HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF

CASUS CENTER FOR ADVANCED SYSTEMS UNDERSTANDING

MARE-Madeira 2025

Habitat-informed home ranges

Using the 'ctmm' R package

Inês Silva

i.simoes-silva@hzdr.de

TECHNISCHE UNIVERSITÄT DRESDEN

CBG Max Planck Institute of Molecular Cell Biology and Genetics

UFZ HELMHOLTZ Centre for Environmental Research

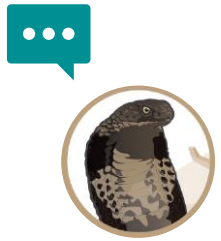
Uniwersytet Wrocławski

SPONSORED BY THE

Federal Ministry of Education and Research

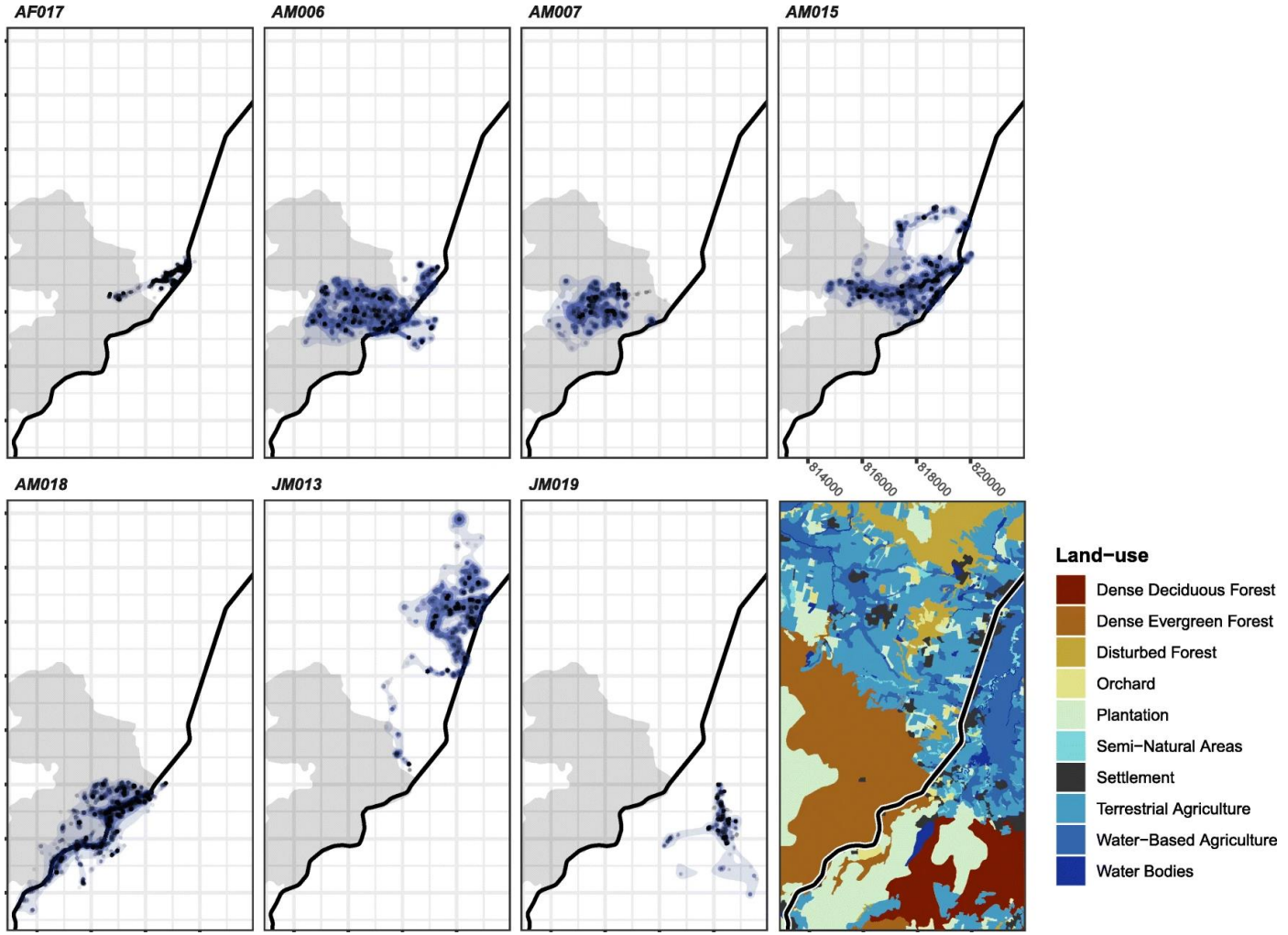
STAATSMINISTERIUM FÜR WISSENSCHAFT KULTUR UND TOURISMUS

Freistaat SACHSEN



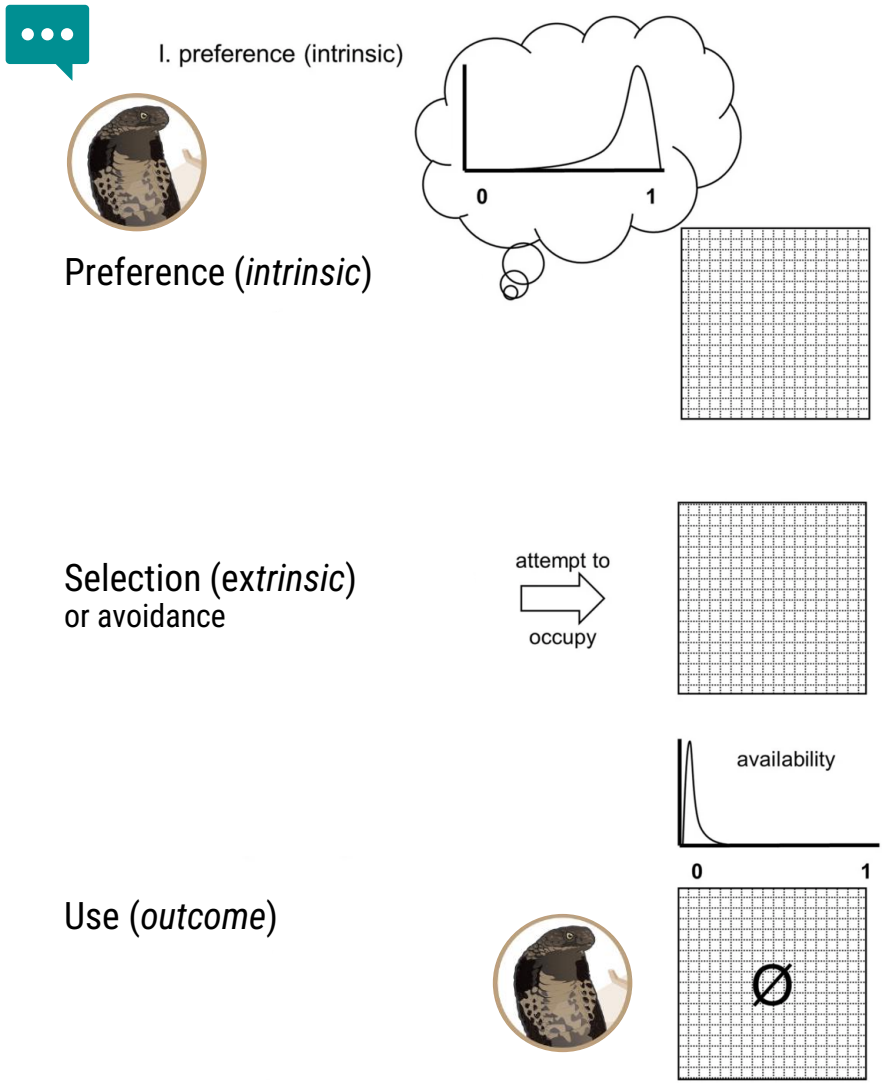
"What landscape features do animals seek or avoid?"

"In which areas of the landscape are animals at risk?"

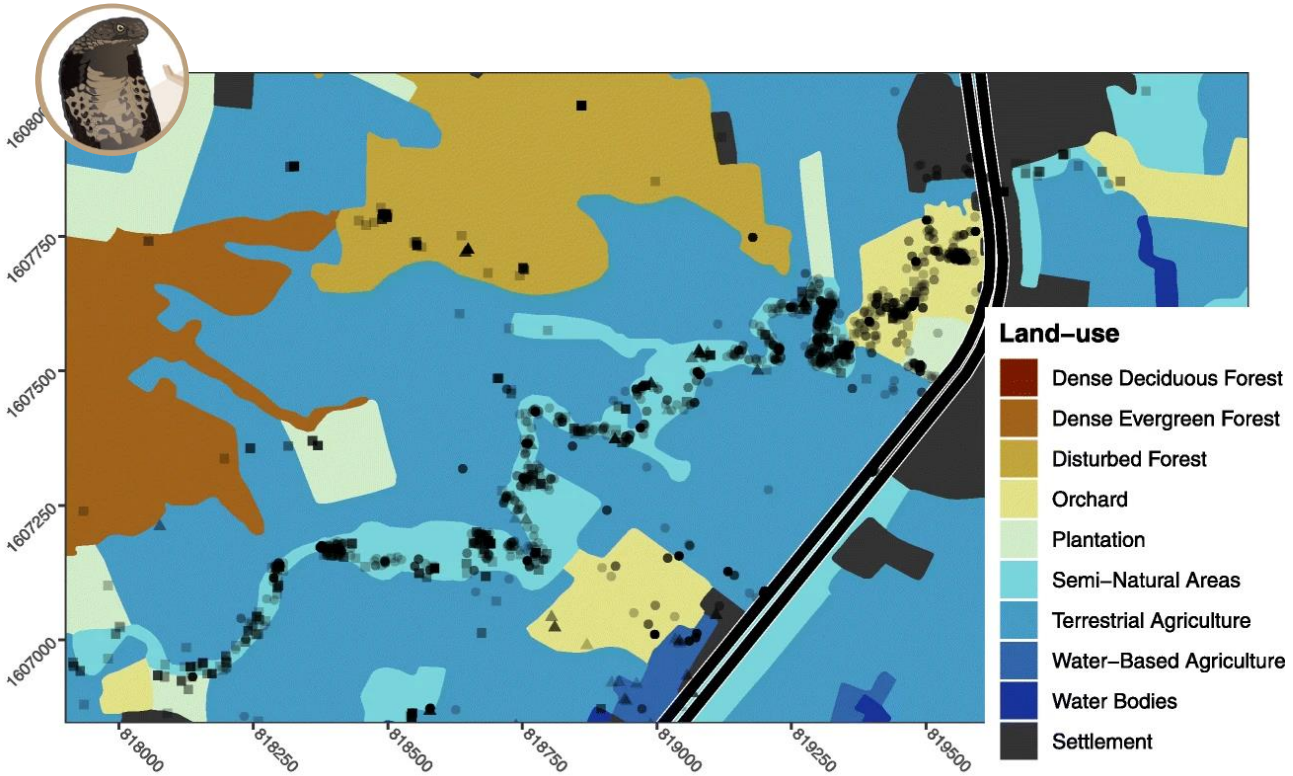


Marshall *et al.* (2020)

DOI: 10.1186/s40462-020-00219-5


I. preference (intrinsic)
0
1
Preference (intrinsic)
Selection (extrinsic)
or avoidance
attempt to
occupy
availability
0
1
Use (outcome)
∅

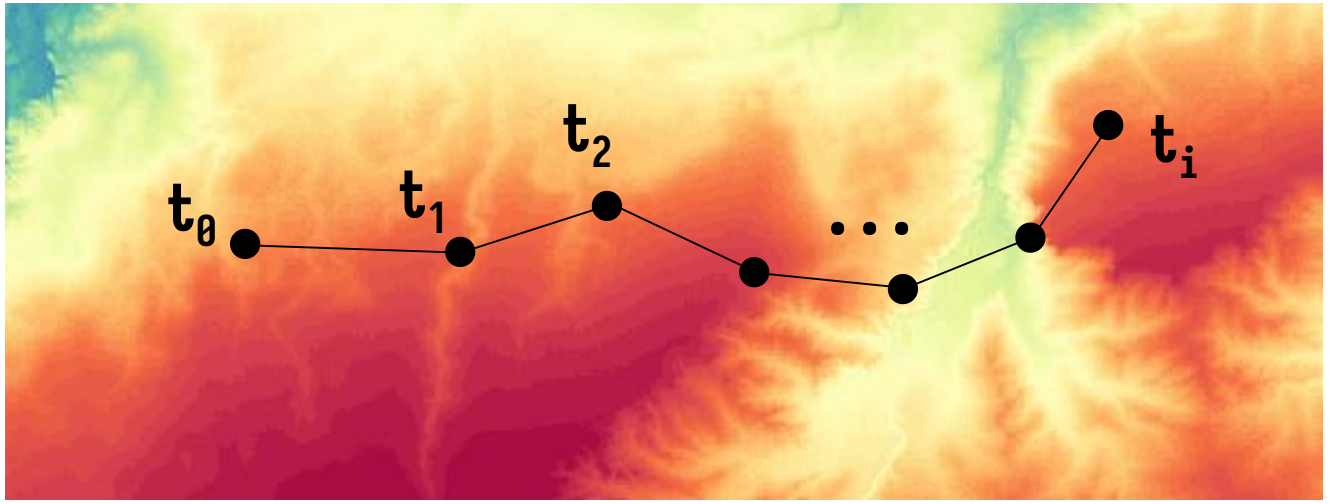
Reliance on **semi-natural areas**,
compared to the surrounding **matrix of agricultural fields**.



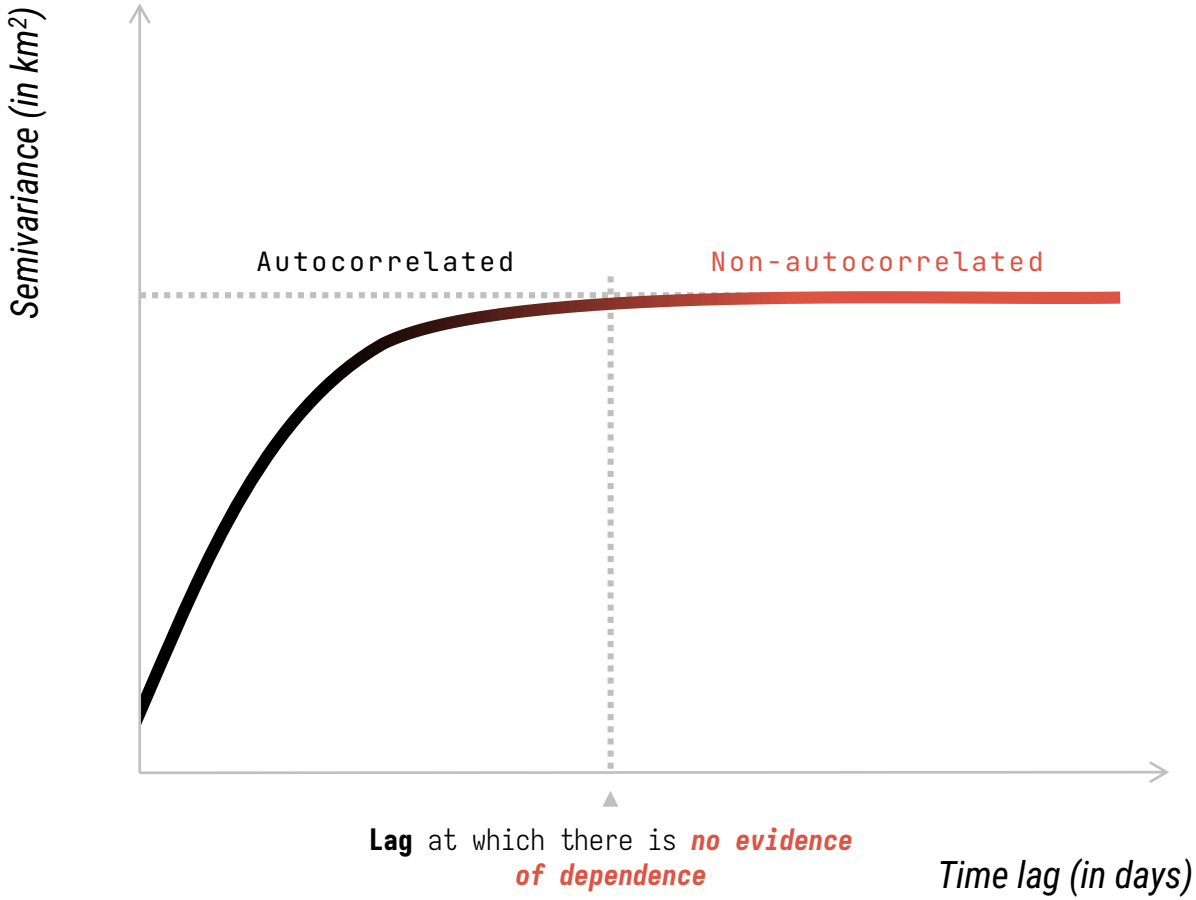
Marshall *et al.* (2020)
DOI: 10.1186/s40462-020-00219-5

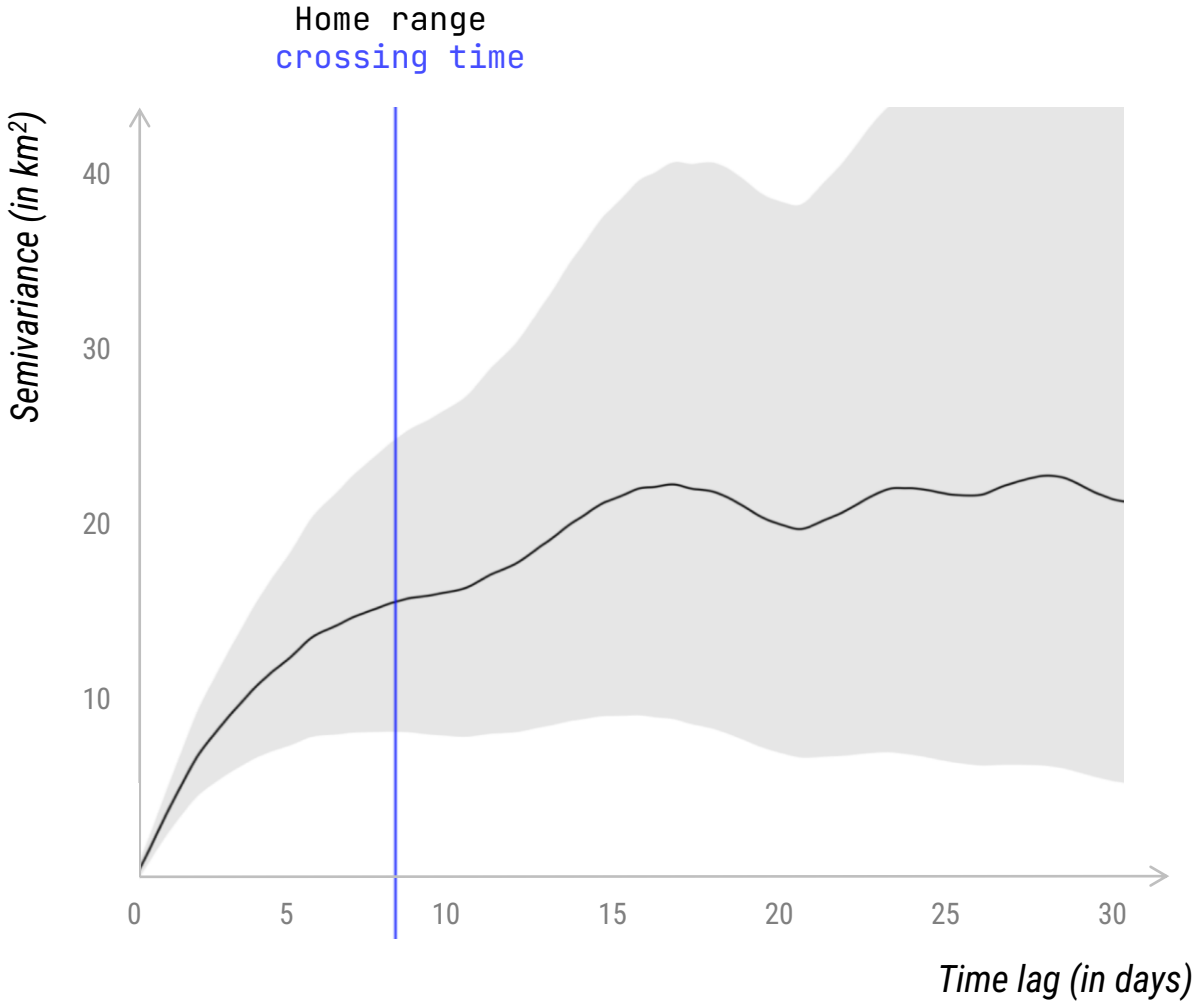
≈ acting as movement corridors through the fragmented landscape?

Assumes that successive positions are independent. However, …



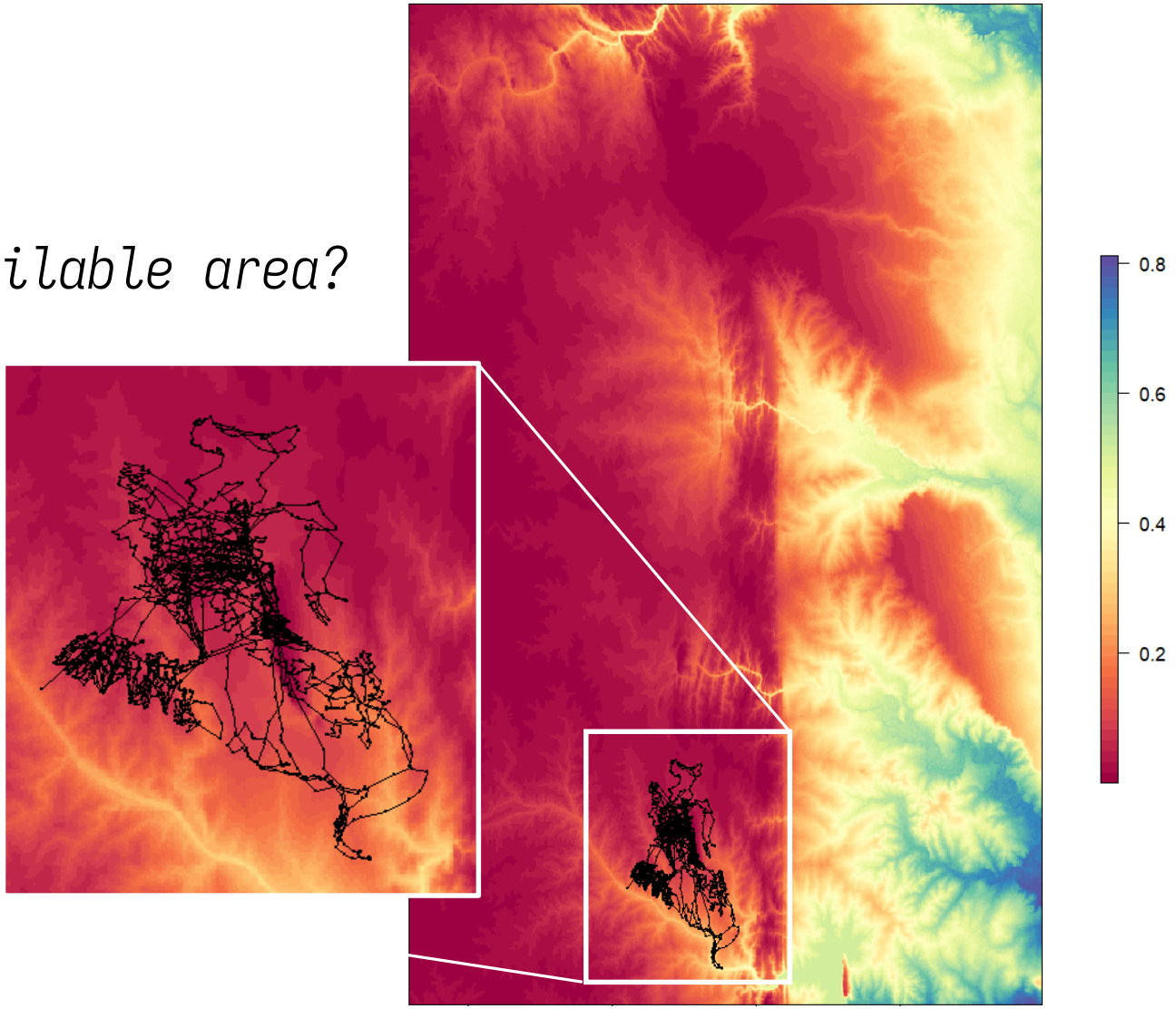
An animal's location at time t_i is a function of both resource selection and its location at time t_i-1.


Semivariance (in km²)
Autocorrelated
Non-autocorrelated
Lag at which there is no evidence of dependence
Time lag (in days)

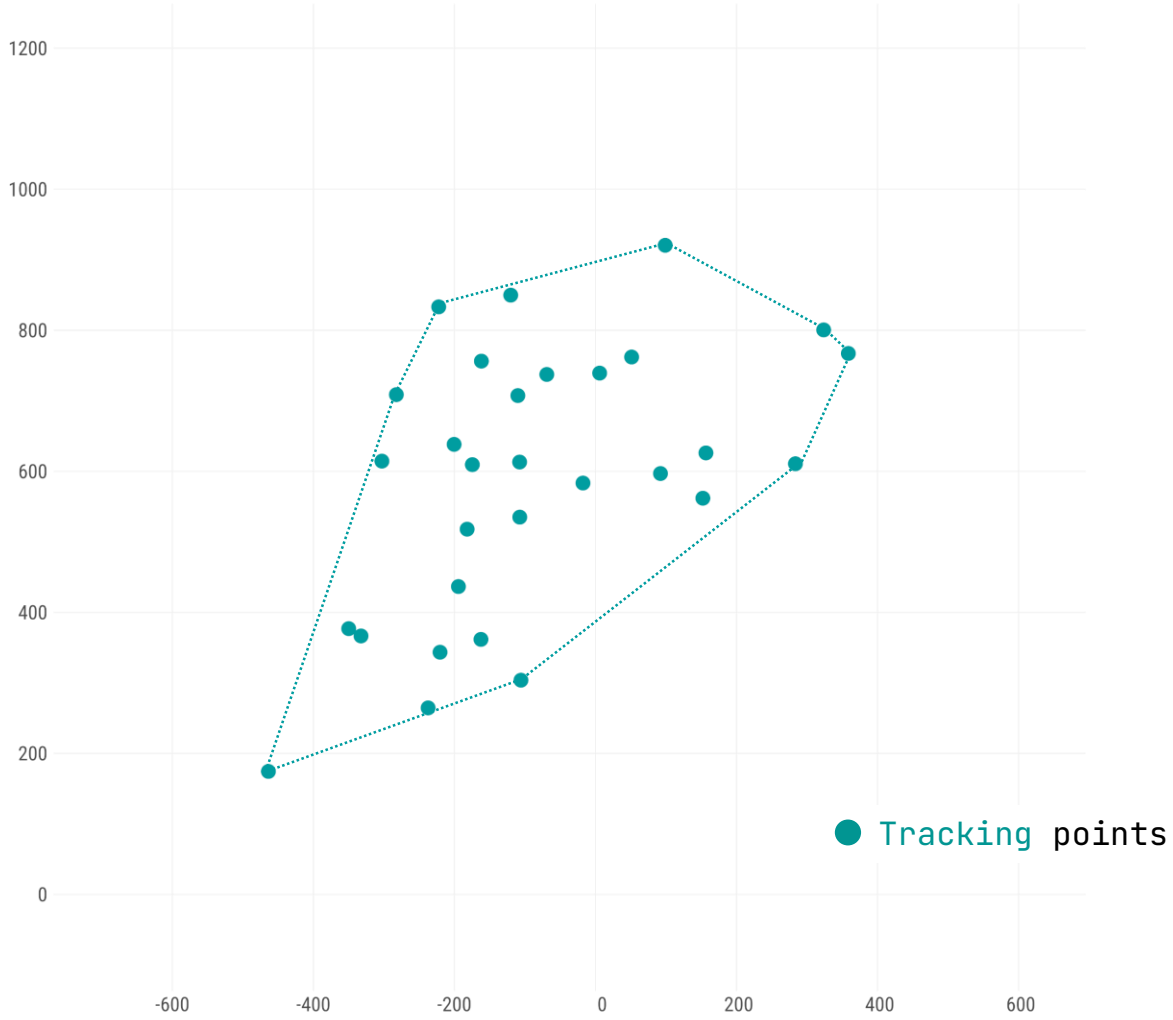


Lag > ***blue***, we are fulfilling the assumptions of RSF.

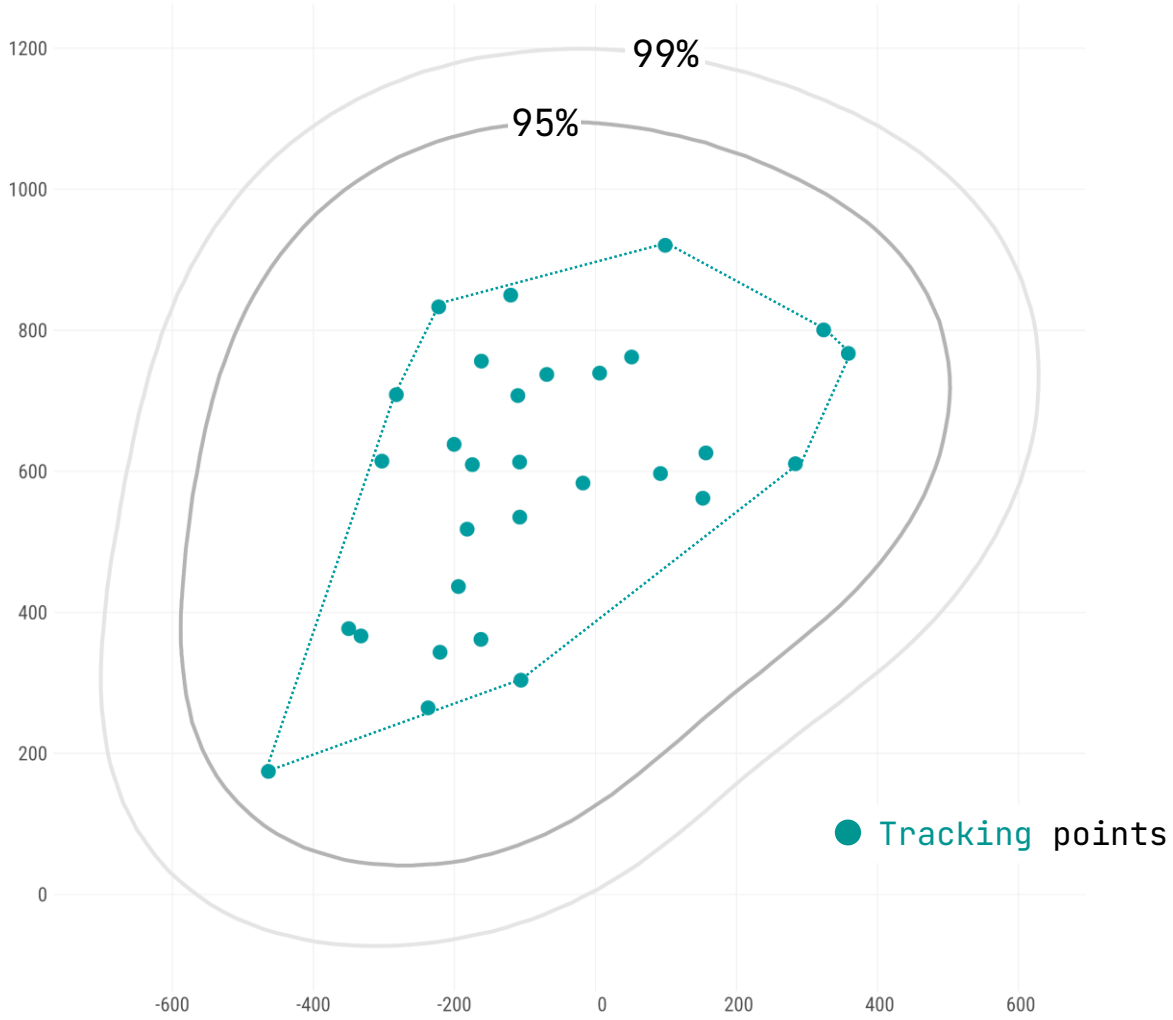
What is the available area?



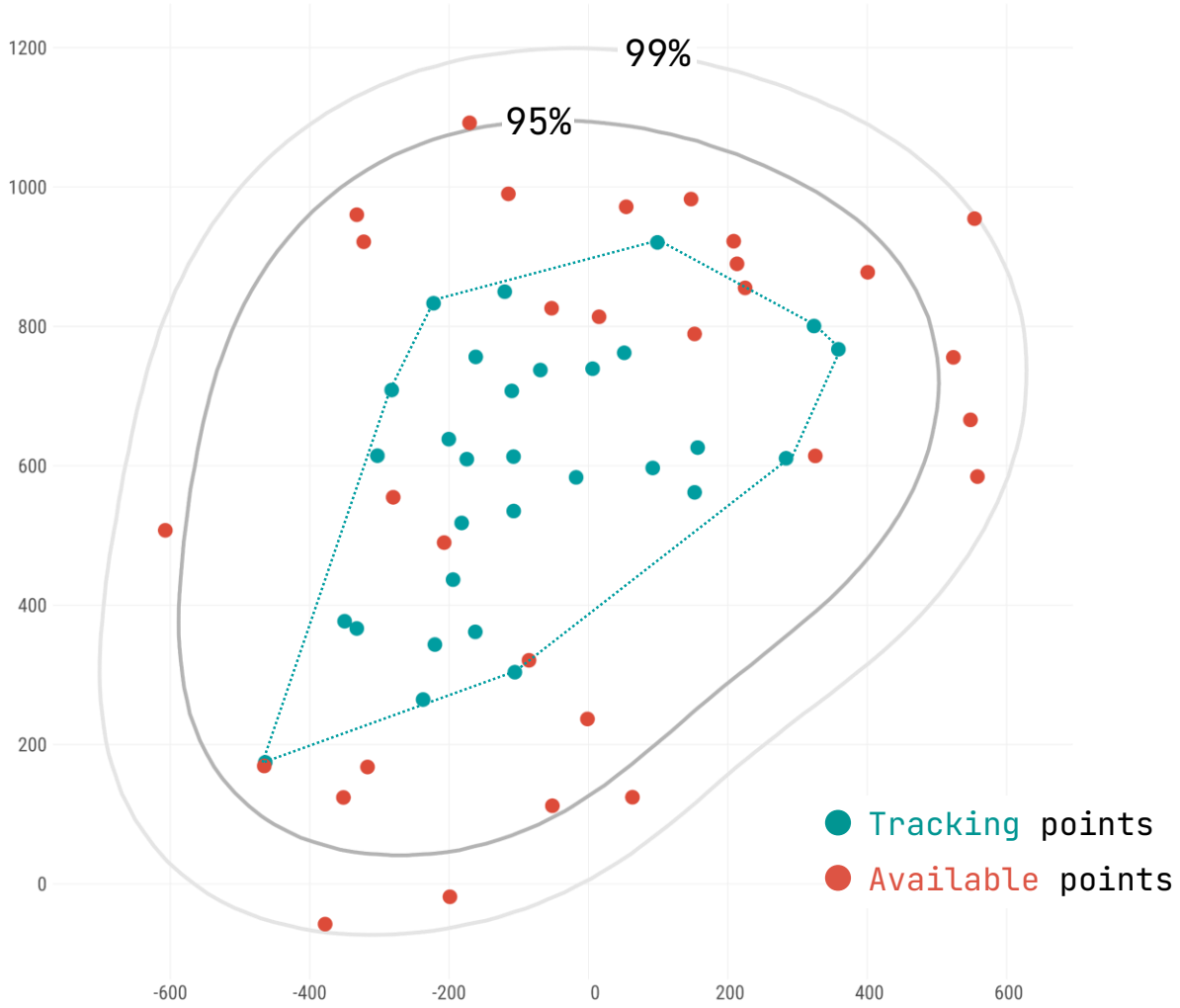
Resource selection functions



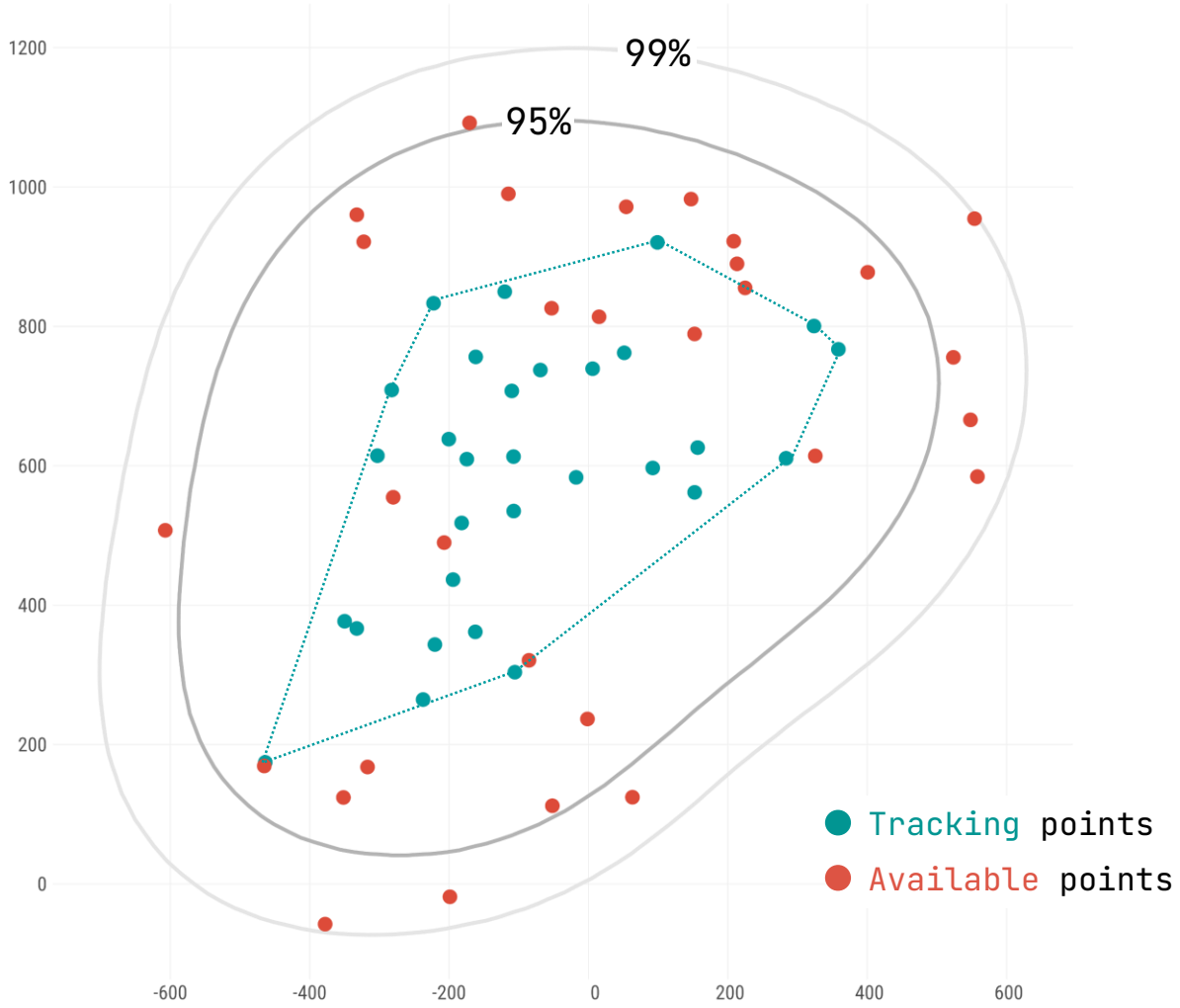
Resource selection functions



i.simoes-silva@hzdr.de



Framed as comparing data to *random* available points.



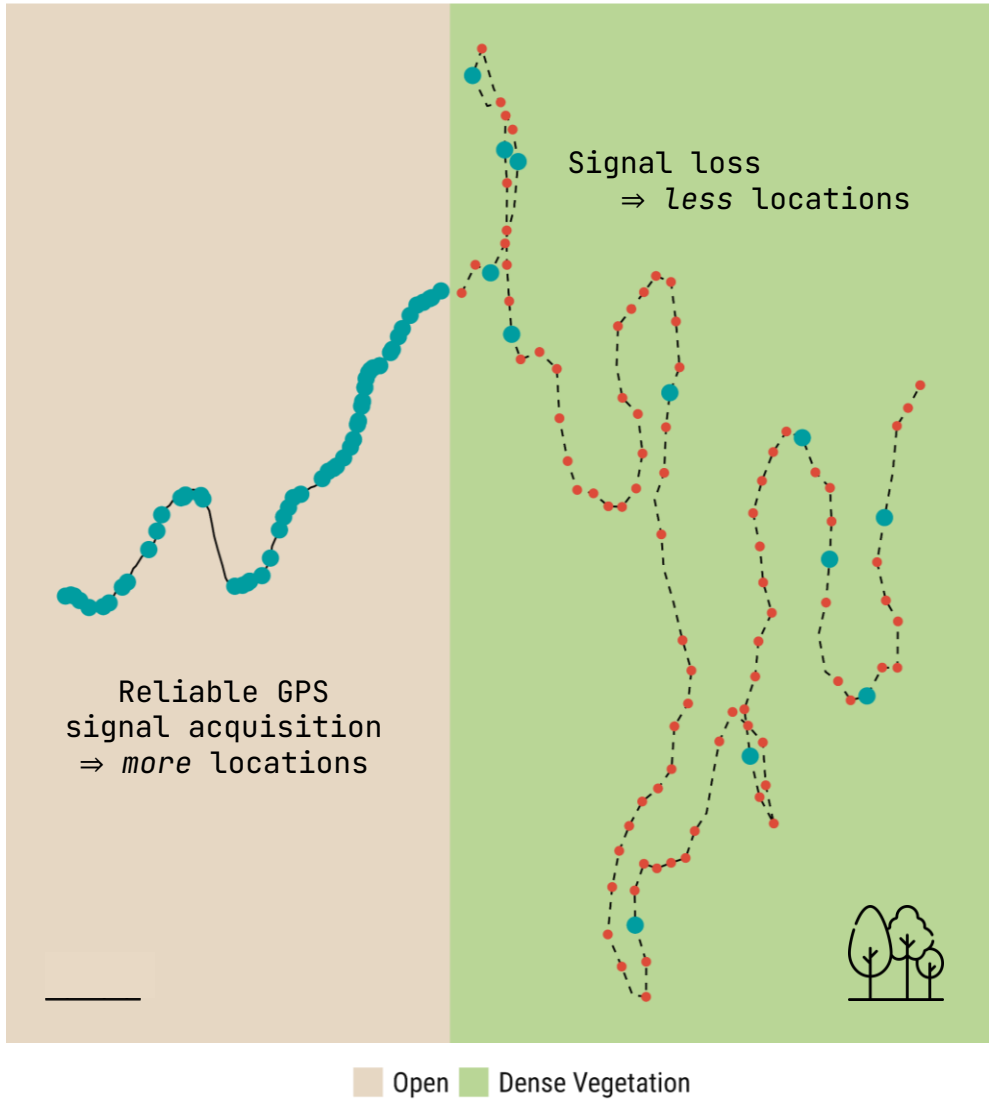
Framed as comparing data to *random* available points.

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.

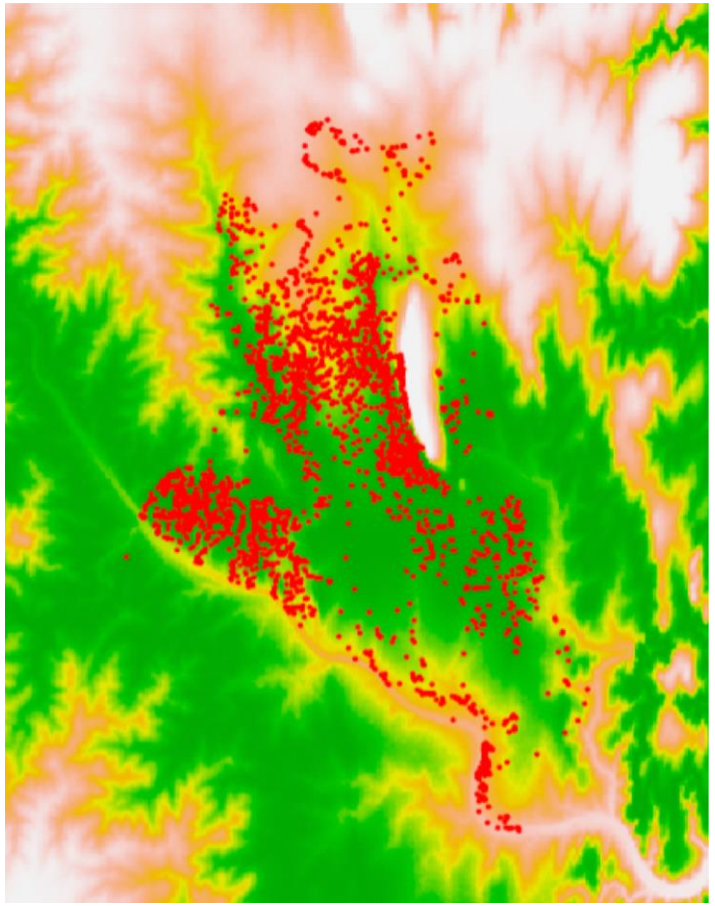
Uncertainty in the available area is not propagated into the RSF models.

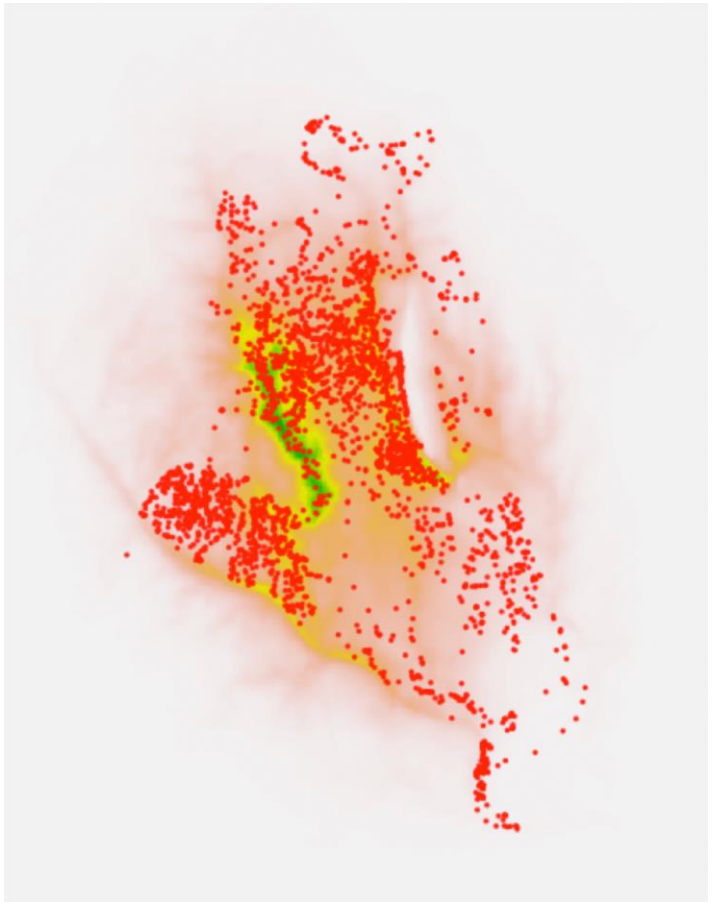


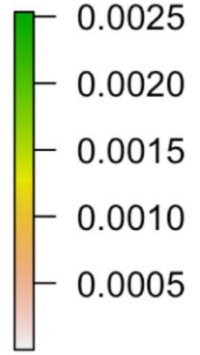
Failing to account for autocorrelation is more problematic if environmental covariates (*e.g.*, **dense vegetation**) cause non-random data gaps.

What is the available area?

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







i.simoes-silva@hzdr.de

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

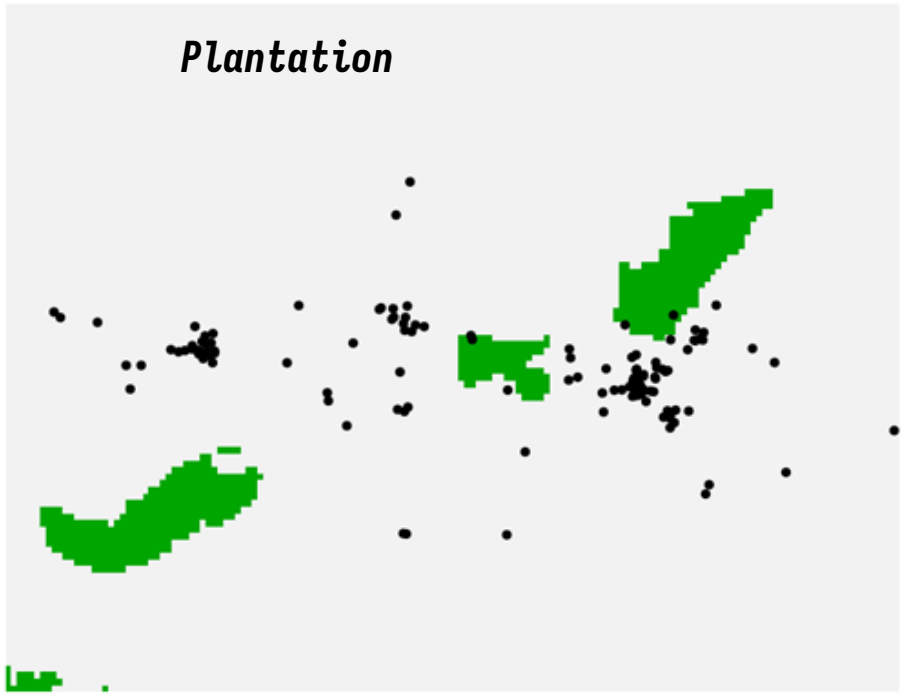
Integrated RSFs

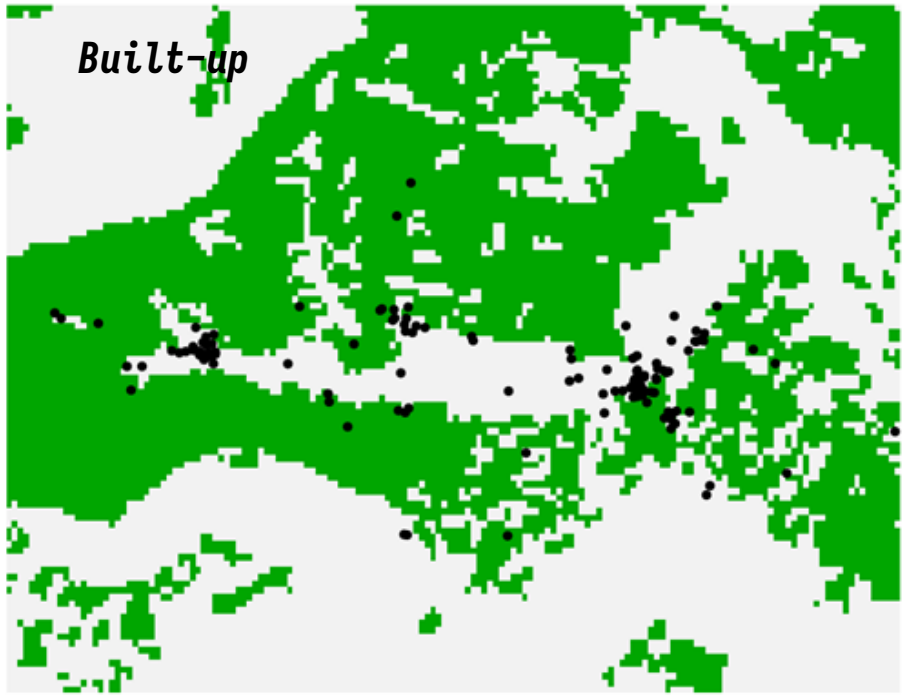
Solutions:

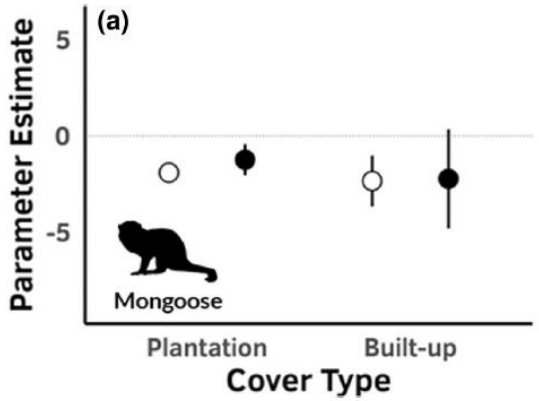
1. Automatically checks for numerical convergence
2. Down-weights data to reduce pseudoreplication
3. Re-weights data to mitigate differential autocorrelation
4. Samples availability according to null movement process

✉ i.simoes-silva@hzdr.de

144 locations over 58 days



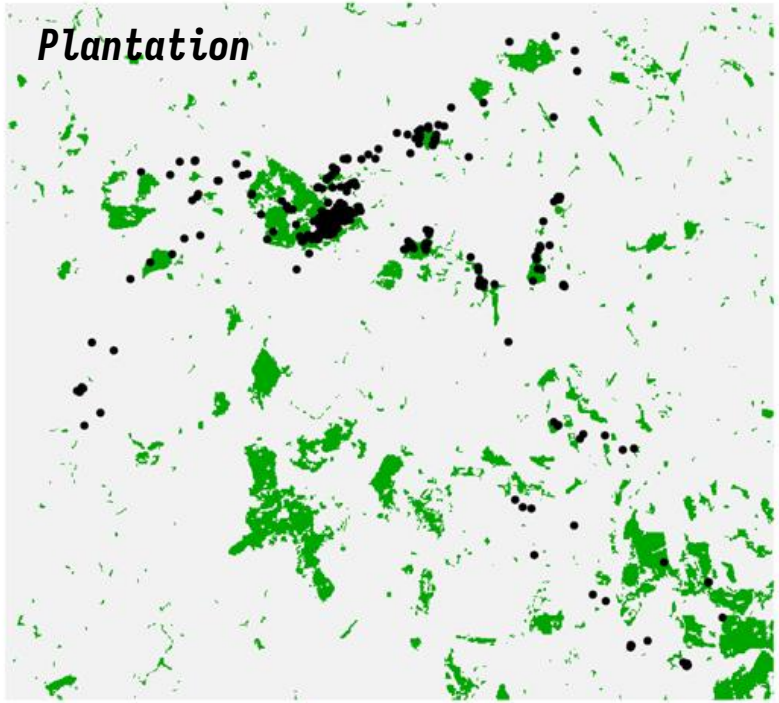


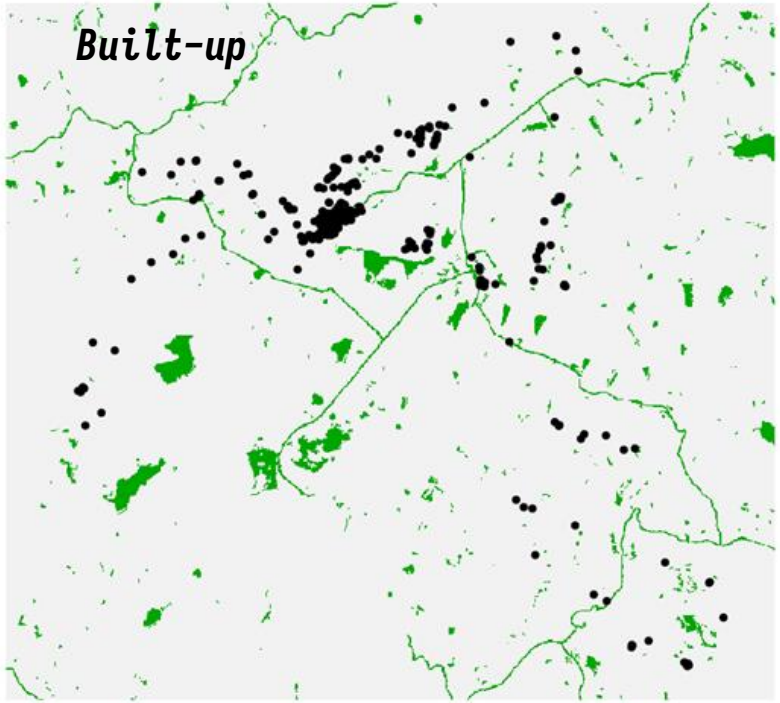


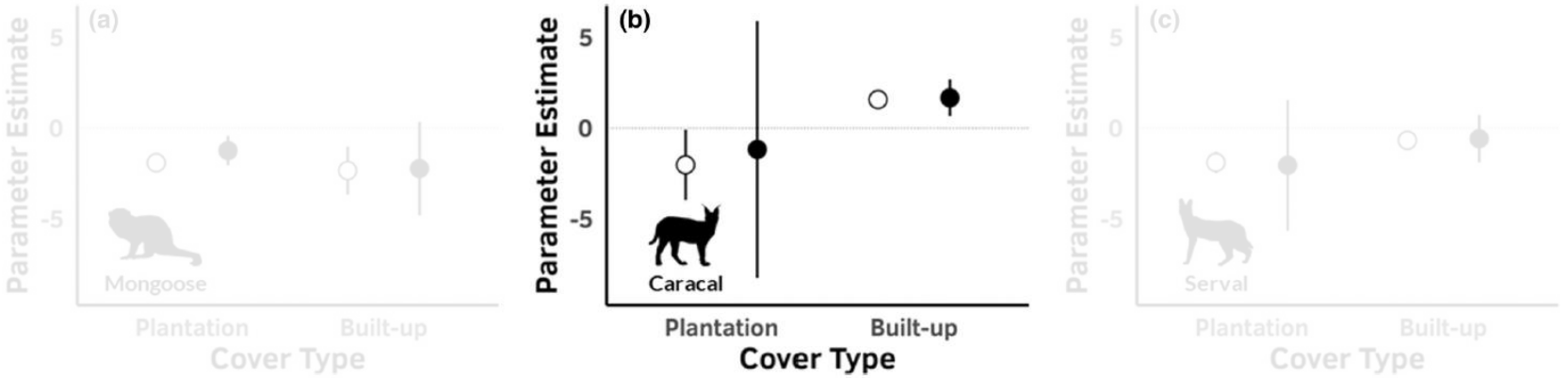
i.simoes-silva@hzdr.de

504 locations over 85 days

Caracal

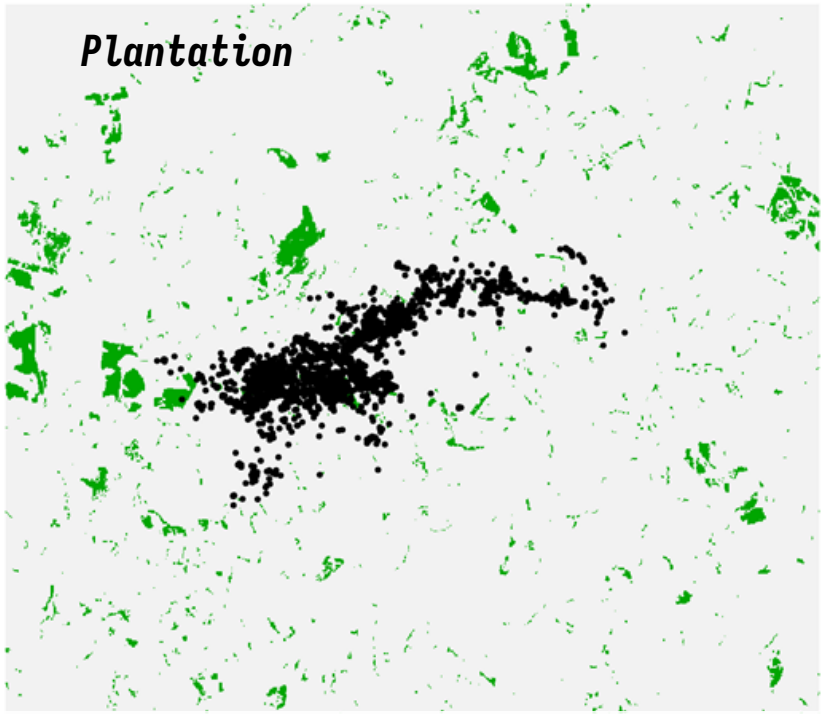


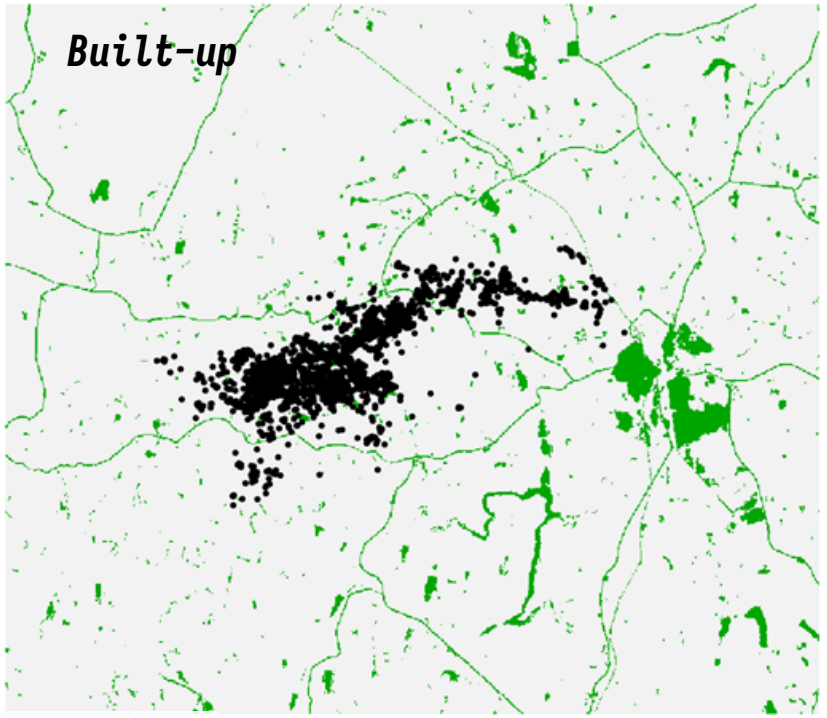


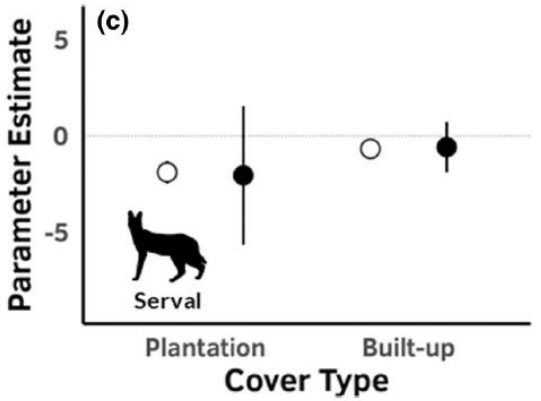


3603 locations over 321 days

Serval







i.simoes-silva@hzdr.de

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

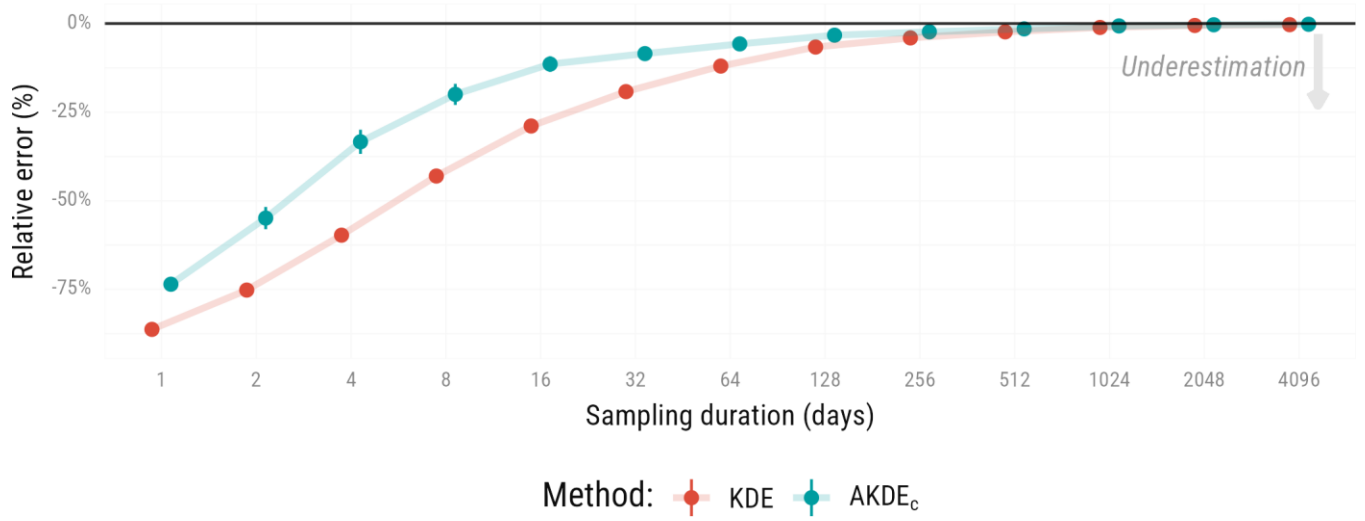
For IID data

- 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

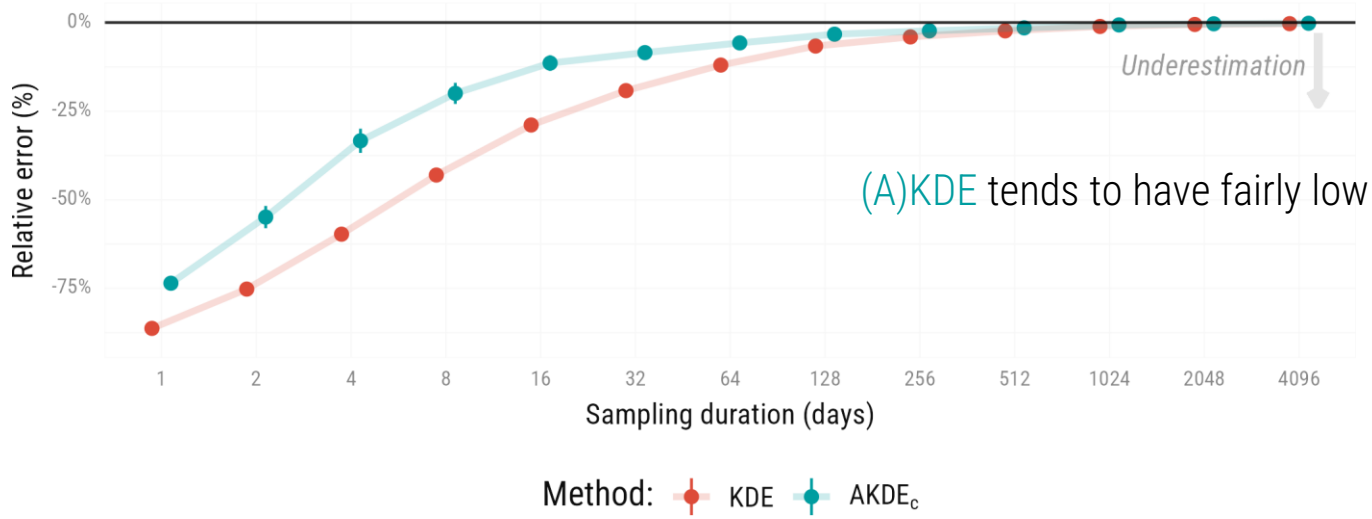
For IID data

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

AKDE

For autocorrelated data

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



(A)KDE tends to have fairly low bias,

KDE

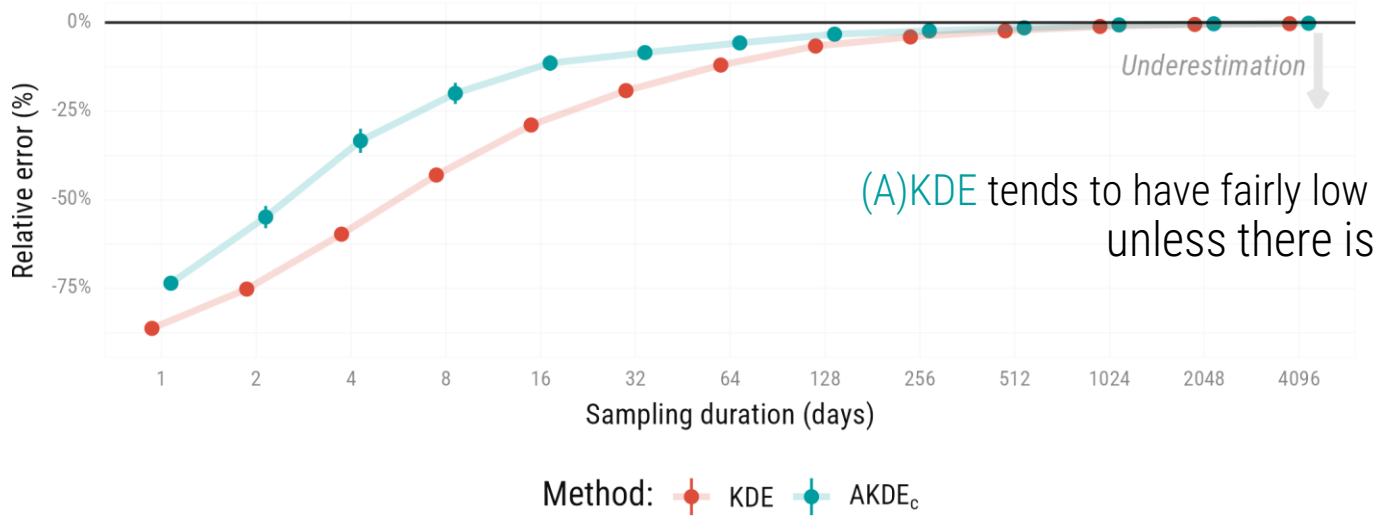
For IID data

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

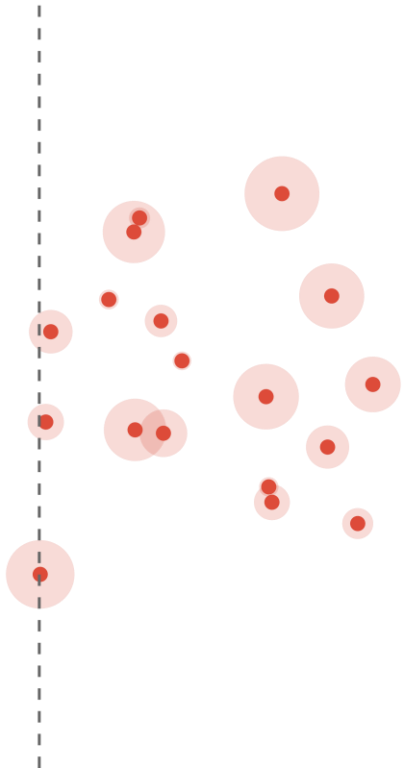
AKDE

For autocorrelated data

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



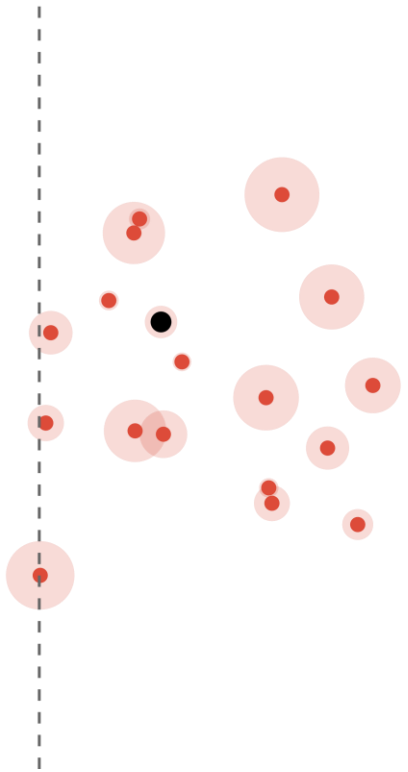
(A)KDE tends to have fairly low bias,
unless there is discontinuity.



"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.

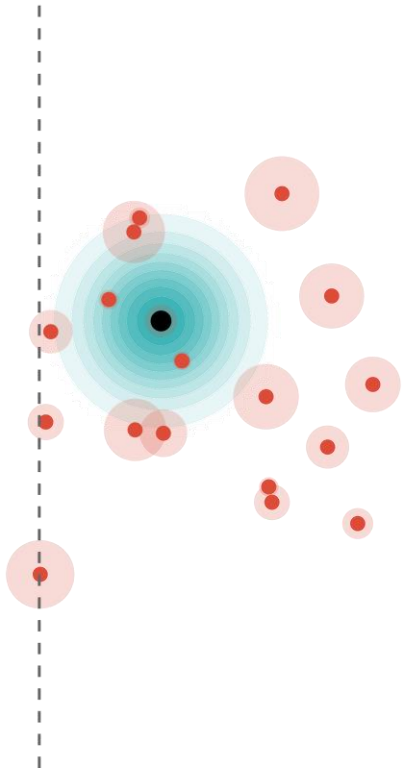
i.simoes-silva@hzdr.de



"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.

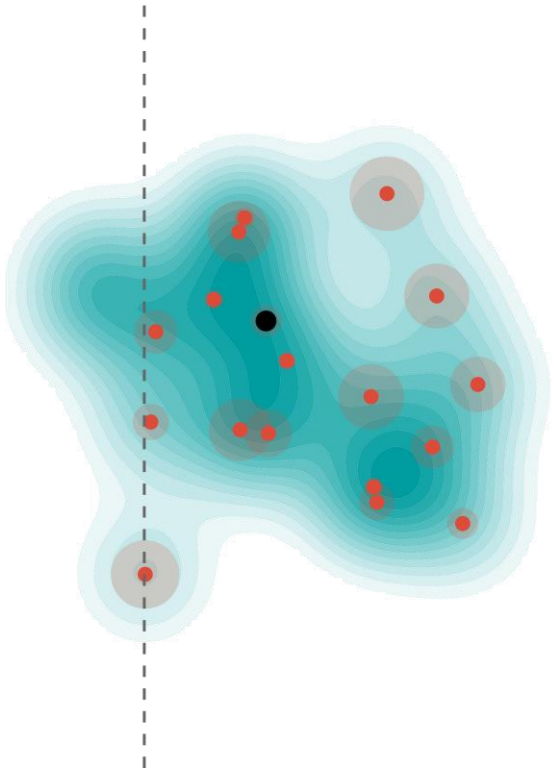
i.simoes-silva@hzdr.de



"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.

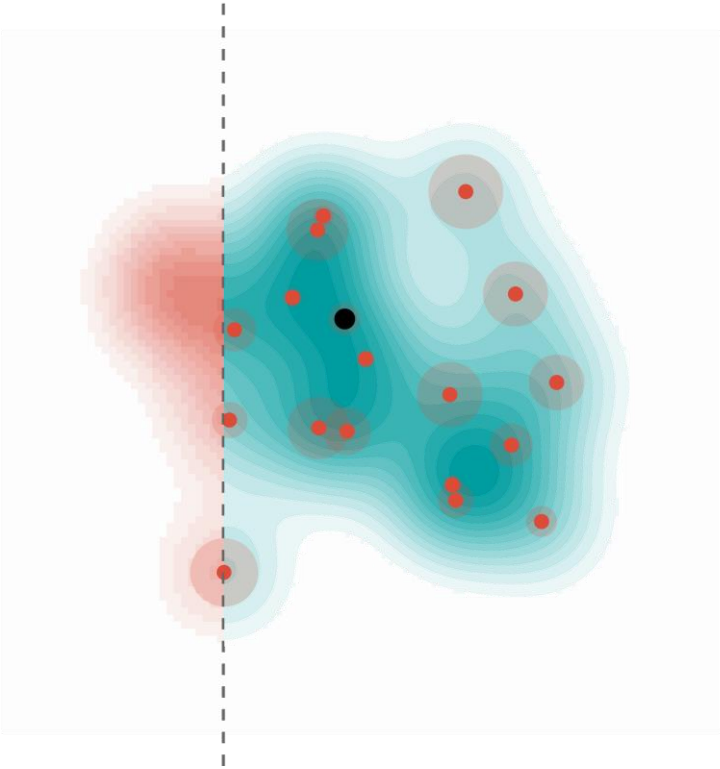
i.simoes-silva@hzdr.de



"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.simoes-silva@hzdr.de

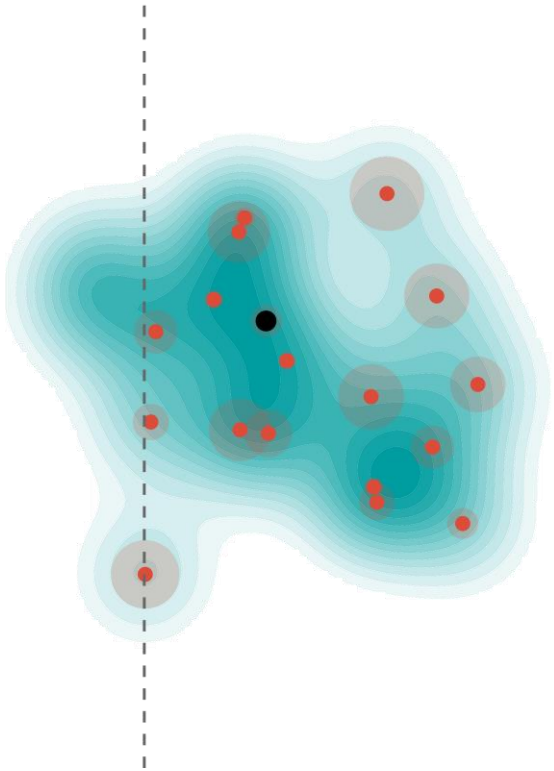


"Spillover bias"

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.

i.simoes-silva@hzdr.de



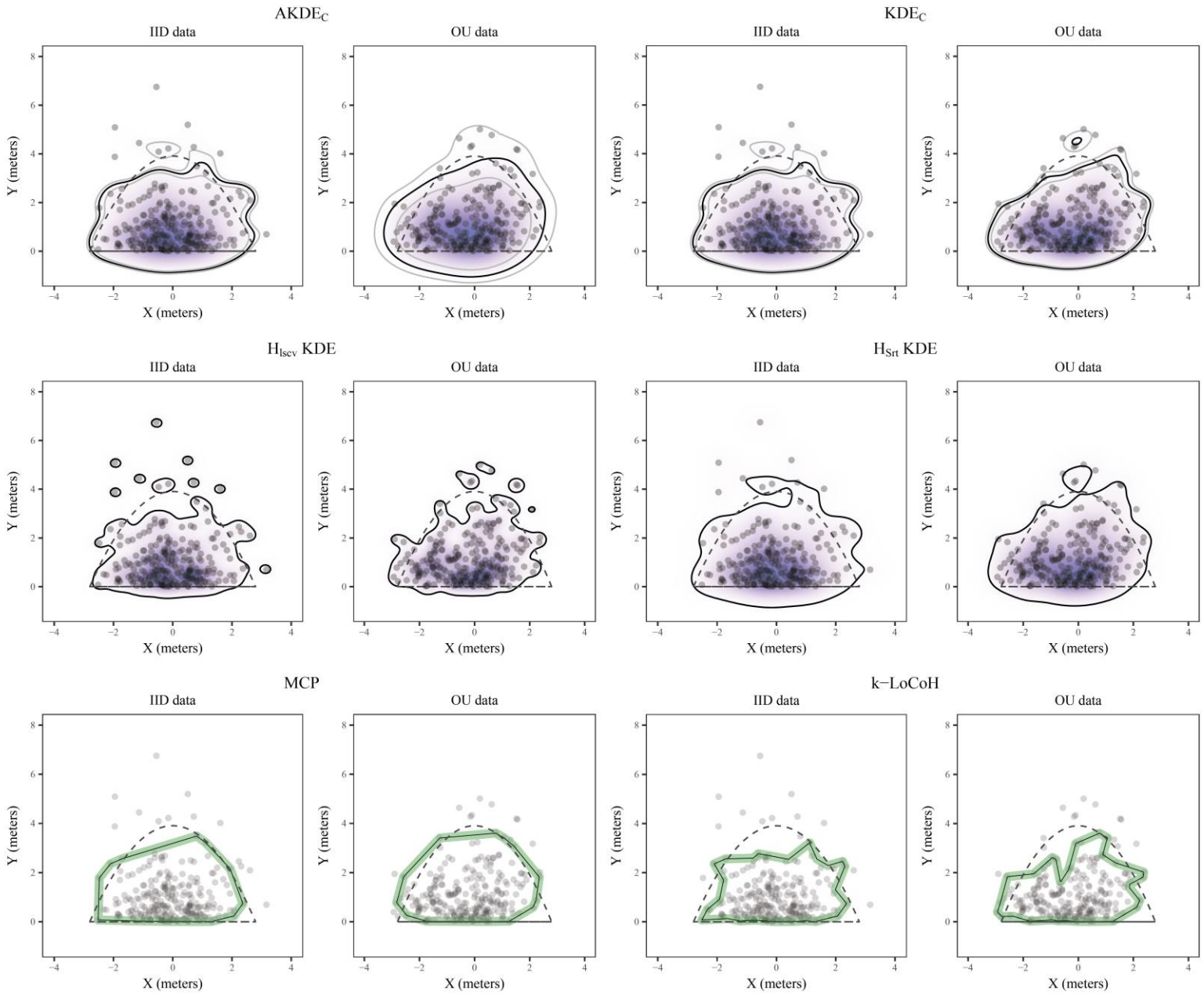
"Discontinuity bias"

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.

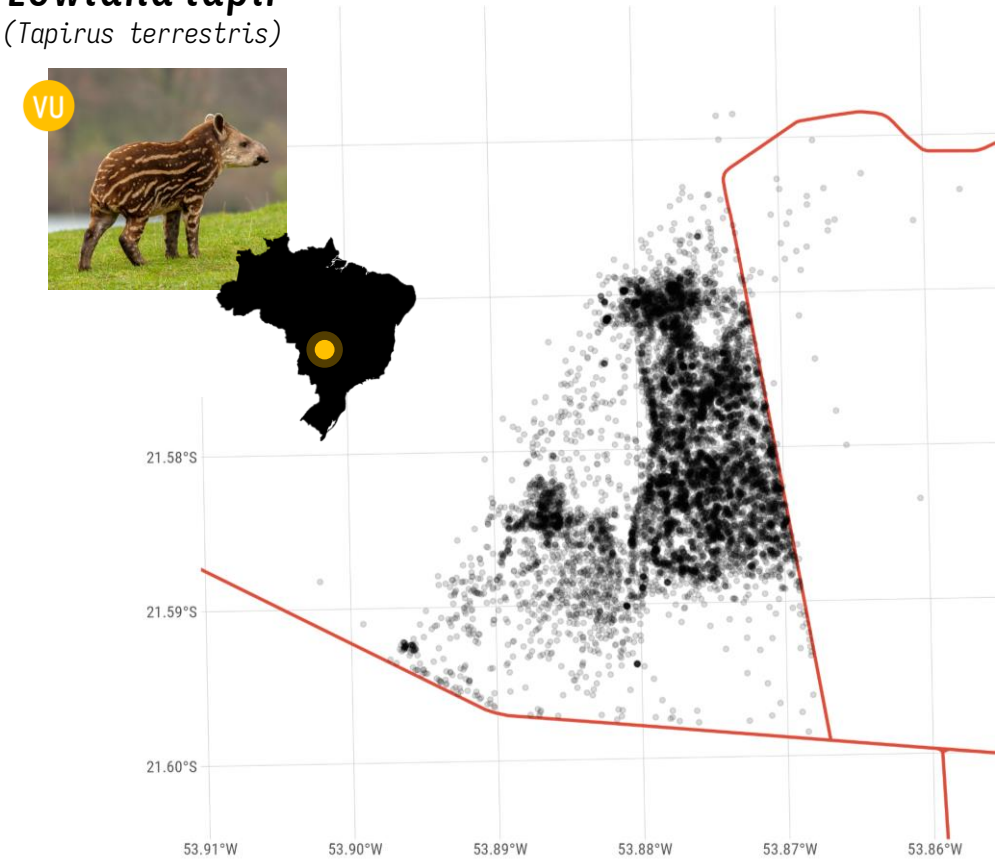
i.simoes-silva@hzdr.de

Method comparison

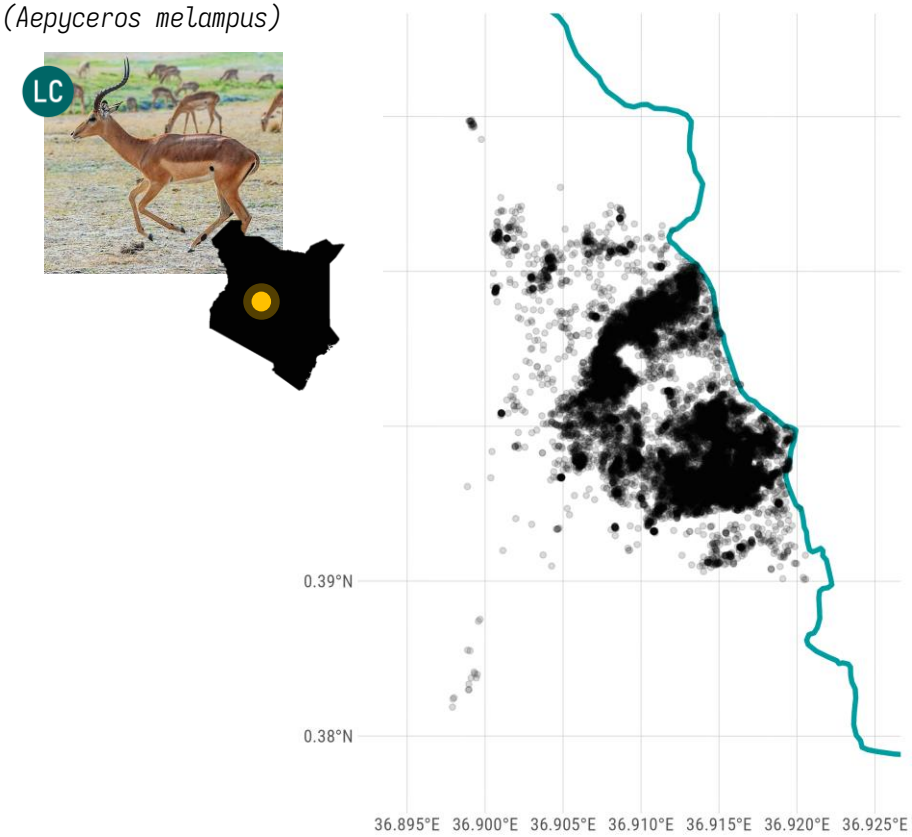


i.simoes-silva@hzdr.de

Lowland tapir
(Tapirus terrestris)



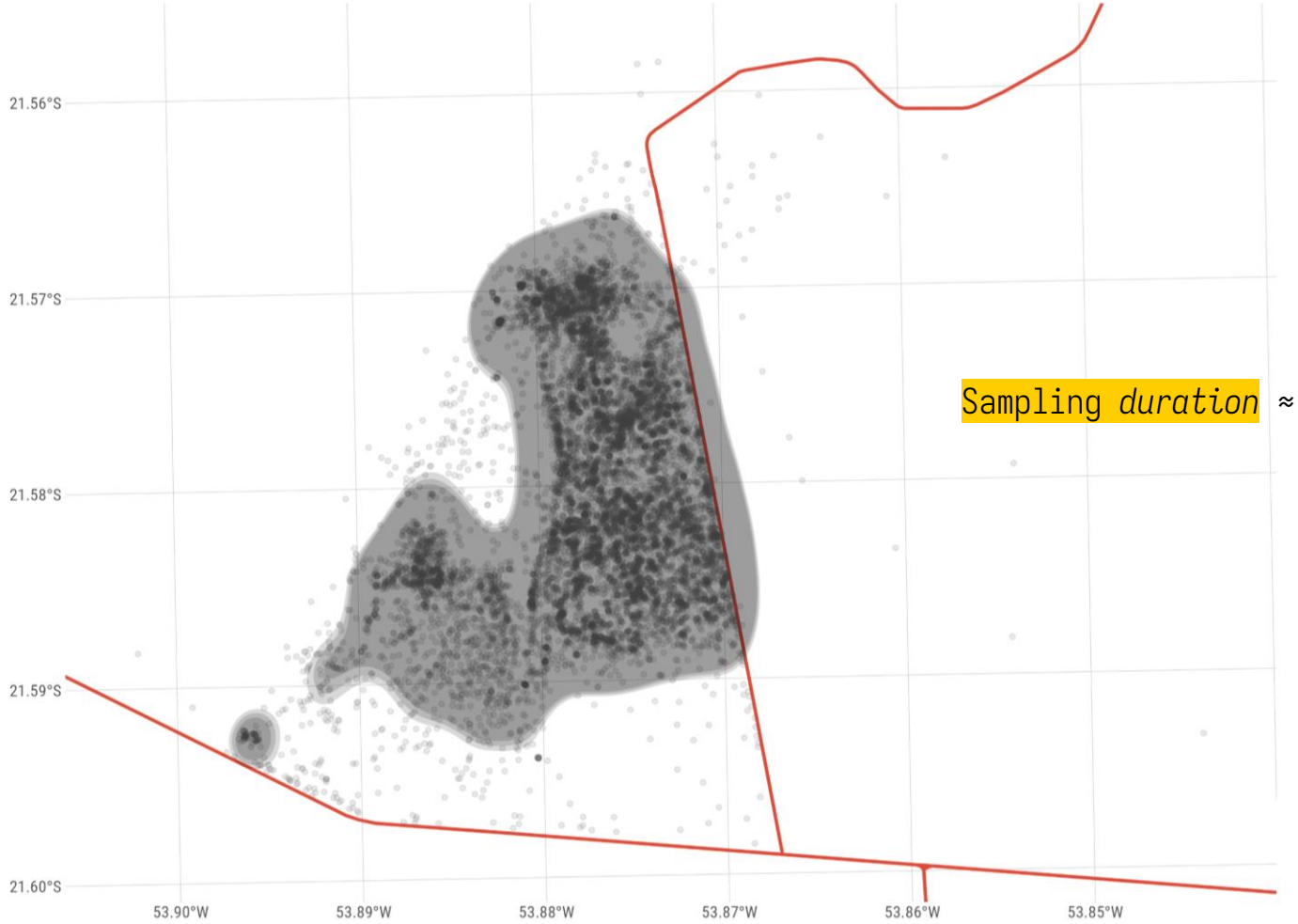
Impala
(Aepyceros melampus)



i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

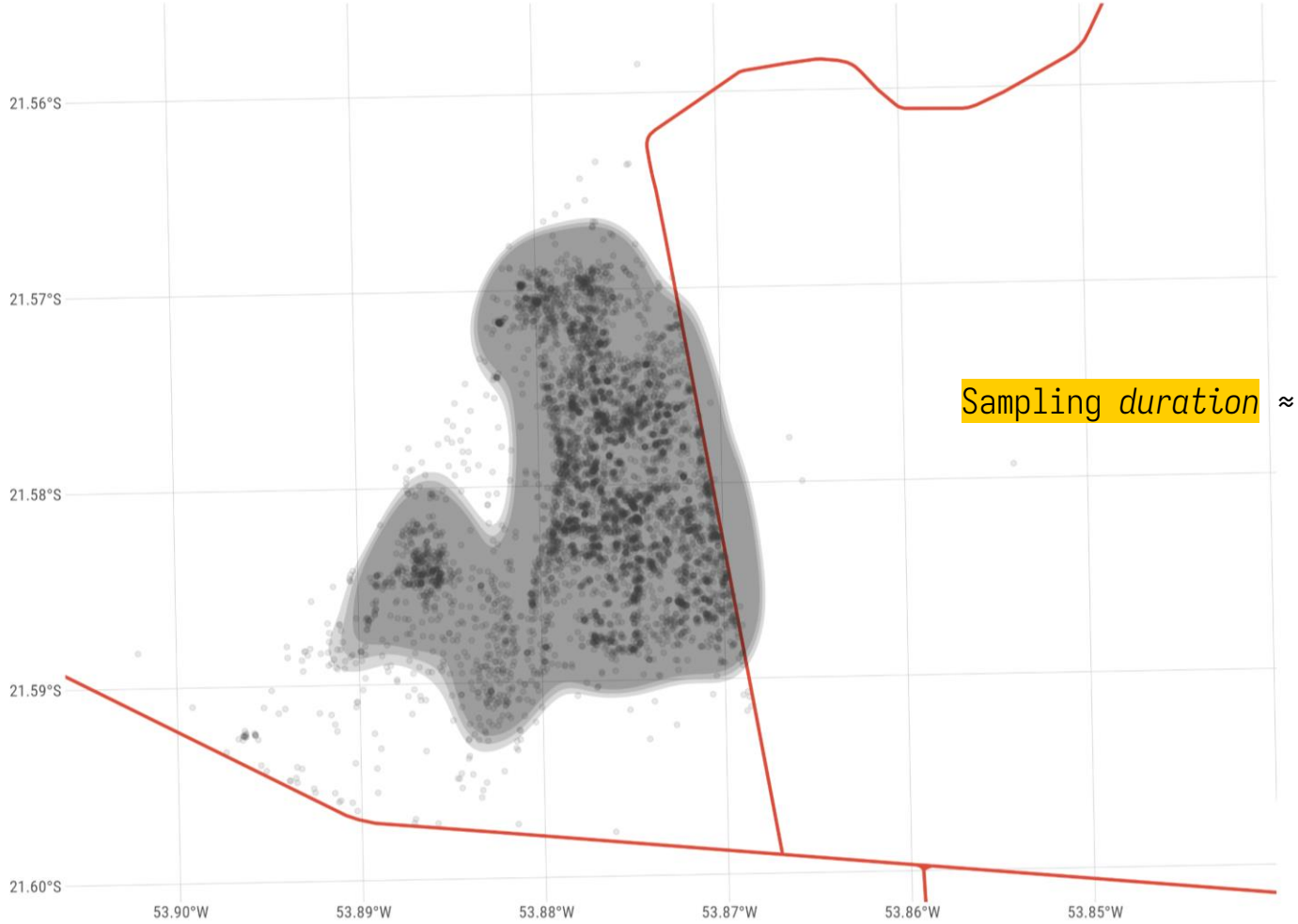


Sampling *duration* ≈ 18 months

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

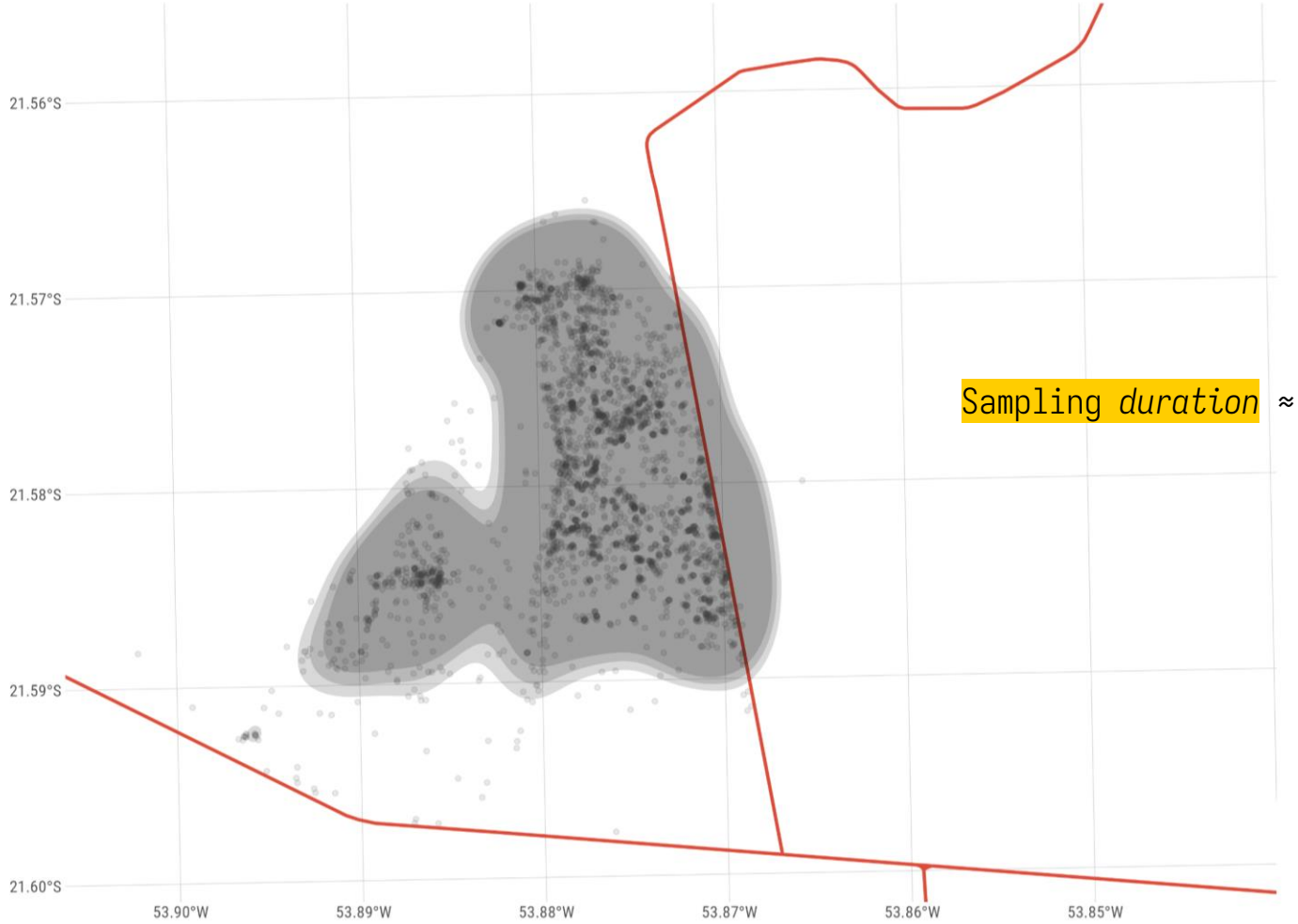


Sampling *duration* ≈ 9 months

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

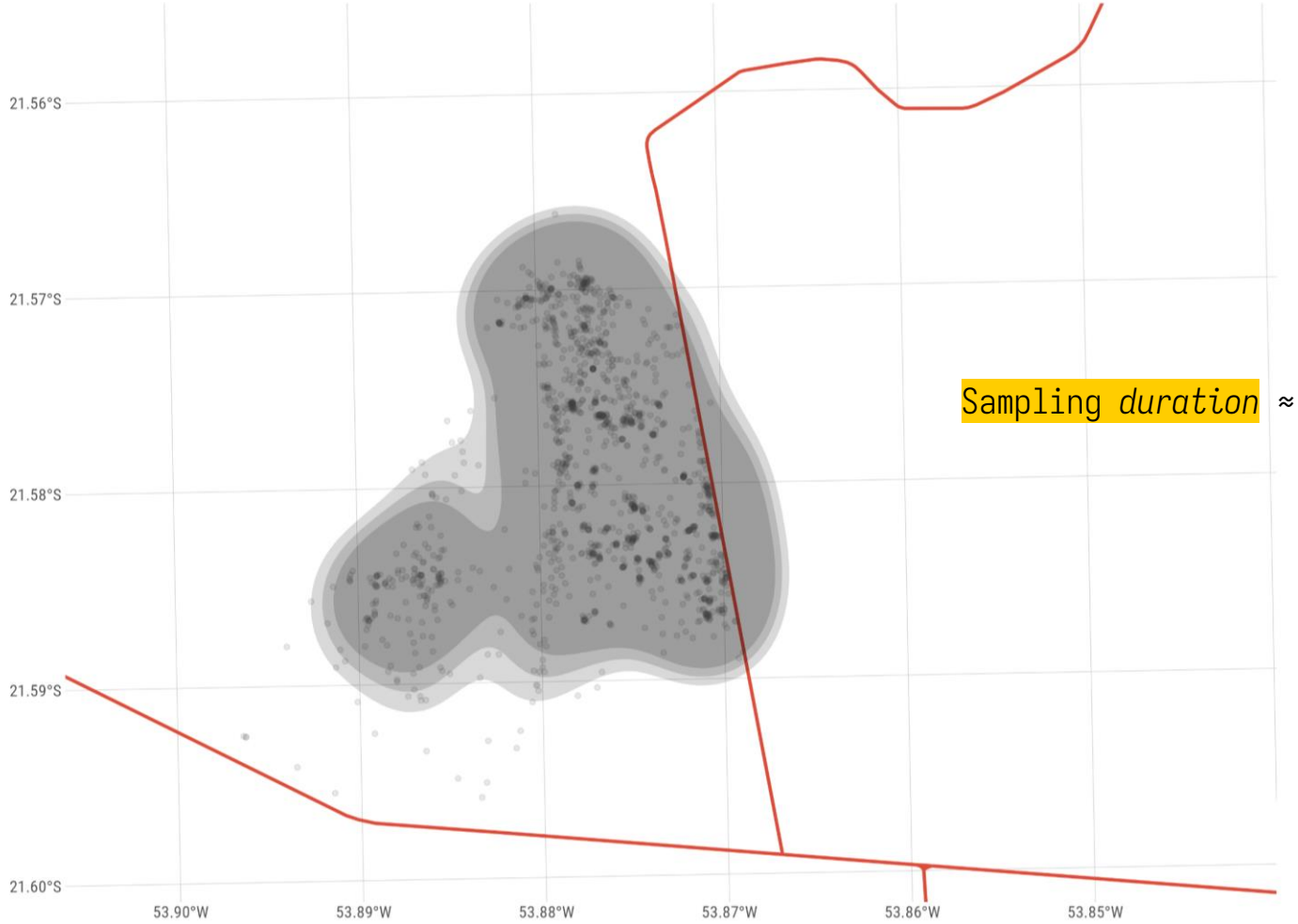


Sampling *duration* ≈ 4.5 months

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

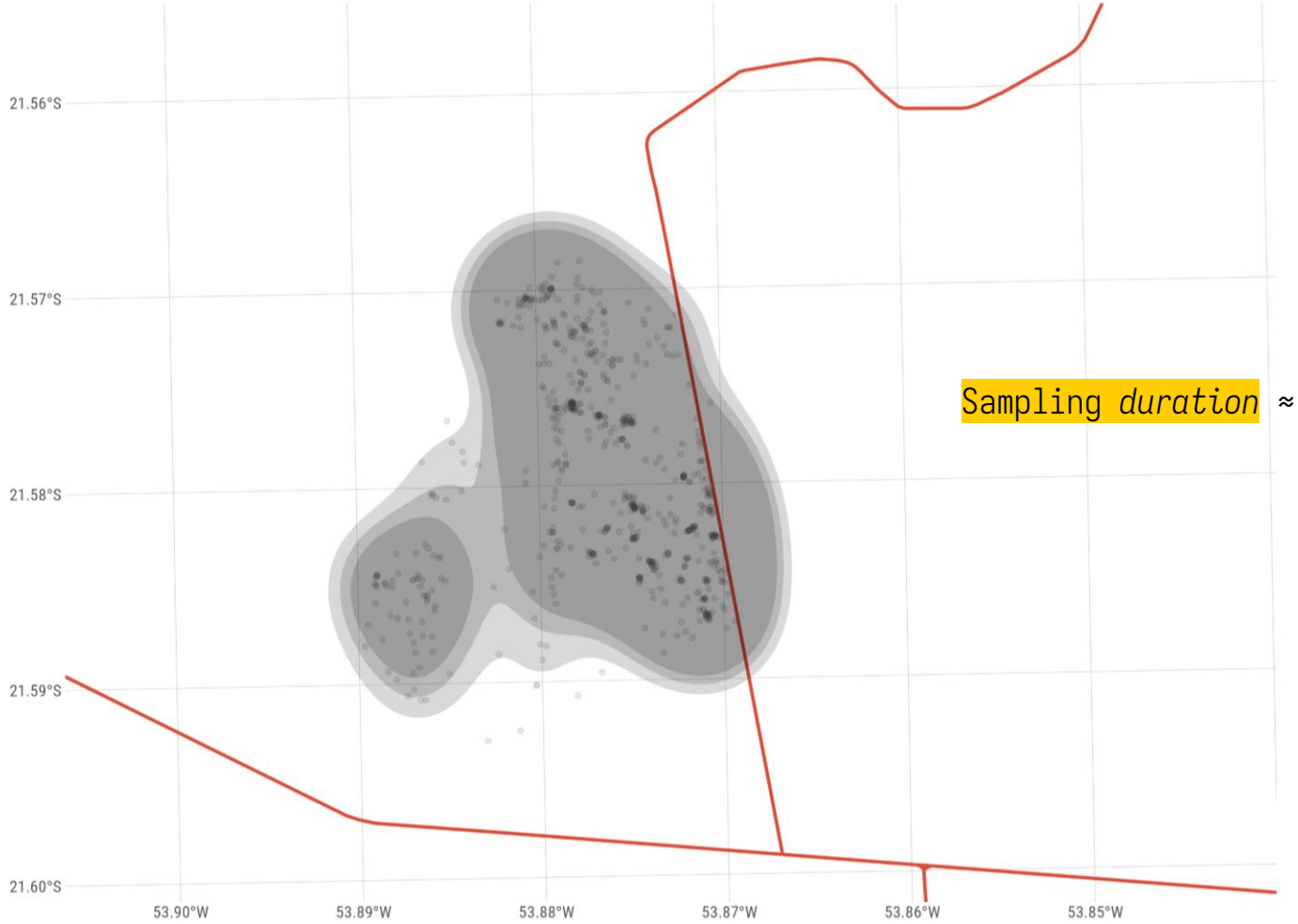


Sampling *duration* ≈ 2.25 months

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

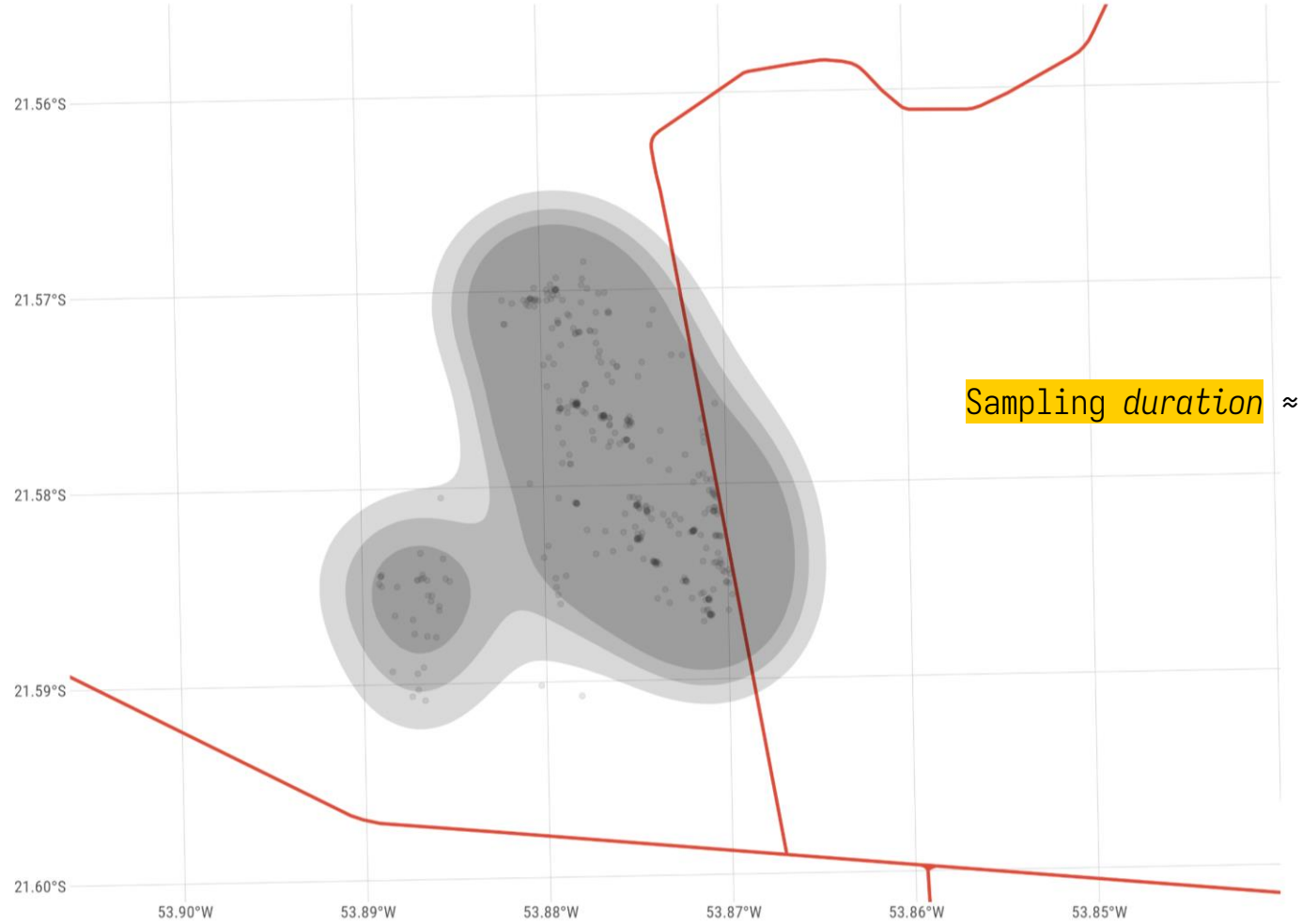


Sampling *duration* ≈ 1.1 months

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

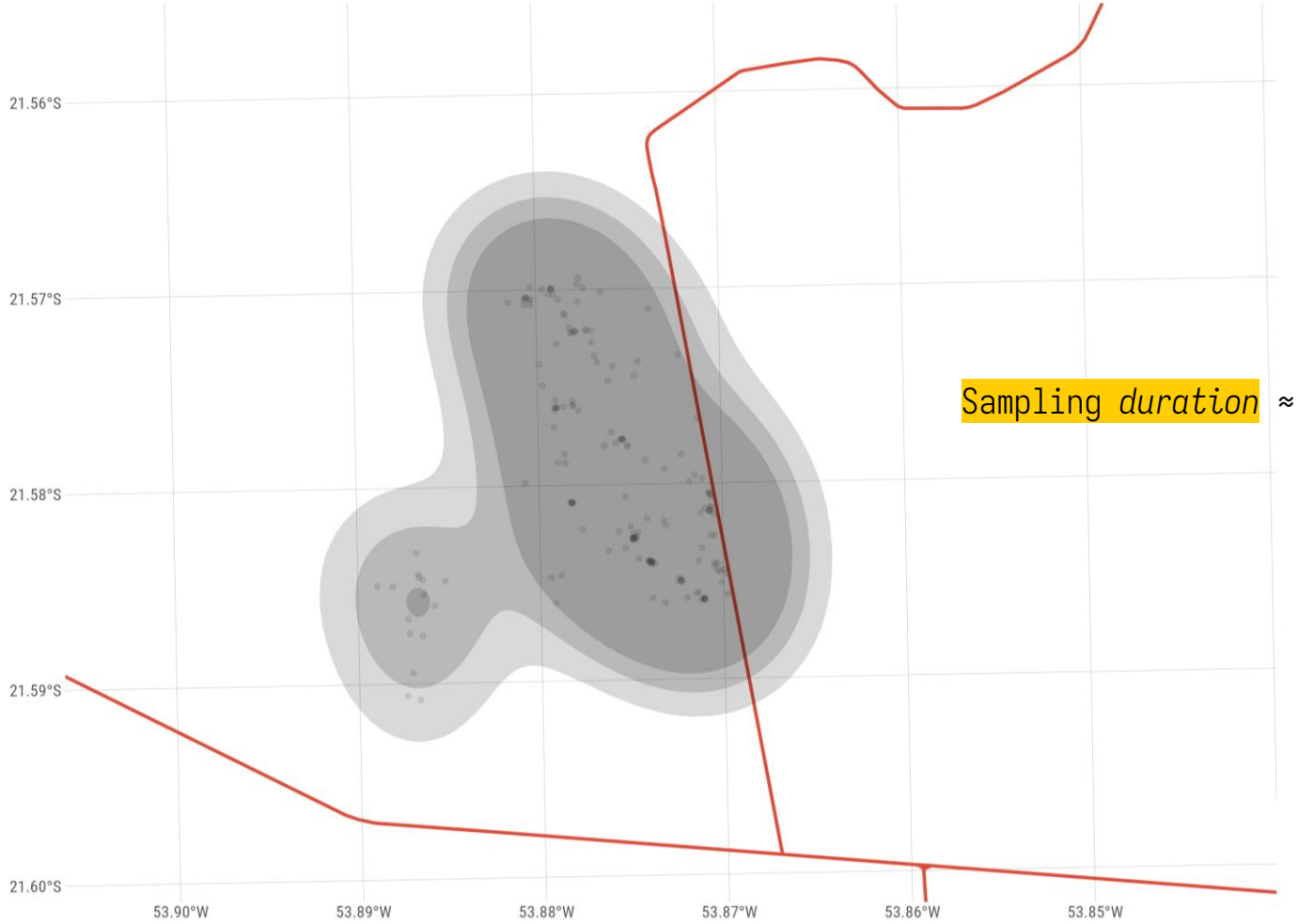


Sampling *duration* ≈ 15 days

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)

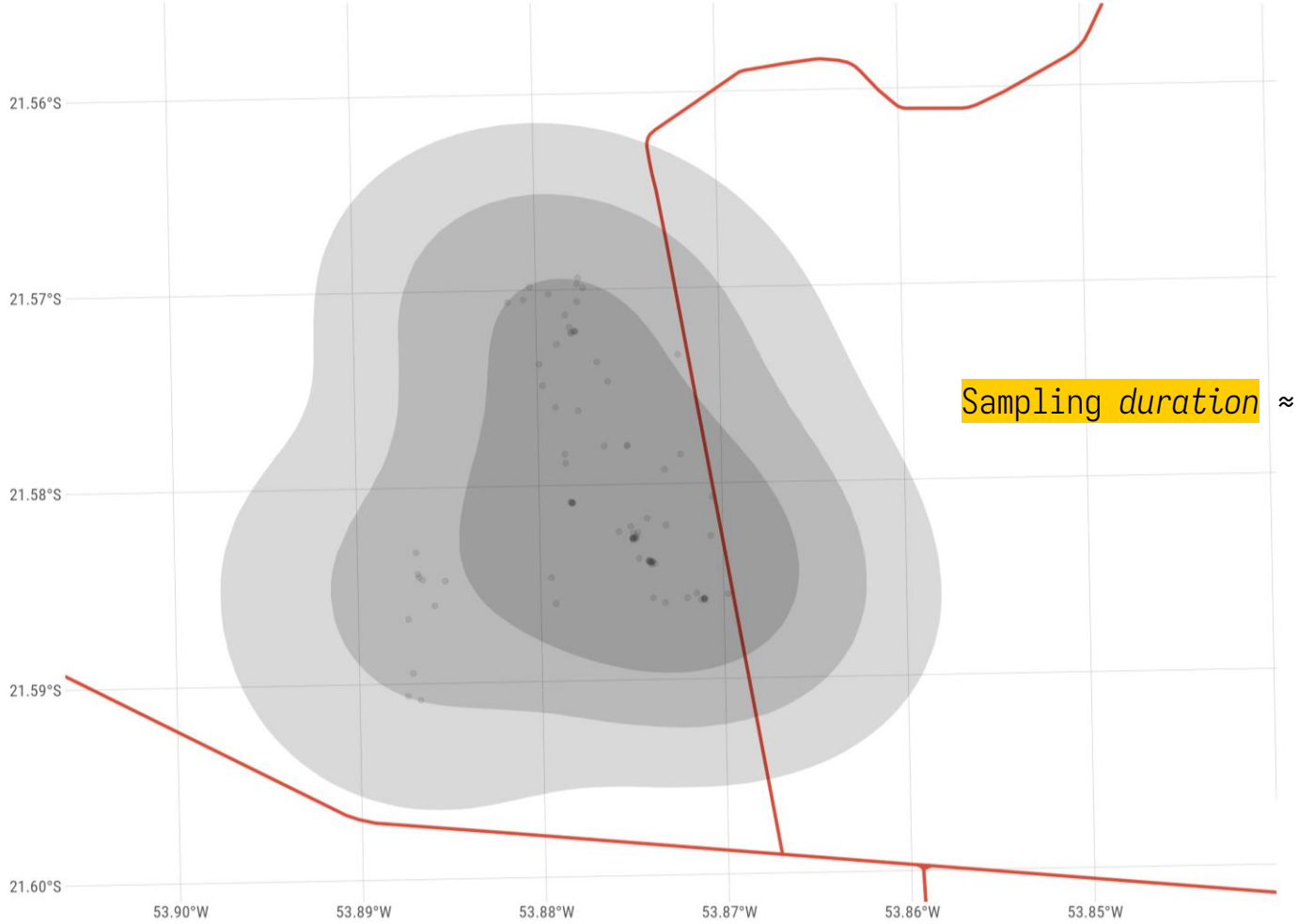


Sampling *duration* ≈ 7.5 days

i.simoes-silva@hzdr.de

Lowland tapir

(Tapirus terrestris)



Sampling *duration* ≈ 15 days

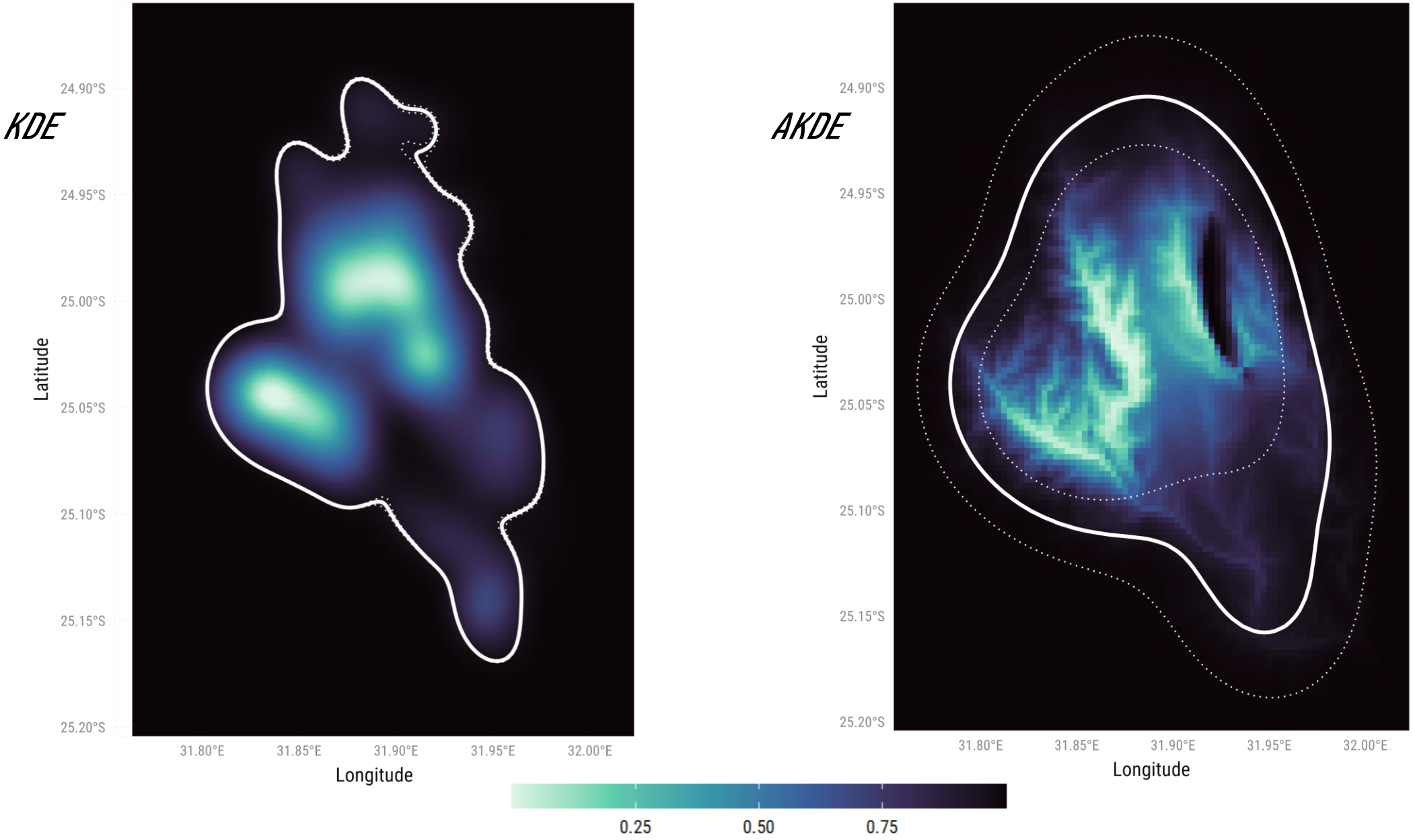
i.simoes-silva@hzdr.de

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!

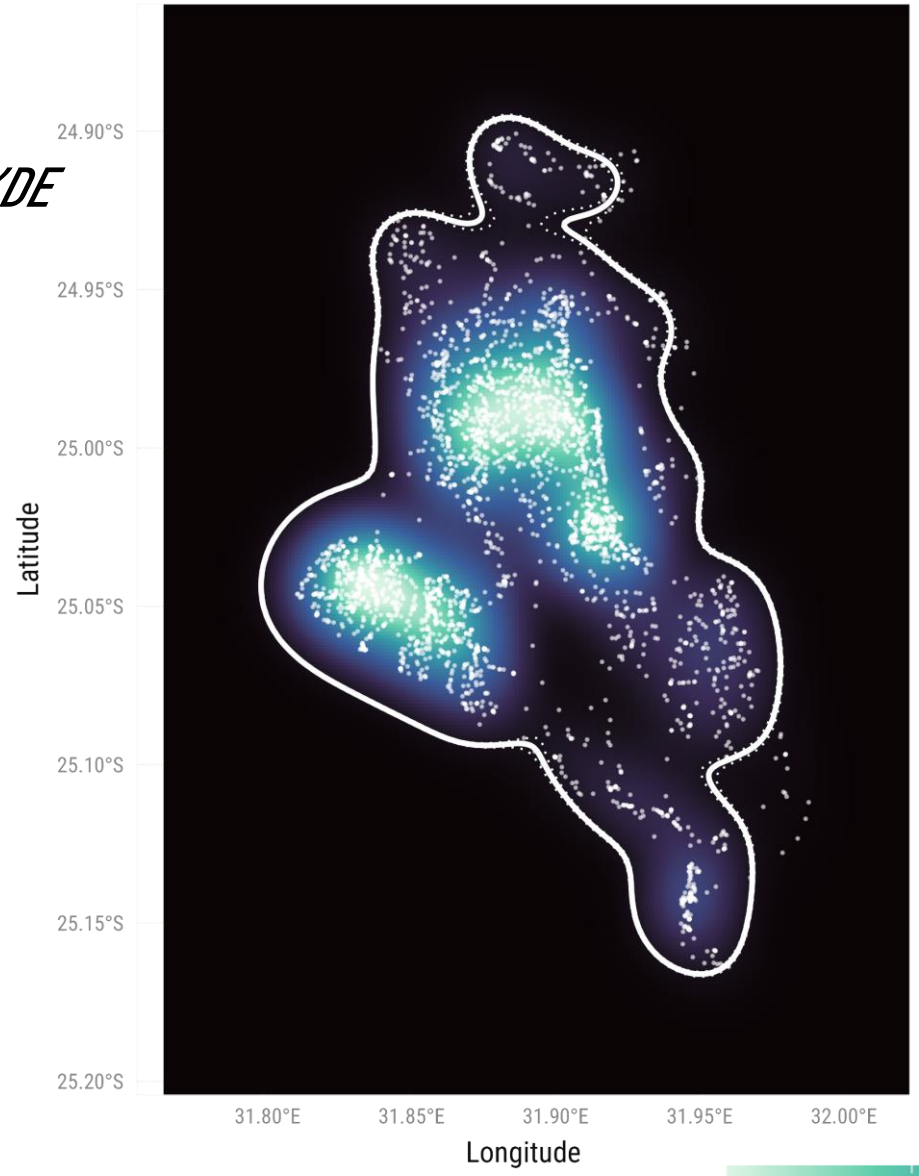
Incorporated into the `ctmm::akde()` function.

Example

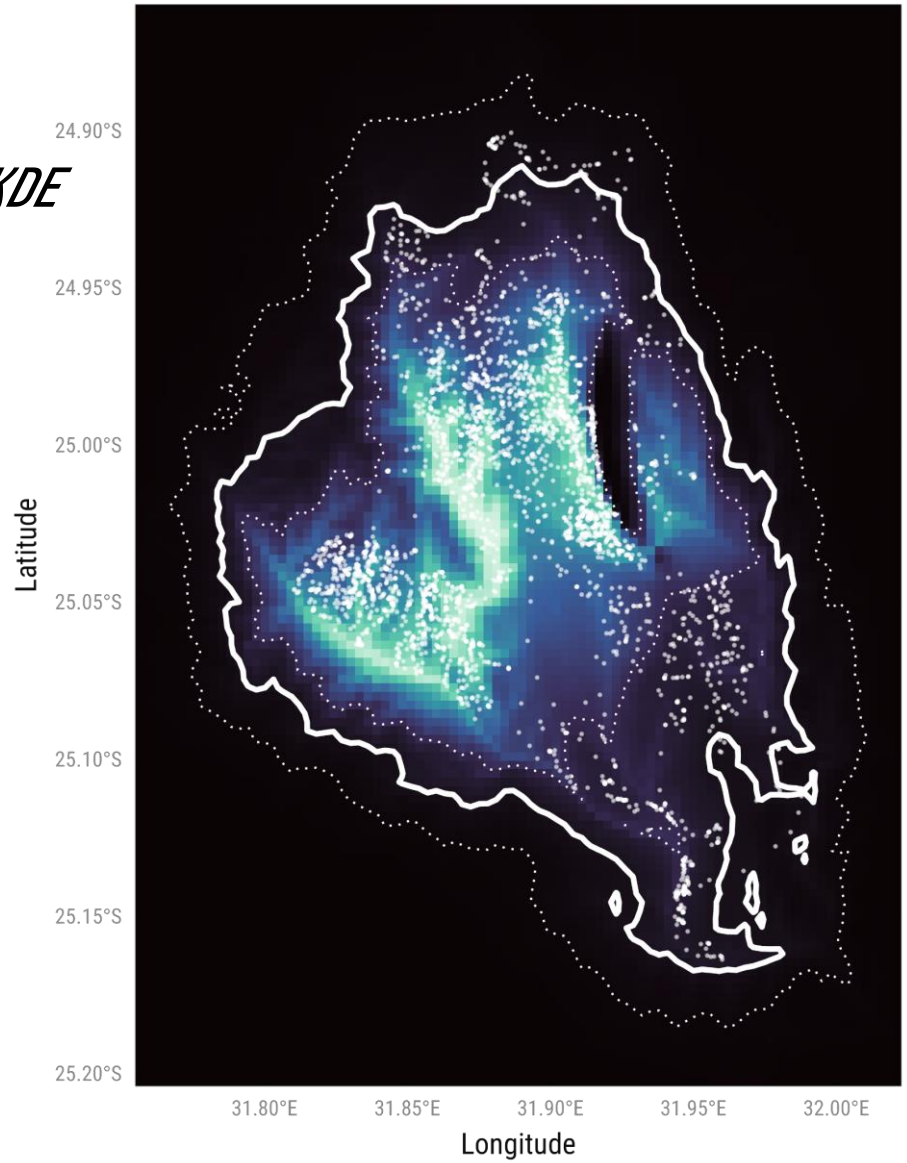


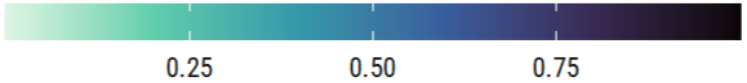
i.simoes-silva@hzdr.de

RSF-KDE

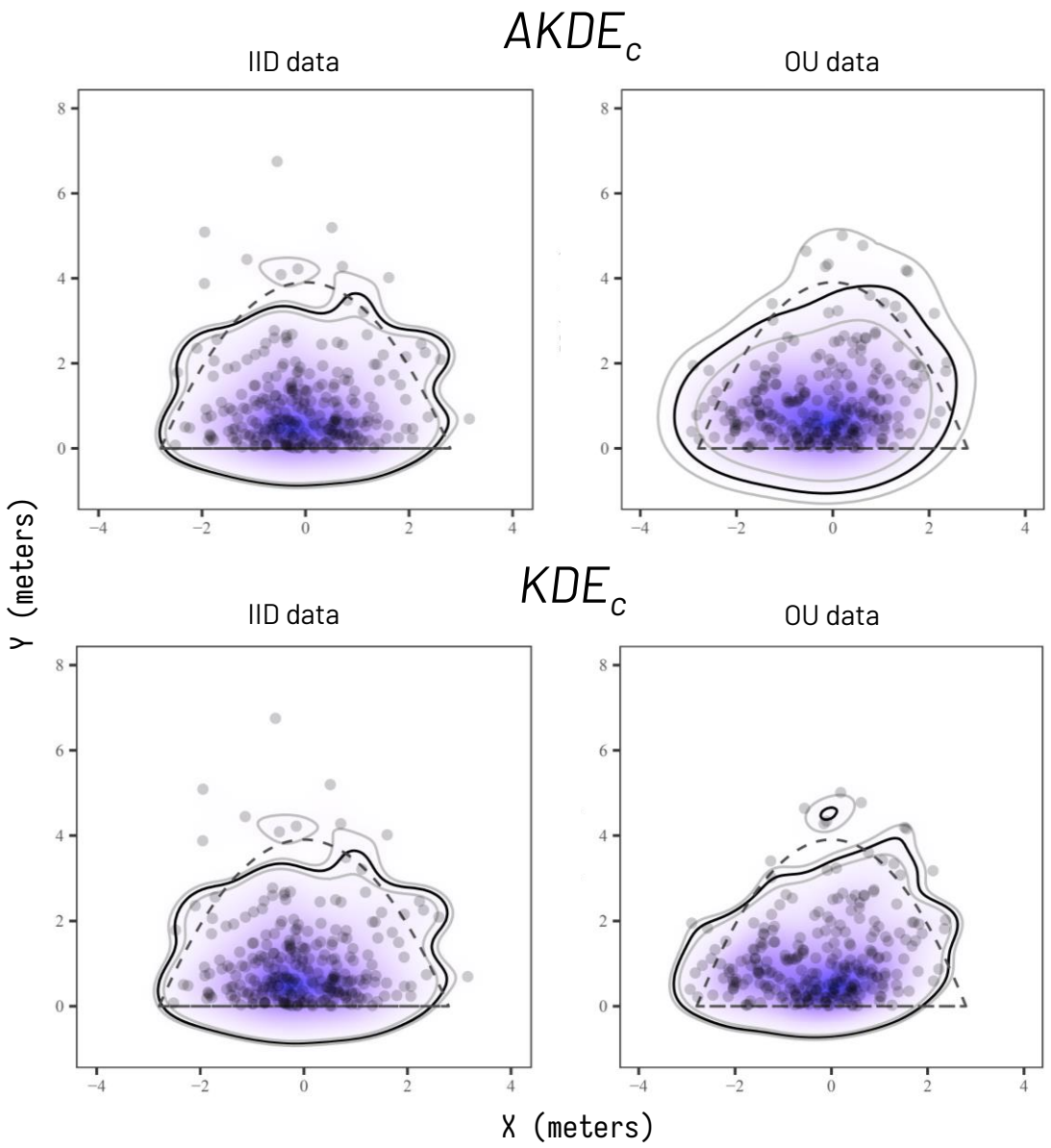


RSF-AKDE





i.simoes-silva@hzdr.de



"Spillover bias"

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

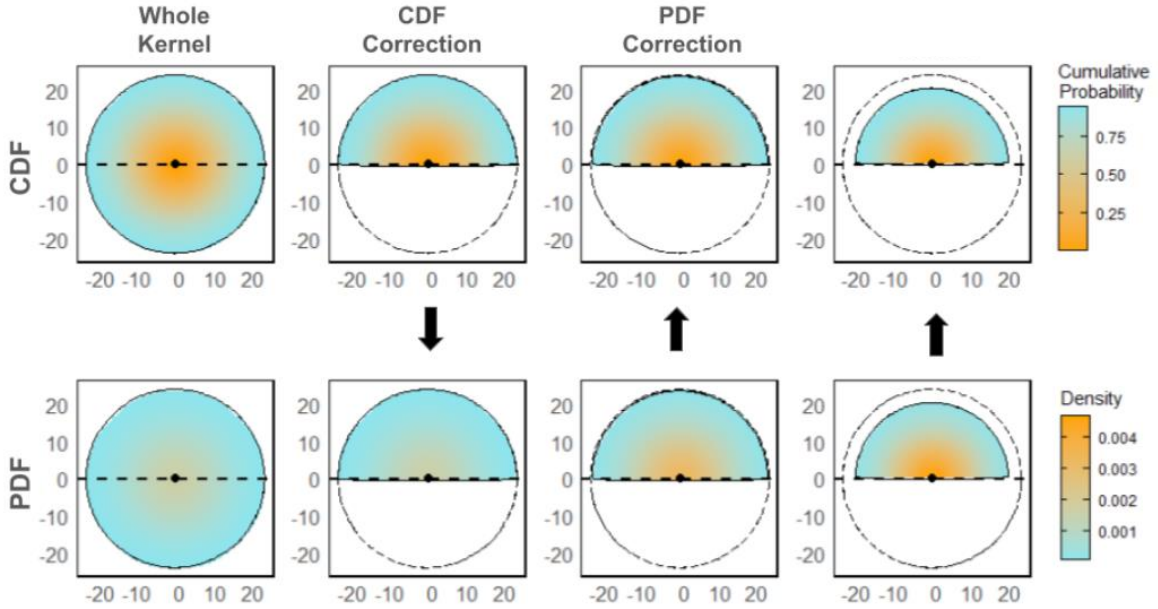
This bias arises when animal movement is constrained by **impassable boundaries**, and is **proportional** to:

- **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)

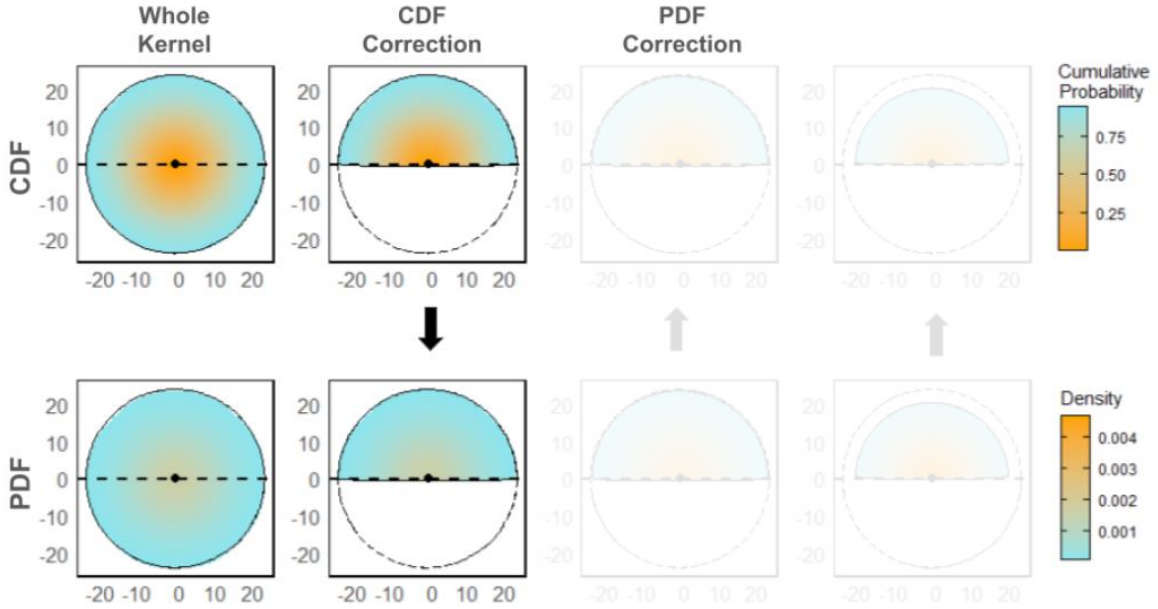


Hollins *et al.* (2024)

DOI: 0.1101/2024.11.20.624379

Corrections to remove this "*spillover bias*":

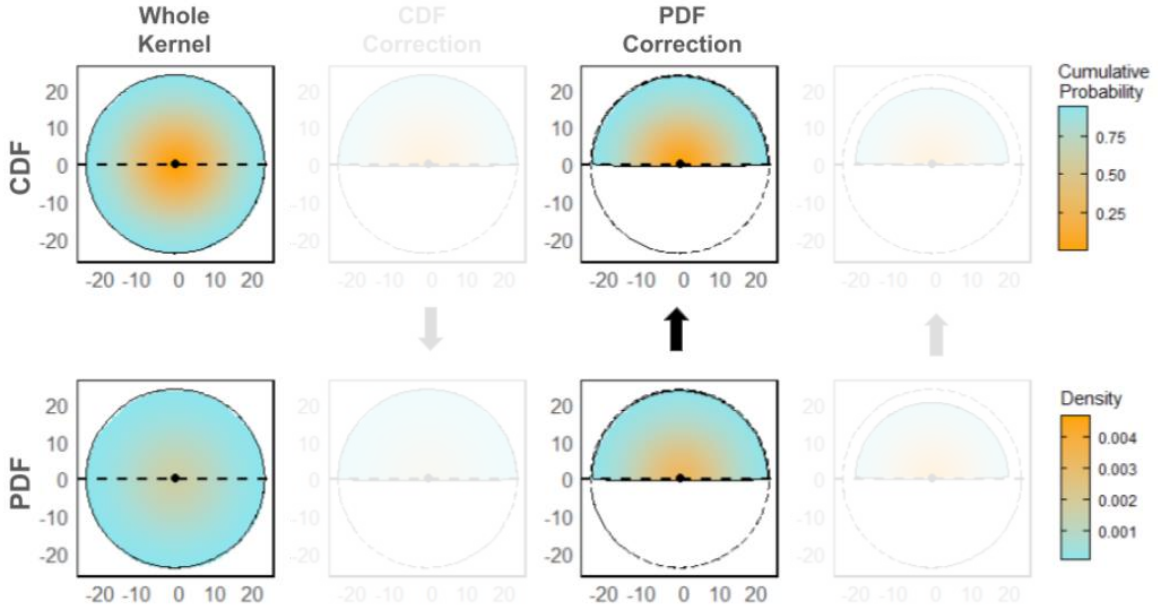
- **Local corrections** (applied to the constituent kernels)
- **Post-hoc corrections** (applied to the PDF or CDF)
  often referred to as "masking" or "clipping"



The removed probability mass of the spillover is **redistributed to the isopleth** from which it was removed on the available boundary side.

Corrections to remove this "*spillover bias*":

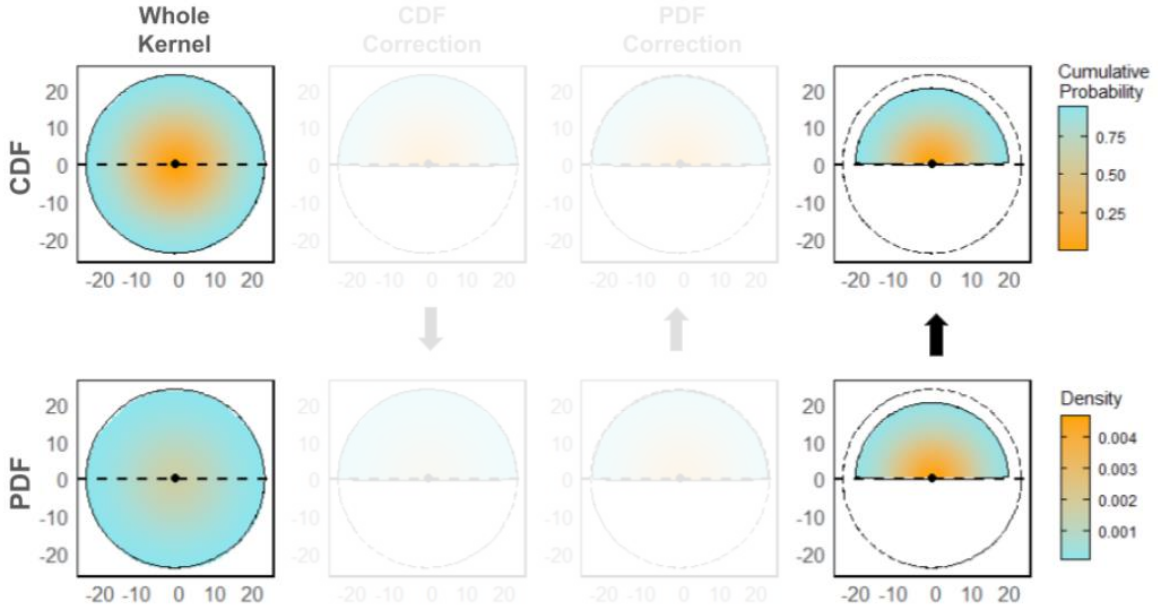
- **Local corrections** (applied to the constituent kernels)
- **Post-hoc corrections** (applied to the PDF or CDF)
  often referred to as "masking" or "clipping"



The removed mass of the range estimate is **redistributed throughout the entire remaining home range extent**, proportionally increasing the probability mass contained within each remaining cell.

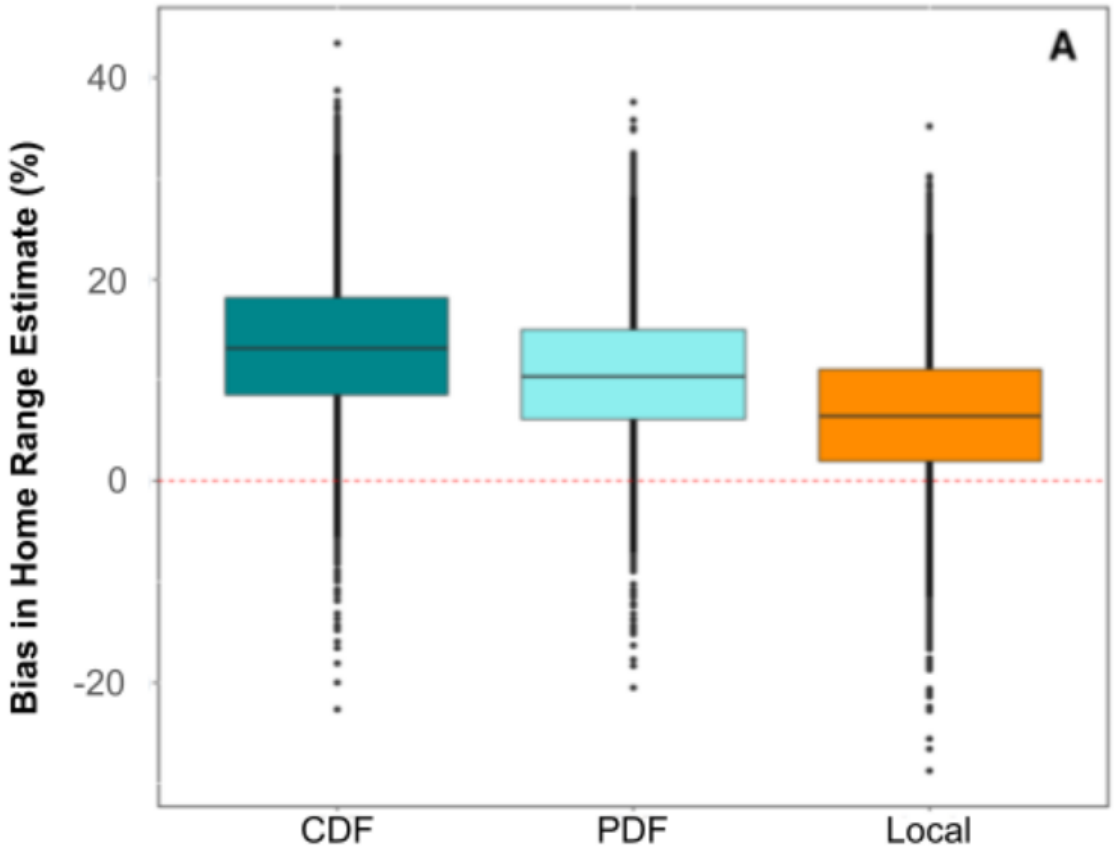
Corrections to remove this "*spillover bias*":

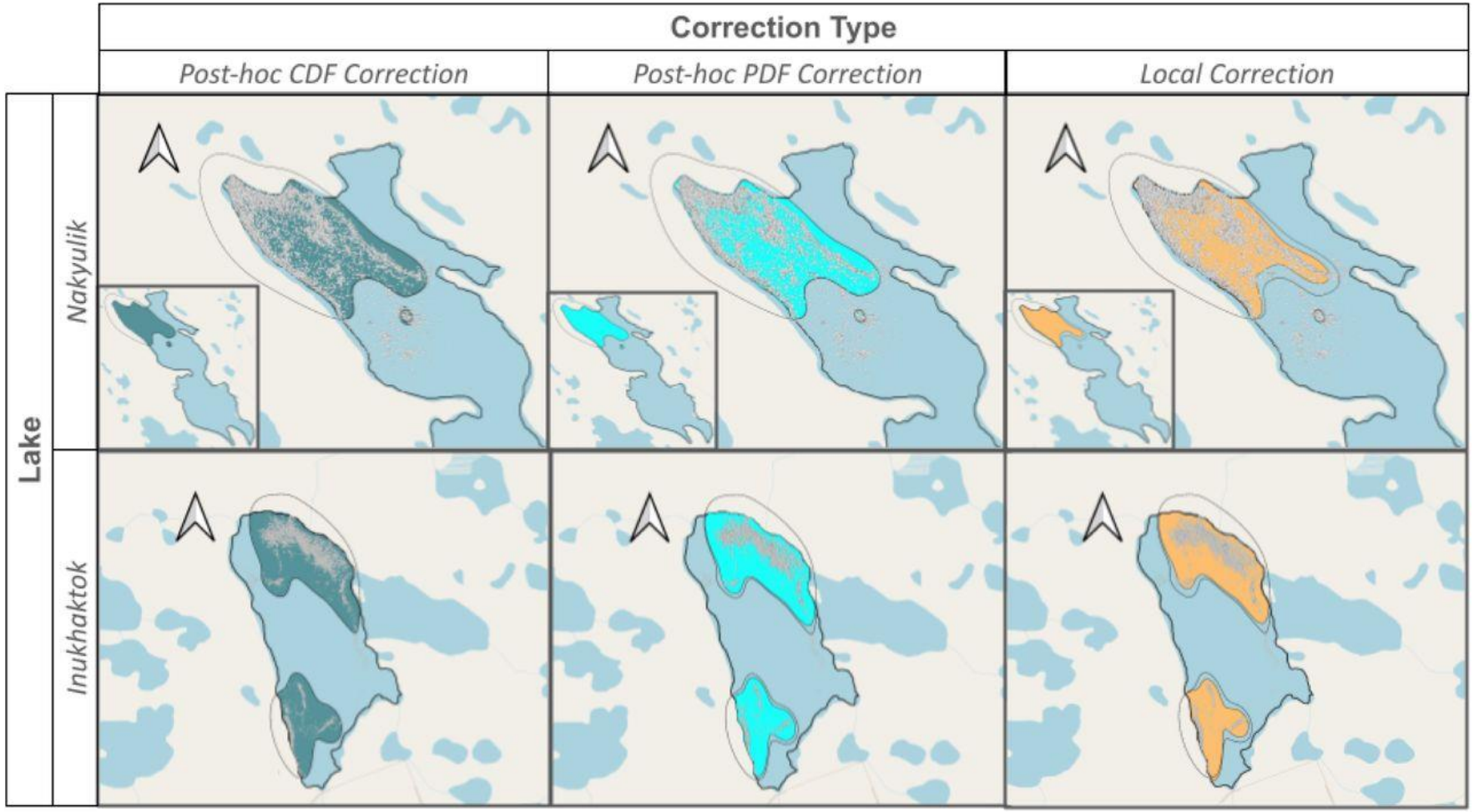
- **Local corrections** (applied to the constituent kernels)
- **Post-hoc corrections** (applied to the PDF or CDF)

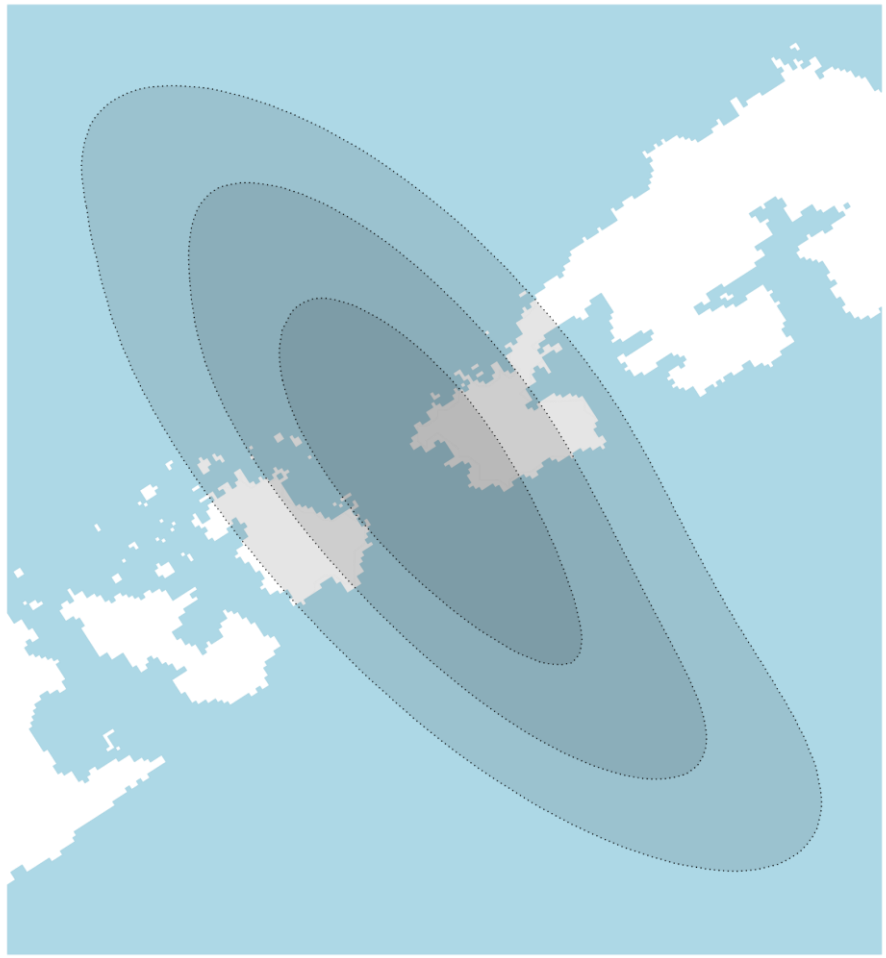


Removed probability mass is then redistributed within the constituent kernel it was removed from before PDF integration.

Dealing with hard boundaries



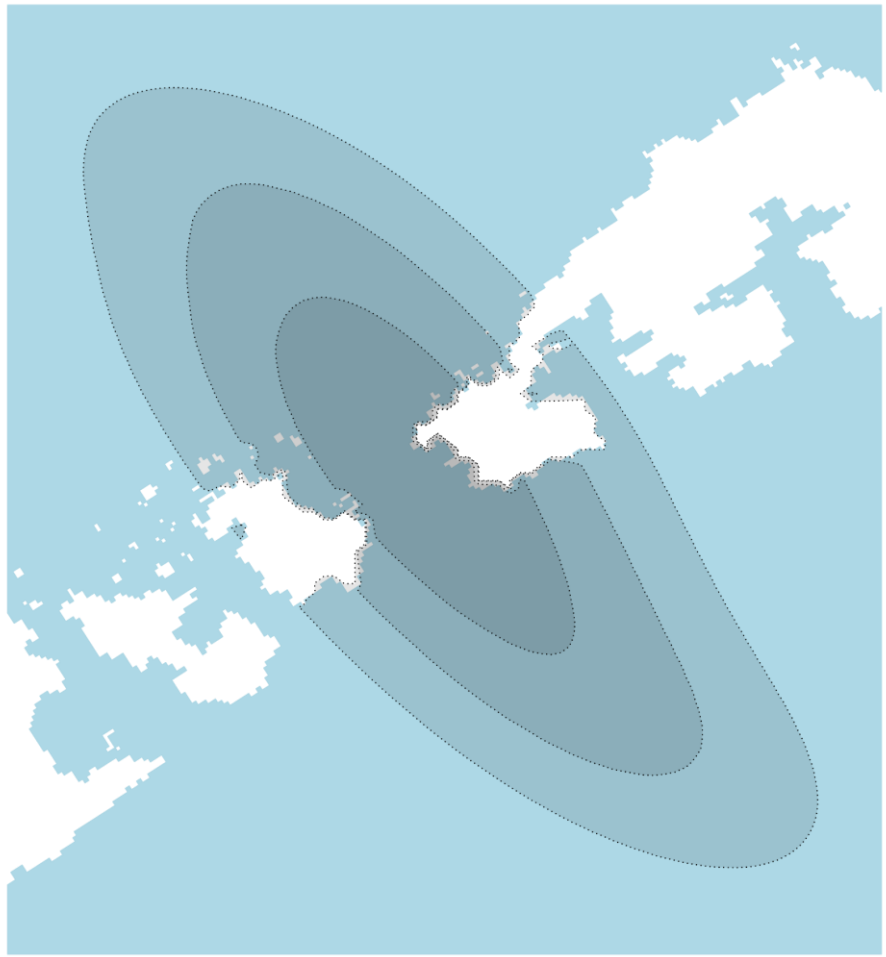

Correction Type
Post-hoc CDF Correction
Post-hoc PDF Correction
Local Correction
Lake
Nakyulik
Inukhaktok



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**.

i.simoes-silva@hzdr.de



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**.

i.simoes-silva@hzdr.de