Bayesian occupancy modeling with acoustic data in spOccupancy

Jeff Doser

Michigan State University

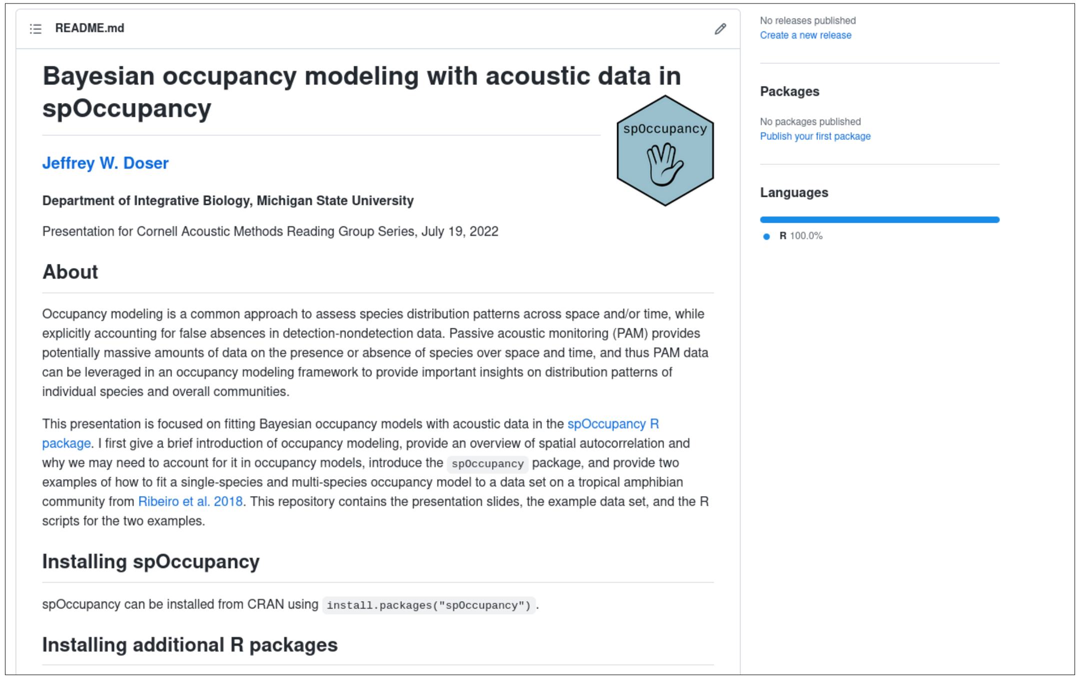
Cornell Acoustic Methods Working Group

July 19, 2022

@jeffdoser18

Overview

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



README.md

Bayesian occupancy modeling with acoustic data in spOccupancy

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

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Languages

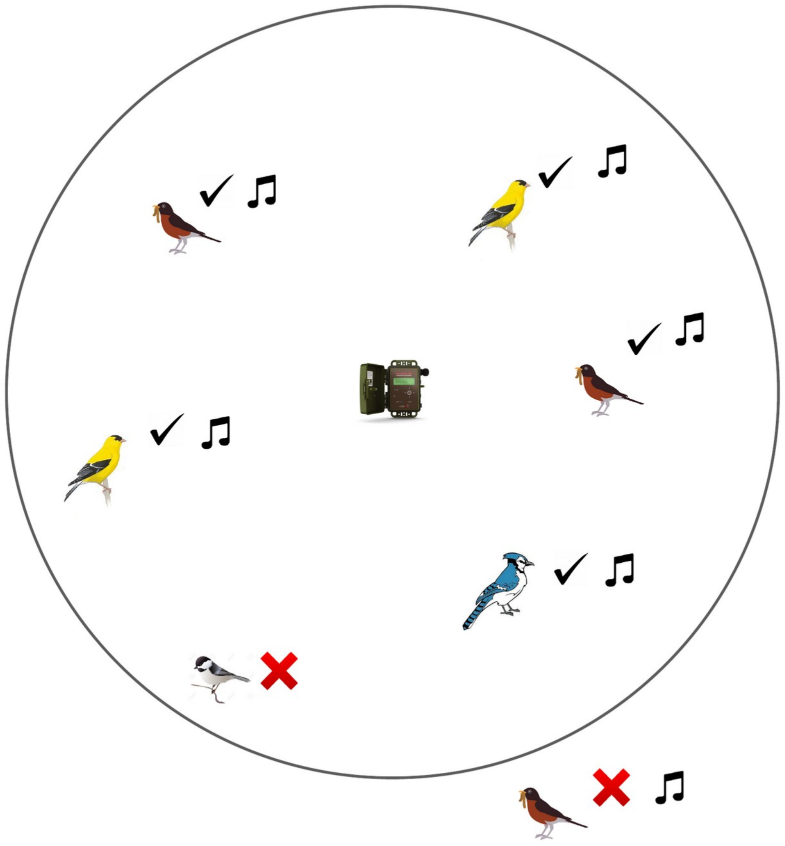
R 100.0%

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

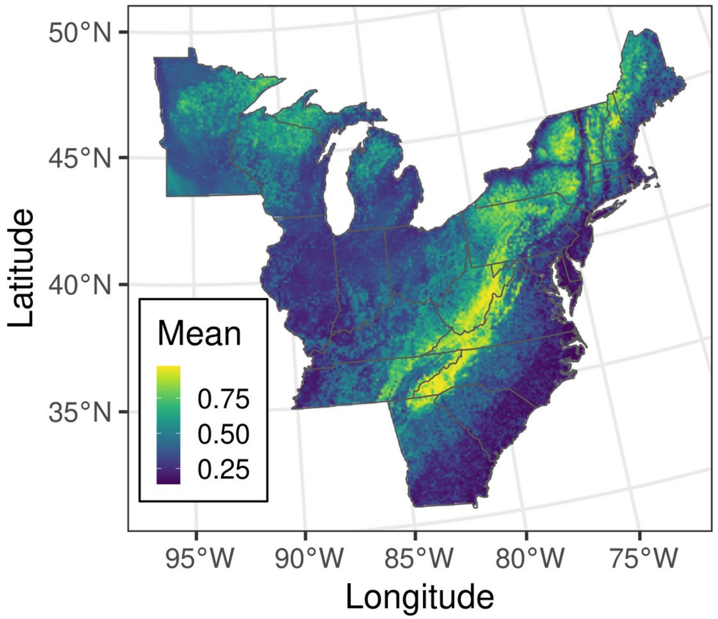
$$y_{j,k} \sim \text{Bernoulli}(p_{j,k} \cdot z_j)$$
$$\text{logit}(p_{j,k}) = \alpha_1 + \alpha_2 \cdot V_{2,j,k} + \cdots + \alpha_r \cdot V_{r,j,k}$$

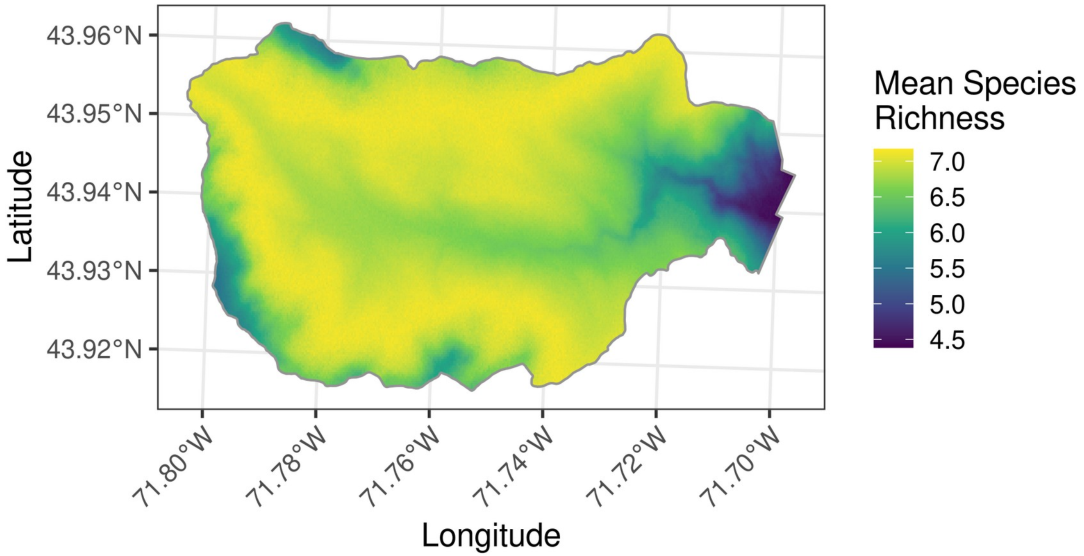
What if we're interested in multiple species?

- 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





Doser et al. (2022)

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

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

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!)

Why Bayesian for occupancy modeling?

1. Interpretation
2. More flexible to accommodate spatial autocorrelation
3. Easy to extend to multi-species frameworks/integrate multiple data sources
4. Uncertainty

Why Bayesian for acoustic data?

1. Ideal for complex data (e.g., highly correlated, multivariate)
2. Readily accommodate false positives from automated algorithms
   - Doser et al. 2021 MEE (abundance)
   - Chambert et al. 2018 MEE; Rhinehart et al. 2022 MEE (occupancy)
3. Easily handle missing values/unbalanced data
4. Prediction

Example data set: tropical amphibians

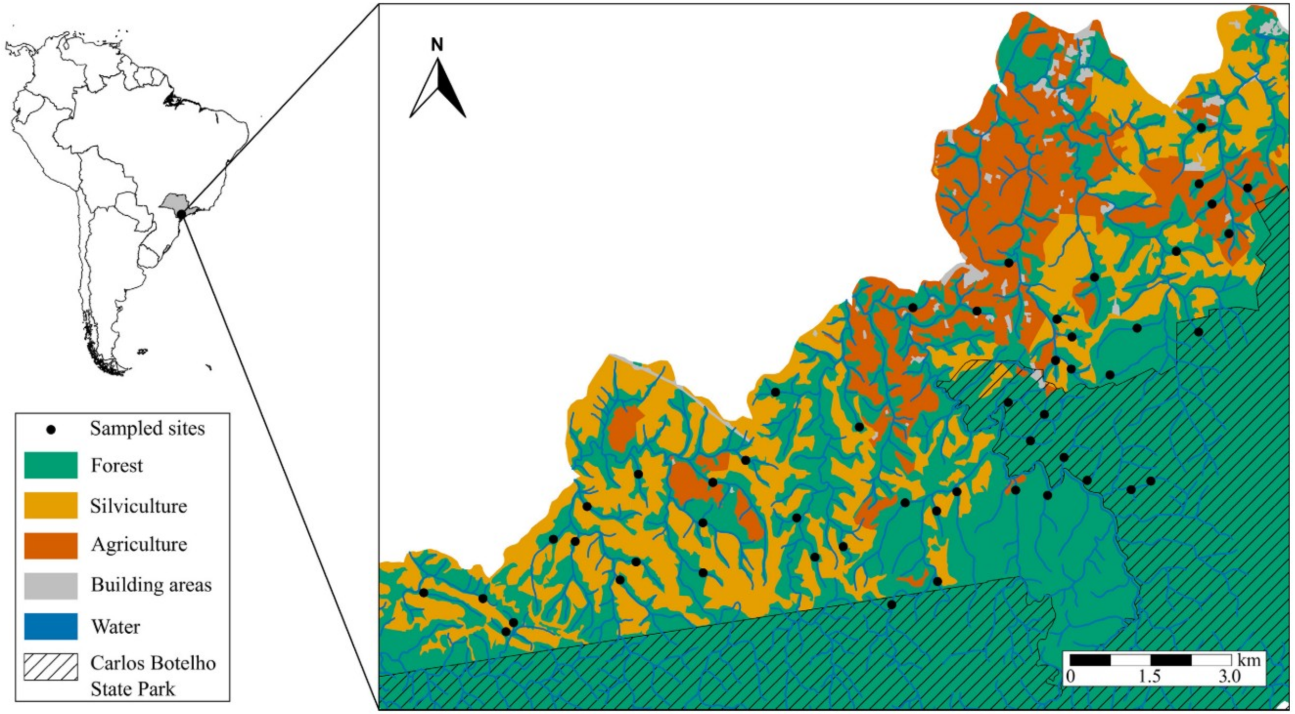
- Data from Ribeiro Jr. Et al (2018) *Eco Apps*
- 50 sites along a gradient of landscape characteristics
- 3 ARU recordings at each site (repeat surveys/visits)
- 36 amphibian species analyzed
- Focus on *Crossodactylus caramaschii*

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*

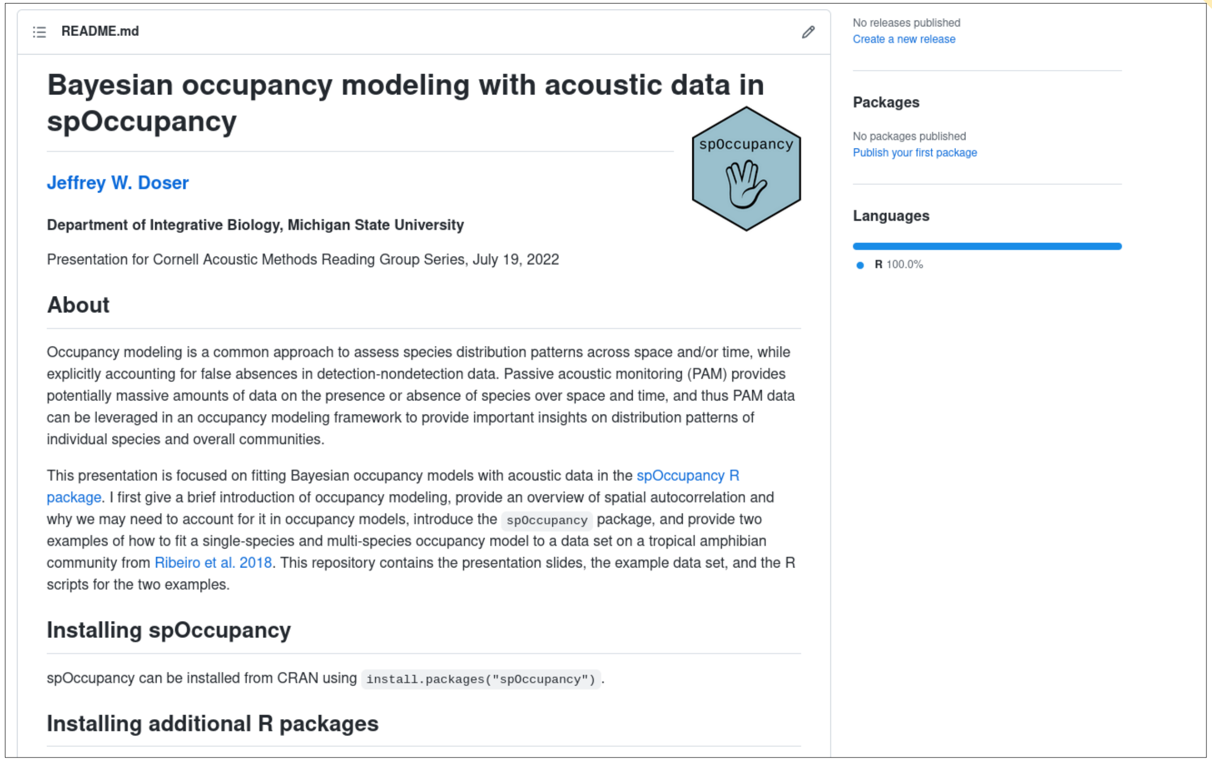


Ribeiro Jr. et al. (2018) *Eco Apps*

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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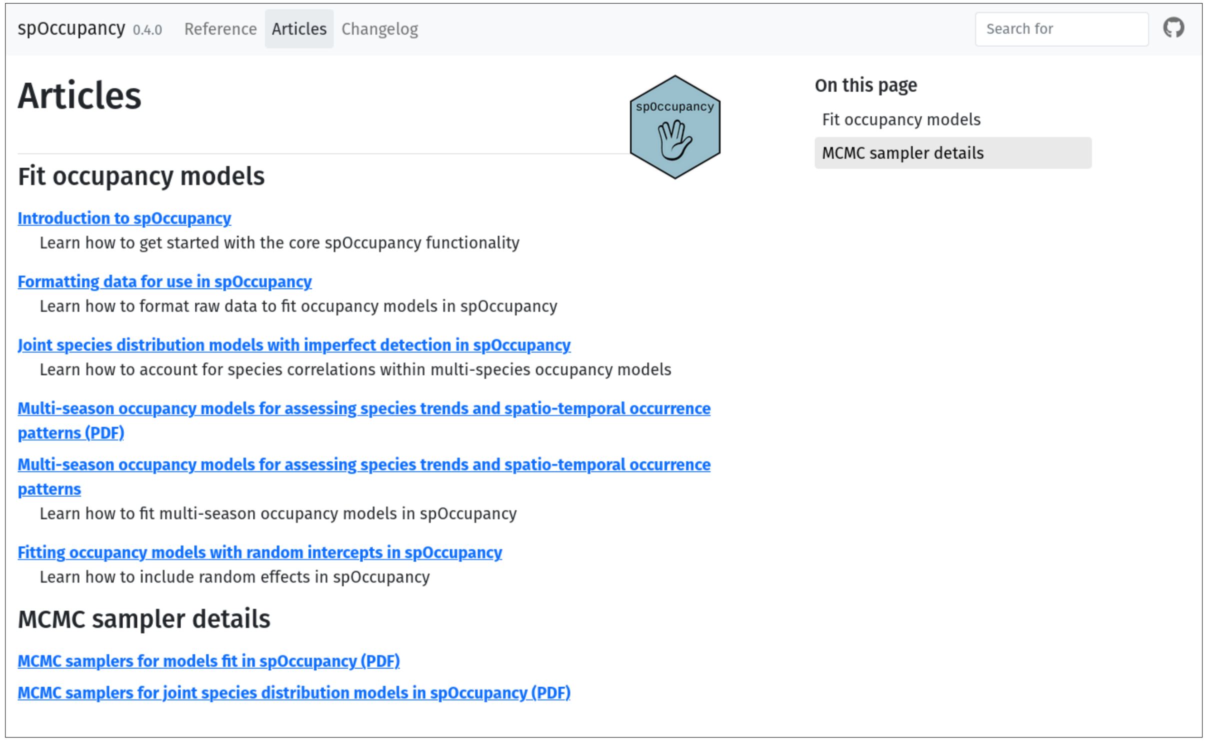


spOccupancy 0.4.0 Reference Articles Changelog Search for

Articles

On this page
Fit occupancy models
MCMC sampler details

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)

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

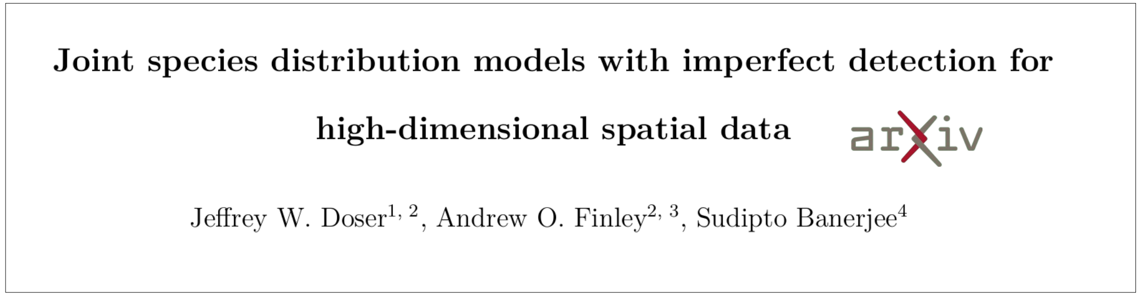
Received: 21 December 2021 | Accepted: 20 April 2022
DOI: 10.1111/2041-210X.13897

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

APPLICATION

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

Jeffrey W. Doser[1,2] | Andrew O. Finley[1,2] | Marc Kéry[3] | Elise F. Zipkin[2,4]



Joint species distribution models with imperfect detection for high-dimensional spatial data

arXiv

Jeffrey W. Doser[1, 2], Andrew O. Finley[2, 3], Sudipto Banerjee[4]

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Thank you!