HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF

CASUS CENTER FOR ADVANCED SYSTEMS UNDERSTANDING

MARE-Madeira 2025

Population-level inferences

Using the 'ctmm' R package

Inês Silva

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UFZ HELMHOLTZ Centre for Environmental Research

Uniwersytet Wrocławski

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Freistaat SACHSEN

Critical patch size

Minimum area requirements

Theoretical concepts

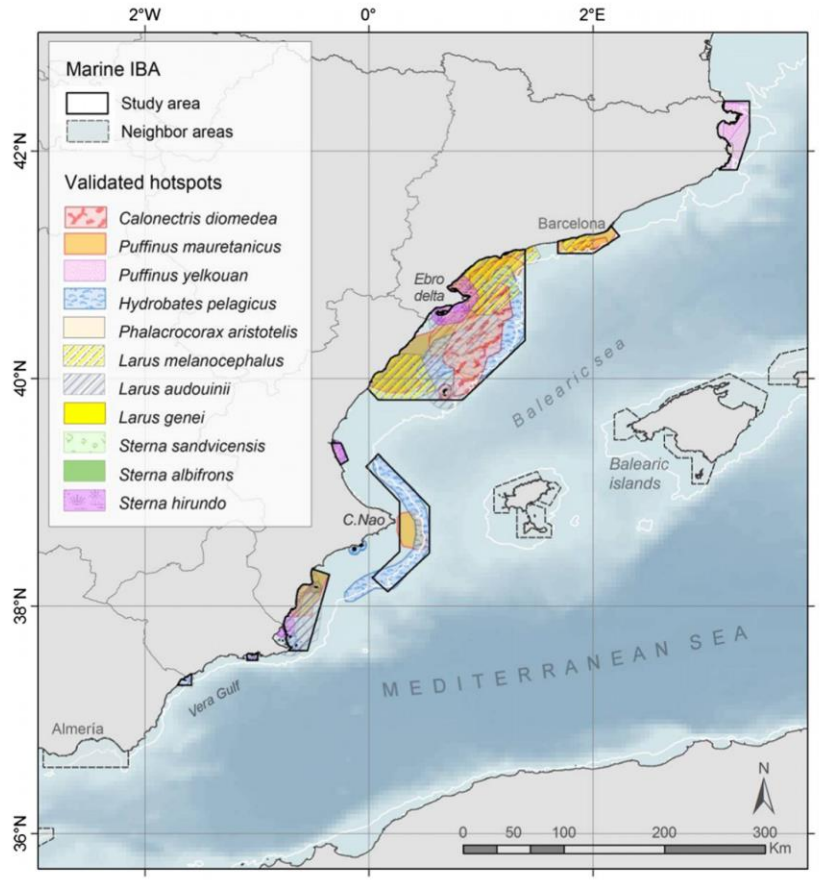
Population-level inferences

Real work applications

Conservation

Management

Using foraging hotspots of pelagic seabirds to identify marine **Important Bird Areas (IBAs)** in Spain.



Arcos *et al.* (2012)

DOI: 10.1016/j.biocon.2011.12.011

Analyses of ecological data should always account for the ***uncertainty***
in the process(es) that generated the data.

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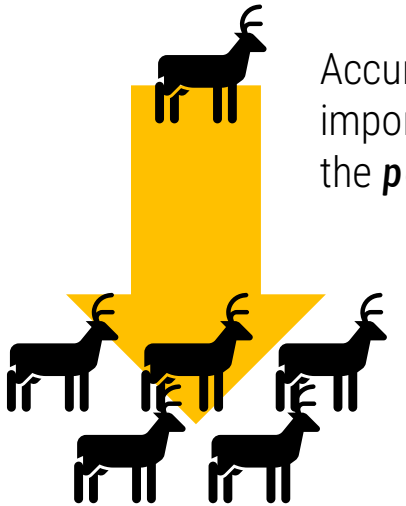
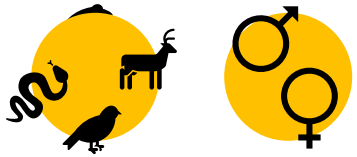


Accurately estimating area requirements is of utmost importance for conservation, from the ***individual*** to the ***population level***.



We want to quantify the effect of covariates, such as ***species***, ***sex***, ***body size***, ***age***, ***habitat***, ***anthropogenic impact***, *etc*…

…even if we are comparing different populations with different ***movement behaviors*** or ***sampling schedules***.

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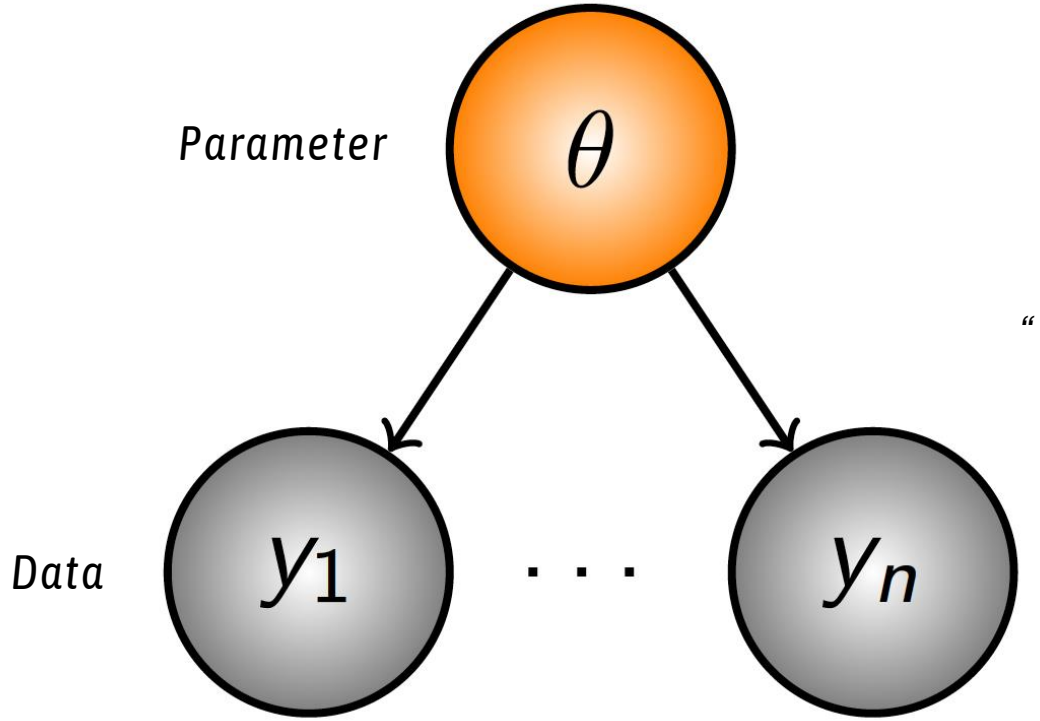
NON-HIERARCHICAL MODELS

How does data inform parameters?

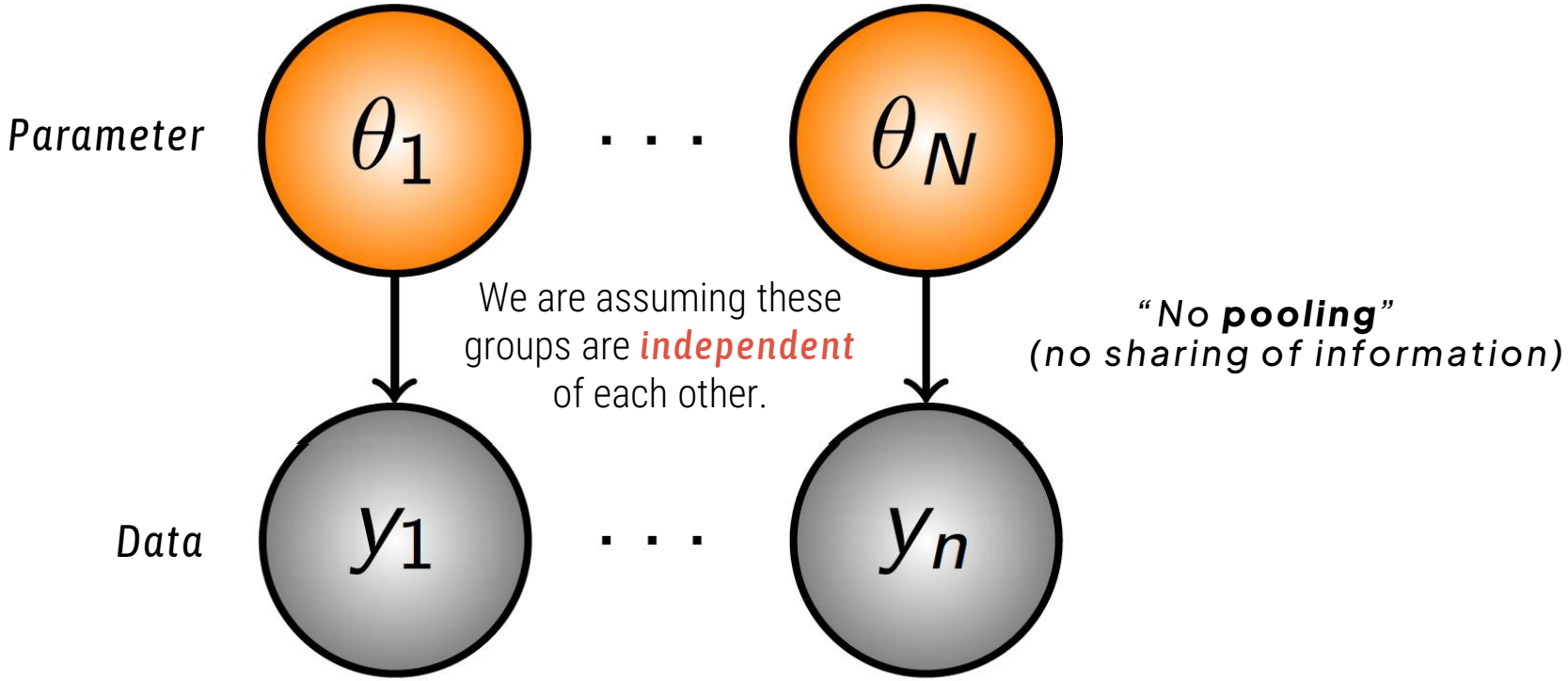


"Complete **pooling**"

Adapted from **Midway (2008)**

NON-HIERARCHICAL MODELS

How does data inform parameters?



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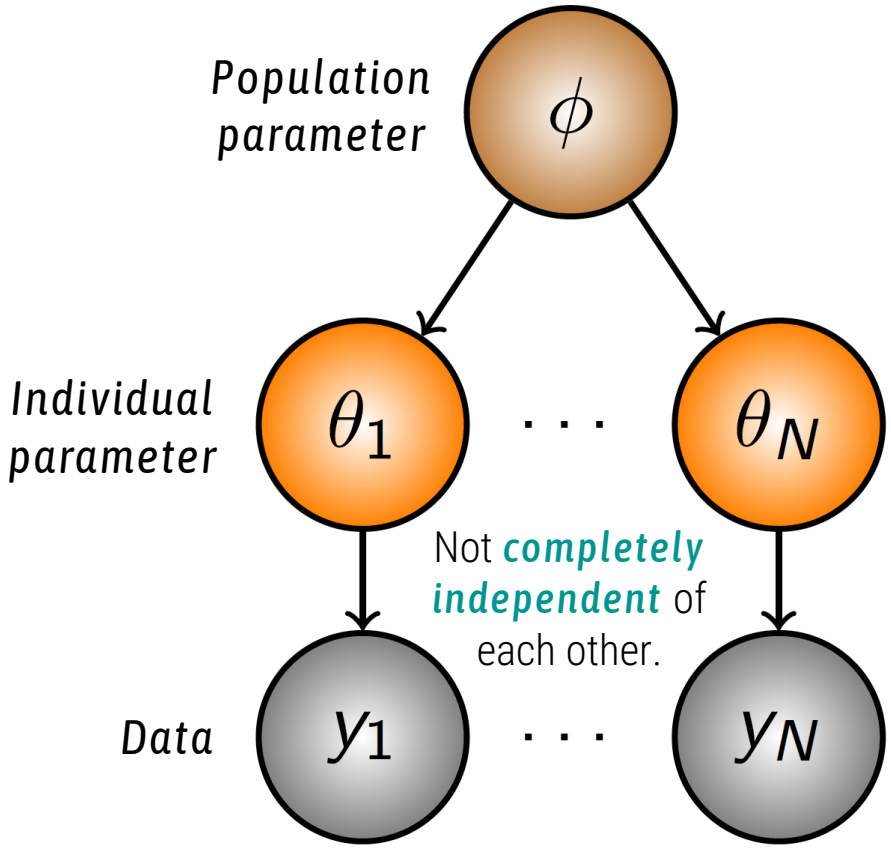

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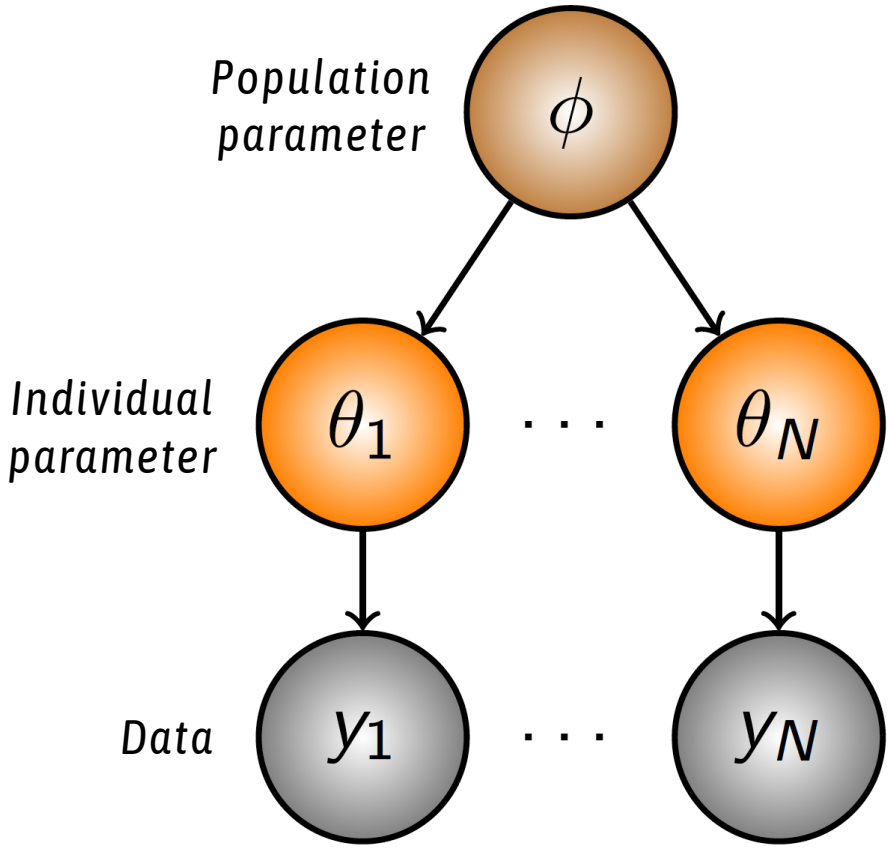
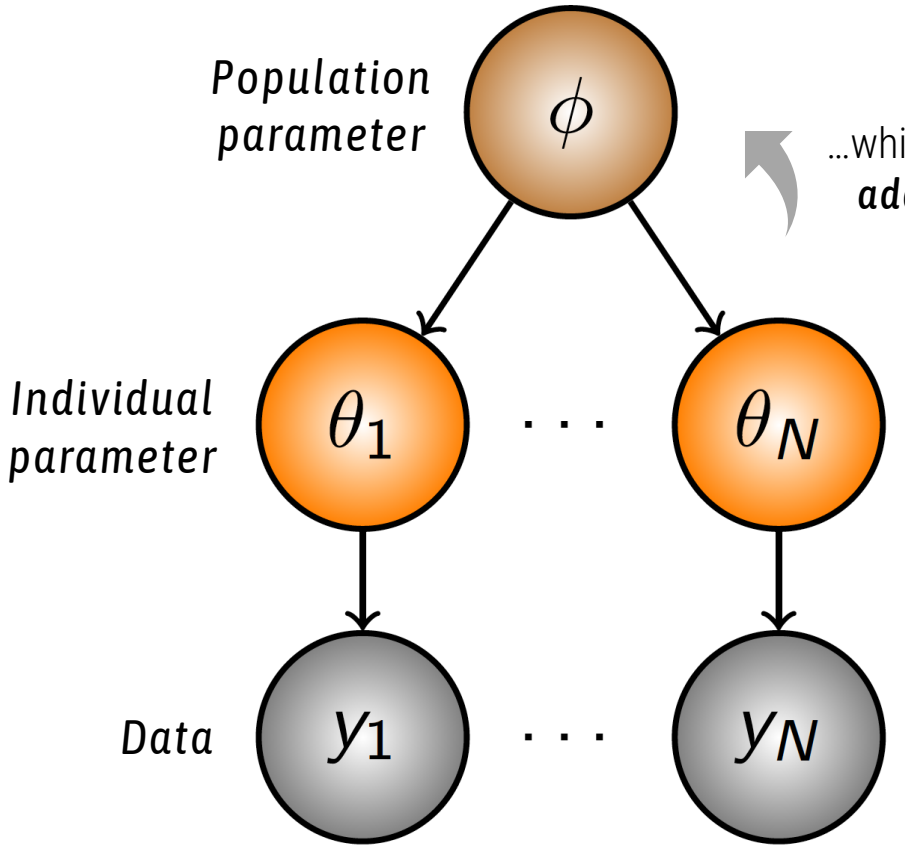


Data inform ***factor-level parameters***, θ…

Adapted from **Midway (2008)**

HIERARCHICAL MODELS

How does data inform parameters?



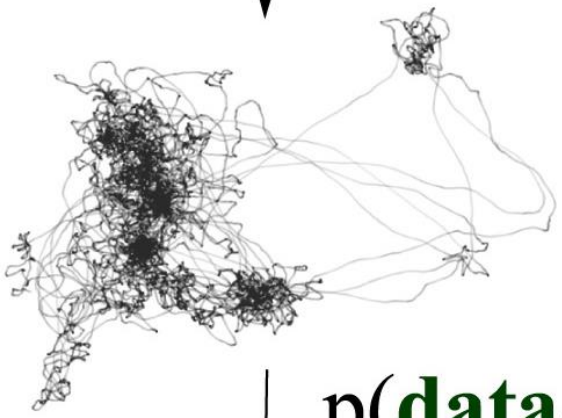
…which are governed by some ***additional parameter***, Φ.

Data inform ***factor-level parameters***, θ…

Adapted from **Midway (2008)**

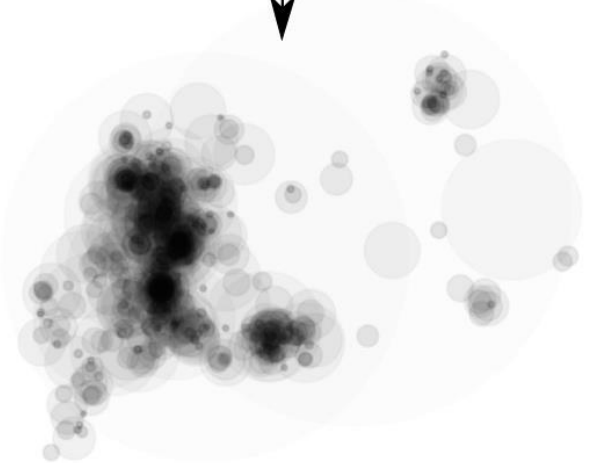
$p(\mathbf{r}_i|\boldsymbol{\theta}_i)$

Trajectory



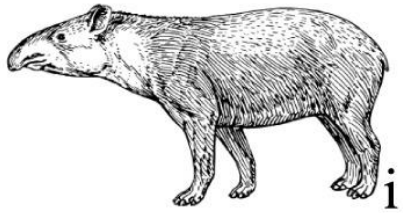
$p(\mathbf{data}_i|\mathbf{r}_i)$

Data



Individual

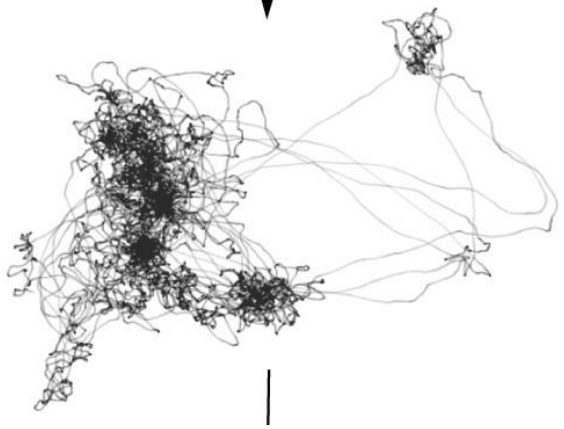
$p(\theta_i|\Theta)$



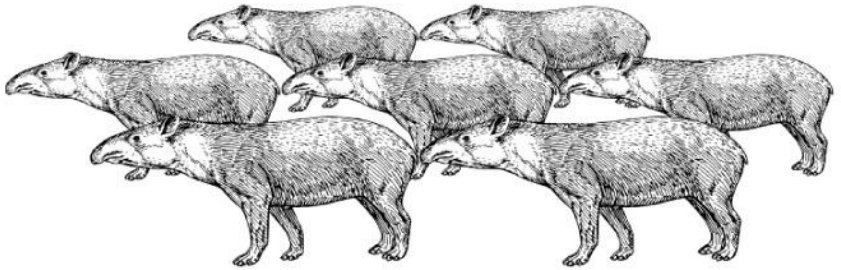
i

$p(r_i|\theta_i)$

Trajectory

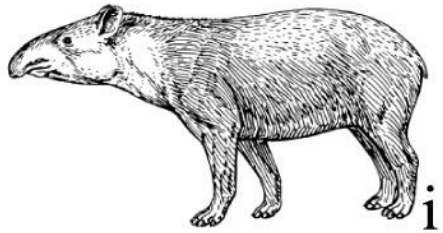


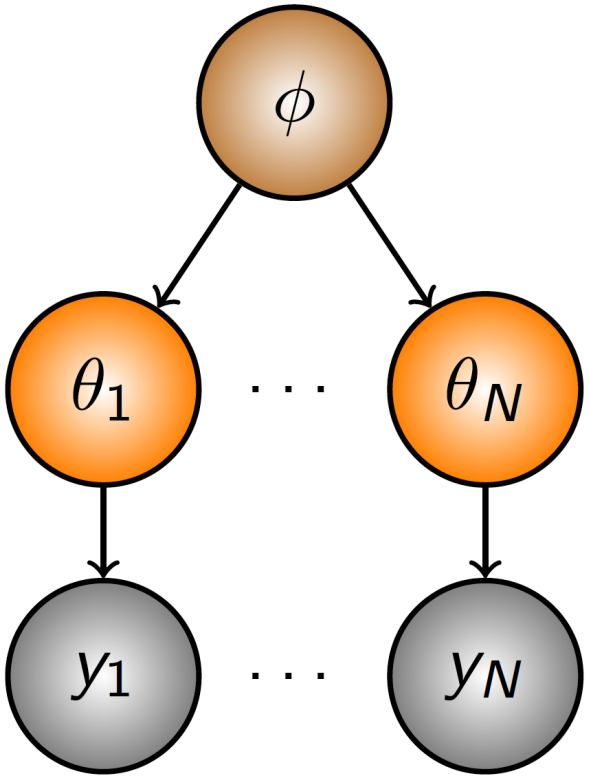
Population



$p(\theta_i|\Theta)$

Individual





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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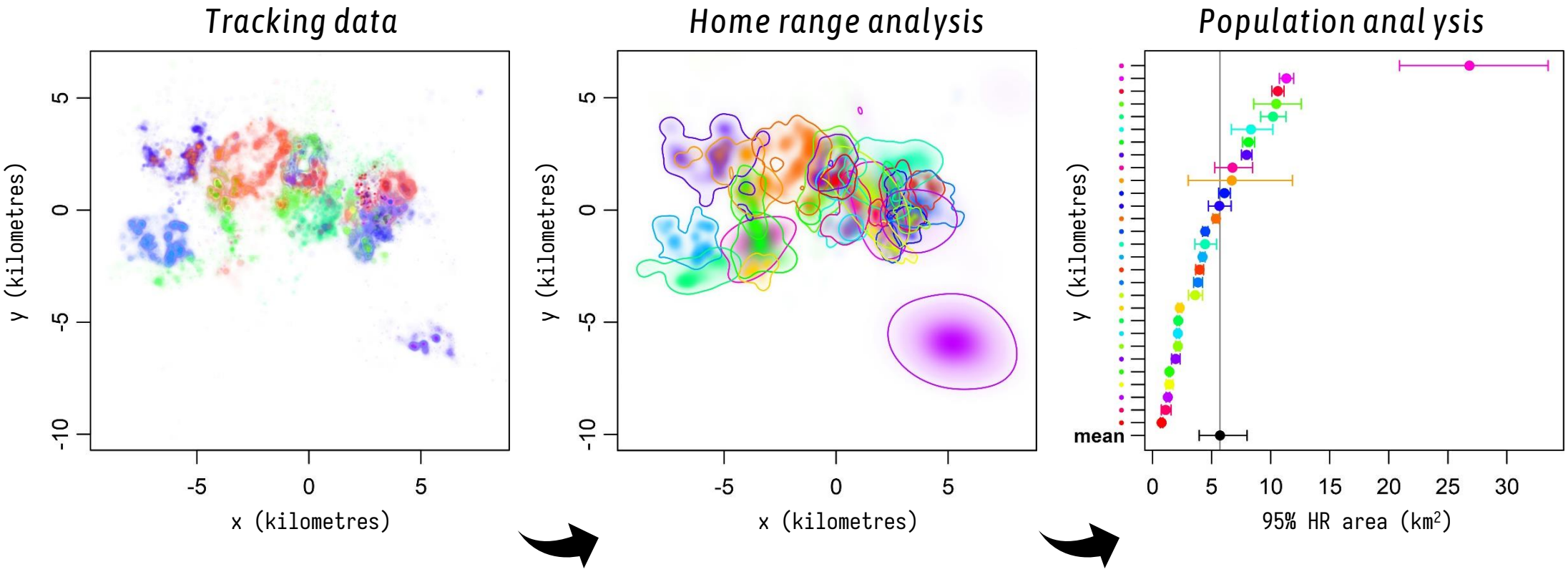


Home range area estimates follow a χ^2 **sampling distribution**

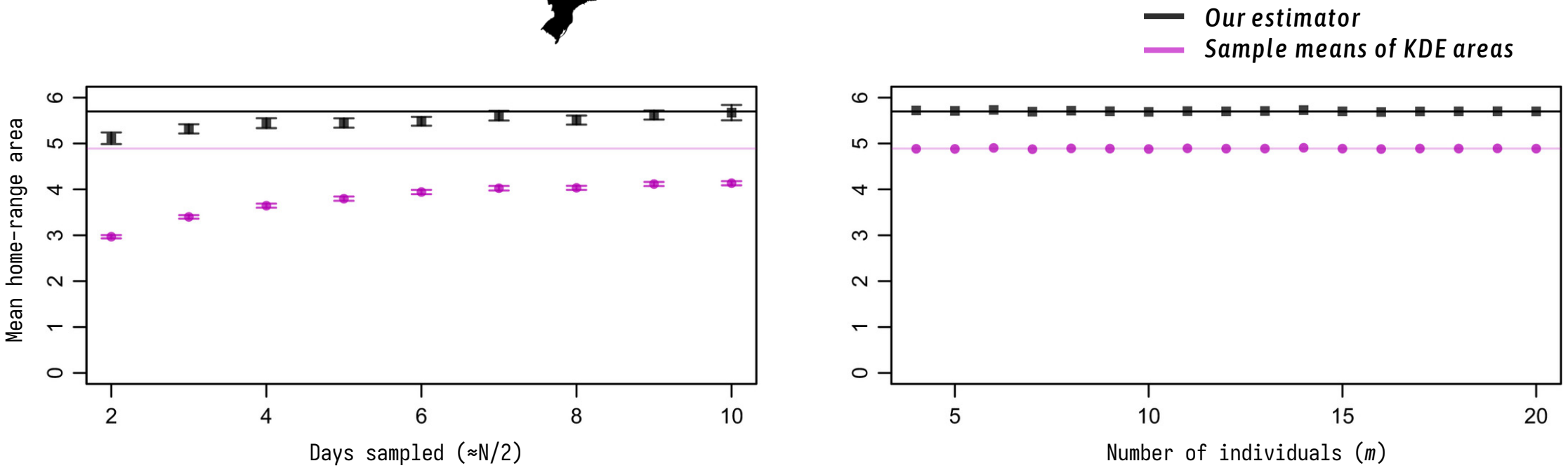
Population of home-range areas follows an **inverse-Gaussian distribution**

A statistically efficient estimator will ***downweight*** uncertain estimates relative to more certain estimates in such a way that the estimated mean has a smaller variance.

Lowland tapir

(Tapirus terrestris)

Tapirs have ***home range crossing times*** (τ_p) of 0.72 days,
(ranging from 0.05–12.8 days)



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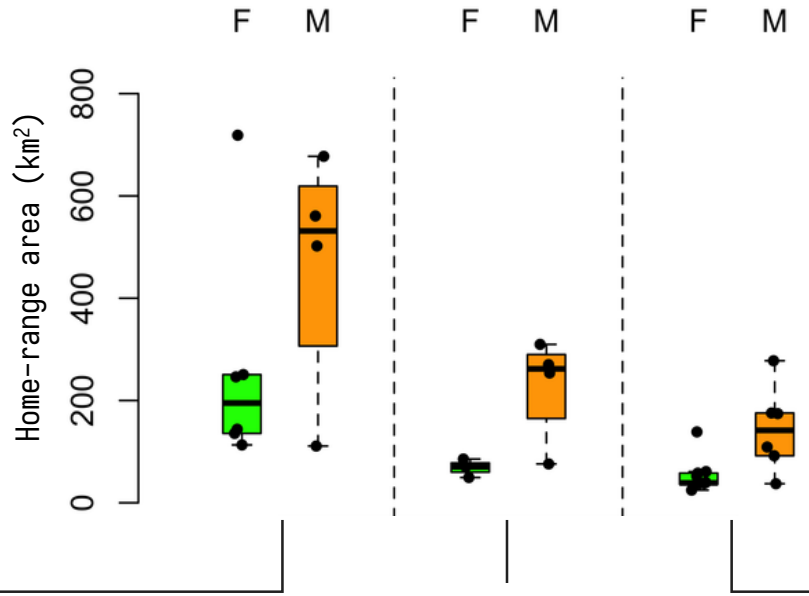
Morato *et al.* (2016)

DOI: 10.1093/jmammal/gyab068

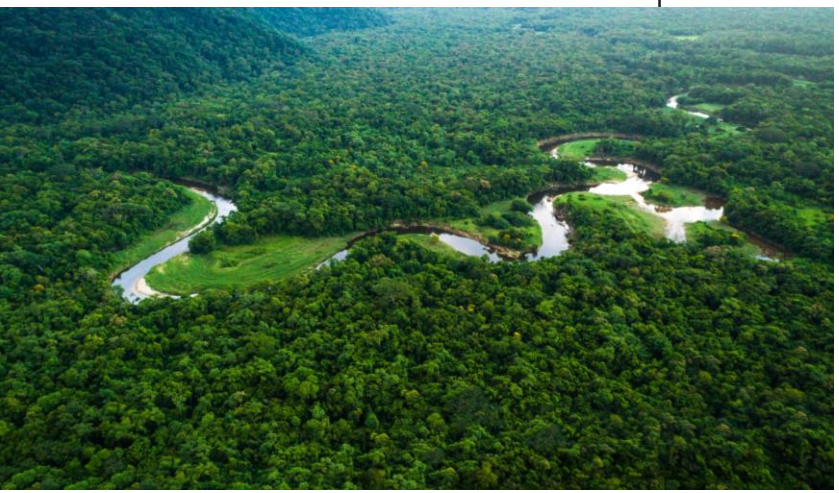


Jaguar

(Panthera onca)

Pete Wilcox

Atlantic forest



Amazon

Pantanal

Frans Lanting

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What's the mean home range area?

Average area used by individuals in a sample

What's the population distribution?

Spatial extent of the population as a whole

Methods:

- (A)KDE of population?
- Union of (A)KDEs?
- Mean of (A)KDEs?

Dual challenge:

Individual temporal autocorrelation
Population variation

Sample
Tracked individuals

≠

Population
Tracked + **untracked** individuals

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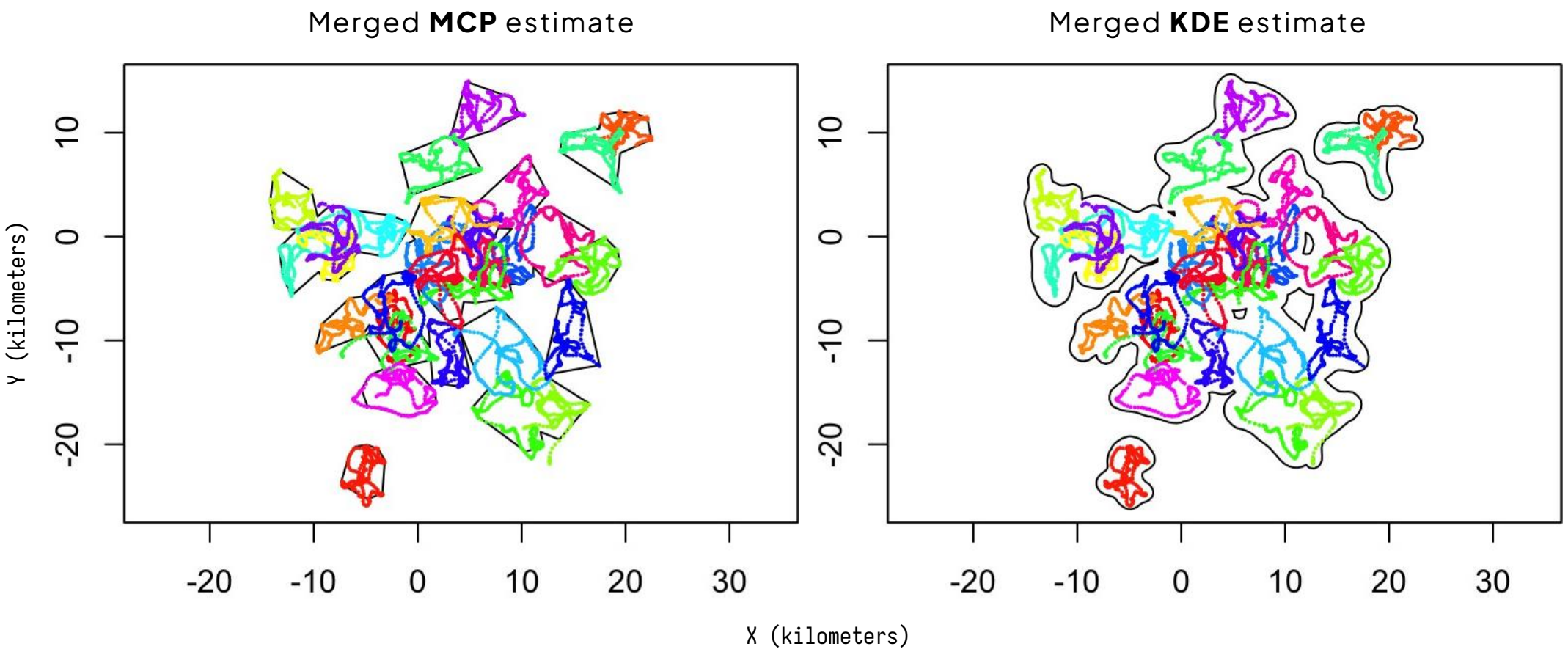
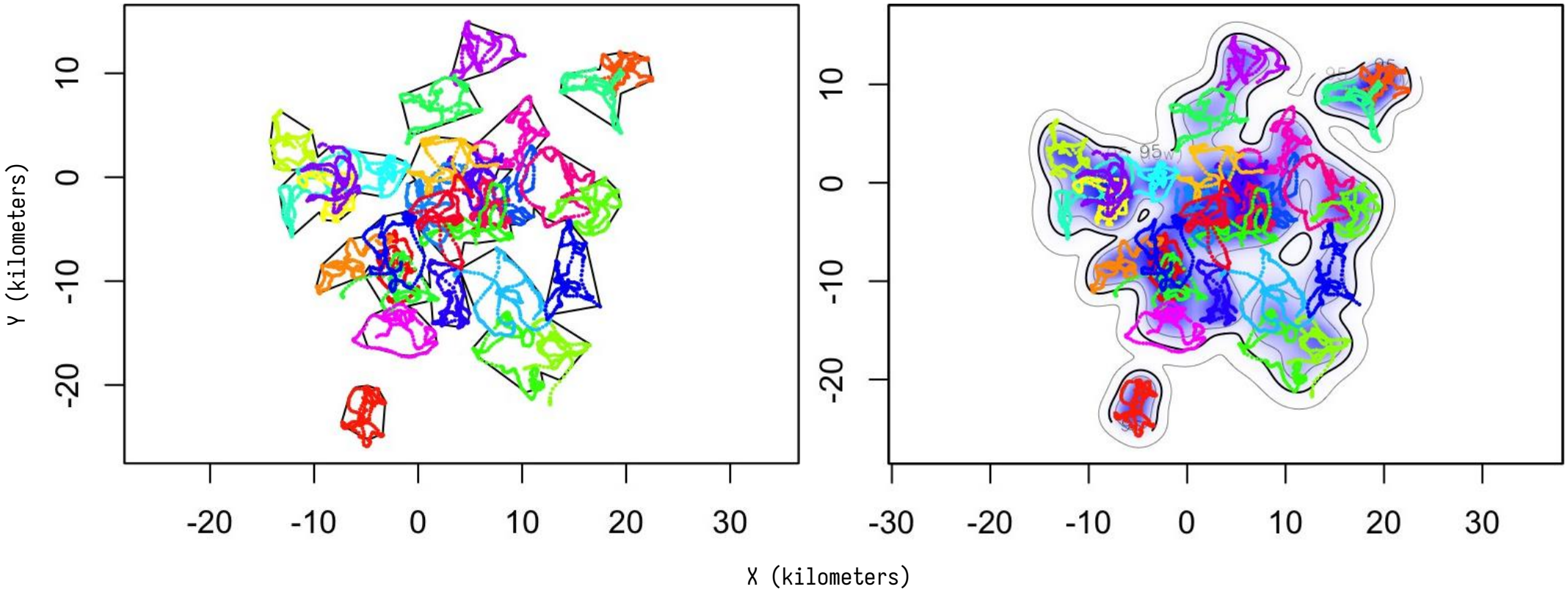

Merged **MCP** estimate
Merged **KDE** estimate
Y (kilometers)
X (kilometers)
10
0
-10
-20
-20
-10
0
10
20
30

Merged **MCP** estimate

Merged **AKDE** estimate



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KDE is a weighted average of kernels, where the optimal *H* minimizes the MISE:

$$\mathrm{MISE}[\mathbf{H}] = \mathrm{E}\left[\iint \left(\hat{p}(\mathbf{x}|\mathbf{H}) - p(\mathbf{x})\right)^2 d\mathbf{x}\right]$$

$$p(\mathbf{x}) = \text{approximation (e.g., Gaussian reference function)}$$

PKDE

$$\mathrm{MISE}[\mathbf{H}] = \mathrm{E}\left[\iint \left(\hat{p}_{\text{pop.}}(\mathbf{x}|\mathbf{H}) - p_{\text{pop.}}(\mathbf{x})\right)^2 d\mathbf{x}\right]$$

$$\hat{p}_{\text{pop.}}(\mathbf{x}|\mathbf{H}) = \sum_{\text{ind.}} \sum_{t} w_{\text{ind.}}(t)\, \kappa(\mathbf{x} - \mathbf{x}_{\text{ind.}}(t)|\mathbf{H}_{\text{ind.}})$$

$p_{\text{pop}}(\mathbf{x})$ requires a hierarchical approximation

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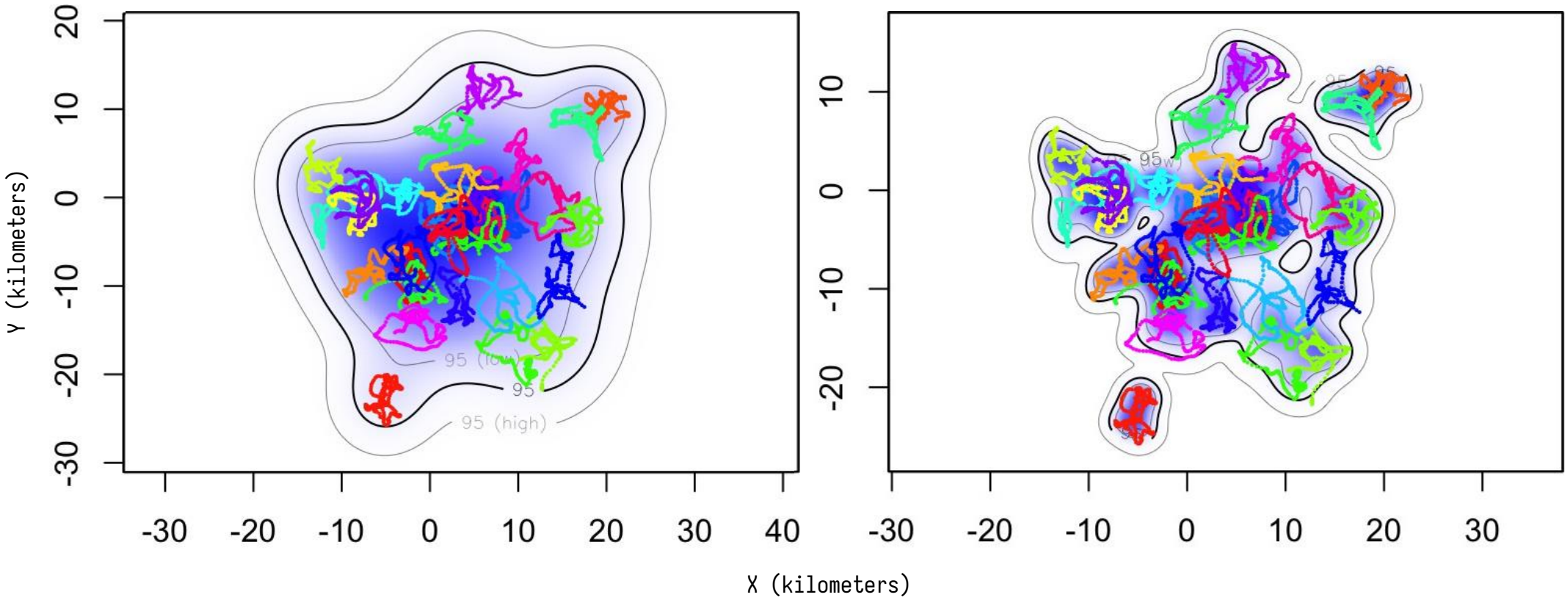
PKDE estimate

Merged **AKDE** estimate



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Saturation curves