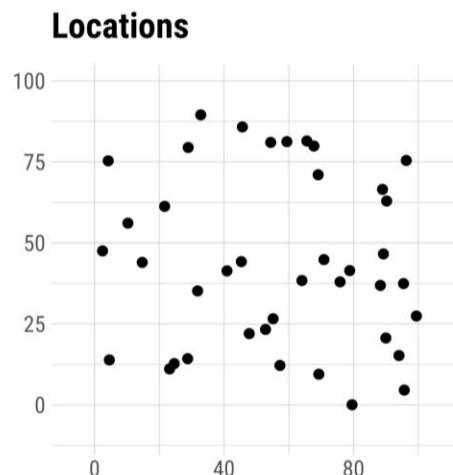
- **Size of the bandwidth.**
- **Amount of time** the animal spends near the boundary.

Adapted from **Noonan et al. (2019)**



Corrections to remove this “spillover bias”:

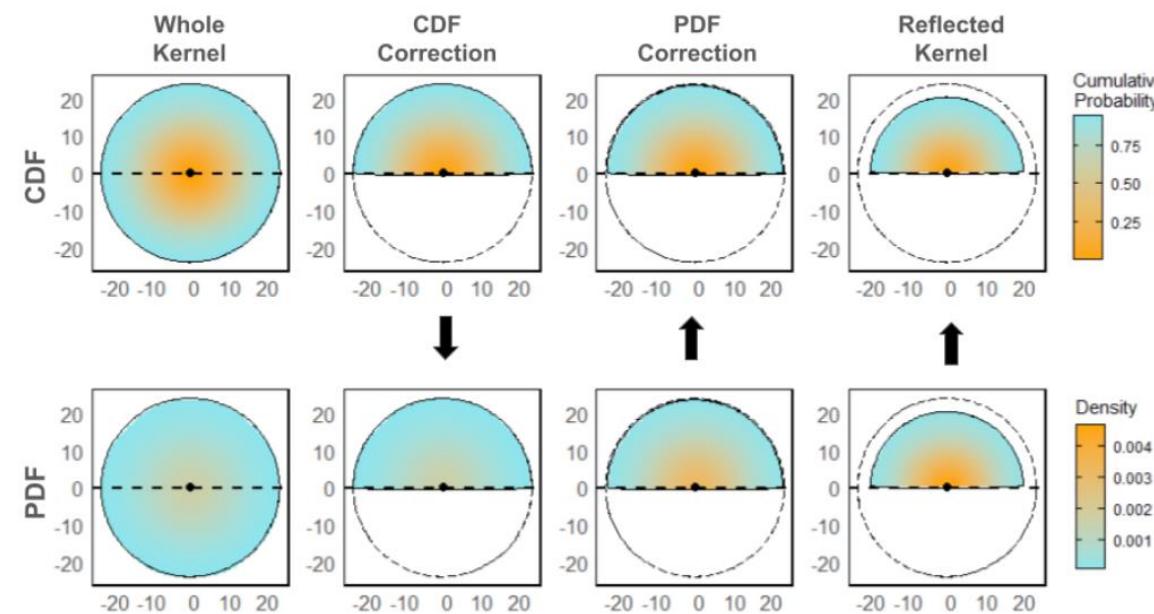
- **Local corrections** (applied to the constituent kernels)
- **Post-hoc corrections** (applied to the PDF or CDF)





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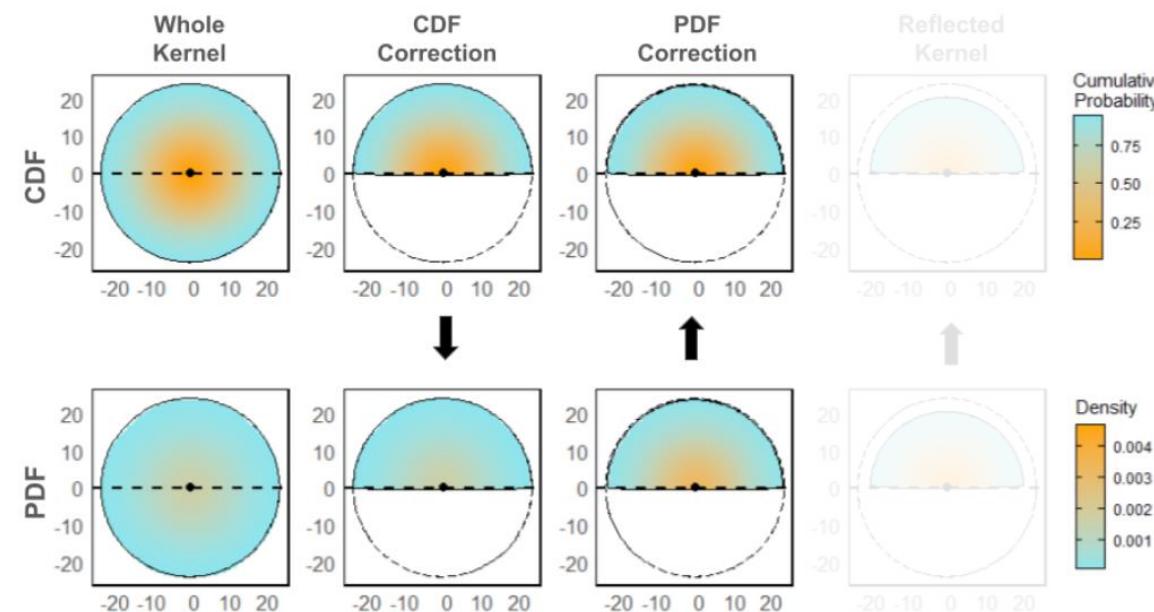
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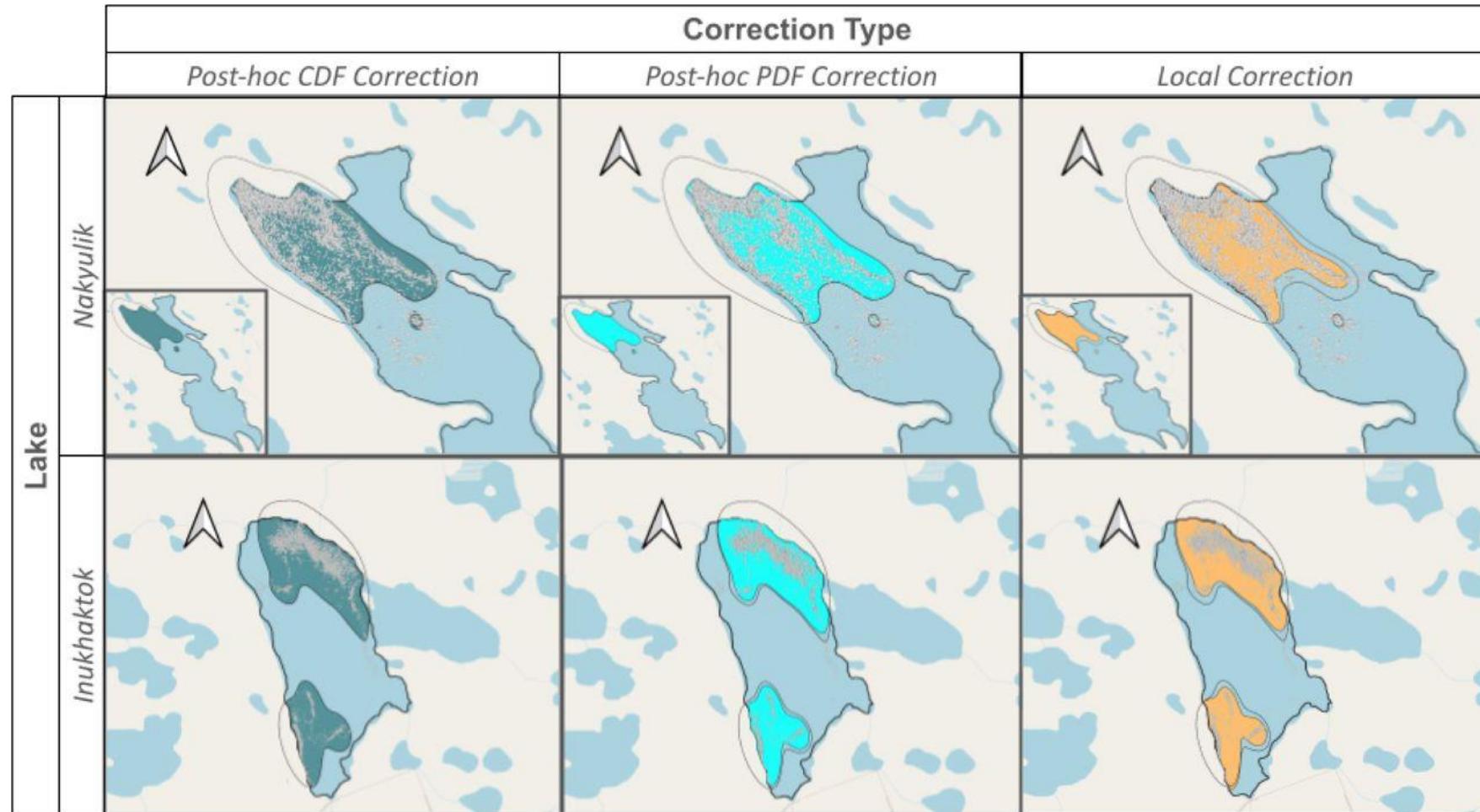
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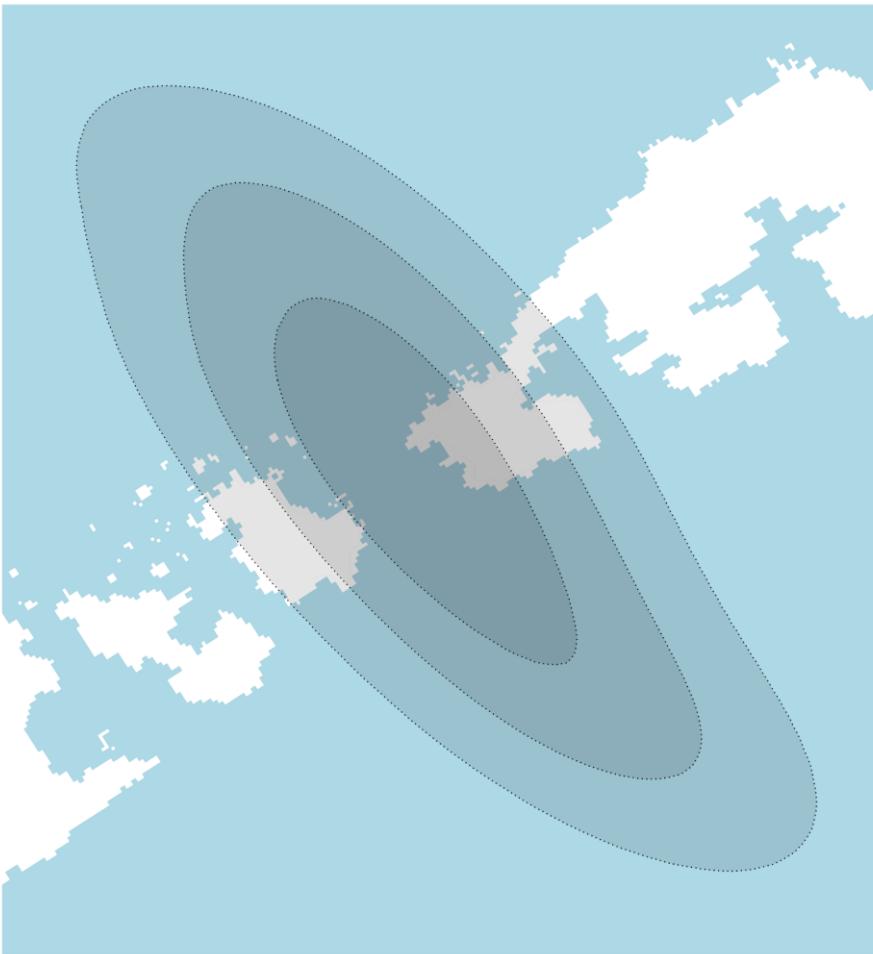
- **Local corrections** (applied to the constituent kernels)
- **Post-hoc corrections** (applied to the PDF or CDF)  
often referred to as “masking” or “clipping”





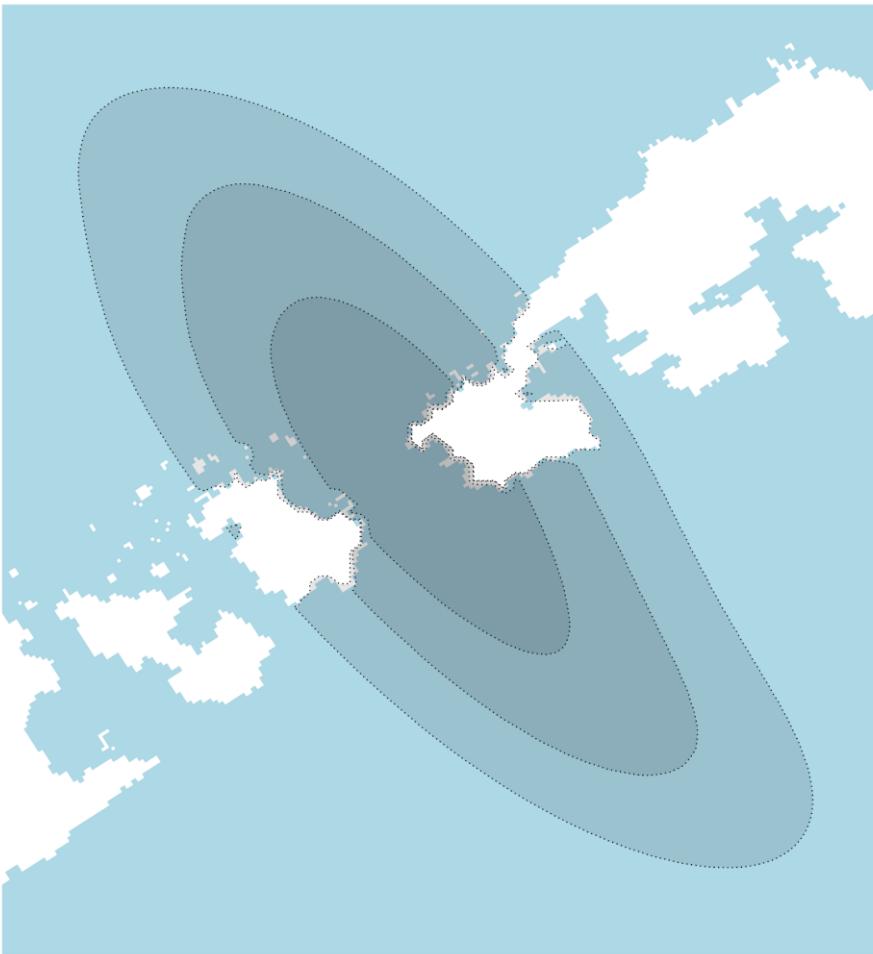
## Dealing with hard boundaries





### *Locally-corrected AKDE*

Each kernel's PDF is **truncated at movement boundaries** to avoid spillover. **Removed probability mass is redistributed** within the same kernel, ensuring the total probability remains valid.



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