Line Transect data in Occupancy Studies: data collection methods and model identifiability

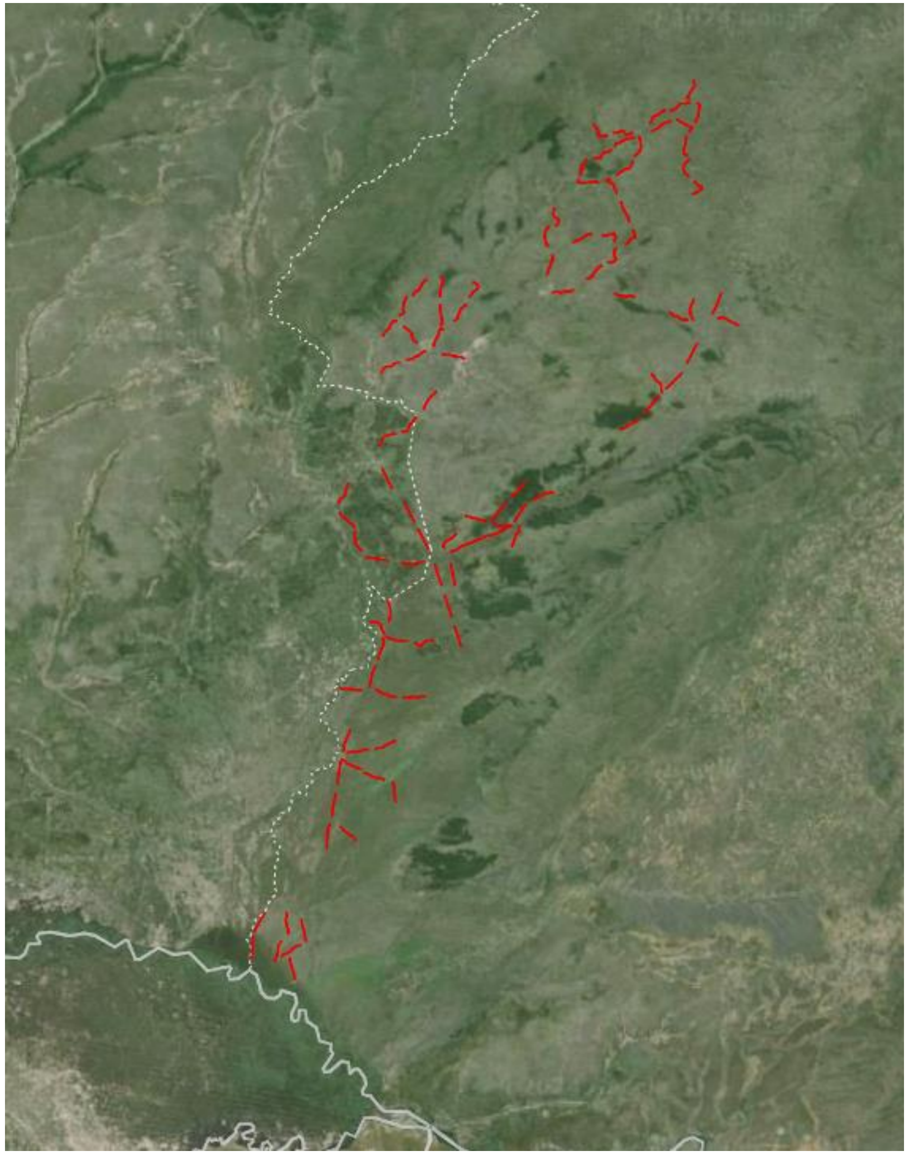
Milly Jones[1,3], Diana Cole[1], Eleni Matechou[1], Nicholas Deere[2], Robin Lines

[1] School of Maths, Statistics, Actuarial Sciences, University of Kent, Canterbury
[2] Durrell Institute of Conservation and Ecology, University of Kent, Canterbury

[3] mj23@kent.ac.uk

Motivating data set

[Lines2019]



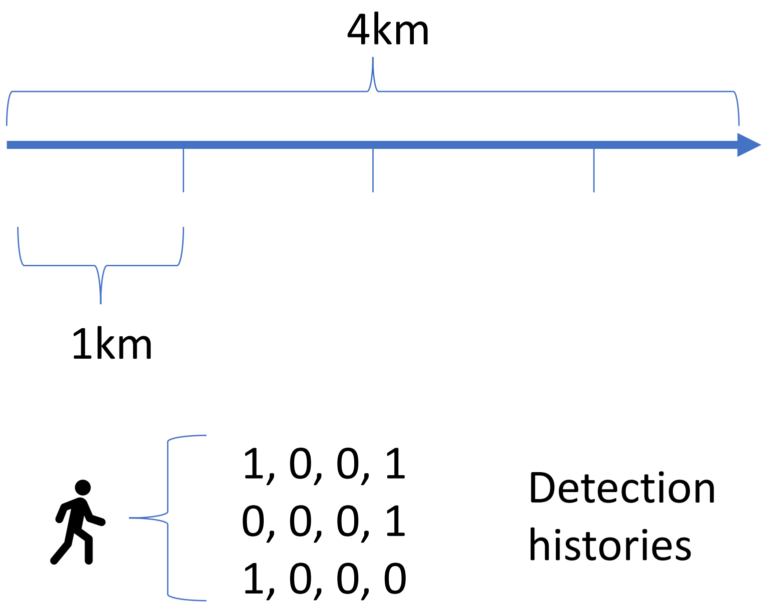
By Lencer (talk) - own work, used:File:Zambezi river basin-de.svg by Eric Gaba (User:Sting) and User:NNWhttp://www.kavangozambezi.org/the_map.php, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=16751696

Motivating data set

2015, large scale spoor detection and species sighting survey
102 line transects, each of length 4 km.

Each transect is visited 3 times over the course of 10 days.
Detection/non-detection histories taken.

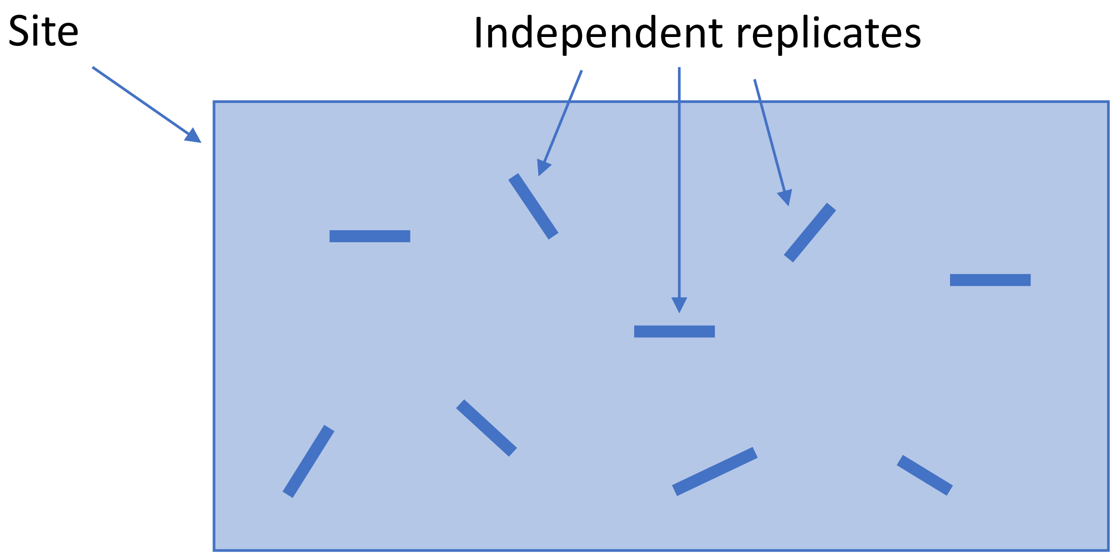
Detections: Leopard (279), Lion (87), Hyena (237), Wild dog (40).



Spatial Replicates

Occupancy studies require replication.

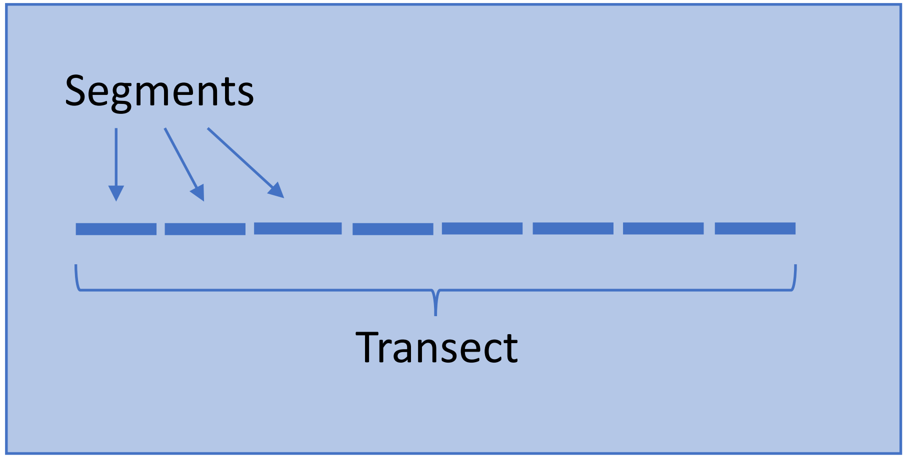
Replication can be spatial as well as temporal.



Random spatial replicates

Established transects at a site are convenient.

Consecutive segments are no longer independent [Kendall2009].



Consecutive segments

Markovian Segment Occupancy

The model: [Hines2010]

1. Site occupancy

$$z_i \sim \text{Bernoulli}(\psi)$$

Notation:

$\psi = \mathbb{P}(\text{site is occupied})$

z_i = occupancy site i

z_{ik} = occupancy segment k, site i

y_{ik} = detection segment k, site i

$\theta_{01} = \mathbb{P}(\text{segment occupied} \mid \text{previous segment unoccupied})$

$\theta_{11} = \mathbb{P}(\text{segment occupied} \mid \text{previous segment occupied})$

$p = \mathbb{P}(\text{detection} \mid \text{segment is occupied})$

Markovian Segment Occupancy

The model: [Hines2010]

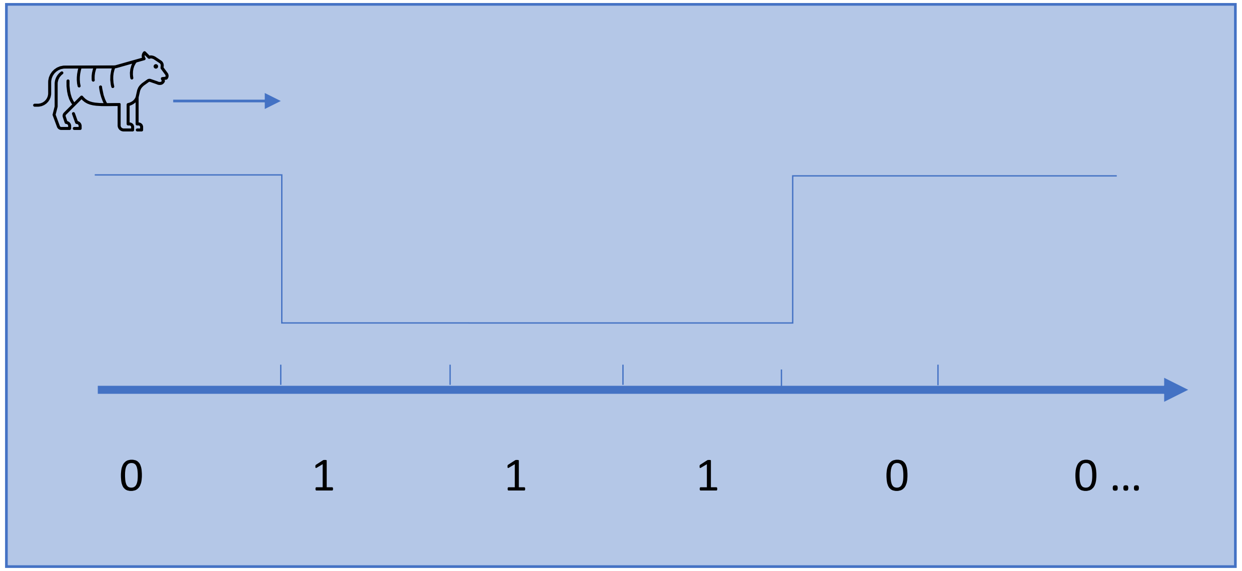
<u>1. Site occupancy</u>

$$z_i \sim \text{Bernoulli}(\psi)$$

<u>2. Segment occupancy</u>

$$z_{ik} | z_i \sim \text{Bernoulli}(z_i \times \theta_{ik})$$

$$\begin{bmatrix} 1-\theta_{01} & \theta_{01} \\ 1-\theta_{11} & \theta_{11} \end{bmatrix}$$



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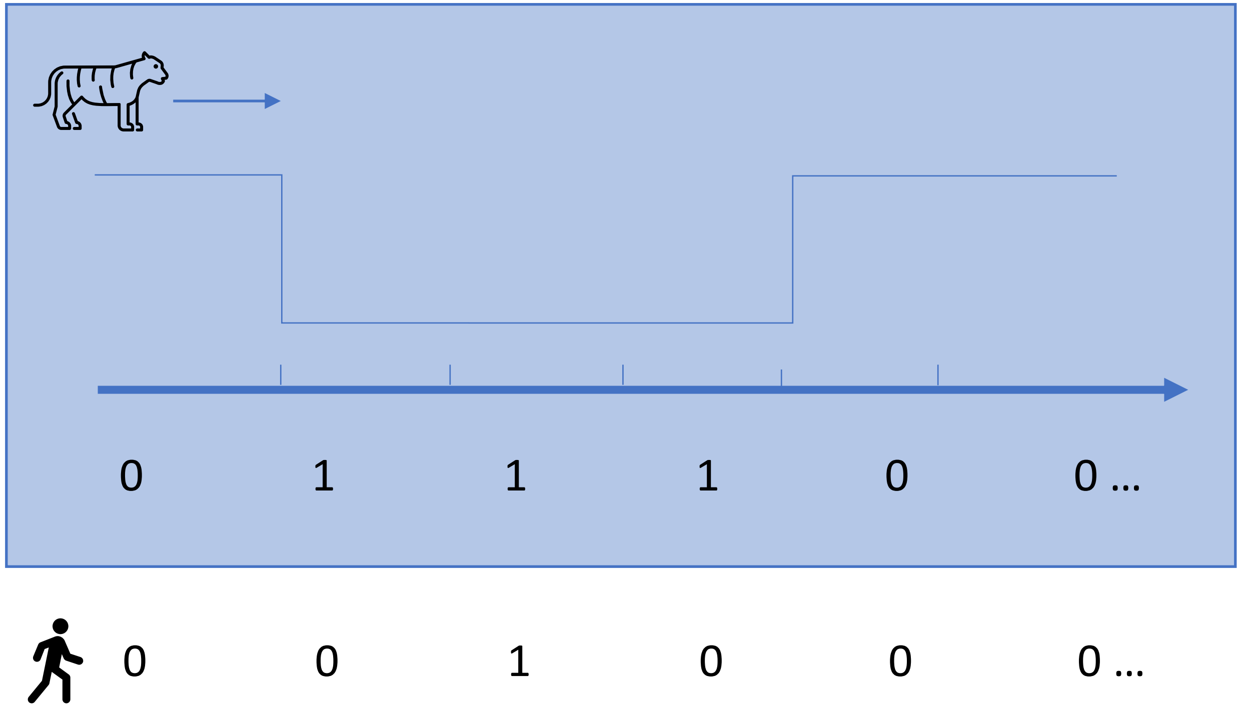
3. Detection

$$y_{ik} | z_{ik} \sim \text{Bernoulli}(z_{ik} \times p)$$



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Identifiability

Full Model

$$z_i \sim \text{Bernoulli}(\psi)$$
$$z_{ik}|z_i \sim \text{Bernoulli}(z_i \times \theta_{ik})$$
$$y_{ik}|z_{ik} \sim \text{Bernoulli}(z_{ik} \times p)$$

$$\theta_{01} = \theta_{11} = \theta$$

Collapses to

Non-identifiable Model

$$z_i \sim \text{Bernoulli}(\psi)$$
$$y_{ik}|z_{ik} \sim \text{Bernoulli}(z_i \times \theta \times p)$$

Can only identify: $(\psi, \theta p)$

Good news! Can still identify ψ

Notation:

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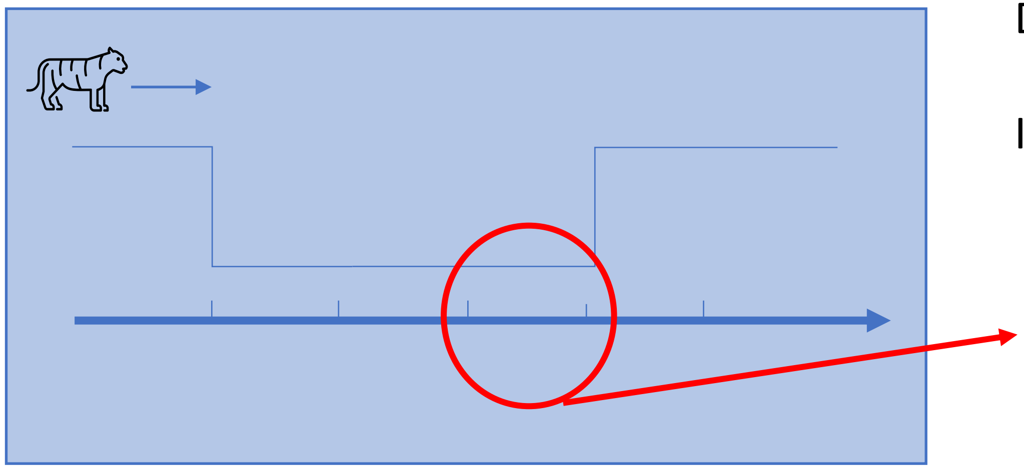
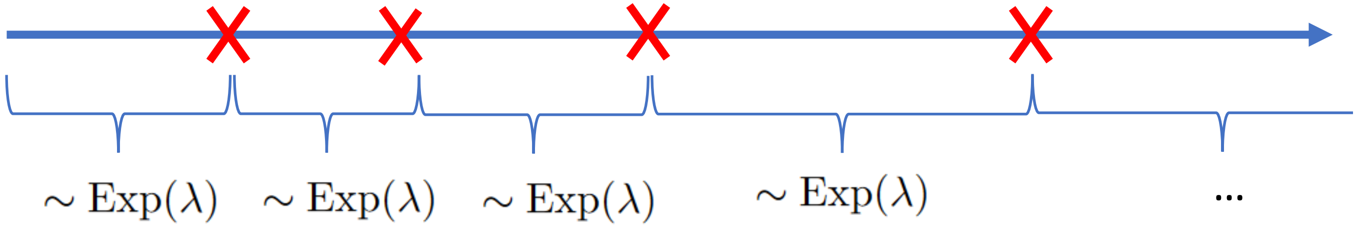
How do we record data: [Pautrel2024]



Detections are made at exponential rate λ on occupied segments.

If all segments have length R: $p = 1 - \exp(\lambda R)$



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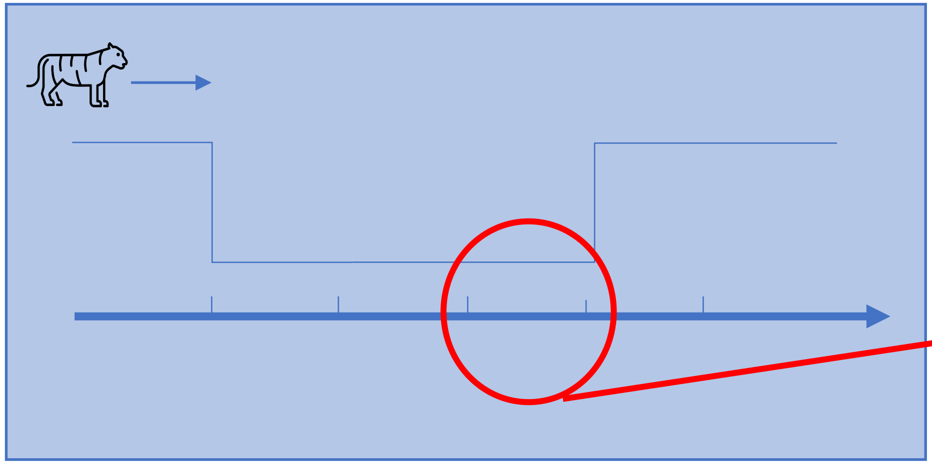

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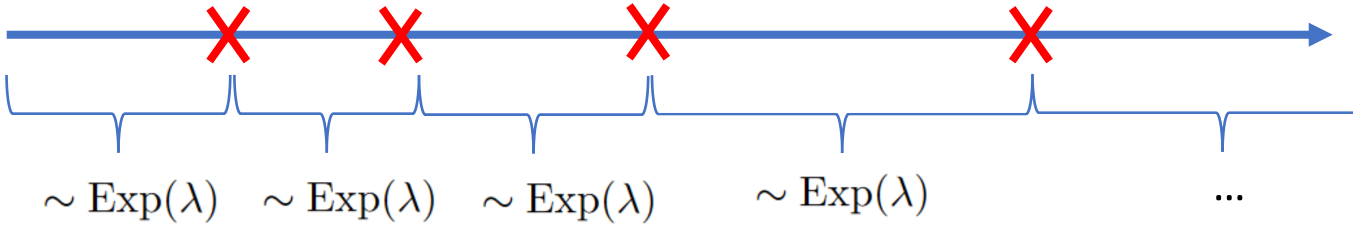
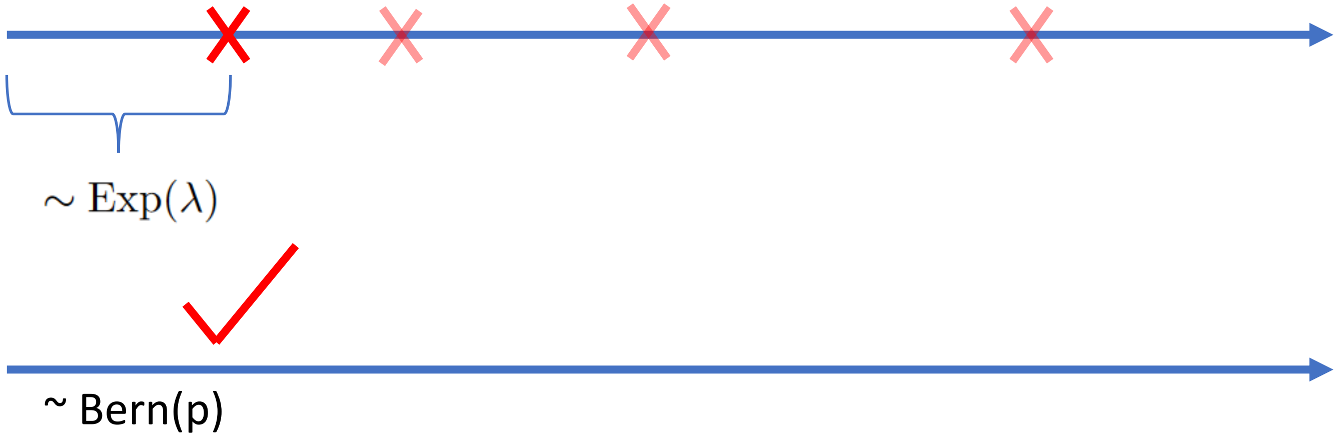


Single Observation – Discrete vs Continuous

Two Observations

All observations



‘Time to first detection’ [Garrard2008]

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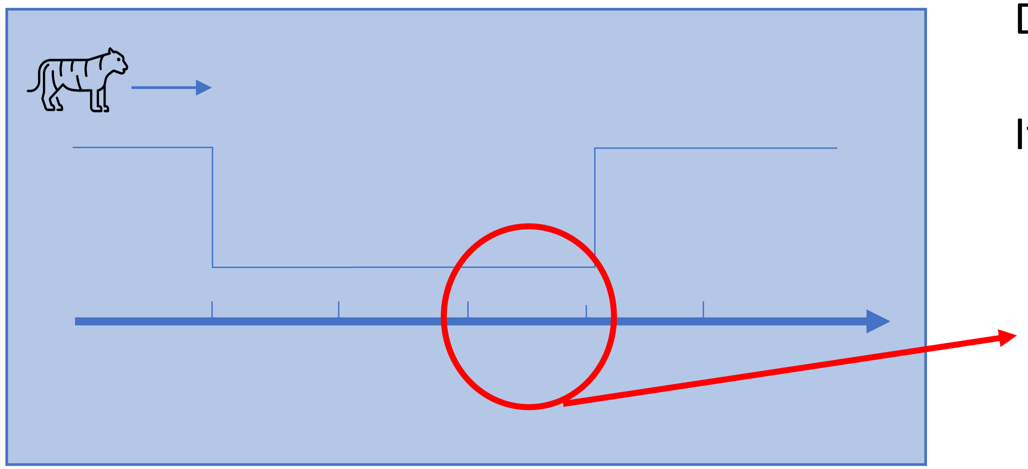

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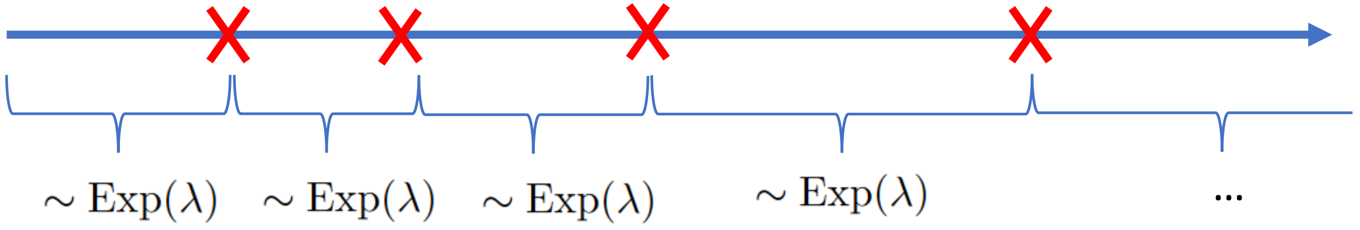
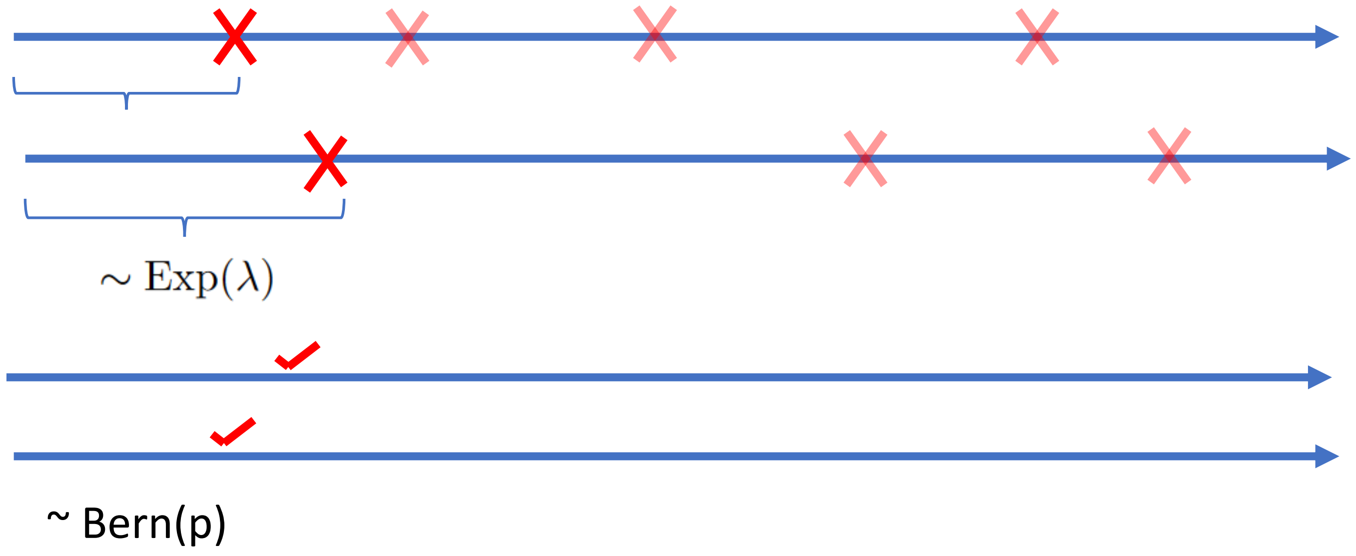
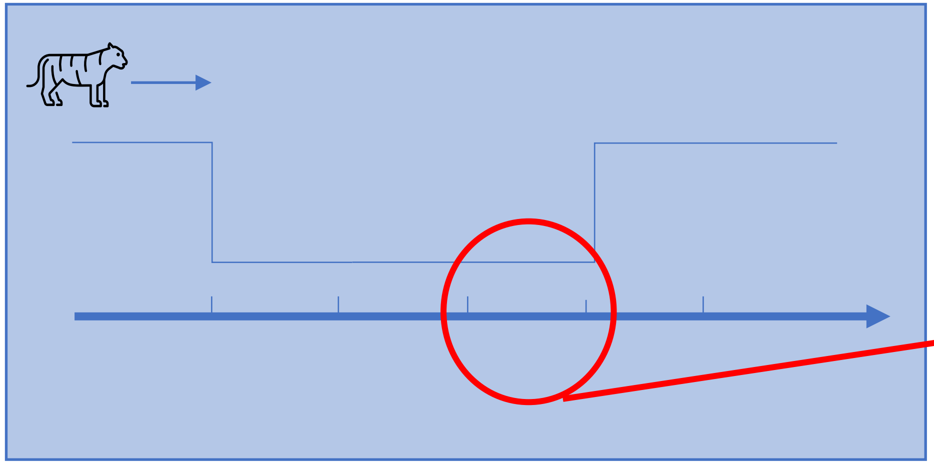


Single Observation | **Two Observations** – Discrete vs Continuous | All observations



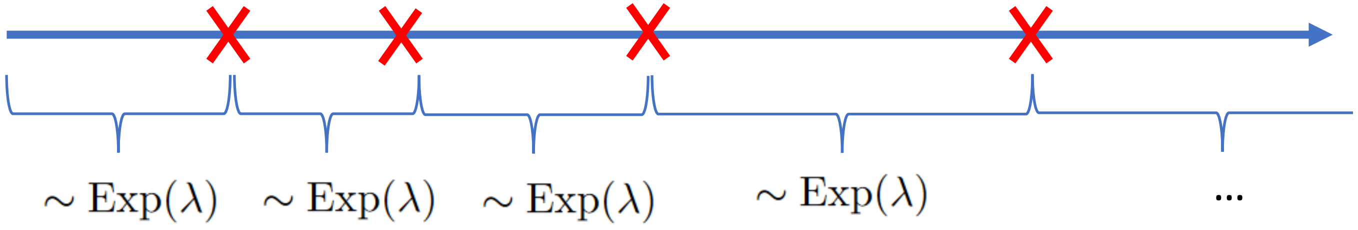
Independent surveys

How do we record data: [Pautrel2024]

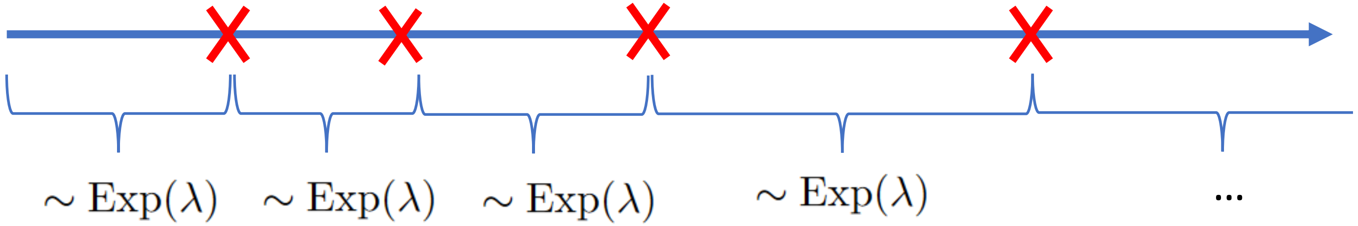


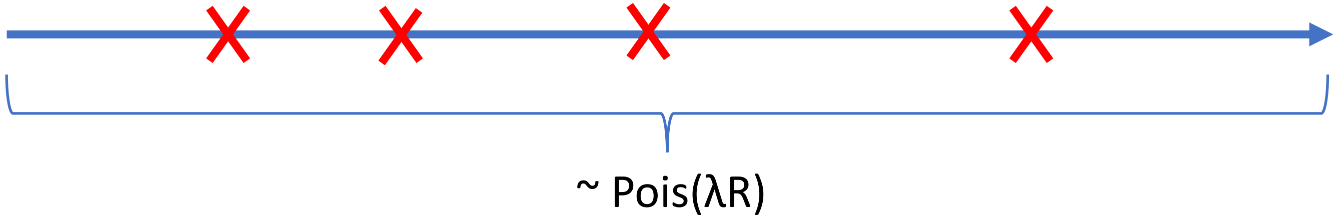
Detections are made at exponential rate λ on occupied segments.

If all segments have length R: $p = 1 - \exp(\lambda R)$



Single Observation | Two Observations | **All observations** – Discrete vs Continuous





Count of observations

Summary:

Single Observation

Discrete

Detection/non-detection

~ Bern(p)

1, 0, 0, 1, 1, …

Continuous

Distance to first detection

~Exp(λ)

x1, -, -, x4, x5, …

≥Two Observations

Discrete

Two independent detection\non-detection

~Bern(p)

1, 0, 0, 1, 1, …
0, 0, 1, 1, 0, …

Continuous

Two independent distance to first detection

~Exp(λ)

x1, -, -, x4, x5, …
-, -, x3, x4, -, …

All Observations

Discrete

Counts

~Pois(λR)

5, 0, 0, 7, 3, …

Continuous

All inter-detection distances

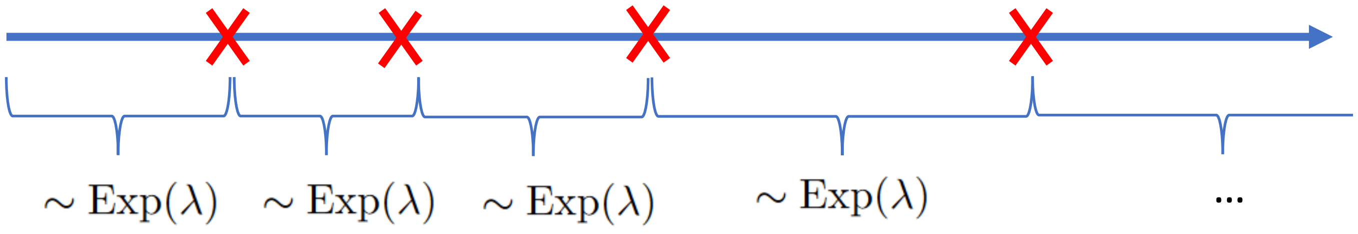
~Exp(λ)

x11, x12, x13, …
x21, x22, x23, …
…

Simulations overview

- We simulate:

1. Site occupancy status
2. Segment occupancy status
3. Continuous detections
4. Discretise as needed



200 sites, 20 segments per transect.

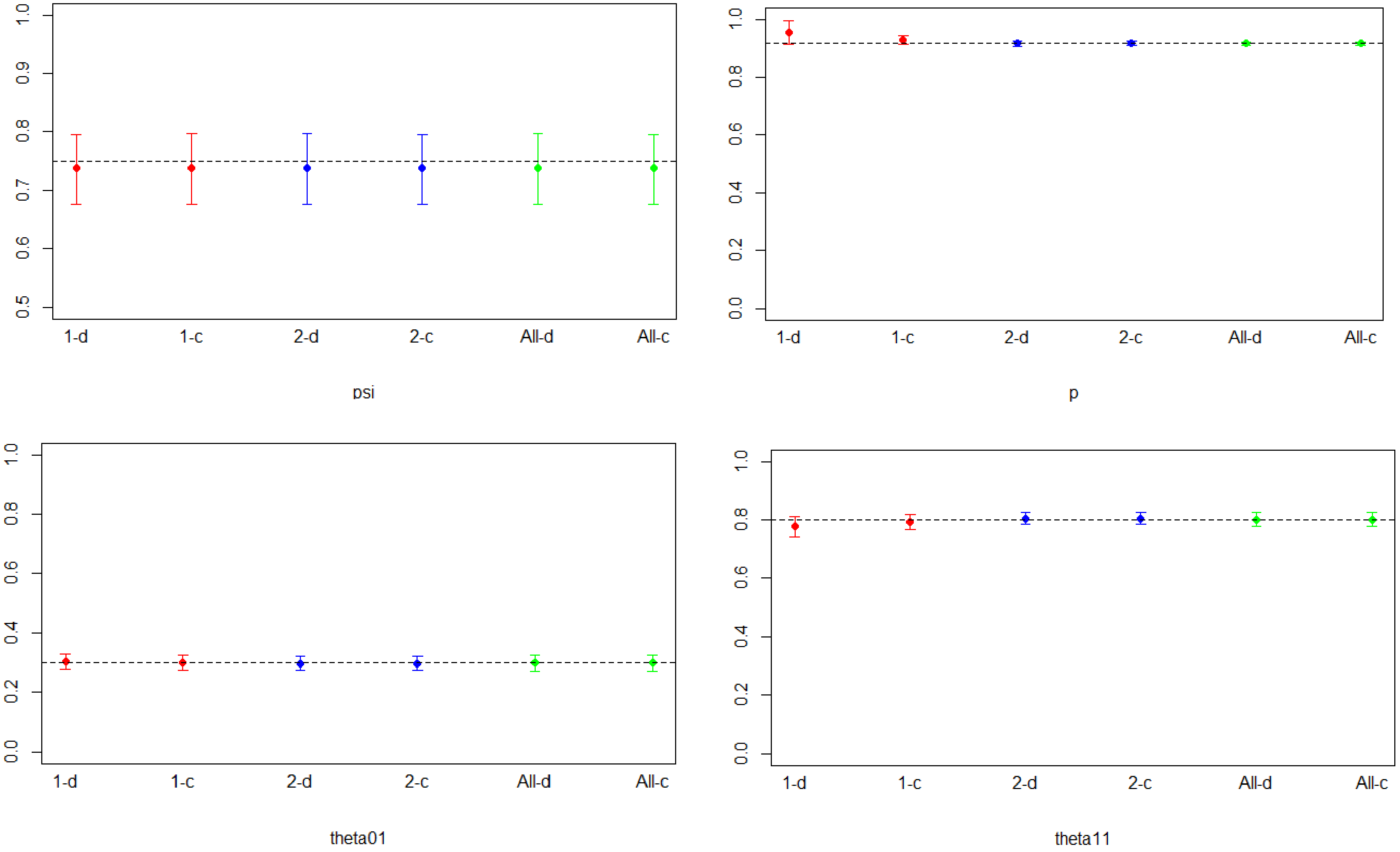
Compare 6 data collection methods.

Recall that: $p = 1 - \exp(\lambda R)$

All models fit in nimble.

Simulations

$\psi = 0.75$
$p = 0.918$
$\theta_{01} = 0.3$
$\theta_{11} = 0.8$



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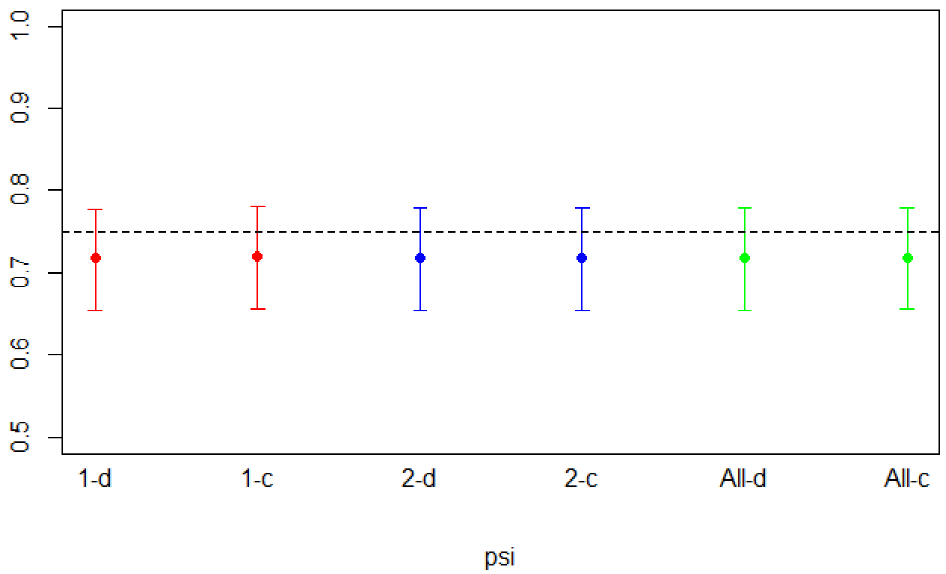
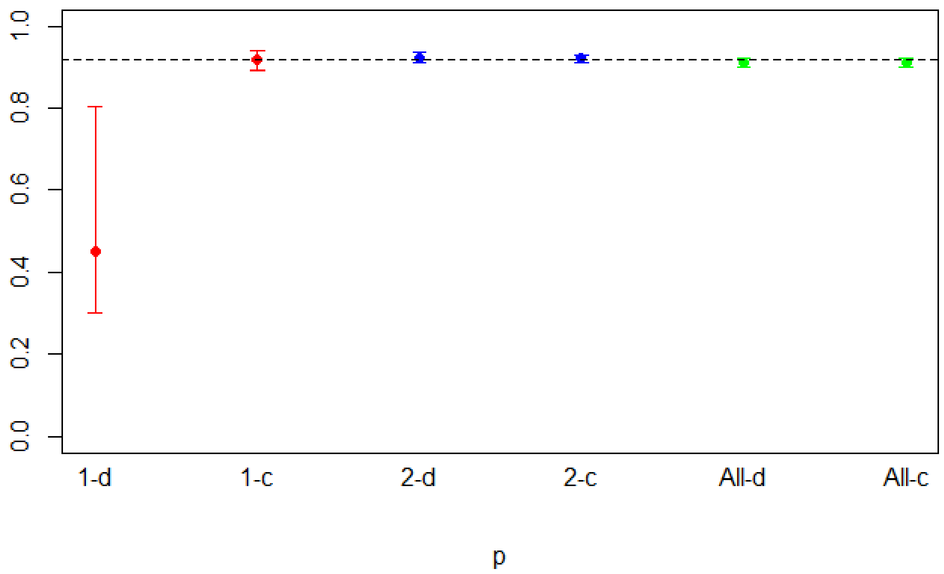
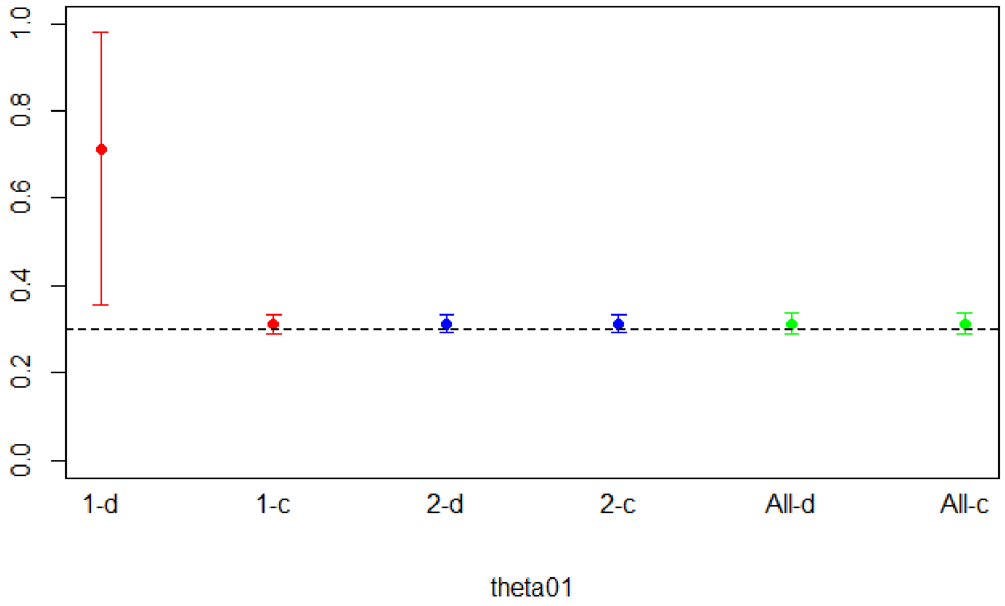
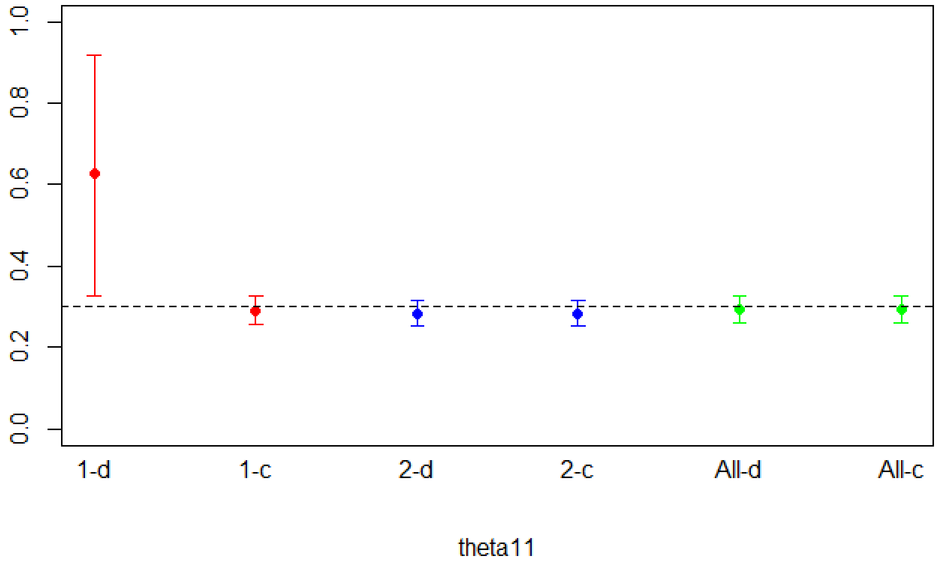


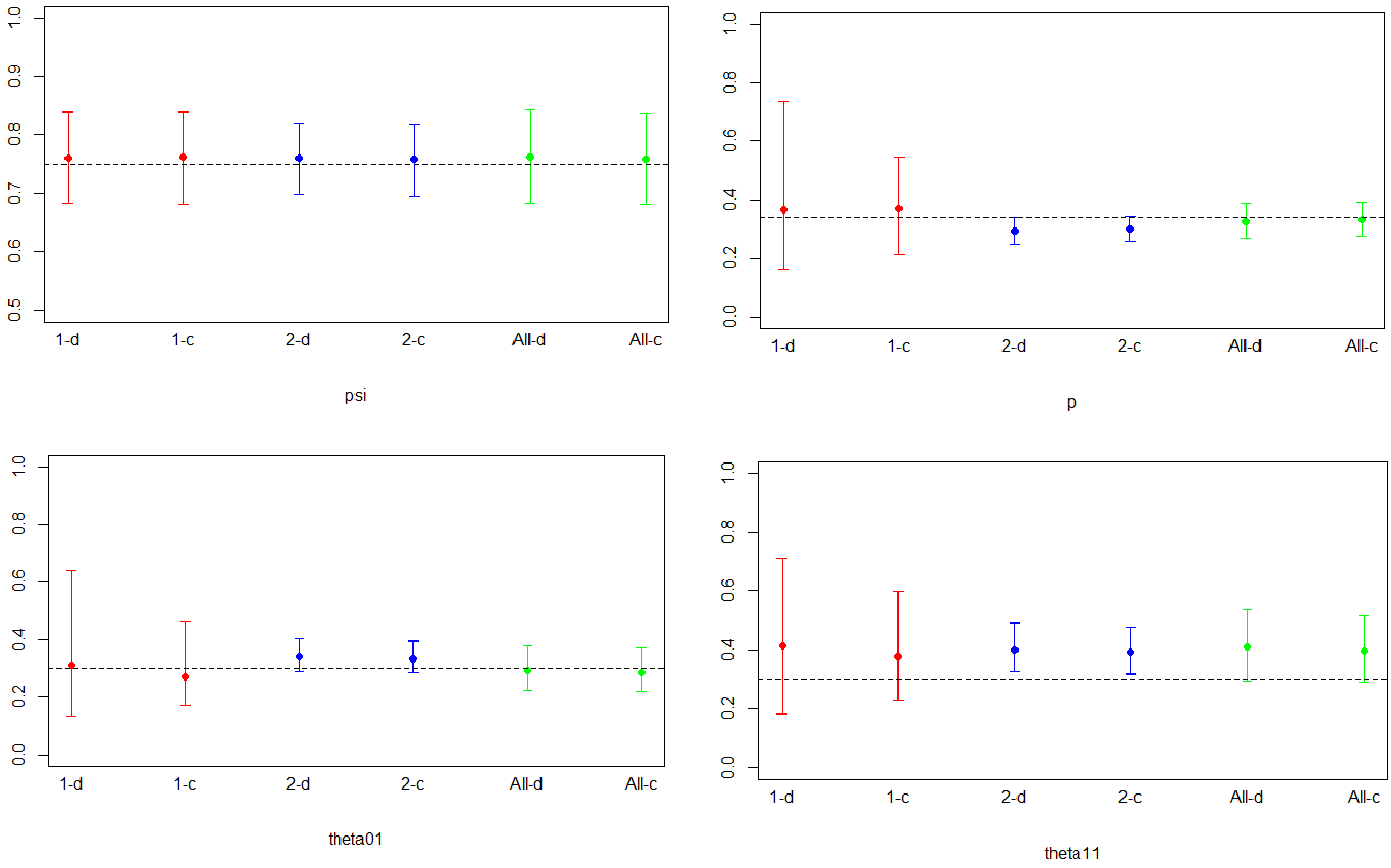


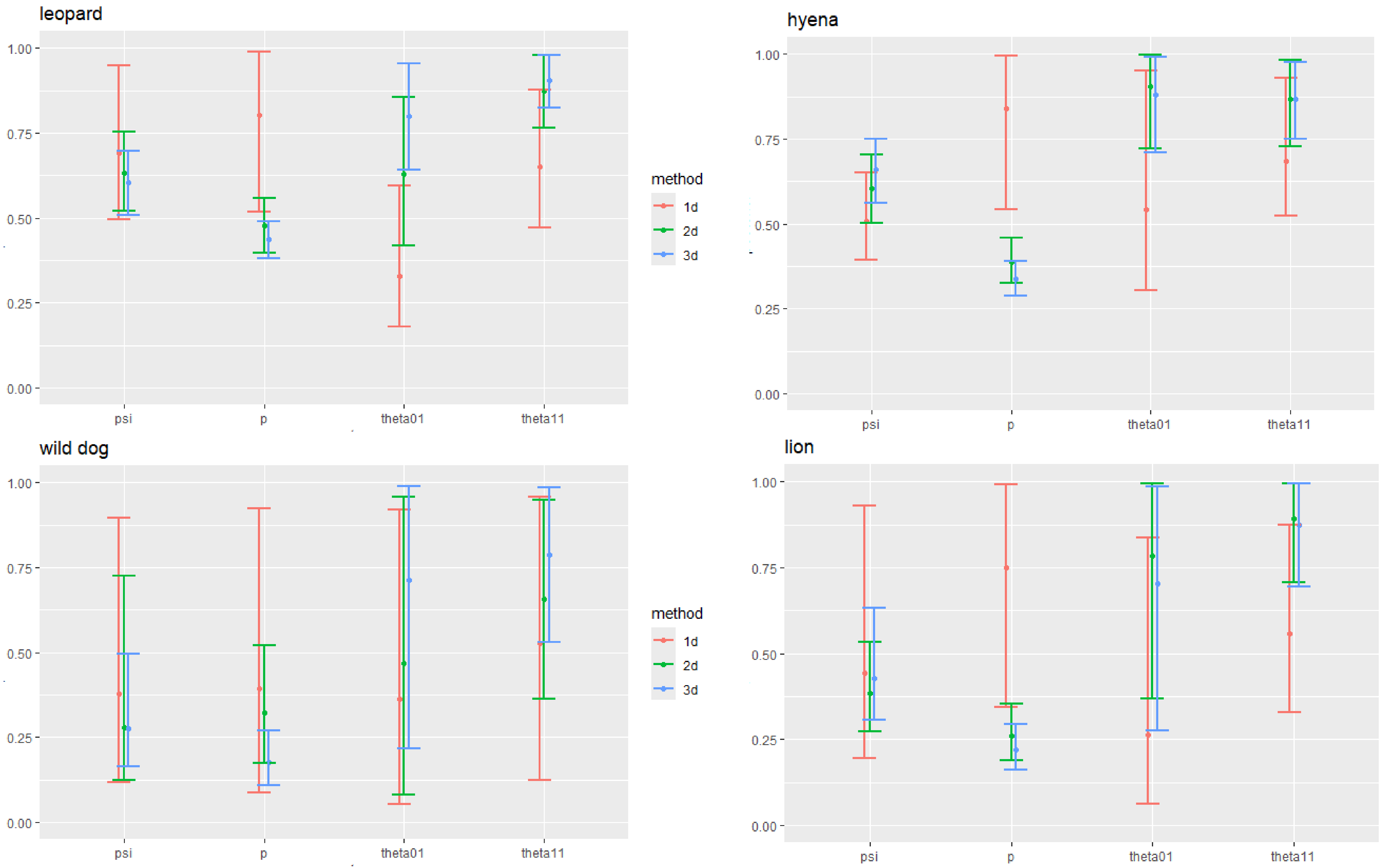




Simulations

$\psi = 0.75$
$p = 0.340$
$\theta_{01} = 0.3$
$\theta_{11} = 0.3$




leopard
hyena
wild dog
lion
1.00
0.75
0.50
0.25
0.00
psi
p
theta01
theta11
method
1d
2d
3d

Conclusion

- Three layer occupancy models using Markovian dependence in segment occupancy and a single detection are not identifiable when spatial correlation does not exist.

- We show that using a single time to detection, two or more independent observations, or counts make the model identifiable even when spatial correlation does not exist.

- Site occupancy probabilities perform well even other parameters struggle.

Where next

Discretising transects into segments is often arbitrary. Continuous models for handling spatial correlation include [Guru2011], involving a 2 state Markov Modulated Poisson Process (2-MMPP).

We have other line transect data collected for occupancy models that include perpendicular distances to observations (distance sampling data).

References

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