ANNUAL REPORT

April 2022 - MARCH 2023

BOREAL AVIAN MODELLING PROJECT

PROJET DE MODÉLISATION AVIAIRE BORÉAL

Highlights from 2022–2023

The Boreal Avian Modelling Project (BAM) is a collaborative group of academic researchers, government scientists, project staff, postdoctoral fellows, and graduate students. We conduct collaborative research in avian ecology and conservation and produce information and data products to fill information gaps and support evidence-based decision-making. We collaborate with a wide range of partners, including federal and provincial governments, academia, industry, Indigenous Peoples and communities, and non-governmental organizations (NGOs).

Highlights from our research and knowledge mobilization activities in 2022-2023 are listed below.

Research & Monitoring

Population Status and Trends

- Compilation of an updated avian database and integration with the WildTrax database platform, updated detectability offsets and spatial covariates, and improved workflow to enable completion of version 5.0 of BAM's landbird density estimates for the entire boreal/hemiboreal region of North Americas. ➡ page 8
- Initiation of the international detectability working group to share knowledge and ideas, and stimulate collaboration, among scientists actively studying imperfect detection. ➡ page 11
- Publication in *Ibis* (Edwards et al. 2022) on the NA-POPS project to develop detection offsets for bird species throughout North America using the QPAD approach. ➡ page 11
- Development of a statistical power analysis for bird monitoring in Haida Gwaii. ► page 12

Species at Risk Status, Recovery Planning

- Manuscript (Leston et al.) in review in *Biodiversity and Conservation* synthesizing our conceptual and analytical framework to support the identification of critical habitat for wide-ranging species, comparing Canada Warbler and Wood Thrush. ► page 12

Habitat Selection

- Methodological development for using Light Detection and Ranging (LiDAR) data to understand avian habitat selection by evaluating the effects of time lag between LiDAR acquisition and bird survey. ► page 14

Climate change impacts

- Continuation of collaborative projects with Environment and Climate Change Canada (ECCC) assessing regional impacts of climate change and forest management on boreal birds and ecosystem services. ► page 16
- Contributed to a publication in *Conservation Science & Practice* (Micheletti et al. 2023) evaluating the conservation efficiency of caribou as an umbrella for 71 co-occurring landbirds in the Northwest Territories ► page 17

Energy & mining impacts and cumulative effects

- Contributed to a manuscript in *Landscape Ecology* (Crosby et al. 2023) identifying domains of scale in cumulative effects of energy sector development on boreal birds in Alberta. ► page 19

Forestry Impacts

- Development of a new project to evaluate the value and resilience of certified forests for eastern forest birds in a changing climate. ► page 21
- Collaboration with forest industry, government, and NGO partners to develop a full co-production approach for research to improve forest management practices for bird conservation in the cross-border region of Bird Conservation Region 12. ► page 22

Conservation Planning

- Identification of co-benefits for boreal forest landbirds as a result of conservation opportunities for caribou across the boreal forest of Canada. ► page 25

Knowledge Mobilization

Data and Data Product Development

The results and outputs of many BAM research projects are synthesized into data products, which we make publicly available to support the conservation and management of boreal birds. More details about our data and data products can be found on page 26 or visit https://borealbirds.ca/explore-our-data/.

- Data products currently available include:
  - Bird **data and methods** to support data standardization
  - **Methods and statistical offsets** to support data integration for 151 landbird species
  - **Density and population size estimates** for over 160 landbird and waterfowl species
  - Model-predicted **species distribution and habitat suitability** maps for 94 boreal bird species
  - **Habitat and landcover associations** for 143 landbird species across Canada
  - Maps of **future landbird and waterfowl densities** and **climate change refugia** across Canada
  - **Conservation planning** and **habitat management tools** and data products

- The BAM GeoPortal was developed and launched as an online platform to facilitate the discovery and accessibility of BAM's spatially referenced data products (https://borealbirds.ca/explore-our-data/). ► page 26

- BAM has acquired national-scale advanced satellite imagery for use in developing future models and data products. ► page 27

- The BAM point count database has been uploaded to WildTrax.ca. Datasets will be openly available to the extent that sharing agreements with data partners permit. To date, the point count data on WildTrax contains approximately 9.9 million observations from 375,000 unique locations across the boreal and hemiboreal region of North America including major datasets from Breeding Bird Surveys (BBS), Breeding Bird Atlases (BBA), Canadian Wildlife Service's (CWS) regional offices, and provincial governments. ► page 28

- Automation of the BAM data standardization process is underway to facilitate the integration and upload of new point count data that will support transparent and reproducible research data management.

- BAM is improving the discovery, accessibility, integration, and use of bird data in Canada as a member of the Canadian Network for Open Avian Data (CanAvian), which is a collaboration with Birds Canada, ECCC, Alberta Biodiversity Monitoring Institute (ABMI), and WildTrax.

Communications

- The BAM website (borealbirds.ca) has been significantly improved and translated into French highlighting data products and conservation partnerships. ➠ page 30

- BAM co-produced or led 7 peer-reviewed publications in 2022-23. ➠ page 30

- BAM research and conservation efforts were highlighted in 11 talks and posters at international or regional conferences, targeted workshops, webinars, and collaborative meetings in 2022-23. ➠ page 30

Project Management

- We wish the best of luck to Teegan Docherty who has moved onto a new opportunity with the Canadian Wildlife Service as the Terrestrial Unit Head in Prairie Region. We thank Teegan for the incredible job she did in managing BAM through unprecedented challenges and advancing our core mission of supporting conservation of boreal birds. Teegan will continue to work with BAM on individual projects.

- We welcomed Elly Knight as the new Avian Quantitative Ecologist for BAM (and the Alberta Biodiversity Monitoring Institute). Elly comes to BAM with nearly 20 years of experience in ornithology. She has a strong interest in using statistical tools in innovative ways to advance ornithological research and conservation and is particularly interested in data integration and machine learning.

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About Us

The Boreal Avian Modelling (BAM) Project is an international scientific collaboration engaged in novel research that supports evidence-based decision-making in bird management and conservation across North America. BAM was initiated in 2004 to address knowledge gaps associated with the management and conservation of boreal birds in North America. While BAM is perhaps best known for amassing and standardizing a large dataset of boreal bird survey data, its contributions to avian research and conservation go well beyond this foundational achievement and its data products and expertise are at the leading edge of avian conservation planning.

BAM is working to develop rigorous analytical model-based approaches to support the management and conservation of the boreal forest region and the bird populations and communities that depend upon it. BAM models have broad applications and advance our ability to: (i) understand the relationships between birds and their environment (e.g., vegetation, climate, disturbance); (ii) predict birds responses to changes through space and time, (iii) assess population status and trends; (iv) design rigorous avian monitoring programs; and (v) evaluate the impacts of management decisions on birds now and in the future...just to name a few.

Our Vision

Conservation of North American boreal-breeding birds and their habitats is guided by rigorous, credible, and collaborative science. BAM believes that North American bird populations can be recovered and sustained through thoughtful actions based on data-driven science.

Our Mission

BAM develops high quality scientific information, products, and guidance addressing pressing management needs. We pursue our vision of conserving North American boreal-breeding birds by providing data-driven science that fills information gaps to guide conservation action. We seek to understand species' large-scale habitat needs and the impacts of human activities, informing both regional and continental conservation.

Our Objectives

1. **ASSEMBLE**, harmonize, and archive standardized boreal bird survey **data**.
2. **DEVELOP** or refine **statistical methods** to analyze these data, to:
    3. **PROVIDE reliable information** on boreal bird distributions, abundances, trends, and habitat associations;
    4. **FORECAST** population consequences of human activity and climate change;
    5. **CONTRIBUTE** to **conservation**, **management**, and **monitoring** of boreal birds and their habitats.
6. **BUILD SUPPORT** for boreal bird conservation via collaborations and outreach.
7. **FACILITATE** further research efforts by generating testable hypotheses about key mechanisms driving boreal bird populations.
8. **ENCOURAGE** public awareness and support education.

Our Structure

The BAM Project Team is composed of academic researchers, government scientists, project staff, postdoctoral fellows, and graduate students. BAM is jointly coordinated by a Steering Committee, which advises on BAM's scientific direction, merit, and relevance. Day-to-day management is overseen by our Coordinating Scientist.

Project execution is facilitated by a dedicated team of staff, post-doctoral fellows, and graduate students. Contributing Scientists provide expert advice and are involved in co-production of relevant science. The collaborative nature of the project is further highlighted by the many individuals who have provided project assistance and support over the years. To learn more about our team visit page 32.

Recognizing Collaborations

Given BAM's highly collaborative structure, we wish to appropriately acknowledge intellectual and financial contributions to projects described in this report. We utilize a three-way classification of projects to indicate the alignment with BAM's core goals and the degree of collaboration involved.

CORE project: A project addressing BAM's core mandate, led from inception to completion by BAM Team Members using BAM funding sources.

CO-PRODUCED project: A project jointly produced by the BAM team and collaborator(s) with funding external to BAM. These are often conceptualized outside of BAM before BAM involvement is solicited. BAM involvement could include intellectual contribution to project goals, data provision, analysis, interpretation of results, and/or BAM financial resources.

INFORMED project: A project addressing BAM's mandate with relatively little contribution from BAM (e.g., data or limited expert knowledge). Alternatively, a project using BAM data or intellectual contribution but not addressing BAM's core mandate.

Learn more at borealbirds.ca

Research & Monitoring

BAM's research and monitoring activities help to develop the scientific foundation for large scale management and conservation of boreal birds. We do this by advancing the theoretical foundations and scientific methodologies underlying effective boreal bird conservation. Our collaborative research projects are designed to address conservation priorities in Canada and throughout North America, and inform conservation planning. Here we describe progress on our research projects from April 2022–March 2023.

Population Status and Trends

Summary: BAM produces reliable information on boreal bird distribution, abundance, trends, and habitat associations to support evidence-based decision-making in migratory bird management and conservation across North America. We continue to evaluate and refine our spatially-explicit approach to estimate population sizes (Sólymos & Stralberg, 2020) and to improve methods to estimate population trends and habitat associations. We also continue to advance methods to integrate and analyse broad, heterogeneous data to estimate avian population size through collaborations with partners such as ECCC and Partners in Flight (PIF).

In 2022-2023 we refined and updated our process for modelling population sizes and distributions of boreal landbirds by expanding our study area and list of environmental covariates, as well as further developing the QPAD approach for estimating detectability offsets. At the same time, we developed a manuscript describing our framework for creating large scale population estimates based on version 4.0 of the National Models. We are continuing to collaborate on the NA-POPS project for developing detection offsets for birds throughout North America. We also worked with Parks Canada to develop a statistical power analysis to inform bird monitoring strategies in Haida Gwaii.

BAM National Density Models Version 4.0 AND 5.0

In 2022-2023, we continued to refine and update our generalized analytical approach for modelling species densities and estimating population sizes. We are currently developing version 5.0 of the BAM National Density Models, which we will use to produce predictions at 5-year intervals to estimate spatially-explicit population trends that incorporate habitat change. With this objective in mind, we have reviewed and updated our list of environmental covariates, and expanded our study area to include hemi-boreal regions of the continental United States, using natural biogeographic, rather than political, boundaries to delineate sub-regions. These new sub-regional boundaries will be based on revisions to the boreal Bird Conservation Regions (BCRs) proposed by Partners in Flight and the Canadian Wildlife Service. This expansion is facilitated by the acquisition of new datasets, inclusion of appropriate eBird data, and refinement of the QPAD approach for estimating detectability offsets. Finally, we are taking the opportunity of developing version 5.0 to improve the reproducibility of our modelling process, which will facilitate efficiency, transparency, consistency, and future modelling efforts. This reproducibility process has been heavily facilitated by the migration of our dataset to WildTrax (see "BAM to WildTrax" project below) and the wildRtrax R package, as well as a transition to cloud-based tools including Google Drive and Google Earth Engine for data storage and geospatial processing. Together, these improvements will allow us to provide partners with robust estimates of status and trends for landbirds in their region of interest and range-wide estimates for all boreal landbird species with suitable sample sizes. To explore our density models v4.0 visit https://borealbirds.github.io/ . While moving forward with the development of new national models, we have simultaneously continued our analysis of version 4.0 outputs, and a manuscript is near completion, with a target submission date of October 2023. See research box 1 for details. [**CORE project**. Contact: Elly Knight or Diana Stralberg]

Box 1. Introducing a generalized modeling framework for broad-scale spatial prediction and population estimation: an example for Canadian landbirds

While moving forward with the development of new national models, we have simultaneously continued our analysis of version 4.0 outputs, and a manuscript is near completion. Our models estimated a total of 4.4 billion breeding bird pairs (singing males) across subarctic Canada, with the largest portion of this represented by boreal and hemi-boreal regions (Figure 1). Forest generalist species made up the largest part of this estimate, followed by boreal forest specialist species. According to our models, the four most abundant landbird species in subarctic Canada were estimated to be Yellow-rumped Warbler (212 million pairs), Dark-eyed Junco (171 million), American Robin (153 million), and White-throated Sparrow (147 million). In the top 20 were boreal mainstays Canada Jay (59.8 million), Magnolia Warbler (84.5 million), and White-winged Crossbill (96.1 million). An analysis of variable importance showed that, across species, the variable set that explained most of the variation in bird abundance was landscape-scale vegetation composition, which mostly consisted of variables representing the mean biomass of individual tree species within up to a 2-km radius. This is in contrast with earlier models (Cumming et al. 2014) that found a dominant influence of climate variables, suggesting that the effect of climate on bird abundance is mostly indirect, via vegetation, but that landscape-scale variables are needed to capture this variation. This may be due to the scale of key population processes (larger than the area surveyed by a point count), or could be a function of local-scale uncertainties in vegetation mapping and/or bird surveys.

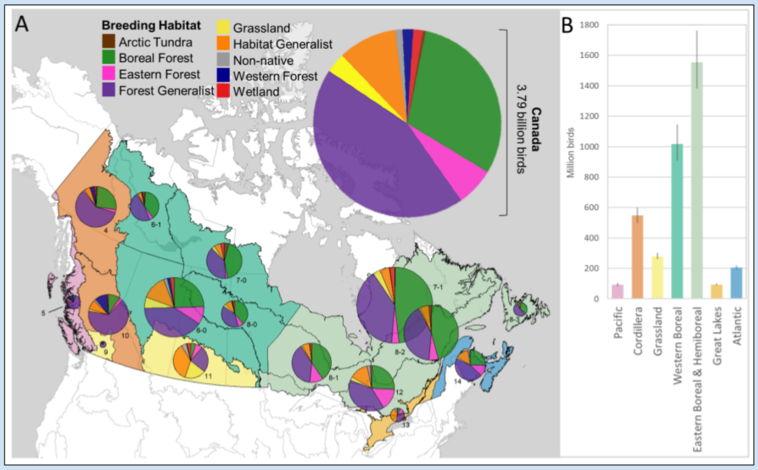


Figure 1. Summary of model-predicted population estimates by regional subunit and habitat type.

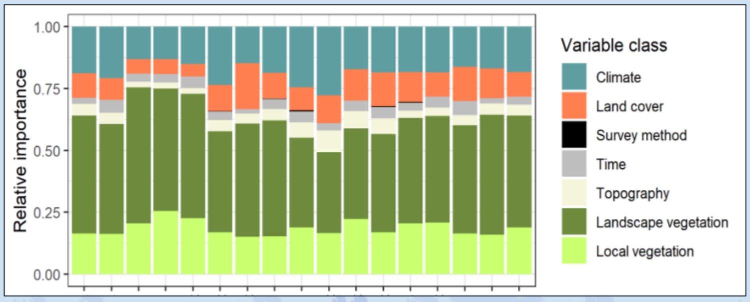


Figure 2. Relative importance of variable classes for 143 landbird distributions in 16 regional subunits, and all of Canada (last column).

https:doi.org/10.5281/zenodo.4042821. Contact: Diana Stralberg, diana.stralberg@nrcan-rncan.gc.ca

QPAD models and R package

A key component of BAM's density and population estimation is the QPAD approach, which uses estimates from distance and removal models to calculate statistical offsets that correct for species-specific variation in probability of detection. To calculate the offsets, we use the coefficients from the distance and removal models that are stored in the QPAD R-package. In 2022-2023, we initiated a review of the QPAD package and began development of version 4. Since 2015, we have amassed a much larger dataset, which allowed us to expand the set of species with offsets from 151 to 187. As part of the dataset expansion, we included ARU data in the removal models for the first time and explored the effect of including a factor that accounts for data collection method (human point count or ARU). Our analyses suggested that data collected by ARU and processed by human observers has higher probability of detection than human point counts, with particularly high probabilities for data processed with the "one tag per individual per minute" approach. We have therefore expanded our QPAD model selection for each species to include this "tag method" factor. We are also reviewing the criteria for inclusion of species in QPAD and are considering additional species that are not typically thought of as "singing birds". As part of version 4 development, we also explored matching the landcover used to estimate perceptibility to the year of data in the model. Work to match landcover to survey year is ongoing and will be considered for inclusion in a future version of this package. We are working to update both the QPAD package and the 'qpad-offsets' Github repository, which will allow users to calculate offsets for their own data using the more exhaustive dataset available in version 4. The changes are currently staged for publication. Once published, those new offset models will allow users to correct for imperfect detection more accurately in their models, allow BAM to more accurately estimate density, and allow all users to account for imperfect detection for a larger suite of landbird species. [**CORE project**. Contact: Elly Knight]

Density estimation from automated recognizer data

Density and population estimation is at the core of wildlife management, particularly at the regional, national, or species range scale. Passive acoustic monitoring and automated recognition have the potential to greatly facilitate population estimation via efficient collection and processing of multi-visit data. Existing examples of density estimation from data processed with recognizers are limited and are not particularly well-suited to application at large geographic scales due to the reliance on context-specific call rates to infer abundance and/or assume closure of individuals across surveys. In response to these limitations, BAM developed a density estimation approach for recognizer data that overcomes these hurdles. This new method will facilitate the use of automated recognition on large archived acoustic datasets to build national density models for species that are poorly surveyed with human point counts. In addition, the method also provides capacity to incorporate habitat covariates and directly estimate the probability of closure. The initial model development was led by Peter Sòlymos and was further refined by Elly Knight as part of her PhD thesis. We are currently testing the model on simulated data to complete a manuscript that will be submitted for peer-review. See research box 2 for more details. We are confident it will be an excellent tool in the toolbox of density estimation, particularly for species assessment and recovery, which occur at large geographic scales. [**CORE project**. Contact: Elly Knight]

Box 2. Deriving density estimates from single-point recordings processed with automated recognition

Passive acoustic monitoring and automated recognition have the potential to greatly facilitate population estimation via efficient collection of multi-visit data. Existing approaches to estimate density from data produced by recognizers are limited and not particularly well-suited for application at large geographic scales.

We developed a five-step density estimation approach for recognizer-acquired data that is based on the theoretical cascade of processes that occur from habitat suitability through to species detection (Figure). First, we used time to detection from the occurrence dataset produced by recognizers to estimate availability for detection. Second, we used conditional likelihood zero-inflated models to estimate occupancy of suitable sites from a dataset of abundance at a subset of our acoustic recordings. Third, we used the results from the previous two steps as inputs for a modified occupancy model that estimates habitat suitability and the probability of species presence during survey (i.e., closure). Fourth, we used a known distance dataset to estimate the effective survey area of our recognizer. Fifth, we combined the parameters from the previous approaches to estimate and predict density and territory size across our study sites and areas.

We used our approach to estimate density of territorial male common nighthawks in four study areas in Canada's western boreal forest: two in recently burned areas ("wildfire") and two in forests of mid to late seral stages ("multi-seral").

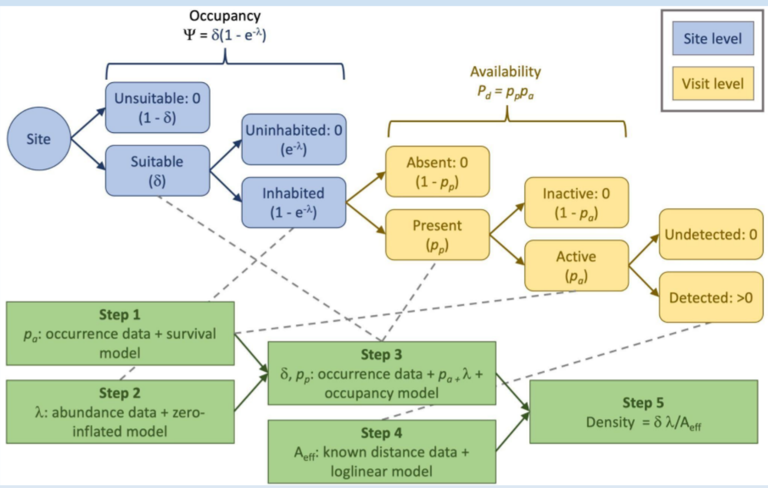


Figure. Overview of modelling framework for estimating density from passive acoustic monitoring data. The top diagram represents the theoretical cascade of processes that occur between survey site selection and species detection. The bottom diagram represents the five steps of the modelling process. The dashed lines indicate connections between the process and the step of the modelling that estimates the probability of that process.

We used two pieces of information to validate our approach. First, density was much higher in wildfire areas (0.038 and 0.030 males/ha) than multi-seral areas (0.000 and 0.005 males/ha), which is congruent with the "disturbance-specialist" habitat preferences of territorial common nighthawks. Second, our territory size estimates for one of the wildfire areas (9.7 ha/male) was nearly identical to estimates from VHF-tagged birds for the same area (10.2 ha/male).

Our novel approach to density estimation is flexible, can be applied at large scales, incorporates habitat effects, and is suitable for mobile species that do not satisfy the closure assumption of multi-visit modelling.

Work in progress. Contact: Elly Knight, ecknight@ualberta.ca

Detectability working group & research

BAM's experience in the arena of bird abundance modelling has given us a unique perspective on the state of the field of detectability research. In 2022-2023, we initiated an international detectability working group in collaboration with the NA-POPS project to share knowledge and ideas and stimulate collaboration amongst scientists actively studying imperfect detection. Our current group meets monthly and has 14 active members, including multiple ECCC scientists and academics from diverse analytical backgrounds. In 2022-23 we have completed a brainstorming and prioritization process, planned a detectability symposium for the 2023 AOS-SCO meeting in London, Ontario, and initiated one major research project. The research project, led by David Iles of ECCC and supported by BAM, aims to understand the extent to which the two components of detectability, perceptibility and availability, are non-independent, and to explore new model types that expand upon the existing QPAD method to further reduce potential biases in density estimates. The detectability working group and research projects will ensure that BAM continues to be a key player in bird abundance modelling, and that we are using the best methods for density estimation to provide managers with robust estimates of landbird status and trends. [**CORE project**. Contact: Elly Knight]

Integrated modelling to determine full-annual cycle correlates of trend

The QPAD offset methods developed by BAM are an essential component of our density estimation approach. However, the statistical offsets provided by QPAD also inform other data integration applications. Data integration can be a particularly valuable tool when species are data sparse, as is the case for the Common Nighthawk, which is poorly surveyed by the Breeding Bird Survey (BBS) and population trends suggest it is experiencing population pressures somewhere within its annual cycle. In 2022-2023, we used offsets for availability from removal modelling to integrate two monitoring datasets for the Common Nighthawk, the BBS and the Canadian Nightjar Survey, and then attributed variation in that monitoring data to environmental conditions experienced by populations across their annual cycle, as determined by GPS tracking data. Preliminary results showed that crop conversion from all stages of the annual cycle had a consistently negative effect on Common Nighthawk breeding abundance, but particularly on the breeding grounds. As forests matured on the breeding grounds there was a negative effect on breeding abundance, but a positive one in other stages of the annual cycle, consistent with full annual cycle habitat selection research. Furthermore, our preliminary results speak to the power of data integration, with the integrated model having stronger results that are more aligned with predictions based on Common Nighthawk ecology than a model using BBS data alone. We presented these results at a 'Big Data' symposium and the Ecological Society of America and Global Nightjar Network conferences in 2022 and are currently writing them up for peer review. We hope to use this work as a case study for the value of statistical offsets for data integration and for developing analytical workflows to understand full annual cycle conservation of migratory landbirds. [**CO-PRODUCED project**. Contact: Elly Knight]

NA-POPS: Point count offsets for population sizes of North American landbirds

The NA-POPS project is a collaborative research program with the goal of developing detectability offsets for habitat and distribution modelling of landbirds throughout North America. To date, NA-POPS has generated estimates of detectability (made up of cue rate and effective detection radius) for 338 landbird species by harmonizing data from over 292 projects, including several from BAM. The results of this project were published in the journal *Ibis* (https://doi.org/10.1111/ibi.13169). Currently, two new projects based on these results are being undertaken by Brandon Edwards: 1) the development of a multi-species QPAD modelling approach that allows for the sharing of information between data-rich species and data-poor species, and 2) the development of methodologies to allow for ARU data to be used in QPAD calculations. The second project, partially funded by a Mitacs Accelerate Grant and Society of Canadian Ornithologists, allowed Brandon to work directly with BAM and ABMI from September 2022 – December 2022 as a visiting researcher. During that time, Brandon worked with Elly Knight, Erin Bayne, and others to develop a workflow to include ARU data into QPAD detectability calculations. This will allow for ARU data to supplement traditional point count data in QPAD and the NA-POPS database, and can both improve estimates for previously modelled species, or create new estimates for species not yet modelled. Brandon is continuing to work on this project as a PhD chapter and presented preliminary results at the EURING Technical Meeting in April 2023. To learn more, visit the NA-POPS website. [**CO-PRODUCED project**. Contact: Brandon Edwards or Diana Stralberg]

Informing survey design: Statistical power analysis for Haida Gwaii

There are questions about how to increase efficiency of wildlife monitoring programs by determining how many sites and/or surveys per site are needed within and across seasons to detect: 1) statistically significant effects of various factors on occupancy; and 2) detecting statistically significant trends in occupancy over time. We used actual data collected with autonomous recording units (ARUs) and simulated occupancy data to estimate statistical power of different combinations of site number and number of recordings per site to detect effects on and trends in occupancy. Data were collected in several ARU studies delivered by Parks Canada in Haida Gwaii, BC, Canada from 2010-2021. We initially used single-season occupancy models on 14 species of landbirds to obtain realistic estimates of occupancy and detection probability. Using these values, we then used simulated data sets with varying numbers of sites and "visits" to estimate 1) power to detect a change in occupancy between two sets of sites (as in different years); and 2) power to detect effects of predictors on initial occupancy, detection, colonization, and extinction at sites across a period of 5 years (50% trend), 7 years (30% trend), and 10 years (10% trend). We found that increasing the number of sites decreased the number of recordings per site required to achieve a power of 0.8 (80% probability of finding a true effect). Power to detect occupancy effects was lower for uncommon species than widespread species. Using the mean occupancy and detection probabilities of the 14 study species at 91 sites, we found sufficient power (0.80) to detect 50% and 30% trends for common species but only 50% changes for rare species. We developed tools (R scripts using the unmarked and shiny packages: https://github.com/LionelLeston/Power-analysis-hierarchical-models) that can be used by others to design their own monitoring programs. [**CO-PRODUCED Project**. Contact: Lionel Leston]

Species at Risk Status, Recovery Planning, and Multi-species Management

Summary: Identifying the location and amount of critical habitat needed by a species is an important step in planning recovery strategies for species at risk (SAR). BAM's research, analytical approaches, and data products support recovery planning and the identification of critical habitat.

In 2022-2023, BAM submitted a manuscript demonstrating the application of a modelling framework supporting identification of critical habitat, applied to Canada Warbler (*Cardellina canadensis*) and Wood Thrush (*Hylocichla mustelina*).

Analytical framework to support critical habitat identification for the recovery of wide-ranging boreal species at risk: a case study with the Canada Warbler and Wood Thrush

In 2022-2023, we completed a manuscript including results from a modelling framework to support identification of critical habitat for Canada Warbler and Wood Thrush. The steps of this framework consist of: 1) reviewing life history requirements and available predictor and survey data for species of interest, and applying BAM-developed methods for harmonizing data from independent studies; 2) delineating management units using geographically weighted regression and cluster analysis to identify regions of differential habitat use by a species; 3) predicting density and distribution of a species using boosted regression trees; 4) predicting how habitat for and density and distribution of a species could change in the future by simulating land-use and climate change; and 5) identifying where to protect or manage important current or future habitat for a species using spatial prioritization exercises (raster overlay analysis). BAM collaborated with scientists at ECCC on the framework and obtained additional bird data from outside of BAM to develop the framework. The framework provides information for supporting the designation of critical habitat by government agencies, but can also be used for other conservation plans. This manuscript has been submitted to the journal *Biodiversity and Conservation* (see publication list; research box 3 for details). [**CO-PRODUCED project.** Contact Lionel Leston]

Box 3. A framework to support the identification of critical habitat for wide-ranging boreal bird species at risk

We developed a reproducible, four-step analytical framework to support the identification of critical habitat for wide-ranging species at risk. The steps include the (i) review of species distribution and life history; (ii) delineation of management units; (iii) evaluation and comparison of current and future potential habitat and population size; and (iv) the prioritization of areas that inform the amount and location of important habitat based on current and future habitat conditions. We tested this framework using Canada Warbler (*Cardellina canadensis*) and Wood Thrush (*Hylocichla mustelina*) as case studies in the Canadian portions of their ranges.

Cluster analysis results from multiple geographically weighted (GW) models used to identify and delineate management units suggested Canada Warbler uses different forest types across Canada, resulting in 3 management units. In contrast, Wood Thrush responds to forest structure similarly (no stable clusters) across Canada suggesting a single management unit. Regional models and future habitat availability showed that Canada Warbler may increase in Nova Scotia but decrease in Alberta. Canada Warbler was predicted to decline with a warming climate in both Nova Scotia and Alberta and with harvest in Alberta. In contrast, Wood Thrush is predicted to increase in eastern Canada and respond positively to a warming climate.

Conservation planning exercises can be used to estimate and identify amounts and locations of habitat for supporting a given amount of the current or future population of Canada Warbler or Wood in different management units (see Figure).

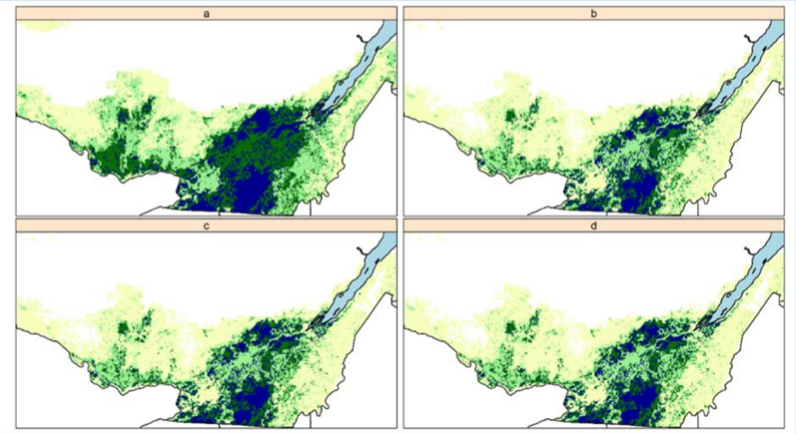


Figure. Maps indicating areas to prioritize as habitat for different percentages of the current Wood Thrush population in southern Quebec. Dark blue = highest ranked areas for maintaining 50% of the current (2020) population. Dark green, light green, yellow areas = additional areas for maintaining 75%, 90%, and 100% of the current population in different scenarios: a) current population density alone; b) current density + 2100 population from best-case Landis scenario; c) current density + 2100 population from medium-case scenario; d) current density + 2100 population from worst-case scenario. Future populations were projected to be higher than current population, so less land was required to maintain current population in scenarios b-d.

This framework provides a systematic approach to inform the identification of critical habitat based on current and future habitat conditions for wide-ranging species.

Work in progress. Contact: Lionel Leston; leston@ualberta.ca

Habitat Selection

Summary: Understanding habitat selection is an important step in predicting species distribution and can enhance ecological forecasting and conservation planning. Over the last three years, BAM has explored large-scale spatial variation in habitat selection across breeding ranges, as well as finer-scale habitat modelling via advanced remote sensing products.

In 2022-2023, we worked to understand how time lag between LiDAR data acquisition and bird surveys influences habitat selection model results for birds across a range of forest successional stages.

The influence of time-lag between LiDAR and wildlife survey data on bird-habitat models.

LiDAR has the potential to improve bird-habitat models by providing high resolution structural covariates, which can give insight into bird-habitat relationships. However, LiDAR acquisitions do not always coincide in time with point count surveys. It is unclear how much this temporal misalignment influences the predictive accuracy of bird-habitat models that use LiDAR derived predictor variables. As disturbance-succession cycles change vegetation structure, eventually LiDAR metrics will no longer reflect ground conditions. Thus, the usefulness of LiDAR explanatory variables will degrade. We evaluated how time-lags between LiDAR acquisitions and bird surveys influenced model robustness for early-successional, mature-forest, and forest generalist birds. We found that for species occupying older, more stable forests, a time difference of up to 15 years has only a small impact on the predictive power of LiDAR based bird-habitat models. However, for early-successional birds, our findings suggest that a time difference of 5-13 years between LIDAR and bird data may reduce model performance. See research box 4 for more details. [**CO-PRODUCED project.** Contact: Brendan Casey]

Box 4. The influence of time-lag between LiDAR and wildlife survey data on bird-habitat models

LiDAR has the potential to improve species distribution models (SDMs) by providing high resolution metrics corresponding to vegetation structure of breeding habitats. LiDAR acquisitions do not always coincide in time with point count surveys. Temporal misalignment between wildlife surveys and LiDAR is common, and succession occurring between species detection and LiDAR data may influence SDM performance. LiDAR's usefulness as a source of explanatory variables can degrade as temporal misalignment increases.

We evaluated how time lag between LiDAR acquisitions and bird surveys influenced model robustness for early-successional, mature forest, and forest generalist bird species. We compared mixed effects logistic regression models for six boreal bird species. For each species, we built 16 models, each representing a different amount of time-lag between LiDAR and point count surveys (between zero and sixteen years). We assessed how differences in resultant predictive distribution maps correlate with forest age.

We found that LIDAR-based SDMs were moderately predictive of occupancy for American Redstart, Black-throated Green Warbler, Mourning Warbler, and White-throated Sparrow. The influence of temporal misalignment on SDMs varied across species with the greatest impact on models for early-successional associates. For species occupying older, more stable forests, temporal misalignment between LiDAR and bird surveys had only a small impact on the predictive power of models. For early-successional birds, our findings suggest that a time difference of 5-13 years between LIDAR and bird data may reduce model performance.

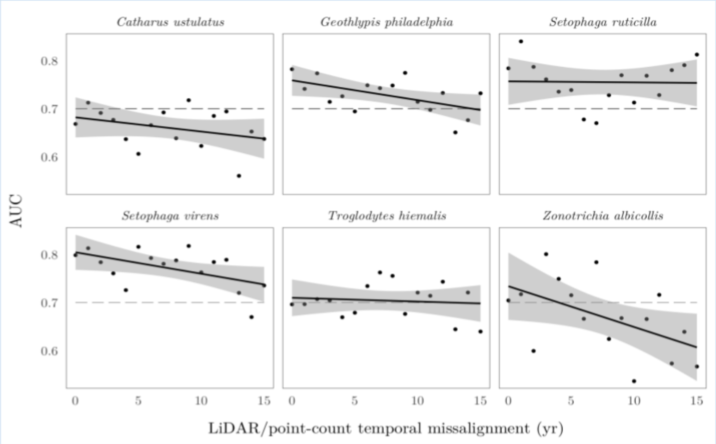


Figure. Plot showing the relationship between model AUC and LiDAR temporal misalignment with bird surveys for each species.

Our results suggest researchers should consider temporal misalignment when applying LiDAR to bird-habitat models. For species associated primarily with mid- to late-successional boreal forests, coincident bird and LiDAR data may not be necessary. Caution should be taken with early-successional species occupying burned and harvested areas, and those that nest and feed near the ground with dense shrub vegetation. For these, we recommend limiting temporal misalignment to <5 years.

Work in progress. Contact: Brendan Casey, bgcasey@ualberta.ca

Detecting and Attributing Land-use and Climate-change Impacts on Boreal Birds

BAM uses modelling and simulation to evaluate drivers of change and quantify impacts of industrial activities on past and future migratory bird populations to inform land-use planning and management. The outcomes of these research projects inform and refine regional, national, and continental scale population & trend estimates and provide methods, tools, and recommendations to support impact assessment, cumulative effects, land-use planning, and management for migratory birds and their habitats.

Climate and Landscape Change Impacts

Summary: BAM has several co-produced research projects that use spatial simulation models combined with avian density models to enhance our understanding of the past and future impacts of climate and landscape change on boreal bird populations, including species at risk. We also use bioclimatic models to evaluate potential distributional responses to climate change. This research advances our understanding of the effects of climate change on boreal bird populations and their forest habitats, which helps inform climate-smart conservation planning and land-use management.

In 2022-2023, BAM continued collaborating on several co-produced projects in Québec, Yukon, and the Northwest Territories. These projects anticipated the magnitude and direction of change in bird populations under climate change, identified climate-change refugia, and evaluated the potential for boreal caribou to act as a conservation umbrella species for birds.

Cumulative effects of climate change and forest management on bird communities and ecosystem services in two contrasting forests in Eastern North America

Understanding the cumulative effects of forest management and climate change on biodiversity, but also on other services provided by forests, such as carbon sequestration and provisioning of wood products, is key to informing long-term management decisions. We projected changes in bird communities, carbon sequestration, and wood fiber production according to various forest management strategies under a changing climate using the spatially explicit forest landscape simulation model LANDIS-II. We focused on two case study areas of Québec, one hemiboreal (Hereford Forest) and one boreal (Montmorency Forest). We estimated that 25% of the bird species studied in the hemiboreal and 6% in the boreal forest will be sensitive to climate change (projected changes in abundance, positive or negative, greater than 25%). Simulations indicated that a decrease in the level of forest harvesting could benefit bird conservation and contribute to climate change mitigation in the boreal forest site. Conversely, in the hemiboreal forest site, trade-offs will be necessary as mitigation of carbon emissions is favored by more intensive forest management that stimulates tree growth and carbon sequestration of otherwise stagnant stands. A manuscript was submitted to *PLOS Climate*. [**CO-PRODUCED project.** Contact: Junior Tremblay]

Regional comparisons of the impacts of climate change and forest management on boreal bird communities of Canada

Climate change is expected to strongly influence boreal bird communities through changes in boreal forest composition and age structure in the coming decades. We used the LANDIS-II forest landscape model to project the impacts of climate change and forest harvesting on boreal bird communities in two provinces of Canada (Alberta and Québec). We found that forest harvesting and climate-related drivers (mainly increases in wildfire) are projected to have substantial impacts on bird communities in both regions.

Changes are projected to occur earlier and more dramatically in the west vs. the east, with reductions in species associated with older coniferous forests and increases in species associated with young forests and open habitats. Our results showed that impacts of climate change and forest harvesting may impact species differently between regions, and regionally-specific measures should be implemented to ensure adequate conservation of climate-sensitive species. [**CO-PRODUCED project**. Contact: Junior Tremblay]

Interpreting predicted shifts in avian distribution in response to climate change in the Northwest Territories

The distribution and abundance of birds are predicted to shift as the climate warms. High-latitude ecosystems like the boreal forest are already experiencing significantly warmer temperatures. Understanding how bird populations respond to climate change is vital for conservation and land-use planning. Ana Raymundo (Ph.D. student with Steve Cumming and Eliot McIntire) is evaluating the future impacts of climate change on the avian community in the Northwest Territories. In 2022-2023, a new analysis estimated and visualized the magnitude and direction of predicted changes in distribution. The manuscript was submitted to *Climate Change Ecology*. See research box 5 for more details. [**CO-PRODUCED project**. Contact: Ana Raymundo]

Box 5. Interpreting predicted avian responses to climate change in the Northwest Territories

Several studies have predicted a shift in bird species' distributions and abundance as the climate warms (Cumming et al., 2014; Stralberg et al., 2015). High-latitude ecosystems such as the boreal forest are already experiencing significant temperature change. The main objective of this project was to evaluate the future impacts of climate change on the avian community in the Northwest Territories. We identified the winners and losers in the short term (2011-2031) and the long term (2011-2091) by comparing the changes in predicted abundances under three contrasting General Circulation Models (GCMs). The GCMs represent the average (CCSM4), greater (CanESM2), and lesser (INM- CM4) levels of both projected temperature and precipitation for the study area. Results show that White-crowned Sparrow is a 'loser' in the long term under the three GCMs whereas Brown-headed Cowbird and Red-winged blackbird are 'winners' under CCSM4 and CanESM2 and Common Yellowthroat and Red-eyed Vireo are winners under INM.CM4 (see Figure).

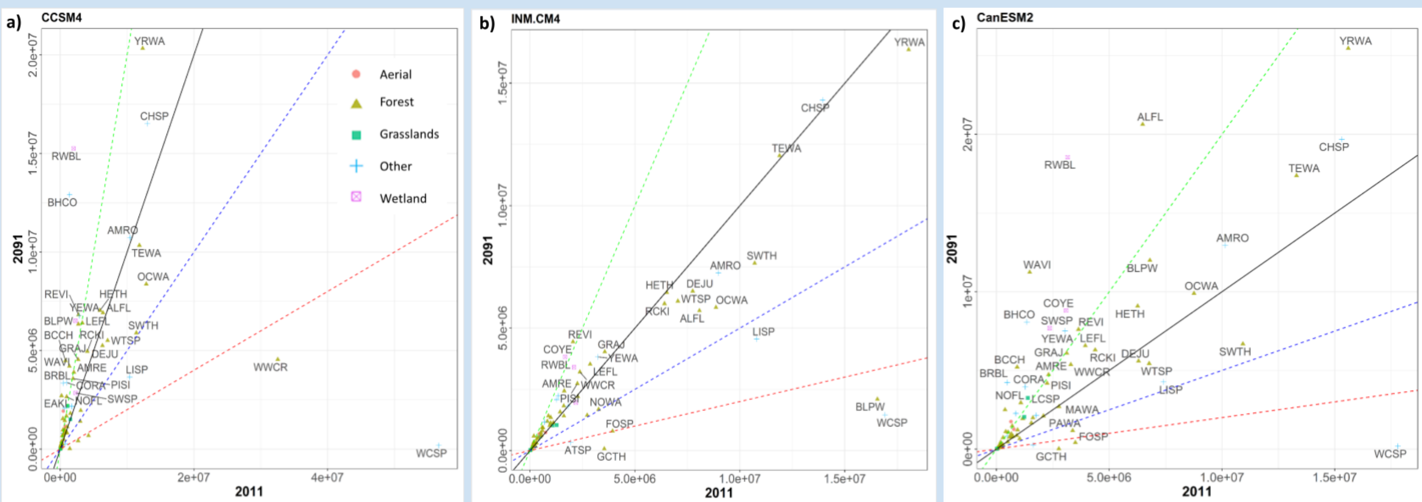


Figure. Long term change between current and future predicted bird species abundances under three GCMs: (a) CCSM4, (b) INM-CM4 and (c) CanESM2. The black line represents 1:1 relationship; the green, blue and red lines are proportional change relationships (slope = 2.0, 0.2 and 0.5, respectively)

Work in progress. Contact: Ana Raymundo; email: angeles-ana-paula.raymundo-sanchez.1@ulaval.ca

The Western Boreal Initiative (WBI)

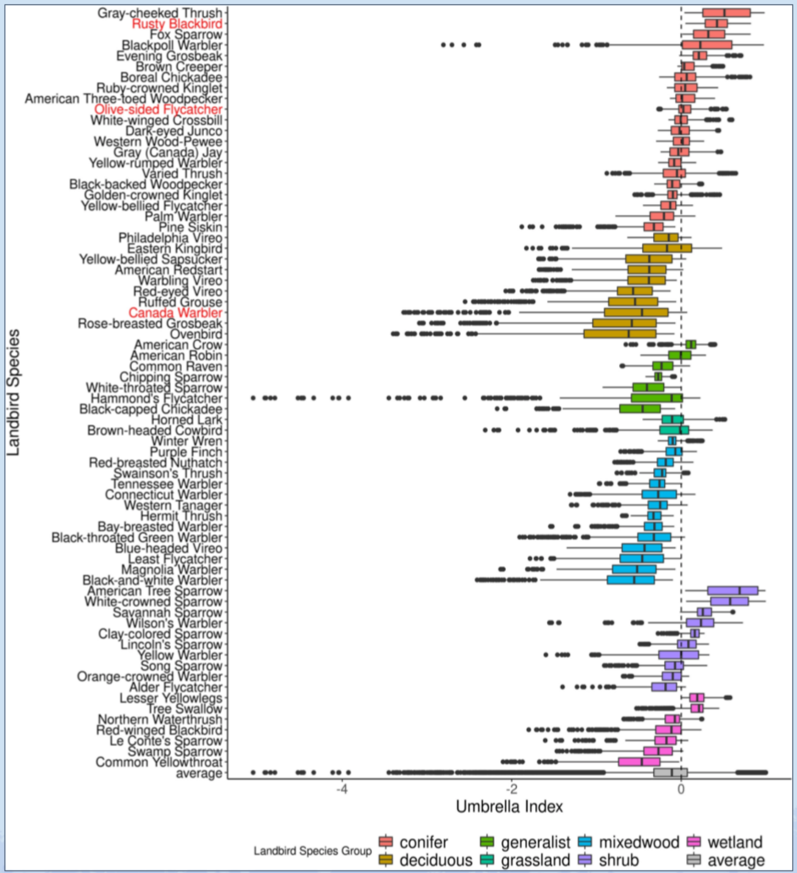
BAM contributes to the Western Boreal Initiative (WBI), which aims to build a powerful and generic toolkit to inform multi-species conservation and protected area planning under current and future climate scenarios in the Western Boreal Forest region of Canada. This project is a collaboration that includes Canadian Forest Services' Pacific Forestry Centre and Northern Forestry Centre, Université Laval, ECCC, and the NWT Department of Environment and Natural Resources, and benefited from additional funding from

CWS Northern Region. In 2022-23, WBI completed work testing the concept that boreal caribou serve as an effective umbrella for conserving landbird populations in the Northwest Territories. The results of this research were recently published in the journal *Conservation Science and Practice* (see publication list; research box 6 for details).

An important component of the WBI is our formal collaboration with Indigenous partners, such as Dene Nation, to determine the best approach to braid ways of knowing (i.e., Traditional Knowledge and Western Science) as it relates to habitat use of boreal caribou. Additionally, Steve Cumming's lab at Université Laval is leading an independent effort to add models of lichen biomass dynamics to our simulation engine. [**CO-PRODUCED project**. Contact: Samuel Haché or Steve Cumming]

Box 6. Will this umbrella leak? A caribou umbrella index for boreal landbird conservation

Conservation approaches that efficiently protect multiple values, such as the umbrella species concept, have been widely promoted to address expected dramatic ecosystem changes. Due to its social and cultural importance, and recent declining trends, boreal populations of woodland caribou have been suggested as potential umbrella species for other declining taxa, including boreal landbirds. We used avian density models and future climate-change projections, coupled with fire-mediated vegetation change projections (landR and FireSense SpaDES models) to evaluate the overlap between priority habitat for caribou and landbirds in the Northwest Territories. Working with co-authors from the Canadian Wildlife Service, the Canadian Forest Service, and the Government of the Northwest Territories, we developed a generic pixel-based umbrella index that focuses on fine-grained habitat overlap between caribou and boreal landbirds. We found that the conservation efficiency of caribou as an umbrella for 71 co-occurring landbirds—three of which are priority species—in the Northwest Territories is generally lower than our random model, as 53% of the species presented negative umbrella index medians with the interquartile range not overlapping zero. We conclude that in cases where area-based targets drive decision-making and the issue at stake involves identifying which areas to conserve—not whether to conserve—woodland caribou may be a leaky umbrella for most co-occurring landbird species and these might need complementary conservation actions.



https://doi.org/10.1111/csp2.12908. Contact: Tati Micheletti, tati.micheletti@gmail.com

Yukon Boreal Cordillera Refugia

Boreal ecosystems are susceptible to rapid, climate-driven vegetation change. Such changes will likely be accelerated by large-scale disturbances such as wildfire, insects and disease, and processes such as permafrost thaw. Identifying climate-change refugia (areas buffered from contemporary climate change) can help inform land-use planning because these "slow lanes" for biodiversity will be important for the conservation and management of boreal and hemiboreal species and ecosystems. The western mountains of Canada are an area identified to have high potential for future cold refugia. BAM collaborated with the CWS and the CFS to develop climate-based species distribution models for 74 landbird species that currently breed in the Yukon portion of the Boreal and Taiga Cordillera. These models were trained on a dataset of bird surveys from >63,000 locations thanks to the contribution of many projects, including those of the USGS in Alaska and CWS in the Yukon and Northwest Territories. We used these models to (1) project end-of-century species' distribution and abundance under multiple climate change scenarios and (2) to identify climate refugia for these species with habitat quality as a constraint. We used climate velocity methods to quantify the probability of colonization of future suitable habitat (macrorefugia score) and then multiplied macrorefugia scores by future habitat quality scores to identify priority conservation areas in the region. [**CO-PRODUCED project.** Contact: Anna Drake]

Energy & Mining Impacts and Cumulative Effects

Summary: Effective management strategies and conservation planning require an understanding of the individual and cumulative impacts of multiple stressors on boreal bird populations. BAM's research has advanced our understanding of the effects of development by the energy and mining sector on boreal birds within a cumulative effects framework and has improved our ability to attribute impacts of these and other sectors on bird populations at local and landscape scales.

In 2022-2023, BAM wrapped up work advancing efforts to assess the potential effects of chromium mining on bird densities and distributions in the Ring of Fire region, Ontario, and evaluating scale-dependent effects of energy development in Alberta on forest bird populations.

Environmental assessment of effects of chromium mining on bird populations in the Ring of Fire region, Ontario

Understanding the potential cumulative impacts of a proposed development on wildlife is an important component of the environmental assessment process. BAM worked collaboratively with ECCC and other partners to develop predictive species distribution models for birds within northern Ontario to understand the potential effects of developing new chromium mines on bird communities within the proposed Ring of Fire development area. In 2022-2023, this research was integrated into the full Ring of Fire Environmental Assessment report. [**CO-PRODUCED project.** Contact: Andrew Crosby or Lionel Leston]

Domains of scale in cumulative effects of energy sector development on boreal birds

Scale domains are regions of the scale spectrum over which ecological patterns remain steady, while transitions between domains are marked by high variability or unpredictability (Wiens 1989). Emergent ecological patterns can differ markedly among scale domains, meaning different conclusions can be drawn from the same analysis conducted at different scales. As a result, investigations of the cumulative effects of environmental variables on habitat selection and species distributions should occur across multiple scales. BAM worked collaboratively with ABMI, using bird occupancy data and spatial predictor data from ABMI, summarized at multiple spatial scales. This project intends to investigate how oil sands development affects bird populations in Alberta and how these changes might reflect scale-specific processes. In 2022-2023, we submitted a manuscript describing this work to the journal *Landscape Ecology*. See research box 7 for details. [**CO-PRODUCED project**. Contact: Andrew Crosby]

Box 7. Hierarchical, multi-scale modeling framework reveals evidence for domains of scale in cumulative effects of development on boreal bird distributions

Many forested areas of the globe formerly considered intact, such as Canada's boreal forest, are undergoing increased industrial development. At large spatial extents, this development creates multiple individual human footprint (HF) disturbances that can interact across space and time, resulting in cumulative effects on ecosystem patterns and processes. Effective regulation of industrial development requires understanding cumulative effects on biodiversity. However, species may exhibit scale-dependent responses to disturbance, leading to uncertainty in our understanding of cumulative effects. For example, at the local scale, individual animals are likely responding directly to habitat alteration from a single disturbance type. As scale increases, we are more likely to see multiple disturbance types interacting to affect the distribution of individuals across the landscape.

We used data on bird species occurrence from a large-scale, grid-based sampling design to estimate cumulative effects of energy sector development on migratory passerine populations at multiple spatial scales within the boreal region of Alberta, Canada. We used a hierarchical, multi-scale modeling approach to compare effects of HF across multiple spatial scales, and evaluate evidence for scale domains in species responses.

We found variable responses to HF among species, disturbance types, and spatial scales, but a consistent scale-dependent pattern showing the most variable responses to HF occurring at the smallest scale, little effect at intermediate scales, and stronger, mainly positive effects on open habitat and generalist species at the largest scales. Model selection among additive, interactive, and total HF models followed the same pattern, with total HF models increasingly dominant at the largest scales.

Our results provide evidence for domains of scale in bird species responses to energy sector development, reflecting local scale habitat selection and landscape scale distributional effects. The consistent pattern of strong positive effects on open habitat species at larger scales suggests the potential for biotic homogenization in high footprint areas. Examining patterns across multiple spatial scales is critical to understand the cumulative effect of disturbance on ecological communities. Our sampling design and modeling approach provides researchers with a greatly improved framework for estimating multi-scale cumulative effects of environmental stressors on wildlife populations and biodiversity.

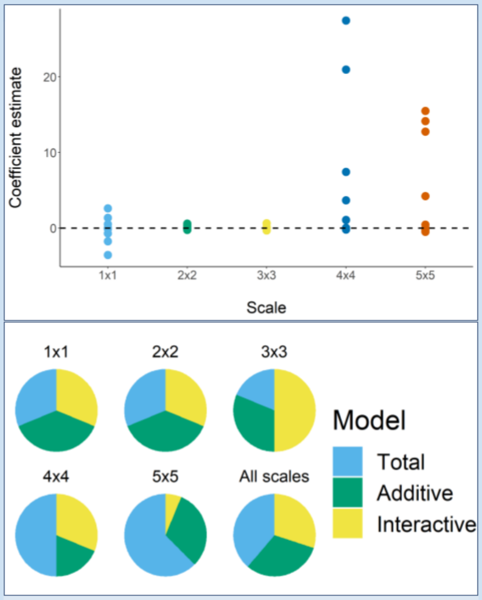


Figure: Plots showing coefficient estimates of the effect of total human footprint across species and scales (top), and the proportion of species for which each of three model types received the highest model weight among sixteen bird species at five spatial scales.

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Work in progress. Contact: Andrew Crosby, crosby@ualberta.ca

Forestry Impacts

Summary: BAM's research aims to improve our understanding of how forest management and harvest practices impact bird populations at local, regional, and national scales. This work is focused on the co-production of actionable science with local forest industry, government, and community partners. Our research activities include projects that identify and attribute the historic, current and future effects of forest harvest, certification, and management decisions on bird populations.

In 2022-2023, we continued to (1) improve methods to assess risk of incidental take during forestry operations in Alberta; (2) assess conservation value of sustainable forestry certification for birds across Canada; and (3) improve our ability to provide actionable science for forest management decisions under land use and climate change. Most notably, the co-production aspect of our collaboration with Sustainable Forestry Initiative, American Bird Conservancy, and the Eastern Habitat Joint Venture in eastern Canada has advanced significantly. This collaboration will greatly improve our capacity to develop tools for foresters and land managers to incorporate bird conservation into climate adaptation planning across Eastern Canada.

Alberta Risk Matrix: Tools for understanding risk of incidental take from forestry operations

Forest companies are required to avoid the incidental take of migratory birds (i.e., killing or harming individuals or disturbing or destroying nests) while carrying out harvest operations. Consequently, the risk of incidental take is used to inform when and where to plan harvest. BAM has provided decision-support tools to forestry companies in Alberta based on bird abundance, conservation priority, and uncertainty that forestry companies use in planning. In 2022-2023, BAM built on previous work (reported on in the 2021-2022 Annual Report) by incorporating forest landscape simulation models into the process of estimating the risk of incidental take, and its potential effect on bird populations. [**CO-PRODUCED project**. Contact: Lionel Leston and Andrew Crosby]

Conservation value to birds of sustainable forestry certification across Canada

A primary goal of sustainable forestry certification is that operators maintain biodiversity on landscapes managed for timber production. Variability in bird communities across space can be a key indicator of biodiversity impacts of harvesting and an index of the conservation value of different areas or forest types. The goal of this research is to evaluate the conservation value of forest certification based on the contribution of certified forest lands to avian species richness within the larger region, relative to the non-certified lands. Our objectives are to: (i) map species richness, community composition, and bird diversity at different scales across Canada; (ii) quantify and contrast the contributions of certified managed forests and non-certified managed forests to bird species diversity; and (iii) quantify the contributions of different forest ecosystem types (e.g., deciduous, conifer, mixed) to breeding bird diversity at local and regional scales. In 2022-2023, we began revising multi-species models to create better estimates of species richness and composition within Bird Conservation Regions. This work involved using an ensemble approach with overlapping ecoregion estimates. In 2023-2024, we will finalize these models and develop additional beta diversity analyses, with the results being developed into a manuscript. This project was developed in collaboration with Sustainable Forestry Initiative, Alberta Pacific Forest Industries Inc., and FUSE Consulting Inc. [**CO-PRODUCED project**. Contact: Andrew Crosby]

Sustainable forestry for bird conservation in the cross-border region of Bird Conservation Region 12

A challenge of forest conservation is maintaining biodiversity in managed forests with climate change. In the cross-border Bird Conservation Region (BCR) 12, Boreal Hardwood Transition, historic and current management systems, policy frameworks, human population density, and ecological and economic factors have combined to create more highly fragmented landscapes in the USA than in Canada. As a result, bird species spanning the nations within BCR 12 experience different conservation challenges and may need different conservation solutions to address the impacts of climate change. This project builds on relationships established during previous SFI grants to continue a cross-border partnership among BAM, Sustainable Forestry Initiative, and the American Bird Conservancy. In 2022-23, we co-hosted an informational webinar (Cross border Forestry Related Bird Conservation Webinar (BAM Project, SFI, ABC), a hybrid workshop in Sault Ste. Marie, Ontario, and completed a report on a co-production framework that engages forestry, government, non-government (e.g., science and advocacy organizations), and academic sectors to guide research development on bird conservation in managed forests of BCR 12. The initial result of this framework is a call for increased communication and leadership for conservation throughout BCR 12. Plans for sustainably managing forests that create and/or maintain high quality habitat to support thriving bird populations that are resilient to climate change must further integrate forester, landowner, and manager knowledge of the landscape mosaic of vegetation and known rates and patterns of regrowth. Our research informs how conservation plans must be compatible with the decision-making process, including the needs and constraints of the forest products sector and providing non-timber value. The next steps include improved relationship building with landowners and with Indigenous knowledge keepers with multi-generational insight into sustainable forestry and the resiliency of forest bird populations to the impacts of climate change. This project is funded by an SFI Conservation Grant awarded to Steve Cumming in April 2022. See research box 8 for more details. [**CO-PRODUCED project**. Contact: Junior A. Tremblay, Andrew Crosby, or Steve Cumming]

Box 8. Toward Cross-Border Conservation in the Face of Climate Change: Using Co-production to Overcome Ecological Complexity and Jurisdictional Barriers

This work focused on building a co-production framework that engages with the forest products, government, non-government (e.g., science and advocacy organizations), and academic sectors to improve research development on bird conservation in managed forests of BCR 12 - Boreal Hardwood Transition. Building on the strengths of project lead organizations (BAM, SFI, ABC), we identified the scope of knowledge needed to assess resiliency of sustainably managed forests in support of bird conservation with climate change and formed a steering committee (StCo) made up of individuals from sectors with that knowledge (n=18; **Figure**). The entire Steering Committee met monthly in June-August 2022, and a focus group (n=10) met weekly from August-October 2022 to prepare for an October workshop (see below). Through the extended networks of StCo members, we identified and engaged with experts in sustainable forest management or emerging forest bird conservation issues and climate impacts from Canada or the United States (n=217). In September 2022, we held and informational webinar that followed guidelines for co-production by explicitly explaining our co-production goal, the ultimate project goals, and the role of each partner organization. In October 2022, we held a hybrid workshop in Sault Ste. Marie, Ontario that focused on listening to knowledge holders (**Photo**).

The initial result of our co-production is a call for increased communication and leadership for conservation throughout BCR 12. Next steps include improved relationship building with landowners, including with Indigenous knowledge keepers with multi-generational insight into sustainable forestry and the resiliency of forest bird populations to the impacts of climate change. Using landscape and bird abundance data shared with us by knowledge holders in BCR 12, we will also build forest simulation models to predict how sustainably managed forests provide high quality breeding habitat to support thriving bird populations that are resilient to climate change..

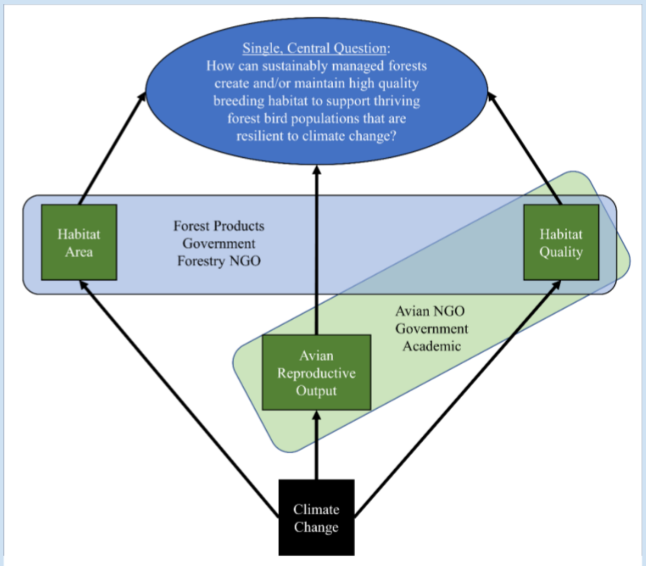


Figure. Our co-production framework for measuring the value and resilience of sustainably managed Boreal Hardwood Transition forests for birds in a changing climate. Successful co-created projects function by focusing on a single, central question because all parties share a singular objective. The single, central question for our co-production is shown in the oval. Dark green squares show the main drivers thought to answer our single, central question. The black square shows the main perturbation to the system that we are focused on. Pale rectangles indicate the wheelhouses of knowledge held by the forest products, government, and forestry NGO (blue), and avian NGO, government, and academic (green) sectors.

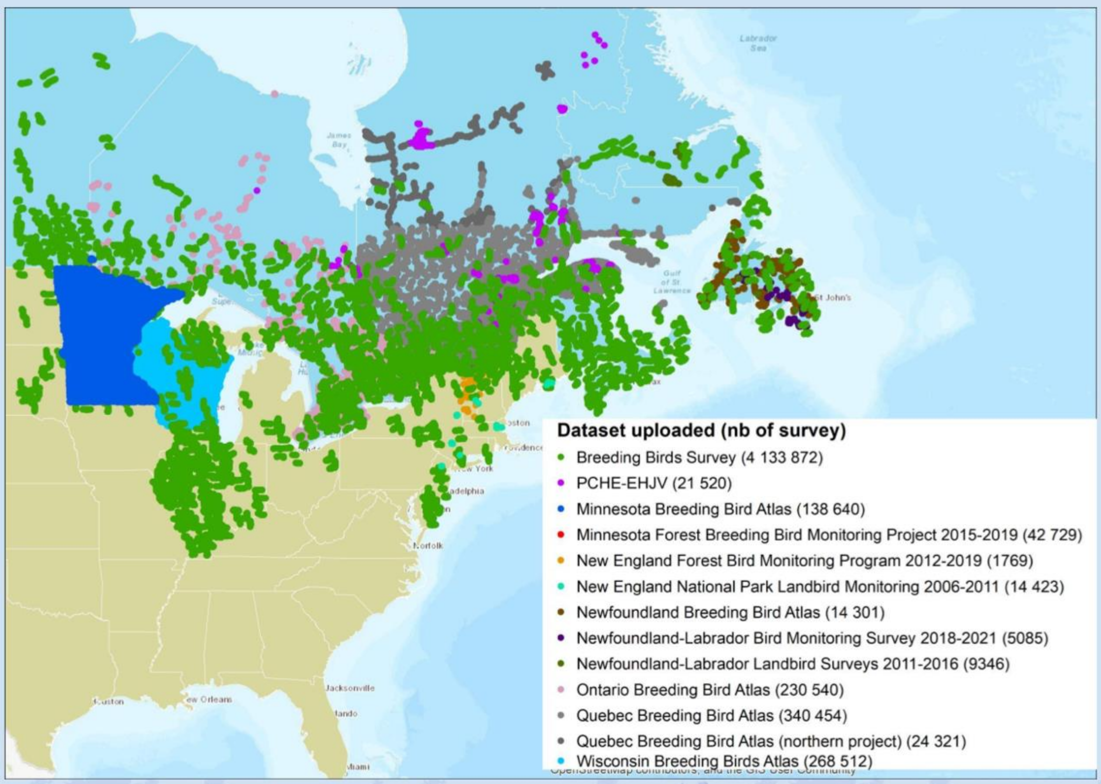
Work in progress. Contact: Maggie MacPherson; email: maggie.macpherson@gmail.com

Identifying Linkages Between Habitat Change and Population Patterns of Forest Birds (EHJV)

Detecting and forecasting avian population responses to habitat change is important for multi-species conservation and land-use planning, as well as status assessment and recovery planning for priority species. To meet the primary goal of this research to improve our understanding of how avian populations respond to habitat change in forested regions of eastern Canada, we convened an Advisory Committee to help guide the filling of avian data gaps and advise on new technical approaches being implemented in eastern Canada that estimate distributional and population responses to habitat change. This project works in parallel with the 'Sustainable forestry for bird conservation' project (above) with shared Steering Committee/Advisory Committee members and geographic overlap. As BAM's avian count data coverage for Eastern Canada is less comprehensive than for Western Canada, the modelling requirements of both projects benefit from the assembly of new avian point count data for the east. We acquired additional ECCC funding to support BAM staff time to process and upload avian count data from 150,328 new locations in the east (see research box 9). We also created a manual to enable independent processing of avian point count datasets using the BAM framework for WildTrax data uploads by data owners themselves (https://github.com/borealbirds/WT-Integration). Next steps include building regionally robust species-specific habitat models of landbird distribution and density specific to the forested portion of the EHJV for priority species. This project is funded by EHJV funding awarded to Steve Cumming and Junior A. Tremblay in March 2022. [**CO-PRODUCED Project.** Contact: Junior A. Tremblay or Steve Cumming]

Box 9. Improving cross-border partnerships through new avian data integration (BCRs 12, 13, 14)

Through our cross-border partnership, BAM Identified 24 new avian point count datasets for eastern Canada and northern United States in BCR 12 (Boreal Hardwood Transition) and BCR 14 (Atlantic Northern Forest), 13 of which were processed and uploaded into WildTrax. To ensure transparency and reproducibility of BAM's models and data products, BAM developed a rigorous workflow for adding new datasets to "the BAM database" housed in WildTrax. This rigorous workflow is available on GitHub to facilitate independent processing of avian point count datasets by data owners (https://github.com/borealbirds/WT-Integration). This resource provides additional detail to the instructions found through WildTrax (https://www.wildtrax.ca/home/resources/guide/projects/point-count-projects.html).



Work in progress. Contact: Mélina Houle, houle.melina@gmail.com

Optimizing for sustainable harvests and bird populations in forest management planning

This project aims to develop and evaluate methods to integrate bird conservation objectives into forestry optimisation models that are used for strategic and operational planning. In 2022-2023, we improved upon and adapted to the SpaDES format, an analytical method called 'post-hoc binning' that produces categories of bird density outcomes for a given study area and set of stand type and age classes based on the BAM national density models (version 4.0). This allowed us to convert national scale models developed using remote sensing to standard forest resource categorizations derived from aerial photography. In 2023-2024, the output of these models (bird density predictions by landscape category) will be incorporated into forestry optimization models to evaluate and compare the harvesting constraints required to achieve different bird density objectives. This will establish an efficient workflow for determining area-specific strategies to combine forest harvesting with bird conservation. This project is led by Isolde Lane Shaw, a PhD student with Steve Cumming at Université Laval. This work is a partnership with the Western Boreal Initiative, the SpaDES development group at the Pacific Forestry Centre (CFS), and ECCC, and benefited from funding from CWS Northern Region. [**CO-PRODUCED project**. Contact: Isolde Lane Shaw]

Black-and-white Warbler (*Mniotilta varia*)

Conservation Planning for Boreal Birds

Summary: BAM facilitates the application of our knowledge and tools to support ECCC and partners in delivering conservation for boreal birds directly or through co-benefits with other programs.

In 2022-2023, BAM continued its close collaboration with ECCC and the Boreal Ecosystems Analysis for Conservation Networks (BEACONS) project to advance large-scale conservation planning. Notably we evaluated conservation co-benefits for boreal caribou and landbirds and contributed to the Prairie Habitat Joint Venture's (PHJV) Western Boreal Implementation plan through the identification of priority areas for habitat conservation.

Identifying co-benefits for boreal caribou and landbirds across the boreal forest of Canada

The new Pan-Canadian Approach to transforming Species at Risk conservation in Canada shifts from a single species approach to one that focuses on multi-species objectives. Within this approach, conservation efforts will focus on shared priorities and identifying co-benefits for biodiversity and ecosystems. To evaluate this principle at a broad scale, we have used our National Models and the Zonation software, a widely used conservation planning tool, to evaluate the potential umbrella value of conservation directed at boreal caribou for avian species in the Canadian boreal forest. Results suggest that caribou is generally not a good surrogate for most migratory bird species, especially wetland-associated and at-risk bird species. However, multi-species, multi-objective spatial prioritizations can identify priority areas for the conservation of both caribou and migratory birds in the boreal region of Canada. We recommend using species abundance data in order to ensure priority areas represent species populations. [**CORE project**. Contact: Teegan Docherty]

Knowledge Mobilization

BAM achieves knowledge mobilization through collaboration and a range of activities related to the production, communication, and use of our research results, including knowledge co-production, dissemination, and exchange with researchers, managers, and knowledge users. We also work to achieve effective knowledge mobilization by making our data and data products publicly available, where appropriate.

Data and Data Products

Summary: The results and outputs of many of our research projects are summarized into data products such as spatial layers, maps, and data tables. BAM makes these data products publicly available to support and facilitate the conservation and management of boreal birds. The data products currently available from BAM include regional and national density estimates for approximately 160 species of landbirds and waterfowl, landbird habitat associations, climate change refugia maps, conservation planning tools, and more. We also provide information and tools to support the use of our statistical approaches to harmonize data, including publications, R packages, and online workshops. Interested parties can access the Maps & Data section on the BAM website (borealbirds.ca) to explore the available data products.

In 2022-2023, we linked habitat suitability maps and critical habitat identification maps through the BAM GeoPortal and continue to add new data products as they are created. We also obtained a large amount of high resolution, advanced satellite imagery from Planet Labs that we will use in the development of new models and data products.

BAM GeoPortal: spatially-referenced data product distribution platform

In 2022-2023, we linked our current and projected map distribution and abundance of breeding waterfowl in Eastern Canada, our species-specific habitat suitability maps for boreal-breeding passerine species, and our habitat identification for Canada warbler, olive-sided flycatcher, and common nighthawk data products to the BAM GeoPortal. As data products are created, we will continue publishing the results on our website and will link the data product on the GeoPortal to facilitate filtering products. See research box 10 for details. [**CORE project**. Contact: Mélina Houle]

Box 10. BAM Geoportal

In 2021-2022, we launched the BAM GeoPortal platform. The BAM GeoPortal is an online catalogue that lists the description, metadata of methods, results, and data products created by BAM. It has a search function to support discovery using the concept of facet and keywords through certain indexed fields. The user can quickly find the desired products even though the data products are not stored on the same data warehouse. By the use of hyperlink, the user gets redirect to the source to download.

The platform aims to make our research results more available to our partners, collaborators, and to all people or organizations who have an interest in conservation and management of boreal avifauna. The portal also includes several levels of data management (administrator, producer, user), security and display.

The BAM GeoPortal is available in French and English.

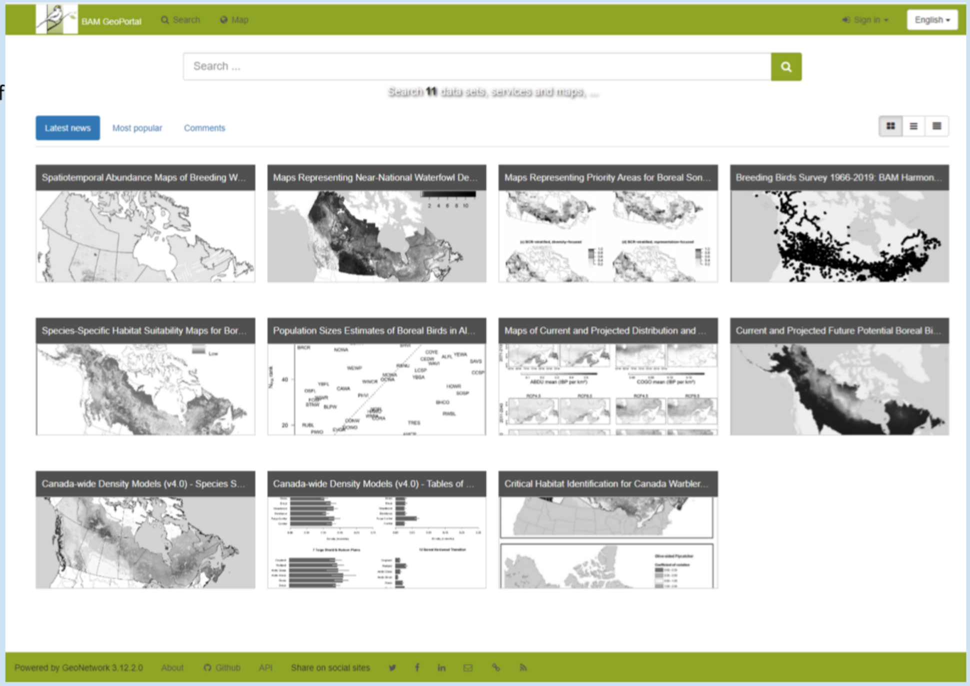


Figure. Screen capture of the BAM Geoportal interface. The BAM Geoportal is a spatially referenced platform that facilitate the discovery and accessibility of our data products.

Work in progress. Contact: Melina Houle, houle.melina@gmail.com

Planet Data Supports Integrated Research Programs in the Boreal Forest

BAM acquired additional funds in 2021-23 to access advanced satellite data from Planet Labs. BAM is collaborating with numerous integrated research programs focused on boreal forests of Canada to use these data to document how environmental changes are altering the ability of the boreal forest to sustain biodiversity and the people that call this ecosystem home. To date, BAM has extracted data that will be used in models and simulations to quantify the impacts of land-use and climate change on past, present, and future boreal bird populations. This work is a collaboration with the Boreal Ecosystem Recovery and Assessment (BERA), the Boreal Ecosystems Analysis for Conservation Networks (BEACONs) Project and the ABMI. To learn more visit: https://borealbirds.ca/planet-data/ [**CO-PRODUCED project**. Contact: Erin Bayne]

Avian Data

Summary: Since 2004, BAM has assembled, harmonized, archived, and managed one of the largest repositories of spatially-referenced avian abundance data in North America. This harmonized database contains over 10 million bird records from the boreal and hemi-boreal regions of North America. We continue to make significant progress towards our goal of improving the accessibility and sharing of this database with our partners and data users through an open data collaboration.

In 2022-2022, we collaborated with ABMI, the Bioacoustic Unit, and WildTrax to launch the point count sensor on WildTrax.ca, an online platform that now hosts our human point count database. We uploaded approximately 140 datasets to WildTrax and worked with data partners to support the sharing of their data. We continued to collaborate with partners from ECCC, Birds Canada, and ABMI to advance avian data accessibility as part of the Canadian Open Avian Data Initiative. Lastly, we developed a workflow and methods to automate the translation of point count data into the BAM and WildTrax data structure.

Open Data Initiative: Migration to the WildTrax Platform

In 2022-2023, we finalized the migration of the BAM point count database into WildTrax. Data discovery and download of all BAM point count data are now available on the platform under the point count sensor. To date, WildTrax has 164 point count projects uploaded which correspond to over 9,000,000 bird observations primarily across Canada and the northern areas of the United States. The successful migration from the BAM database v6 to the WildTrax platform eased the accessibility to compiled and harmonized point count data, while honouring the agreements of data contributors. We have also connected the WildTrax database to Birds Canada's Nature Counts database so that users can find data in both locations. We continue collaborating with our partners and others in order to expand data contribution and facilitate avian conservation and research. See research box 11 for more details on how data is handled in WildTrax.

Box 11. Point count data lifecycle in the WildTrax ecosystem

WildTrax is an online platform for managing, storing, processing, sharing and discovering biological and environmental sensor data, which as of 2023, now hosts the complete BAM database! In 2019, BAM moved its database to the WildTrax system in order to make the data more publicly accessible and to reduce workload on the BAM team. WildTrax was selected as the data repository because:

- Data is stored in a database on a secure, backed-up server
- Access is controlled via a user management system, through which data can be shared with other users and the public
- Sampling locations can be viewed on a map
- Users can download data directly via the website

Over the past three years, BAM has worked with ABMI and the Bioacoustic Unit at the University of Alberta to develop the infrastructure to store and manage historic point count data in WildTrax. As of 2023, WildTrax has now 164 point count projects uploaded which correspond to over 9,000,000 bird observations across Canada and the northern United States.

The WildTrax platform provides more than data storage and downloads; BAM has also collaborated with ABMI to create tools that allow the user to complete a full point count data lifecycle from raw data input to statistical model output (Figure). In addition to the WildTrax online interface, these tools include:

- R code that allows users to harmonize their data for WildTrax upload
- A wildRtrax R package with tools to download, clean, and format WildTrax data reports directly in R, including formatting for QPAD offset calculation

The WildTrax ecosystem allows users to easily store and manage data, and to access and integrate data from multiple projects and even data types. Together, these tools improve the potential use of avian data, facilitate data integration, reduce workloads, and improve BAM's own workflows and reproducibility. Moreover, the WildTrax ecosystem is a set of living tools that can be adapted for future user needs.

www.wildtrax.ca, https://github.com/ABbiodiversity/wildRtrax
Contact: Elly Knight, ecknight@ualberta.ca

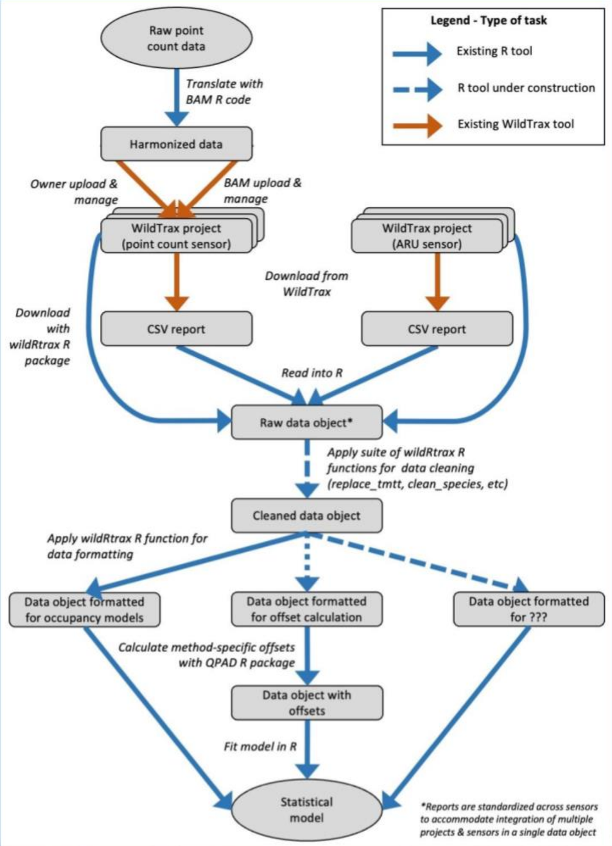


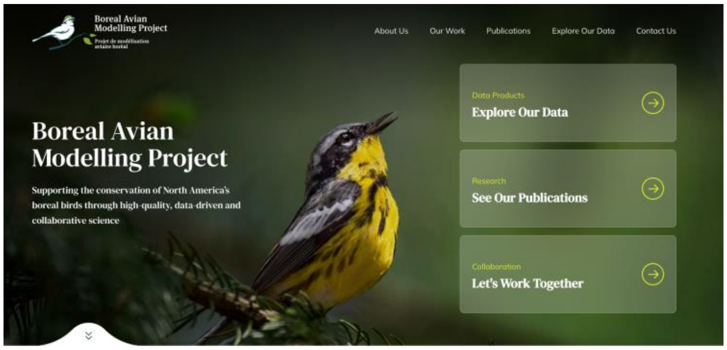
Figure. Generalized lifecycle of avian point count data in the WildTrax ecosystem from raw data to statistical model

Communications

To increase the application of our results, BAM strives to communicate our findings and make them accessible to a wide-ranging audience using a variety of formats and platforms, including scientific publications, technical reports, presentations, webinars and workshops, and our website.

Updates and Translation of the BAM Website

In 2022-23, BAM initiated and completed the development of a new website. Our goal with the redesign is to improve the presentation of content and increase efficiency in finding and understanding materials for the reader. The current website is available in both English and French, and can be viewed at https://borealbirds.ca/ [**CORE project**. Contact: Oussama Bouarakia & Hana Ambury]



Outreach & Publications

We communicate BAM research via webinars, publications in peer-reviewed journals, presentations, and reports.

BAM Publications

BAM Core Publications

No BAM Core publications were published between January 2022 and March 2023.

BAM Co-produced Publications

Publications from BAM Co-produced projects between January 2022 and March 2023.

Crosby AD, Leston L, Bayne EM, Sólymos P, Mahon CL, Toms J, Docherty T, Song, Samantha J. In Press.Domains of scale in cumulative effects of energy sector development on boreal birds. Landscape Ecology. doi: 10.1007/s10980-023-01779-8.

Edwards, B.P.M., Smith, A.C., Docherty, T.D.S., Gahbauer, M.A., Gillespie, C.R., Grinde, A.R., Harmer, T., Iles, D.T., Matsuoka, S.M., Michel, N.L., Murray, A., Niemi, G.J., Pasher, J., Pavlacky, D.C., Jr, Robinson, B.G., Ryder, T.B., Sólymos, P., Stralberg, D. and Zlonis, E.J. (2023), Point count offsets for estimating population sizes of north American landbirds. Ibis, 165: 482-503.

Leston, L., E. Bayne, J. D. Toms, C. L. Mahon, A. Crosby, P. Sólymos, J. Ball, S. J. Song, F. K. A. Schmiegelow, D. Stralberg, and T. D. S. Docherty. 2022. Comparing alternative methods of modelling cumulative effects of oil and gas footprint on boreal bird abundance. Landscape Ecology.

Micheletti, T., Haché, S., Stralberg, D., Stewart, F. E. C., Chubaty, A. M., Barros, C., Bayne, E. M., Cumming, S. G., Docherty, T. D. S., Dookie, A., Duclos, I., Eddy, I. M. S., Gadallah, Z., Haas, C. A., Hodson, J., Leblond, M., Mahon, C. L., Schmiegelow, F., Tremblay, J. A., … McIntire, E. J. B. (2023). Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. Conservation Science and Practice, 5(4), e12908.

Leston L, Dénes FV, Docherty TD, Tremblay JA, Boulanger Y, Van Wilgenburg SL, Stralberg D, Sólymos P, Haché S, Laurent KS, Weeber R, Drolet B, Westwood AR, Hope D, Jeff Ball J, Song SJ, Cumming SG, Bayne EM,Schmiegelow FKA. A framework to support the identification of critical habitat for wide-ranging species at risk under climate change.

Guillemette Labadie, Philippe Cadieux, Lucas Moreau, Fidele Bognounou, Evelyne Thiffault, Dominic Cyr, Yan Boulanger, Diana Stralberg, Pierre Grondin, Junior A. Tremblay. A multi-criteria approach to assess the avian biodiversity and carbon benefits of climate change and forest management in Eastern North American forests. Submitted.

BAM Informed Publications

Publications we're aware of that use BAM data, methods, or expert knowledge, published between January 2022and March 2023.

Lawley, C. J. M., M. G. E. Mitchell, D. Stralberg, R. Schuster, E. McIntire, and J. R. Bennett. 2022. Mapping Canada's Green Economic Pathways for Battery Minerals: Balancing Prospectivity Modelling With Conservation and Biodiversity Values.

Presentations

Presentations given by BAM Team Members between January 2022 and March 2023.

Crosby, A., 2023. Domains of scale in cumulative effects of energy sector development on boreal birds.

Drake, A., 2022. Identifying boreal climate refugia to inform species/ecosystem conservation action in a changing landscape.

Labadie, G., 2023. Bird community vulnerability induced by climate change and forest management in the commercial forest of Quebec.

Labadie, G., n.d. Cumulative impact of climate change and forest management on bird community in mixed and boreal forests in Québec.

Lane Shaw, I., 2022. Piecewise smoothing: A method of summarising bird population density models for use in forest management planning.

Leston, L., 2023a. Power Analysis in Occupancy Models of Acoustic Data from Haida Gwaii, BC, Canada.

Leston, L., 2023b. Initial analysis results from Gwaii Haanas National Park Reserve Bird Monitoring Program.

Leston, L., 2022. Boosted regression tree models of bird abundance in Nova Scotia.

MacPherson, M., 2023. Toward Cross-Border Conservation with Climate Change: Using Co-production to Overcome Ecological Complexity and Jurisdictional Barriers.

Raymundo, A., 2022. Birds ringing the bell on climate change in the Northern Canadian boreal forest.

Raymundo, A., n.d. Birds ringing the bell on climate change in the Northern Canadian boreal forest.

Stralberg, D., 2023a. Climate-informed land-use planning: Identifying efficient conservation investments in an uncertain future (invited).

Stralberg, D., 2023b. Climate-change refugia: Informing forest planning in an uncertain future (invited).

Tremblay, J., 2022. A Regional Comparison of the Impacts of Climate Change and Forest Harvesting on Boreal Bird Communities of Canada.

Webinars and Workshops

Webinars and workshops organized or co-organized by BAM, hosted between January 2022 and March 2023

MacPherson, M., 2023. How to leverage random forest modelling and ensemble modelling to predict bird distributions using eBird data.

MacPherson, M., 2022. Translating management practices into bird population estimates in 50 years.

Maggie MacPherson, Crosby, A., 2022. A fully collaborative co-production framework for forestry-related bird conservation.

Project Management

The Structure of the BAM Project

The BAM Team

The BAM Project is supported by a core team of researchers, staff, and students, as well as extensive contributions of time, expertise, data and financial support from many partners and organizations.

Project Team

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Partnerships

Our partners have made important contributions to the success of the BAM project by providing avian data, access to environmental covariates, and financial support. The BAM project would not exist without the generous contributions of its funding and data partners. If you notice any errors, please inform Hana Ambury (ambury@ualberta.ca) as soon as possible so they can be corrected.

Funding Partners

We are grateful to the following organizations that have provided funding to the BAM Project.

Founding organizations and funders

Environment & Climate Change Canada University of Alberta The Canadian BEACONs Project

Financial and In-kind support to BAM in 2022-2023

- Boreal Ecosystems Analysis for Conservation Networks (BEACONs)
- Environment & Climate Change Canada (ECCC), Canadian Wildlife Service
- Environment & Climate Change Canada, Science and Technology Division
- Mitacs Accelerate Program
- Oil Sands Monitoring (OSM) Program
- The Sustainable Forestry Initiative
- Université Laval
- University of Alberta
- Natural Resources Canada (NRCan), Canadian Forest Service (CFS)
- Ducks Unlimited Canada
- Nature Conservancy of Canada

Data Partners

The following institutions and individuals have provided or facilitated provision of bird and environmental data to the Boreal Avian Modelling Project. If you notice a name is missing, please inform Hana Ambury (ambury@ualberta.ca) so we can correct the omission.

Avian Data

Institutions:

Acadia University
Alaska Bird Observatory
Alaska Natural Heritage Program
Alaska Science Center
Alberta Biodiversity Monitoring Institute
Alberta Pacific Forest Industries Inc.
AMEC Earth & Environmental
AREVA Resources Canada Inc.
Avian Knowledge Network
AXYS Environmental Consulting Ltd.
BC Hydro
Bighorn Wildlife Technologies Ltd.
Birds Canada
Canadian Natural Resources Ltd.
Canadian Forest Products Ltd.
Daishowa Marubeni International Ltd
Devon Canada
Environment and Climate Change Canada
Fish & Wildlife Compensation Program
Golder Associates Ltd.
Government of British Columbia
Government of Saskatchewan
Government of Yukon
Hinton Wood Products
Hydro-Québec Équipement
Interfor
Kluane Ecosystem Monitoring Project
Komex International Ltd.
Louisiana Pacific Canada Ltd.
Manitoba Breeding Bird Atlas
Manitoba Hydro
Manitoba Model Forest Inc.
Manning Diversified Forest Products Ltd.
Maritimes Breeding Bird Atlas
Matrix Solutions Inc.
MEG Energy Corp.
Mirkwood Ecological Consultants Ltd.
The Nature Conservancy
Northeast Temperate Network
Ontario Ministry of Natural Resources
OPTI Canada Inc.
PanCanadian Petroleum Limited
Parks Canada
Petro Canada
Pope & Talbot Ltd.
Principal Wildlife Resource Consulting
Regroupement Québec Oiseaux
Rio Alto Resources Int'l Inc.
Shell Canada Ltd.
STRIX Ecologic al Consulting
Suncor Energy Inc.
Tembec Industries Inc.
Tolko Industries Ltd.
U.S. Army
U.S. Fish and Wildlife Service
U.S. Geological Survey, Alaska Science Center
U.S. National Park Service
Université de Moncton
Université du Québec à Montréal
Université du Québec en Abitibi Témiscamingue
Université Laval
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University of British Columbia
University of Guelph
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P. Papadol
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S. Swanson
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P. Vernier
M-A. Villard
D. Whitaker
T. Wild
J. Witiw
S. Wyshynski
M. Yaremko

Breeding Bird Atlas: We thank the Breeding Bird Atlas Projects for supplying data, the thousands of volunteers involved in the data collection, the regional coordinators, as well as the various atlas project partners including: BC Field Ornithologists, BC Nature, Biodiversity Centre for Wildlife Studies, Bird Studies Canada, British Columbia Ministry of Environment, Federation of Ontario Naturalists, Louisiana Pacific, Manitoba Conservation, Nature Manitoba, The Manitoba Museum, Manitoba Hydro, The Nature Conservancy of Canada, Natural History Society of Prince Edward Island, Nature NB, Nova Scotia Bird Society, Nova Scotia Department of Natural Resources, Ontario Field Ornithologists, Ontario Ministry of Natural Resources, Pacific Wildlife Foundation, Prince Edward Island Department of Natural Resources, Regroupement Québec Oiseaux

Breeding Bird Survey: We would like to also thank the hundreds of skilled volunteers in Canada and the US who have participated in the BBS over the years and those who have served as State, Provincial, or Territorial coordinators for the BBS.

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Docherty et al. *In prep*. Evaluating the umbrella potential of the boreal caribou to achieve multi-species conservation in the Canadian boreal forest.

Edwards, B. et al. In review. Point Count Offsets for Population Sizes of North American Landbirds.

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Leston L. et al. In review. A framework to support the identification of critical habitat for wide-ranging species at risk. Biodiversity and Conservation.

Micheletti, T., Haché, S., Stralberg, D., Stewart, F.E.C., Chubaty, A.M., Barros, C., Bayne, E.M., Cumming, S.G., Docherty, T.D.S., Dookie, A., Duclos, I., Eddy, I.M.S., Gadallah, Z., Haas, C.A., Hodson, J., Leblond, M., Mahon, C.L., Schmiegelow, F., Tremblay, J.A., Van Wilgenburg, S.L., Westwood, A.R., McIntire, E.J.B., 2023. Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. Conservat Sci and Prac 5, e12908. https://doi.org/10.1111/csp2.12908.

Wiens JA. 1989. Spatial Scaling in Ecology Published by : British Ecological Society Stable URL : https://www.jstor.org/stable/2389612 Spatial scaling in ecology1. Functional Ecology 3:385–397.

Boreal Avian Modelling Project

Annual Report April 2022 - March 2023

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Projet de modélisation aviaire boréal

COVER PHOTO:

Black-throated Green Warbler: Cameron Meuckon (CC)

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