birdnetTools 2.0: Linking BirdNET outputs to occupancy modeling in R

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Executive Summary

Passive acoustic monitoring, using sound recorders to monitor wildlife, is transforming how scientists study biodiversity. Machine learning tools such as BirdNET, one of the most advanced algorithms available, can automatically identify bird species from thousands of hours of audio recordings. A powerful way to use these data is through occupancy modeling, which estimates where species occur and how likely they are to be detected. However, converting BirdNET's raw output into the structured format required for occupancy analysis in R remains a major hurdle for many ecologists.

`birdnetTools` 2.0 will remove this barrier by expanding the existing `birdnetTools` R package to produce detection matrices ready for three of the most widely used occupancy modeling packages: `spOccupancy`, `unmarked`, and `ubms`. Building on current tools for data import, cleaning, and validation, we will create new core function(s) (e.g., `birdnet_det_mat()`) and user-friendly, step-by-step tutorials. This upgrade will make it far easier to move from raw audio to reproducible occupancy estimates, empowering researchers and conservationists to monitor birds at large scales and strengthen the R ecosystem for biodiversity science.

Signatories (project team)

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

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 leads the BirdNET Ecology Team, focusing on the application of BirdNET algorithms for landscape-scale biodiversity monitoring and community ecology. 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 the most widely used algorithm for automated bird species identification from audio recordings, capable of recognizing more than 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 BirdNET outputs) (Tseng 2025) streamline acoustic data analysis. A key application of BirdNET detections is generating species presence–absence data for occupancy modeling, which provides estimates of species distribution, detectability, and occurrence (e.g., Wood, Cruz, and Kahl (2023)). However, preparing BirdNET outputs for these models is challenging, especially for users without advanced programming skills. Existing R packages for occupancy analysis, including `unmarked`, `ubms`, and `spOccupancy` (Doser et al. 2022), require highly specific data formats and multi-step workflows, creating barriers to efficient and reproducible analysis.

This project aims to reduce the gap between BirdNET's raw detection tables and the structured inputs required by occupancy models. By enhancing `birdnetTools`, which already handles data import, cleaning, and summarization, we will add function(s) to transform BirdNET predictions into detection matrices and provide streamlined workflows specifically tailored for occupancy modeling. This project will enable ecologists and conservation practitioners to move from raw audio to model-ready data with minimal effort.

The proposal

Overview

We will expand `birdnetTools` functions to transform BirdNET detections into presence/absence detection matrix (input for `spOccupancy`, `unmarked`, and `ubms`). This adds a new data-wrangling path to the existing workflow, as illustrated in Figure 1 A. Occupancy modeling requires three key data components:

- **Detection matrix** (sites × surveys) indicating species presence (1) or absence (0).
- **Site covariates** (sites × covariates), such as habitat type, elevation, or other site-level descriptors.
- **Survey covariates** (sites × surveys × covariates), such as weather conditions, time of day.

New function(s) will streamline the creation of the **detection matrix** by building on existing `birdnetTools` capabilities (e.g., data import, cleaning, validation) and adding tools to extract site and survey information, aggregate detections, and reshape outputs into the formats required by three of the most common R-based occupancy modeling packages, `spOccupancy`, `unmarked`, and `ubms`. The proposed workflow is shown in Figure 1 B.

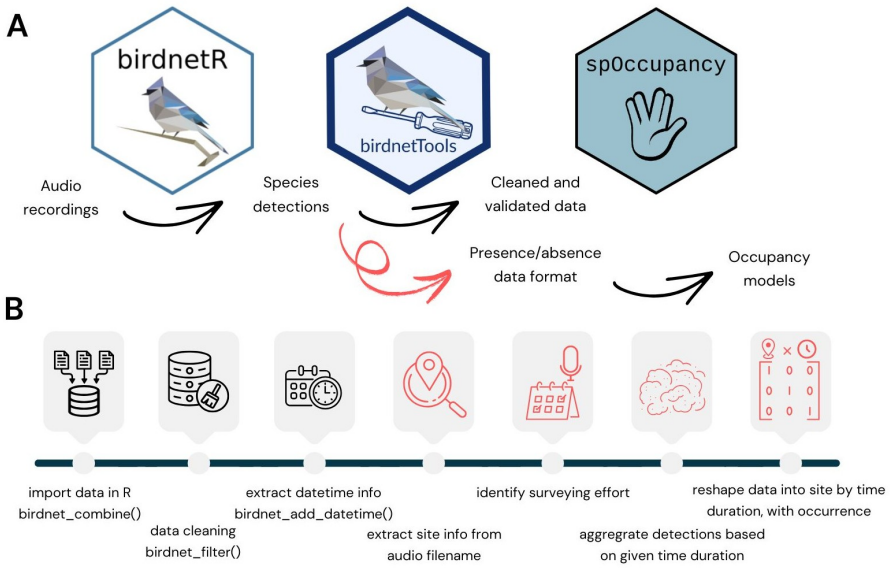

Figure 1: Workflow from raw audio files to occupancy models. Black arrows and graphics represent the current workflow, while red text and arrows indicate the proposed extensions for the package expansion.

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` (e.g., functions `PGOcc()` or `spPGOcc()`), `unmarked` (e.g., functions `occu()` or `colext()`), or `ubms` (e.g., functions `stan_occu()` or `stan_colext()`).

`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

Start-up phase

The planning phase will be completed within the first month of the project:

- ☐ Confirm and document open-source license (MIT).
- ☐ Set up GitHub repository with contribution guidelines, code of conduct, and issue templates.
- ☐ Establish reporting and feedback workflow via GitHub Issues/Discussions.
- ☐ Draft initial project roadmap and share with collaborators for feedback.
- ☐ Schedule bi-weekly check-ins between project contributors.

Technical delivery

The technical delivery phase will span months 2 to 5 of the project. Key milestones include:

- ☐ Month 2.: Finalize function specifications and data format requirements in collaboration with `spOccupancy` developers.
- ☐ Month 3: Develop and test initial versions of occupancy-specific functions in `birdnetTools` (i.e., the minimum viable product).
- ☐ Month 4: Create example workflows and vignettes demonstrating end-to-end analyses.

- ☐ Month 5: Conduct community testing, gather feedback, refine functions, and prepare for package release.
- ☐ Long term: The package will be distributed via CRAN and/or the rOpenSci R-universe to ensure broad accessibility for R users worldwide.
- ☐ Long term: Project updates and outcomes will be communicated through posts on the R Consortium blog, as well as via relevant R community events (e.g., useR! conference, ISC meetings).

Budget & funding plan

We request funding to support personnel time for developing, testing, and documenting the new `birdnetTools` functionality. 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 + 16	$1,008
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 + 60 = 212	$7,632

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 run 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.

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.

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.

Tseng, Sunny. 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.