Bayesian occupancy modeling with acoustic data in spOccupancy

Jeff Doser

Michigan State University

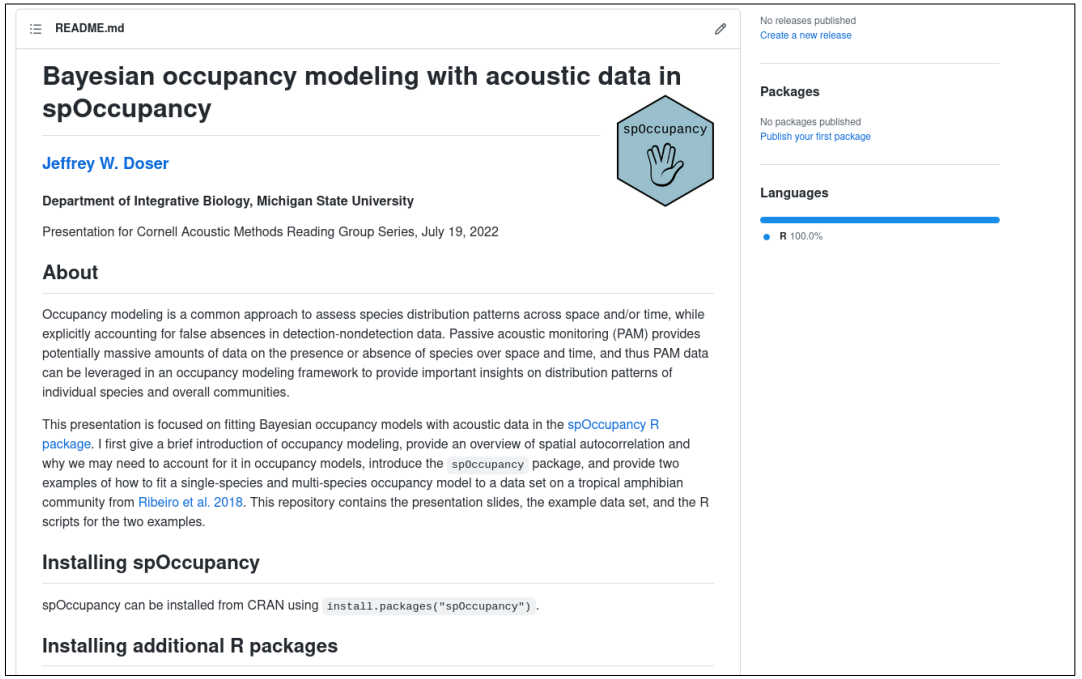
Cornell Acoustic Methods Working Group

July 19, 2022

@jeffdoser18

Overview

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



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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.

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Languages

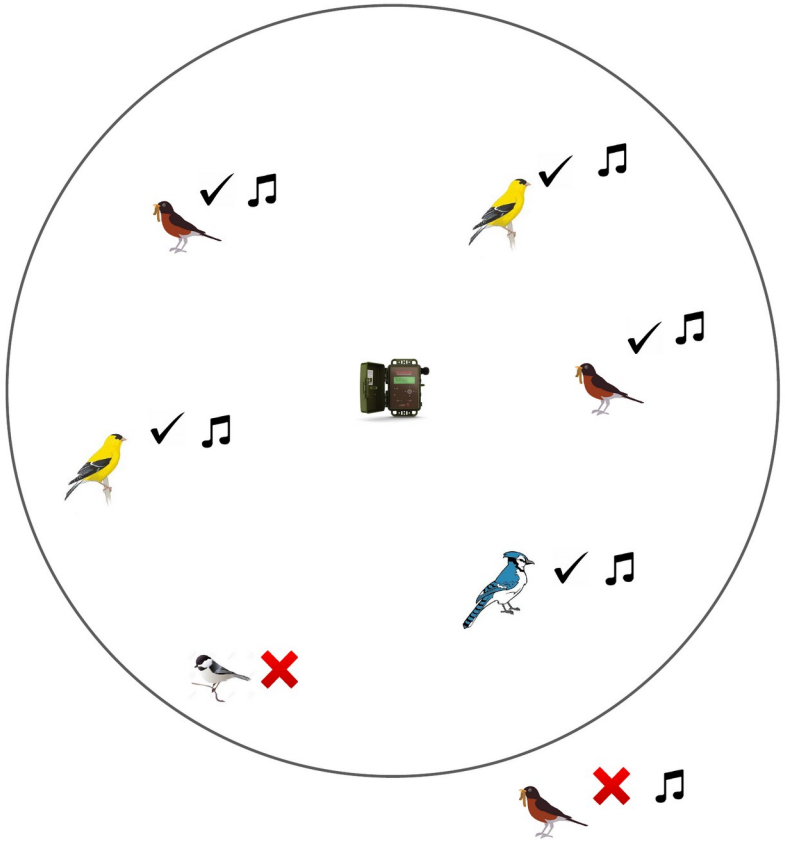
R 100.0%

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

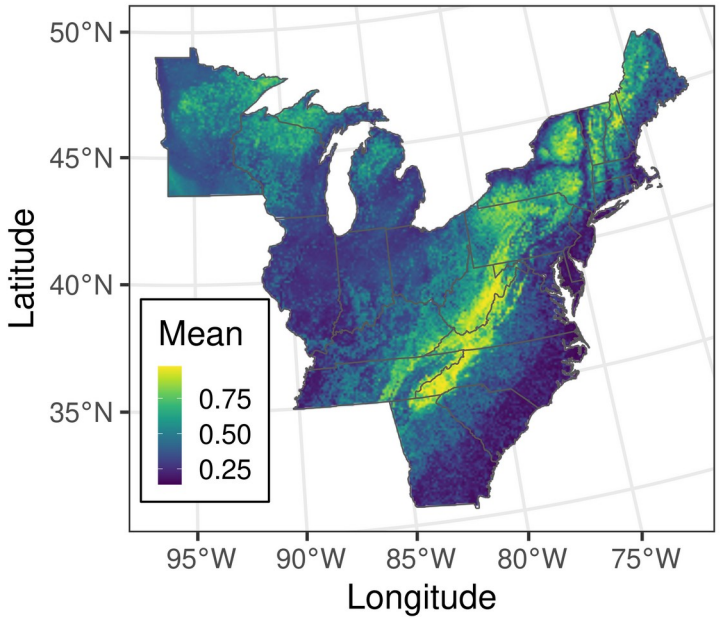
$$z_j \sim \text{Bernoulli}(\psi_j)$$
$$\text{logit}(\psi_j) = \beta_1 + \beta_2 \cdot X_{2,j} + \cdots + \beta_r \cdot X_{r,j}$$

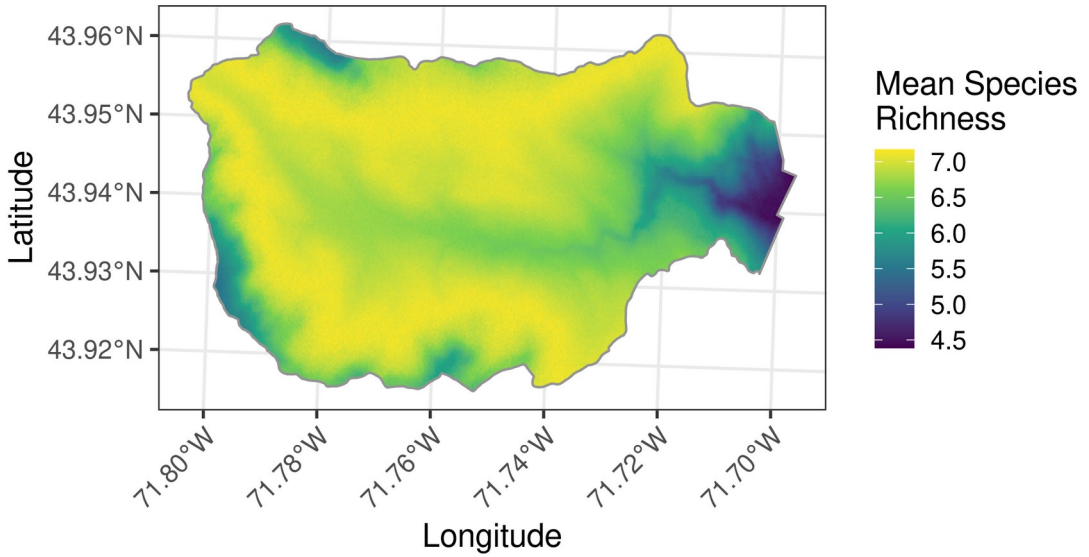
Detection (observation) sub-model

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

Spatial autocorrelation

- Things closer together in space tend to be more similar than things farther apart
- What leads to spatial autocorrelation in species distributions?
  - Environmental drivers
  - Biotic factors (e.g., dispersal, conspecific attraction)
- Residual spatial autocorrelation: spatial correlation in estimates *after* including spatial covariates
  - Account for using spatial random effects





Doser et al. (2022)

Single-season spatial occupancy model

Occupancy (ecological) sub-model

$$z_j \sim \text{Bernoulli}(\psi_j)$$
$$\text{logit}(\psi_j) = \beta_1 + \beta_2 \cdot X_{2,j} + \cdots + \beta_r \cdot X_{r,j} + \text{w}_j$$
$$\text{w}_j \sim \text{Normal}(0, \boldsymbol{\Sigma})$$

Detection (observation) sub-model

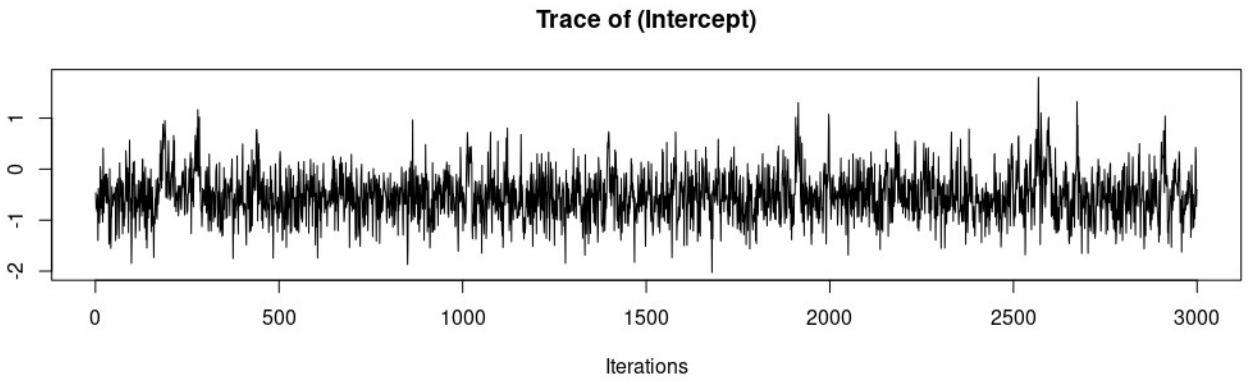
$$y_{k,j} \sim \text{Bernoulli}(p_{j,k} \cdot z_j)$$
$$\text{logit}(p_{j,k}) = \alpha_1 + \alpha_2 \cdot V_{2,j,k} + \cdots + \beta_r \cdot V_{r,j,k}$$

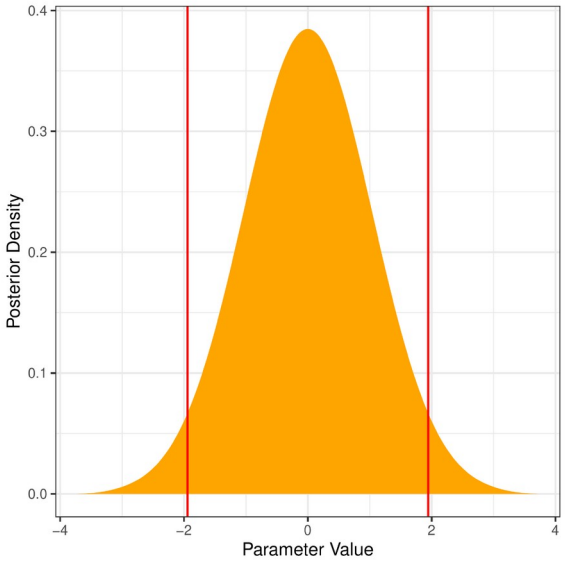
spOccupancy

- 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!)

Bayesian computation: MCMC

- Markov Chain Monte Carlo (MCMC) sampling
  - Produces a sequence of dependent, random numbers
  - Eventually converges towards the posterior distribution
  - Posterior distribution: what we use to get parameter estimates, get credible intervals, etc.





Bayesian computation: MCMC

- What do you need to specify?
  - Priors
  - Initial values
  - Number of samples/iterations
  - Burn-in: initial part of the chain that we throw away
  - Thinning rate: how often do you want to save a sample?
- How to determine convergence?
  - Run multiple chains with different starting values
  - If the chains eventually look the same, you can assume convergence

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

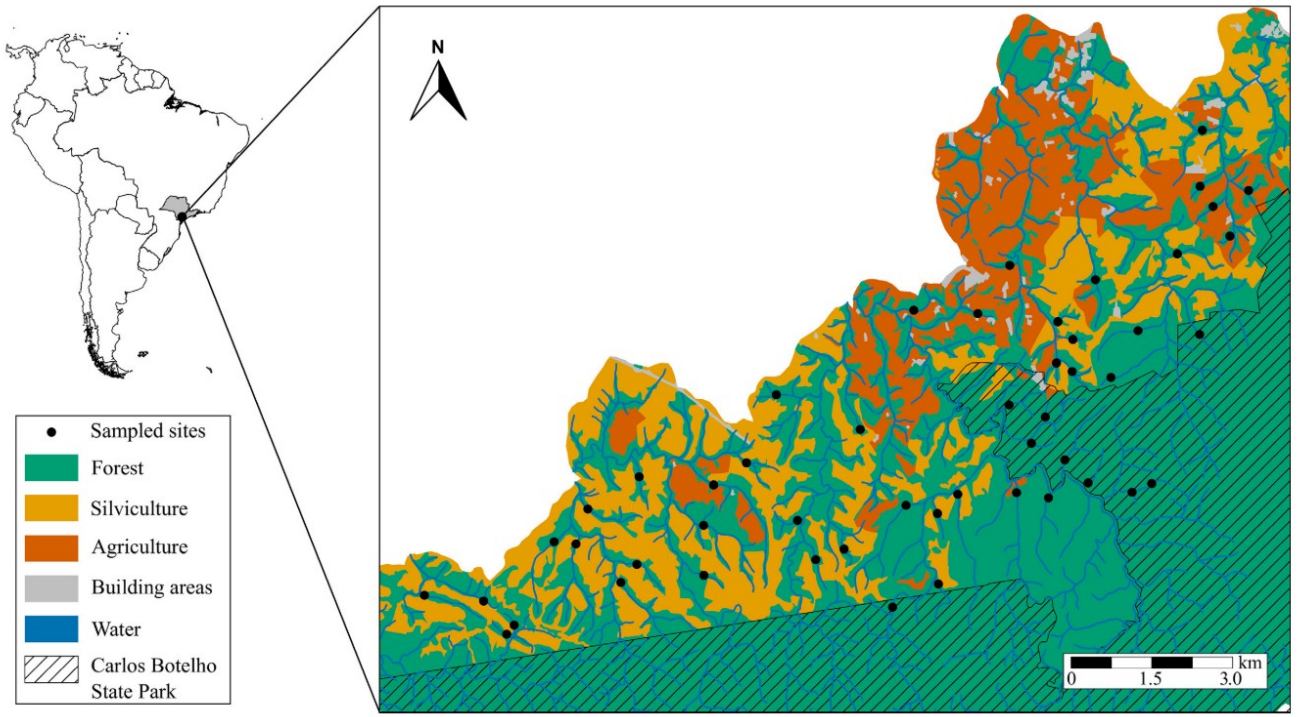
- Data from Ribeiro Jr. Et al (2018) *Eco Apps*
- 50 sites along a gradient of landscape characteristics
- 3 ARU recordings at each site (repeat surveys/visits)
- 36 amphibian species analyzed
- Focus on *Crossodactylus caramaschii*

Ecological Applications, 28(6), 2018, pp. 1554–1564

Effects of agriculture and topography on tropical amphibian species and communities

José Wagner Ribeiro, Jr.,[1,2,4] Tadeu Siqueira,[1] Gabriel Lourenço Brejão,[3] and Elise F. Zipkin[2]

[1]*Institute of Biosciences, São Paulo State University (Unesp), Avenida 24A 1515, Rio Claro, São Paulo 13506-900 Brazil*
[2]*Department of Integrative Biology and Ecology, Evolutionary Biology, and Behavior Program, East Lansing, Michigan 48824 USA*
[3]*Institute of Biosciences, Humanities and Exact Sciences, São Paulo State University (Unesp), Rua Cristóvão Colombo 2265, São José do Rio Preto, São Paulo 15054-000 Brazil*

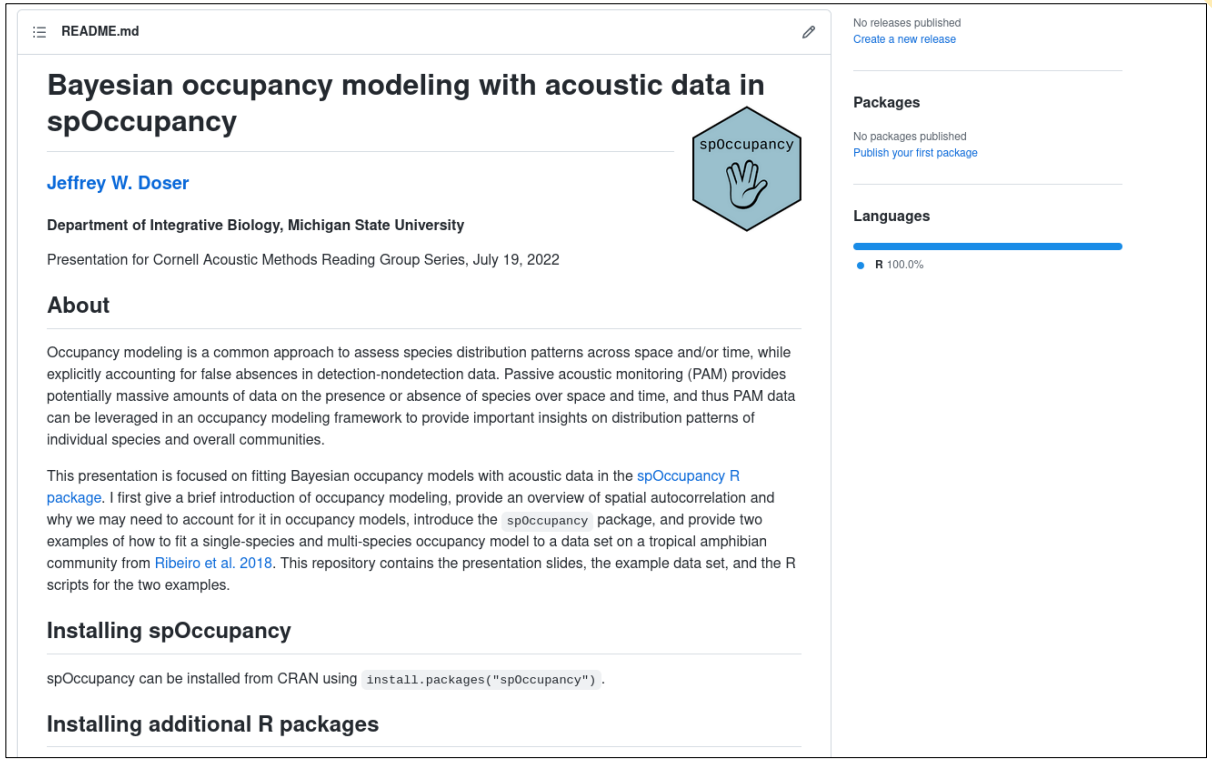


Ribeiro Jr. et al. (2018) *Eco Apps*

spOccupancy workflow

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

Switch to RStudio



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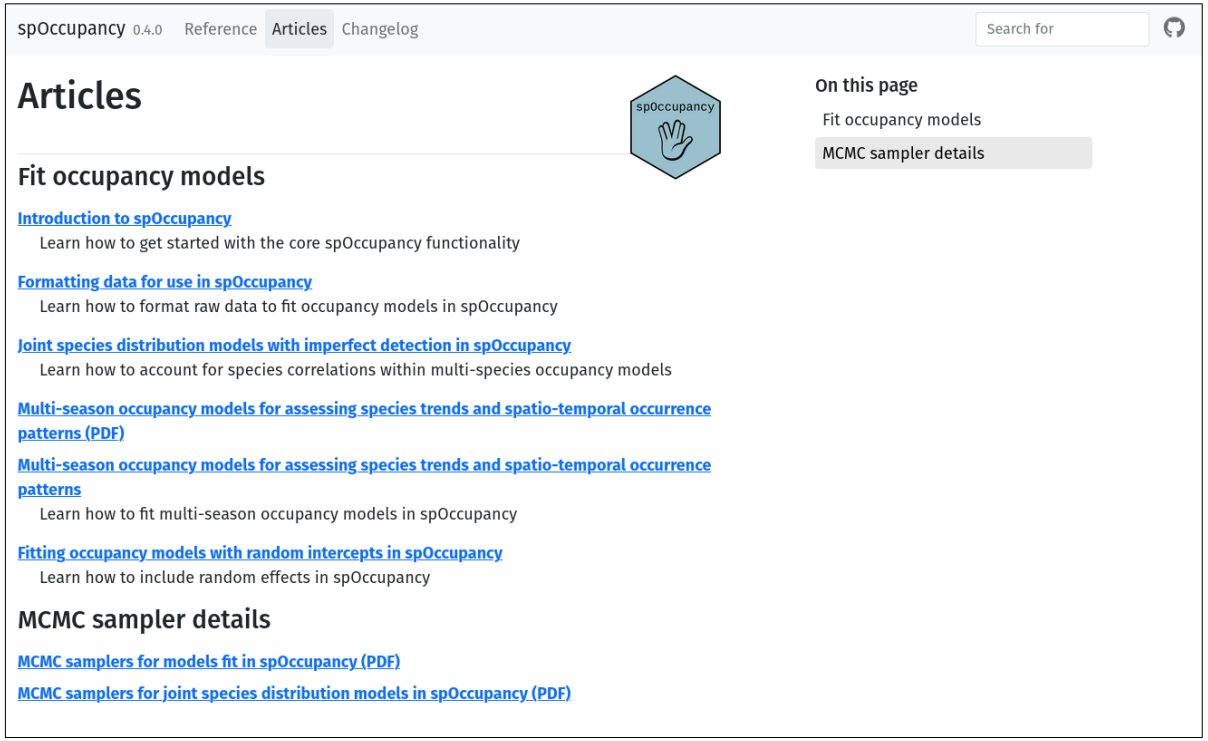
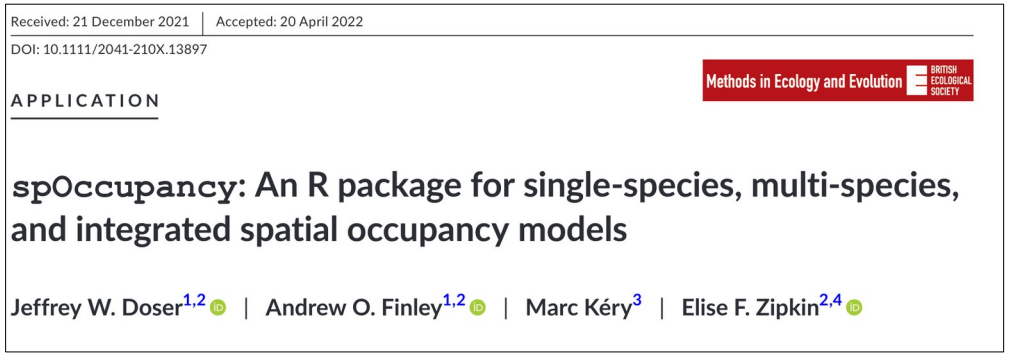
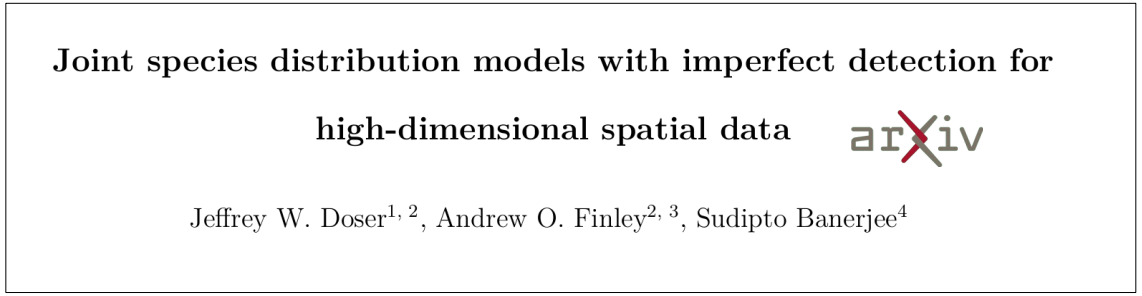


- Package Website
- GitHub development page
- MEE intro paper
- arXiv preprint
- @jeffdoser18
- Email: doserjef@msu.edu





Acknowledgments

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Thank you!