birdnetTools 2.0: Linking BirdNET outputs to occupancy modeling in R

Sunny Tseng Connor M. Wood

2025-10-01

Executive Summary

Passive acoustic monitoring is transforming biodiversity research, allowing scientists to study birds across vast landscapes using audio recordings. Machine learning tools such as BirdNET can automatically identify thousands of species from audio recordings, but converting its outputs into the structured format required for occupancy modeling, a key method for estimating where species occur and how likely they are to be detected, remains a major hurdle. `birdnetTools 2.0` will remove this barrier by expanding the existing package to produce detection matrices compatible with widely used occupancy modeling R packages: `spOccupancy`, `unmarked`, and `ubms`. By streamlining data import, cleaning, validation, and preparation for modeling, this upgrade of `birdnetTools` will make it easier for researchers and conservationists to generate reproducible occupancy estimates from raw audio recordings. The project will also include step-by-step tutorials and example workflows, empowering ecologists to monitor bird populations at large scales and strengthening the R ecosystem for biodiversity science.

Signatories (project team)

Sunny (Yi-Chin) Tseng – PhD Candidate, University of Northern British Columbia

Sunny is an avian bioacoustic ecologist and the creator of `birdnetTools`, an R package for post-processing BirdNET output. Sunny's expertise combines bioacoustics and quantitative ecology to monitor bird communities at landscape scales. She has conducted bird acoustic research in Siberia, Taiwan, Canada, and Lithuania, collecting audio recordings from over 300 species. For this project, Sunny will lead package development, maintain the repository, and update functions and documentation based on user feedback.

Connor M. Wood – Research Faculty, Cornell Lab of Ornithology

Connor is a researcher with the K. Lisa Yang Center for Conservation Bioacoustics with the Cornell Lab of Ornithology. His research focuses on population ecology and conservation biology, and his team generally applies machine learning tools to extract biodiversity data from large-scale audio datasets. He has extensive experience developing and implementing bioacoustic tools to inform conservation strategies, and regularly uses BirdNET outputs as occupancy model inputs. For this project, Connor will provide expertise on occupancy modeling and statistical methods, ensuring the package outputs are ecologically relevant and meet the needs of end users.

The Problem

BirdNET is a leading algorithm for automated bird species identification from audio recordings, capable of recognizing over 6,000 species (Kahl et al. 2021). R packages such as `birdnetR` for running BirdNET (Günther and BirdNET Team 2025) and `birdnetTools` for post-processing outputs (Tseng and BirdNET Team 2025) already streamline acoustic analyses. A key application of BirdNET results is occupancy modeling, which estimates species occurrence and detectability (Wood, Cruz, and Kahl 2023). However, occupancy packages in R, such as `unmarked` (Fiske and Chandler 2011), `ubms` (Kellner et al. 2021), and `spOccupancy` (Doser et al. 2022), require tightly structured detection matrices that are difficult to prepare from BirdNET's raw predictions. This formatting hurdle slows analysis and discourages ecologists who lack advanced programming skills.

Enhancing birdnetTools to directly convert BirdNET predictions into model-ready detection matrices will fill this gap, enabling researchers and conservation practitioners to move efficiently from raw audio to reproducible occupancy estimates.

The proposal

Overview

`birdnetTools 2.0` will streamline the workflow from BirdNET outputs to occupancy models in R (Figure 1 A). The package will produce the **detection matrix**, a (site × survey) matrix indicating species presence (1), absence (0), or missing data (NA), ready for use in `spOccupancy`, `unmarked`, and `ubms`. Building on existing functions for data import, cleaning, and validation, new core functions (e.g., `birdnet_det_mat()`) will extract site and survey information, aggregate detections, and reshape outputs into the formats required by

these occupancy packages (Figure 1 B). Example vignettes will guide users through end-to-end analyses, from BirdNET predictions to occupancy modeling results, with minimal additional coding.

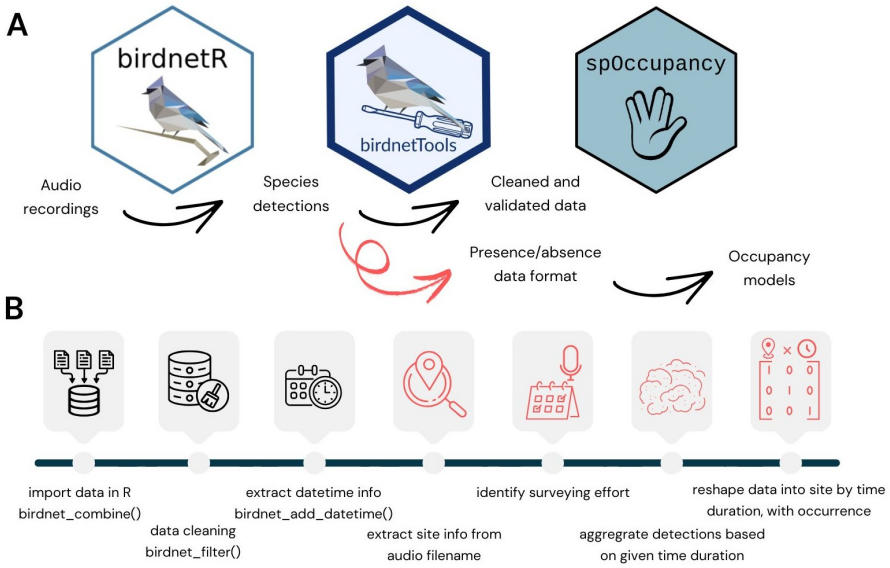

Figure 1: Workflow from raw audio files to occupancy models. Black arrows and graphics represent the current workflow, while red text and arrows indicate the proposed extensions for the package expansion.

Minimum viable product and external dependencies

The minimum viable product will be a core function, `birdnet_det_mat()`, which converts BirdNET's long-format prediction tables into a site × survey **detection matrix**, the critical missing piece in the existing software ecosystem. This matrix will contain 1s (species detected above a specified confidence score), 0s (audio recorded but no qualifying detections), and NAs (no recording during that interval). That table, the **detection matrix**, can readily be ingested by `spOccupancy`, `unmarked`, or `ubms` (e.g., via functions `PGOcc()`, `occu()`, or `stan_occu()`, respectively).

`birdnetTools` relies on several R packages to support its core functionality, including `av`, `tuneR`, and `seewave` for audio processing, and `dplyr` for data wrangling. A full list of dependencies is available in the `DESCRIPTION` file of the `birdnetTools` repository.

Project plan

The project will run over five months, starting with setup and continuing through development, testing, and release:

- Month 1 – Start-up: Confirm open-source license (MIT) and set up the GitHub repository with contribution guidelines and issue templates. Establish reporting and feedback workflows, including bi-weekly check-ins, and draft the initial project roadmap.
- Months 2 & 3 – Development: Implement and test initial occupancy-specific functions in `birdnetTools` (minimum viable product).
- Month 4 – Workflows and vignettes: Create example analyses demonstrating end-to-end workflows from BirdNET outputs to occupancy models.
- Month 5 – Testing and release: Conduct community testing, refine functions and documentation, and prepare for package release.

Long-term, the package will be distributed via CRAN and/or the rOpenSci R-universe, and project outcomes will be communicated through R Consortium blog posts and community events (e.g., useR!, ISC meetings).

Budget & funding plan

Estimated costs are based on a five-month project divided into three deliverable-based milestones, calculated at an hourly rate of **USD 36/hour**.

Milestone	Deliverables	Hours (Sunny + Connor)	Estimated cost (USD)
Phase 1 Planning (2025 Dec.1 - 31)	Finalize data formats and function specs.	12 + 12	$864
Phase 2 Development (2026 Jan.1 - Mar.31)	Implement core functions, create example workflows.	80 + 16	$3,456
Phase 3 Testing & release (2026 Apr.1 - 30)	Conduct community testing, refine code and documentation	60 + 28	$3,168
Total		152 + 56 = 208	$7,488

Success

This project will be considered successful when `birdnetTools 2.0` provides a stable, CRAN-ready release that enables users to convert BirdNET output into detection matrices and fit occupancy models in `spOccupancy`, `unmarked`, or `ubms` with minimal additional coding. Success will be measured by (1) the release of the new core function(s) (e.g., `birdnet_det_mat()`) and accompanying vignettes, (2) positive feedback and reproducible test results from community beta testing, and (3) adoption of the new workflow by early users as demonstrated through GitHub issues, discussions, and citations.

Future work will be to develop additional functions that support occupancy model covariates. For example, a `birdnet_effort_mat()` function could generate a matrix with the same site × survey dimensions as the detection matrix but populated with the number of input audio files per interval. This "effort matrix" would provide a straightforward detection covariate for occupancy modeling.

References

Doser, Jeffrey W., Andrew O. Finley, Marc Kéry, and Elise F. Zipkin. 2022. "spOccupancy: An r Package for Single-species, Multi-species, and Multi-season Occupancy Models." *Methods in Ecology and Evolution* 13 (8): 1670–78. https://doi.org/10.1111/2041-210X.13897.

Fiske, Ian J., and Richard B. Chandler. 2011. "Unmarked: An r Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance." *Journal of Statistical Software* 43 (10): 1–23. https://doi.org/10.18637/jss.v043.i10.

Günther, Felix, and BirdNET Team. 2025. *birdnetR: Deep Learning for Automated (Bird) Sound Identification*. https://birdnet-team.github.io/birdnetR/.

Kahl, Stefan, Connor M. Wood, Maximilian Eibl, and Holger Klinck. 2021. "BirdNET: A Deep Learning Solution for Avian Diversity Monitoring." *Ecological Informatics* 61. https://doi.org/10.1016/j.ecoinf.2021.101236.

Kellner, Kenneth F., Nicholas L. Fowler, Tyler R. Petroelje, Todd M. Kautz, Dean E. Beyer Jr., and Jerrold L. Belant. 2021. "ubms: An R Package for Fitting Hierarchical Occupancy and n-Mixture Abundance Models in a Bayesian Framework." *Methods in Ecology and Evolution* 13: 577–84. https://doi.org/10.1111/2041-210X.13777.

Tseng, Sunny, and BirdNET Team. 2025. *birdnetTools: R Package for Working with BirdNET Output*. https://birdnet-team.github.io/birdnetTools/.

Wood, Connor M., Alicia Barceinas Cruz, and Stefan Kahl. 2023. "Pairing a User-Friendly Machine-Learning Animal Sound Detector with Passive Acoustic Surveys for Occupancy Modeling of an Endangered Primate." *American Journal of Primatology* 85 (8): e23507. https://doi.org/10.1002/ajp.23507.