HZDR
HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF

CASUS
CENTER FOR ADVANCED SYSTEMS UNDERSTANDING

MARE-Madeira 2025

Optimizing animal tracking projects

Using the 'movedesign' application

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 can I do with the data
I've already collected?

What are your priorities?

I want to know everything!

i.simoes-silva@hzdr.de

- Define research questions
- Identify spatiotemporal scales
- Choose sampling design
- Collect animal tracking data
- Analyze data, mitigate biases
- Assess conclusions

- Define research questions
- Identify spatiotemporal scales
- Choose sampling design
- Collect animal tracking data
- Analyze data, mitigate biases
- Assess conclusions

Cost of devices (& data transfer), challenges during deployment, and technological limitations,

can all constrain study design.

“To consult the statistician after an experiment is finished is often merely to ask him to conduct a postmortem examination. He can perhaps say what the experiment died of.”

Fine-scale processes:

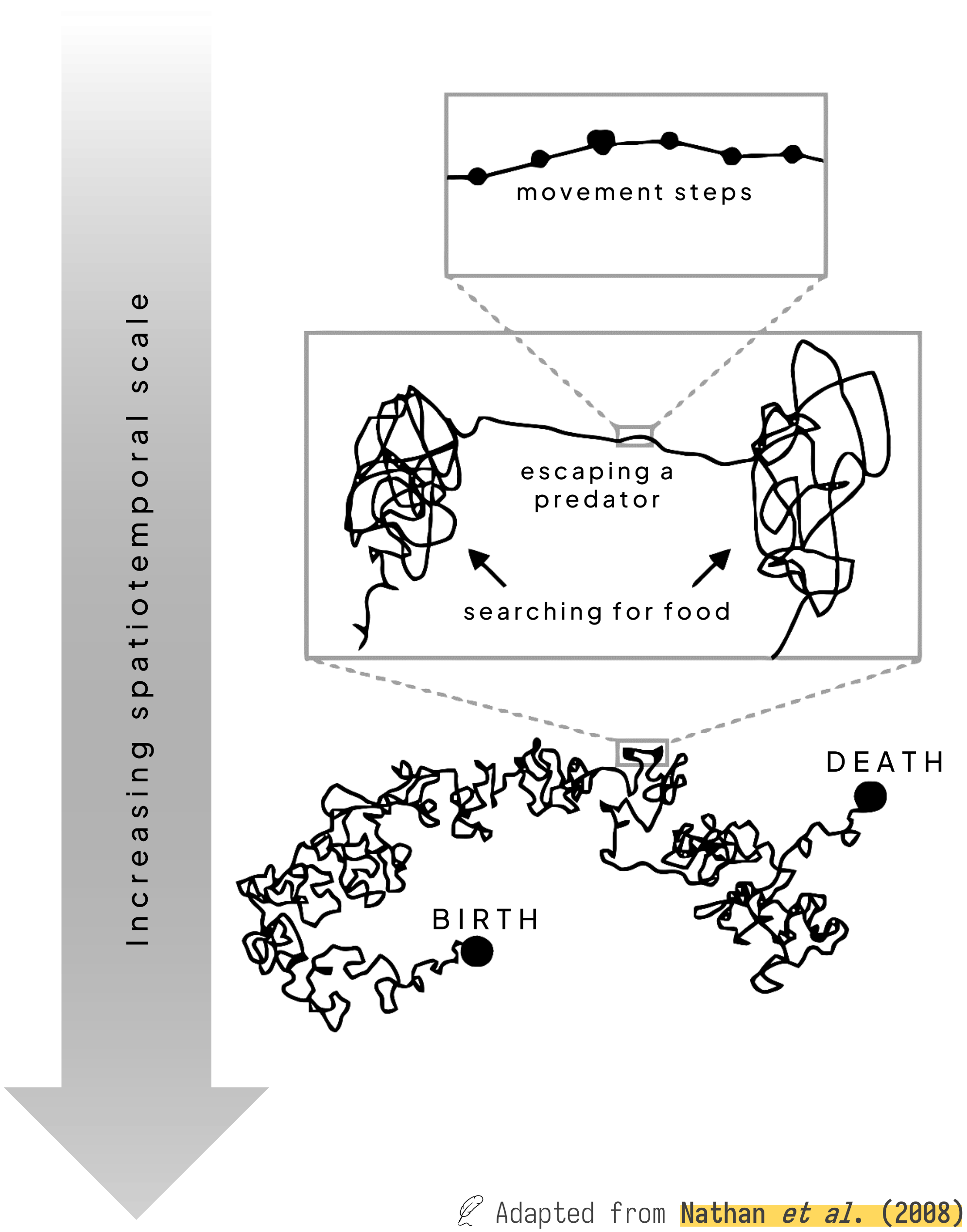
SPEED/DISTANCE — capture how far animals travel (and rate at which these distances are covered).

— To link behavior and energetics,
— As indicators of anthropogenic disturbance.

Large-scale processes:

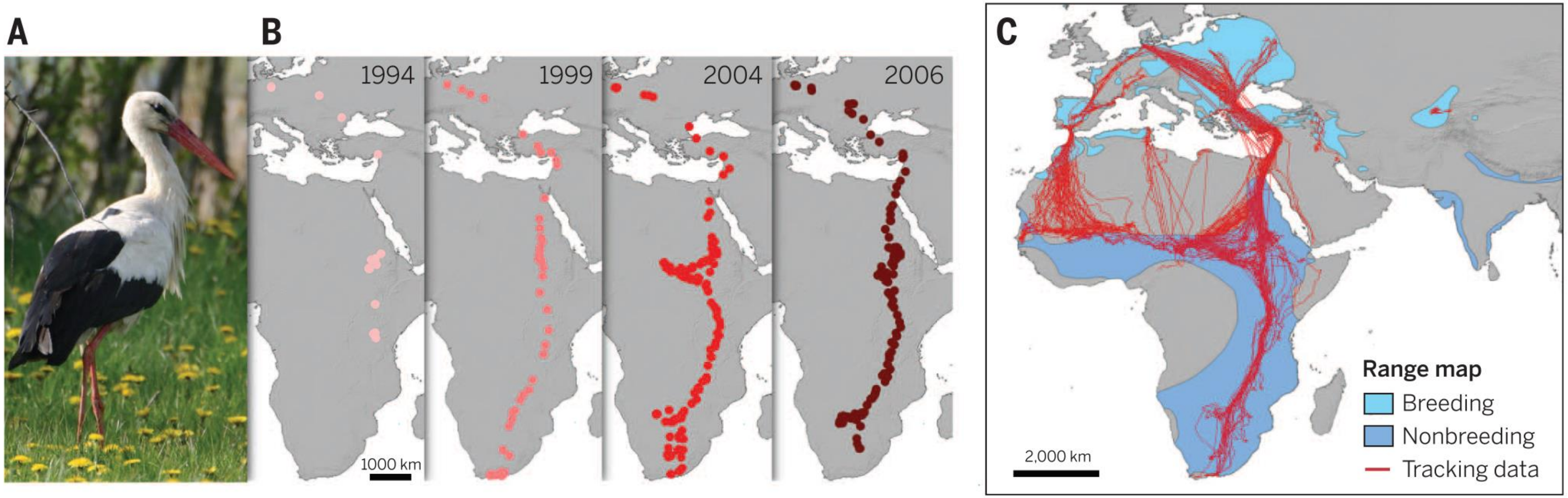
HOME RANGE — capture the area repeatedly used throughout an animal's **lifetime**.

— For protected area delineation,
— To reduce human-wildlife conflict,
— To control the spread of infectious diseases.



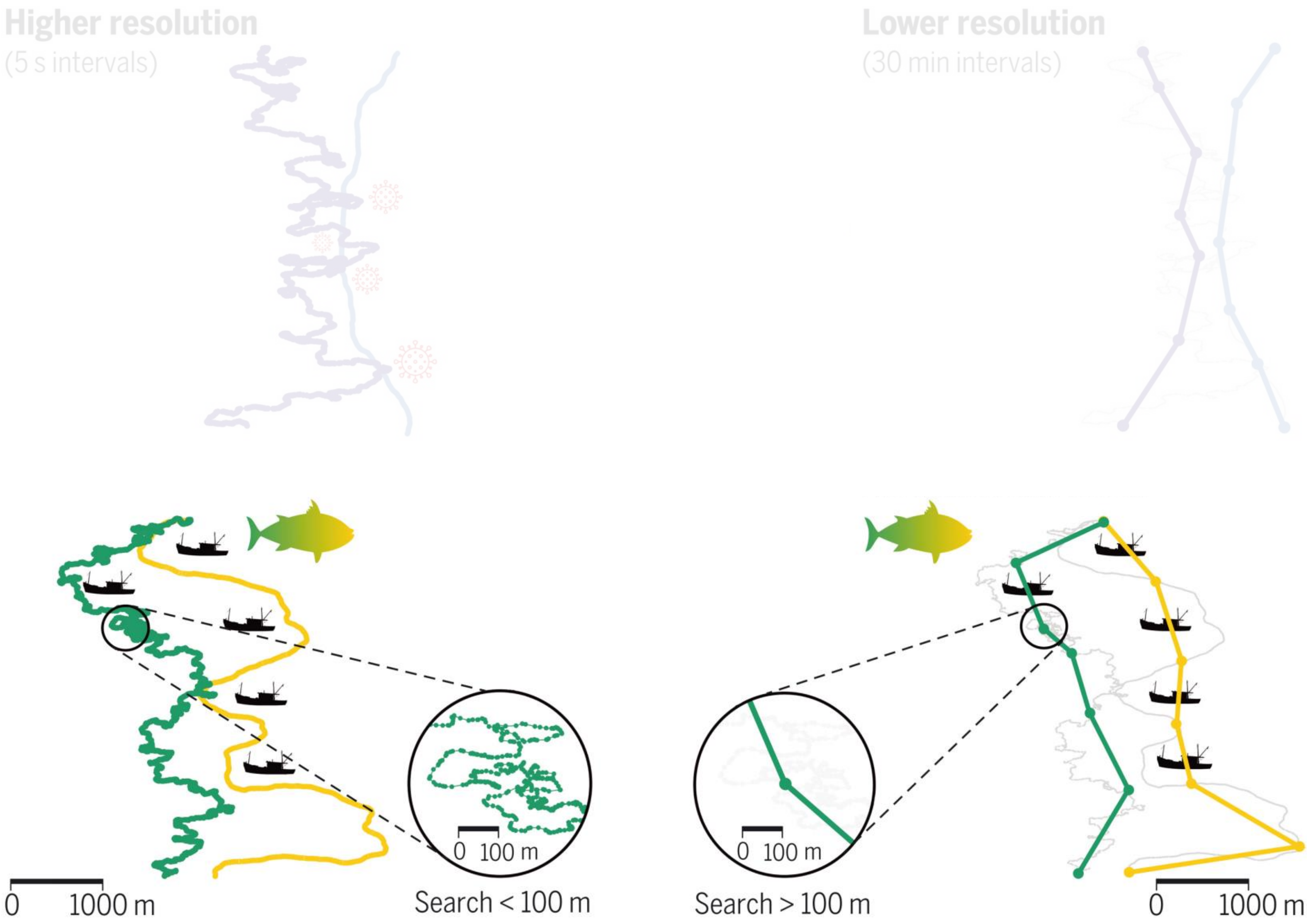
Adapted from **Nathan *et al.* (2008)**

A white stork (*Ciconia ciconia*) (**A**) was tagged with a GPS tracking device as a 3-year-old nonreproductive juvenile in Germany in 1994, and was tracked until her death in 2006 (**B**).

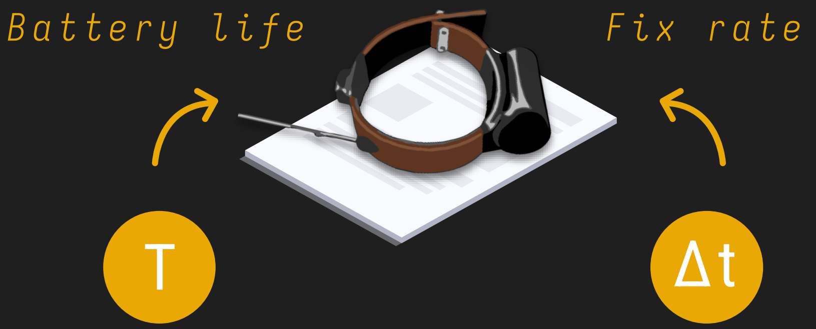


Adapted from **Kays *et al.* (2015)**
DOI: 10.1126/science.aaa2478

Nathan *et al.* (2022)



- Define research questions
- Identify spatiotemporal scales
- Choose sampling design
- Collect animal tracking data
- Analyze data, mitigate biases
- Assess conclusions



SAMPLING DURATION

How long is an animal tracked for?

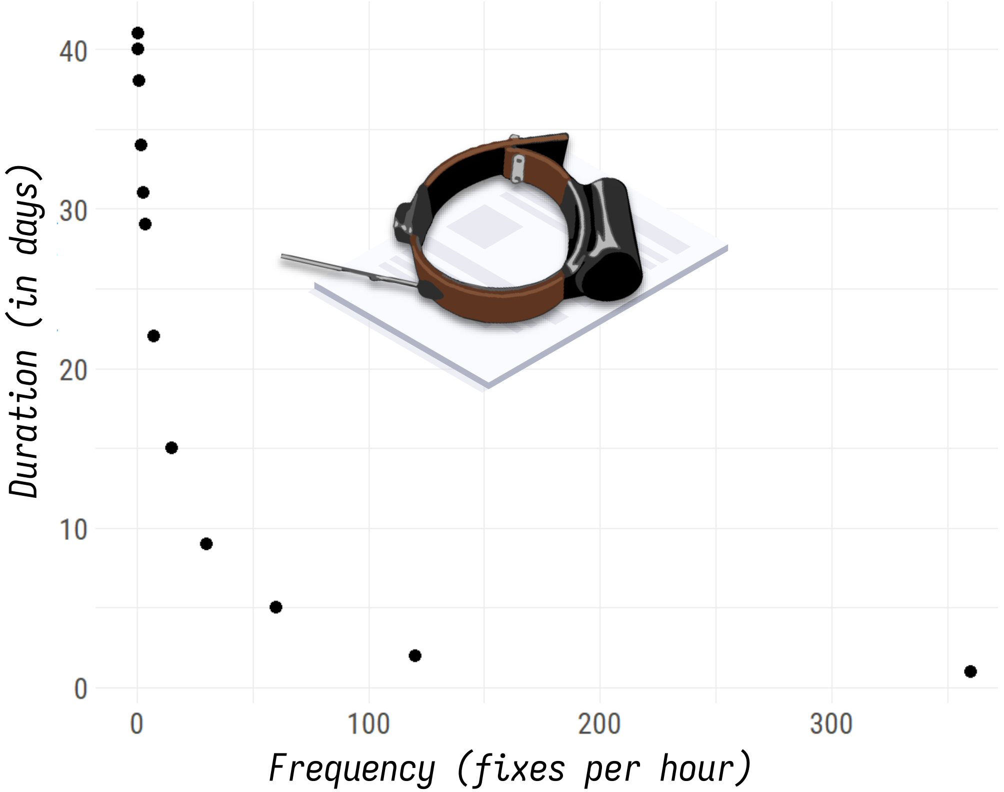
SAMPLING FREQUENCY

How frequently are locations collected?

i.simoes-silva@hzdr.de

Trade-off between long battery life and high resolution of GPS devices.

Choosing a higher fix rate leads to lower battery life.



i.simoes-silva@hzdr.de

Define research questions

Identify spatiotemporal scales

Choose sampling design

Collect animal tracking data

Analyze data, mitigate biases

Assess conclusions

1\.

Animal movement paths are realizations of continuous stochastic processes,

2\.

Summarize behavior using characteristic timescales,

τ_p

Position autocorrelation timescale

τ_v

Velocity autocorrelation timescale

i.simoes-silva@hzdr.de

- Define research questions
- Identify spatiotemporal scales
- Choose sampling design
- Collect animal tracking data
- Analyze data, mitigate biases
- Assess conclusions

1.
Animal movement paths are realizations of continuous stochastic processes,

2.
Summarize behavior using characteristic timescales,

τ_p — *Position autocorrelation timescale*

τ_v — *Velocity autocorrelation timescale*

3.
These timescales impose constraints on sampling design that *must* be met for sufficiently large (*effective*) sample sizes.

i.simoes-silva@hzdr.de

- Define research questions
- Identify spatiotemporal scales
- Choose sampling design
- Collect animal tracking data
- Analyze data, mitigate biases
- Assess conclusions

1.

Animal movement paths are realizations of continuous stochastic processes,

2.

Summarize behavior using characteristic timescales,

τ_p — *Position autocorrelation timescale*

τ_v — *Velocity autocorrelation timescale*

3.

These timescales impose constraints on sampling design that *must* be met for sufficiently large (*effective*) sample sizes.

i.simoes-silva@hzdr.de

'movedesign'
Silva *et al.* (2023)

Objectives:

Develop a systematic approach, akin to statistical power analysis, to determine optimal sampling parameters in animal tracking projects.

Analytical targets:

We considered three common estimates —home range area, speed and distance traveled.

Like any statistical tool, these methods still require sufficiently large ***effective sample sizes*** to achieve high accuracy.

A successful animal tracking project requires a sampling schedule that leads to sufficiently ***large (effective) sample sizes***.

Sample sizes

Absolute sample size
Total number of locations

n

T + Δt

Sampling ***duration***

How long is an animal tracked for?

Sampling ***frequency***

How frequently are locations collected?

$\neq$

Effective sample size

N_{area}

number of ***statistically independent locations***

N_{speed}

number of ***statistically independent velocities***

For autocorrelated data, $N < n$, and often $N \ll n$

i.simoes-silva@hzdr.de

A successful animal tracking project requires a sampling schedule that leads to sufficiently ***large (effective) sample sizes***.

Sample sizes

Effective sample size

N_{area}

number of ***statistically independent locations***

N_{speed}

number of ***statistically independent velocities***

Out of 72% of 369 empirical datasets with >1,000 total observations:

Only 4% had an N_{area} >1,000,
30% had an N_{area} < 30.

Noonan *et al.* (2019)

DOI: 10.1002/ecm.1344

i.simoes-silva@hzdr.de

τ_p

Position autocorrelation timescale

T

SPACE-USE

- [x] HOME RANGE

SAMPLING DURATION

How long is an animal tracked for?

MOVEMENT BEHAVIOR

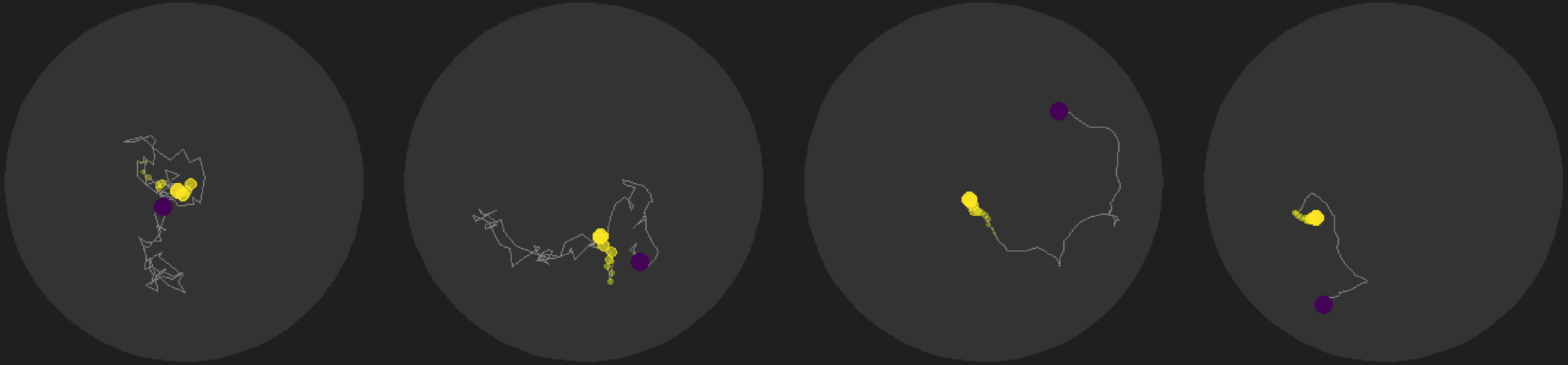
- [ ] SPEED & DISTANCE

Understanding *sample sizes*

τ_v

Velocity autocorrelation timescale

τ_v = 1 minute τ_v = 1 hour τ_v = 12 hours τ_v = 1 day



Δt

SPACE-USE

☐ HOME RANGE

SAMPLING FREQUENCY

How frequently are locations collected?

MOVEMENT BEHAVIOR

☑ SPEED & DISTANCE

Define research questions

Identify spatiotemporal scales

Choose sampling design

Collect animal tracking data

Analyze data, mitigate biases

Assess conclusions

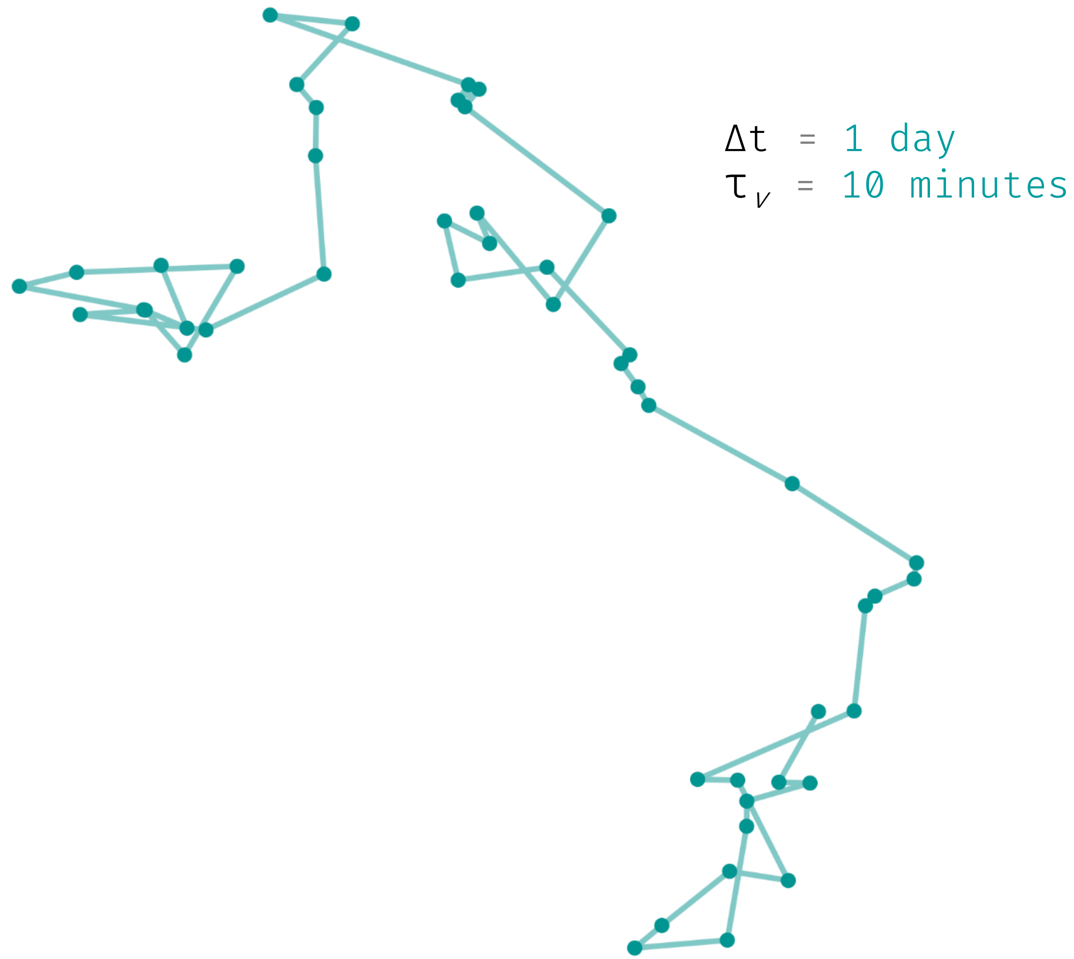
It is not physically possible for animal movement to be uncorrelated. Now, the questions are:

1. Can you detect a signature of these correlations in your data?

2. And is this data sufficient to answer specific research questions?

i.simoes-silva@hzdr.de

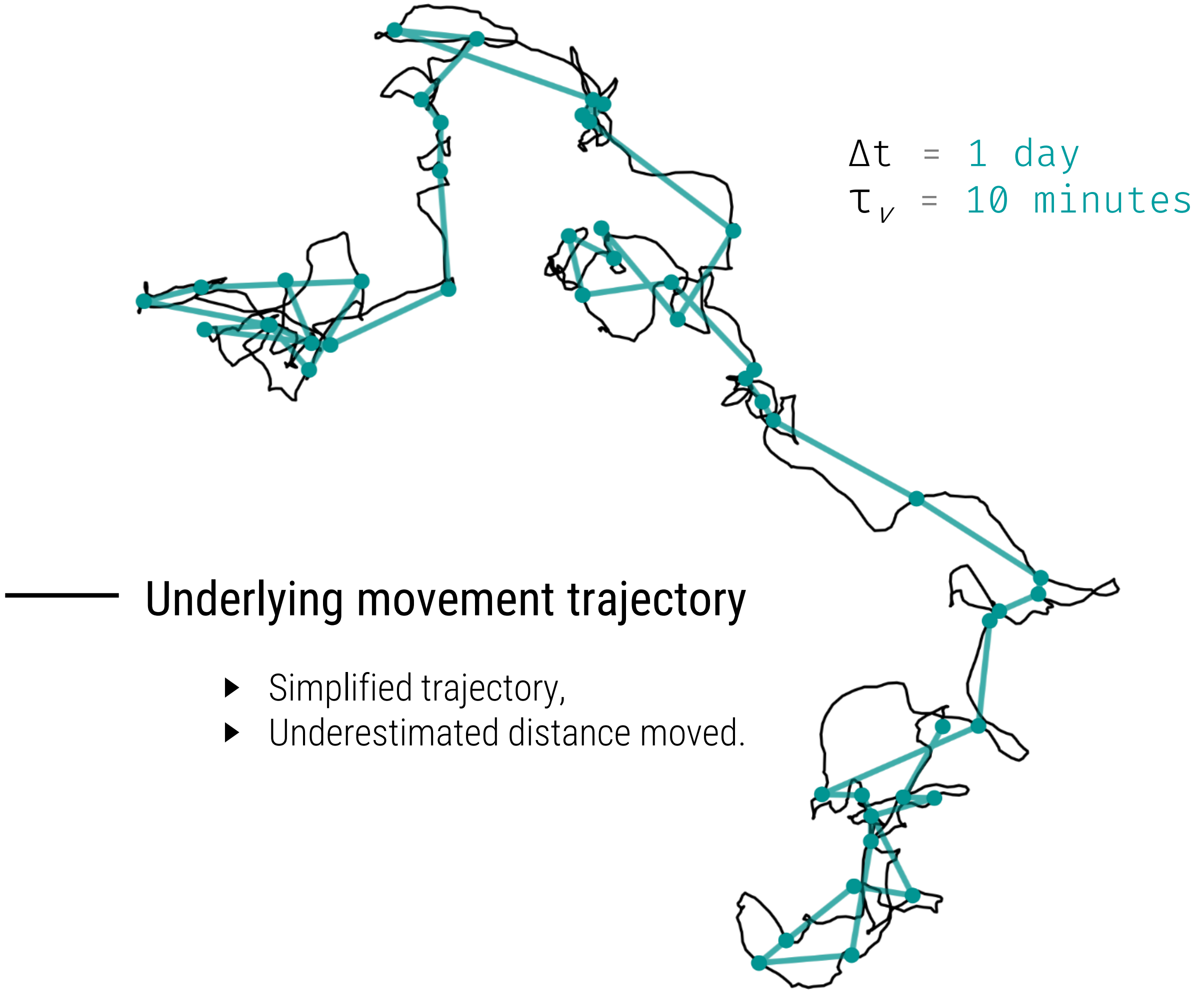
Simulated tracking dataset with a new location once per day, $\tau_v > \Delta t$.



Simulated tracking dataset with a new location once per day, $\tau_v > \Delta t$.

We must carefully consider the frequency of data collection!

For the same Δt, this bias will be greater for individuals with more tortuous movement (shorter τ_v).



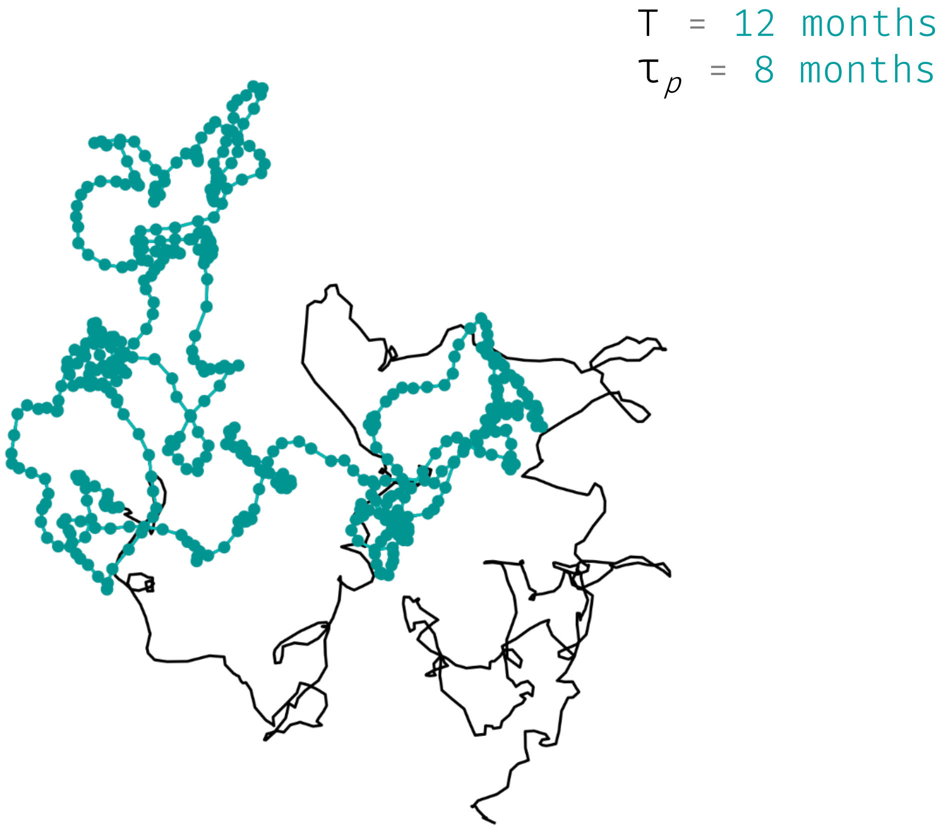
- Simplified trajectory,
- Underestimated distance moved.

Simulated tracking dataset with a duration of 6 months, $\tau_p > T$.

T = 6 months
τ_p = 8 months

i.simoes-silva@hzdr.de

Simulated tracking dataset with a duration of 6 months, τ_p > T.



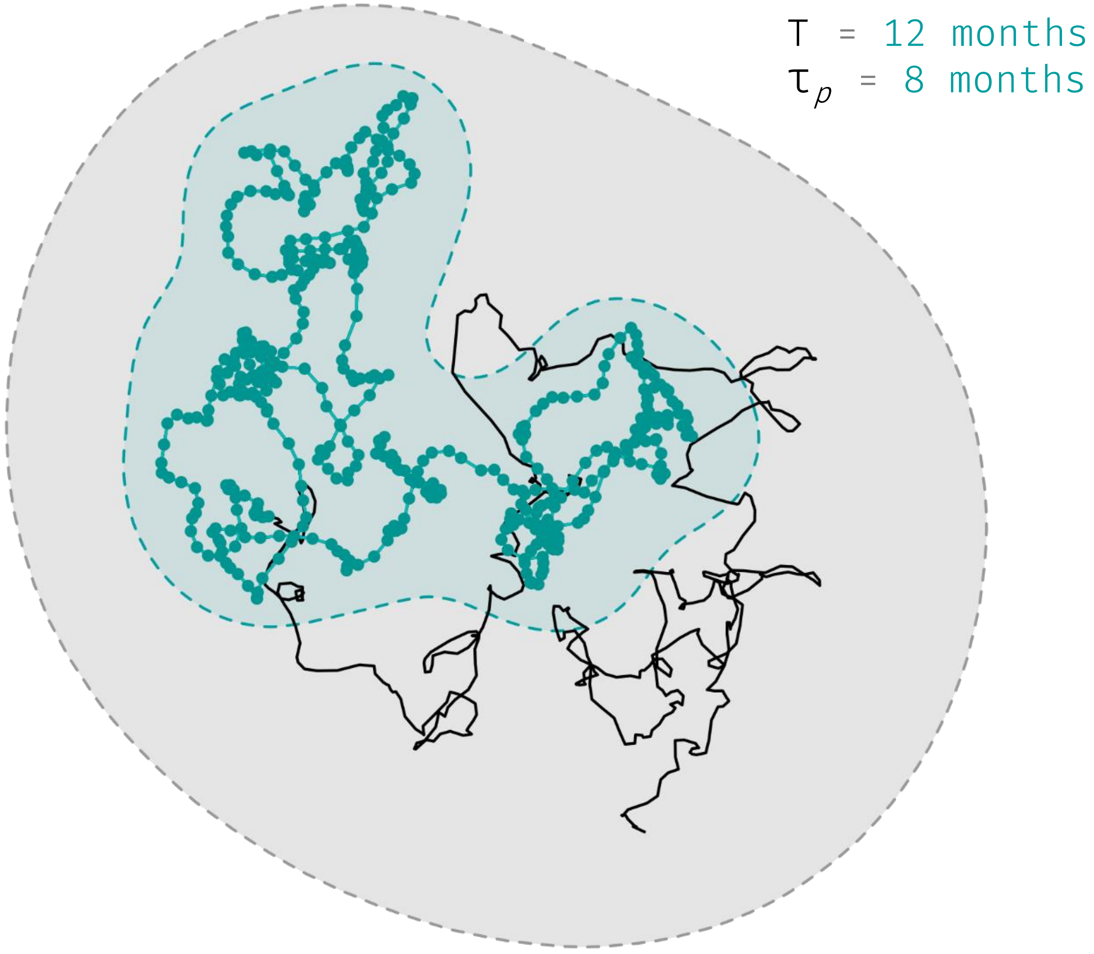
Movement trajectory for the following **6 months**.

i.simoes-silva@hzdr.de

Simulated tracking dataset with a duration of 6 months, τ_p > T.

We must carefully consider the duration of data collection!

For the same T, the extent of this bias will be greater for individuals with longer crossing times (τ_p).



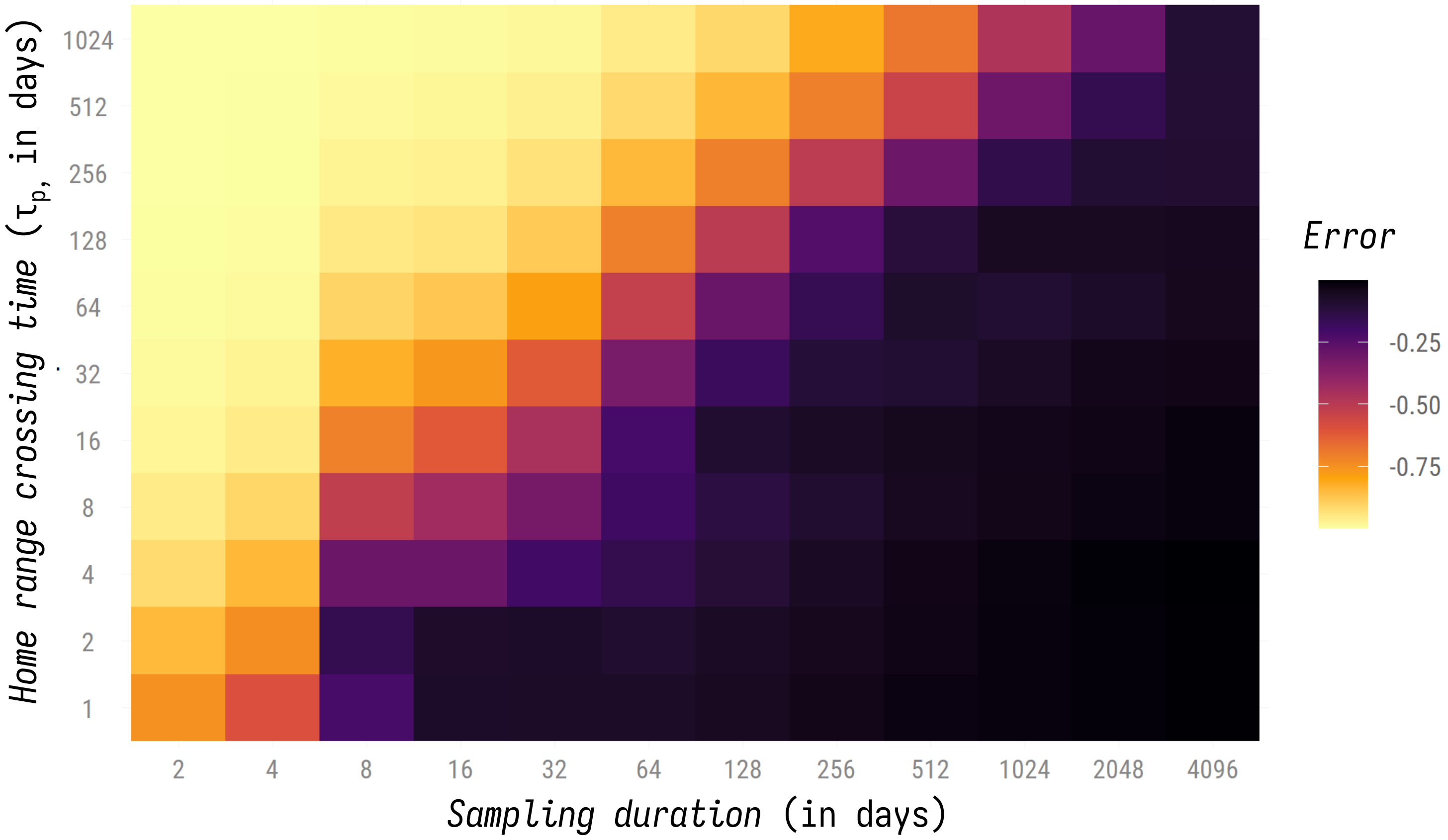
Movement trajectory for the following **6 months**.

- Sampling missed used areas.
- Underestimated home range.

i.simoes-silva@hzdr.de

1. Home ranges — **Autocorrelated** Kernel Density Estimator **(AKDE)**:

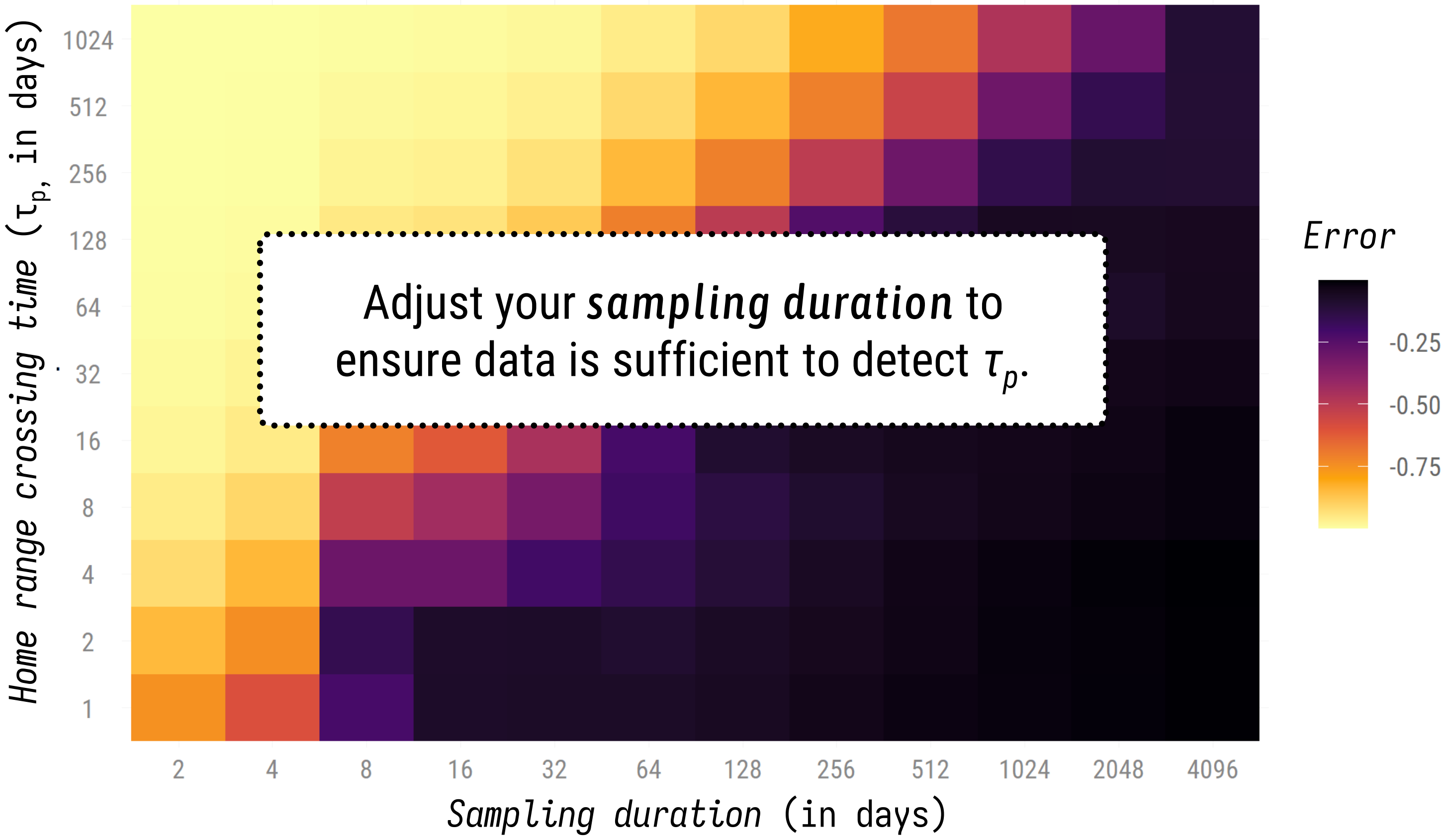
Fleming *et al.* (2015)



i.simoes-silva@hzdr.de

1. Home ranges — Autocorrelated Kernel Density Estimator (AKDE):

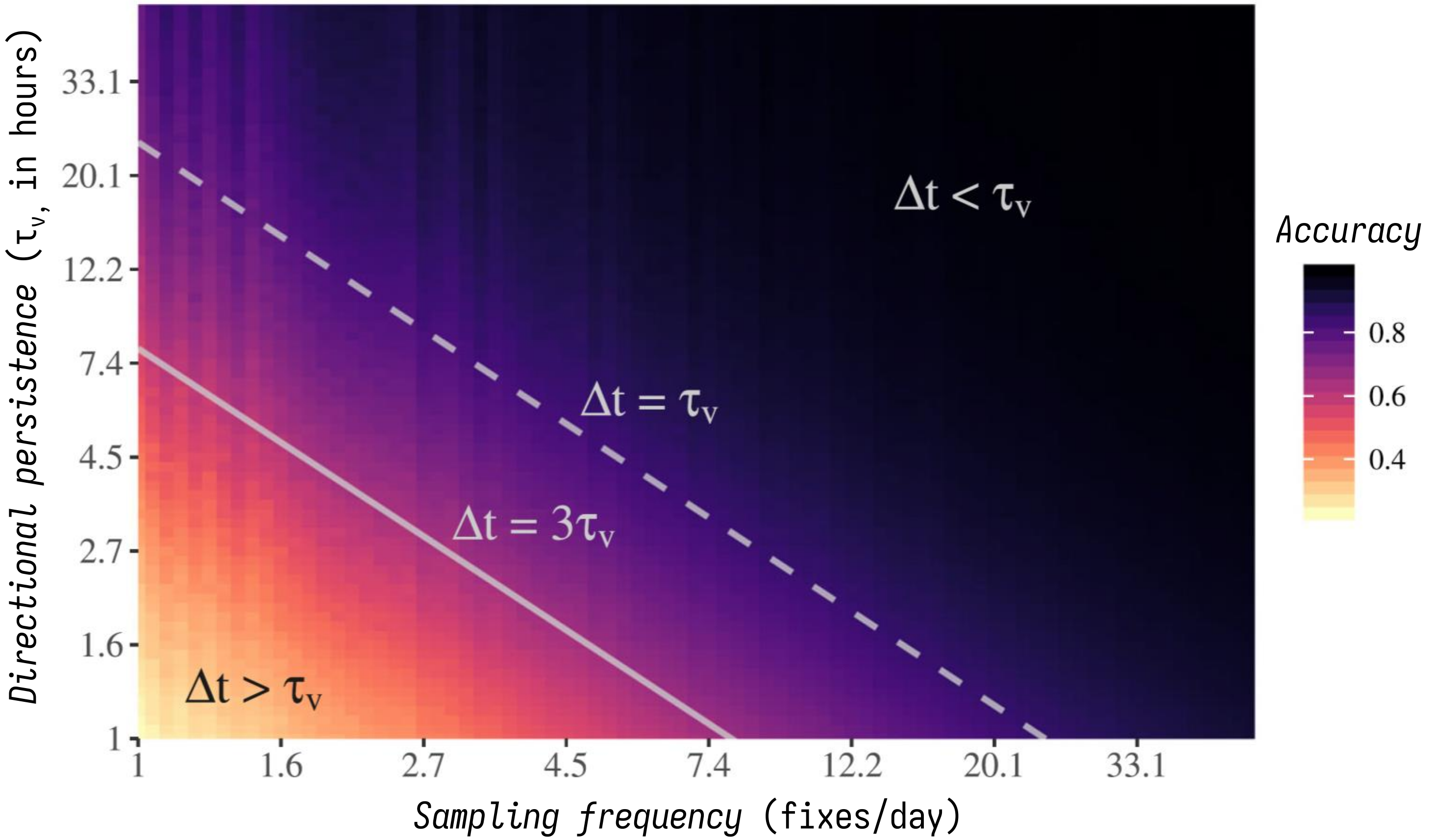
Fleming *et al.* (2015)



i.simoes-silva@hzdr.de

2. Speed & distance — Continuous-time speed and distance (CTSD):

Noonan *et al.* (2019)



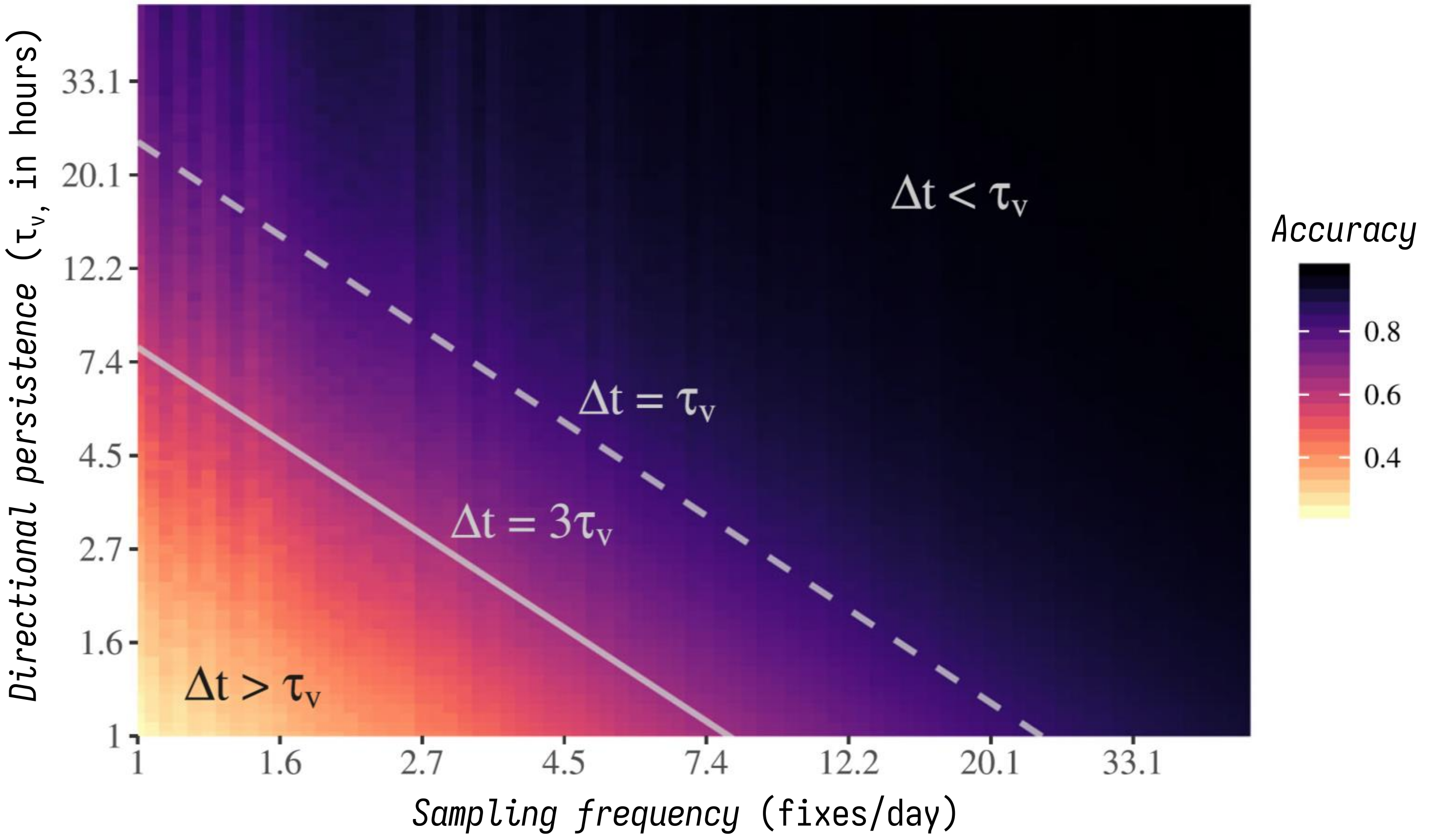
If $\Delta t > 3\tau_v$, no statistically significant signature of the animal's velocity will remain in the location data.

If $3\tau_v > \Delta t > \tau_v$, there will be some positive bias (τ_v can not be accurately estimated).

i.simoes-silva@hzdr.de

2. Speed & distance — Continuous-time speed and distance (CTSD):

Noonan *et al.* (2019)

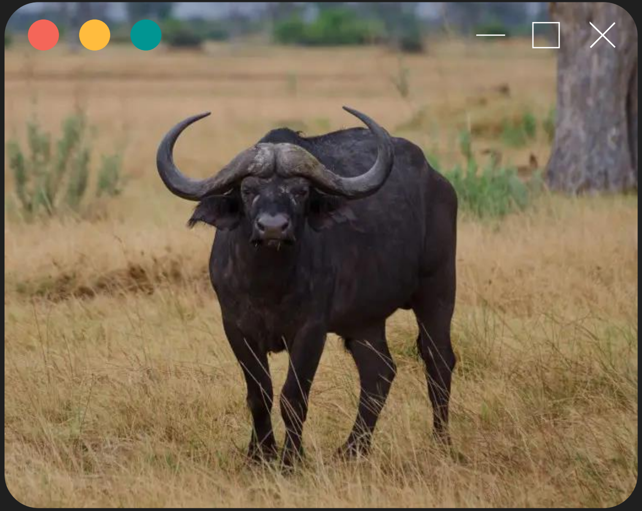


Adjust your ***sampling interval*** to ensure data is of ***sufficient resolution*** to detect τ_v.

$$\Delta t \leq 3\tau_v$$

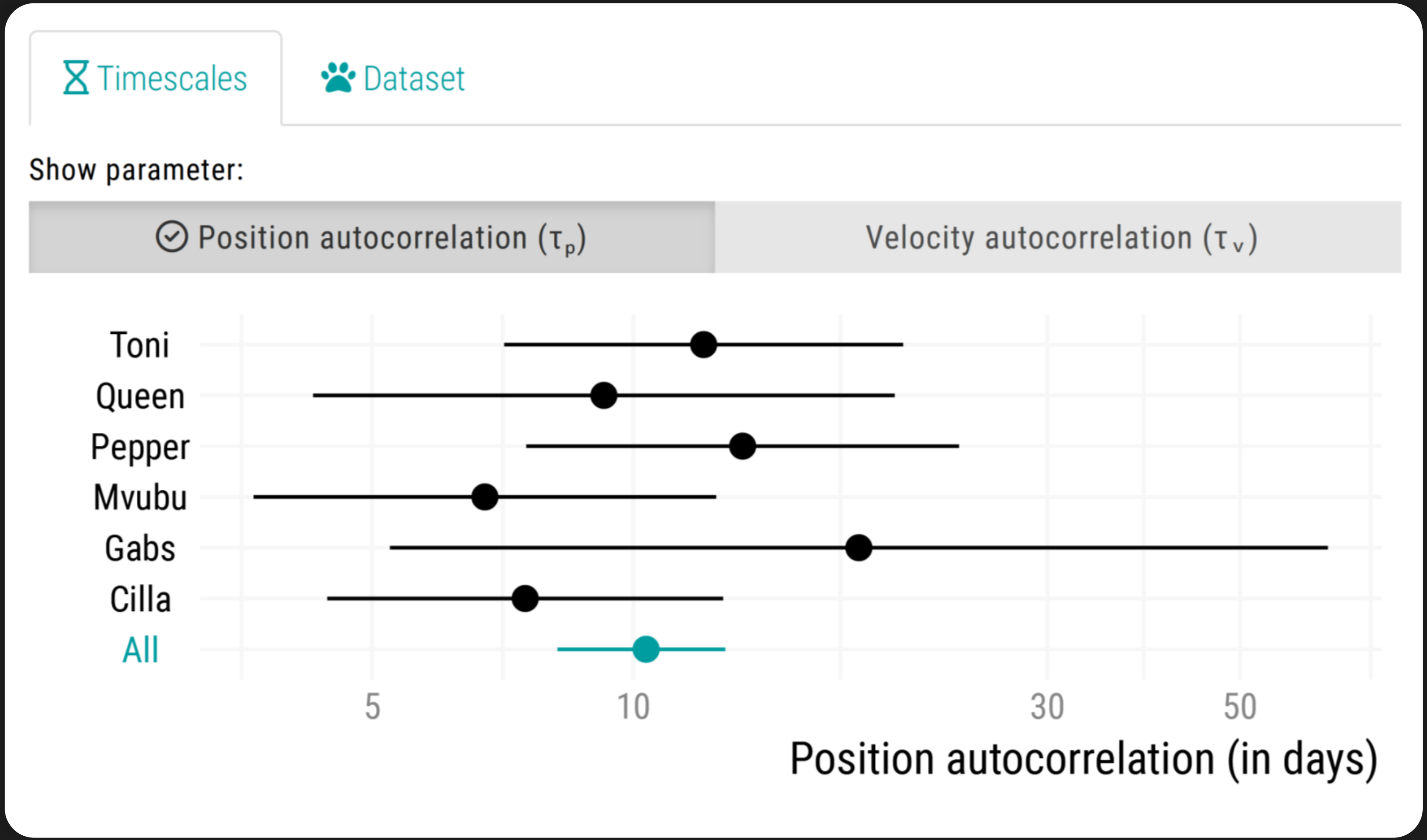
i.simoes-silva@hzdr.de

African buffalo
(Syncerus caffer)

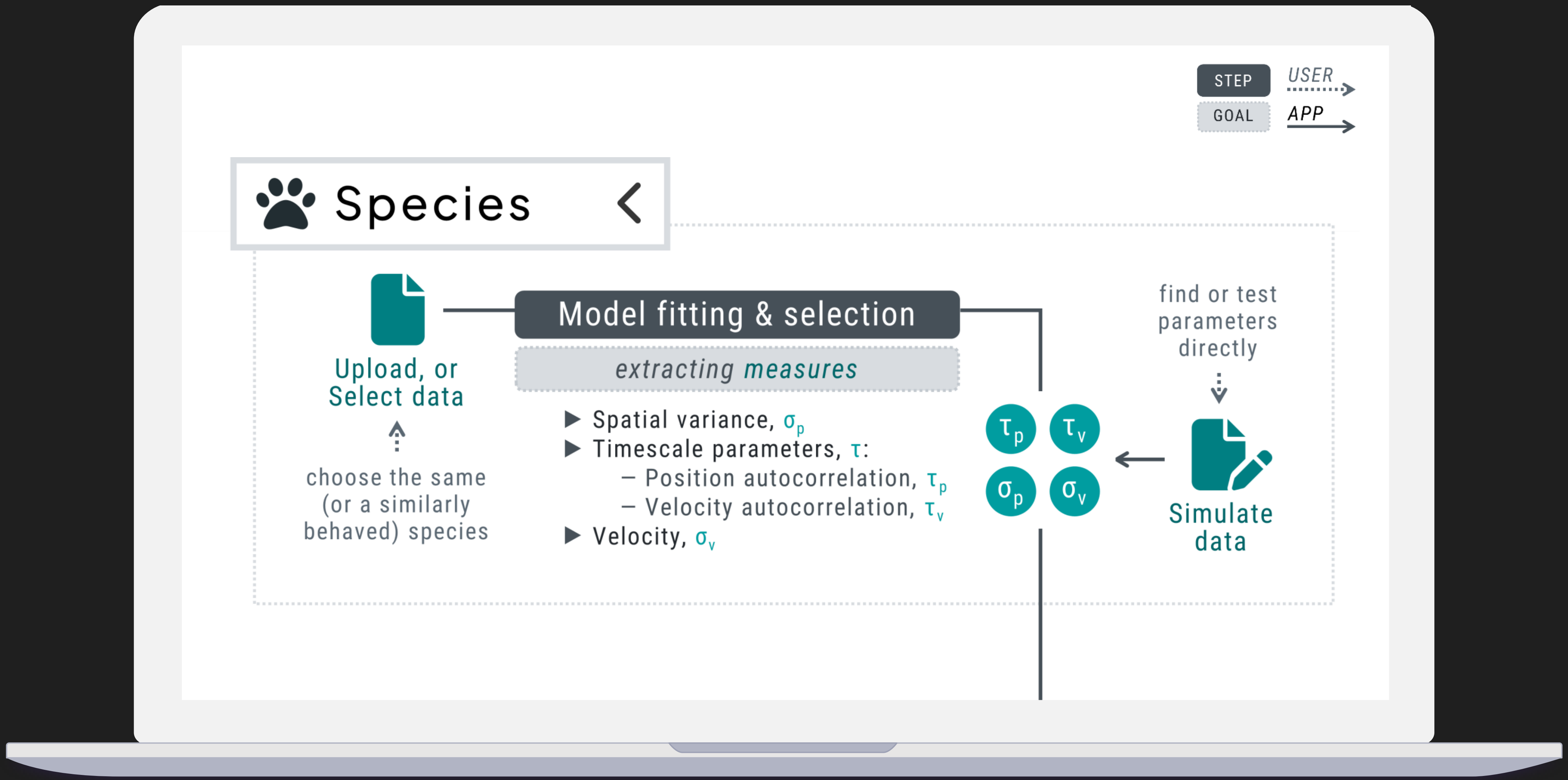


Position autocorrelation
10.3 days
8.2 – 12.8
(τ_p)

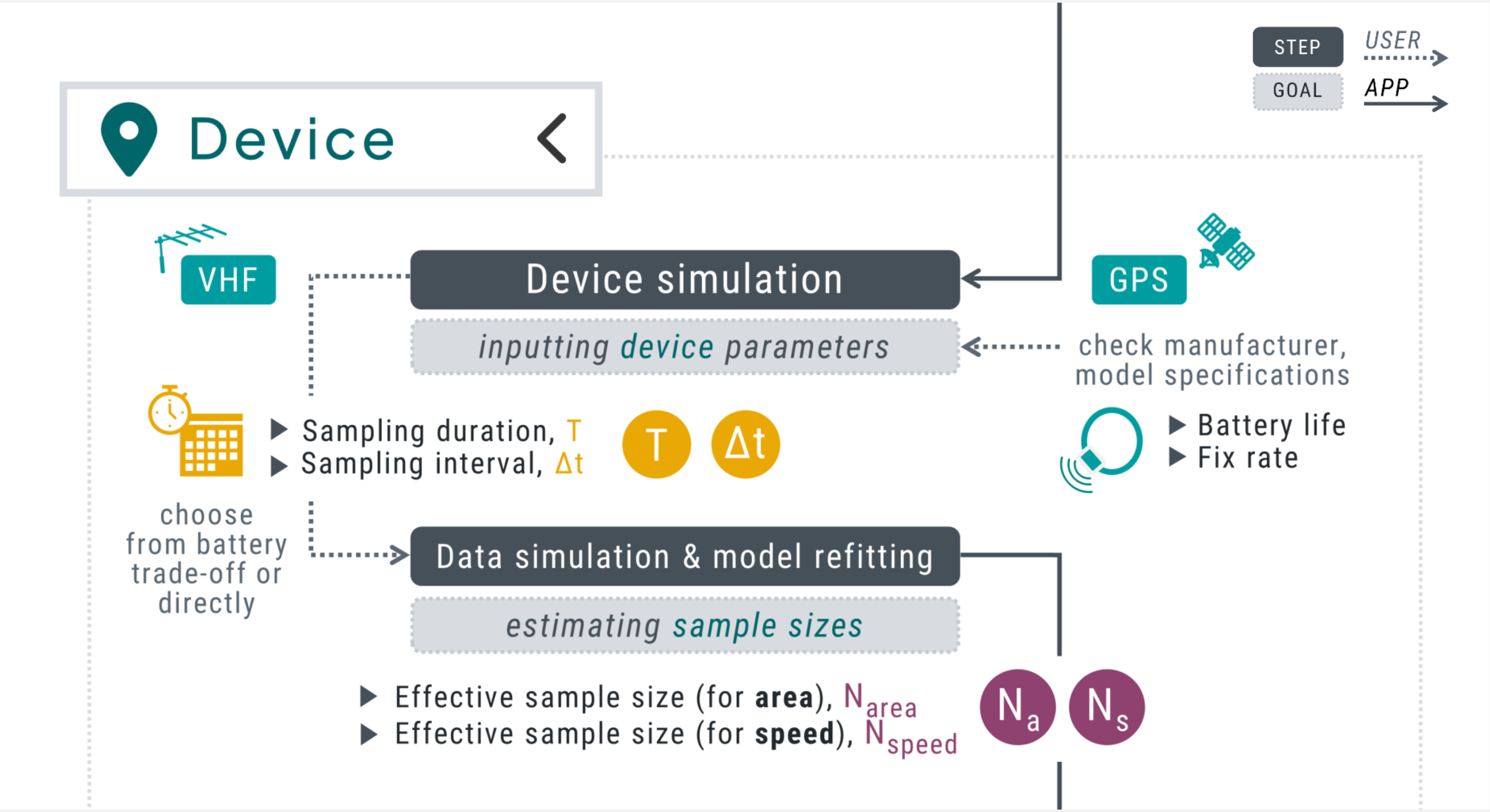
These parameters are fairly ***conservative*** at the species- and population-level.



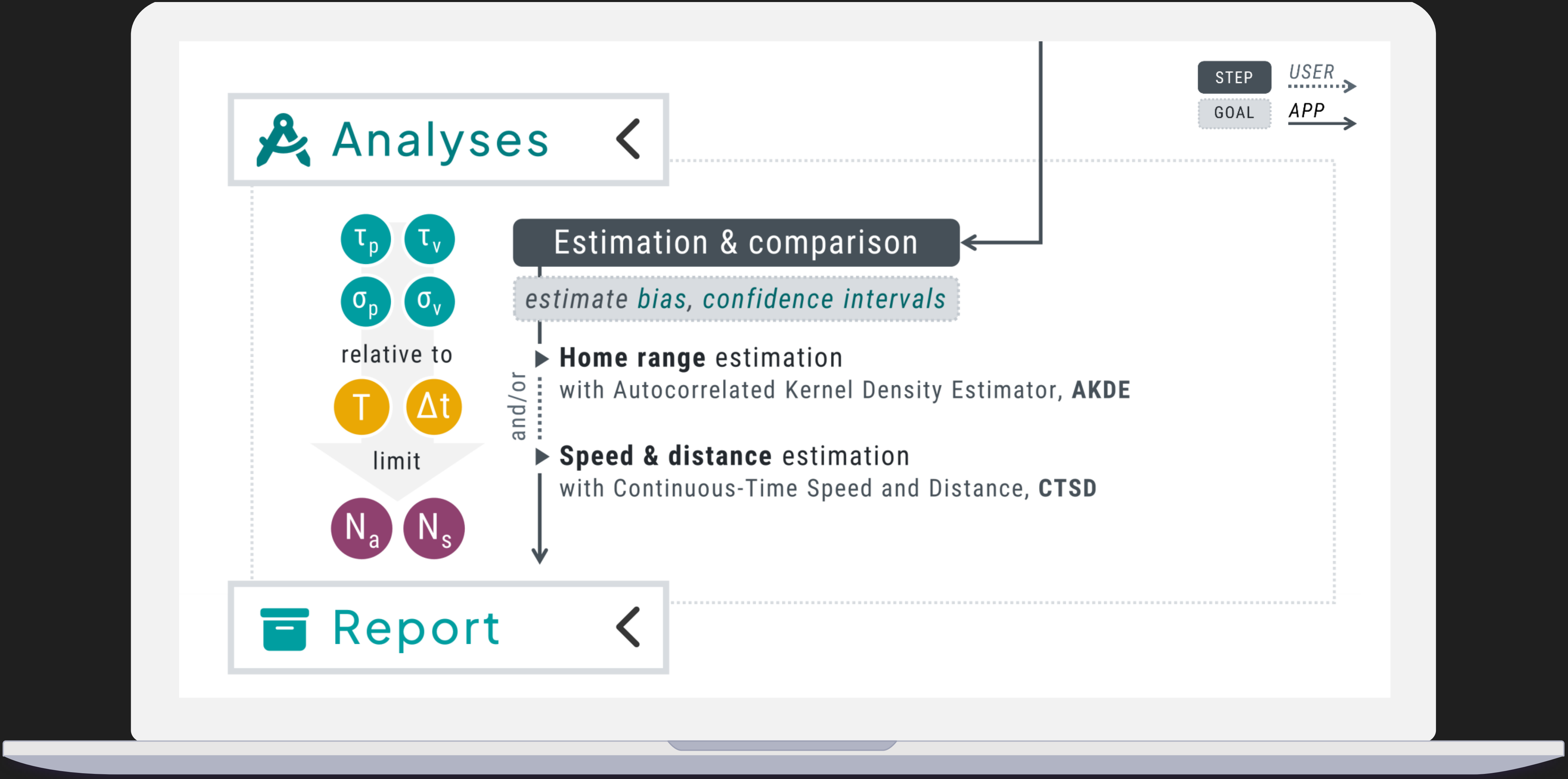
i.simoes-silva@hzdr.de



i.simoes-silva@hzdr.de



i.simoes-silva@hzdr.de



i.simoes-silva@hzdr.de

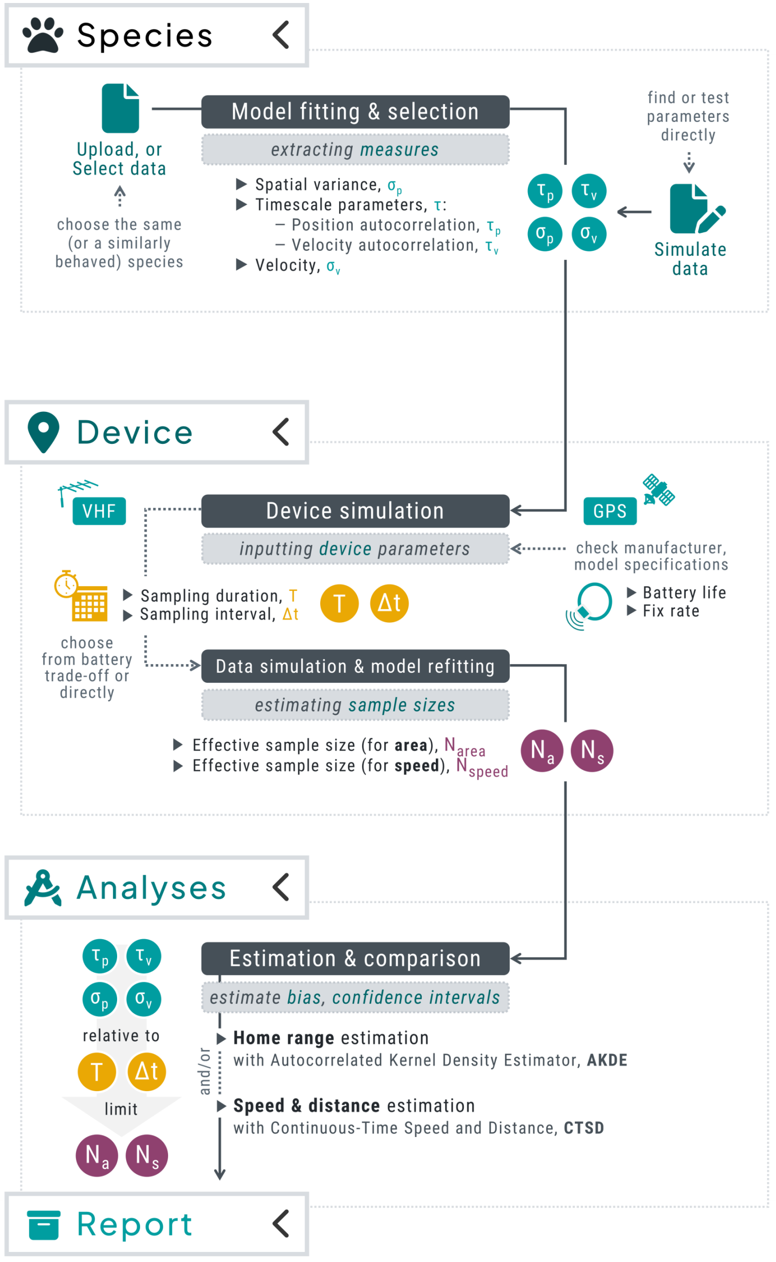
movedesign

New version (v0.3.0):

- Run multiple simulations for:
  - a predefined (*population*) sample size,
  - an iteratively higher sample size,

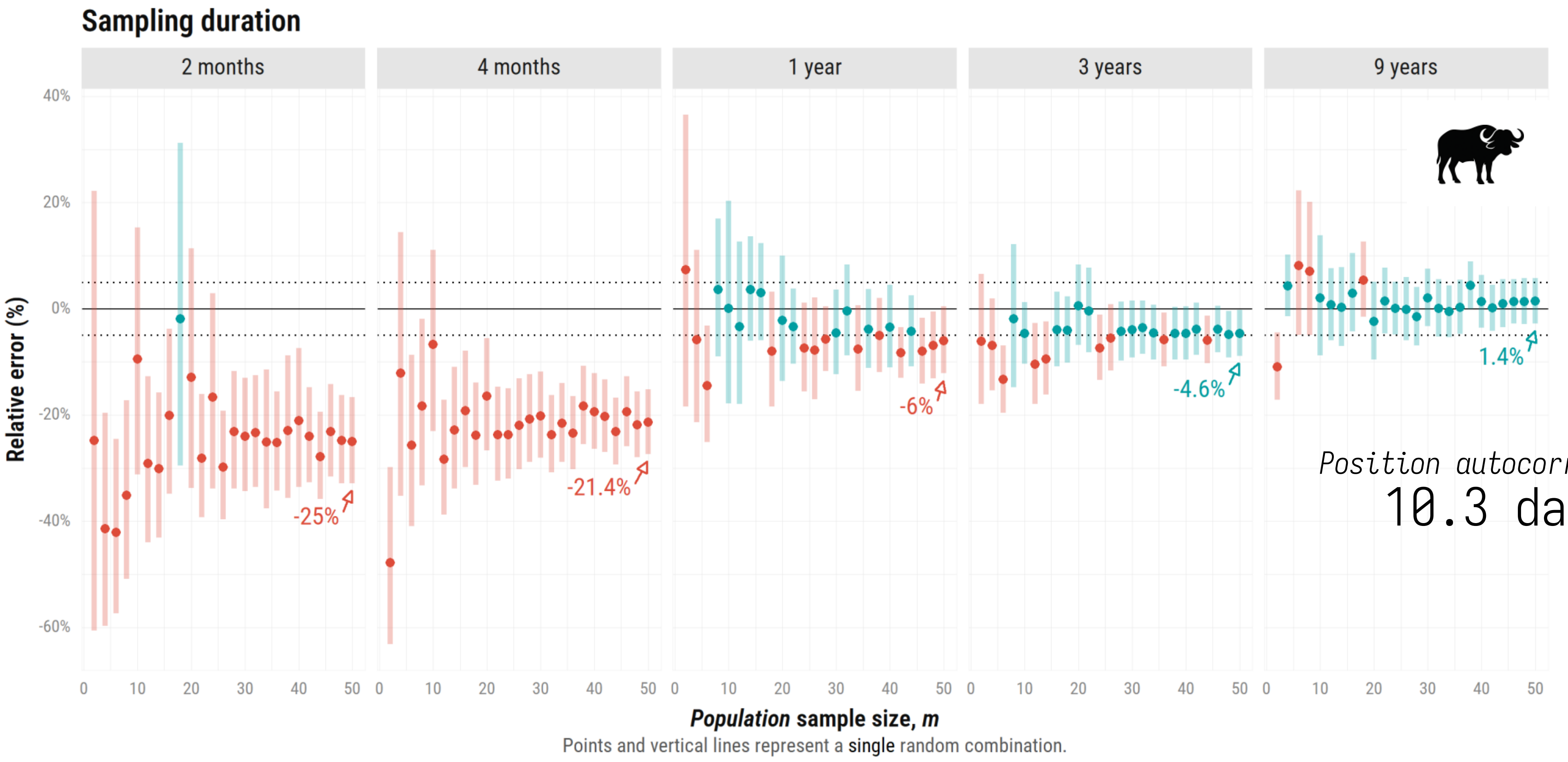
  until error is below a specified threshold.

- Get estimates for:
  - mean of sampled population,
  - compare means of two sampled populations. (*e.g.*, males/females)



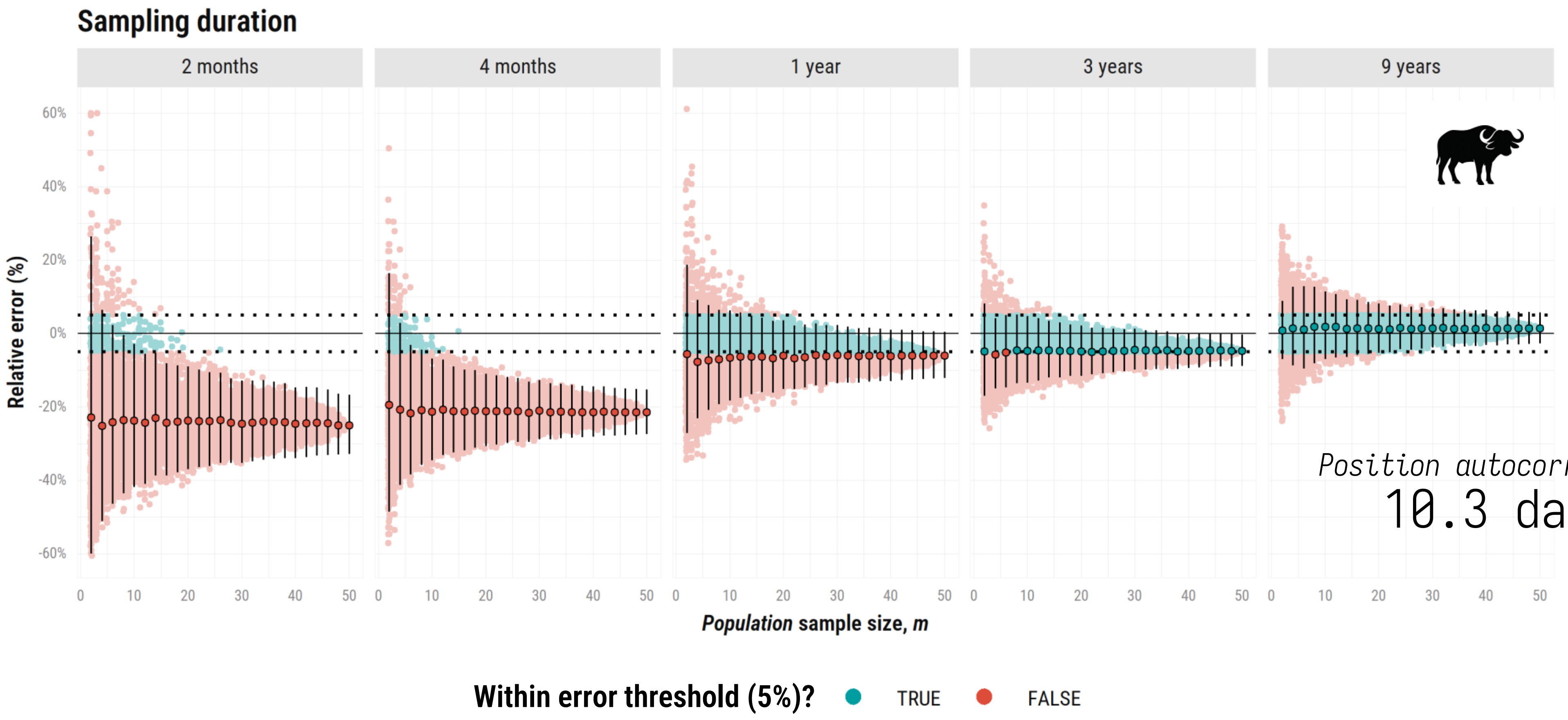
i.simoes-silva@hzdr.de

3.1. **Population-level** inferences — mean home range areas



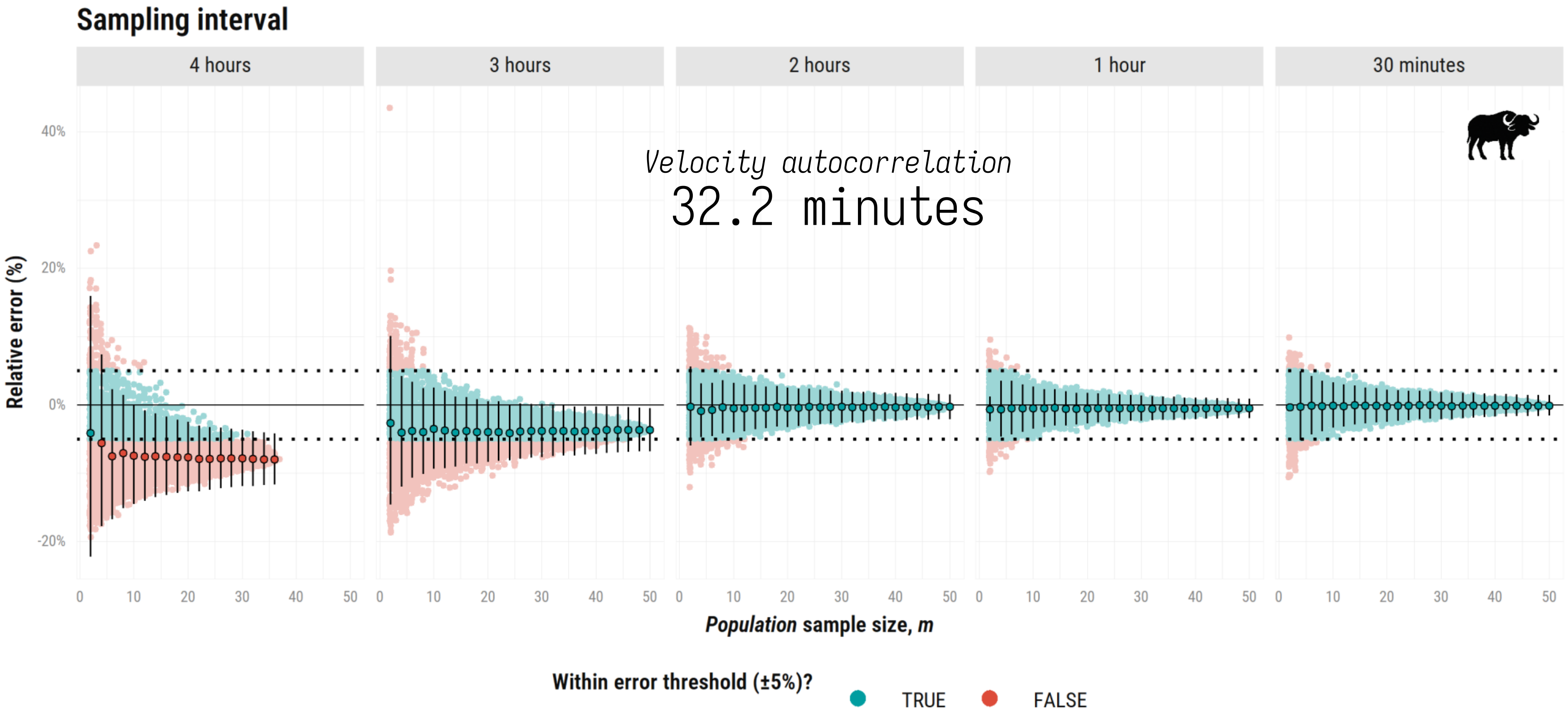
Position autocorrelation
10.3 days

3.1. **Population-level** inferences — mean home range areas



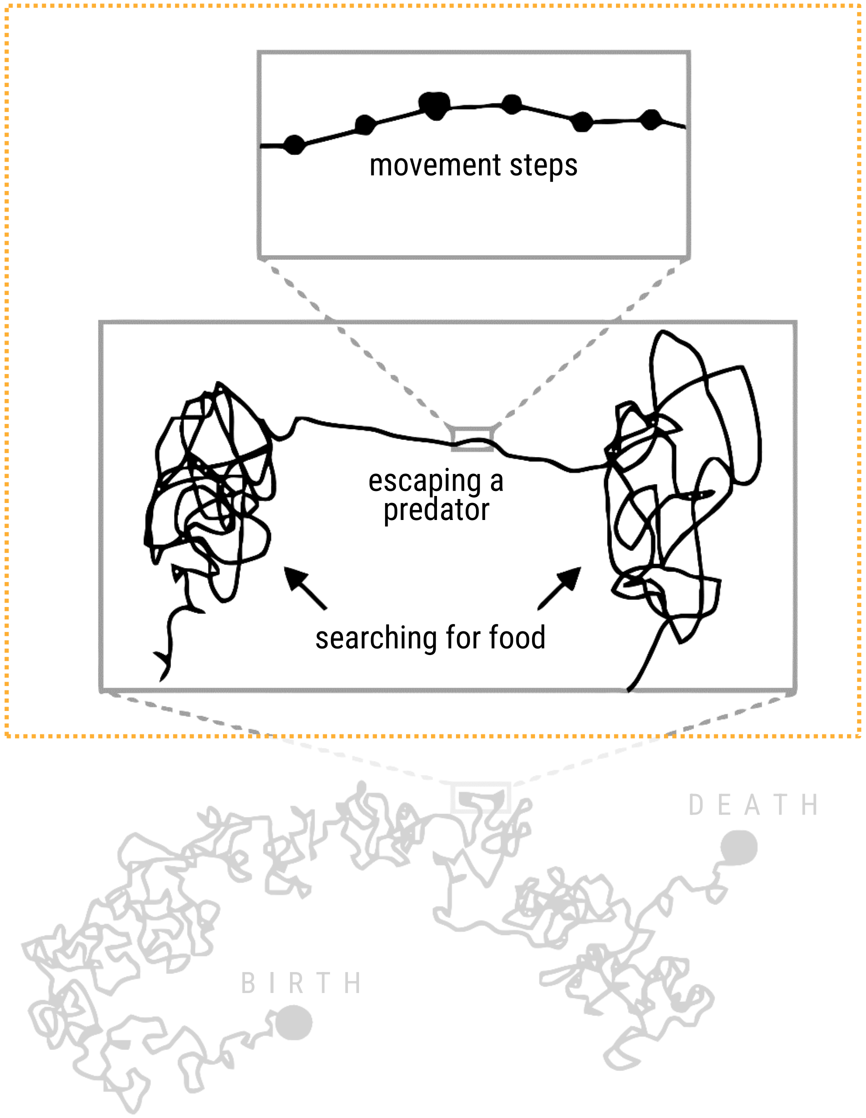
Position autocorrelation
10.3 days

3.2. **Population-level** inferences — mean movement speed



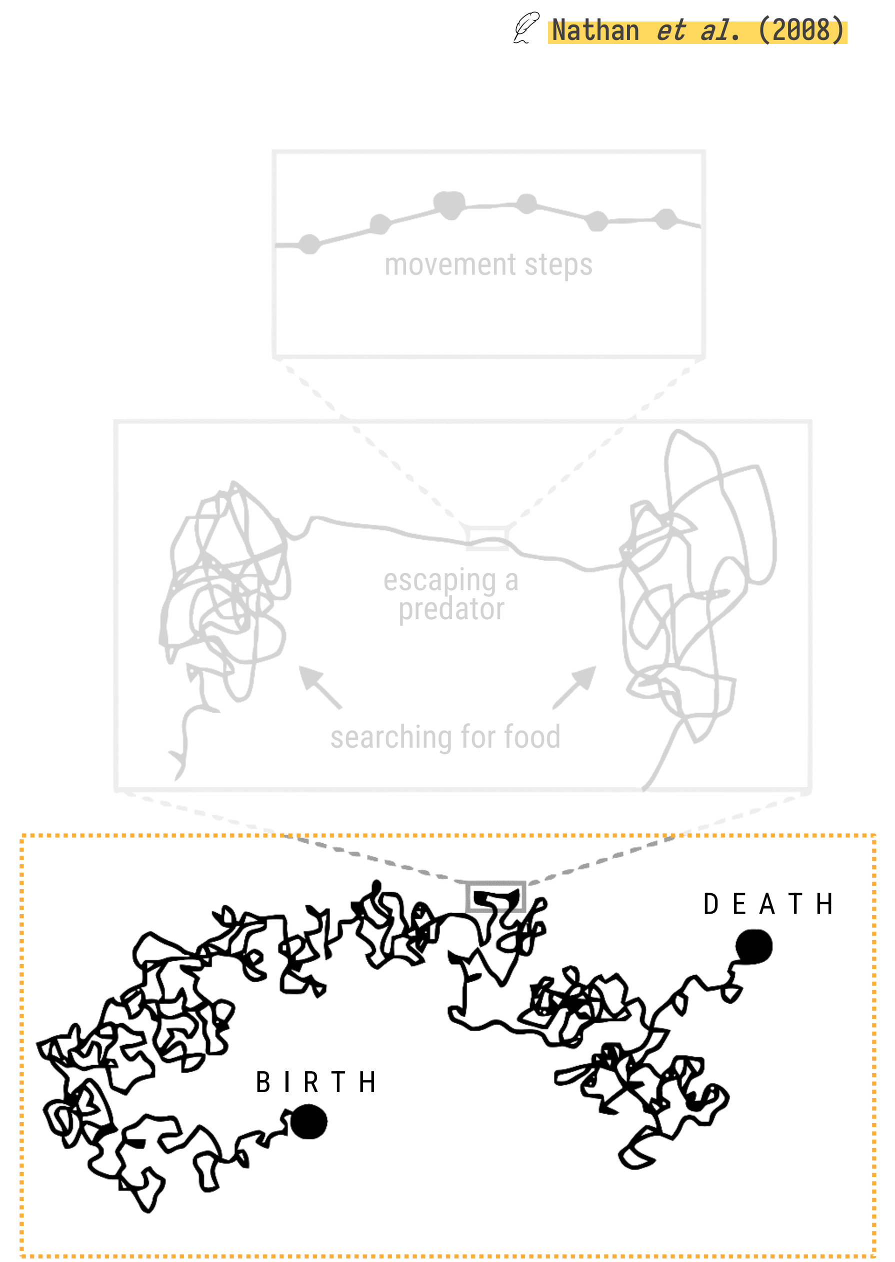
i.simoes-silva@hzdr.de

Nathan *et al.* (2008)



If the goal is speed & distance estimation, adjust your ***sampling interval*** (Δt) to ensure data is of sufficient resolution to detect τ_v.

i.simoes-silva@hzdr.de

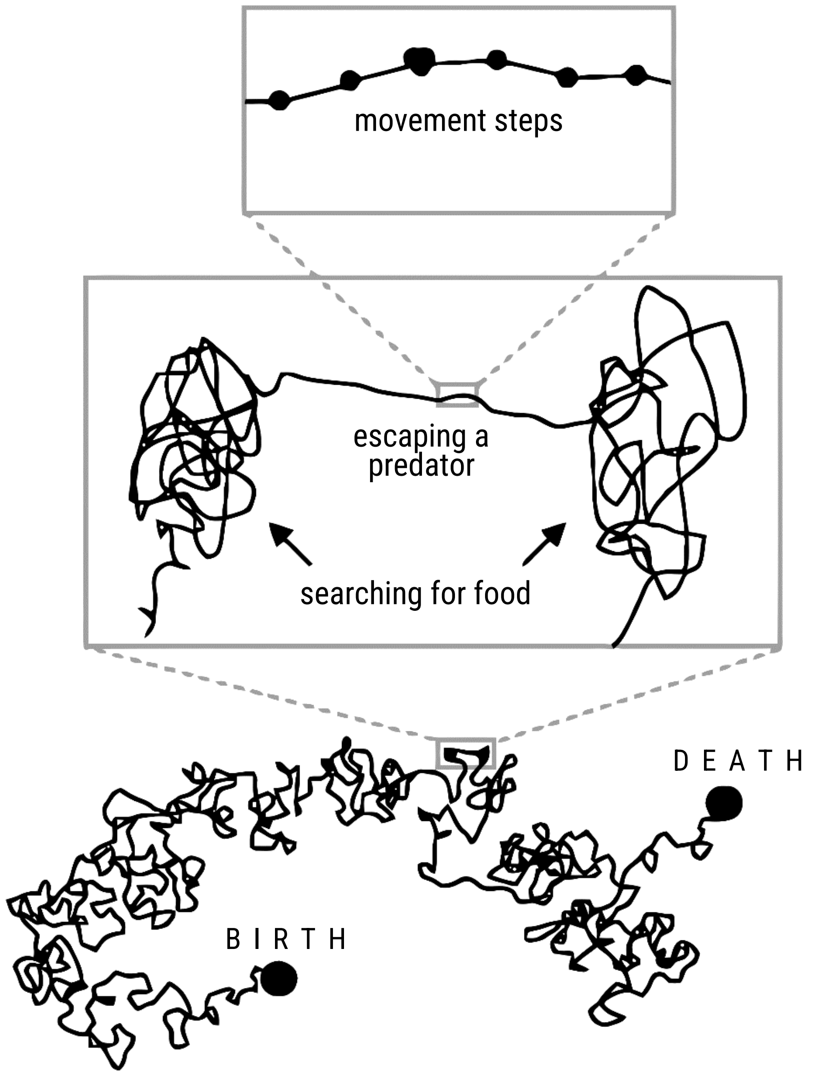


If the goal is ***speed & distance estimation****,* adjust your ***sampling interval*** (Δt) to ensure data is of sufficient resolution to detect τ_v.

If the goal is ***home range area estimation****,* adjust your ***sampling duration*** (T) to ensure data is sufficient to detect τ_p.

i.simoes-silva@hzdr.de

Nathan *et al.* (2008)



If the goal is speed & distance estimation,
adjust your ***sampling interval*** (Δt) to ensure data is of sufficient resolution to detect τ_v.

If the goal is home range area estimation,
adjust your ***sampling duration*** (T) to ensure data is sufficient to detect τ_p.

If both,
You may be able to address large-scale and fine-scale questions, but not always ***concurrently***.

i.simoes-silva@hzdr.de

Get informed:
Collect **pilot data**, and/or look at published studies & datasets.

Make smart decisions:
Consider ***spatiotemporal scales*** relative to ***questions***.

Keep it simple:
Use ***even sampling rates*** if possible. Don't get too clever!

Try before you buy:
Check it first with ***simulated data***. →

Divide and conquer:
Use different individuals to answer different questions.

If you must sample unevenly…

Keep it simple:
Use no more than **two** different sampling rates.

Try before you buy:
Simulate with uneven sampling first. Still works?

Mind your math:
Use sampling rates that are ***integer multiples***.

Be careful:
Check for ***artifacts*** introduced by uneven sampling.

Be realistic:
No, you can't have it all!

i.simoes-silva@hzdr.de