ANNUAL REPORT

April 2023 - March 2024

Boreal Avian Modelling Project

Project de modélisation aviaire boréal

Highlights from 2023–2024

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 April 2023 - March 2024 are listed below.

Research and monitoring

Population status and trends

- Progress towards the completion of version 5.0 of BAM's landbird density models for the boreal/hemiboreal region of North America. ► page 8
- Manuscript (Stralberg et al., in revision) documenting version 4.0 of BAM's landbird density models is under revision in the journal *Ecosphere*. ► page 8

Species at risk status and recovery planning

- Article (Leston et al. 2024) published in the journal *Biodiversity and Conservation* synthesizing a conceptual and analytical framework to support the identification of critical habitat for wide-ranging species, comparing Canada Warbler and Wood Thrush. ► page 12

Climate and landscape change impacts

- Article (Labadie et al. 2024) published in the journal *PLOS Climate* on the cumulative effects of climate change and forest management on bird communities and ecosystem services in two contrasting forests in Eastern North America. ► page 13
- Article (Raymundo et al. 2024) published in the journal *Climate Change Ecology* forecasting spatially-explicit changes in the densities of 72 boreal landbird species using integrated climate change projections and a forest dynamics model in the Northwest Territories. ► page 16

Energy and mining impacts, and cumulative effects

- Article (Crosby et al. 2023) published in the journal *Landscape Ecology* identifying the spatial scales at which cumulative effects of energy sector development (oil and gas) act on boreal songbirds in Alberta. ► page 19
- Initiation of a new project funded by Environment and Climate Change Canada (ECCC) to assess and mitigate the impacts of development projects on forest-associated migratory bird species across subarctic Canada. ► page 19

Forestry impacts

- Article (MacPherson et al. 2024) published in the journal *The Forestry Chronicle* synthesizing a co-production framework to conduct research that will inform forest management practices for bird conservation in the cross-border Great Lakes region. ► page 22
- Initiation of a new project with Natural Resources Canada (NRCAN) exploring opportunities to assess forest degradation using our national-scale models of forest birds as indicators of change. ► page 24

Conservation planning for boreal birds

- Development of spatial prioritizations using BAM's national-scale density models to identify regional priority areas for the conservation of forest and wetland-associated bird species across eastern Canadian provinces, as part of the Eastern Habitat Joint Venture. ► page 26

Monitoring and sampling

- BAM continues to support Environment and Climate Change Canada (ECCC) with the development and implementation of the Boreal Optimal Sampling Strategy (BOSS) by providing BAM data, products and tools. ► page 27

Knowledge mobilization

Data and data products

- 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. ► page 28
- The BAM GeoPortal is an online platform that facilitates the discovery and accessibility of our spatially referenced data products. ► page 28
- BAM continues to improve the discovery, accessibility, integration, and use of bird data in Canada as a member of the Canadian Open Avian Data initiative (CanAvian). The BAM point count database is available in the online platform WildTrax under the BAM organization. Datasets are openly available to the extent that sharing agreements with data partners permit. ► page 30
- Automation of the BAM data standardization process is facilitating the integration and uploading of new point count data. The automation workflow is publicly available through our GitHub platform (https://github.com/borealbirds/WT-Integration). ► page 30

Outreach and knowledge delivery

- We are contributing to the development of a communications experiment based on the critical habitat identification framework for species at risk (Leston et al. 2024) that will compare preferences and perspectives about the communication approach and application of this framework among different audiences. ► page 32

Communications

- BAM co-authored six peer-reviewed articles in 2023-2024. ► page 33
- In 2023-2024, our contributions to research and conservation were highlighted in one workshop organized by BAM, and in five talks at international and regional conferences. ► page 34

New BAM Team members

- Dr. Oussama Bouarakia has taken his role as the new Program leader for BAM. With a multidisciplinary and multilingual background, Oussama has conducted scientific research on diverse topics (zoology, ecology, evolutionary biology and social sciences). He has also worked as a project manager and educator in NGOs focused on science awareness, environmental issues and youth capacity building.

- Four new Postdoctoral fellows joined the BAM team and are now working on BAM-core or co-produced projects:
  - Dr. Angela Moreras (Laval University) is conducting research on the response of avian populations to habitat change in forested regions of eastern Canada.
  - Dr. Shirin Varkouhi (Laval University) is studying forest management practices and their impacts on bird populations across eastern Canada.
  - Dr. Brendan Casey's (University of Alberta) main research interests include remote sensing and species distribution models for boreal forest birds.
  - Dr. Mannfred Boehm's (University of Alberta) work is focused on estimating and mitigating impacts of development on forest-associated migratory bird species.

- We welcomed Siu Chung Wu as our new Geospatial data analyst. Siu Chung brings his technical skills in geomatics.

Table of contents

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 the direction, merit, and relevance of BAM's science activities. Day-to-day management is overseen by our program leader.

Project execution is facilitated by a dedicated team of staff, postdoctoral fellows, and graduate students. Contributing Scientists provide expert advice and are involved in co-production of relevant science. The collaborative nature of BAM is evidenced by the many individuals who have provided project assistance and support over the years. To learn more about our team visit page 35.

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.

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

BAM 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.

BAM-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 and 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 2023–March 2024.

Population status and trends

Summary:

BAM is working to produce 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.
In 2023-2024, we moved toward the completion of our latest forest landbird models for northern North America (version 5.0). This involved expanding our study area and developing reproducible and generalizable modeling workflows and diagnostics, such as estimates of variance and sampling coverage. We are continuing to participate in the NA-POPS project for developing detection offsets for landbirds throughout North America, the Partners in Flight (PIF) Population Estimation Working Group, and the PIF Detectability Working Group. In 2023-2024, we also joined the Northern Ontario Bird Modelling Working Group to help improve landbird models in this sparsely sampled region and contribute to conversations around best modeling practices for landbirds.

BAM national density models version 4.0 and version 5.0

In 2023-2024, we continued to refine and update our generalized analytical approach for modelling landbird species densities and estimating population sizes. We are working to complete 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, with a focus on choosing products that can be temporally matched to bird survey data to accurately represent the environmental conditions during the time of survey. We have also expanded our study area to include the 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 and inclusion of appropriate eBird data. We have also developed new methods to blend model predictions from individual regions to create continuous prediction areas across the boreal and hemiboreal. Finally, we have developed additional geospatial products to complement mean density predictions, including variation in predictions, sampling density, and areas of extrapolation to better inform how our density models should be interpreted and applied.

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. While moving forward with the development of version 5.0 of the national models, we have simultaneously continued our analysis of version 4.0 outputs, and a manuscript (Stralberg et al.) describing our framework for

creating large-scale population estimates based on version 4.0 of the National Models is currently under revision in the journal *Ecosphere*. Visit https://borealbirds.github.io/ to explore version 4.0 of our density models. We presented our modeling approach to a symposium on data analyses for breeding bird atlases at the Conference of the American Ornithological Society/Society of Canadian Ornithologists (London, Ontario, 2023). See research box 1 for additional information.

[**CORE project**. Contact: Elly Knight]

Research box 1. BAM landbird density models version 5.0

Version 5.0 of BAM's landbird density models represents a substantial improvement over version 4.0 in modelling area, sampling coverage across that modelling area, and covariates included in the models.

Together, these improvements have greatly reduced extrapolation in the models. Extrapolation occurs when a model is used to make predictions within areas that contain environmental covariates beyond the range of the data used to train the model.

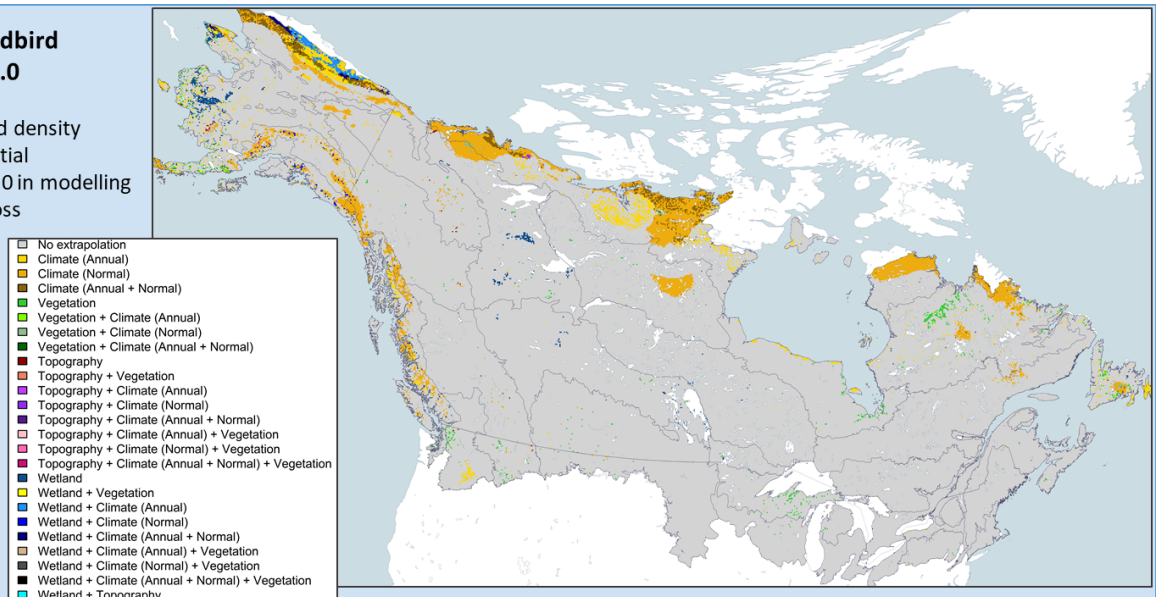


Figure. Area and covariate category of extrapolation in version 5 of the BAM landbird density models. Extrapolation calculations based on covariate layers for the year 2020.

The reduction in extrapolation for version 5.0 of the models should improve the accuracy of the predictions across Canada, particularly in areas that were previously undersampled like the James Bay lowland region of Northern Ontario. Remaining extrapolation in the models is primarily due to areas with climate averages that are outside the range of sampling in the far north and high elevation mountain ranges on the Pacific coast. There continue to be patches of vegetation covariate extrapolation in northern Québec and Newfoundland within Canada, and Michigan within the United States. Extrapolation across several covariate groups occurs in Alaska. We hope to work with partners to improve sampling in these regions for version 6.0 of the BAM landbird density models.

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

Workflow reproducibility

In 2023-2024, we used the opportunity while developing version 5.0 to improve the reproducibility of our modeling process, which will improve efficiency, transparency, consistency, and future modeling efforts. This reproducibility process starts with the wildRtrax R package that produces a date-stamped data product download, from the BAM point count database that has been migrated to WildTrax. All data storage occurs on cloud-based tools like Google Drive and we use Google Earth Engine for data storage and geospatial processing wherever possible. Most importantly, team members use a public GitHub repository to store and share all computer code used for the modeling process, including frequent review and code sharing (https://github.com/borealbirds). These reproducibility initiatives will be used to inform the development of templates and best management practices around information management within BAM.

[**CORE project**. Contact: Elly Knight]

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 2023-2024, we paused production of version 4 of the QPAD R-package for an in-depth analysis of how the detection process varies between human point counts and autonomous recording (ARU) surveys. Comparison of these two data types suggests that human error in the point count process may actually be leading to underestimation of the probability of detection, and that simply including detection type in QPAD models may introduce biases into density estimates for areas or time periods that are dominated by a particular survey method. We initiated the production of a manuscript for peer-review that compares the detection process between point counts and ARU surveys and how differences affect estimates of availability and perceptibility, the two components of detectability. Production of version 4 of the QPAD R package, including the addition of new species, will resume following resolution of the best approach for integration of point count and ARU data within the QPAD framework.

In 2023-2024, we also presented a QPAD workshop on "Detectability offsets to combine survey data from independent boreal bird studies" at the Conference of the American Ornithological Society/Society of Canadian Ornithologists (London, Ontario, 2023).

[**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. We are currently refining empirical models and simulation models using the new approach prior to submission as a peer-reviewed manuscript.

[**CORE project**. Contact: Elly Knight]

Detectability working group

BAM's experience within bird abundance modelling has given us a unique perspective on the state of the field of detectability research. In 2023-2024, we continued to co-chair an international detectability working group in collaboration with the NA-POPS project. This year, the group continued their investigation of non-independence between the two components of detectability, availability and perceptibility, as well as discussion of best approaches to studying detectability, and much more. We also proposed and organized a Special Feature issue in the journal *Ornithological Applications*, which will be accepting manuscripts for submission and publication in 2024-2025. 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]

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

BAM is a collaborator in the NA-POPS (Point count offsets for population sizes of North American landbirds) large-scale, multi-agency research project. NA-POPS's goal is to provide open-source detectability offsets for habitat-based modelling of landbird density 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. To learn more, visit the NA-POPS website (https://na-pops.org/). In 2023-2024, BAM provided feedback on NA-POPS' proposed approach to use hierarchical models to estimate offsets for data sparse species. BAM also continues to sit on the Partners in Flight (PIF) Population Estimation working group to provide advice on the inclusion of NA-POPS's offsets in updating population estimates of North American bird species. We provided input and supporting analyses for key decision points in that process, including contributing to a peer-reviewed manuscript being drafted for submission in a Special Issue on North American bird management.

[**CO-PRODUCED project**. Contact: Elly Knight]

Northern Ontario Bird Modelling Working Group

In late 2023, scientists from Environment and Climate Change Canada (ECCC) convened the Northern Ontario Bird Modeling Working Group (NOBWG). With a primary focus on northern Ontario, the purpose of this group is to coordinate and enhance the extraction of information from emerging bird datasets and to tailor methods, results communications, and products to the needs of relevant sectors. Participants in the working group include representatives from federal and provincial government agencies, academic institutions, and NGOs. Outcomes from this working group may be useful for other jurisdictions for which northern bird data availability is expanding (e.g., Québec). BAM was invited to join the NOBWG, attended a three-day kick off meeting in Ottawa, Ontario in March 2023, and continues to participate in initiatives of the working group.

[**CO-PRODUCED project**. Contact: Elly Knight]

Species at risk status and recovery planning

Summary:

Identifying the location and amount of critical habitat needed by a species at risk (SAR) is an important step in recovery planning. BAM's research, analytical approaches, and data products support recovery planning and the identification of critical habitat. In 2023-2024, BAM published an article demonstrating the application of a modelling framework supporting identification of critical habitat, applied to Canada Warbler and Wood Thrush.

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 2023-2024, we published an article in the journal Biodiversity and Conservation (Leston et al. 2024) that applied a modelling framework to support identification of critical habitat for Canada Warbler (*Cardellina canadensis*) and Wood Thrush (*Hylocichla mustelina*). 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, density and distribution of a species could change in the future by simulating land-use and climate change; and 5) using spatial prioritization exercises (raster overlay analysis) to identify areas where protection or management of current or future habitat would contribute to the recovery of a SAR. 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.

[**CORE project.** Contact: Lionel Leston]

Detecting and attributing land-use and climate change impacts on boreal birds

BAM uses modelling and simulation to evaluate drivers of change in bird distribution and abundance, and to quantify impacts of climate change and industrial activities on past and future migratory bird populations to inform land-use planning and management. These research projects provide methods, tools, and recommendations to support impact assessment, land-use planning, and habitat management for migratory birds and their habitats.

Climate and landscape change impacts

Summary:

Boreal ecosystems are experiencing a rapid change in climate, which threatens important breeding habitats for some boreal forest landbirds. BAM continues to co-produce several research projects that use spatial simulation models combined with avian density models to enhance our understanding of potential future impacts of climate and land cover changes on boreal bird populations, including species at risk. We have also used bioclimatic models to evaluate projected 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, in turn, helps to inform climate-smart conservation planning and land-use management.

In 2023-2024, BAM continued collaborative work on several co-produced projects in Québec, Yukon, and the Northwest Territories, leading to two new publications. In the Yukon, new bioclimatic models were used to project avian responses to climate change and identify potential climate change refugia. In Québec, bird models were coupled with forest landscape simulations (LANDIS-II) to assess carbon trade-offs and co-benefits. In the Northwest Territories, bird models were coupled with forest growth and fire models in SpaDES, and used to anticipate the magnitude and direction of change in bird populations under climate change.

Projected impacts of climate change and disturbances on eastern boreal birds

Assessing the cumulative effects of forest management and climate change on biodiversity and ecosystem services, including carbon sequestration and storage and provisioning of wood products, is key to informing long-term forest management and conservation decision making. Using bird models for Québec, we projected changes in forest composition and structure 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 the Québec province: one hemiboreal (Hereford Forest) and one boreal (Montmorency Forest). We then assessed projected changes to bird assemblages, as well as to sensitive and at-risk species. As part of an integrated assessment, we compared the best possible forest management measures aimed at preserving avian diversity to the optimal forest management measures for mitigating carbon emissions to the atmosphere. See research box 2 for additional information. An article on this research was published in the journal *PLOS Climate* (Labadie et al. 2024).

Research box 2. Cumulative effects of climate change and forest management on bird communities and ecosystem services in two contrasting forests in Eastern North America

Forest management and climate change were projected to lead to significant changes in bird assemblages in both types of forest through changes in forest composition. We projected an increase in deciduous vegetation which favored species associated with mixed and deciduous stands to the detriment of species associated with older, coniferous forests. Changes were more pronounced in Hereford Forest (hemiboreal) than Montmorency Forest (boreal). In addition, Hereford's bird assemblages were mainly affected by climate change, while those in Montmorency Forest were more impacted by forest management.

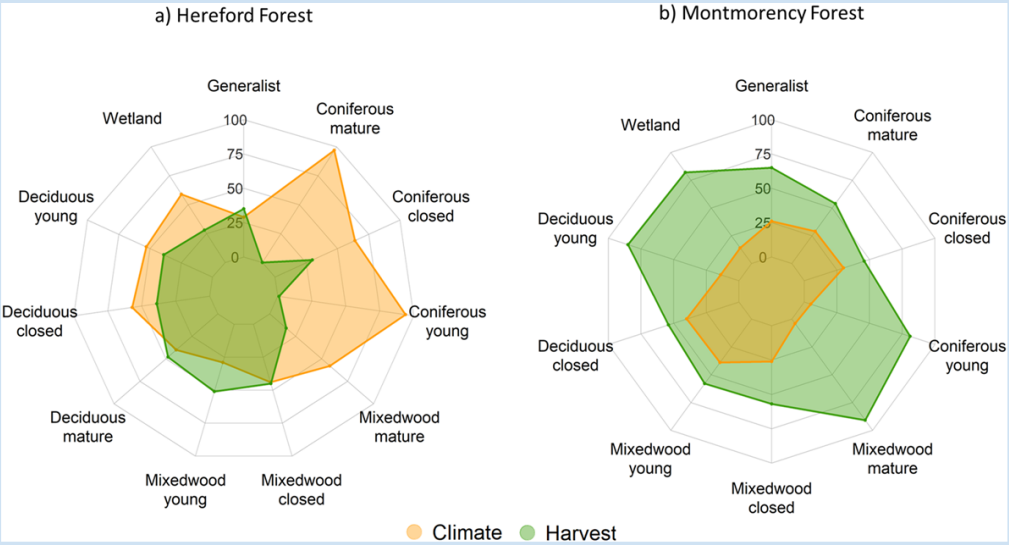


Figure. The relative contribution of drivers of change (climate change and forest management) as values of ω2 (mean), under RCP 8.5 at year 2100 relative to the change simulated under baseline climate.

We estimated that 25% of Hereford and 6% of Montmorency species will be sensitive to climate change (projected changes in abundance, positive or negative, greater than 25%). According to the simulations, a decrease in the level of forest harvesting could benefit bird conservation and contribute to reduction of carbon emissions in the boreal forest area. Conversely, in the hemiboreal forest area, trade-offs will be necessary, as mitigation of carbon emissions is favored by more intensive forest management that stimulates the growth and carbon sequestration of otherwise stagnant stands.

doi.org/10.1371/journal.pclm.0000293. *Contact: Junior Tremblay, junior.tremblay@ec.gc.ca*

As a follow-up, we investigated the impacts of climate change and forest management on bird species assemblages in the boreal forests of Québec over the 2020–2100 horizon. Using spatially explicit simulations of forest landscapes and empirical abundance models for 73 bird species, we examined shifts in bird species' distributions and habitat changes under various climate scenarios (see research box 3 for additional information). This research underscores the necessity of integrating disturbance regimes and comprehensive habitat modeling to better predict and manage the impacts of climate change on avian biodiversity in boreal ecosystems. Our results suggest that targeted conservation actions will be crucial for mitigating future climate-driven distribution shifts and population declines of boreal birds. An article (Labadie et al.) based on this work is currently under review.

Research box 3. Projecting bird assemblage responses to climate-driven changes in managed boreal forest landscapes of Québec

We examined the complex interplay between climate change and forest management-induced changes in forest composition and structure, which can have profound effects on bird habitats.

The study also incorporated the effects of wildfire, demonstrating its significant influence on bird distribution shifts along an east-west axis. Notably, increases in wildfires may drive northwestward shifts of species associated with human-temperate forests, which can benefit from landscapes dominated by younger stands and pioneer tree species.

Our findings highlight a range of sensitivity among bird assemblages across latitude. The results indicate that species associated with boreal coniferous and mixed forests are at greater risk of decline, especially in southern regions, compared to more generalist species, which showed greater adaptability to changing conditions.

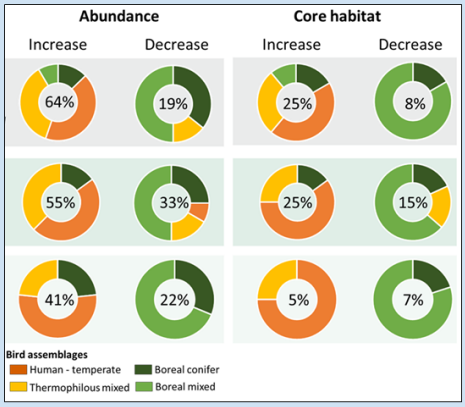


Figure 1. Percent of bird species that are predicted to be sensitive to the cumulative impact of climate change and forest management under RCP 8.5 in 2100. The cumulative impact of forest management and climate change are considered important when bird species associated to a bird species assemblage show an increase or a decrease in their abundance or the size of their core habitat of more than 25% compared to the reference period (i.e., 2020).

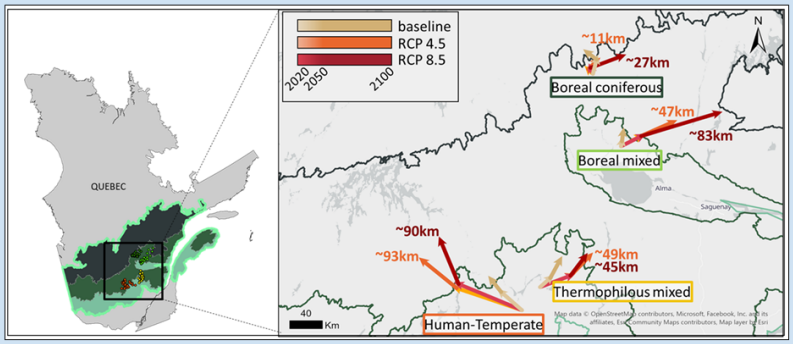


Figure 2. Direction and distance of predicted range centroid shift of bird assemblages in 2050 (light color) and 2100 (dark color) under baseline, RCP 4.5 and RCP 8.5 climate scenarios. The origin of the arrows corresponded to the centroid in the reference period (2020) for each bird assemblage. Values in red and orange corresponded to the distance (in Km) between the centroid in 2020 and the centroid under RCP 8.5 and RCP 4.5, respectively, in 2100 for each bird assemblage.

Work in progress. Contact: Junior Tremblay, junior.tremblay@ec.gc.ca

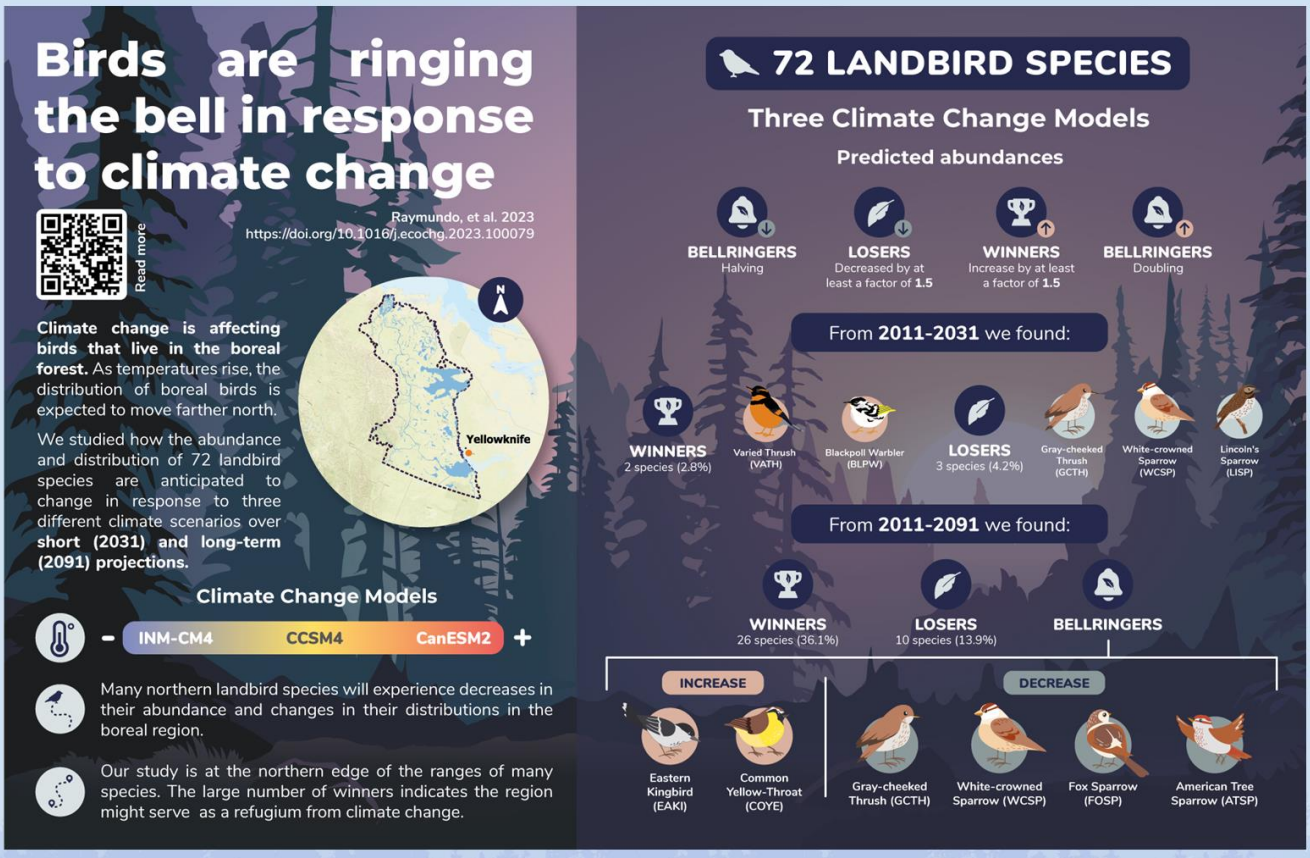
A third objective of the project was to study changes in bird species abundance and distribution in the commercial forests of Québec in response to the cumulative effects of forest management and climate change. We conducted spatially explicit simulations of forest landscapes to estimate how changes in forest composition would alter bird community composition, density, and habitat suitability based on 97 bird species empirical distribution models. Our analysis revealed changes in the composition of boreal landscapes with an increase in land use and climate change, resulting in an increased proportion of deciduous vegetation. Subsequently, we predicted changes in bird community composition and regional distribution. Ultimately, this research will provide valuable insights into the maintenance of the integrity of bird populations to the cumulative impacts of forest management and climate change in the boreal forest. This information is essential for developing conservation strategies and promoting sustainable forest management to mitigate the effects of these disturbances on bird communities and the boreal forest ecosystem as a whole. An article (Labadie et al.) highlighting this research will be submitted soon.

[**CO-PRODUCED project.** Contact: Junior Tremblay]

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

Recent research builds on work by Micheletti et al. (2021), broadening the scope to explore climate-driven shifts in boreal bird populations in the Taiga Plains ecozone. By integrating forest dynamics and climate change projections, we mapped potential range and density changes for 72 boreal landbird species and identified those species likely to benefit or suffer from climate change (see research box 4 for additional information). Our work highlights the role of the Northwest Territories as a potential climate refugium for some species, reinforcing the importance of adaptive management strategies. This research aligns with the broader objectives of the Western Boreal Initiative (WBI), which aims to balance forest management with conservation efforts, considering both ecological and socio-economic factors. In expanding on the WBI's original focus, this study provides valuable insights into biodiversity conservation in the face of climate change. An article (Raymundo et al. 2024) on this research was published in the journal *Climate Change Ecology*.

Research box 4



doi.org/10.1016/j.ecochg.2023.100079. *Contact: Ana Raymundo, AARAS2@ulaval.ca*

Resilience, the ability of ecosystems to recover and adapt while maintaining their functions, is critical for supporting biodiversity under changing environmental conditions. This study examined community resilience among 72 landbird species in the Northwest Territories, focusing on functional diversity (i.e., the variety of ecological roles species play) and functional redundancy (i.e., the extent to which different species can perform similar functions). Together, these attributes contribute to resilience by ensuring ecosystem stability and adaptability to disturbances. Using climate-sensitive models for forest dynamics (*LandR CS*) and wildfire (*FireSense*), we projected how tree species and habitat will shift for two-time frames, short- (2011-2031) and long-term (2011-2091). We then evaluated how these changes will affect the densities of the 72 bird species. Using a cross-scale resilience model, we assessed changes in functional redundancy and diversity, and found that northern regions are predicted to experience a decline in resilience over time. Conservation strategies must account for the spatial variability in vulnerability, prioritizing efforts to strengthen resilience in areas most susceptible to functional loss. This work expands the scope of the Western Boreal Initiative (WBI) by incorporating biodiversity and ecosystem stability into the broader framework. It provides a more nuanced understanding of species adaptation to climate change, enriching WBI's objectives to support adaptive management and conservation of vulnerable ecosystems. See research box 5 for additional information.

[**CO-PRODUCED project.** Contact: Ana Raymundo]

Research box 5. Predicting landbird communities resilience in the Taiga Plains of the Northwest Territories

Guided by a cross-scale resilience model, we examined functional diversiy and redundancy to assess community resilience.

Our findings suggest southern regions are predicted to show greater resilience, while nothern regions could experience a decline in redundancy and increased community reorganization.

Conservation efforts should prioritize vulnerable areas by maintaining habitat heterogeneity and connectivity to support species adaptation and range shifts.

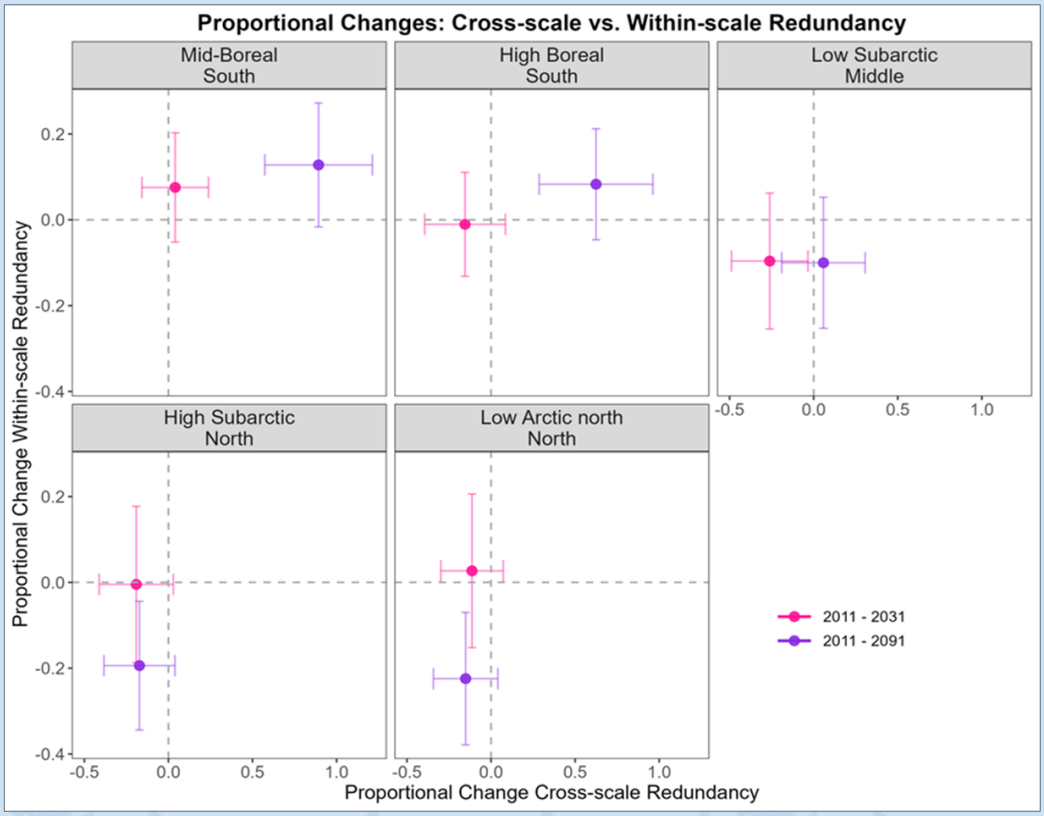


Figure. Proportional change in cross-scale and within-scale redundancy by year intervals in the Taiga Plains in the Northwest Territories, Canada. Dots represent the mean proportional change and the bars, represent the standard error.

Work in progress. Contact: Ana Raymundo, AARAS2@ulaval.ca

Yukon boreal cordillera climate change refugia

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. We collaborated with the Canadian Wildlife Service and the Canadian Forest Service to develop climate-based species distribution and abundance models (SDMs) for 46 landbird species that currently breed in the Boreal and Taiga Cordillera ecoregions in northwest Canada and Alaska, USA. We used these models to project species' distributions and abundances in the region by the year 2100 under multiple climate change scenarios, and then identified climate change refugia by accounting for plant colonization potential. See research box 6 for additional information. An article (Drake et al.) will be submitted soon.

[**CO-PRODUCED project.** Contact: Anna Drake]

Research box 6. Identifying northwest boreal climate refugia to inform species conservation action in a changing landscape

Our refugia-corrected population change estimates indicate that approximately one quarter of our modelled species will decline in the region by the year 2100.

These species are more likely to be conifer-specialists or occupy subalpine and tundra/alpine vegetation zones, and their populations tend to have more restricted current ranges and/or use high elevation habitat in the Cordilleras.

In contrast, our results indicate that the region will become more suitable for many long-distance migrants.

Geographically, our work highlights low elevation sites within the upper reaches of watersheds as areas that will retain or gain high value for a diversity of landbird species by 2100, making them important sites for stewardship and conservation.

Most of these areas do not fall within current IUCN-designated protected areas and are subject to greater anthropogenic disturbance.

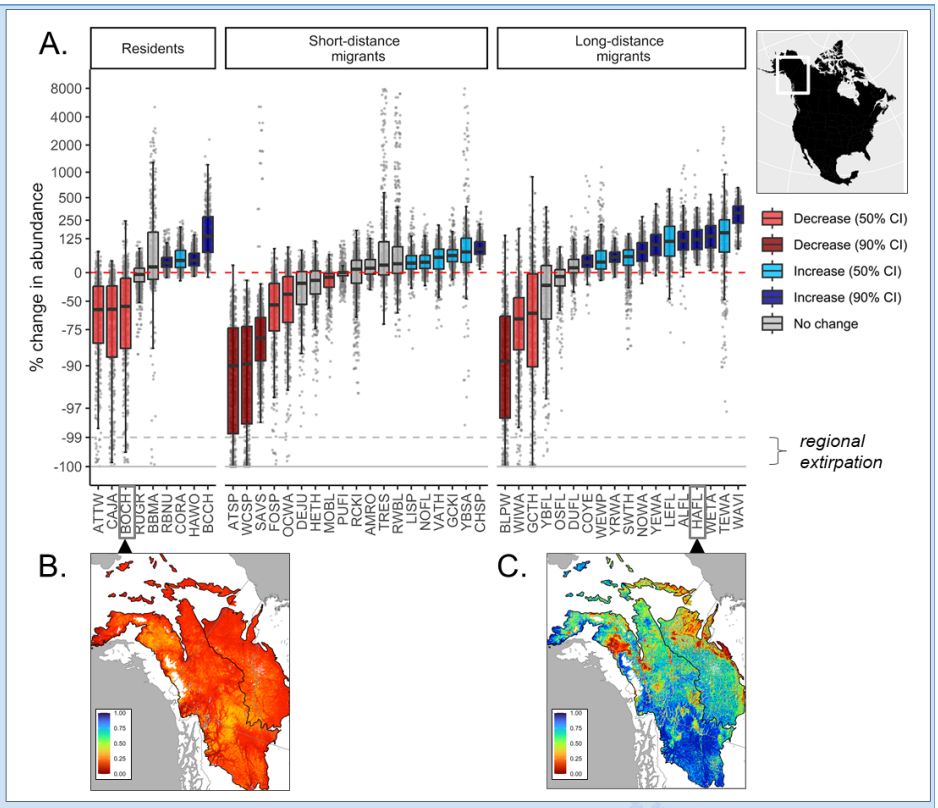


Figure. Projected change in abundance for 46 landbird species by 2100 within the Taiga and Boreal Cordillera (A). Illustrative maps of future suitable refugia space for a projected-to-decrease species, Boreal Chickadee *Poecile hudsonicus* (B) ; and a projected-to-increase species, Hammond’s Flycatcher *Empidonax hammondii* (C). Six species had 95% CIs that included regional extirpation scenarios.

Work in progress. Contact: Anna Drake, anna.drake@nrcan-rncan.gc.ca

Energy and 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 2023-2024, we identified domains of scale in the observed responses of migratory songbirds to oil sands development in Alberta. We also worked on the evaluation of boreal birds' colonization/extinction dynamics in Alberta's oil sands region. Additionally, we initiated a project to inform the impact assessment and mitigation of industrial developments on forest-associated migratory bird species across subarctic Canada. Furthermore, we started developing a framework for using quantitative wildlife data to assess the state of active or passive ecological restoration of industrial footprint.

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 (Alberta Biodiversity Monitoring Institute), using bird occupancy data and spatial predictor data from ABMI, summarized at multiple spatial scales. This project investigates how oil sands development affects bird populations in Alberta and how these changes might reflect scale-specific processes. An article (Crosby et al. 2023) was published in the journal *Landscape Ecology*.

[**CO-PRODUCED project**. Contact: Andrew Crosby]

Impact assessment of forest-associated migratory bird species

In 2023-2024, we initiated a new ECCC-funded project to inform impact assessments of development projects across subarctic Canada. The overarching goal of this project is to leverage BAM landbird density models to quantify past cumulative effects of resource industries, and use these results to predict the impacts of proposed developments, specifically within the Impact Assessment (IA) process. This IA-focused project has four major phases: (1) To evaluate the need for offsetting by quantifying the cumulative effects of development on migratory birds, under both historical and future perspectives; (2) Develop a framework to calculate the offsets for a proponent's project contributions to these cumulative effects; (3) Identify priority offset habitats on the landscape that match the proponent's contribution to cumulative effects; and (4) Develop value-added products in collaboration with other IA fund recipients and relevant government personnel (e.g. Impact Assessment Agency).

Foundational to the completion of Phase 1 (quantifying cumulative effects on boreal birds) are models describing changes in species density across time. In 2023-2024, the latest version of the BAM National Models (version 5.0) computational pipeline was developed and tested. Several aspects of the version 4.0 models were foundational to the improvement and development of version 5.0, e.g., the performance metrics of the version 4.0 models were used alongside Avian Conservation Assessment Database (ACAD) rankings to identify priority species for the version 5.0 pipeline. This ensures that species of conservation concern with accurate density

models will be available for the development of Phase 2 (develop impact summary). As the first version 5.0 models are completed, we are analyzing their outputs for quality control, and developing automated methods for identifying predictor variables that are driving trends (e.g. vegetation, climate, year).

The completion of Phase 1 depends on reliable models describing changes in species density across time. To this end, code is currently in development to estimate species density within user-specified areas and timeframes of interest across the boreal. This functionality will be core to mobilizing BAM models within the IA framework, as proponents or reviewers could enter the proposed development footprint to obtain a baseline estimate of species diversity and density affected. These programmatic tools are being organized into a forthcoming R package "BAMexploreR" which will allow broader public access to BAM's version 5.0 models.

BAM researchers have met with policy analysts from the Impact Assessment Agency (IAA) to get feedback on how results from the IA project could best inform IAA initiatives, e.g., how version 5.0 models can be incorporated into an IAA offsetting tool in development, including integration of non-avian wildlife. Their input has been and will continue to be central to Phase 4 (value-added products). We also identified the ECCC Draft Offsetting Policy for Biodiversity (version 1.2) as the logical framework for guiding Phase 3 (offset ratios and guidelines). We identified where version 5.0 models will best contribute to offsetting within the context of this policy. Ultimately, the mechanisms outlined in this draft policy, and the needs communicated by IAA personnel, will guide our decisions in Phase 2 (calculate offsets) and Phase 3 (identify priority habitat).

This project is funded by an ECCC Impact Assessment grant awarded to Erin Bayne and Diana Stralberg.

[**CORE project**. Contact: Mannfred Boehm]

Oil sands monitoring of colonization/extinction of boreal birds

BAM uses species distribution models (SDMs) to predict occupancy and abundance at sites that vary in habitat features and human footprint. SDMs can be configured as dynamic occupancy models to determine species persistence at a site over time, which serves as a measure of habitat quality assuming persistence and quality are positively correlated. From January-March 2024, we worked with two curated point count datasets (one each for Ovenbird and Yellow Rail occupancy). Point counts in these datasets came from sites with at least 2 years of visits (needed to quantify persistence), and the amount of different types of oil and gas footprint changed across years at some of the sites in each dataset. We ran models for Ovenbird and Yellow Rail in JAGS (JAGS 2023, Plummer 2003) using the runjags package (Denwood 2016) in R, and evaluated models using the Widely Applicable Information Criterion (WAIC), leave-one-out cross-validation (LOO-IC), and Area-Under-the-Curve (AUC).

Ovenbird models predicted weak effects of oil sand footprint amount or cumulative effects on colonization or persistence. Predicted turnover decreased while persistence of Ovenbird at sites increased over time with added footprint. In contrast, Yellow Rail models predicted a stronger negative effect of industrial plants and mines on persistence of Yellow rails (i.e., a more positive distance coefficient) and higher probabilities of persistence closer to roads, seismic lines, and low-activity wells. In other words, predicted turnover increased while persistence of Yellow Rail at sites decreased over time with the addition of oil and gas footprint. We also curated similar point count data sets for several upland old-growth forest indicator species (Canada Warbler, Bay-breasted Warbler, Brown Creeper, Cape May Warbler and Pileated Woodpecker), using human and ARU-based point count data stored on the WildTrax repository. We resurveyed 92 of these points from May 28-June 30 in 2024. Dynamic occupancy models for these species will be run in the spring of 2025.

Funding for this project was provided by the Joint Canada-Alberta Oil Sands Monitoring Program.

[**CO-PRODUCED project**. Contact: Lionel Leston]

Ecological framework for assessing and incorporating reclamation success into SDMs and conservation planning

The boreal forests of Canada are subject to forestry and in western Canada, oil and gas development. While the effects of these industries on different kinds of wildlife at the time of development and industrial activity (harvest, construction, energy extraction) are increasingly well understood, we do not understand as well 1) how long it takes for wildlife to reoccupy different footprints once activity has ended and a footprint is allowed to regenerate, and 2) how fast wildlife re-use of footprint occurs in response to different active restoration strategies. Using point count data from mines and oil/gas footprint subject to reclamation activities, we propose to use case studies from Alberta (and possibly other boreal forest provinces) to show how SDMs may be used to predict return of wildlife species to reclaimed footprint and how these SDMs may be applied to land use and conservation planning. Funding for this project was provided by ECCC.

[**CO-PRODUCED project**. Contact: Lionel Leston]

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 2023-2024, we improved our ability to provide actionable science for bird conservation in managed forests and to inform forest management decisions under land-use and climate change. We also continued to develop and evaluate methods to integrate bird conservation objectives into forestry optimisation models that are used for strategic and operational planning. Additionally, we began a project on the assessment of forest degradation and how BAM models can help identify the responses of focal bird species' populations to degradation-related predictors on a national scale.

Sustainable forestry for bird conservation in the cross-border region of BCR 12

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 Sustainable Forestry Initiative (SFI) grants to continue a cross-border partnership among BAM, SFI, and the American Bird Conservancy (ABC).

In 2023-2024, we published a paper (MacPherson et al. 2024) in the journal *The Forestry Chronicle* synthesizing 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 and Junior A. Tremblay in April 2022. See research box 7 for additional information.

[**CO-PRODUCED project**. Contact: Maggie MacPherson]

Research Box 7. Sustainable forestry for bird conservation in the cross-border region of BCR 12

The co-production framework for cross-border forest bird conservation integrating the best practices for co-production to respond to the needs of resource managers and invest in building long term relationships.

Figure 1: We addressed the boxes in green, while our next-steps are shown in hues of grey. The order of steps follow arrows from deeper to lighter hues. Researchers adapt requested tools to new information from those who will use or be impacted by the tools' use prior to releasing for use. This co-production framework for cross-border forest bird conservation uniquely narrows specifically into the project's scope, context, and relationships with individuals, while the tools produced aim to be flexible for adaptive application.

Figure 2: Successful co-produced projects function by focusing on single, central questions because all parties share a singular objective. The single, central question of this study is in the oval and dark green squares show the main drivers thought to answer this question. The black square shows the main perturbations to the system. Pale rectangles indicate the wheelhouses of knowledge held by (blue) the forest products, government, forestry science and advocacy and academic groups, and (green) by avian science and advocacy, government, and academic groups.

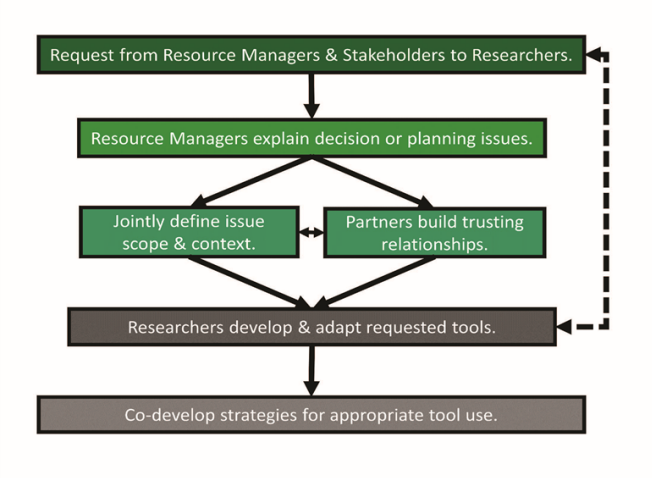


Figure 1. Co-production framework for cross-border forest bird conservation.

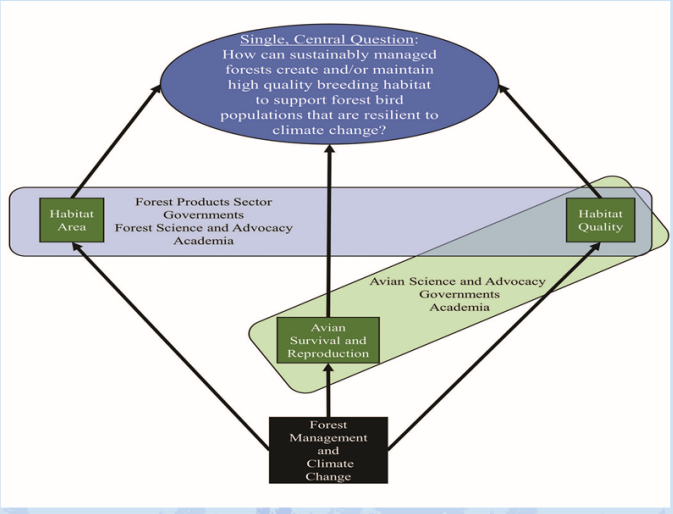


Figure 2. The conceptual framework specific to this co-produced research on cross-border forest bird conservation.

doi.org/10.5558/tfc2024-013. *Contact: Maggie MacPherson, maggie.macpherson@gmail.com*

Value and resilience of SFI forests for eastern forest birds in a changing climate

To evaluate the impacts of past and present forest management on bird populations in SFI-certified vs. non-certified forests, we need spatial predictions of bird species abundances under current and past conditions. The current generation of BAM's national models enable this through the use of time-series of spatial covariates. To evaluate the resilience of SFI managed forests and their conservation value for birds under potential future climate regimes, we are using the *LandR* vegetation dynamics model to forecast future forest conditions under climate change. Forecasts of bird species abundances are then derived by applying regional versions of the national bird models to the forecast landscapes.

In 2023-2024, our team undertook a project to assemble spatial data representing forest inventory and management practices both within and outside SFI-certified forest lands across Eastern Canada. Recognizing that the *LandR* and its climate-sensitive version (*LandR CS*) were initially developed for boreal forest systems of Western Canada, we built upon this robust foundation to adapt and expand the model for new geographical contexts. Specifically, we parameterized the model to suit the Eastern Canadian provinces by incorporating data from provincial and NFI permanent sample plots. This adaptation was designed to be effective for both the climate-sensitive and non-sensitive versions of *LandR*. To ensure the consistency and accuracy of the new dataset integrated into the models, we ran comprehensive simulations using both models across the Eastern provinces. These simulations were tailored to various eastern tree species, allowing us to assess the impact of climate change on the growth and abundance of these species.

This project was made possible through the additional support of the SFI Conservation Grant awarded to Steve Cumming and Junior Tremblay in April 2022.

[**CO-PRODUCED project**. Contact: Shirin Varkouhi]

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. Through this project the piecewise smoothing method has been developed, which is a reproducible and flexible method using SpaDES modules that summarize the BAM landbird density models into a format that can be readily incorporated into forest management planning models (bird density by forest age and class).

In 2023-2024, the piecewise smoothing method was further streamlined from the previous year's version, and a first manuscript (Lane Shaw et al.) was completed and will be submitted for publication in 2024-2025. A second manuscript (Lane Shaw et al.) is also in production. In this second manuscript the piecewise smoothing models will be further refined and tested using improved inputs, particularly updated BAM bird density models and forest resource inventory data.

This work is led at Steve Cumming's Lab at Laval University through a partnership with the Western Boreal Initiative (WBI), 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]

Assessing forest degradation using national-scale focal forest bird indicators

In 2023-2024, we began assessing forest degradation using national-scale focal forest bird indicators. This work includes developing spatially explicit species population trend estimates, Canada-wide, over a 35-year time window beginning in 1985. Using species distribution models and hind-casted predictions based on temporally matched, remotely-sensed, forest data we are then quantifying the relative contribution, on the landscape, of forest traits to this assessment of population change. This project is funded by and developed in partnership with the Natural Resources Canada ForSITE (Forest Systems Information and Technology Enhancement) program.

[**CO-PRODUCED project**. Contact: Anna Drake]

Live tree retention in harvests as a tool to increase species abundance over time

In managed areas of the boreal forest, live trees are retained in harvested areas to provide ecological services for species adapted to natural disturbances. This project tested whether these retention patches benefitted birds as harvested areas regenerated (see research box 8). Additionally, to address the challenge of variable song detection distances between forested and open conditions, a new distance-based sound detection space truncation method was developed to accurately sample birds on the landscape. The method was pivotal in evaluating bird responses to retention patches; without this methodological advancement, the impact of retention patches on songbird abundance was vastly underestimated. When evaluated using unlimited distance surveys, retained trees had a negligible effect on bird abundance, whereas applying detection distance truncation highlighted the importance of retention on forest birds. An article on this research (Lebeuf-Taylor et al. 2024) was accepted in the journal *Ornithological Applications*.

[**INFORMED project**. Contact: Isabelle Lebeuf-Taylor]

Research box 8. Live tree retention in harvests as a tool to increase species abundance over time

The results showed that early to mid-seral songbirds were relatively more abundant around retention patches, particularly after 10 years of regeneration.

While patch sizes (0.1 to 1.2 hectares) did not show a linear relationship with bird abundance, edge effects stemming from the configuration of these patches emerged as key determinants of abundance for most of the species studied.

Birds were more abundant in harvested areas near retention patches at all distances from the remnant forest.

However, species typically associated with mature forests were not more likely to use the regenerating forest when live tree retention was present, regardless of patch size.

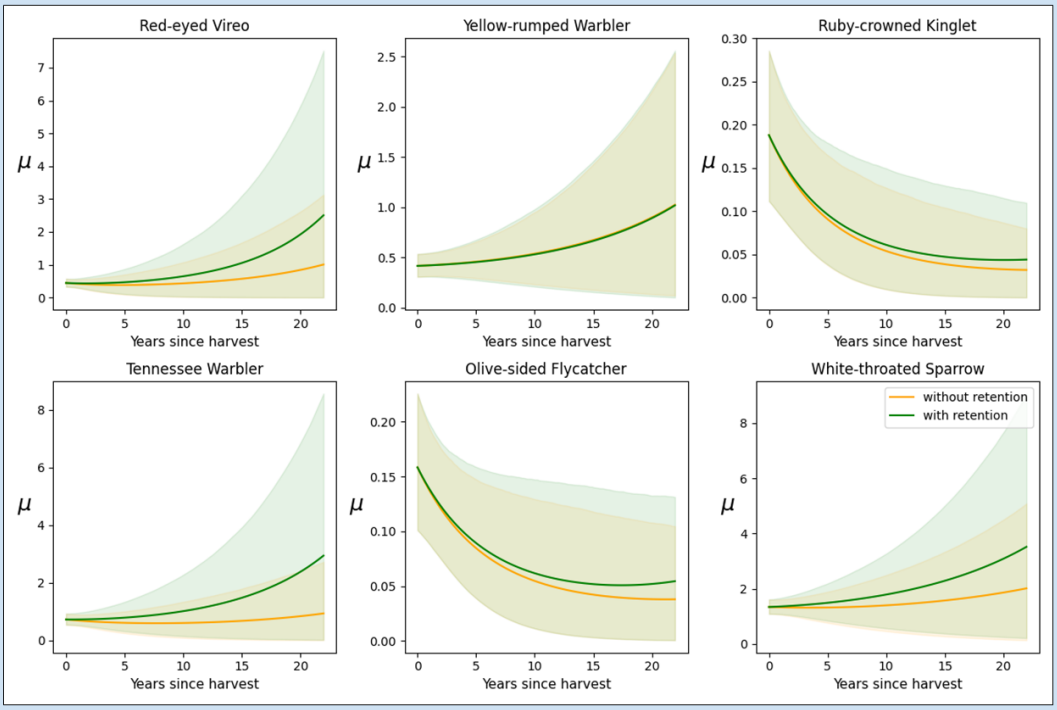


Figure. Abundance relationships in the 150 m truncation model support the hypothesis that small retention patches increase in value as the harvest regrows for the Tennessee Warbler, White-throated Sparrow, and Red-eyed Vireo. μ is the estimated relative abundance, and solid lines show mean predictions and shaded areas are 83% credible intervals.

doi.org/10.1093/ornithapp/duae055. *Contact: Isabelle Lebeuf-Taylor, lebeufta@ualberta.ca*

Colonization and persistence dynamics of Black-throated Green Warblers in response to long-term habitat fragmentation

Habitat fragmentation poses a significant threat to habitat specialists like the Black-throated Green Warblers (*Setophaga virens*) who are generally more vulnerable to the effects of habitat fragmentation than generalist species. This project investigated the long-term impacts of habitat fragmentation on this interior, older forest specialist, which is listed as a species of special concern in Alberta.

Using 25 years of point count data from Calling Lake, AB, the project applied dynamic occupancy models to assess how distance to anthropogenic edges — such as seismic lines, roads, pipelines, and harvested areas— affects colonization, persistence, and turnover rates. The results showed that Black-throated Green Warblers were more likely to colonize and persist at sites that are further from edges, particularly edges associated with seismic lines and harvested areas, which are the most abundant edge types in the study area. The models identified stable sites with lower turnover, which should be prioritized for conservation for this species, compared to sites with higher turnover. Despite the study area containing suitable habitat for this species, a ~40% decline in annual occupancy probability was observed over the 25-year period, alongside high site turnover. Further investigation into this species' response to fragmentation across the province is needed to determine whether these effects are localized or reflect broader regional or provincial patterns. Ultimately, these findings underscore the need for targeted conservation of stable, undisturbed older forest habitat, which will require collaboration with our forestry partners, including the Forest Resource Improvement Association of Alberta (FRIAA).

An article based on this work is currently under review. Funding for this project was provided by Alberta Pacific Forest Industries Inc., the Forest Resource Improvement Association of Alberta (FRIAA), the Natural Sciences and Engineering Research Council of Canada (NSERC), the Oil Sands Monitoring Program, and the Alberta Conservation Association (ACA).

[**BAM-INFORMED project**. Contact: Taylor Hart]

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 2023-2024, through the Eastern Habitat Joint Venture (EHJV), we developed spatial prioritizations using BAM's national-scale density models to identify regional priority areas for the conservation of forest and wetland-associated bird species. Additionally, through the Western Boreal Initiative, BAM models were used to evaluate the potential for boreal caribou to act as a conservation umbrella for landbirds in the Taiga Plains of the Northwest Territories.
BAM also continued its close collaboration with ECCC and the Boreal Ecosystems Analysis for Conservation Networks (BEACONs) project to advance large-scale conservation planning.

Identifying linkages between habitat change and population patterns of forest birds

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 in the cross-border region of BCR 12' project (see page 23, in the Theme: Forestry Impacts) 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.

In 2023-2024, 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. 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). We used these data and BAM's national-scale density models (version 4) to develop spatial prioritizations and identify regional priority areas for the conservation of forest and wetland-associated bird species across the Eastern Habitat Joint Venture (EHJV). These results will serve as a baseline for the subsequent planned activities. This project is funded by EHJV funding awarded to Steve Cumming and Junior Tremblay in March 2022.

[**CO-PRODUCED project**. Contact: Angela Moreras]

Monitoring and sampling

Summary:

BAM continues to support ongoing improvements of monitoring programs and status assessments for migratory birds by identifying data gaps in species coverage and informing future survey efforts, as well as supporting existing federal and provincial monitoring efforts by providing open-source tools and resources.
In 2023-2024, we continued supporting ECCC's development and implementation of the Boreal Bird Monitoring Program (BBMP) through the implementation of the Boreal Optimal Sampling Strategy (BOSS).

Boreal Bird Monitoring Program

BAM continues to support ongoing improvements of monitoring programs and status assessments for migratory birds, including species at risk, by supporting existing federal and provincial agencies' monitoring efforts in identifying and filling data gaps in species coverage. We provide open-source tools and resources to support monitoring and sampling across North America, including our large-scale density models. BAM continues to support ECCC and the Boreal Bird Monitoring Program (BBMP), which aims to provide adequate spatial and temporal survey coverage to estimate population status and trends and meet the information needs for management of migratory birds, species at risk and impact assessments, as relevant to boreal migratory bird conservation. The BBMP continues to implement and refine the Boreal Optimal Sampling Strategy (BOSS) with the aid of data products and tools provided by BAM. This partnership is facilitated by involvement of several ECCC biologists in both BAM and the BBMP.

One key goal of ECCC's BBMP is to collect data to estimate current status and distribution of boreal birds. ECCC contributing scientists are examining map products representing regions of extrapolation in BAM's most recent national models (version 5.0) to prioritize ongoing sampling efforts. Strategically sampling in locations that are most likely to reduce statistical uncertainty in species distribution models enhances the immediate value of ongoing BBMP sampling efforts.

We continue to support ECCC and their development and implementation of BOSS through the provision of BAM data, products and tools. We also continue to work closely with ECCC staff involved in the BBMP to ensure that acoustic data and historic point counts representing the boreal region are being added to WildTrax as part of our efforts to meet open data standards, including the improvement of data access and stewardship opportunities for Indigenous partners in remote communities.

[**CO-PRODUCED project**. Contact: Steve Van Wilgenburg, Samuel Haché]

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 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.
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.

BAM's 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;
- Regional and national **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 land cover 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.

More details about our data and data products can be found on our website: https://borealbirds.ca/explore-our-data/.

BAM GeoPortal: spatially-referenced data product distribution platform

As data products are created, we will continue publishing the results on our website and will link the data products on the GeoPortal to facilitate filtering products. To learn more, visit our BAM GeoPortal website.

[**CORE project**. Contact: Mélina Houle]

Advanced remote sensing improves bird-habitat models

BAM is collaborating with numerous integrated research programs focused on boreal forests of Canada to use advances in remote sensing to improve bird models. Erin Bayne and Brendan Casey have been testing the efficacy of Google Earth Engine, Planet Satellite cluster, and LiDAR to improve bird/habitat models. Specifically, the use of LiDAR data has been shown to produce much better models for Canada Warbler by improving our understanding of shrub structure. Satellite imagery also provides much more refined estimates of the degree of tree species intermixing that improves models considerably relative to polygons derived from aerial photography. The mixture of coniferous and deciduous species in a stand is a key determinant of species richness in many areas as well as being important for predicting the status of Black-throated Green Warbler.

Metrics of tree senescence from advanced remote sensing data have been used to improve predictions of habitat use by Pileated Woodpecker, which in turn has been shown to improve nest finding in the field to protect their cavities during activities involving forest clearing (see research box 9 for additional information and for the Web application we created for Pileated Woodpecker).

Finally, recovery of energy sector footprints is being measured by using daily green up rates to assess how the state of forest recovery influences bird response. To learn more visit: https://borealbirds.ca/planet-data/.

[**CO-PRODUCED project**. Contact: Brendan Casey]

Research box 9. Predicting Pileated Woodpecker habitat using spectral indicators of tree health

The *Migratory Bird Convention Act* (MBCA) and the *Migratory Birds Regulations, 2022* (MBR 2022) are designed to protect and conserve migratory birds. Recent amendments to the MBR 2022 require year-round protections of unoccupied Pileated Woodpecker nesting cavities for 36 months before removal or destruction is allowed. Efficient compliance with the MBR 2022 requires an understanding of where Pileated Woodpecker are located. Towards this, we are developing a set of tools to help users identify where Pileated Woodpecker are likely to be and where additional monitoring is and is not needed to find nests.

Remote sensing data, including spectral indicators of tree senescence and forest and single-tree structural characteristics, can improve Pileated Woodpecker habitat models and aid in locating nesting cavities.

We used acoustic point counts and spectral indicators of tree stress from Sentinel-2 satellites to estimate the probability of Pileated Woodpecker occupancy using boosted regression trees (BRTs). Key predictors in the model included the proportion of deciduous forests, canopy height, and spectral signs of tree stress from the Normalized Distance Red and Shortwave Infrared (NDRS) Index, all of which were positively associated with Pileated Woodpecker drumming in Alberta.

The resulting predictive map informed targeted ground searches for nest cavities during the summer field season, following nest search protocols developed by Simran Baines, a PhD student in Erin Bayne's lab (University of Alberta).

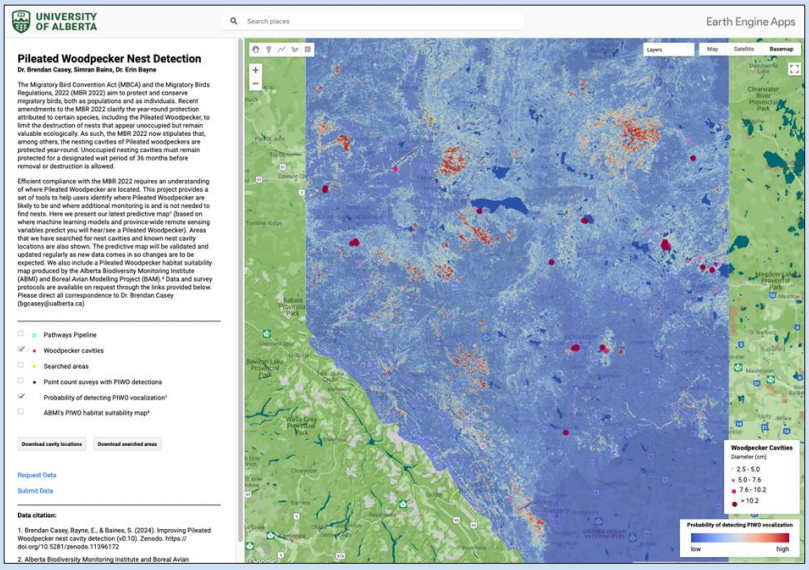


Figure. Pileated Woodpecker web application: https://ee-bgcasey-piwomodels.projects.earthengine.app/view/pileatedwoodpecker

Additionally, we created a web application (see Figure) that displays our predictive map, areas surveyed for Pileated Woodpecker nest cavities and known nest cavity locations. The map will be continuously validated and updated as new data becomes available.

doi.org/10.5281/zenodo.11396172, work in progress. Contact: Brendan Casey, brendan.casey@ualberta.ca

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 13 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 2023-2024, we continued uploading new datasets to WildTrax and working with existing data partners to support the sharing of their data. We also maintained our collaboration with partners from ECCC, Birds Canada, and ABMI to advance avian data accessibility as part of the Canadian Open Avian Data Initiative (CanAvian). Lastly, we continued improving the workflow and methods to automate the translation of point count data into the BAM and WildTrax data structure.

Canadian Open Avian Data Initiative (CanAvian) and the WildTrax platform

BAM continues its efforts to improve the discovery, accessibility, integration, and use of bird data in Canada as a member of the Canadian Open Avian Data initiative, which is a collaboration with Birds Canada, ECCC, Alberta Biodiversity Monitoring Institute (ABMI), and WildTrax.

BAM-held point count data can be accessed on the WildTrax online platform (wildtrax.ca) under the Point Count sensor. The platform has a data discovery interface that allows the user to visualize point count data by organization and/or project. In 2023-2024, we revisited data sharing agreement with data partners to increase accessibility, and we worked with some of them to build harmonization scripts to transpose point count data into the WildTrax format. The harmonization process that translated the source point count data into the WildTrax format can be found on GitHub under their respective projects (github.com/borealbirds/WT-Integration). We also successfully integrated point count data from 7 new projects into WildTrax, which corresponds to an addition of 656,252 new bird detections. See research box 10 for additional information.

WildTrax hosts both point count and ARU data that can now be integrated together. WildTrax can also be queried using the R package called WildRtrax. The successful migration from the BAM database v.6 to the WildTrax platform improved the access 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.

[**CORE project**. Contact: Mélina Houle]

Research box 10.
BAM-WildTrax integration

To date, WildTrax has 202 point count projects uploaded which corresponds to over 13,000,000 bird observations from 404,642 unique locations primarily across the boreal and hemiboreal region of North America (Canada and the northern areas of the United States), including major datasets from Breeding Bird Surveys (BBS), Breeding Bird Atlases (BBA), Canadian Wildlife Service's regional offices (CWS), and provincial governments.

Currently, 73 of the point count projects are listed as "Mappable" in WildTrax, i.e. the data are displayed on a map for discovery so that WildTrax users are aware of their existence and can request access.

50 point count projects are listed as "Public", i.e. all components of the data are publicly available in visualizations and available for download to any WildTrax user without request.

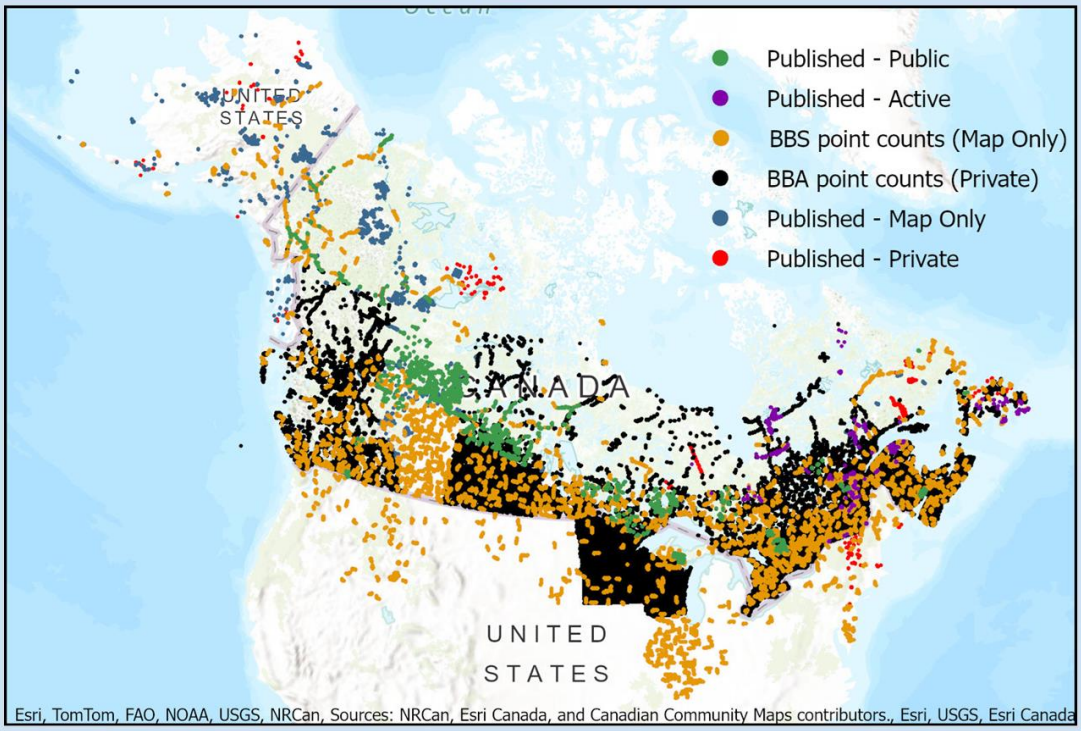


Figure. Distribution of point count locations available on the WildTrax online platform.

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

Communication and outreach

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

Communications experiment on the critical habitat identification framework

We are contributing to the development of a communications' experiment, led by Alana Lajoie O'Malley (Westwood Lab at Dalhousie University) based on the critical habitat identification (CHID) framework for species at risk (Leston et al. 2024, see page 12 for the CHID framework). The study is applying a mixed-methods survey approach including both closed- and open-ended questions to compare preferences and perspectives about the communication and application of new scientific knowledge about species at risk in Canada among different audiences, including users and producers of knowledge in federal and provincial/territorial governments, NGOs, co-management boards, and community-based organizations.

Based on existing research, this project starts from the understanding (1) that the perceived usefulness and reliability of new conservation knowledge is a critical determining factor in its application, (2) that the perception of usefulness and reliability is likely to differ across people differently situated within the science-policy nexus and (3) that different audiences are likely to prefer different approaches to communicating research results. From this starting place, the study will help develop a better understanding of what communications approaches might lead government policymakers and civil society actors to perceive new policy-relevant knowledge about species at risk to be useful and reliable. Recognizing that communications approaches represent only one element of the broader interaction between evidence and policy making, the survey also sets out to generate a better picture of scientists', policymakers', and policy advocates' views on the broader relationship between evidence and decision-making about species at risk in Canada.

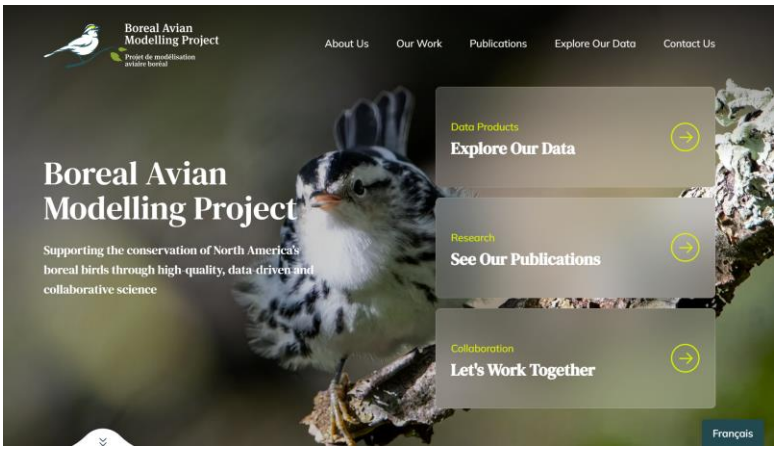
[**CO-PRODUCED project**. Contact: Oussama Bouarakia]

Updates of the BAM Website

We continue to update the BAM website with new content, improve navigability for users and facilitate access to materials.

Our website is available in both English and French, and can be viewed at borealbirds.ca.

[**CORE project**. Contact: Oussama Bouarakia]



Publications and communications

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

Core Publications

Publications from BAM Core projects published between April 2023 and March 2024.

Leston, L., Dénes, F.V., Docherty T.D.S., Tremblay J.A., Boulanger Y., Van Wilgenburg S.L., Stralberg D., Sólymos P., Haché S., St. Laurent K., Weeber R., Drolet B., Westwood A.R., Hope D.D., Ball J., Song S.J., Cumming S.G., Bayne E., Schmiegelow F.K.A., 2024. A framework to support the identification of critical habitat for wide-ranging species at risk under climate change. *Biodiversity and Conservation* 33: 603–628. https://doi.org/10.1007/s10531-023-02761-1.

Co-produced Publications

Publications from BAM Co-produced projects between April 2023 and March 2024.

Binley, A.D., Edwards, B.P.M., Dansereau, G., Knight, E.C., Momeni-Dehaghi, I., 2023. Minimizing Data Waste: Conservation in the Big Data Era. *The Bulletin of the Ecological Society of America* 104(2): e02056. https://doi.org/10.1002/bes2.2056.

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BAM-Informed Publications

Publications we're aware of that used BAM data, methods, or expert knowledge, published between April 2023 and March 2024.

Adams, C.A., Clair, C.C.S., Knight, E.C., Bayne, E.M., 2024. Behaviour and landscape contexts determine the effects of artificial light on two crepuscular bird species. *Landscape Ecology* 39: 83. https://doi.org/10.1007/s10980-024-01875-3.

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MacPhail, A.G.*, Yip, D.A.*, Knight, E.C.*, Hedley, R., Knaggs, M., Shonfield, J., Upham-Mills, E., Bayne, E.M., 2023. Audio data compression affects acoustic indices and reduces detections of birds by human listening and automated recognisers. *Bioacoustics* 33(1): 74–90. https://doi.org/10.1080/09524622.2023.2290718. *Equal contributions

Presentations

Presentations given by BAM Team members between April 2023 and March 2024.

Knight, E.C., Sólymos, P., Stralberg, D., Drake, A., Docherty, T.D.S., Crosby, A.D., Houle, M., Leston, L., Haché, S., Ball, J., Bayne, E.M., Song, S., Cumming, S.G., Schmiegelow, F., An integrated modeling framework for broad-scale spatial prediction and population estimation from varying survey protocols. *American Ornithological Society & Society of Canadian Ornithologists - Société des Ornithologistes du Canada Joint Conference*. London, Ontario, August 2023. Oral presentation.

Leston, L., Dénes, F.V., Docherty, T.D.S., Tremblay, J.A., Boulanger, Y., Van Wilgenburg, S.L., Stralberg, D., Sólymos, P., Haché, S., St. Laurent, K., Weeber, R., Drolet, B., Westwood, A.R., Hope, D.D., Ball, J., Song, S.J., Cumming, S.G., Bayne, E., Schmiegelow, F.K.A., A framework to support the identification of critical habitat for wide-ranging species at risk under climate change (Un cadre pour soutenir l'identification d'habitats essentiels pour les espèces à large répartition menacées par le changement climatique). *American Ornithological Society & Society of Canadian Ornithologists - Société des Ornithologistes du Canada Joint Conference*. London, Ontario, August 2023. Oral presentation.

Raymundo, A., Micheletti, T., Haché, S., Stralberg, D., Stewart, F.E.C., Tremblay, J.A., Barros, C., Eddy, I.M.S., Chubaty, A.M., Leblond, M., Mahon, C.L., Van Wilgenburg, S.L., Bayne, E.M., Schmiegelow, F., Docherty, T.D.S., McIntire, E.J.B., Cumming, S.G., Birds ringing the bell on Climate Change in the Northern Canadian boreal forest. *American Ornithological Society & Society of Canadian Ornithologists - Société des Ornithologistes du Canada Joint Conference*. London, Ontario, August 2023. Oral Presentation.

Knight, E.C., Harrison, A., Marra, P., Scarpignato, A., Van Wilgenburg, S., Bayne, E.M., Common Nighthawk roosting habitat selection across the annual cycle suggests behavioural trade-offs. *BOUSci23: Global Flyways*. Online, November 2023. Oral & Twitter presentation.

Knight, E.C., Rhinehart, T., de Zwaan, D.R. Weldy, M.J., Cartwright, M., Hawley, S.H., Larkin, J.L., Lesmesiter, D., Bayne, E.M., Kitzes., J., Individual identification in acoustic recordings: Applications and opportunities in ecological research. *Alberta Chapter of The Wildlife Society & Canadian Section of The Wildlife Society Joint Conference*. Jasper, Alberta, March 2024. Oral presentation.

Webinars and Workshops

Webinars and workshops organized or co-organized by BAM, hosted between April 2023 and March 2024.

Leston, L., Knight, E., “Detectability offsets to combine survey data from independent boreal bird studies” QPAD workshop. *American Ornithological Society & Society of Canadian Ornithologists - Société des Ornithologistes du Canada Joint Conference*. London, Ontario, August 2023.

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.

Steering Committee:

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- Ana Raymundo, Laval University (Ph.D. supervisor: Steven Cumming). angeles-ana-paula.raymundo-sanchez.1@ulaval.ca
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- C. Lisa Mahon, Wildlife biologist, CWS- Northern Region, ECCC. lisa.mahon@ec.gc.ca
- Steve Matsuoka, Research wildlife biologist, USGS Alaska Science Centre. smatsuoka@usgs.gov

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 Oussama Bouarakia, the BAM Program leader (oussama.bouarakia@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 and Climate Change Canada
University of Alberta
The Canadian BEACONs Project

Financial and in-kind support to BAM in 2023-2024

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

Data partners

Numerous 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 Oussama Bouarakia, the BAM Program leader (oussama.bouarakia@ualberta.ca) so we can correct the omission.

Institutions:

Acadia University
Alaska Bird Observatory
Alaska Natural Heritage Program
Alaska Science Center
Alberta Biodiversity Monitoring Institute
Alberta Pacific Forest Industries Inc.
Alberta Research Council Inc
AMEC Earth & Environmental
AREVA Resources Canada Inc.
Avian Knowledge Network
AXYS Environmental Consulting Ltd.
BC Breeding Bird Atlas
BC Hydro
Bighorn Wildlife Technologies Ltd.
Birds Canada
Canada Centre for Remote Sensing
Canadian Forest Products Ltd.
Canadian Forest Service
Canadian Natural Resources Ltd
Canadian Wildlife Service
Daishowa Marubeni International Ltd
Devon Canada
Ducks Unlimited Canada
Environment and Climate Change Canada
Fairbanks
Fish & Wildlife Compensation Program
Global Land Cover Facility
Golder Associates Ltd.
Government of British Columbia
Government of Saskatchewan
Government of Yukon
Hinton Wood Products
Hydro-Québec Équipement
Interfor
Jasper National Park of Canada
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.
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Ministry of Environment & Climate Change Strategy (BC)
Minnesota Department of Natural Resources
Mirkwood Ecological Consultants Ltd.
National Data Center
Natural Research Council of Canada
Natural Resources Canada
NatureServe
NEON
Newfoundland and Labrador Hydro
Northeast Temperate Network
Numerical Terradynamic Simulation Group
Ohio Department of Natural Resources
Ohio Division of Wildlife
Ontario Breeding Bird Atlas
Ontario Ministry of Natural Resources
OPTI Canada Inc.
Oregon State University
PanCanadian Petroleum Limited
Parks Canada
Parks Canada (Mountain National Parks Avian Monitoring Database)
Petro Canada
Pope & Talbot Ltd.
Principal Wildlife Resource Consulting
Quebec Breeding Bird Atlas
Regroupement Québec Oiseaux
Rio Alto Resources International Inc.
Saskatchewan Environment
Science & Technology Branch
Shell Canada Ltd.
STRIX Ecological Consulting
Suncor Energy Inc.
Tembec Industries Inc.
The Nature Conservancy
Tolko Industries Ltd.
United States Army
United States Fish and Wildlife Service
United States Geological Survey
United States Geological Survey, Alaska Science Center
United States National Park Service
Université de Moncton
Université du Québec à Montréal
Université du Québec en Abitibi-Témiscamingue
Université Laval
University of Alaska Fairbanks
University of Alberta
University of British Columbia
University of Guelph
University of Minnesota
University of Minnesota Duluth
University of New Brunswick
University of Northern British Columbia
URSUS Ecosystem Management Ltd.
Vermont Center for Ecostudies
West Fraser Timber Co. Ltd.
Weyerhaeuser Company Ltd.
Wildlife Resource Consulting Services MB Inc.
Yukon College

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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Boreal Avian Modelling Project

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Boreal Chickadee (*Poecile hudsonicus*):

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