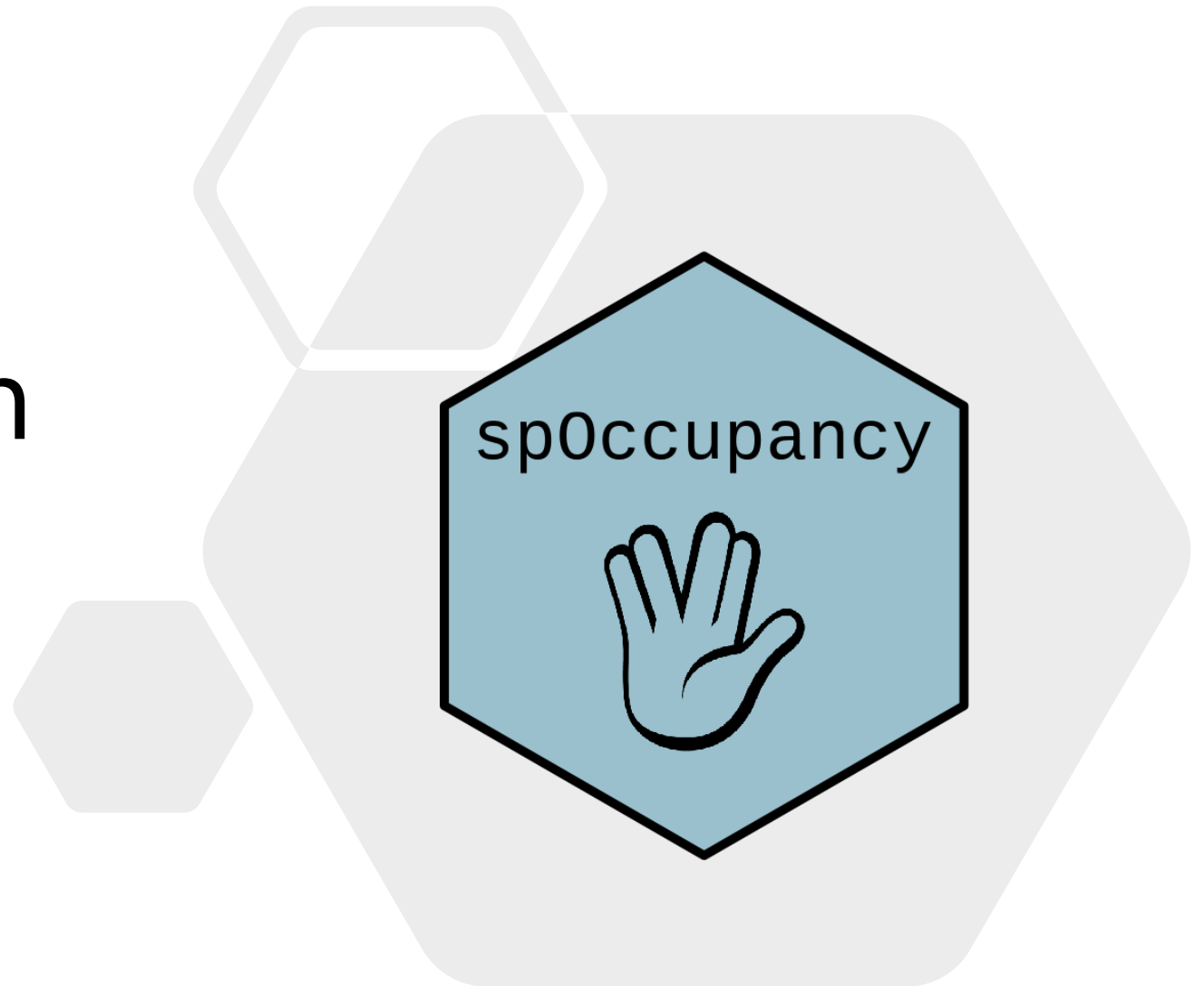


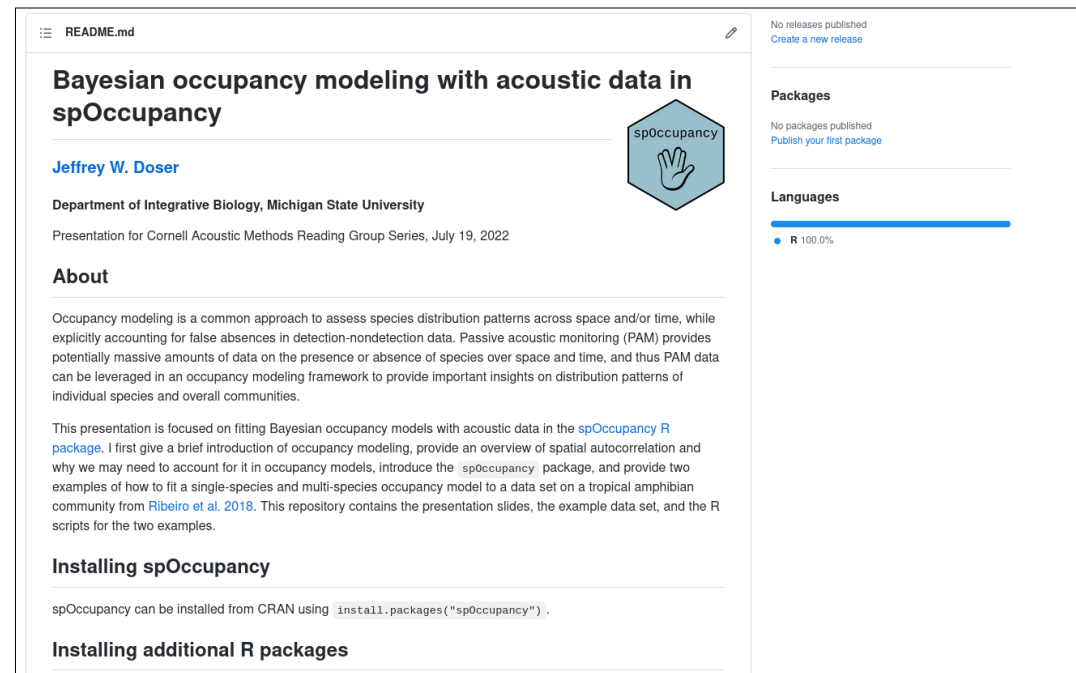
Bayesian occupancy modeling with acoustic data in spOccupancy

Jeff Doser
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Cornell Acoustic Methods
Working Group
July 19, 2022



Overview

- Occupancy modeling in passive acoustics
- Overview of spatial autocorrelation
- spOccupancy syntax and example
 - Single-species modeling
 - Multi-species modeling

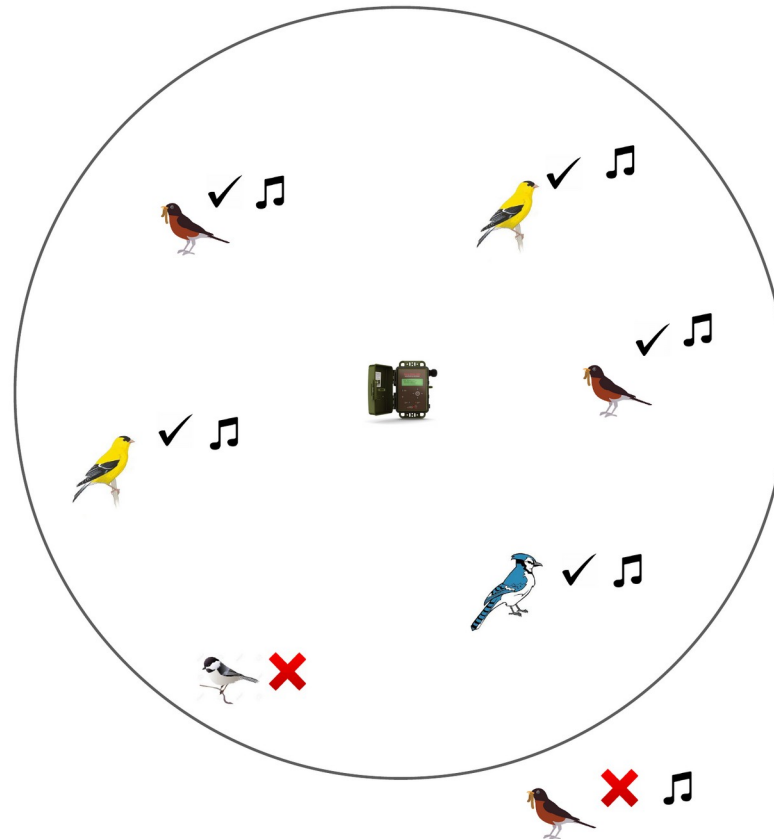


<https://github.com/doserjef/acoustic-spOccupancy-22>

Motivation

- Goal: understand occupancy patterns/dynamics across space and/or time of one (or more) species
 - More broadly: where do species occur in both space and how does this change over time?
 - Relevant for ecological theory, conservation, management, etc.
- Two important complexities:
 1. Imperfect detection
 2. Spatial autocorrelation

Imperfect detection in passive acoustics



Data for occupancy modeling

Detection-nondetection matrix

Site	Survey 1	Survey 2	Survey 3	Survey 4
1	1	0	0	1
2	0	0	0	0
3	1	1	0	NA
4	1	NA	0	NA
5	0	1	1	1
6	0	0	0	1

- Basic idea: obtain repeated surveys at a given site to account for imperfect detection
- ARUs -> easy to obtain replicate surveys (i.e., multiple recordings per site)
- Assume no false positives

Occupancy model

Occupancy (ecological) sub-model

$$z_j \sim \text{Bernoulli}(\psi_j)$$
$$\text{logit}(\psi_j) = \beta_1 + \beta_2 \cdot X_{2,j} + \dots + \beta_r \cdot X_{r,j}$$

Detection (observation) sub-model

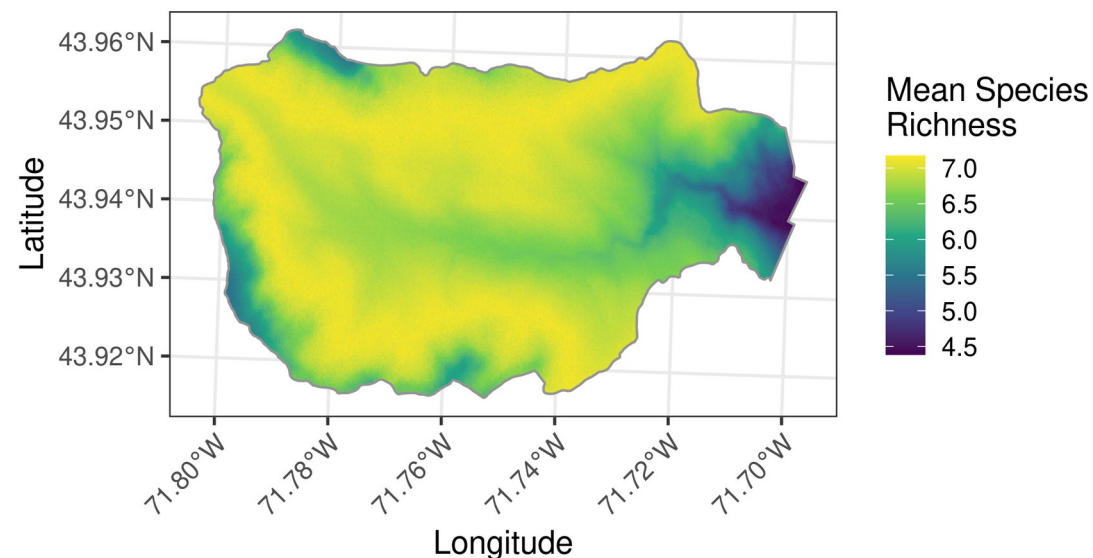
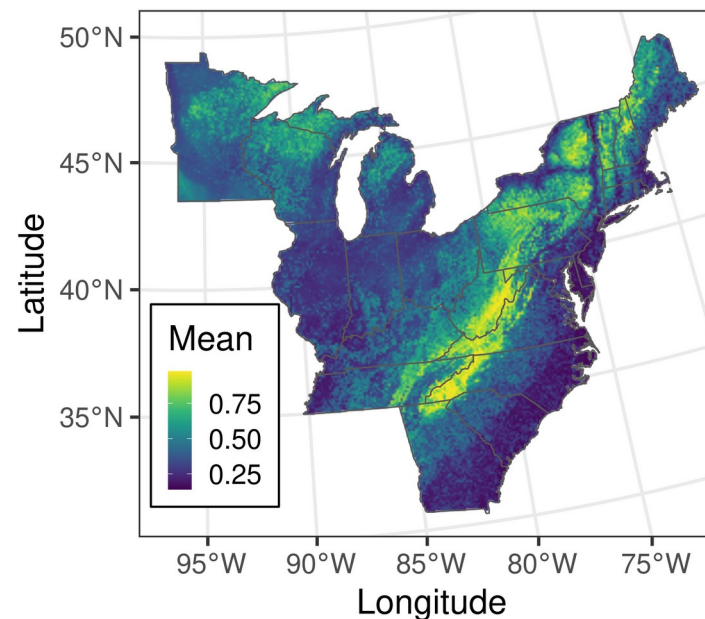
$$y_{j,k} \sim \text{Bernoulli}(p_{j,k} \cdot z_j)$$
$$\text{logit}(p_{j,k}) = \alpha_1 + \alpha_2 \cdot V_{2,j,k} + \dots + \alpha_r \cdot V_{r,j,k}$$

What if we're interested in multiple species?

- First approach: fit separate single-species occupancy models
 - Easy to do
 - Models are fast
 - Requires adequate sample size, often won't work for rare species
 - Does not directly estimate community-level parameters
- Alternative approach: Multi-species (community) occupancy model
 - Dorazio et al. (2005), Zipkin et al. (2009)
 - Estimates occupancy for multiple species simultaneously
 - Treats species as random effects -> more precise estimates
 - Allows occupancy estimation for rare species as a result of "borrowing strength"
 - Longer model run times

Spatial autocorrelation

- Things closer together in space tend to be more similar than things farther apart
- What leads to spatial autocorrelation in species distributions?
 - Shared use of environmental space
 - Underlying environmental drivers (e.g., elevation, climate) are spatially correlated
 - Dispersal
 - Conspecific attraction



How to account for spatial autocorrelation?

- Spatial covariates
 - Often sufficient, but may not always be available
- *Residual spatial autocorrelation*: spatial correlation in data *after* including spatial covariates
 - Missing covariates
 - Biotic factors (e.g., dispersal, conspecific attraction)
 - Use spatial random effects

Single-season spatial occupancy model

Occupancy (ecological) sub-model

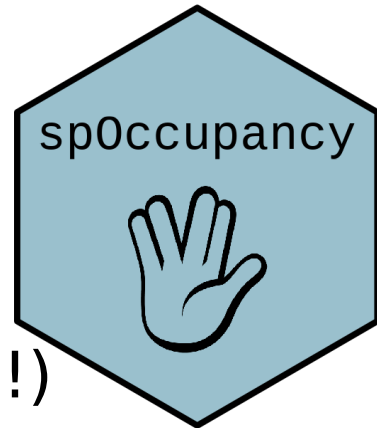
$$\begin{aligned}z_j &\sim \text{Bernoulli}(\psi_j) \\ \text{logit}(\psi_j) &= \beta_1 + \beta_2 \cdot X_{2,j} + \cdots + \beta_r \cdot X_{r,j} + w_j \\ w_j &\sim \text{Normal}(0, \Sigma)\end{aligned}$$

Detection (observation) sub-model

$$\begin{aligned}y_{k,j} &\sim \text{Bernoulli}(p_{j,k} \cdot z_j) \\ \text{logit}(p_{j,k}) &= \alpha_1 + \alpha_2 \cdot V_{2,j,k} + \cdots + \beta_r \cdot V_{r,j,k}\end{aligned}$$

spOccupancy

- Designed to fit Bayesian single-species and multi-species occupancy models
- Options to accommodate spatial autocorrelation (efficiently!)
- Workflow completely in R (no Bayesian programming languages necessary)
- Additional functionality:
 - Data integration
 - Species correlations
 - Multi-season (spatio-temporal) models (hot off the press!)



Benefits of Bayesian analysis

1. Interpretation
2. More flexible to accommodate spatial autocorrelation
3. Easy to extend to multi-species frameworks/integrate multiple data sources
4. Uncertainty
5. Ideal for complex data (e.g., highly correlated, multivariate)
6. Readily accommodate false positives from automated algorithms
 - Chambert et al. 2018, Doser et al. 2021, Rhinehart et al. 2022

Example data set: tropical amphibians

Ecological Applications, 28(6), 2018, pp. 1554–1564
© 2018 by the Ecological Society of America

- Data from Ribeiro Jr. Et al (2018)
Eco Apps
- 50 sites along a gradient of landscape characteristics
- 3 ARU recordings at each site (repeat surveys/visits)
- 36 amphibian species analyzed
- Focus on *Crossodactylus caramaschii*



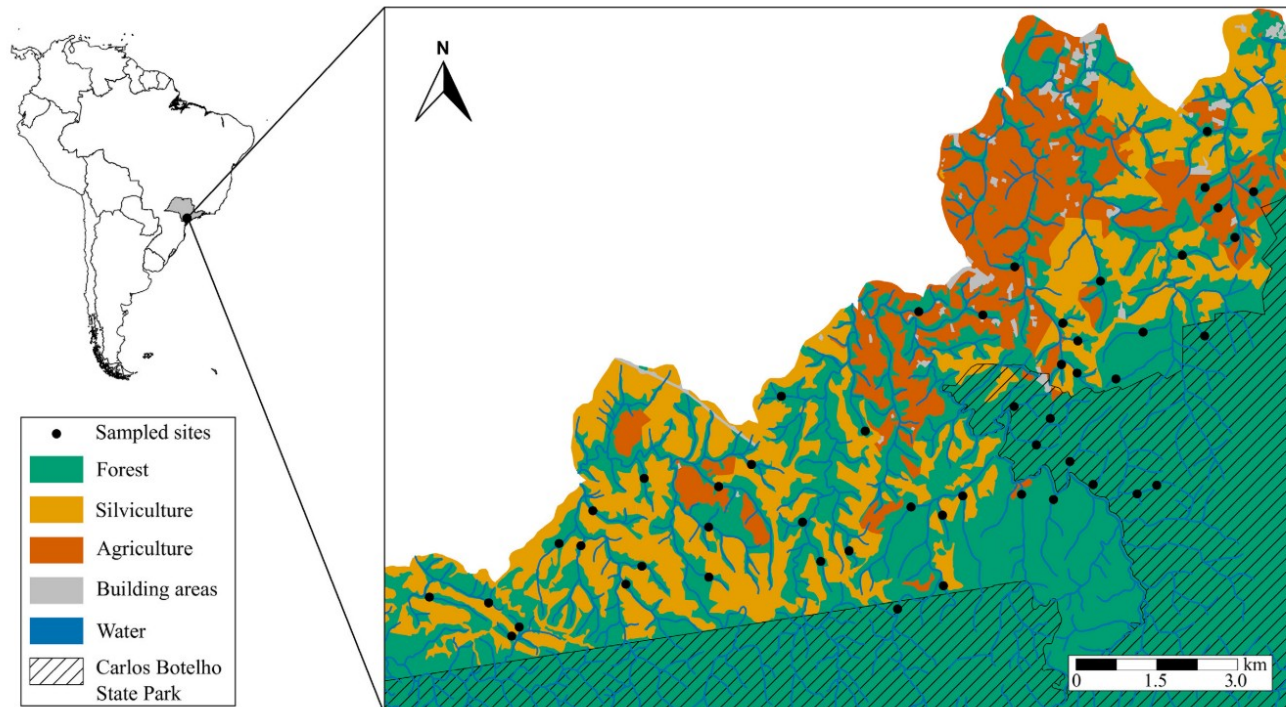
Effects of agriculture and topography on tropical amphibian species and communities

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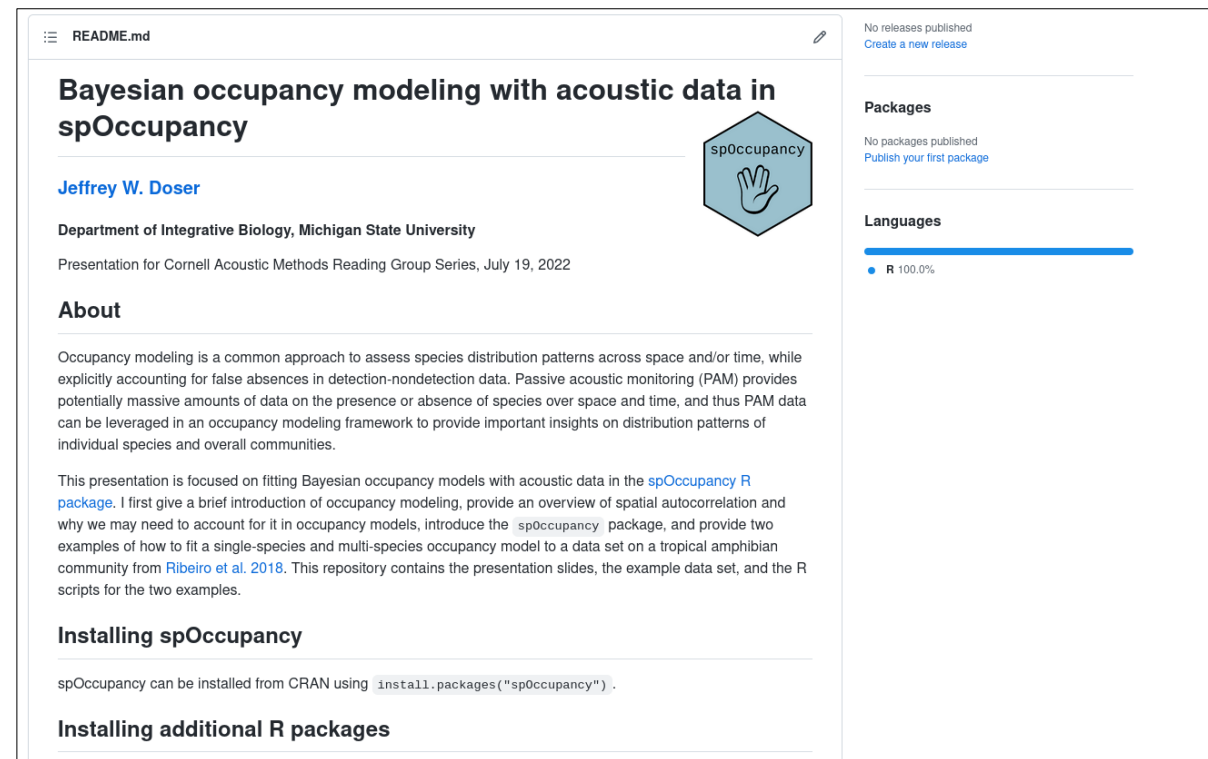


Ribeiro Jr. et al. (2018) *Eco Apps*

spOccupancy workflow

1. Data simulation/prep
2. Model fitting
3. Model validation
4. Model comparison
5. Posterior summaries
6. Prediction

Switch to RStudio



The screenshot shows the GitHub README for the `spOccupancy` package. The title is "Bayesian occupancy modeling with acoustic data in spOccupancy" by Jeffrey W. Doser, from the Department of Integrative Biology at Michigan State University. The README includes an "About" section explaining that occupancy modeling is used to assess species distribution patterns from passive acoustic monitoring (PAM) data. It also mentions that the presentation focuses on fitting Bayesian occupancy models with acoustic data in the `spOccupancy` R package. The "Installing spOccupancy" section shows the command to install the package from CRAN: `install.packages("spOccupancy")`. The "Installing additional R packages" section is partially visible. On the right side of the README, there are sections for "Packages" (No packages published) and "Languages" (R 100.0%).

README.md

Bayesian occupancy modeling with acoustic data in spOccupancy

Jeffrey W. Doser

Department of Integrative Biology, Michigan State University

Presentation for Cornell Acoustic Methods Reading Group Series, July 19, 2022

About

Occupancy modeling is a common approach to assess species distribution patterns across space and/or time, while explicitly accounting for false absences in detection-nondetection data. Passive acoustic monitoring (PAM) provides potentially massive amounts of data on the presence or absence of species over space and time, and thus PAM data can be leveraged in an occupancy modeling framework to provide important insights on distribution patterns of individual species and overall communities.

This presentation is focused on fitting Bayesian occupancy models with acoustic data in the [spOccupancy R package](#). I first give a brief introduction of occupancy modeling, provide an overview of spatial autocorrelation and why we may need to account for it in occupancy models, introduce the `spOccupancy` package, and provide two examples of how to fit a single-species and multi-species occupancy model to a data set on a tropical amphibian community from [Ribeiro et al. 2018](#). This repository contains the presentation slides, the example data set, and the R scripts for the two examples.

Installing spOccupancy

spOccupancy can be installed from CRAN using `install.packages("spOccupancy")`.

Installing additional R packages

No releases published
[Create a new release](#)

Packages

No packages published
[Publish your first package](#)

Languages

R 100.0%

spOccupancy resources

spOccupancy 0.4.0

Reference


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Articles



Fit occupancy models

[Introduction to spOccupancy](#)
Learn how to get started with the core spOccupancy functionality

[Formatting data for use in spOccupancy](#)
Learn how to format raw data to fit occupancy models in spOccupancy

[Joint species distribution models with imperfect detection in spOccupancy](#)
Learn how to account for species correlations within multi-species occupancy models

[Multi-season occupancy models for assessing species trends and spatio-temporal occurrence patterns \(PDF\)](#)
[Multi-season occupancy models for assessing species trends and spatio-temporal occurrence patterns](#)
Learn how to fit multi-season occupancy models in spOccupancy

[Fitting occupancy models with random intercepts in spOccupancy](#)
Learn how to include random effects in spOccupancy

MCMC sampler details

[MCMC samplers for models fit in spOccupancy \(PDF\)](#)
[MCMC samplers for joint species distribution models in spOccupancy \(PDF\)](#)

On this page

[Fit occupancy models](#)


[MCMC sampler details](#)

- [Package Website](#)
- [GitHub development page](#)
- [MEE intro paper](#)
- [arXiv preprint](#)
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DOI: 10.1111/2041-210X.13897


APPLICATION



spOccupancy: An R package for single-species, multi-species, and integrated spatial occupancy models

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Joint species distribution models with imperfect detection for

high-dimensional spatial data 

Jeffrey W. Doser^{1, 2}, Andrew O. Finley^{2, 3}, Sudipto Banerjee⁴

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Andy Finley



Elise Zipkin



Marc Kéry



Sudipto Banerjee

Data: [José Wagner Ribeiro Jr.](#)



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Thank you!