ANIMOVE 2022

CONTINUOUS-TIME MOVEMENT MODELS

Center for Advanced Systems Understanding (CASUS)
Helmholtz-Zentrum Dresden-Rossendorf (*HZDR*)

HOME RANGE OVERLAP

USING THE CTMM R PACKAGE

Inês Silva, Chris Fleming
i.simoes-silva@hzdr.de

OVERLAP

@ Jenny van Twillert

@ Debbie Stewart

Quantifying overlap can provide an informative metric for:

interspecific competition,
territoriality,
mating systems,
social network structure,
and contact rates (disease transmission),
many more.

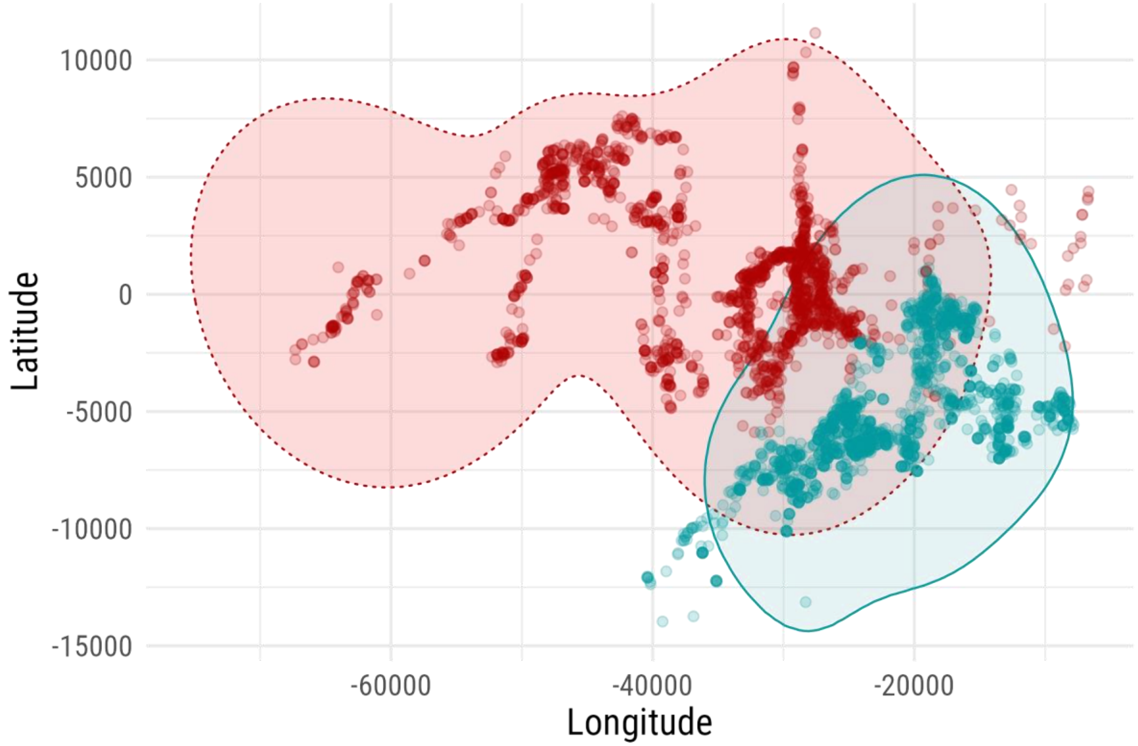
OVERLAP

Home range overlap captures potential for interactions.

Numerous overlap indices available, many are *ad-hoc*, and none have confidence intervals.

Fieberg & Kochanny (2005)

DOI: 10.2193/0022-541X(2005)69



What do you need:

1. Comparable home range estimates. ✓

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1. Comparable home range estimates. ✓

   e.g. dealing with unmodelled autocorrelation,
   small effective sample size,
   temporally-biased sampling.

What do you need:

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2. An interpretable, relatively unbiased overlap index.

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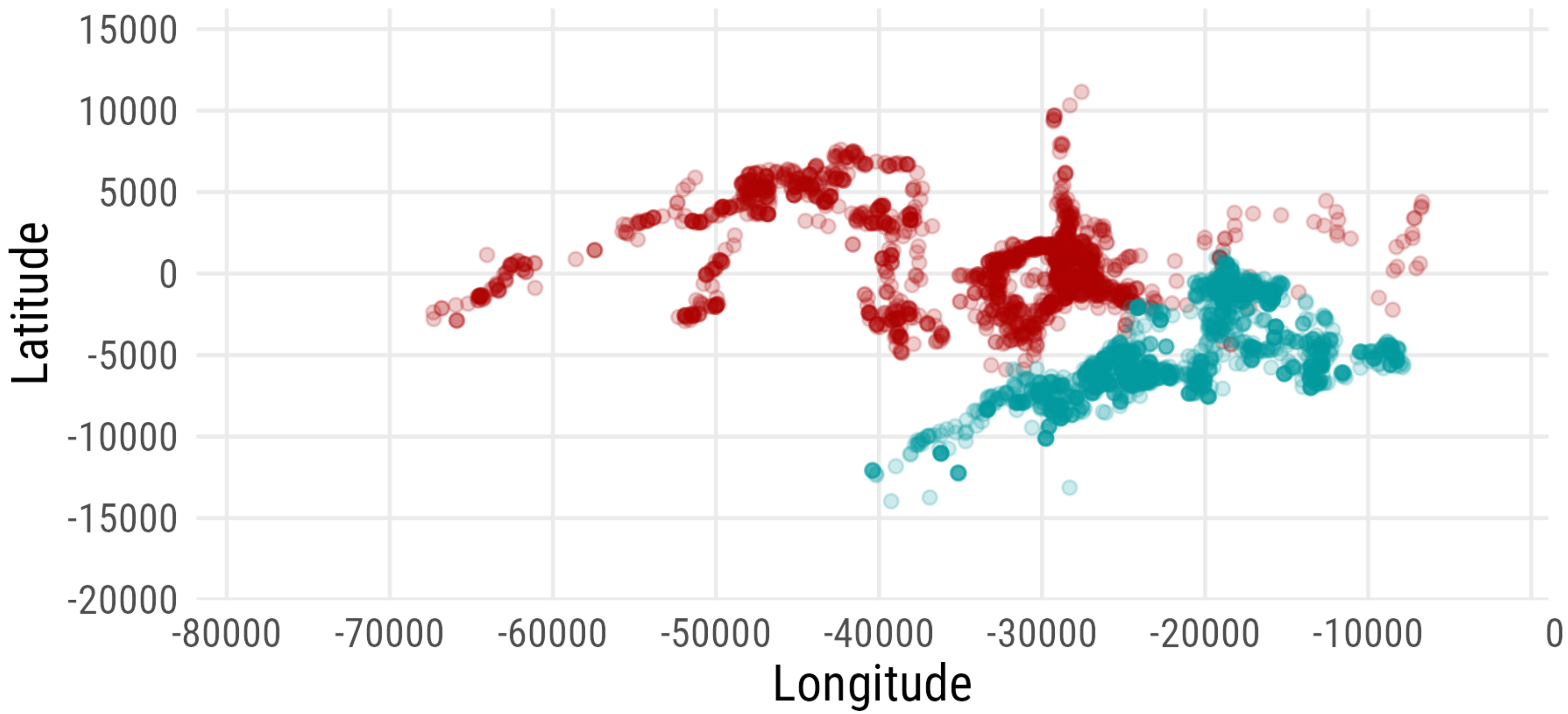
2. An interpretable, relatively unbiased overlap index.
3. A way to propagate uncertainty in home range estimates *into* overlap estimates.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10000
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Latitude
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-10000
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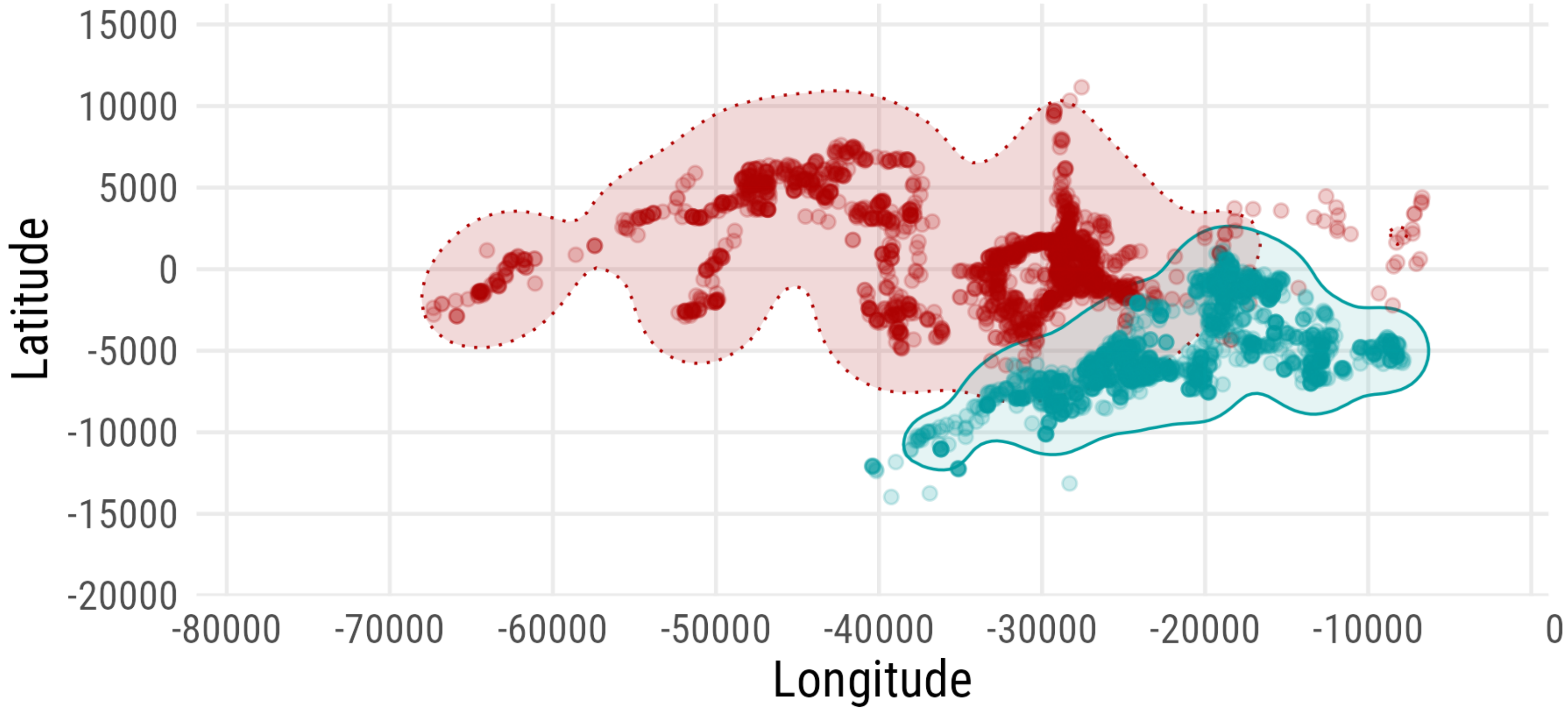
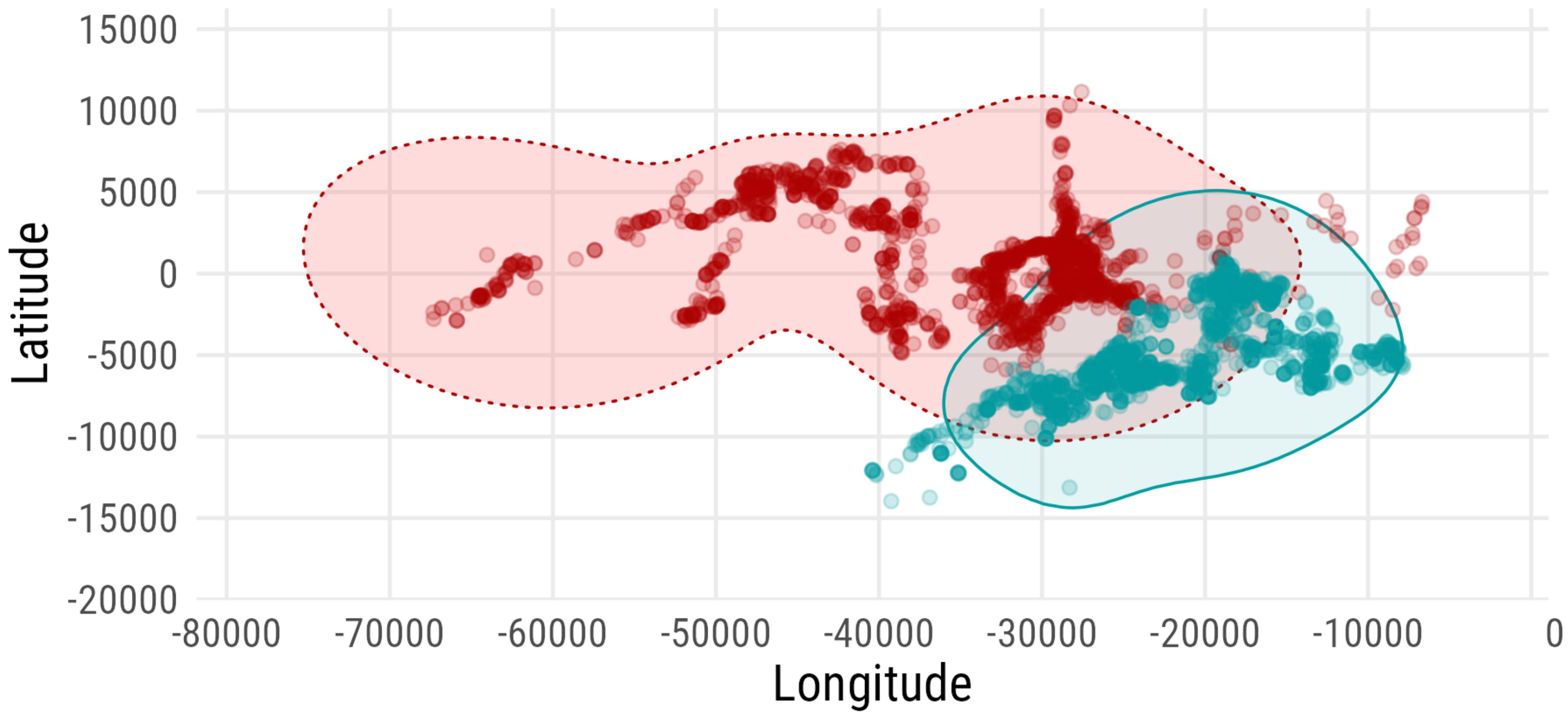
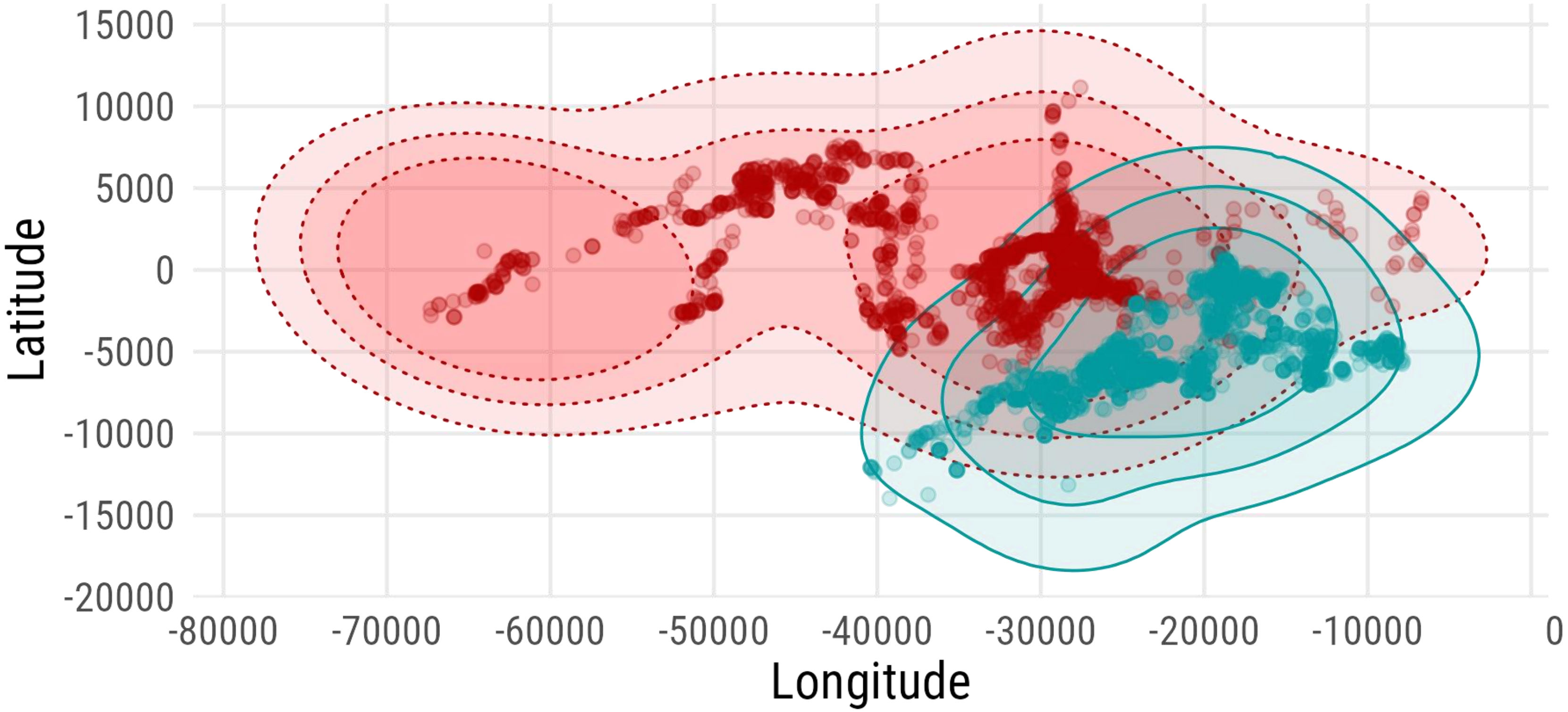
Longitude



Kernel density estimator (KDE)



Autocorrelated Kernel density estimator (AKDE)



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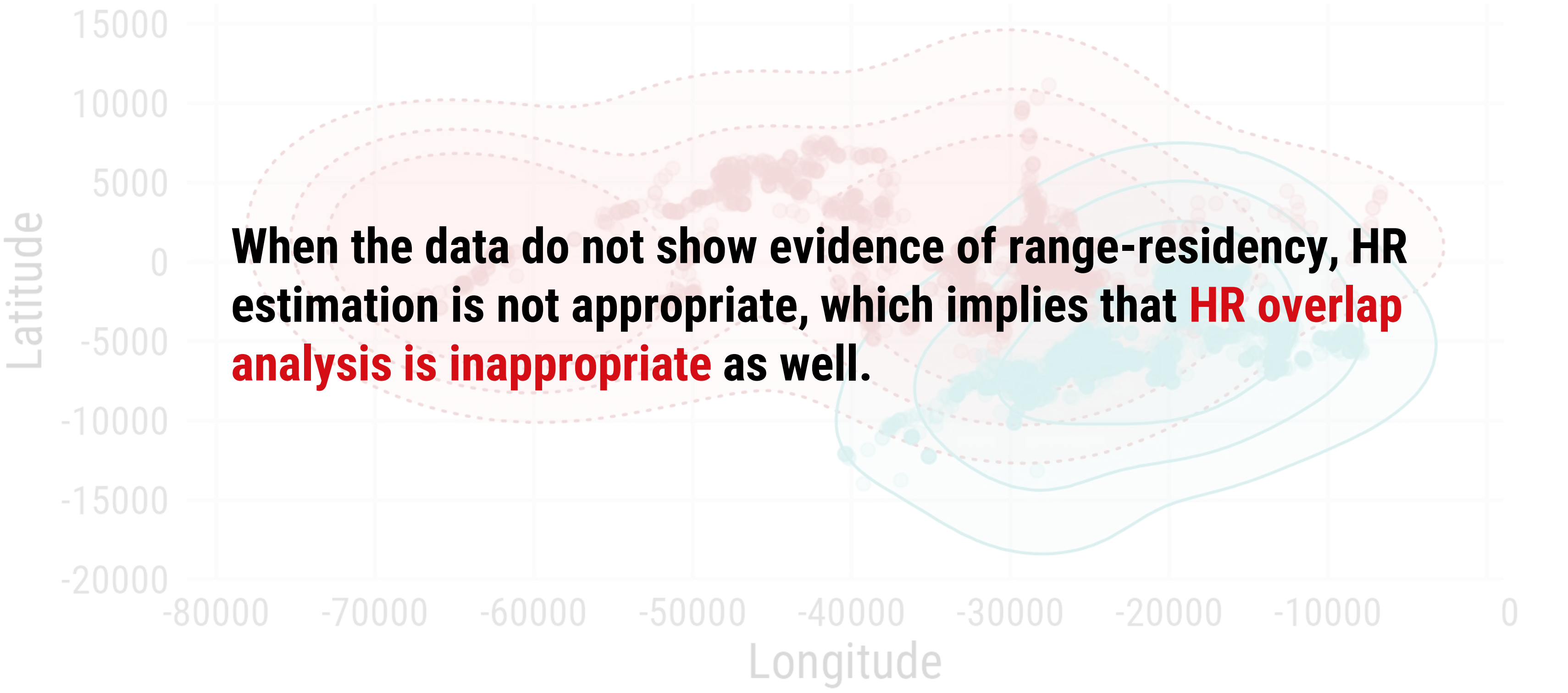
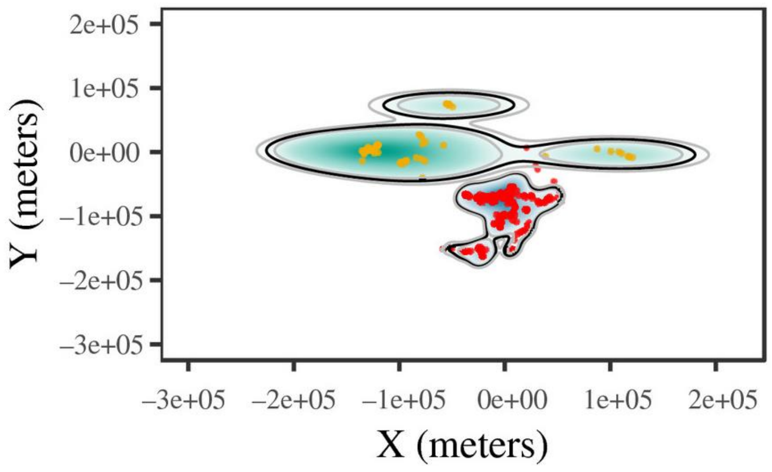


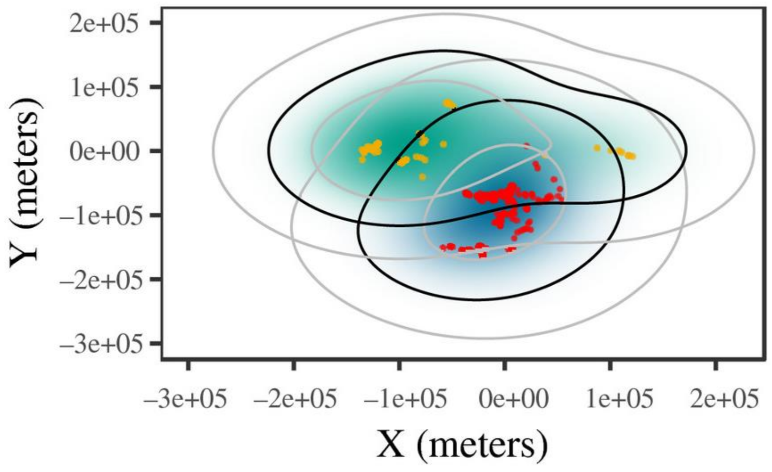
When the data do not show evidence of range-residency, HR estimation is not appropriate, which implies that HR overlap analysis is inappropriate as well.

Autocorrelated Kernel density estimator (AKDE)

OVERLAP



Y (meters)
2e+05
1e+05
0e+00
−1e+05
−2e+05
−3e+05
−3e+05
−2e+05
−1e+05
0e+00
1e+05
2e+05
X (meters)



Y (meters)
2e+05
1e+05
0e+00
−1e+05
−2e+05
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−1e+05
0e+00
1e+05
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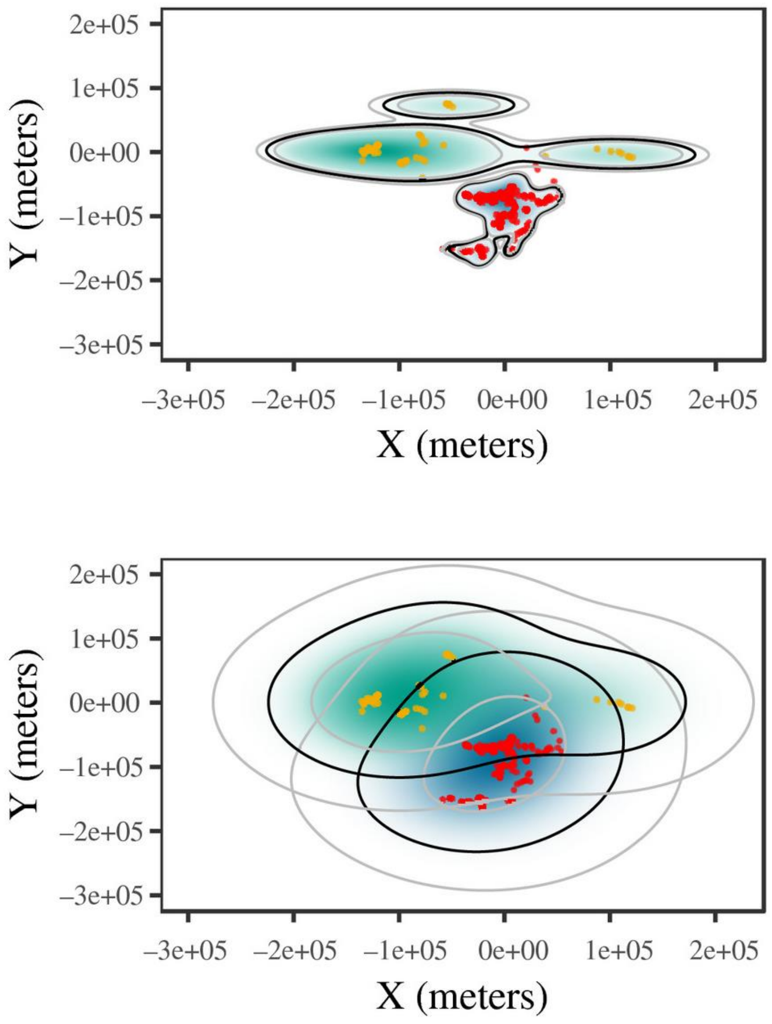
X (meters)

OVERLAP


2e+05
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Y (meters)
−3e+05 −2e+05 −1e+05 0e+00 1e+05 2e+05
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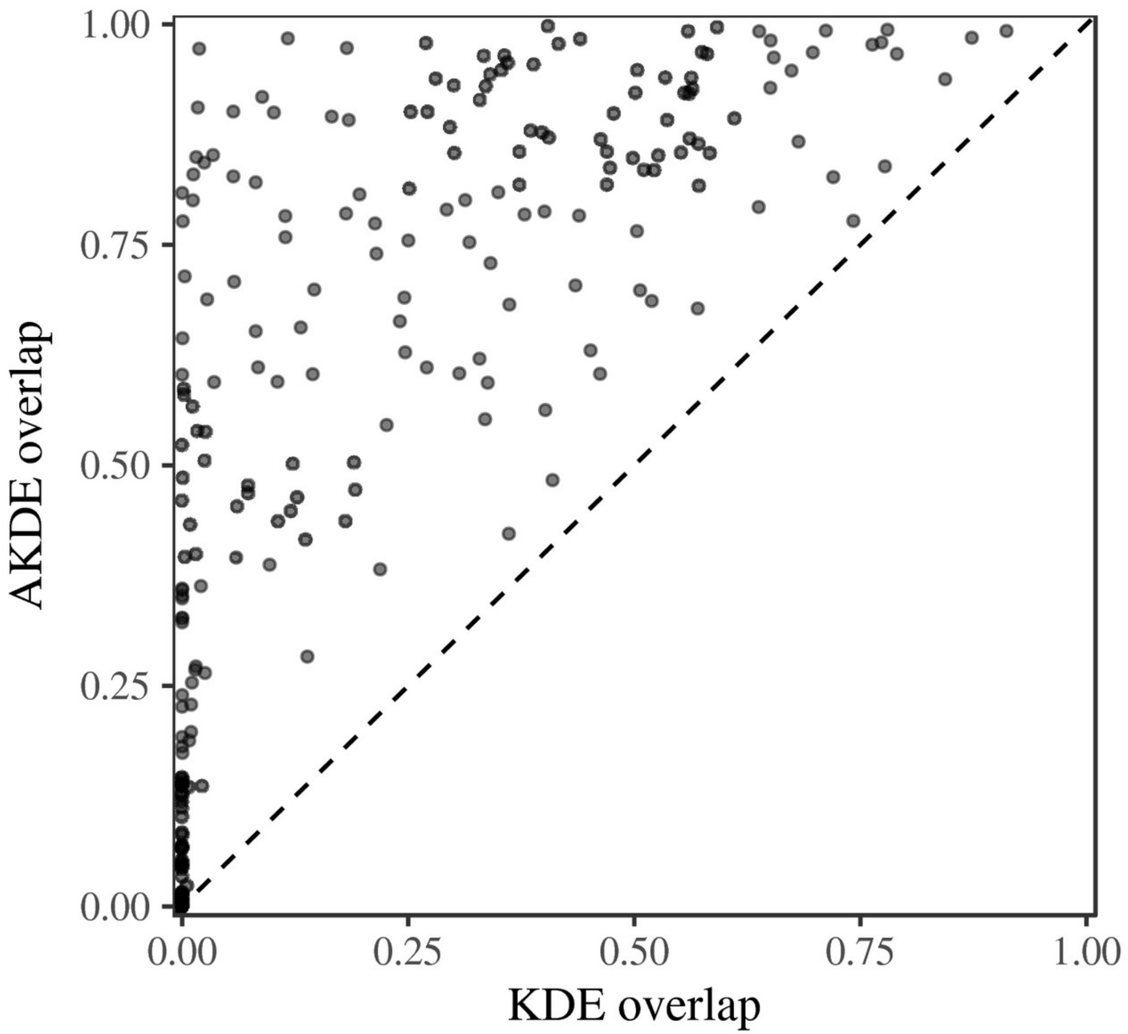
1.00
0.75
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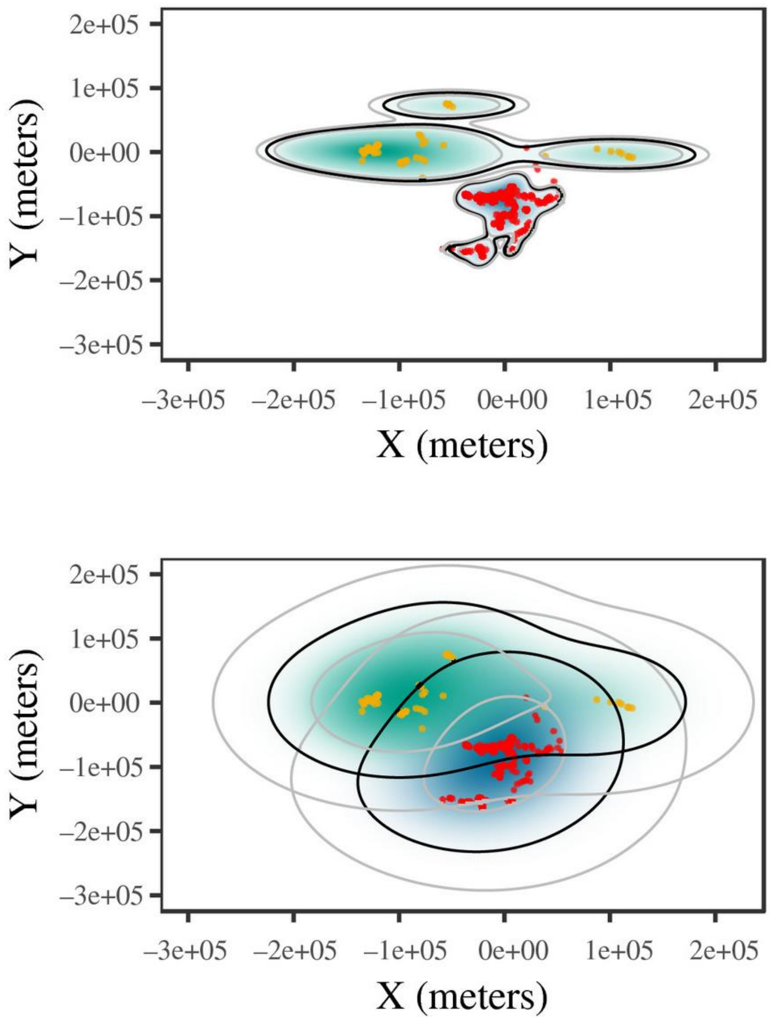
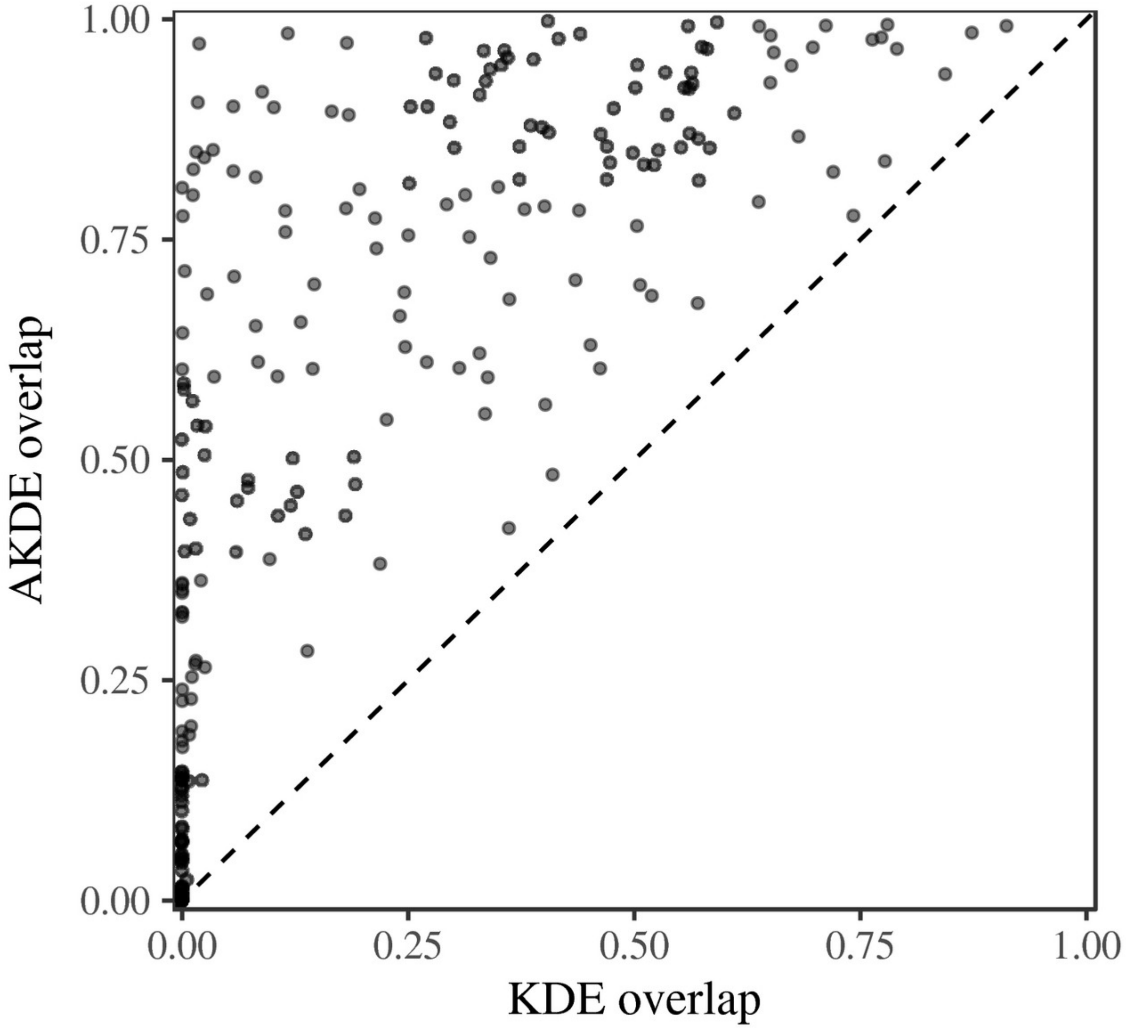
0.25
0.00
AKDE overlap
0.00 0.25 0.50 0.75 1.00
KDE overlap

OVERLAP





Important when considering biologically meaningful conclusions from these analyses.

What do you need:

1. Comparable home range estimates. ✓
2. An interpretable, relatively unbiased overlap index.
3. A way to propagate uncertainty in home range estimates *into* overlap estimates.

Bhattacharyya coefficient (BC)

measure of similarity between two probability distributions

BC ranges from ***zero*** (no overlap) to **1** (identical distributions).

Fieberg & Kochanny (2005)

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BC ranges from ***zero*** (no overlap) to **1** (identical distributions).

= Bias-corrected AKDE HR estimates
= Bias-corrected BC estimator.
= Approximate CIs for the BC point estimate.

Winner *et al.* (2018)
DOI: 10.1111/2041-210X.13027

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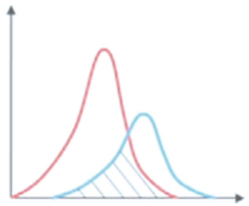

Bhattacharyya distance
(Overlap of the PDFs)

Utilization Distribution Overlap Index (UDOI)

measure of space sharing
(quantifies HR similarity while incorporating information about shared space use)

UDOI equals **1** between identical distributions (space use is uniform), but may **exceed 1** for highly concentrated distributions with a high overlap.

Tilberg & Dixon (2022)

DOI: 10.1111/2041-210X.13813

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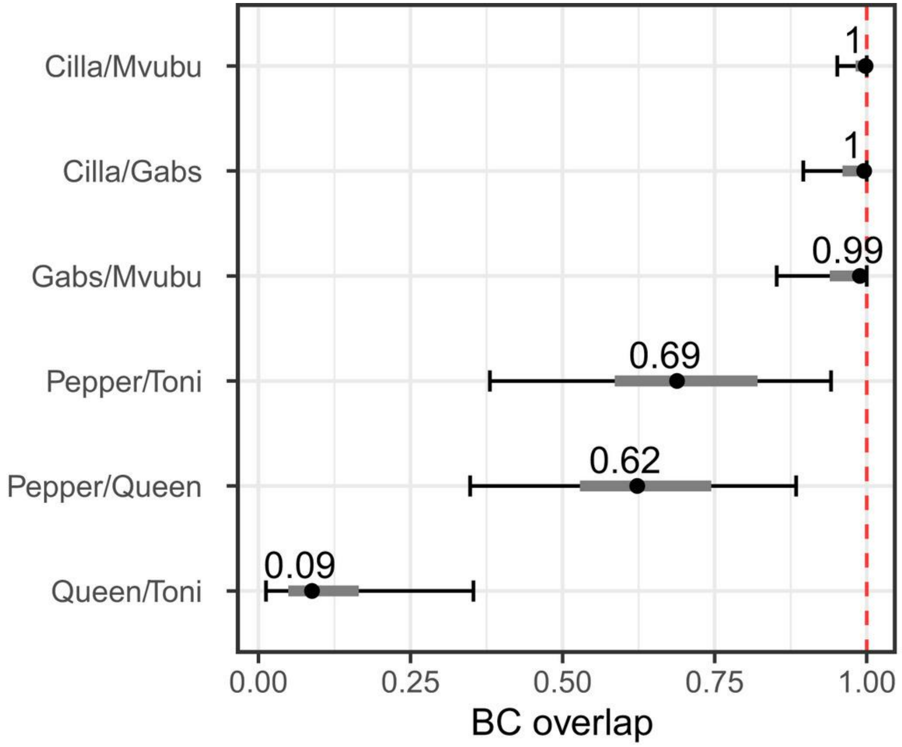

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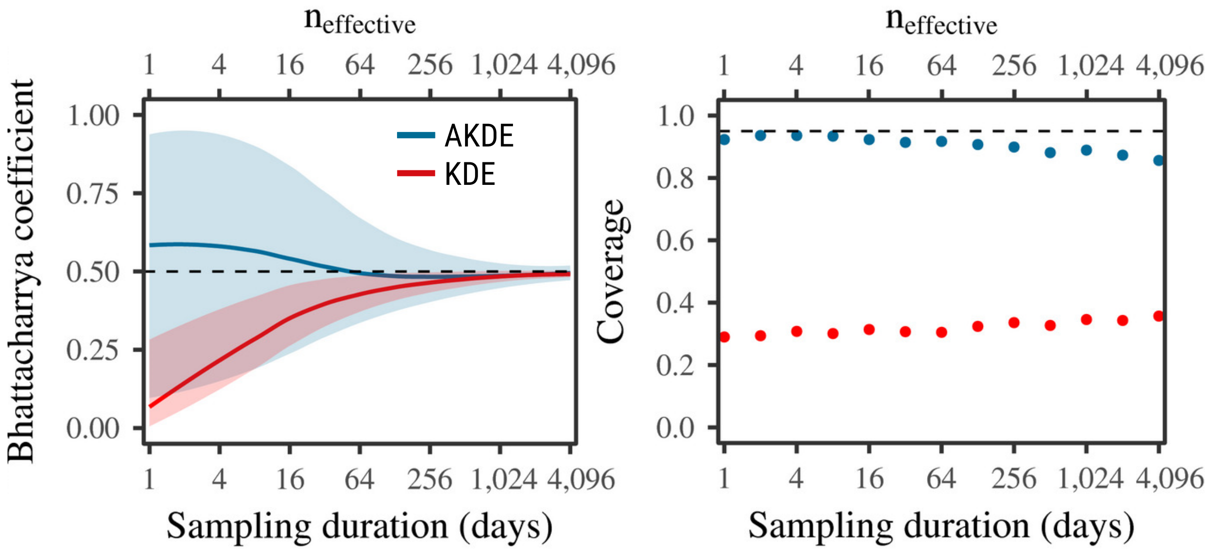
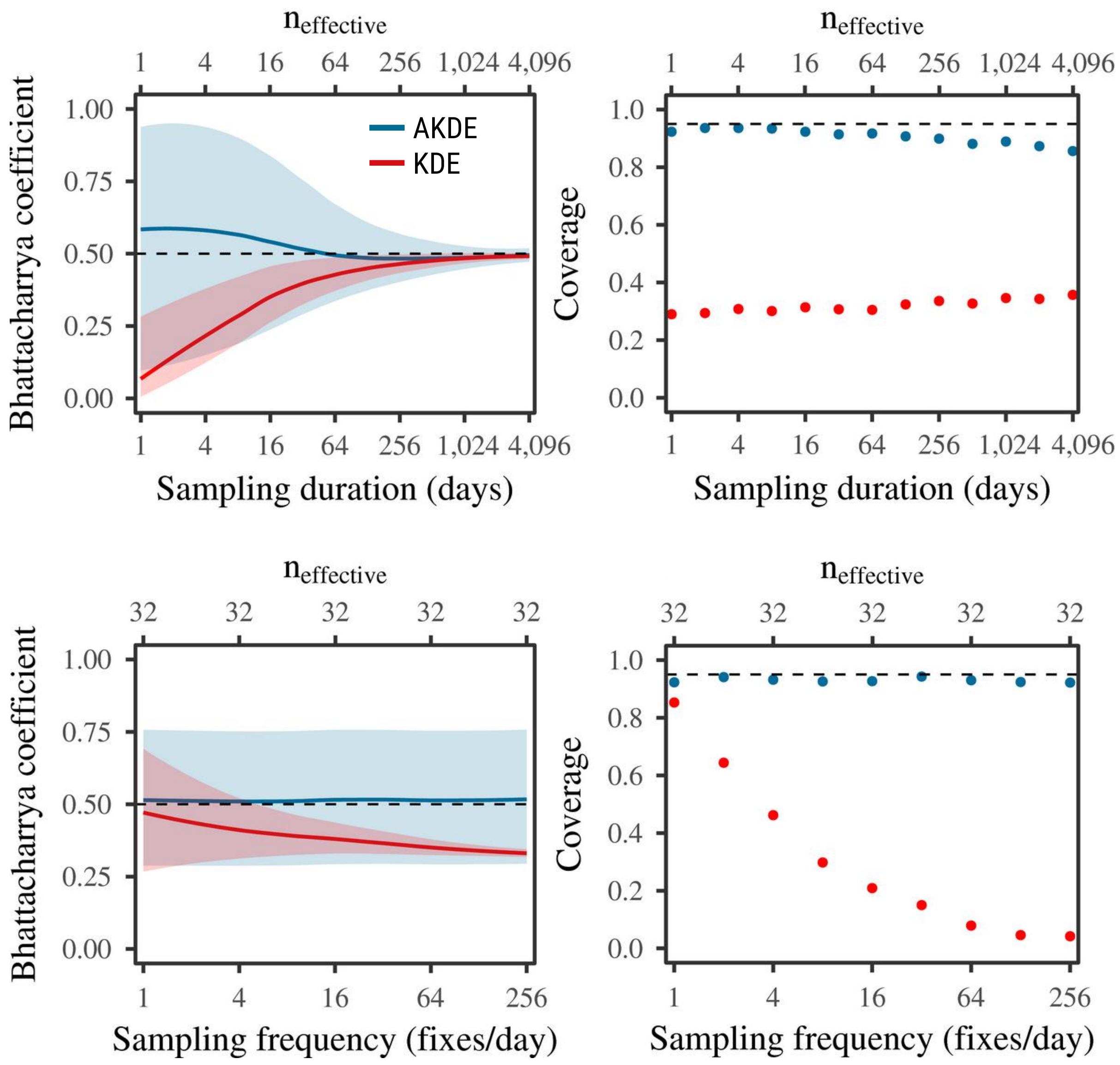
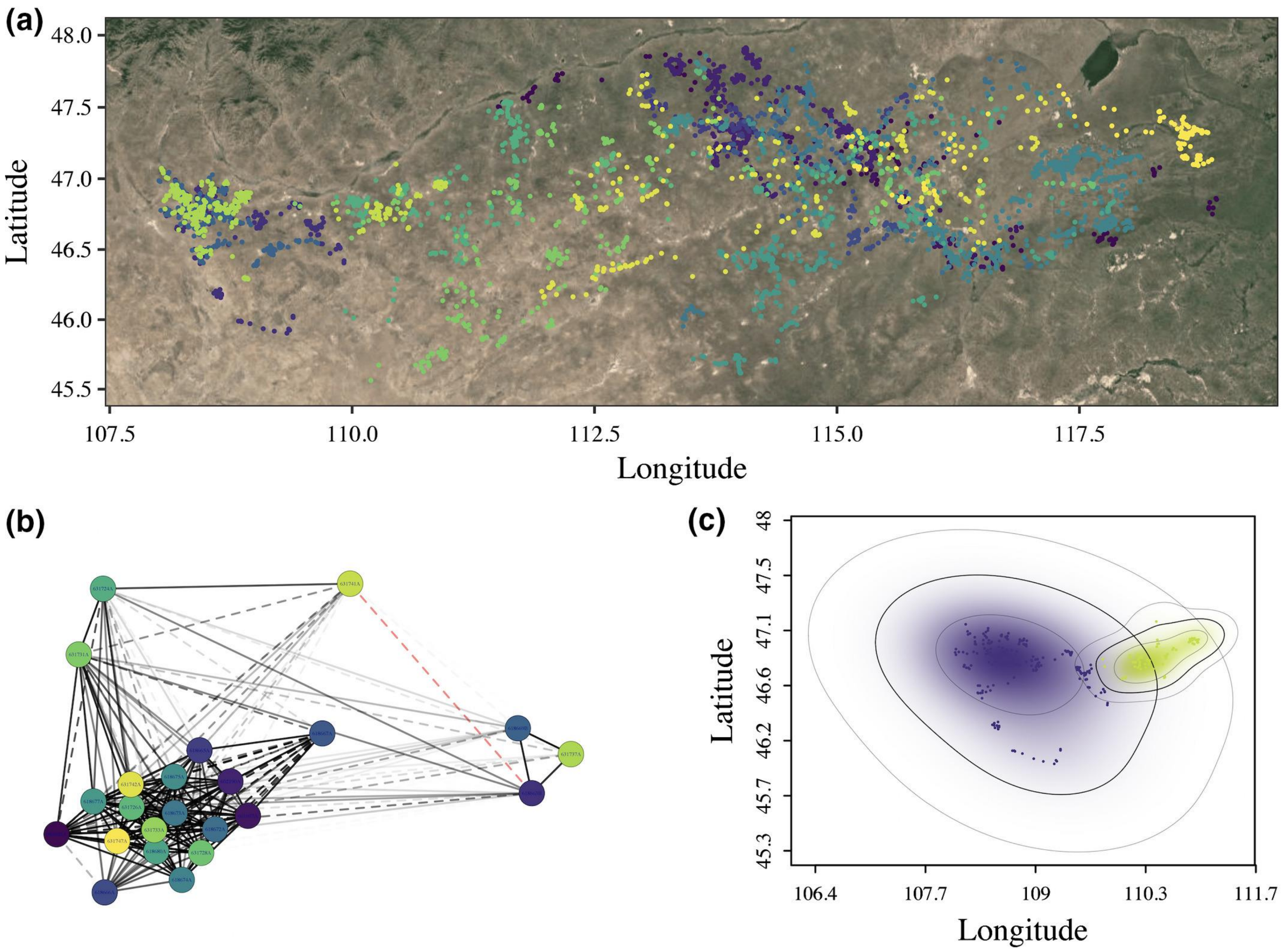
OVERLAP ESTIMATION



OVERLAP ESTIMATION



OVERLAP ESTIMATION



OVERLAP ESTIMATION

- The first inferential framework for overlap.
- Meaningful comparisons (e.g. different sampling regimes and/or movement behaviors).

  = can be validly be compared across studies
- Stepping stone to higher level processes.

Winner *et al.* (2018)
DOI: 10.1111/2041-210X.13027

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ANIMOVE 2022

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HOME RANGE ENCOUNTER RATES

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Encounters as keystone events

Understanding large-scale ecological processes

predator–prey dynamics

@ Antero Topp

@ Amy Long

Intraspecific interactions

@ Ryan Dorgan

human–wildlife conflict

Encounters as keystone events

Understanding large-scale ecological processes

predator–prey dynamics

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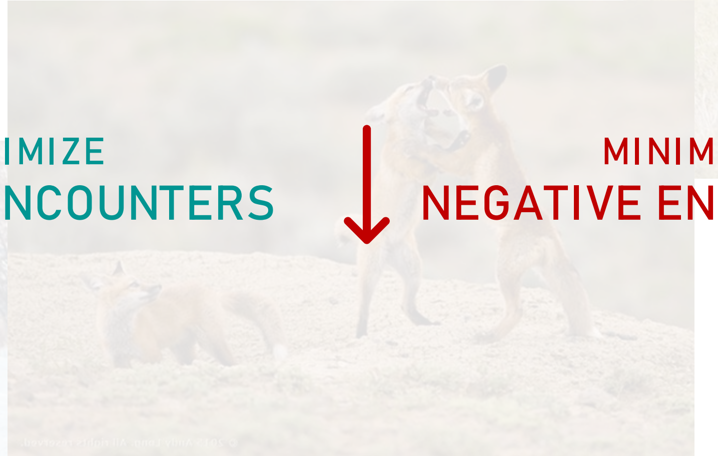
↑ MAXIMIZE
POSITIVE ENCOUNTERS

↓ MINIMIZE
NEGATIVE ENCOUNTERS



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Intraspecific interactions

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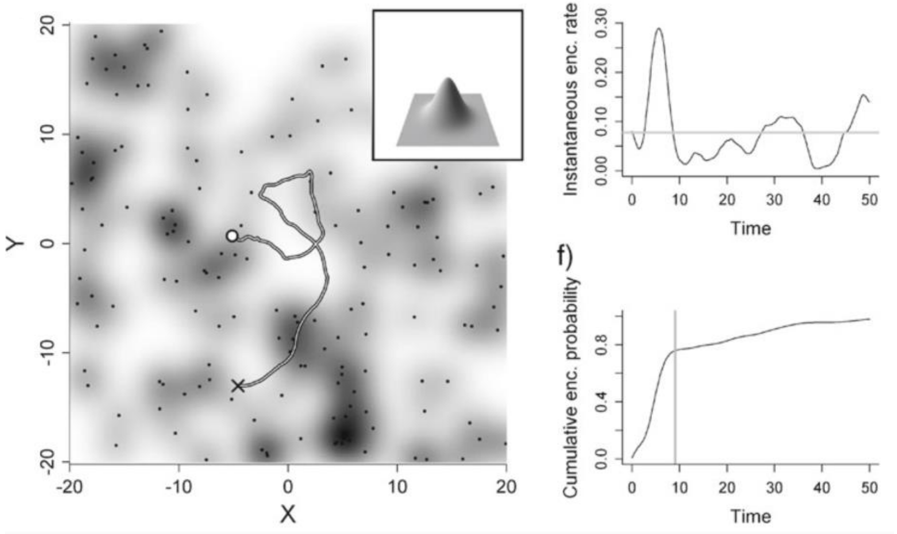
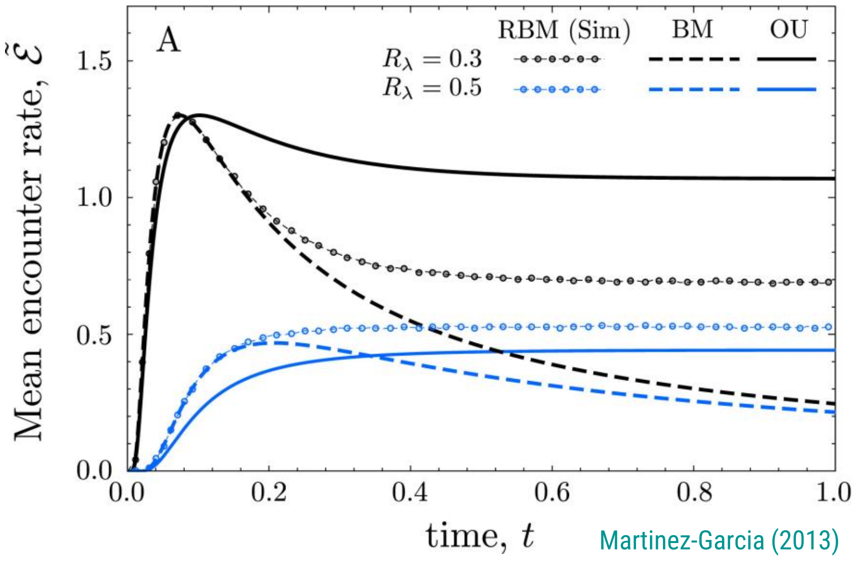
human–wildlife conflict

Encounter theory has not kept pace with the developments in animal tracking or movement modelling.

- Mainly focused on *estimating encounter rates*.



Gurarie & Ovaskainen (2013)



Martinez-Garcia (2013)

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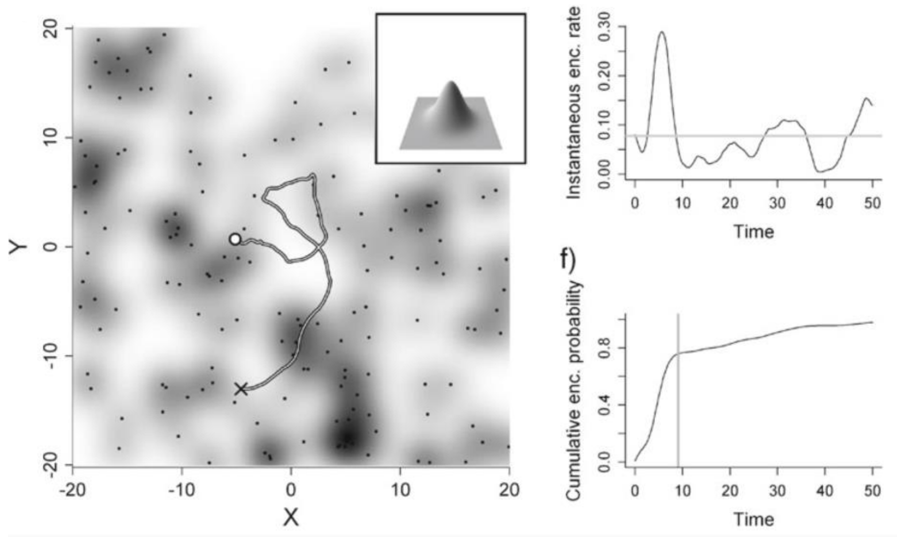
Relating *individual movement* with the *spatial locations* of encounter events



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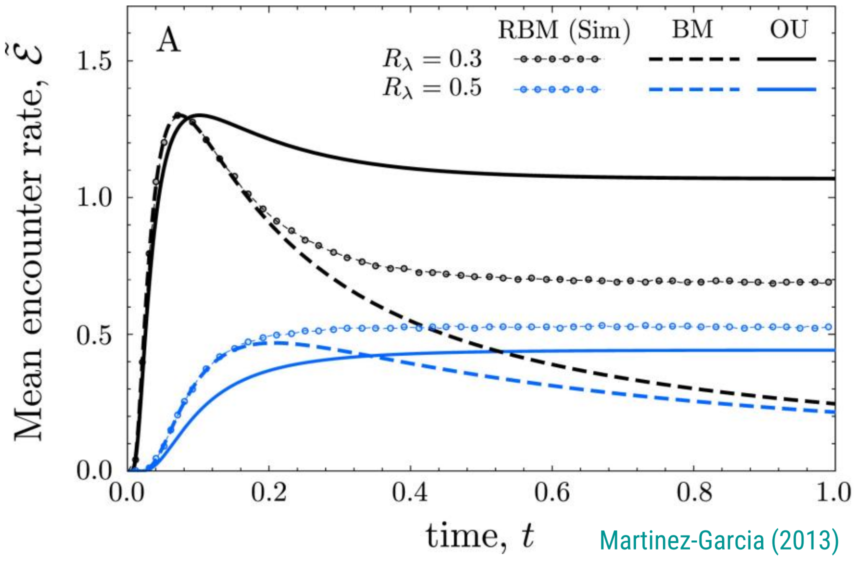


Martinez-Garcia (2013)

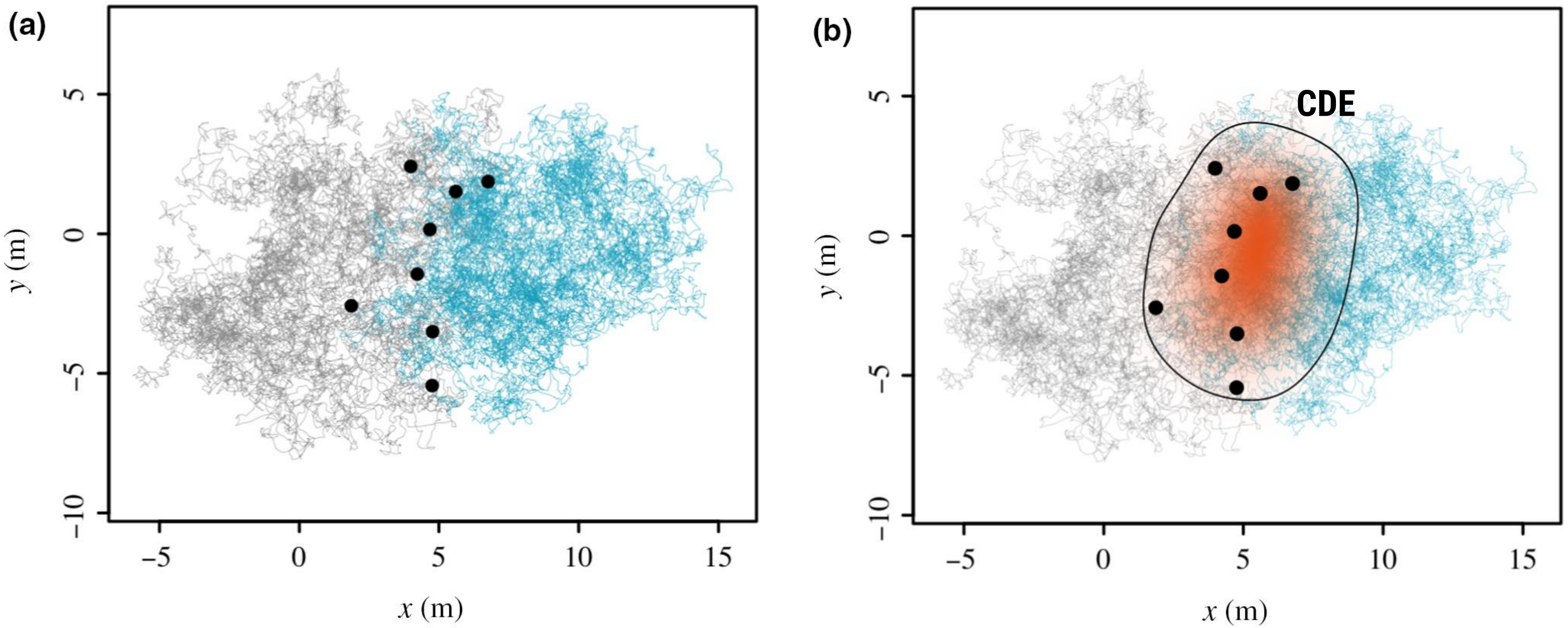
Conditional Distribution of Encounter events (CDE)

Described in Noonan *et al.* (2021)

10.1111/2041-210X.13597

Based on work by Martinez-Garcia et al. (2020) incorporating non-uniform space use into encounter theory.

ENCOUNTERS



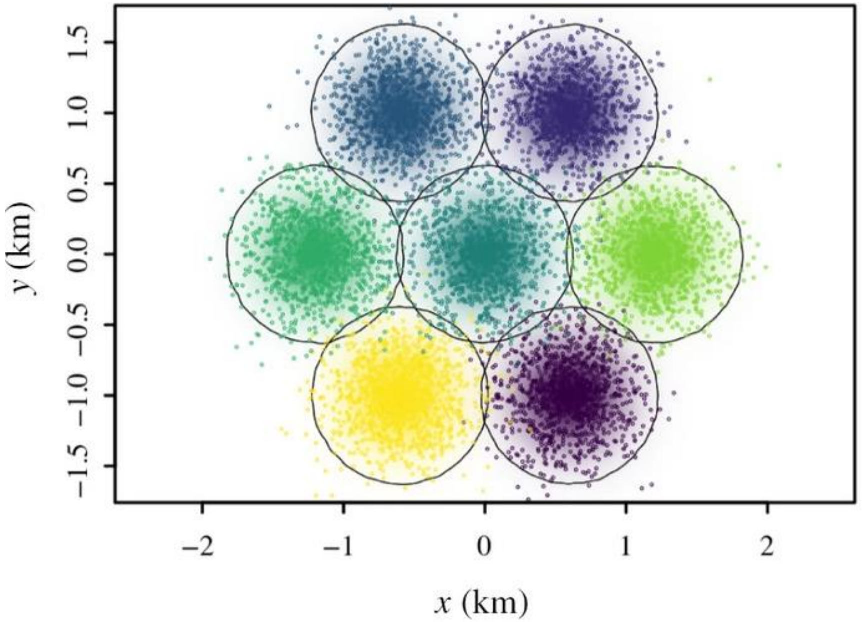
The CDE between individuals i and j is given by:

$$\mathrm{CDE}_{ij}(\mathrm{r}) = \frac{p_i(\mathrm{r})\, p_j(\mathrm{r})}{\iint d^2\mathrm{r}'\, p_i(\mathrm{r}')\, p_j(\mathrm{r}')}$$

All you need is information on the different home ranges!

Overlapping home ranges with **permeable borders**

Simulated tracking data for a population of 7 individuals with equally sized, regularly spaced home ranges.



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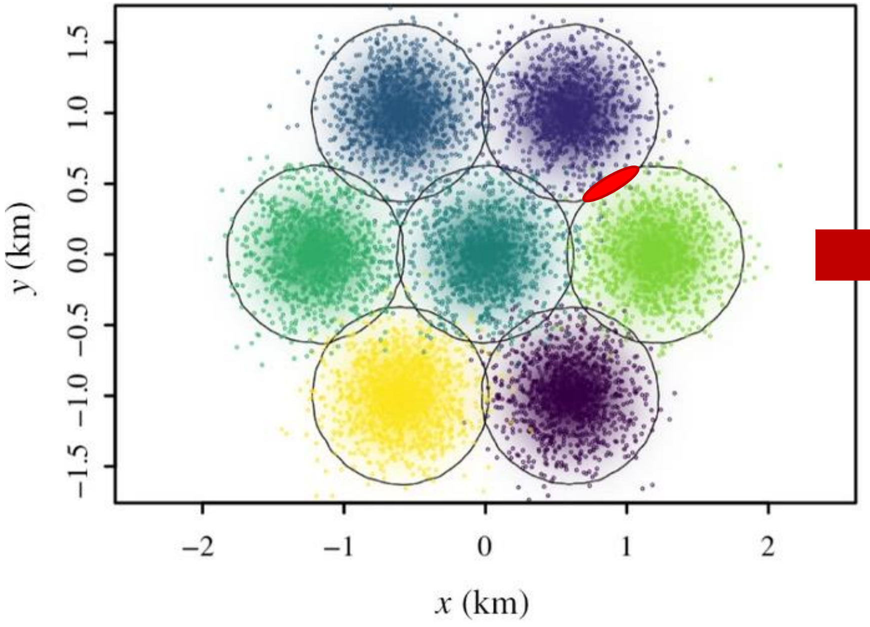
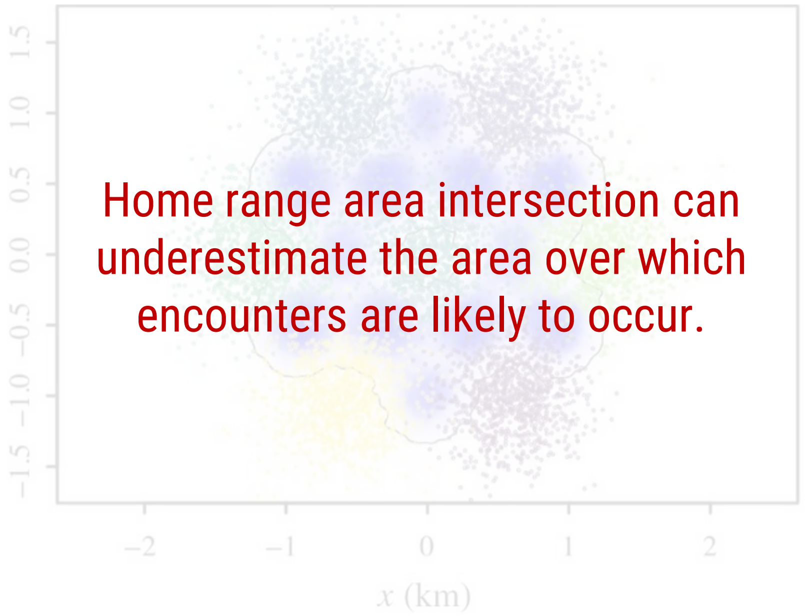
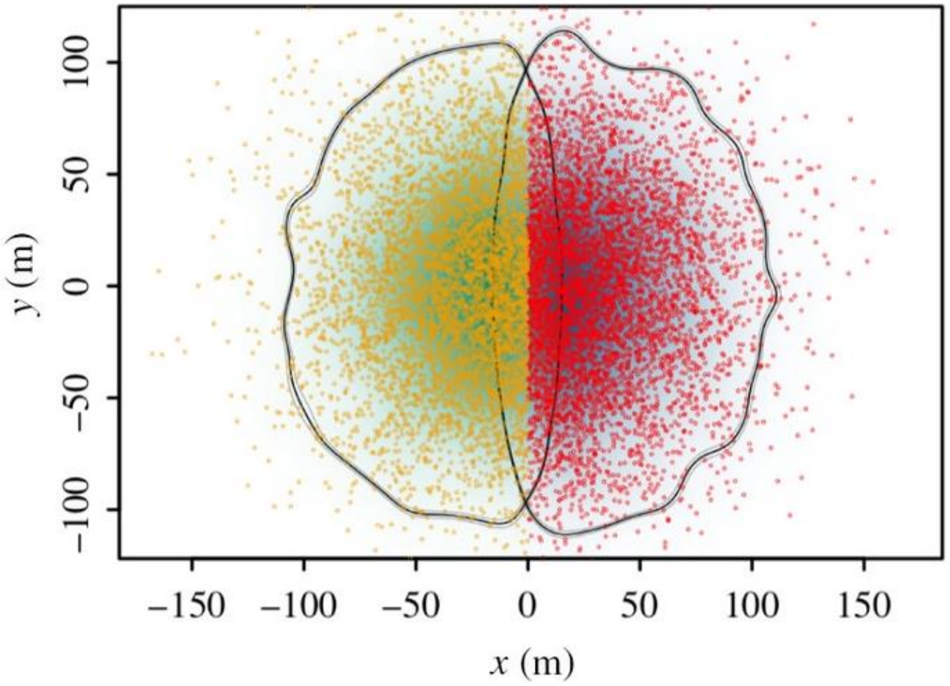




Home range area intersection can underestimate the area over which encounters are likely to occur.

Exclusive home ranges with **hard borders**.

Simulated tracking data for 2 individuals with a hard territorial border between mutually-exclusive home ranges.



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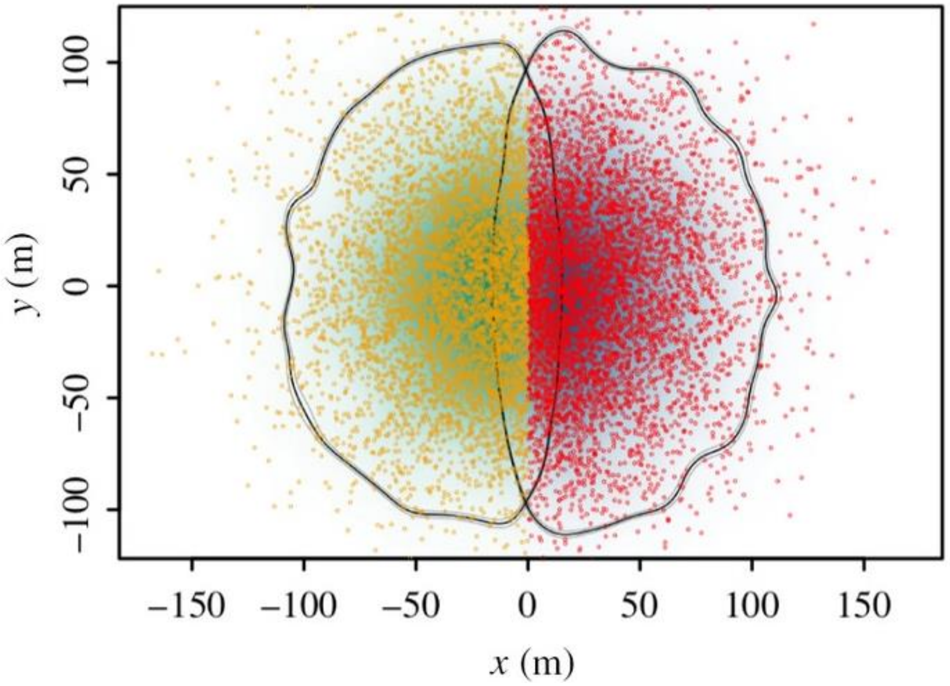
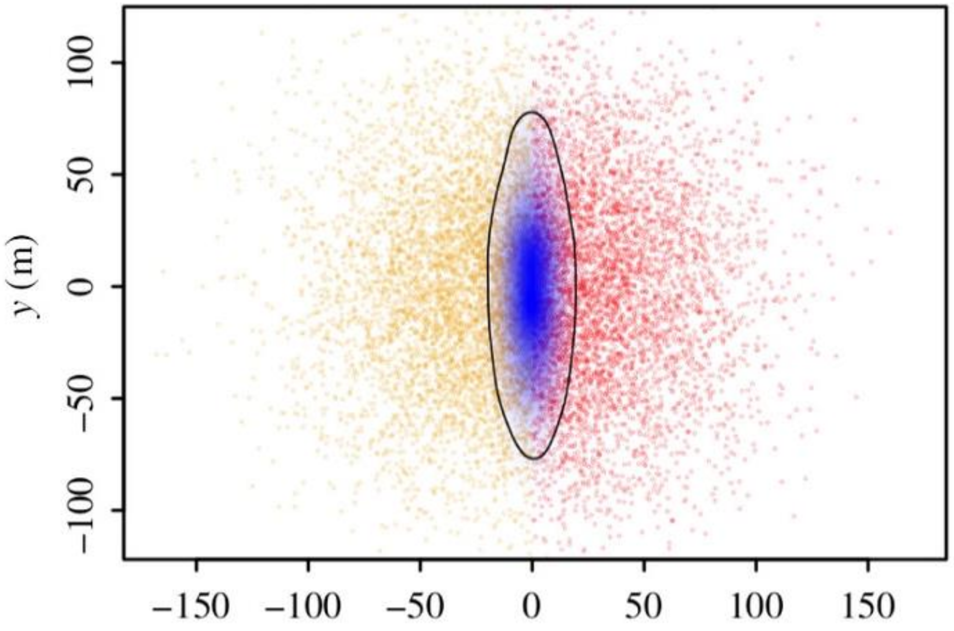
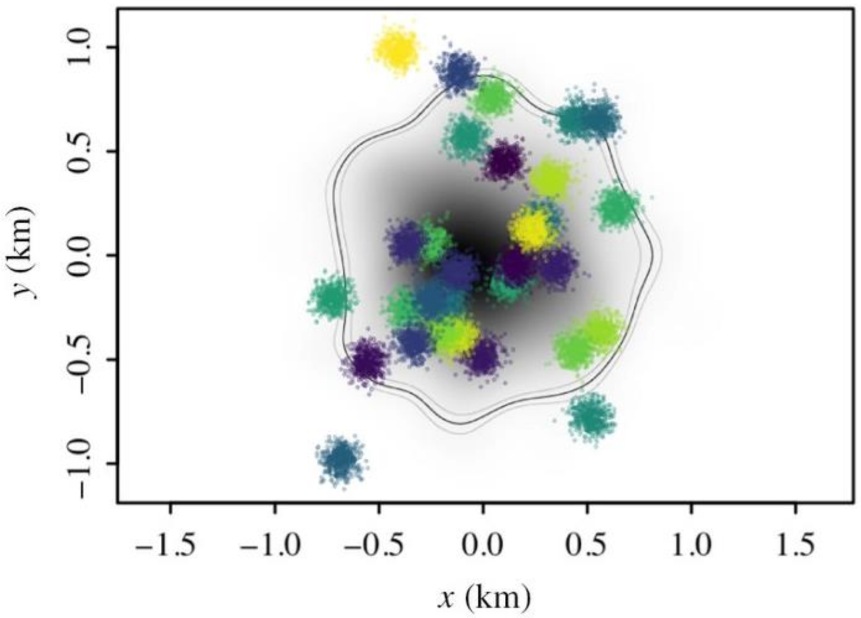
CDE can be used to identify the location of territorial borders.





Predator–prey encounters

Simulated tracking data for a predator with a large home range that encompassed a population of 30 prey individuals.



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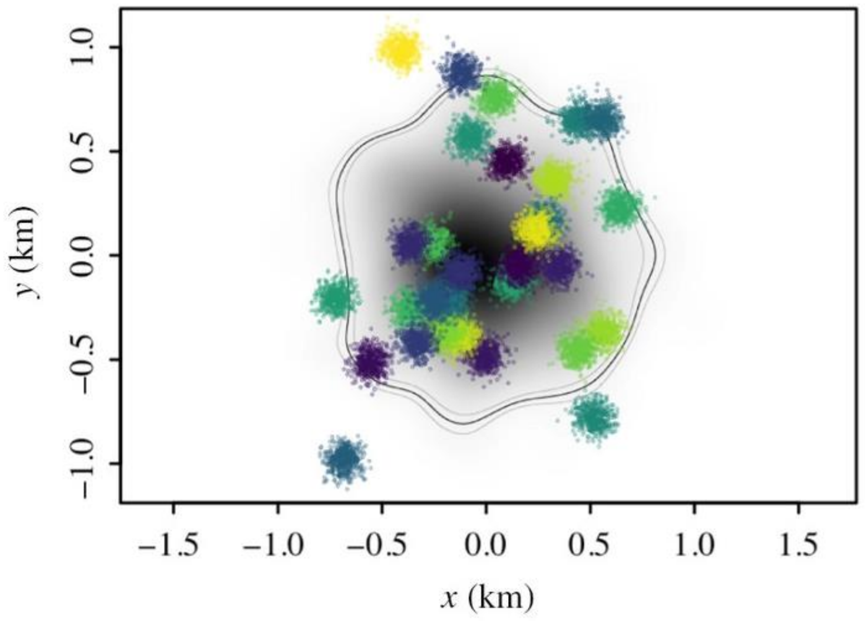
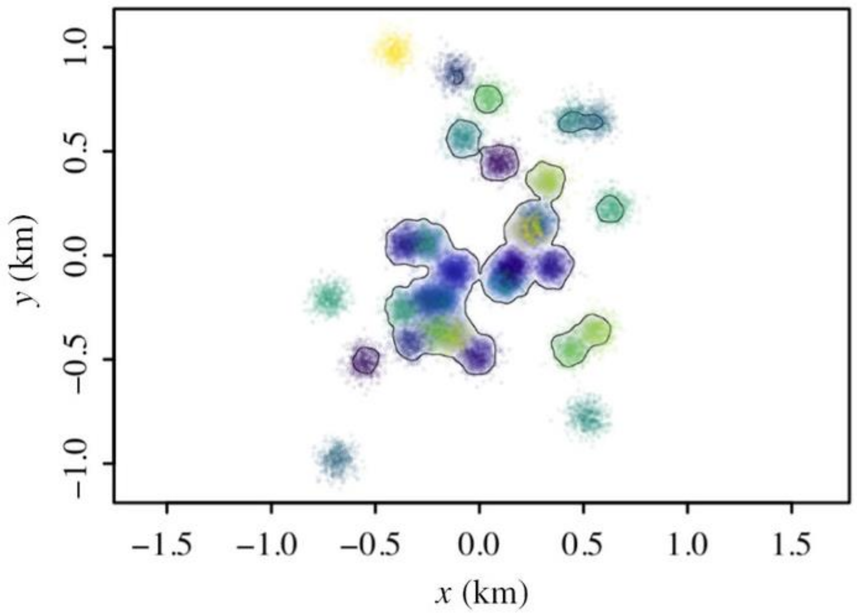




WHITE-FACED CAPUCHINS

CEBUS CAPUCINUS

@ John Fader

On BCI, Panama, capuchins are group-living, with intense and potentially lethal inter-group competition.

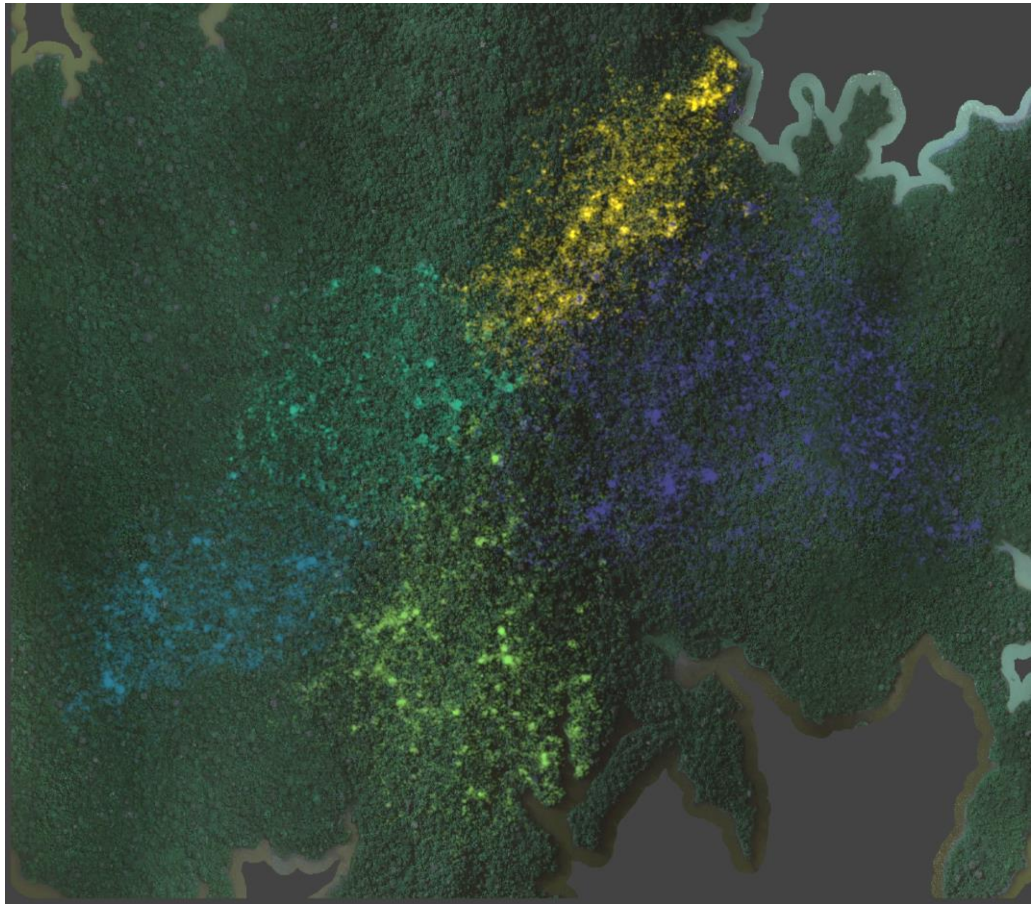
Encounter probability plays an important role in governing **capuchin behavior**.

WHITE-FACED CAPUCHINS

CEBUS CAPUCINUS

@ John Fader

CDE estimation on GPS data from 5 individuals belonging to neighbouring social groups



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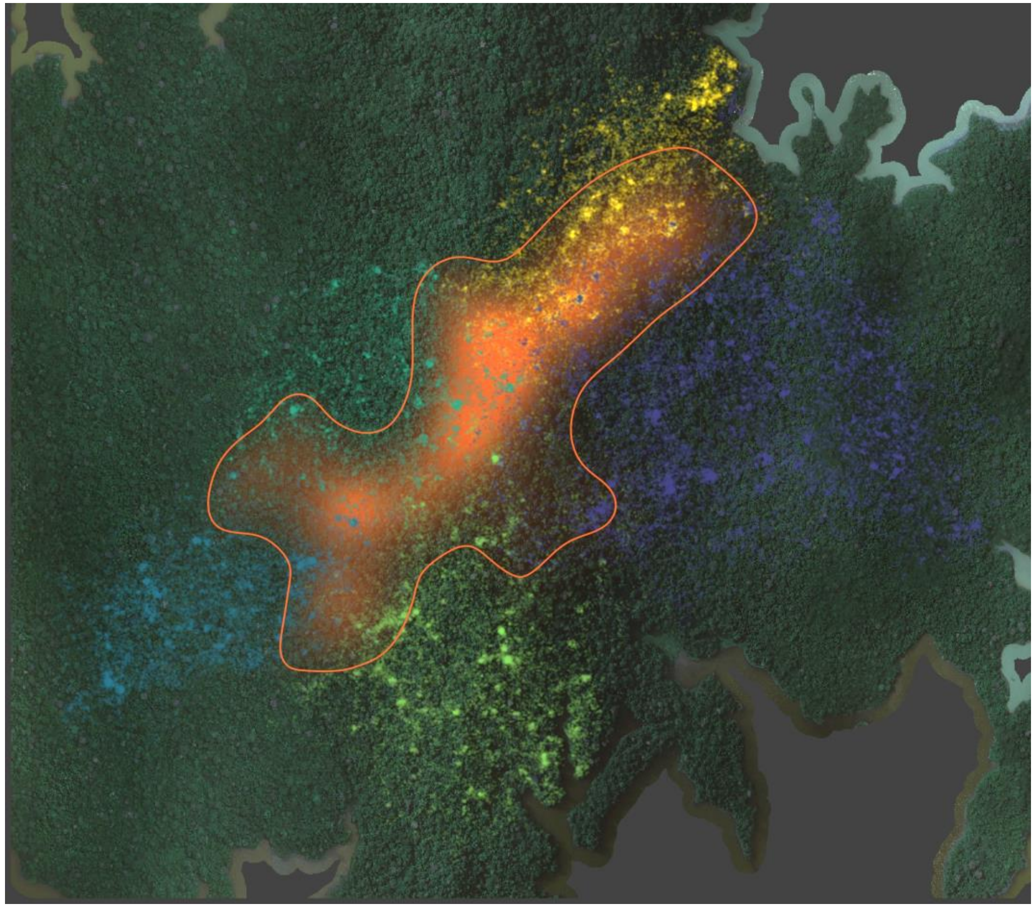

ENCOUNTERS

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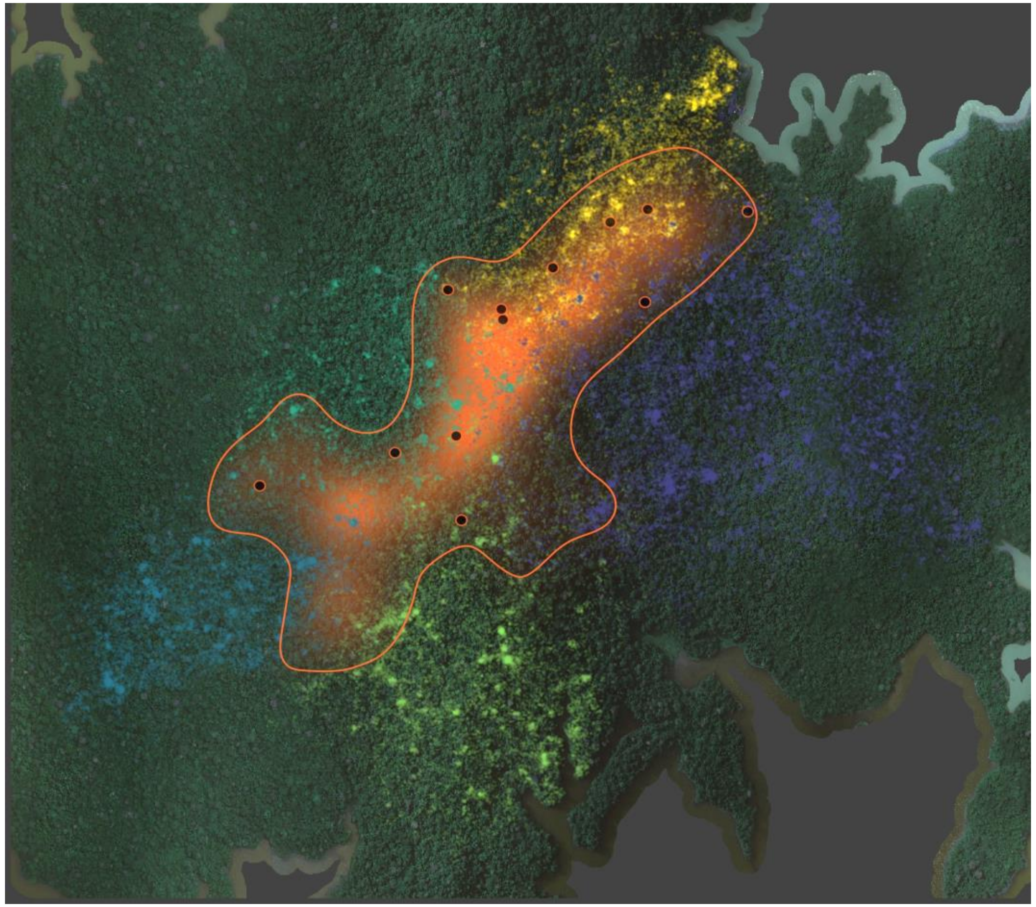

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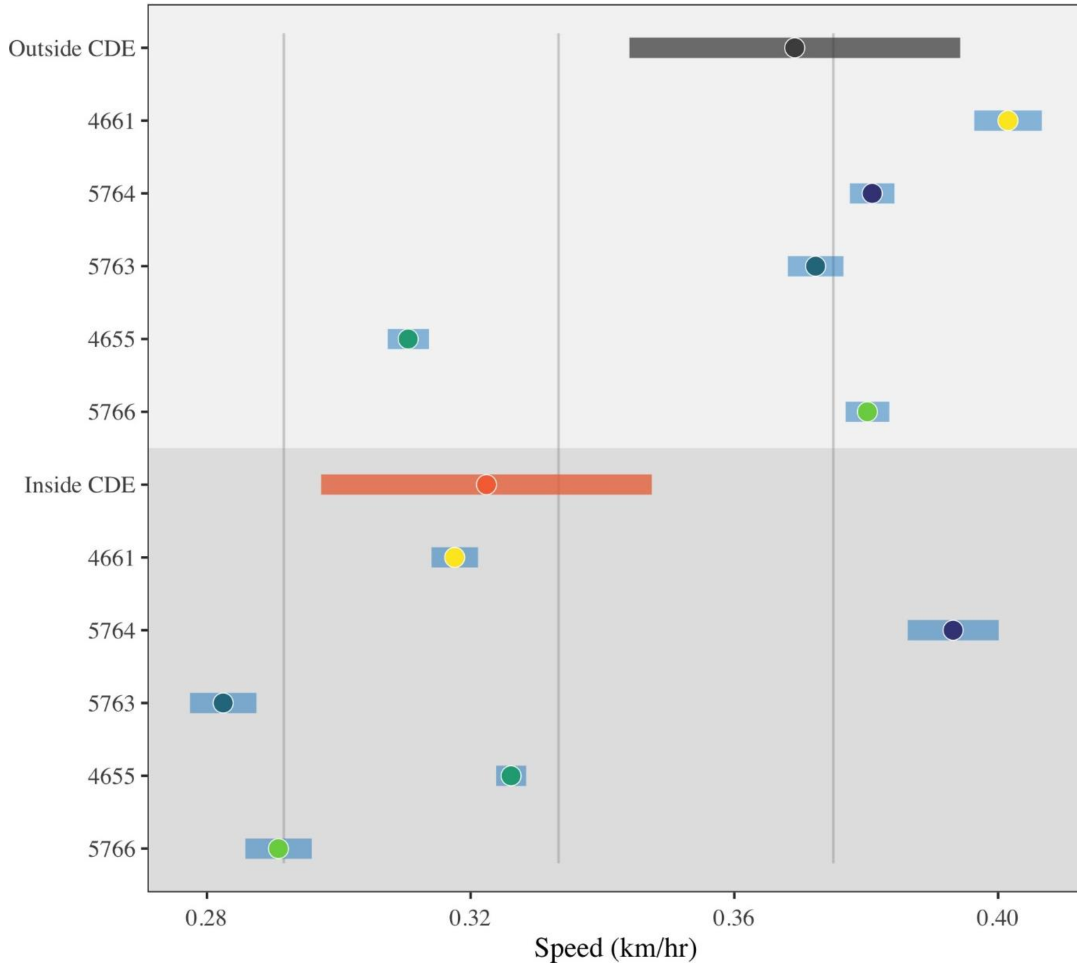


Capuchins also modified their movement according to local encounter probability, moving significantly more slowly in the 95% CDE area.

SLEEPY LIZARDS

TILIQUA RUGOSA

@ Michael Gardner

The sleepy lizard is a large herbivorous skink from temperate regions of Australia.

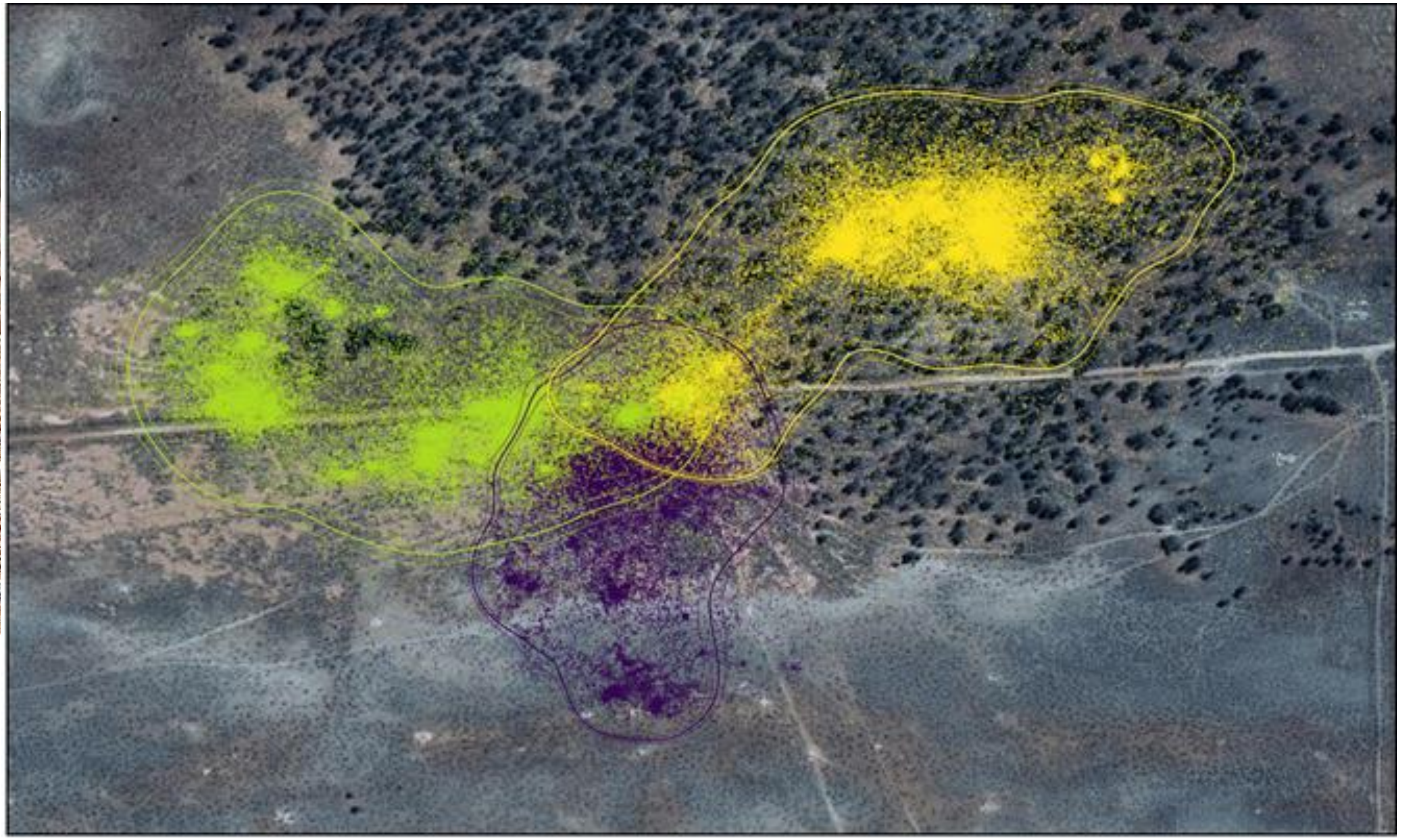
Sleepy lizards home ranges often overlap extensively with **conspecifics**.
Kerr & Bull (2006)

ENCOUNTERS

SLEEPY LIZARDS

TILIQUA RUGOSA

@ Michael Gardner



ENCOUNTERS

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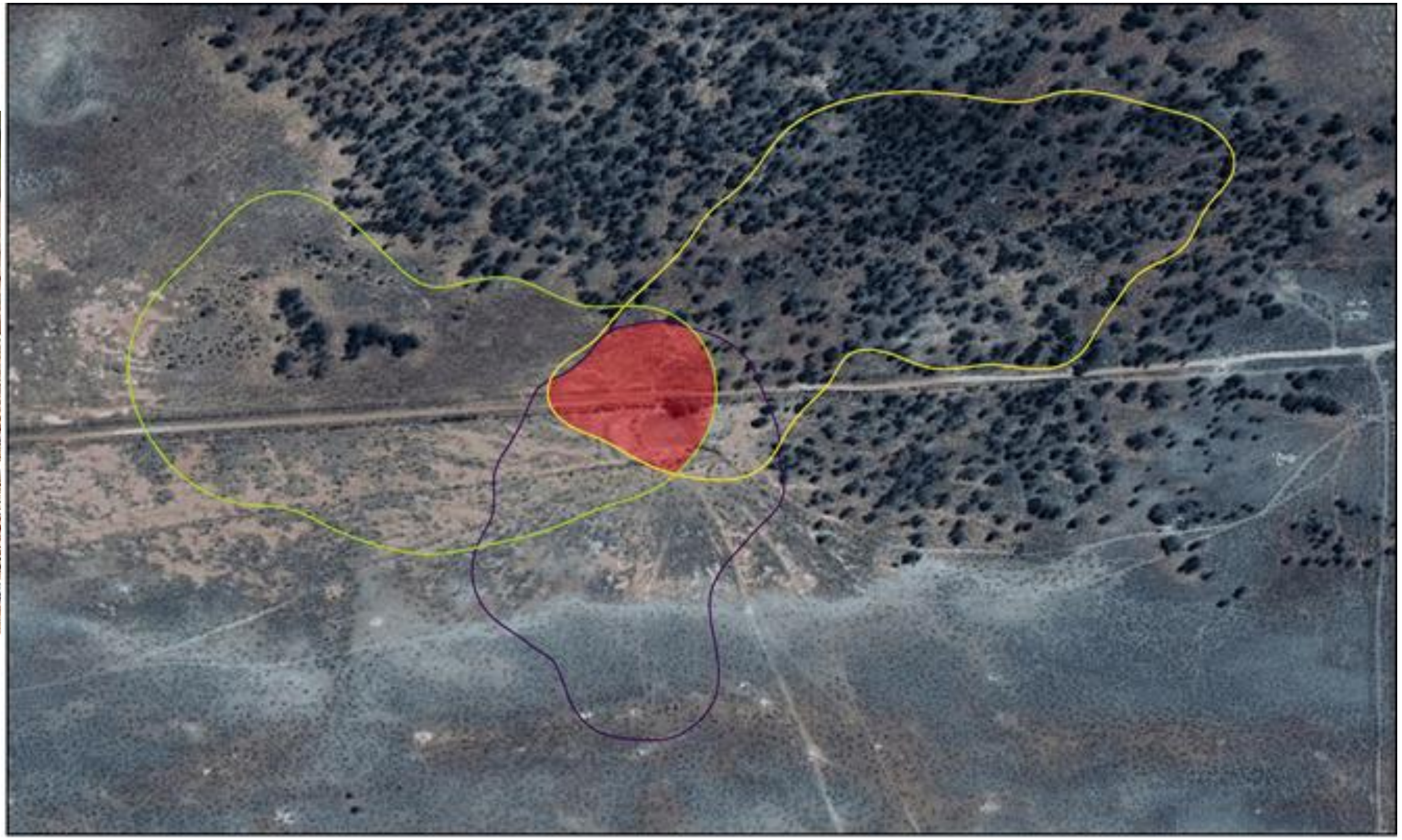

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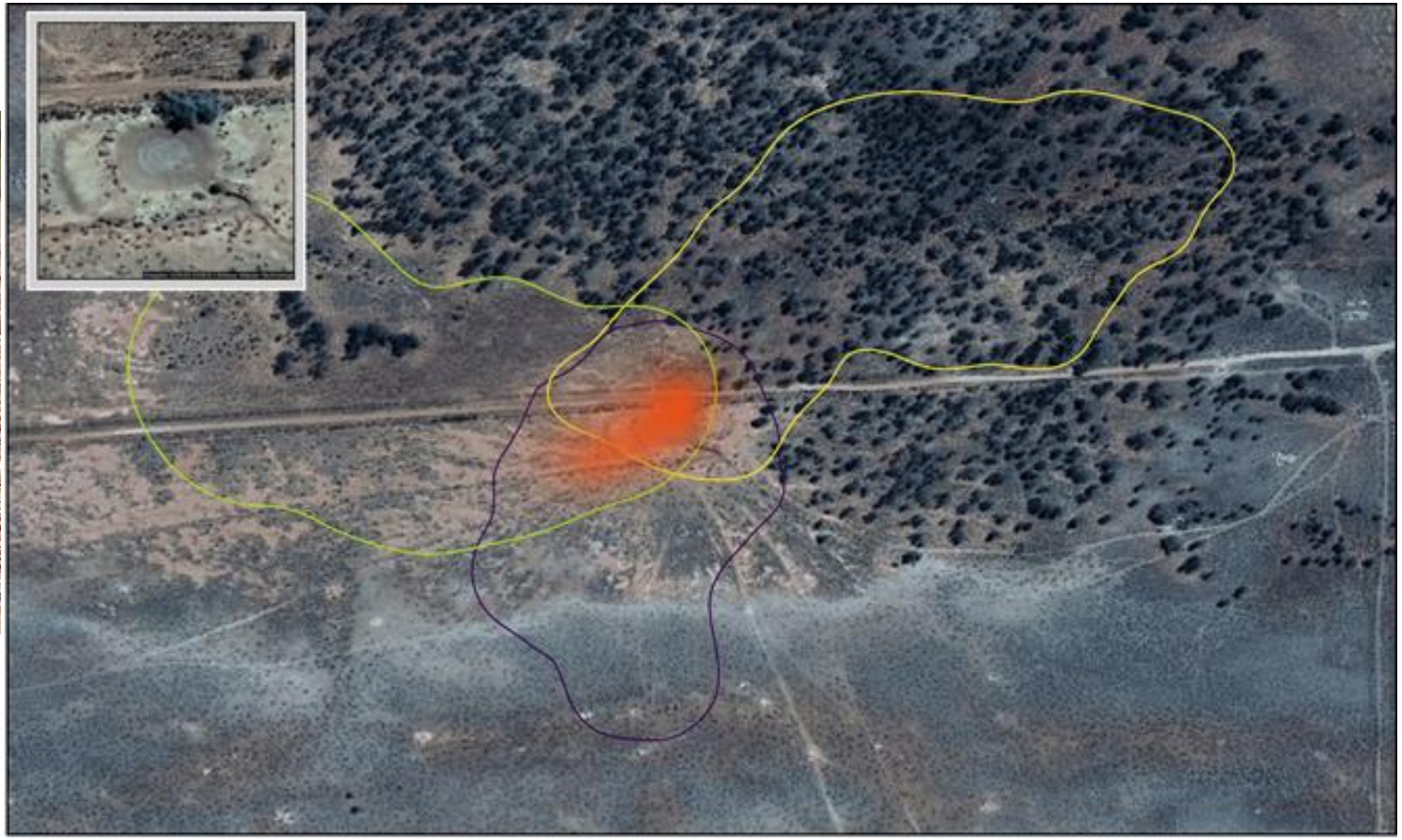

Conditional Distribution of Encounter events (CDE)

Described in Noonan *et al.* (2021)
10.1111/2041-210X.13597

There are three key assumptions for CDE estimation:

1. Stationarity in the movement processes;
2. Encounters are local events;
3. Movement is uncorrelated across individuals.

Good coverage of the local population is also necessary for the CDE to fully capture the spatial distribution of encounters.

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HOME RANGE META-ANALYSES

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META-ANALYSES

Accurately estimating *area requirements* is of utmost importance for conservation, from the *individual* to the *population level*.

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We want to quantify the effect of covariates, such as species or taxa, sex, body size, age, movement characteristics, conspecific density, habitat, human influences, etc…

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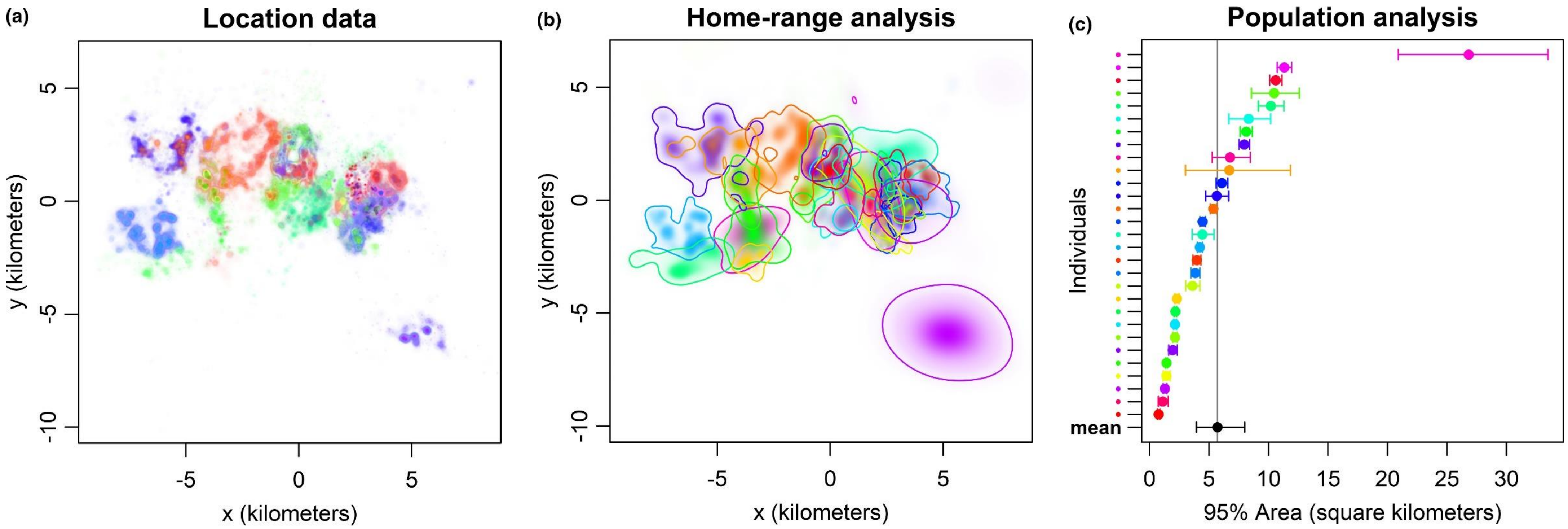
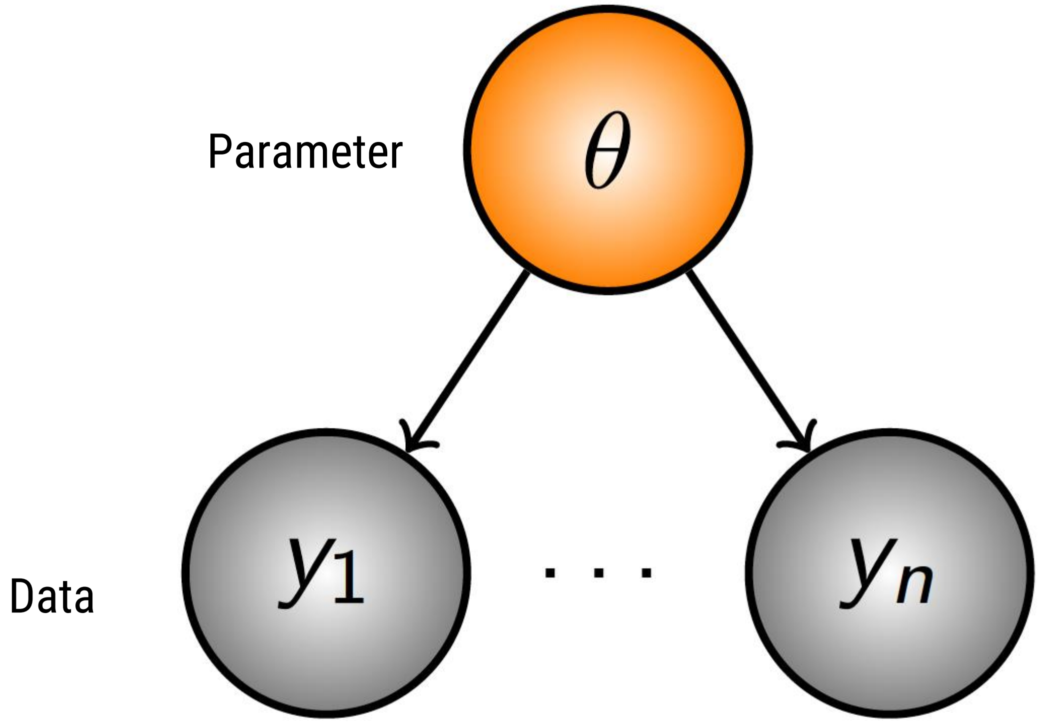
.. Even if we are comparing different populations with different movement behaviors or sampling schedules.

META-ANALYSES



NON-HIERARCHICAL MODELS

How does data inform parameters?



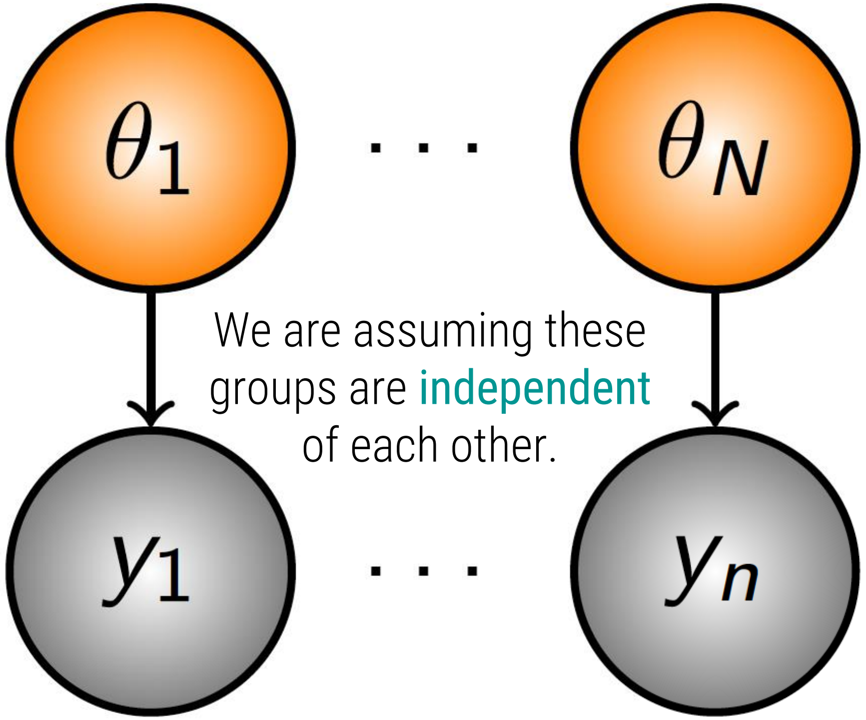
Adapted from Midway (2008)

NON-HIERARCHICAL MODELS

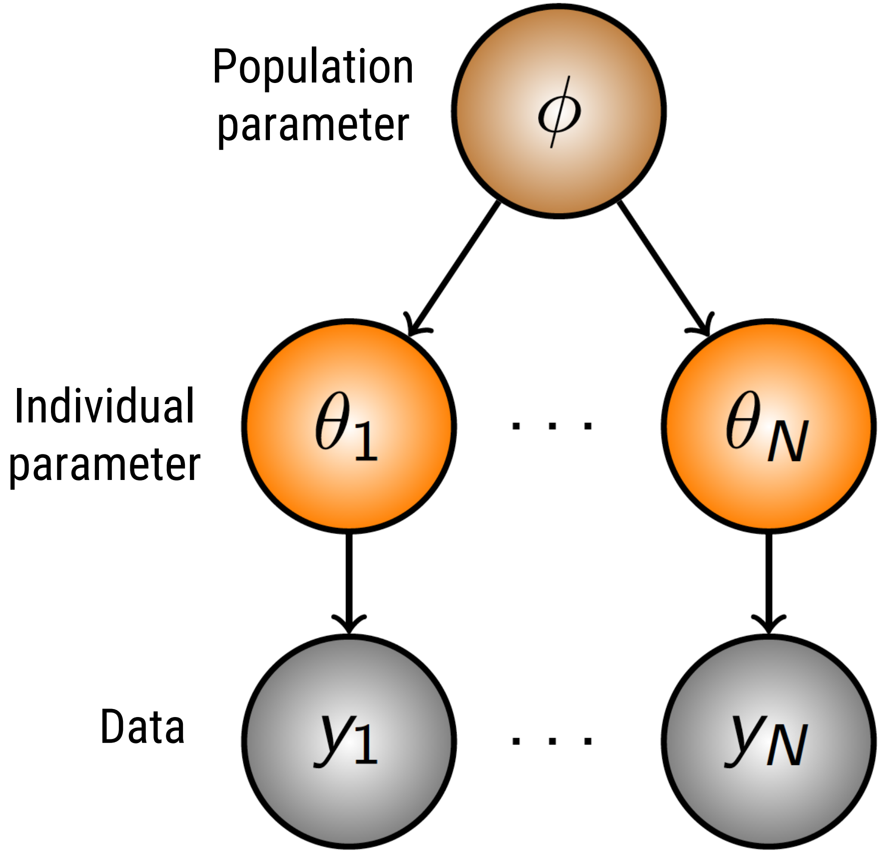
How does data inform parameters?

Parameters

Data



HIERARCHICAL MODELS



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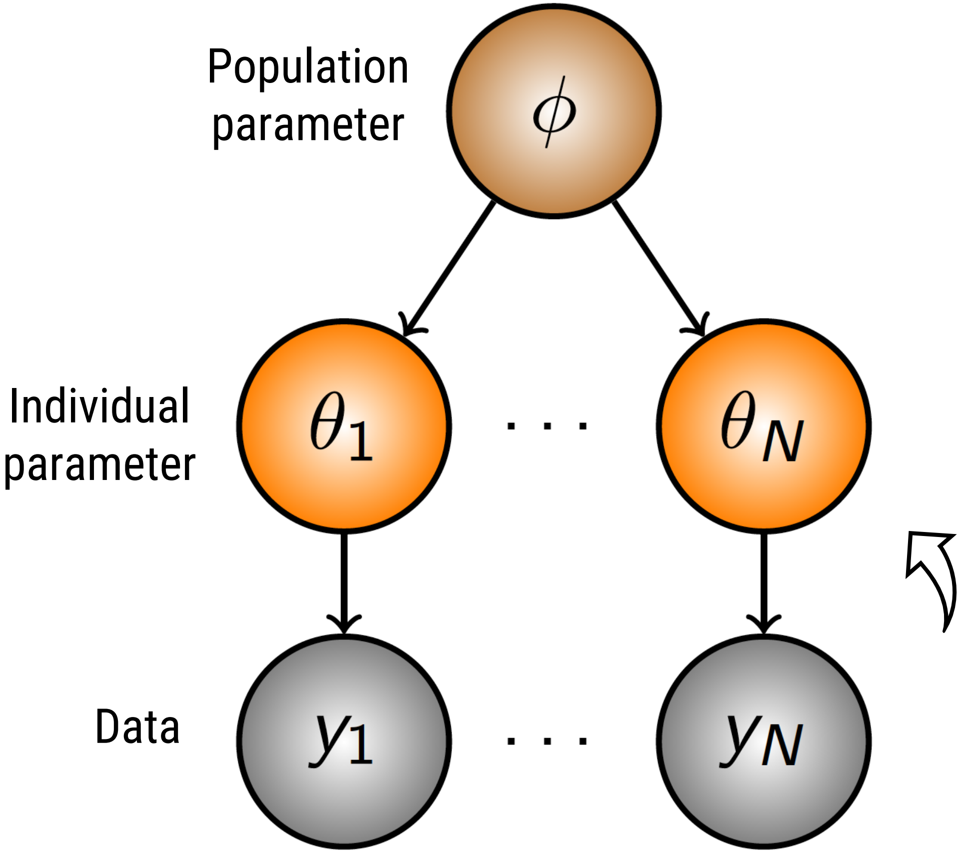
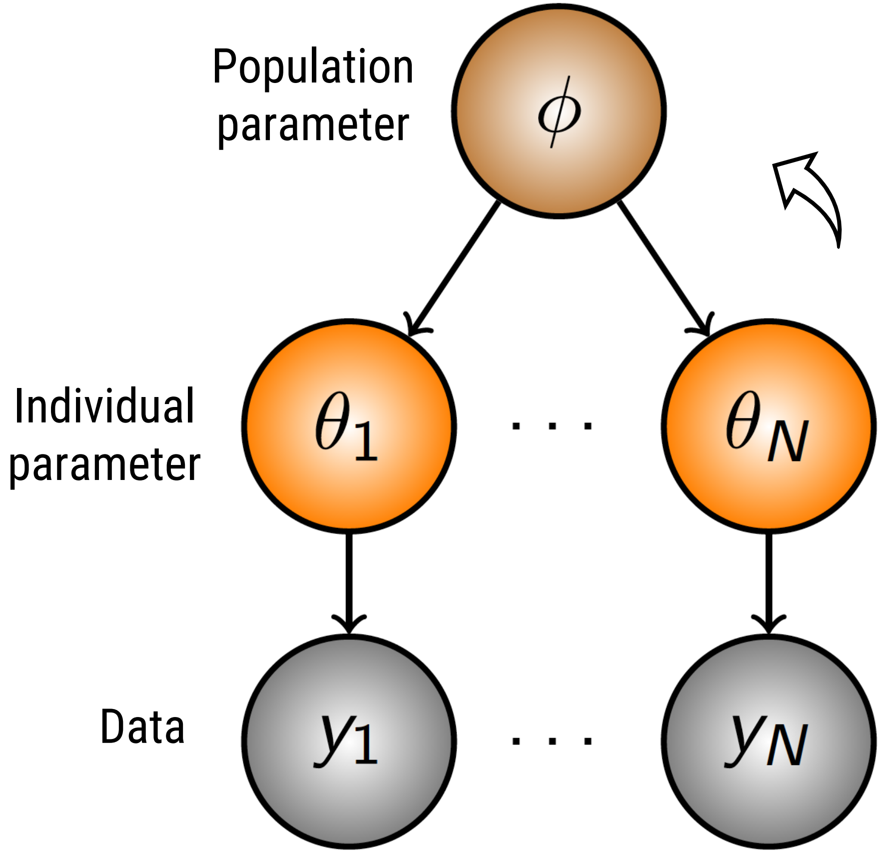


The data inform factor level parameters…

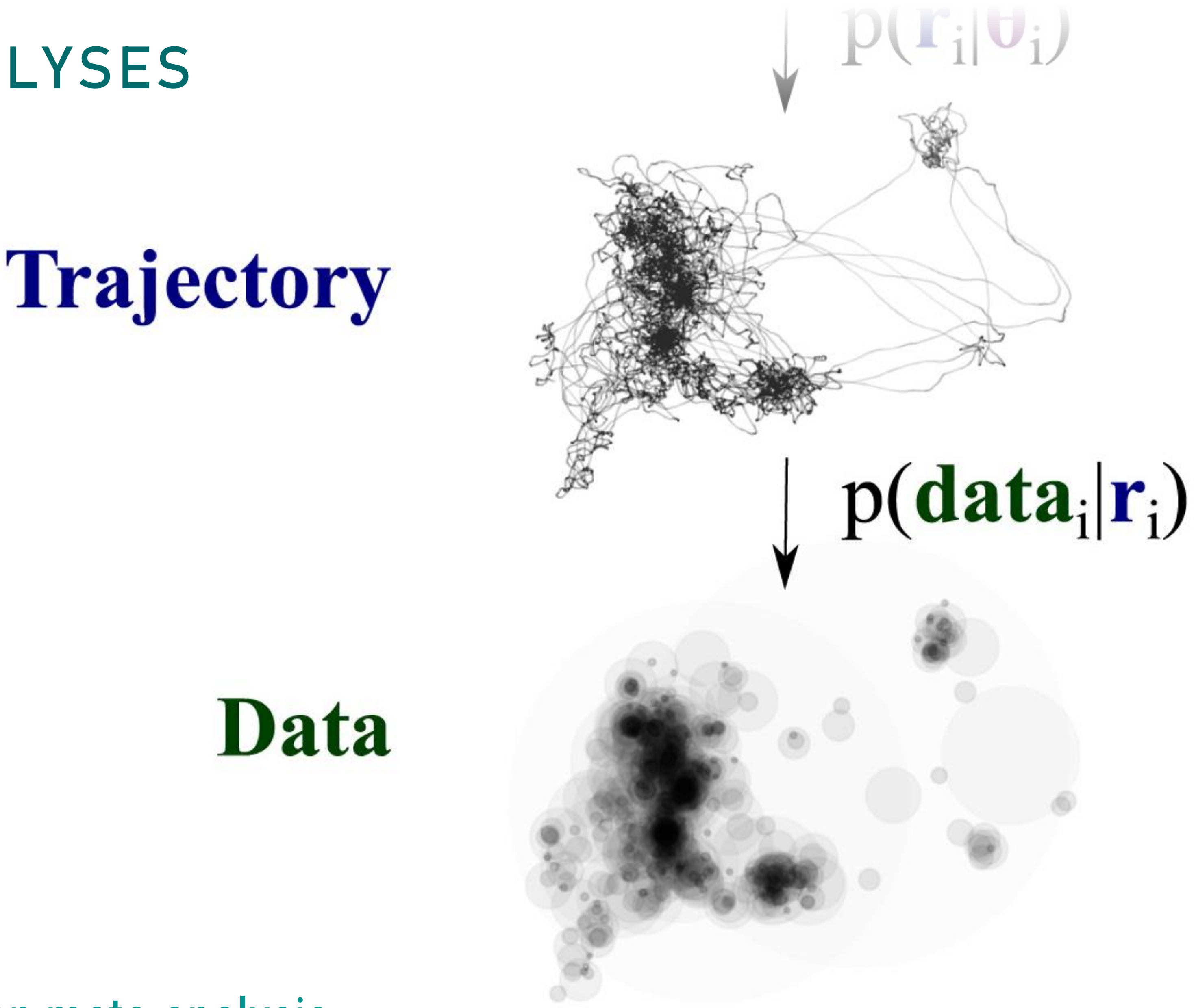
HIERARCHICAL MODELS



…which are governed by some additional parameter.

The data inform factor level parameters…

META-ANALYSES

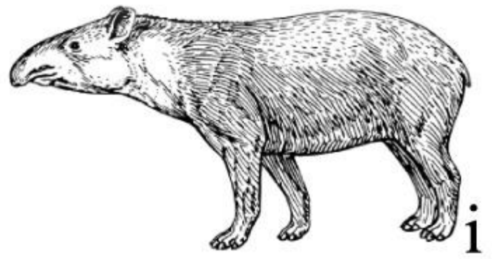


χ^2 inverse-Gaussian meta-analysis

META-ANALYSES

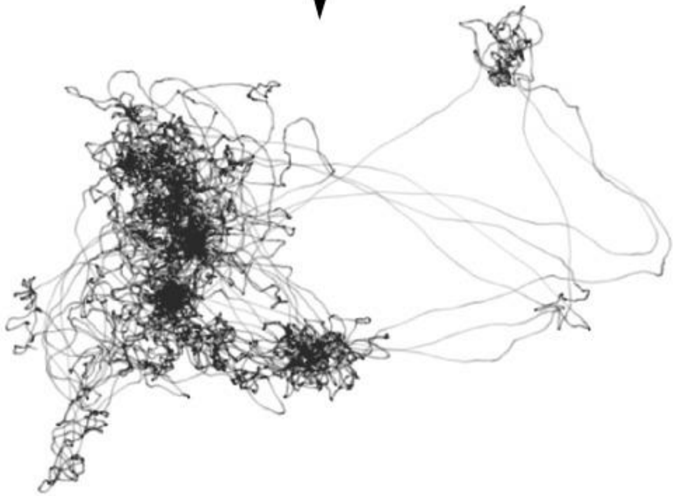
$p(\theta_i|\Theta)$

Individual

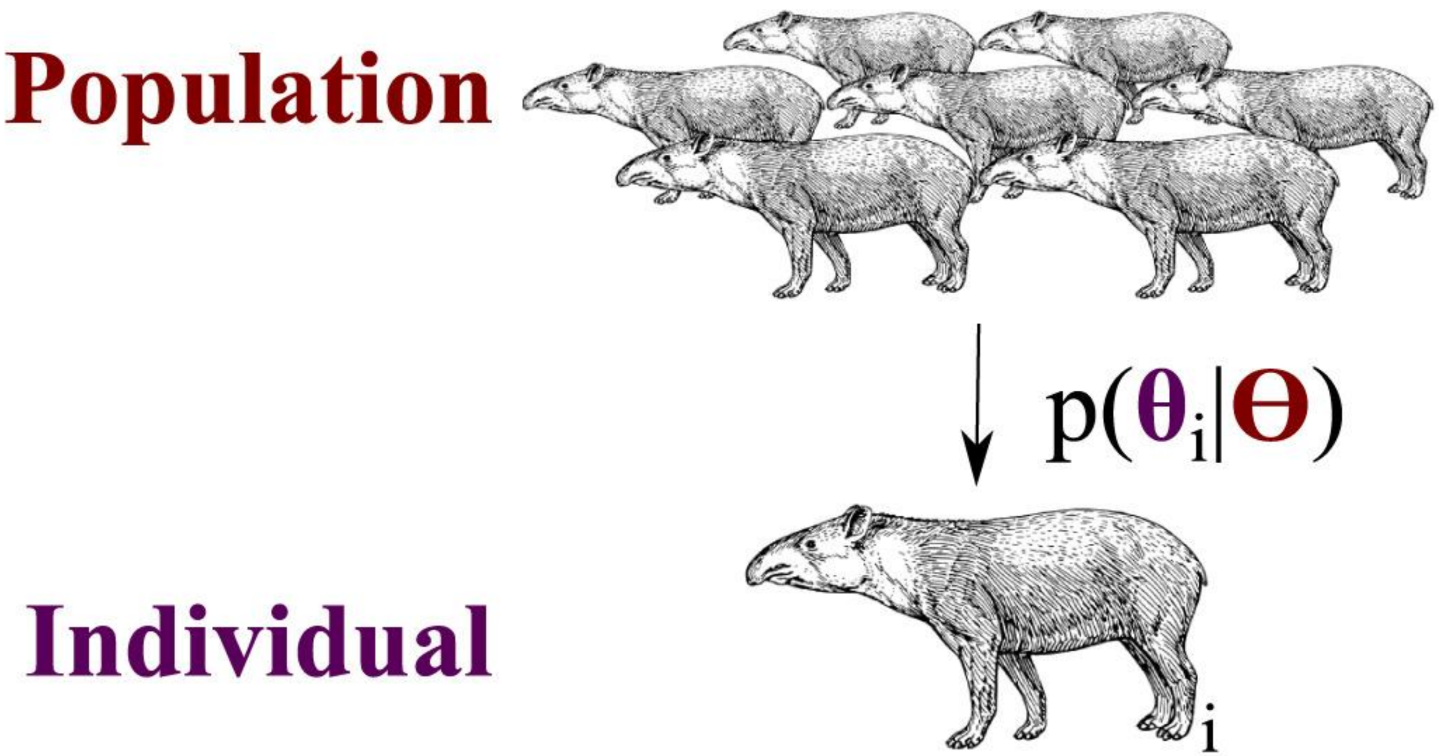


$p(\mathbf{r}_i|\theta_i)$

Trajectory



META-ANALYSES

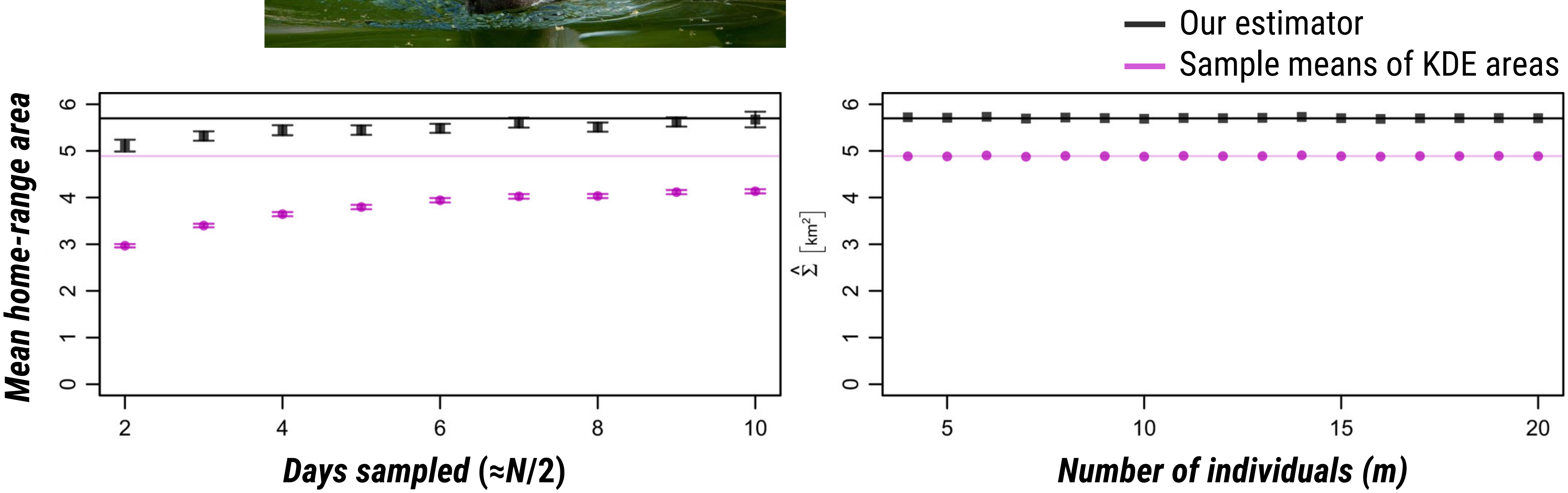


META-ANALYSES

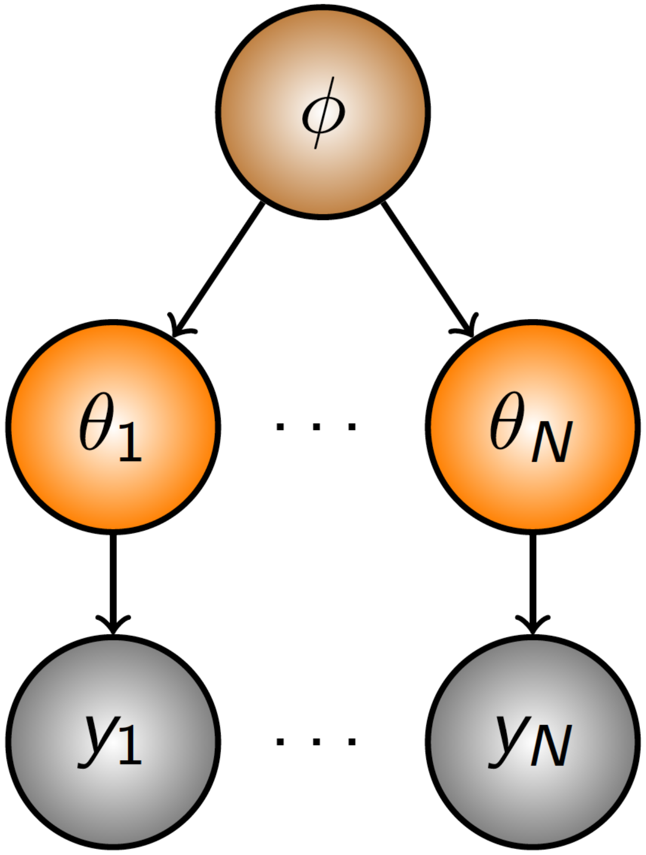
LOWLAND TAPIR

TAPIRUS TERRESTRIS

Tapirs have HR crossing times (τ_p) of 0.72 days, ranging from 0.05 to 12.8 days.



META-ANALYSES



Conclusions

This framework facilitates population-level inference with as few as **2–3 observed home range crossings (τ_p)** and similarly small **number of individuals (m)**.

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