Model-based data integration: a primer and practical guide

Nick Golding & Saras Windecker
ISEC 2022

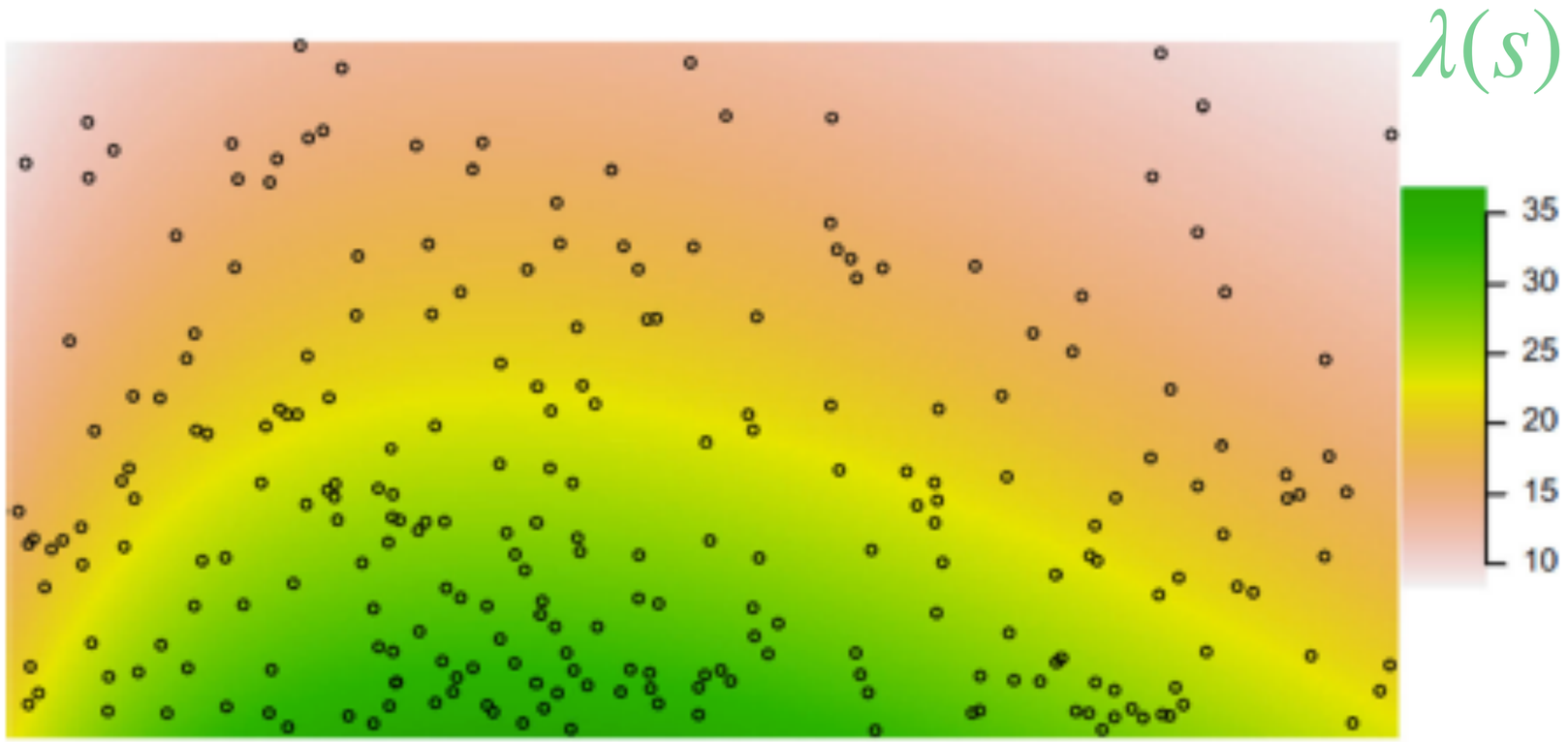
How did we come to this?

Data integration combines datasets by explicitly modelling their data collection processes, incorporating their biases, and propagating as much information as possible about the process of interest.

What is the aim of the work?

What is the aim of the work?

Distribution of individuals of a species (relative abundance) across space.



Fithian W, Elith J, Hastie T, Keith DA. Bias correction in species distribution models: pooling survey and collection data for multiple species. Methods Ecol Evol. 2015;6(4):424-438. doi:10.1111/2041-210X.12242

What is the motivation for data integration?

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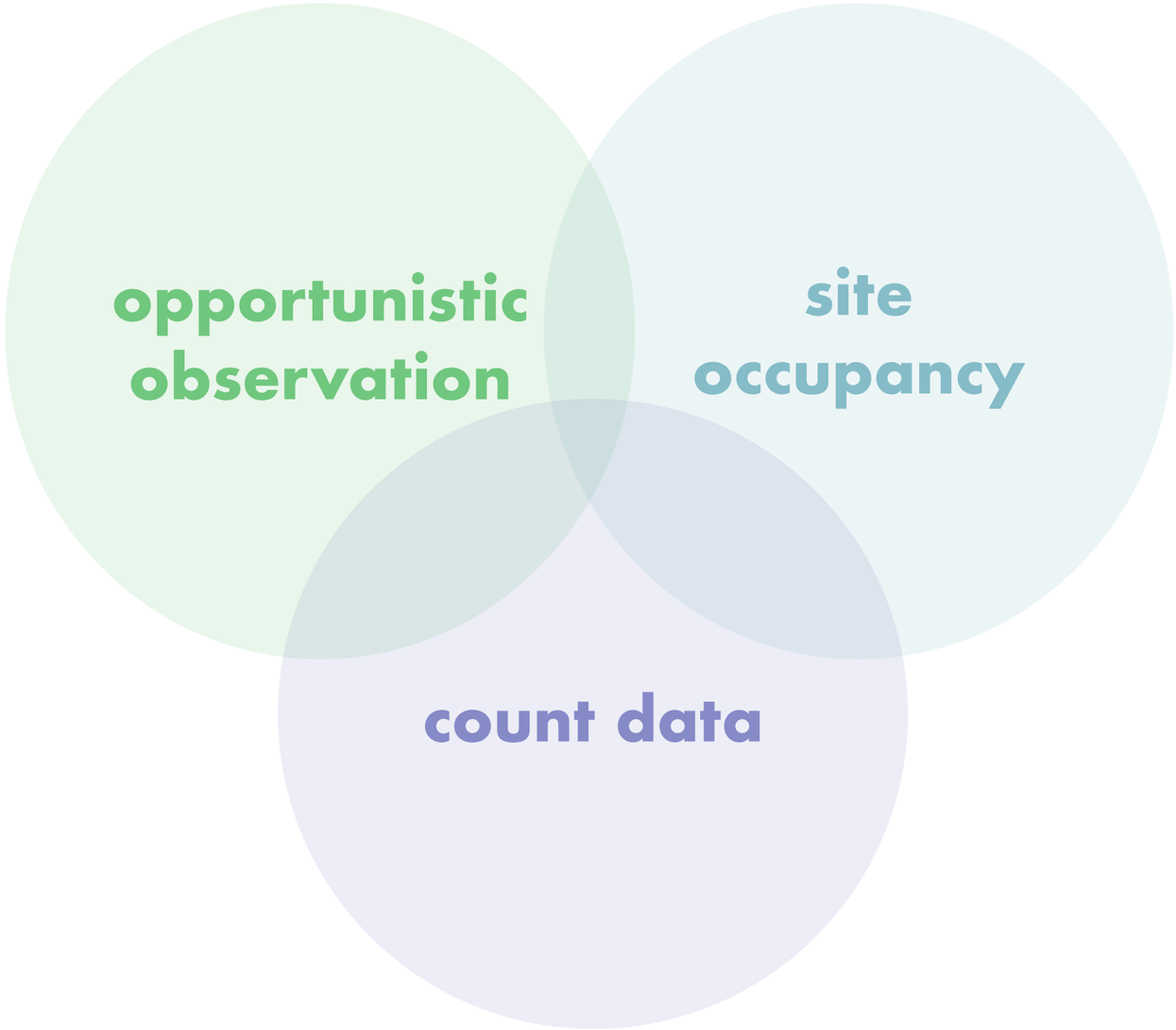
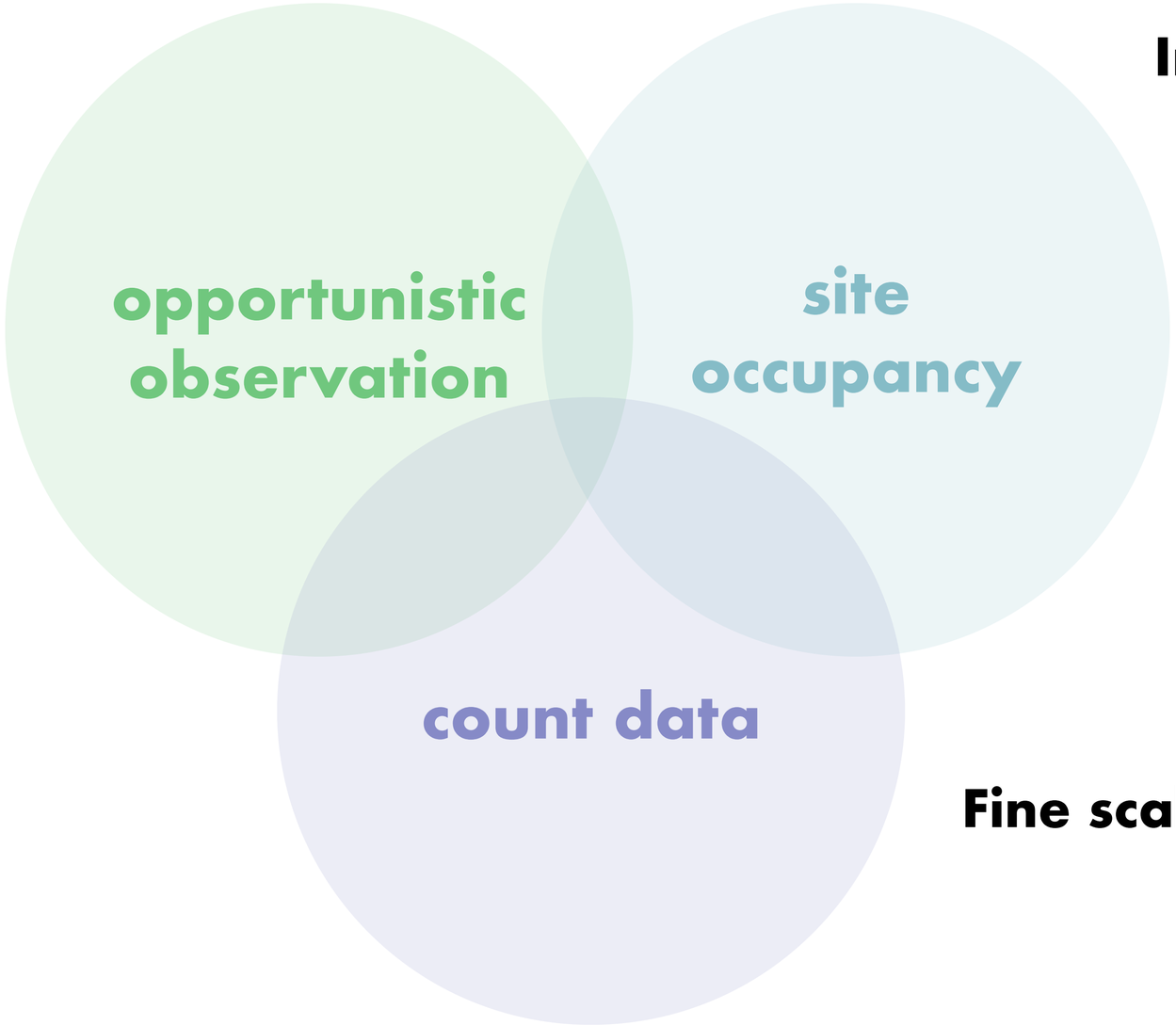
Capitalise on many different data types, none of which are perfect.



Vary in extent.

Broad scale

Intermediate scale

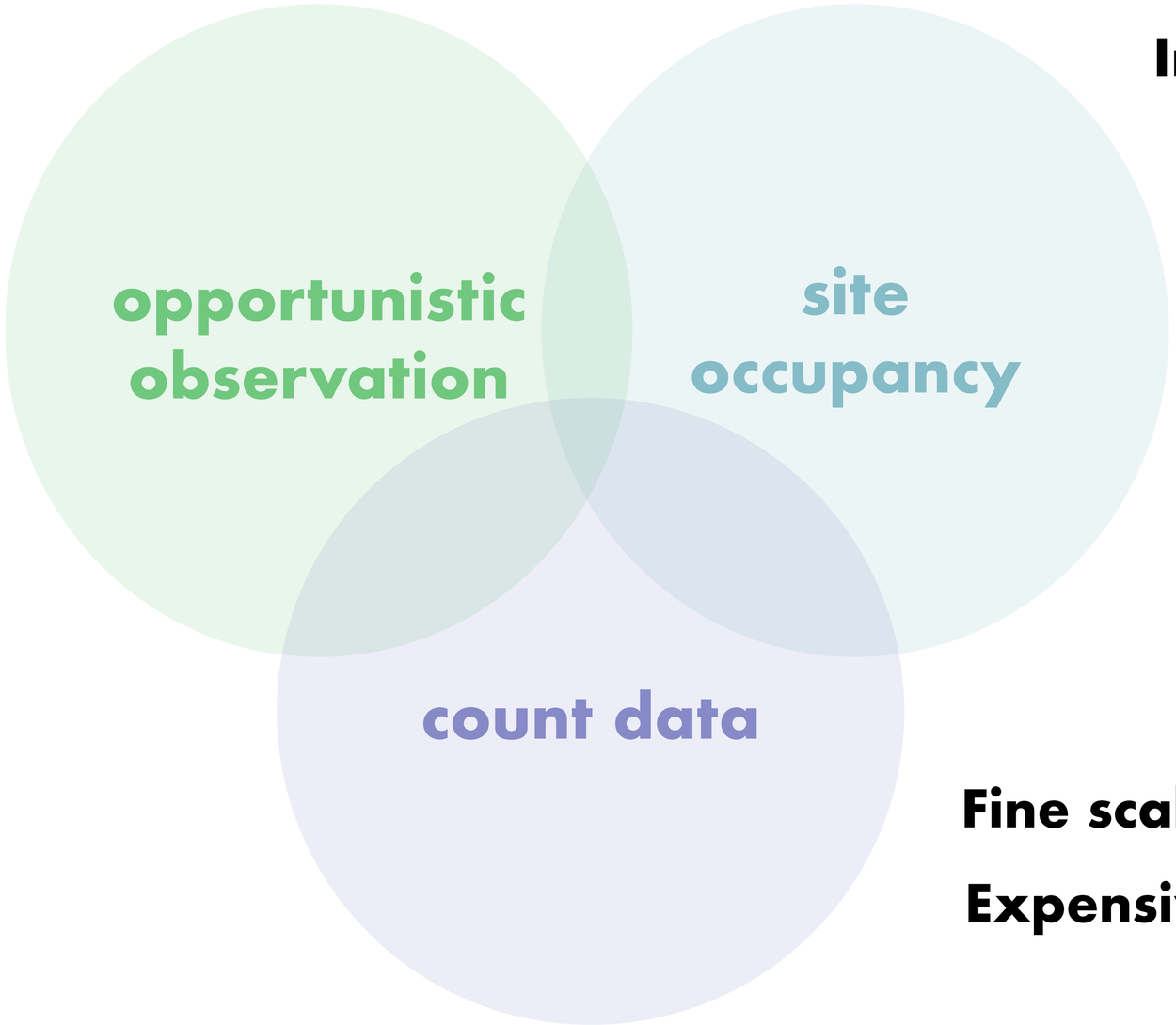


Fine scale

Vary in extent. And unique biases.

Broad scale

Biased



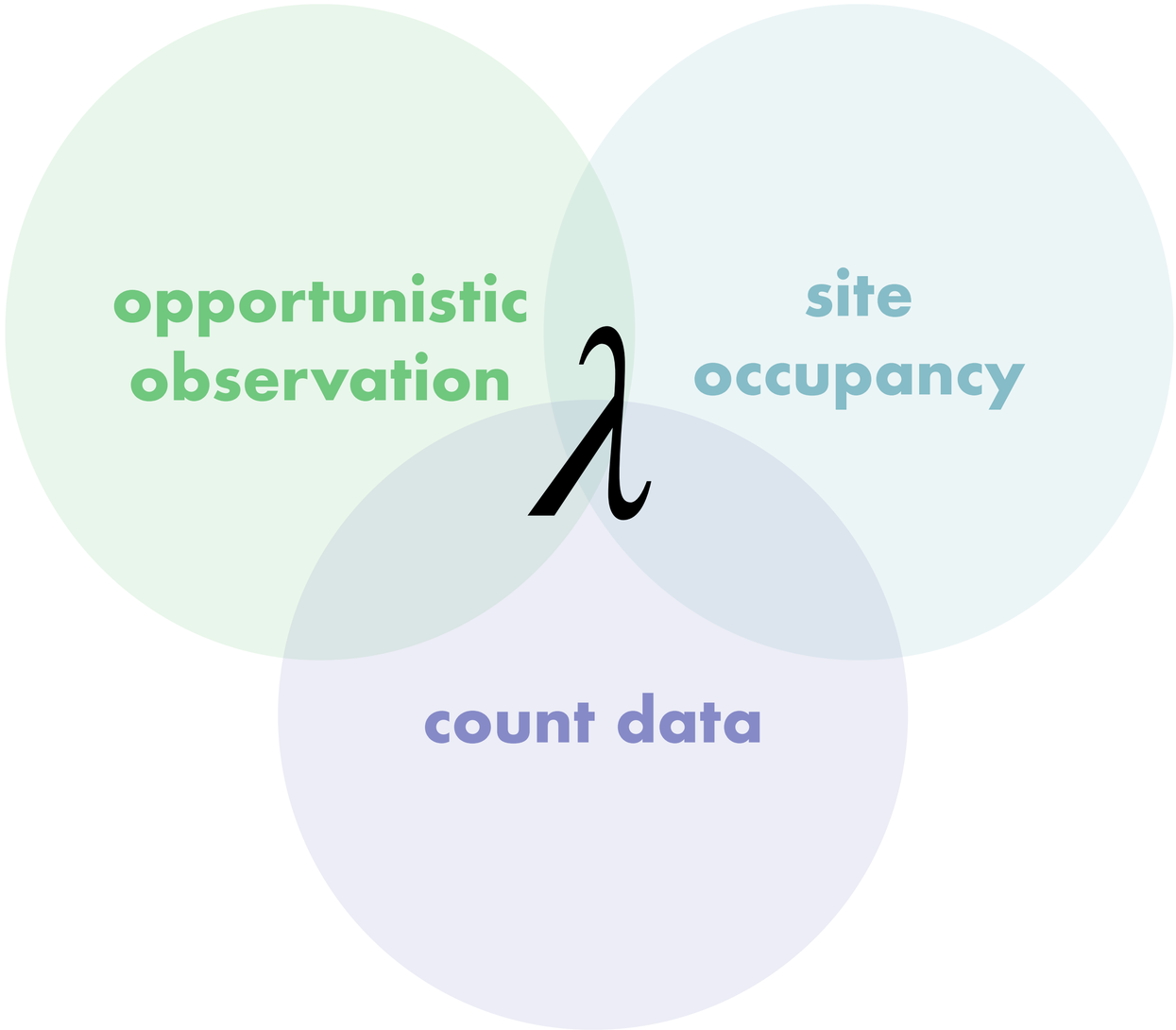
Intermediate scale

Imprecise

Fine scale

Expensive/hard to get

Can use a mechanistic link between data types to establish a common parameter of spatial distribution.



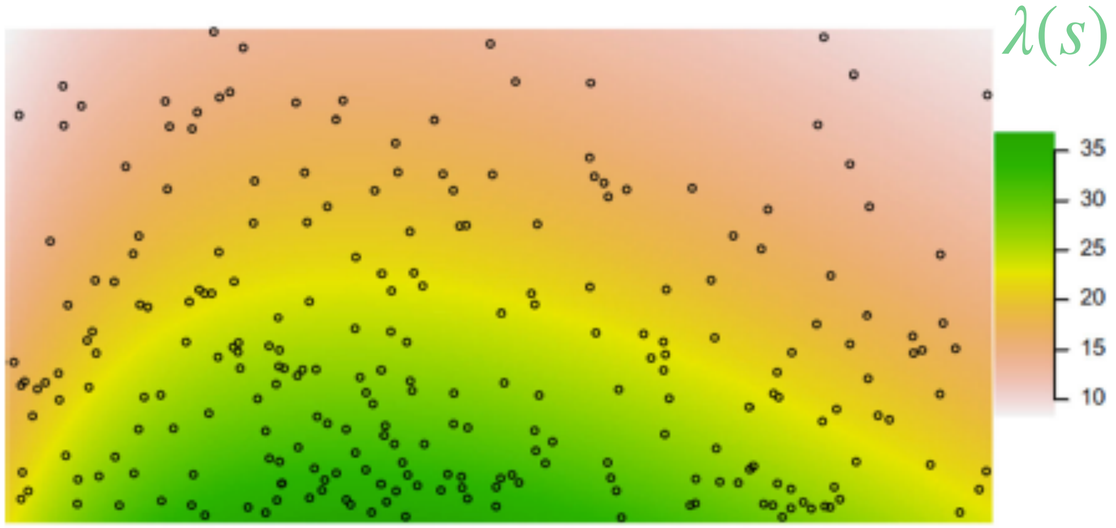
count data

What is the data?

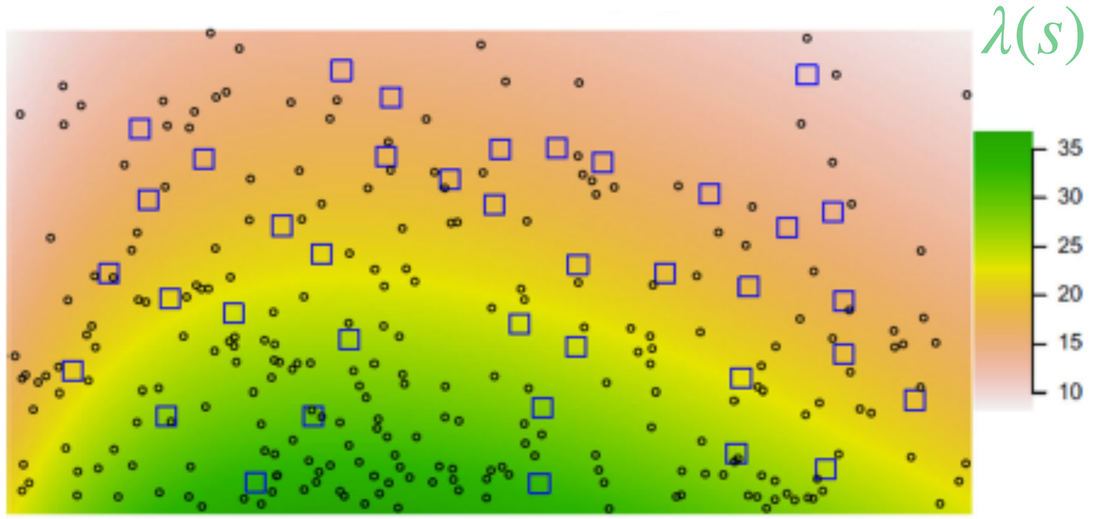
Spotlighting count of possums in 5 min search of 50 m radius.

Restricted spatial extent.

“The truth”



Density across space



Structured survey data

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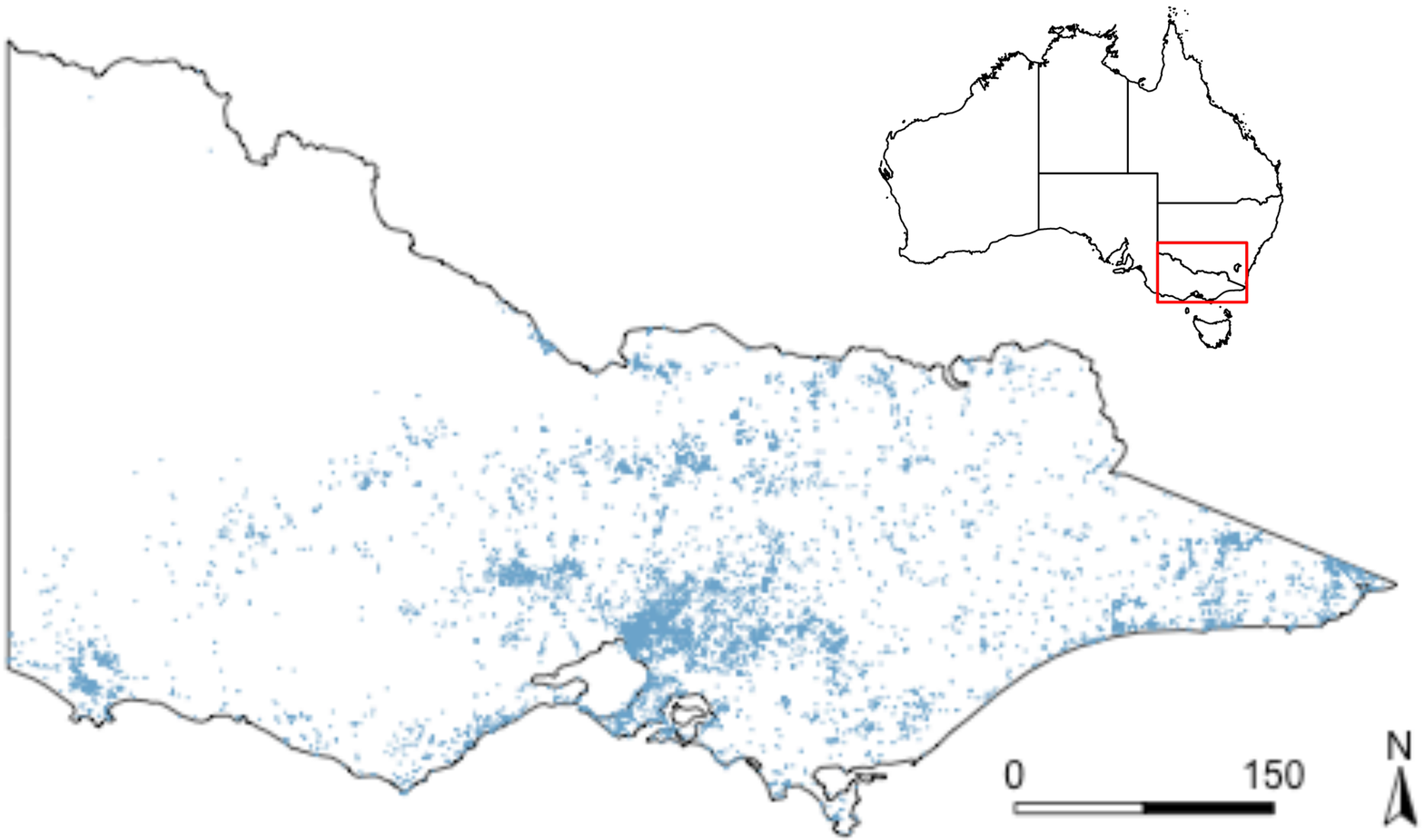
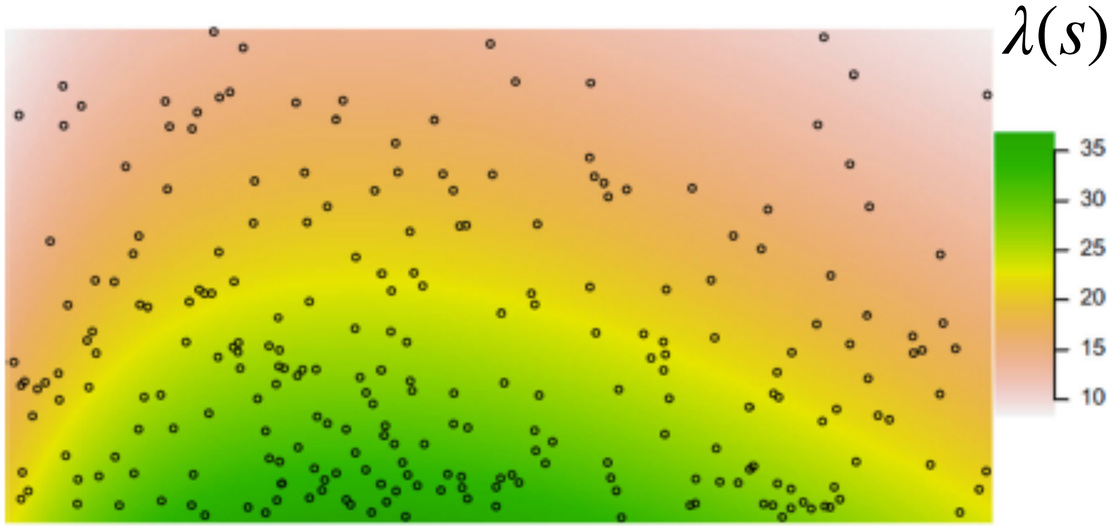
What is the data?

opportunistic observation

Broad scale Atlas of Living Australia presence only possum records.

Biased opportunistic/ citizen science data.





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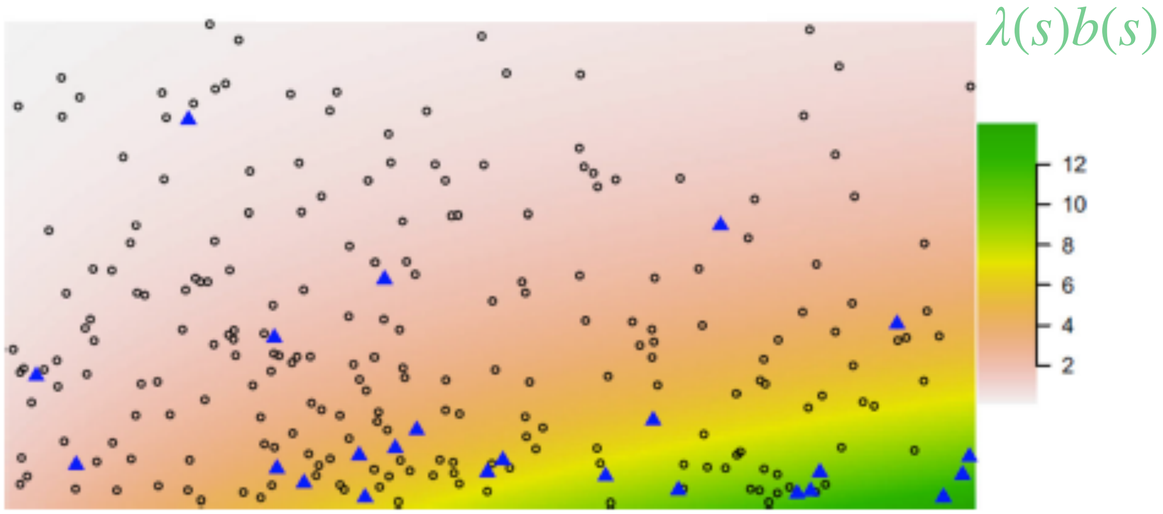

Biased opportunistic observations

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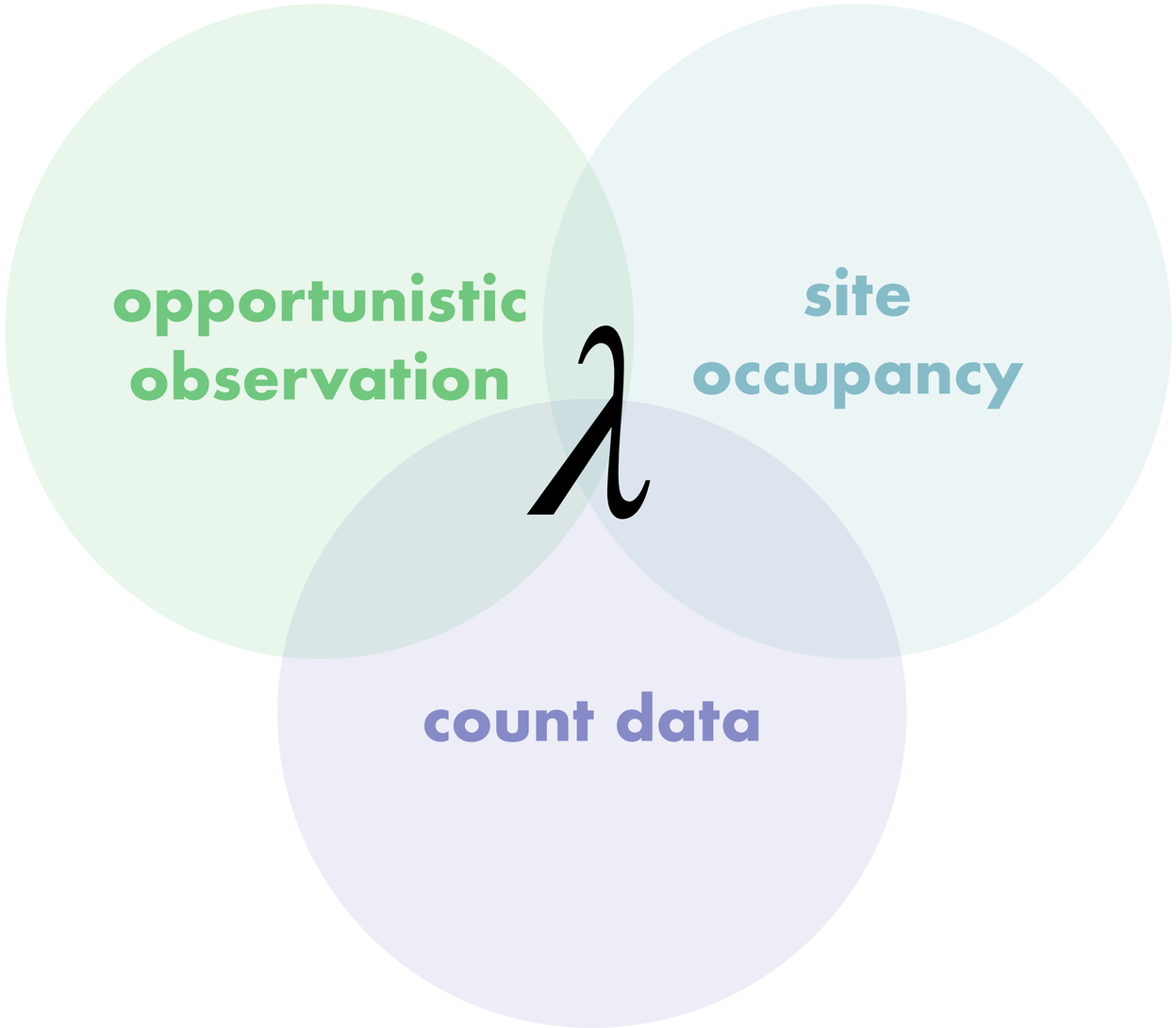
site occupancy

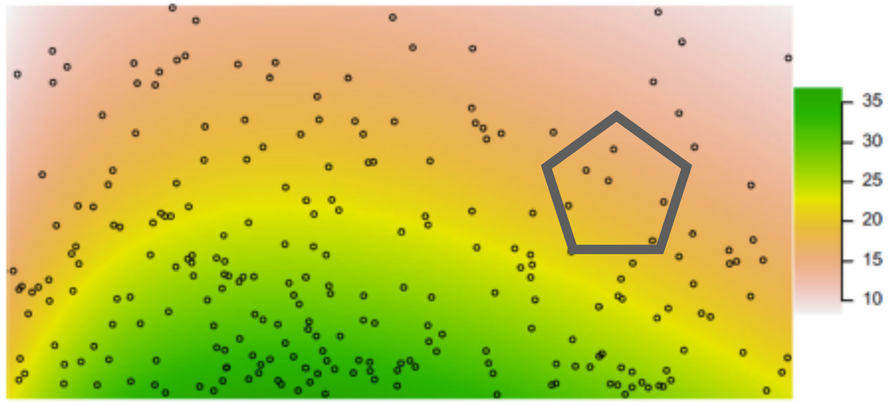
What is the data?

Scats detected/not detected in 10 m radius.

Imprecise proxy for detection of possums.

What is the model?





Inhomogenous Poisson point process

The number of points in any given region is Poisson (regardless of the location, size, or shape of the region)

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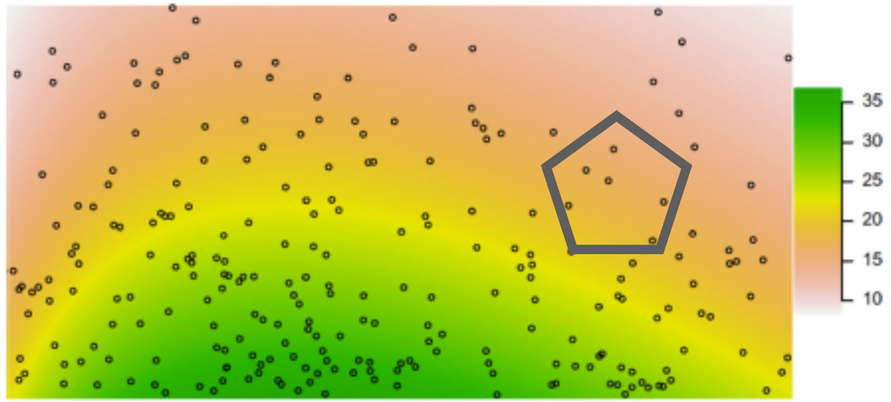

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Expected # points in a region *R* (parameter of Poisson) = $\int_R \lambda(s)ds$

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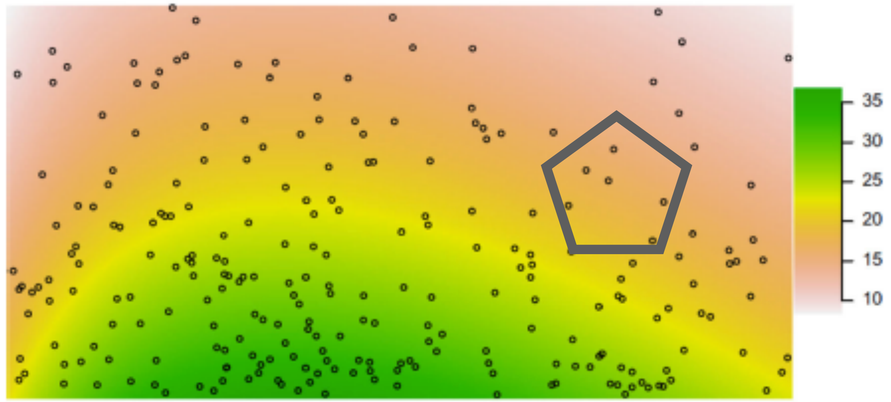

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If $\lambda(s)$ is constant over *R*, with $\lambda(s) = \lambda_R$ and has area A_R then:

$$\frac{\text{Expected number of points in } R}{A_R} =$$

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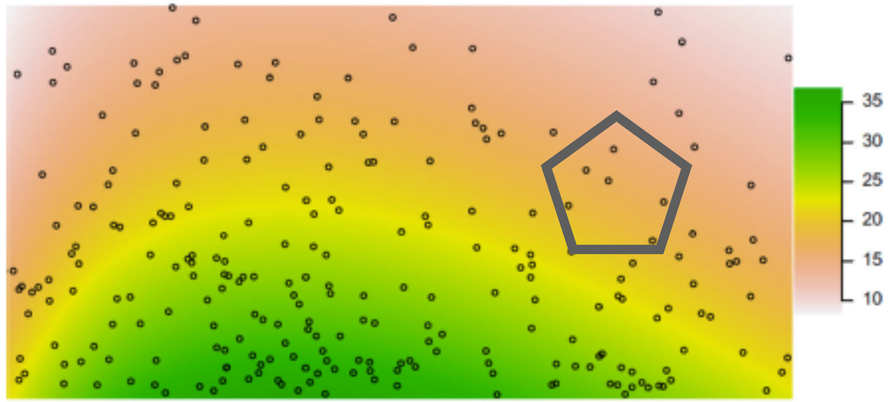

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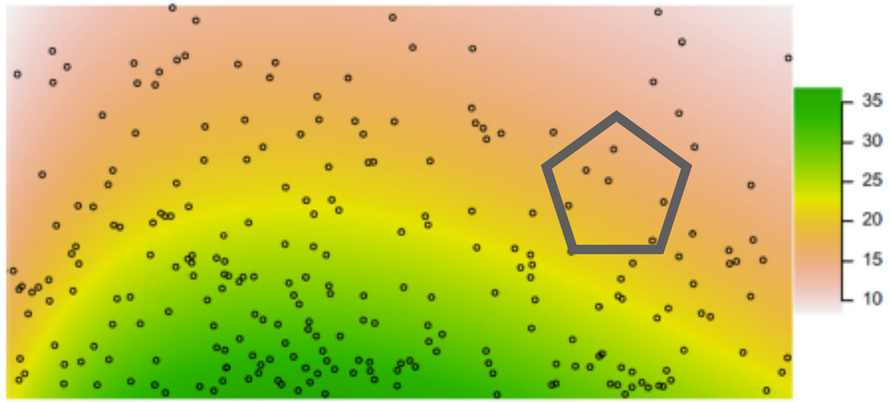

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The possum density process model linking all data types

$$\text{Expected \# possums in region } i = \int_i \lambda(s)ds \approx \lambda_i a_i$$

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Possum density in i : $log(\lambda_i) = \alpha + \beta * TreeCover_i$

The possum density process model linking all data types

Expected # possums in region i $= \int_i \lambda(s)ds \approx \lambda_i a_i$

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count data

What is the model?

$$count_i \sim Poisson(\lambda_i)$$

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count data

What is the model?

$$count_i \sim Poisson(\lambda_i A_{search})$$

$$log(\lambda_i) = \alpha + \beta * TreeCover_i$$

50 m search radius = A_search

count data

What is the model?

Equivalent to:

$$count_i \sim Poisson(\lambda_i)$$

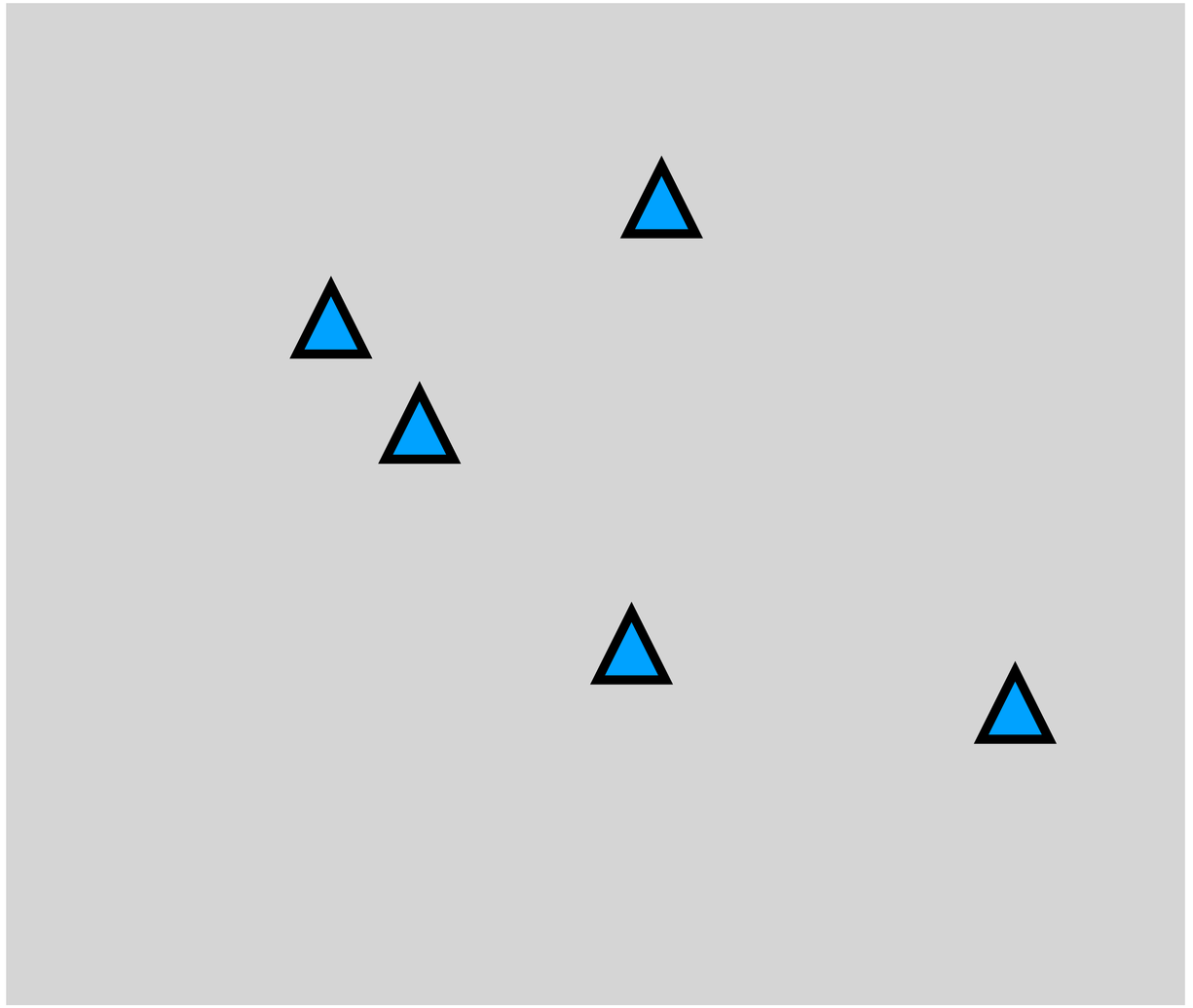
$$log(\lambda_i) = \alpha + \beta * TreeCover_i + log(A_{search})$$

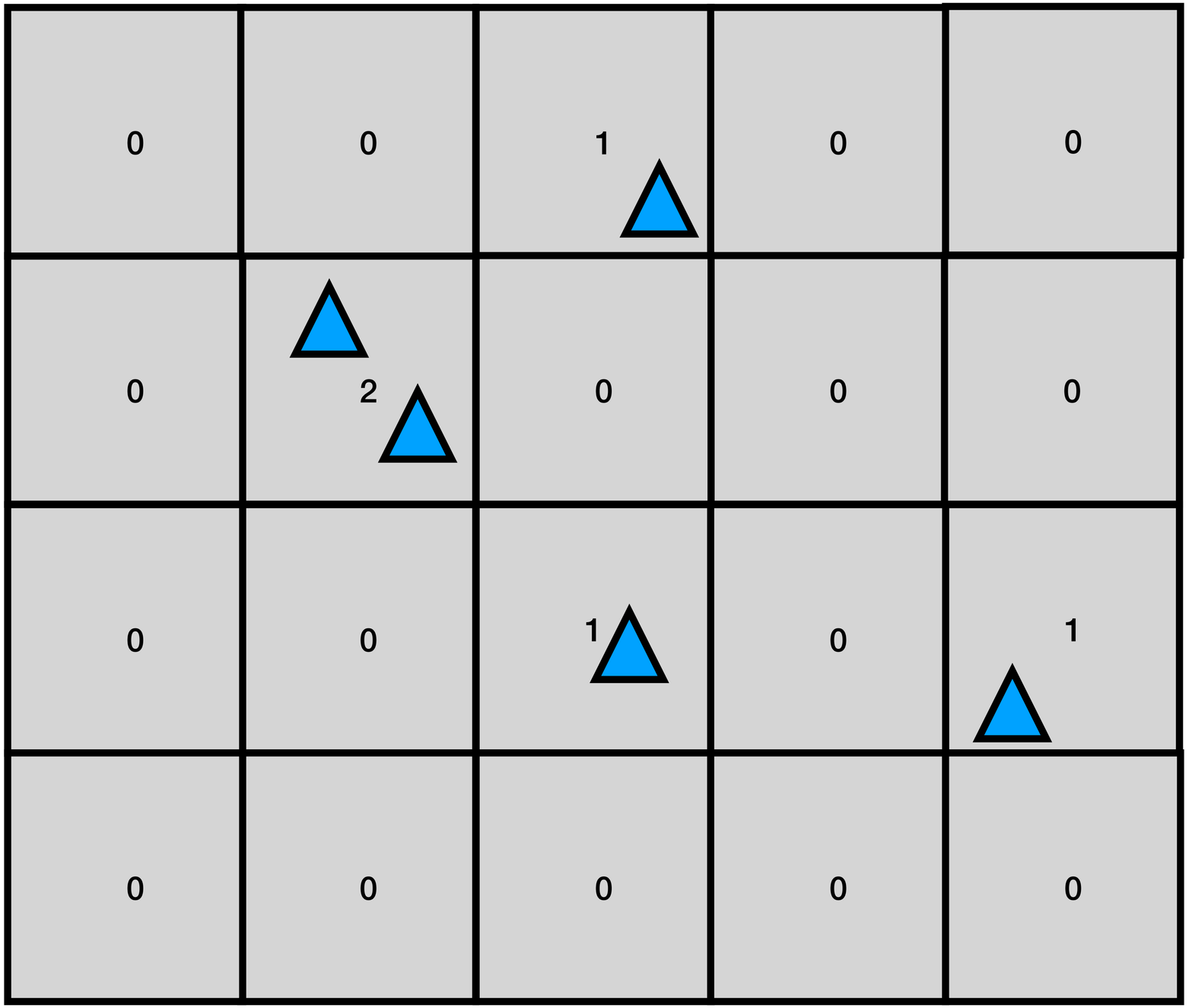
opportunistic observation

What is the model?

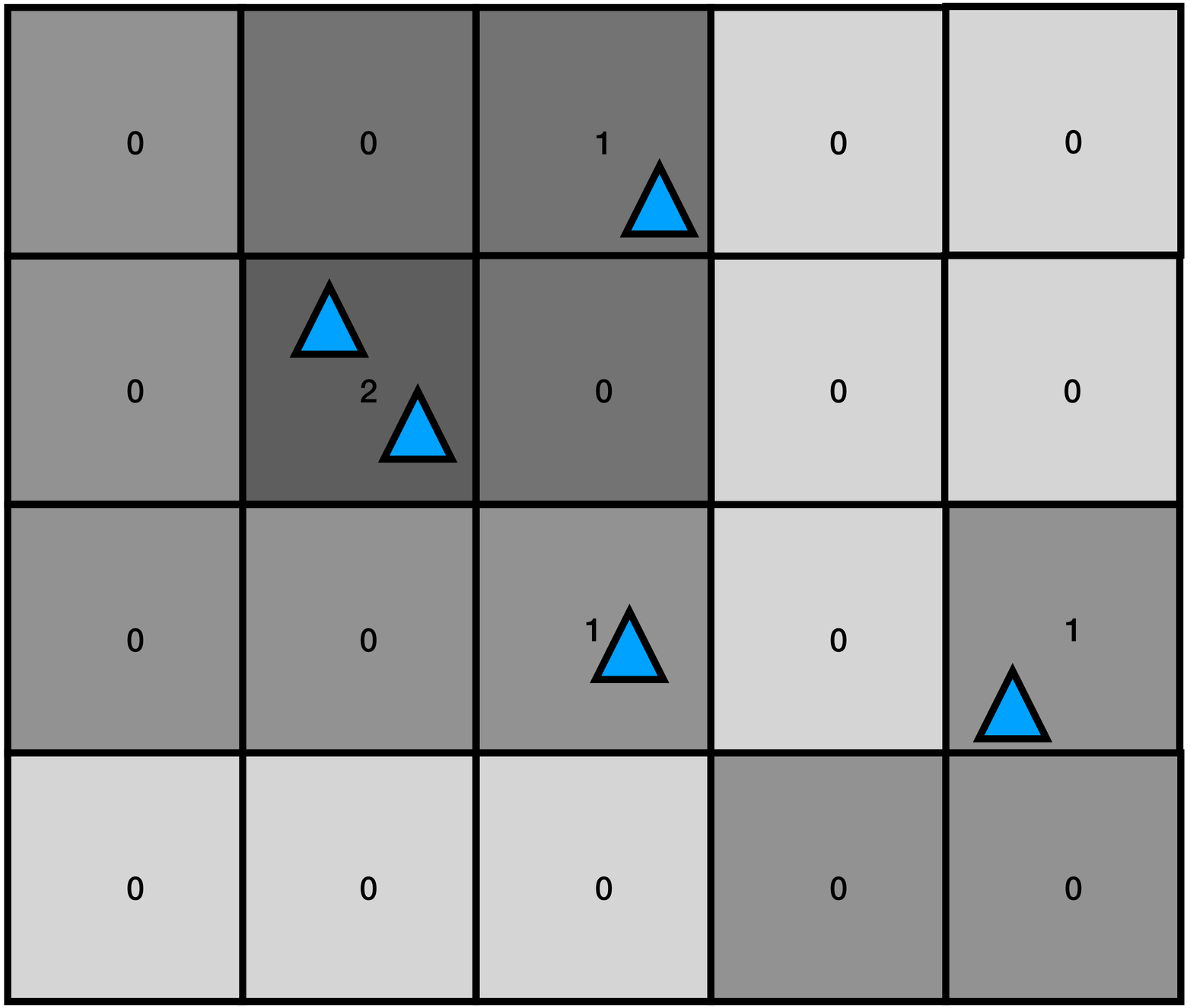
$$po \sim IPPP\big(\lambda(s)b(s)\big)$$

How to fit IPP to point data (cellwise count method)




0
0
1
0
0
0
2
0
0
0
0
0
1
0
1
0
0
0
0
0

J = 20



opportunistic observation

What is the model?

$$po \sim IPP\left(\lambda(s)b(s)\right)$$

$$po_j \sim Poisson\left(\lambda_j b_j A_j\right)$$

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$$po \sim IPP\left(\lambda(s)b(s)\right)$$

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opportunistic observation

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$$log(\lambda_j) = \alpha + \beta * TreeCover_j$$

$$log(b_j) = \alpha_{bias} + \beta_{bias} CityAccess_j$$

opportunistic observation

What is the model?

$$po \sim IPP\big(\lambda(s)b(s)\big)$$

Equivalent to:

$$po_j \sim Poisson\big(\Lambda_j A_j\big)$$

$$log(\Lambda_j) = \alpha + \beta * TreeCover_j + \alpha_{bias} + \beta_{bias} CityAccess_j$$

site occupancy

What is the model?

$$occ_k \sim Bernoulli(\psi_k)$$

$$det_k | occ_k \sim Bernoulli(occ_k p_k)$$

site occupancy

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In this case, we are assuming perfect detection $p_k = 1$

site occupancy

so we are modelling ψ_k instead of p_k

What is the model?

$$occ_k \sim Bernoulli(\psi_k)$$

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$$\psi_k = 1 - e^{-Abund_k}$$

site occupancy

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"cloglog" link

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site occupancy

What is the model?

$$Scat_k \sim Bernoulli(\psi_k)$$

$$ScatDet_k | Scat_k \sim Bernoulli(Scat_k p_k)$$

$$\psi_k = 1 - e^{-AbundScat_k}$$

But we are modelling scats not possums directly

$$AbundPossum_k = \lambda_k * A_{search}$$

$$\lambda_k = \alpha + \beta * TreeCover_k$$

site occupancy

What is the model?

$$Scat_k \sim Bernoulli(\psi_k)$$

$$ScatDet_k | Scat_k \sim Bernoulli(Scat_k p_k)$$

$$\psi_k = 1 - e^{-AbundScat_k}$$

So we need the link between possum abundance and abidance of scats

$$AbundScat_k = \alpha_{ScatDet} * AbundPossum_k$$

$$AbundPossum_k = \lambda_k * A_{ScatDet}$$

$$\lambda_k = \alpha + \beta * TreeCover_k$$

We do not need to fit these in JAGS, can be fit in glm framework, but we want to make the maths explicit.

Over to the code....

Thank you!

More reading:

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Guillera-Arroita, G. (2017), Modelling of species distributions, range dynamics and communities under imperfect detection: advances, challenges and opportunities. Ecography, 40: 281-295. https://doi.org/10.1111/ecog.02445

Nick J.B. Isaac, Marta A. Jarzyna, Petr Keil, Lea I. Dambly, Philipp H. Boersch-Supan, Ella Browning, Stephen N. Freeman, Nick Golding, Gurutzeta Guillera-Arroita, Peter A. Henrys, Susan Jarvis, José Lahoz-Monfort, Jörn Pagel, Oliver L. Pescott, Reto Schmucki, Emily G. Simmonds, Robert B. O'Hara. 2020. Data Integration for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution, 35:1, 56-67, https://doi.org/10.1016/j.tree.2019.08.006.

Simmonds, E.G., Jarvis, S.G., Henrys, P.A., Isaac, N.J.B. and O'Hara, R.B. (2020), Is more data always better? A simulation study of benefits and limitations of integrated distribution models. Ecography, 43: 1413-1422. https://doi.org/10.1111/ecog.05146

THE UNIVERSITY OF MELBOURNE

Quantitative & Applied Ecology Group

Australian Government
National Health and Medical Research Council

Atlas of Living Australia
sharing biodiversity knowledge