ANNUAL REPORT

April 2024 – March 2025

Boreal Avian Modelling Project

Projet de modélisation aviaire boréal

Executive Summary 2022-25

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. Over the past 20 years, BAM has evolved from a data collation initiative into a national-scale, solution-oriented scientific program that develops robust, accessible, and policy-relevant bird models that make the most out of existing datasets and provide decision-makers with the tools they need to conserve boreal avian diversity in the face of accelerating environmental change.

With our last three-year workplan, BAM made important progress in supporting the conservation of Canada's boreal birds. Our biggest achievement in this period was advancing our population models, which bring together more than 1.45 million bird surveys to show where birds are found, how many there are, and, with the newest version, how these patterns have changed over time. The newest version of the models now produces estimates for every five years from 1990 to 2020, making it possible to track long-term changes in bird population numbers alongside shifts in climate, wildfire, and forestry.

Between 2022 and 2025, BAM worked on developing practical tools that apply these models to decision making. These include a tool for identifying critical habitat for species at risk, a method for measuring the impacts of industrial development on bird populations, a way to assess how forest degradation contributes to bird declines, and a tool to help foresters create harvest plans that minimize incidental impacts to bird populations. We also studied how birds respond to forestry, mining, wildfire, and climate change, producing new insights to guide management and land-use planning.

BAM also focused on ensuring our science is translated into resources that partners, practitioners, and the public can use. In 2022, BAM joined the Canadian Open Avian Data Initiative, migrated our 9 million record database to the open-access WildTrax platform, and contributed over half a million new bird records, allowing for improved discovery and access of bird data in Canada. We launched a suite of new model access and interpretation tools designed for diverse users with different technical backgrounds. We also continued to share our findings widely through publications, presentations, and webinars, while gathering feedback from partners to improve future tools.

Together, these efforts mark BAM's mission as a national program that delivers science-based solutions. By turning diverse bird data into clear, practical tools, we support decision-makers to conserve boreal birds in a time of rapid environmental change. Looking forward, BAM will continue to support Canada's environmental commitments and indicators by focusing on the development of open-access, model-based tools to support a variety of bird conservation and land use decision making needs, and the outreach to get these tools into the hands of users. BAM will continue to innovate our models, including the incorporation of artificial intelligence to make the most of acoustic data and expanding model products to other groups of birds of conservation concern. To support that goal, BAM will be joining Biodiversity Pathways in 2025, becoming part of a registered non-profit organization and strengthening our ability to connect science with policy and practice for the benefit of Canada's biodiversity.

Résumé analytique 2022-25

Le projet de modélisation aviaire boréal (BAM) est une collaboration scientifique internationale qui conduit des recherches novatrices pour appuyer la prise de décisions fondées sur des données probantes en matière de gestion et de conservation des oiseaux en Amérique du Nord. Au cours des 20 dernières années, BAM est passé d'une initiative de collecte de données à un programme scientifique à l'échelle nationale axé sur des solutions, qui développe des modèles ornithologiques robustes, accessibles et pertinents afin de mieux orienter les décisions politiques. Le programme maximise l’utilisation des ensembles de données existants et fournit aux décideurs les outils nécessaires pour préserver la diversité aviaire boréale face à l'accélération des changements environnementaux.

Grâce à notre dernier plan de travail triennal, BAM a réalisé d'importants progrès dans le soutien à la conservation des oiseaux boréaux du Canada. Notre plus grande réussite durant cette période a été l'amélioration de nos modèles de population, qui intègrent plus de 1,45 million de points d’écoute. Grâce à ces modèles, nous pouvons identifier où se trouvent les oiseaux, estimer leur abondance et, avec la plus récente version, observer l’évolution de ces tendances au fil du temps. Cette version des modèles fournit désormais des estimations pour chaque période de cinq ans entre 1990 et 2020, permettant ainsi de suivre l’évolution à long terme des populations d'oiseaux en lien avec les changements climatiques, les feux de forêt et l'exploitation forestière.

Entre 2022 et 2025, BAM a travaillé à l'élaboration d'outils pratiques qui appliquent ces modèles à la prise de décision. Cela inclut: un outil servant à identifier les habitats essentiels aux espèces en péril, une méthode permettant de mesurer les impacts du développement industriel sur les populations d'oiseaux, une approche pour évaluer comment la dégradation des forêts contribue au déclin des populations d'oiseaux, ainsi qu'un outil destiné aux forestiers pour aider dans l'élaboration des plans de récolte réduisant les impacts accidentels sur les populations d'oiseaux. Nous avons également étudié la façon dont les oiseaux réagissent à la foresterie, à l'exploitation minière, aux incendies de forêt et aux changements climatiques, ce qui a permis d'obtenir de nouvelles informations pour orienter la gestion et l'aménagement du territoire.

BAM s'est également efforcé de veiller à ce que nos travaux scientifiques soient transformés en ressources concrètes et accessibles pour nos partenaires, les praticiens et le grand public. En 2022, BAM a rejoint l'Initiative canadienne de données ouvertes sur les oiseaux, a migré sa base de données de 9 millions d'enregistrements vers la plateforme en libre accès WildTrax et a contribué en ajoutant plus d'un demi-million de nouveaux enregistrements d'oiseaux à celle-ci, facilitant ainsi la découverte et l'accès aux données aviaires au Canada. Nous avons lancé une série de nouveaux outils d'accès et d'interprétation des modèles conçus pour divers utilisateurs ayant des connaissances techniques différentes. Finalement, nous avons continué à diffuser largement nos résultats par le biais de publications, de présentations et de webinaires, tout en recueillant les commentaires de nos partenaires afin d'améliorer les outils futurs.

Ensemble, ces efforts marquent la mission de BAM en tant que programme national qui fournit des solutions fondées sur la science. En transformant diverses données sur les oiseaux en outils clairs et pratiques, nous aidons les décideurs à préserver ces derniers à une époque de changements environnementaux rapides. Dans un avenir rapproché, BAM continuera à soutenir les engagements et les indicateurs environnementaux du Canada en mettant l'accent sur le développement d'outils en libre accès, basés sur des modèles, afin de répondre à divers besoins en matière de conservation des oiseaux et de prise de décision concernant l'utilisation du paysage, ainsi que sur la sensibilisation afin de mettre ces outils à la disposition des utilisateurs. BAM continuera à innover dans ses modèles, notamment en intégrant l'intelligence artificielle afin de tirer le meilleur parti des données acoustiques et en élargissant les produits de modélisation à d'autres groupes d'oiseaux dont la conservation est préoccupante. Pour soutenir cet objectif, BAM rejoindra le Biodiversity Pathways en 2025, devenant ainsi membre d'une organisation à but non lucratif enregistrée et renforçant sa capacité à relier la science à la politique et à la pratique au profit de la biodiversité du Canada.

Highlights from 2024–25

Population status and trends

- Accepted publication of a foundational manuscript documenting the general BAM modeling approach using version 4 models in the journal *Ecosphere* (Stralberg et al. in press). ► page 14
- Finalized the modeling workflow for version 5 of BAM's landbird density models, now international in extent and based on over 1.45 million surveys—nearly 4× more data than version 4. ► page 14
- Co-led an international working group and co-guest-edited a Special Feature in *Ornithological Applications* on detectability, including five articles by BAM researchers. ► page 15
- Joined a new multidisciplinary, collaborative project to enhance the application of bird models in the Hudson Bay Lowlands through expert review and decision support tools. ► page 16

Climate and landscape change impacts

- Contributed to multiple studies forecasting boreal bird responses to climate change and forest disturbance, including major modeling efforts in Québec, the Northwest Territories, and the Yukon Boreal Cordillera. ► pages 19-22
- Collaborated with Nature Canada and the Cree Nation Government to assess the impact of the 2023 wildfire season on bird populations in Eeyou Istchee, and initiated a Canada-wide follow-up analysis. ► page 22

Energy and mining impacts, cumulative effects

- Developed a machine learning-based pipeline to model reference landscape conditions and assess cumulative impacts on bird populations for impact assessment, demonstrated using Canada Warbler in the Atlantic Northern Forest. ► page 24

- Initiated work to evaluate the potential of boreal birds as indicators of well site reclamation success using remote sensing and WildTrax data. ► page 26

Forestry impacts

- Developed tools to integrate BAM's bird density models into forest harvest planning, including a novel method for creating "bird yield tables" and classifying species by habitat associations. ► page 28

- Advanced analyses of forest degradation and habitat fragmentation, revealing species-specific sensitivities to disturbance configuration, forest age, and spatial patterns using version 5 models. ► page 30

- Published new findings on live tree retention, showing that patch configuration and proximity to intact forest influence long-term bird abundance post-harvest (Lebeuf-Taylor et al. 2025). ► page 31

Conservation planning for boreal birds

- Initiated regional-scale models for Eastern Canada incorporating new habitat change drivers (e.g., forestry roads, insect defoliation) to support multi-species conservation planning and status assessment. ► page 34

Monitoring and sampling

- Supported national implementation of the Boreal Bird Monitoring Program by helping ECCC target under-sampled regions and habitats, and by providing spatial layers to guide optimal survey placement. ► page 36

- Co-authored two peer-reviewed studies on acoustic classification, including the new HawkEars AI classifier for Canadian species and a review of individual identification methods in bioacoustic data. ► page 36

Data and data products

- Developed new tools to access BAM landbird models, including a Google Earth Engine app, the BAMexploreR R package, and a forthcoming Shiny interface to support conservation and planning workflows. ► page 39
- Expanded public access to BAM's point count data on WildTrax, launched the CanAvian website with partners, and added 10 new projects, particularly in eastern Canada. ► page 42

Communications and outreach

- Collaborated on a national survey to evaluate how stakeholders interpret and apply the BAM critical habitat identification framework, informing more effective science-to-policy communication. ► page 43
- Conducted a bilingual user survey on BAM data products, with 54 respondents providing valuable input to guide future tool development and delivery improvements. ► page 44

Citation

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Note: Components of this report were produced with support from generative AI to synthesize contributions from individual project leads and were subsequently reviewed and edited for tone and accuracy.

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About Us

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

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

Our vision

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

Our mission

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

Our objectives

- **ASSEMBLE**, harmonize, and archive standardized boreal bird survey **data**.
- **DEVELOP** or refine **statistical methods** to analyze these data, to:
    - **PROVIDE reliable information** on boreal bird distributions, abundances, trends, and habitat associations;
    - **FORECAST** population consequences of human activity and climate change;
    - **CONTRIBUTE** to conservation, management, and monitoring of boreal birds and their habitats.
- **BUILD SUPPORT** for boreal bird conservation via collaborations and outreach.
- **FACILITATE** further research efforts by generating testable hypotheses about key mechanisms driving boreal bird populations.
- **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 53.

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.

Research and Monitoring

Research and monitoring are at the core of BAM's vision and mission and comprise the majority of our work. Our research and monitoring are distributed across seven core thematic areas.

Population status and trends

Three Year Summary

Many of BAM's keystone contributions are around population status and trends, where we develop methodological innovations for boreal bird monitoring and conversation. Over the past three years, BAM has advanced our capacity to produce robust, spatially explicit estimates of landbird population status and trends across the boreal and hemiboreal forests of North America. Central to this progress is the refinement of BAM's landbird density models, which underwent major improvements from versions 4 to 5 planned for release later in 2025. These models now incorporate updated environmental covariates, expanded geographic extent, including Alaska and the lower 48 U.S. states, and improved methods to blend regional predictions. A key focus has been aligning environmental inputs temporally with survey data and ensuring reproducibility through cloud-based workflows and public code repositories.

Simultaneously, BAM continues to study detection probability to refine QPAD detectability offsets, an essential component of our density modeling. Ongoing work by the BAM-led detectability working group has produced new insights into the relationship between availability and perceptibility, improved our understanding of ARU versus human survey methods, and helped identify and correct a long-standing time zone bug in QPAD calculations. A new special feature in the journal *Ornithological Applications* will showcase some of these contributions. BAM continues to work towards methods for incorporating automated recognizer data into density estimation workflows.

Through collaboration with NA-POPS and Partners in Flight, BAM has also contributed to a new continental framework for estimating bird populations, which uses BAM's QPAD framework and extends it to data-sparse species. Finally, by partnering on regional initiatives such as the Northern Ontario Bird Modelling Working Group, BAM continues to support conservation-relevant applications of our modelling products, with a focus on decision-making in data-sparse regions. These cumulative efforts are establishing BAM's density models as a keystone product for landbird monitoring, conservation planning, and impact assessment at national and international scales.

BAM landbird density models

In 2024-2025, we finalized the workflow for version 5 of our landbird density models, which have been renamed from the term "national models" to reflect that these models are now international in extent, covering the entire boreal and hemiboreal forest including Alaska and some of the lower 48 states. Unfortunately, we had to restart refitting the models in 2024–2025 (see "QPAD bug" below); however, this process resulted in a larger dataset for model fitting of 1.45 million surveys (1 million more than version 4) and refinements to workflow and model covariates. We restarted model fitting for 70 species of conservation priority, and the interim products of those models are already being used by BAM Team members for various projects (see "Northern Ontario Bird Modelling Working Group", "Impact assessment of forest-associated migratory bird species", "Classifying forest landbird species into habitat grouping", and "Assessing forest degradation using national-scale indicators" below), and by partners at NRCan for studying forest degradation and natural range of variation. Finalized model products will also be used by ECCC collaborators to evaluate current and cumulative impacts of climate change and land use to inform multispecies conservation across Canada. In 2024-2025, we communicated about our in-progress version 5 models to several groups including at the Partners in Flight conference and to the Boreal Partners in Flight group. Most notably, our manuscript documenting the general model approach using the version 4 models was accepted for publication in the journal *Ecosphere* (Stralberg et al. in press) and will serve as a cornerstone citation for the BAM density models, which are becoming BAM's keystone product for conservation and land use planning.

[**CORE project** with support from NRCan. Contact: Elly Knight]

Detection probability

In 2024-2025, we continued our work to understand detection probability towards updating detectability offsets and the QPAD R package. We continued to co-chair an international detectability working group, which works on the non-independence between the two components of detectability—availability and perceptibility—, removing error and bias from distance estimates, testing assumptions of removal models to estimate availability, and much more. As part of the working group, we co-guest-edited a Special Feature on detectability in the journal *Ornithological Applications*. The Special Feature is nearing completion, with five articles under review or published by BAM Team members. Those articles range from understanding the influence of vegetation and weather on perceptibility to predicting detection probabilities for rare and under-sampled bird species. One of the articles was a Core BAM project, comparing various components of the detection process between in-person point counts versus point counts collected with autonomous recording units (ARUs) to understand how to improve QPAD estimates (**Research Box 1**). Ongoing detection probability research to improve existing estimates and integration with ARU data is critical to ensure we are using the best density estimation methods to provide managers with robust estimates of landbird status and trends.

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

Research Box 1. Insights into detection probability of forest bird surveys from comparison of in-person and passive acoustic monitoring point counts

Historically, bird population monitoring has relied on in-person point counts, but passive acoustic monitoring (PAM) transcribed by experts is increasingly being used. Using matched datasets from North America's boreal forest, we found that despite structural similarities, PAM and in-person point counts differ in their detection processes, leading to distinct detectability estimates. PAM had higher cue rate estimates due to earlier detections, finer temporal resolution, and the exclusion of visual cues. Removing visual detections from in-person counts did not significantly affect perceptibility, and observer effects were consistent across methods. Lower detectability in in-person counts led to 14.7% higher density estimates when used as offsets. We suggest that PAM-based availability estimates—particularly for species primarily detected aurally—reduce bias and support integration of legacy and modern datasets. Future work should explore alternatives to removal modelling and investigate detection processes in automated classifiers to further improve detectability estimates.

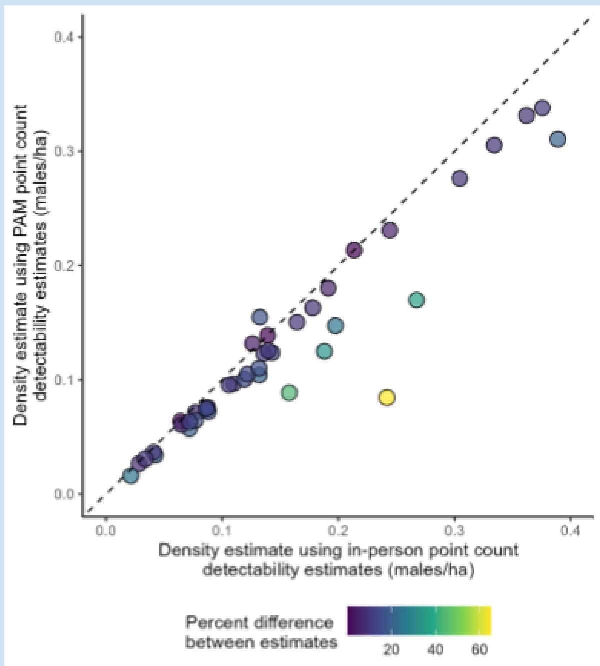


Figure: Density estimates of landbirds from a large dataset of in-person point counts using detection probability estimates that represent the in-person point count detection process (x-axis) versus those that represent the passive acoustic monitoring (PAM) point count detection process when acoustic recordings are annotated by human experts (y-axis). Each point represents one of 45 landbird species. The dashed line represents the 1:1 ratio where density estimates between survey methods are equal; below the line indicates a higher estimate using point count detectability estimates and above the line indicates a higher estimate using PAM detectability estimates.

Knight et al. In revision. Submitted to Ornithological Applications Contact: Elly Knight, ecknight@ualberta.ca

Population estimation

BAM is a collaborator in the large-scale, multi-agency NA-POPS (Point count offsets for population sizes of North American landbirds) research project. We continue to collaborate with the NA-POPS project and Partners in Flight (PIF) on improving population estimates for North American birds. In 2024-2025, we officially joined the NA-POPS project as a co-owner to facilitate synergy between

QPAD and NA-POPS moving forward. We continued to sit on the PIF Population Estimation working group, and contributed to a manuscript that incorporates the QPAD approach into a new, more quantitative PIF framework for estimating bird populations. That manuscript will be submitted to a PIF Special Feature in the journal *Avian Conservation and Ecology* in 2025-2026.

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

Northern Ontario Bird Modelling Working Group

BAM continued to participate in the Northern Ontario Bird Modeling Working Group (NOBWG) alongside partners from Environment and Climate Change Canada (ECCC), the province of Ontario, Birds Canada, and more. 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. In 2024-2025, BAM partnered with the Alberta Biodiversity Monitoring Institute (ABMI) on a project to enhance the use and interpretation of bird model products to inform environmental decision-making in the Hudson Bay Lowlands and other sparsely sampled regions. Funded by Environment and Climate Change Canada (ECCC), the initiative will develop tools and guidance to support expert evaluation of bird models and their application in assessing biodiversity co-benefits, cumulative effects, and environmental impacts. The project kicked off at a two-day hybrid workshop with the NOBMWG in Ottawa, Ontario, in mid-January 2025, where BAM presented the in-progress version 5 density models and participated in the meetings. Those in-progress version 5 models were used as the basis for a half-day virtual workshop with multiple potential users (i.e., taxonomic experts, managers and modelers) to get an initial impression of how taxonomic experts interact with modelling products when reviewing them.

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

QPAD bug

In late March 2025, we discovered and fixed a bug in the code for calculating QPAD offsets that dated back approximately ten years. The bug was within the code used to adjust time zones and therefore affects QPAD offsets used 1) for species with time since sunrise in the top model, and 2) in areas outside the mountain time zone. Since QPAD offsets only adjust the intercept of model estimates, this bug will only affect model outcomes if 1) models were built for density or population estimates per se, or 2) models were compared or integrated across time zones. Relative patterns of density (e.g., habitat coefficients) within time zones should be unaffected.

In response to this discovery, we undertook the following actions:

- Fixed the bug in all versions of the code that calculate QPAD offsets and posted a note on those repositories to inform users
- Developed and implemented adjustment factors to post-hoc correct the predicted density surfaces for version 4 of the BAM landbird models
- Posted a note about the bug in locations where version 4 of the models can be accessed
- Updated the accepted peer-reviewed manuscript based on version 4 of the models prior to publication (see "BAM landbird density models" above)
- Recalculated offsets for version 5 of the BAM landbird models and reran the models
- Created a GitHub repository to document, explain, and provide solutions for the bug
- Contacted external partners that were known to be affected by the bug to support correction

If you have been affected by this bug, please see the BAM QPAD correction repository for further details or email bamp@ualberta.ca for assistance.

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

Species at risk status and recovery planning

Three Year Summary

Between 2022 and 2025, BAM contributed to species at risk recovery planning through the development and publication of an analytical framework to support critical habitat identification for wide-ranging boreal landbirds. This framework, co-produced with scientists at ECCC, was applied to two priority species, Canada Warbler and Wood Thrush. The approach integrates BAM's harmonized datasets with spatial modelling tools to predict species density and distribution under current and future land use and climate scenarios, and uses spatial prioritization to identify high-value areas for conservation. The resulting peer-reviewed article (Leston et al. 2024) provides a replicable methodology for informing critical habitat designations under Canada's *Species at Risk Act* and is broadly applicable to other wide-ranging species. This work highlights BAM's role in advancing science-based tools to support species recovery planning at national scales.

Climate and landscape change impacts

Three Year Summary

Over the past three years, BAM has significantly advanced its understanding of how climate change and landscape disturbance are reshaping boreal bird communities. Through numerous collaborations, we have contributed to a growing body of evidence on the cumulative effects of climate, wildfire, and forest management on avian biodiversity across eastern, western, and northern boreal regions.

In Québec, a multi-year modeling initiative used LANDIS-II simulations combined with BAM's density models to assess how forest composition, structure, and bird communities will shift under various climate and management scenarios. Results from this work show that while forest harvesting plays a role, climate—especially under high-emission scenarios—is projected to become the dominant driver of bird population change by 2100. Affected species include those associated with older conifer forests, which are expected to decline as disturbance regimes intensify. Meanwhile, in the Northwest Territories and Yukon, BAM supported landscape-scale studies identifying potential climate refugia and areas of high conservation priority. These projects integrated bird distribution models with climate velocity, habitat quality, and functional diversity metrics, offering new approaches to prioritizing areas for protection in the face of accelerating change. In 2024–2025, BAM also supported a community resilience assessment showing that northern regions may be especially vulnerable to functional biodiversity loss.

Building on this knowledge, BAM has also focused on more specific disturbances associated with climate change. We responded to the unprecedented 2023 wildfire season by developing tools to estimate fire-related bird impacts at regional and national scales. We also supported studies examining avian responses to compound disturbances—wildfire and mountain pine beetle—in the Canadian Rockies. Together, these efforts provide essential insights for forecasting biodiversity change and inform conservation planning in an era of intensifying climate and land-use pressures. BAM's role in these projects ensures that bird conservation is grounded in cutting-edge science and designed to support adaptation at multiple scales.

Projected impacts of climate change and disturbances on eastern boreal birds

As part of our ongoing efforts to understand and project the impacts of climate and land-use change on boreal bird populations, BAM contributed to a new study that modeled future bird assemblages across Québec's commercial forests (Labadie et al. 2025; **Research Box 2).** Using LANDIS-II forest landscape simulations combined with BAM density models for 73 landbird species, the study assessed how climate change, wildfire, and forest management may reshape habitat conditions and bird distributions by 2100. Results showed that climate change—particularly under high emissions scenarios—will increasingly dominate over forest management as the main driver of shifts in species abundance and core habitat size. Species associated with boreal coniferous and mixedwood forests were projected to decline in abundance, particularly in the southern boreal, while species associated with human-temperate and thermophilous mixed forests may expand northward. Wildfire was identified as a key driver of change in the northern boreal, reinforcing the importance of accounting for natural disturbance regimes in forecasting biodiversity responses. This research highlights the urgency of incorporating dynamic disturbance and forest structure changes into climate adaptation and conservation planning for boreal birds. This is the latest in a series of publications for this project that BAM has contributed to (Labadie et al. 2024).

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

Research Box 2. Projecting bird assemblage responses to climate-driven changes in managed boreal forest landscapes of Québec

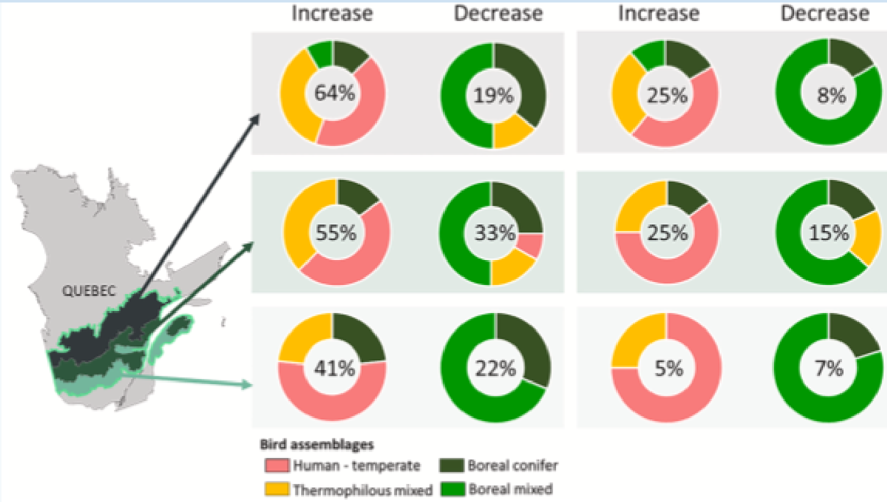


Figure: Percent of bird species that are predicted to be sensitive to the cumulative impact of climate change and forest management under RCP 8.5 in 2100. The cumulative impact of forest management and climate change are considered important when bird species associated to a bird species assemblage show 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). The three bioclimatic subdomains are indicated on the map: the mixedwood (light green), boreal fir-white birch (medium green), and boreal spruce-moss (dark green) bioclimatic subdomains.

Climate change is a significant threat to biodiversity, particularly in northern ecosystems. This study explored how climate change and forest management will influence bird assemblages in Québec's boreal forests from 2020 to 2100. Using forest landscape simulations and abundance models for 73 bird species, we found that species associated with boreal coniferous and mixedwood forests are especially at risk of population decline, particularly in southern areas, while generalist species showed greater adaptability. Wildfire was a key driver of distribution shifts, especially in the northwest, where increased fire activity may facilitate the expansion of temperate-associated species into younger, regenerating forests. By 2100, climate change—both directly and through wildfire—is expected to exceed forest management as the dominant force shaping bird habitats. These findings underscore the importance of incorporating dynamic disturbance regimes into habitat modeling and conservation planning to better anticipate and mitigate future climate-driven impacts on boreal bird populations.

Labadie et. al 2025. https://doi.org/10.1016/j.biocon.2024.110956 Contact: Junior Tremblay, junior.tremblay@ec.gc.ca

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

In 2024-2025, we continued to evaluate how climate change and forest dynamics are likely to shape the future of boreal landbird communities in the Taiga Plains ecozone of the Northwest Territories. Using integrated species distribution models and LandR, a climate-sensitive forest dynamics model, we projected density changes for 72 boreal bird species under three global circulation models for both short-term (2031) and long-term (2091) horizons. We identified species likely to increase ("winners"), decrease ("losers"), or exhibit strong directional changes ("bellringers") in abundance, revealing that climate-driven shifts in bird distributions are expected to intensify over time and follow a pronounced southeast-to-northwest gradient. Notably, the Northwest Territories is projected to serve as an important long-term refugium for several species. To assess potential impacts on ecological functions and community resilience, we grouped species by functional traits and applied cross-scale resilience metrics. Our results indicate that the southern Taiga Plains currently support higher functional redundancy, suggesting greater resilience, while northern areas may experience more substantial reorganization of bird communities under future climate conditions. These findings highlight the importance of proactive conservation strategies aimed at preserving functional diversity, maintaining habitat heterogeneity, and supporting the adaptive capacity of northern bird communities in the face of accelerating environmental change. This work was a highly collaborative initiative between BAM, NRCan, ECCC, the National Audubon Society, and Bird Conservancy of the Rockies.

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

Integrating climate vulnerability into conservation assessments

Incorporating climate vulnerability into conservation assessments is critical for identifying at-risk species to future changes in climate. We used North America–wide species distribution models developed by Audubon to evaluate how climate vulnerability influenced Partners in Flight conservation scores (ACAD database) for 586 bird species. We found that 41% (242 species) experienced an increase in conservation threat scores when considering climate. Examining the ecological factors influencing score increases, breeding biome was the strongest predictor, with Arctic and Northern Forest (boreal) breeders exhibiting the highest increases in conservation threat scores. Breeding habitat, guild, and migration strategy were also significant predictors, with tundra breeders, shorebirds, and migratory species more likely to experience threat score increases when considering climate. Several species that are currently in steep decline are also projected to have greater than 50% range loss under future climate change. These findings emphasize the importance of climate vulnerability in conservation prioritization, particularly for species that are already exhibiting early signs of decline.

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

Yukon boreal cordillera climate change refugia

We continued our project on Yukon boreal cordillera climate change refugia in 2024-2025. The mountainous Taiga and Boreal Cordillera regions are expected to serve as climate refugia for landbirds by the end of the century. We modeled the climate niche space of 46 bird species and predicted their distribution and abundance within the Cordilleras by 2100, while accounting for biotic velocity. We found that nearly half of these species, especially long-distance migrants, are likely to benefit from changing conditions in this region, while about a quarter are likely to decline, with six potentially being extirpated. Projected-to-decline species were more likely to currently occupy high elevations, have small ranges, or be projected to move up-slope by 2100. Shared refugia for multiple species tended to occur at lower elevations in southern watersheds. These areas are currently of high value for landbirds, have less protection, and are exposed to greater anthropogenic disturbance, suggesting they should be focal regions for stewardship or protection. This work is a collaboration with NRCan, the United States Geological Survey, and the Wildlife Conservation Society of Canada. This work was submitted as a peer-reviewed manuscript in 2024-2025 and is currently under revision.

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

Assessing impacts of the 2023 wildfire season on birds

In response to the extreme 2023 wildfire season, which severely impacted areas across northern Québec including Eeyou Istchee, BAM collaborated with Nature Canada on a project led in support of the Cree Nation Government to assess potential impacts on wildlife populations. We focused on bird populations affected by the fires, using version 4 of the landbird density models and 2020 waterfowl abundance maps to quantify the number and proportion of birds likely present in burned or smoke-affected areas. For each species with available data, we calculated total population size within Eeyou Istchee and the proportion expected to have occurred in: (1) the fire footprint, (2) unburned areas exposed to high levels of smoke for 30 days or more, and (3) unburned areas with high smoke exposure for at least 15 days. To support transparency and future application, we developed a SpaDES module to automate this analysis, allowing flexible application across species, years, and geographies. Building on this work, a broader analysis of the 2023 fire season's impacts across Canada has now been initiated as part of a PhD research project. This expanded analysis will estimate fire-related bird losses by province and Bird Conservation Region, with special attention to old forest-associated species. A manuscript was initiated in 2024–2025 and is expected to be completed and submitted for publication in 2025–2026.

[**CO-PRODUCED project**. Contact: Isolde Lane Shaw]

Avian responses to forest disturbances in the Canadian Rockies

Disturbance regimes in the Canadian Rockies have changed substantially over the past century. Historically frequent, low intensity, patchy fires have been replaced by increasingly large, severe, and stand-replacing events, while the mountain pine beetle (MPB) hyperepidemic has affected millions of hectares of forest since 1999. These shifts—driven by settler colonial fire suppression and anthropogenic climate change—have altered forest structure and composition, with uncertain consequences for wildlife. In particular, it remains unclear how bird communities—widely used indicators of ecosystem change—are responding to novel combinations of disturbance type, severity, extent, and recovery trajectories.

In 2024-2025, BAM supported the completion of an MSc thesis that examined how bird communities are responding to changing forest disturbance regimes in the Canadian Rockies, shaped by fire suppression, climate change, and MPB outbreaks. Using ARUs, the study assessed avian species richness, composition, and species-level responses to two broad-scale disturbances: the 2017 high-severity Kenow Wildfire in Waterton Lakes National Park and post-MPB outbreak management in Jasper National Park and the Southern Rockies. Results showed that elevation was the dominant driver of bird community structure, but wildfire amplified species losses at mid-elevations, particularly for old-growth forest specialists. In post-MPB landscapes, bird communities in Jasper differed clearly by disturbance type (burned, harvested, or left-standing), while those in the Southern Rockies—affected earlier—showed convergence and possible legacy wildfire effects. Across both systems, patchy and spatially distinct disturbance patterns supported greater heterogeneity in avian responses. These findings underscore the importance of spatial scale, disturbance history, and landscape heterogeneity in post-disturbance recovery and highlight the need for forest management strategies that sustain biodiversity in increasingly dynamic mountain ecosystems. Both chapters of the thesis will be submitted for publication in 2025-2026.

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

Energy and mining impacts and cumulative effects

Three Year Summary

Over the past three years, BAM has continued to contribute to a growing body of research on the cumulative impacts of energy and mining development on boreal birds across Canada, with a focus on integrating our landbird density models into environmental assessments, understanding spatial scale effects, and developing tools to inform offsetting and reclamation strategies.

In northern Ontario, BAM collaborated on an environmental assessment of the proposed Ring of Fire mining development, using predictive models to estimate potential impacts on bird communities and has continued to work with the Northern Ontario Bird Modelling Working Group (NOBMWG) to support bird modelling in this region. In Alberta, our collaboration with ABMI led to a landmark publication demonstrating how conclusions about oil sands impacts vary across spatial scales, emphasizing the importance of scale in cumulative effects assessment. We also supported the use of ARU-based data and dynamic occupancy models to document declines in Yellow Rail populations near mining infrastructure and are extending this work to old-forest indicator species. With support from ECCC's Environmental Damages Fund, we also began developing a framework for incorporating well site reclamation trajectories into species distribution models to better reflect post-disturbance recovery, quantify recovery of well sites for boreal birds, and use boreal birds as a bioindicator for footprint recovery.

In 2023, we initiated a major Impact Assessment (IA) project funded by ECCC to integrate BAM density models into federal IA processes. This work includes development of a reference condition analysis pipeline, tools for offset calculation, and the BAMexploreR package to estimate bird densities in project-specific footprints. In 2024-2025, we implemented machine learning approaches to "backfill" high-impact footprints with likely natural vegetation and compared resulting population estimates to observed conditions, demonstrating, for example, a 19,000-male difference in Canada Warbler abundance in Atlantic forests due to human footprint.

Together, these efforts demonstrate BAM's capacity to support robust, streamlined approaches to impact assessment and mitigation planning through high-resolution, reproducible, and ecologically grounded modeling approaches, supporting informed decision-making across Canada's resource sectors.

Impact assessment of forest-associated migratory bird species

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. In 2024-2025, we developed a modelling pipeline for reference condition analysis (**Research Box 3**). At the core of this pipeline is a machine learning approach for "backfilling" areas of high human footprint (urban, agricultural, industrial; Hirsh-Pearson et al. 2022) with reasonable estimates of natural vegetation cover and composition. The backfilling models work by learning about the abiotic conditions (e.g., climate, soil composition, terrain) that are associated with vegetation characteristics in areas with relatively low human footprint. Then, given an area with high human impacts, these models estimate the probable natural vegetation that would occur, given the local abiotic conditions. This preliminary pipeline was developed in Bird Conservation Region 14 (BCR 14; Atlantic Northern Forest), as it is the smallest BCR for which we have bird density models, allowing faster computation time during testing. In principle, this pipeline can be implemented in any BCR, although the distinct biogeography and industrial history of each BCR will undoubtedly necessitate some level of customization. [Code development](#) for this pipeline is updated regularly.

Research Box 3. Developing a backfilling protocol for quantifying the impacts of human-caused disturbances

Quantifying the effects of human disturbance is hindered by a lack of a reference state, or knowledge of what the environmental conditions prior to disturbance. "Backfilling" with machine learning can create a reference state, which can then be used to estimate change in bird populations with and without human disturbance on the landscape. The work directly supports Canada's federal offsetting policy and will be expanded with high-resolution imagery and model enhancements in 2025–2026.

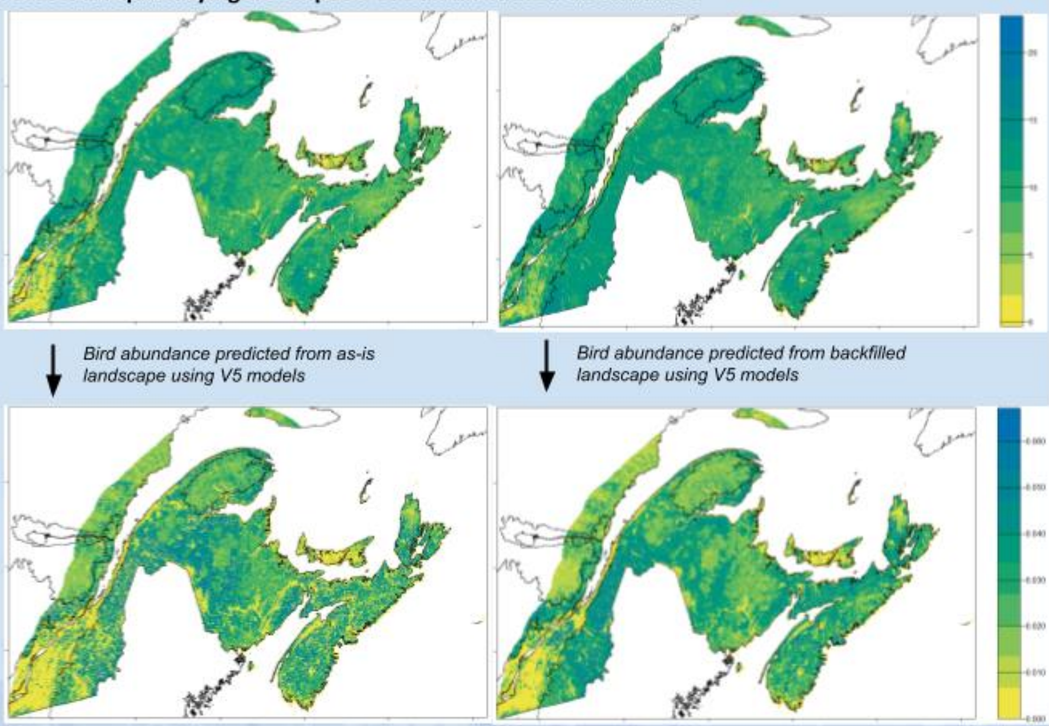


Figure: Overview of backfilling approach in Bird Conservation Region 14 for Canada Warbler. Top panels show forest canopy height, one of the most influential biotic predictors of Canada Warbler abundance. Bottom panels show predicted Canada Warbler abundance year 2020. Left panels show current conditions and predictions and right panels show backfilled predictions., population estimate. Colours represent the number of males per hectare. The estimate of Canada Warbler males in BCR 14 increased 19,413 after backfilling (639,311 males to 658,724 males).

Work in progress. Contact: Mannfred Boehm, mannfred@ualberta.ca

After generating reference landscape conditions, we used BAM version 5 models to estimate population size in an "intact" landscape. For demonstration purposes, we present results for Canada Warbler (*Cardellina canadensis*), a species of conservation concern in the Atlantic Northern Forest (Westwood et al. 2020). We then compared the theoretical "intact" population estimate with observed population and concluded that, all else being equal, population changes can be attributed to changes in human footprint. Given that by visual inspection, the largest human impacts in BCR 14 are urbanization, we assume most of the observed change is driven by the footprint of human settlement in this region. Precise quantitative attribution will soon be possible by parsing specific elements from the Canada Human Footprint layer (Hirsh-Pearson et al. 2022). The value of this modelling procedure is that it can be adapted to quantify changes in bird populations driven by specific impacts (e.g. mining, oil and gas, refineries, and associated infrastructure such as roads). In BCR 14, the Canada Warbler population estimate increased by 19,413 males when high human footprint areas were replaced with estimates of naturally occurring vegetation (658,724 males estimated in intact landscape, 639,311 males in disturbed landscape).

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

Oil sands monitoring of colonization/extinction of boreal birds

As part of the Oil Sands Monitoring Program in northeastern Alberta, we continued to assess the effects of oil sands development on Yellow Rail (*Coturnicops novaeboracensis*) populations, combining acoustic data collected with ARUs from 2016 to 2023 with remote sensing predictors to model dynamic occupancy across wetland sites. Using Bayesian hierarchical models, we found that Yellow Rail occupancy declined significantly across the region, with particularly steep declines near surface oil sands mining operations—58% in the East Mine region and 26% in the West Mine region over the study period. Occupancy, colonization, and persistence were all negatively associated with variables linked to industrial footprint, such as proximity to wells, seismic lines, and landscape features indicative of hydrological alteration. Sites with more stable wetland conditions and fewer signs of industrial disturbance supported a more consistent Yellow Rail presence. These findings highlight the species' sensitivity to cumulative land-use change in the oil sands region and demonstrate the value of integrating acoustic monitoring with satellite remote sensing to assess industrial impacts on wetland-dependent bird populations. This study will be submitted for peer review in 2025-2026.

[**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 (e.g., 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. In 2024-2025, we partnered with Alberta Innovates to assess the potential of remote sensing variables for assessing well site reclamation. We also assessed existing bird survey datasets in the WildTrax platform that have been conducted on abandoned and/or reclaimed well sites to understand the process of well site regeneration for birds. Next steps for this project will be to quantify the recovery trajectory of well sites as habitat for boreal bird species and to explore model-based approaches that use boreal birds as bioindicators for well site reclamation.

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

Forestry impacts

Three Year Summary

BAM has undertaken a wide range of projects to understand and mitigate the impacts of forestry on boreal landbirds, with particular focus on informing sustainable forest management through science-based tools and collaborative planning frameworks. From large-scale trend assessments to localized evaluations of colonization and persistence dynamics, BAM's forestry-related research is enabling partners to make informed decisions that balance timber production with the conservation of boreal bird populations and forest biodiversity.

A key collaboration initiated between 2022-2025 was with partners at Natural Resources Canada (NRCan) towards model-based approaches to understanding, quantifying, and mitigating the effects of forest degradation on Canada's forests. The BAM landbird density models are being used for a variety of degradation indicators, including attribution of boreal bird population change to forest attributes, with the goal of contributing to Canada's State of the Forests indicator.

A core theme across multiple initiatives has been integrating bird conservation objectives into forestry decision-making. We advanced novel optimization tools such as "bird yield tables" and SpaDES modules, which translate BAM's landbird density models into formats usable within forest management planning systems. These tools are now being applied to evaluate trade-offs between harvest targets and conservation outcomes, and to assess forest degradation using bird-based indicators across Canada. BAM also played a key role in evaluating the value of SFI-certified forests for bird conservation, adapting forest dynamics models (LandR) for eastern Canada to assess future resilience under climate change. Through cross-border collaborations in Bird Conservation Region 12 and with the Eastern Habitat Joint Venture, we've developed co-production frameworks and filled major avian data gaps to support regionally relevant conservation planning.

Our work has also documented which management approaches benefit or harm boreal bird populations, particularly when related to forest structure, age, and configuration to bird populations. Recent studies showed that live tree retention can support bird abundance over multi-decade timescales post-harvest, and that spatial configuration of mixedwood stands is critical for habitat specialists. Species-specific analyses, such as long-term dynamic occupancy modeling of Black-throated Green Warbler, underscore the negative impacts of fragmentation and highlight the need for protection of stable, older forests.

Optimizing sustainable harvests

This project advances a novel method for incorporating bird conservation objectives into forest planning optimization models. The approach enables users to efficiently summarize BAM's landbird density models into "bird yield tables," which provide predicted bird densities by forest age and class—formats readily usable within forest management planning tools (**Research Box 4**). Developed as a suite of SpaDES modules, the method is fully reproducible and adaptable to different datasets and geographies across Canada or other forested regions with suitable wildlife data. In 2024-2025, the first manuscript describing the method (Lane Shaw et al. in revision) underwent several rounds of revision and will be resubmitted in 2025-2026.

[**CO-PRODUCED project**. Contact: Isolde Lane Shaw]

Research Box 4. Piecewise smoothing of predicted species density maps: A method of integrating wildlife conservation objectives into forest management planning

The use of categorical forest class suitability estimates can help integrate wildlife conservation into forest management planning, but generating these estimates for each management area is often costly and time-consuming. To address this, we developed an open-source, reproducible "piecewise smoothing" method that uses existing regional data to produce "wildlife yield tables" by mapping species density estimates onto forest and age classes relevant to management. Demonstrated using 20 songbird species in northern Alberta, the method effectively captures species-specific variation in density and offers strong flexibility. It allows users to tailor parameters to local conditions and species, increasing its applicability and precision. With further refinement, this approach can be used across Canada—or globally—to rapidly incorporate wildlife values into forest planning, offering a scalable solution for balancing ecological and economic goals.

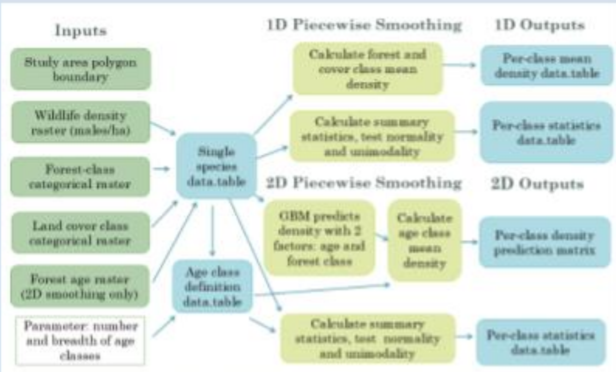


Figure 1: Workflow diagram illustrating the Piecewise Smoothing method, detailing the sequential steps involved in applying the technique, from data input to the final smoothed output.

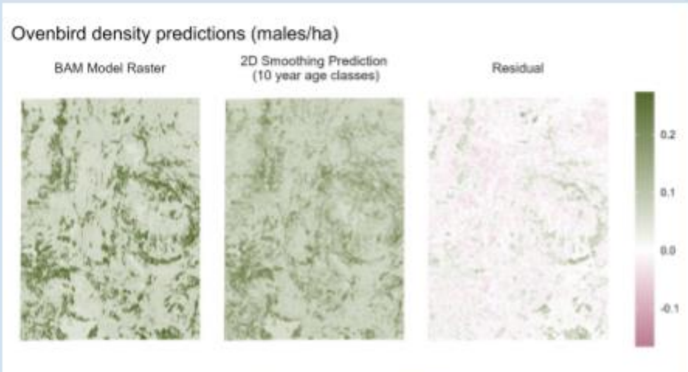


Figure 2: A comparison of the BAM model raster, raster of mapped 2D predictions, and raster of mapped residual values for Ovenbird.

Lane-Shaw et al. In revision. Contact: Isolde Lane-Shaw, rachel-isolde.lane-shaw.1@ulaval.ca

Classifying forest landbird species into habitat groupings

To support regional conservation and forest management planning, we developed a method to classify forest landbird species into generalized habitat groupings based on simplified species distribution modeling (**Research Box 5**). Using a reduced version of the version 5 landbird density modeling workflow, we predicted species abundances at the Bird Conservation Region (BCR) level as a function of key habitat variables: forest cover, proportion conifer, proximity to water, and forest stand age. Species were grouped according to whether their predicted use of each cover type exceeded its availability within a BCR, indicating evidence of habitat selection. Resulting groupings include conifer-, deciduous-, or mixedwood-associated species; wetland-associated species; and species associated with young, mid-, or old-forest age classes. This approach provides a standardized framework for linking bird communities to forest structure and composition, enabling clearer assessments of how different management practices may influence biodiversity across boreal landscapes.

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

Research Box 5. Grouping species by habitat preference

Appropriately grouping species with shared habitat preferences is important for detecting community responses to land cover change. Often species are grouped (e.g. as "old forest associated") based on small-scale studies. However, the same species may show different habitat selection across broad geographical areas and extrapolating habitat associations from one region to another is therefore risky. The objective of this work was to predict species occurrence at a BCR-level across Canada based on four, general, habitat features.

Modeling methods mirrored the more complex BAM landbird models but with a much-reduced covariate set: % forest cover, deciduous/conifer dominance, stand age, and proximity to water. Species predicted occurrence vs. habitat availability within each BCR was then used to quantify BCR-specific habitat "selection" (where proportional species use exceeded proportional habitat availability) and "avoidance" (where use was less than habitat availability). Species were then classified as: forest-associated, conifer-/mixedwood-/deciduous-associated, old (>100 yr)/mature (>=50yr)/young (<50yr) stand-associated and wetland-associated within each BCR. As predicted, species did not always show the same habitat associations across Canada.

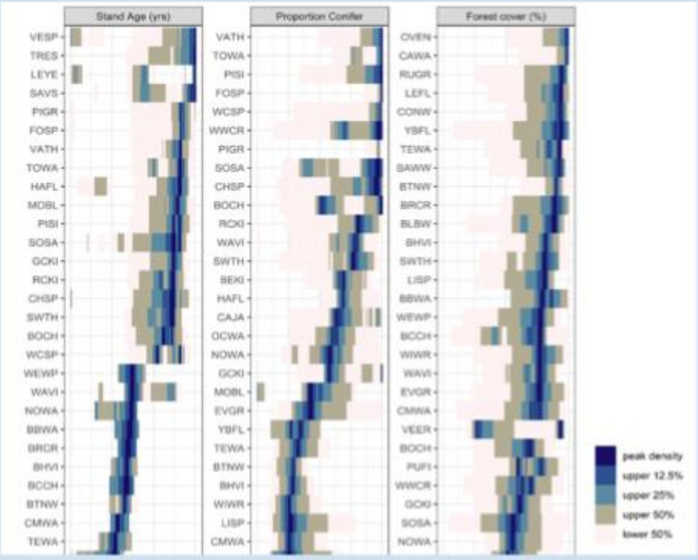


Figure: Example density of boreal bird species by forest stand age (left), proportion of conifer (center), and forest cover (right) to group species by habitat preference in Bird Conservation Region 61. Bottom axis scale varies, image for illustrative purposes.

Contact: Anna Drake, Anna.Drake@nrcan-rncan.gc.ca

Assessing forest degradation using national-scale indicators

We are continuing to use the in-progress version 5 BAM landbird density models to assess forest degradation in Canada. This work involves generating spatially explicit population trend estimates over a 35-year period (1985–2020), using BAM's species distribution models and hindcasted predictions based on historical remotely sensed forest data. In 2024-2025, we advanced this work by partitioning the relative contributions of climate change, landscape change, and unexplained temporal factors to predicted changes in bird populations for several mature and old forest preference species (see "Classifying forest landbird species into habitat groupings" above). We partitioned contributions by constructing artificial time series in which all but one group of time-varying predictors were held constant, allowing us to isolate the influence of each driver. These analyses enable us to investigate species-specific sensitivities to environmental change and better quantify the forest characteristics most associated with long-term population trends. The project is funded by and developed in partnership with Natural Resources Canada's 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 2024-2025, we refined and published our research on live tree retention in harvests as a tool to increase species abundance over time (Lebeuf-Taylor et al. 2025). We demonstrated that small live tree retention patches in harvested boreal forests support an increased abundance of several bird species over time—as long as a decade or more post-harvest. Using a novel method to limit detection distances in passive acoustic surveys, the study revealed that retention effects were significantly underestimated with traditional unlimited-radius sampling. Species such as Red-eyed Vireo, Tennessee Warbler, and White-throated Sparrow were more abundant in retention areas after 10–22 years of regeneration. Edge configuration of patches, more than size alone, influenced bird responses, and patches located nearer to unharvested forest were used more. These findings underscore the importance of incorporating spatial configuration and regeneration timelines into retention strategies and forest planning.

[**CO-PRODUCED project**. Contact: Isabelle Lebeuf-Taylor]

Defining mixedwood forests from a bird's perspective

Conventional definitions of boreal mixedwood forests often overlook the spatial complexity that matters to birds, focusing instead on broad tree composition categories. To better understand how birds respond to mixedwood conditions, we used a spatially explicit approach to examine how three species—Bay-breasted Warbler, Tennessee Warbler, and Black-throated Green Warbler—respond to gradients in coniferous-deciduous composition, forest age, and spatial arrangement of trees across more than 8,600 point counts in Alberta. Using boosted regression tree models, we found that bird responses were highly scale-dependent. The proportion of conifer was the strongest predictor for all species, but responses to forest age and spatial configuration varied. Bay-breasted Warbler showed strong sensitivity to fine-grain spatial patterns and local (150 m) extent, preferring older, intimately mixed stands. Tennessee Warbler preferred younger stands, while the other two species responded positively to forests over 60 years old. These findings suggest that Alberta's current reforestation policies, which emphasize conifer proportions without addressing spatial configuration, may be insufficient to support mixedwood-associated birds. Defining mixedwood forests in ways that reflect avian habitat perception—especially at fine spatial scales—is critical for effective conservation and forest management.

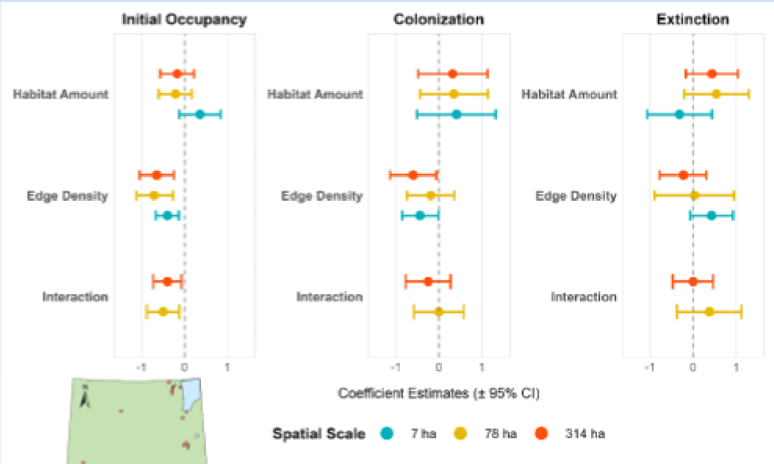
[**CO-PRODUCED project**. Contact: Leonard Patterson]

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*) and Canada Warbler (*Cardellina canadensis*) who are generally more vulnerable to the effects of habitat fragmentation than generalist species. We used dynamic occupancy models to reveal a 58% decline over a 25-year period in Black-throated Green Warbler occupancy, driven by reduced persistence near habitat edges and low colonization rates insufficient to offset local extinctions. We similarly showed that Canada Warblers have higher extinction than colonization rates, and that large disturbances negatively affect Canada Warbler colonization (Hart and Bayne *In review;* **Research Box 6**). This research, part of a broader analysis of fragmentation impacts on forest-dependent species, demonstrated that large polygonal disturbances (e.g., cutblocks, mines) had greater negative effects on occupancy than narrow linear features (e.g., seismic lines), particularly at territory and local spatial scales. By comparing increasingly detailed definitions of fragmentation, the study highlighted the importance of species-specific responses to disturbance configuration. This methodological framework provides a scalable approach for evaluating how forestry, oil and gas extraction, and mining alter forest structure and degrade habitat. It offers a valuable tool for informing land-use planning by quantifying the relative impact of different industrial footprints and identifying which types of features act as functional barriers to species persistence and recovery.

[**CO-PRODUCED project**. Contact: Taylor Hart]

Research Box 6. Habitat amount-fragmentation interactions drive Canada Warbler dynamics across spatial scales



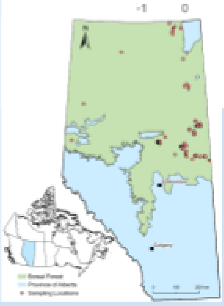


Figure: Model-averaged coefficient estimates (± 95% CI) from dynamic occupancy models showing effects of habitat amount, edge density, and their interaction on Canada Warbler initial occupancy, colonization, and extinction probabilities at three spatial scales (7 ha, 78 ha, and 314 ha). All coefficients were derived from model averaging of the top models (ΔAIC < 2) at each spatial scale.

The Canada Warbler has experienced significant population declines across its range. To understand how landscape change affects its population dynamics in Alberta's boreal forest, we used a multi-scale dynamic occupancy modeling approach with species-specific habitat definitions. We assessed the relative effects of habitat amount and fragmentation, testing interactions between habitat proportion and edge density, and evaluating three definitions of fragmentation to identify functional barriers from the species' perspective. Our results showed that local extinction rates were more than four times higher than colonization rates, aligning with ongoing declines. Edge density negatively affected both initial occupancy and colonization at all spatial scales, with stronger negative effects in areas with greater habitat amounts at broader scales (78 and 314 ha). Larger polygonal disturbances had greater impacts than narrow linear features such as seismic lines. These findings emphasize that preserving habitat amount alone is insufficient; spatial configuration plays a critical role in sustaining Canada Warbler populations. Conservation efforts should focus on maintaining large, unfragmented forest patches, especially in high-quality habitat areas, while future research should consider fine-scale habitat attributes like understory structure and moisture regimes to refine conservation strategies.

Hart & Bayne In revision. Contact: Taylor Hart, tah@ualberta.ca

Conservation planning for boreal birds

Three Year Summary

Over the past three years, BAM has supported evidence-based conservation planning through the integration of our bird density models and framework with spatial prioritization tools. We evaluated the potential for multi-species conservation strategies under the Pan-Canadian Approach to Species at Risk, finding that while boreal caribou are not effective surrogates for most migratory birds, particularly wetland and at-risk species, multi-objective approaches can identify shared priority areas. Building on this work, we collaborated with the Eastern Habitat Joint Venture (EHJV) to fill avian data gaps in eastern Canada and to identify conservation priorities for forest and wetland-associated bird species. With over 150,000 new point counts processed and integrated into the BAM framework, we developed regional spatial prioritizations and initiated region-specific modeling tailored to eastern forest ecosystems. These efforts have improved our ability to forecast population responses to habitat change and will guide future conservation strategies across dynamic landscapes.

Linkages between habitat change and population patterns

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 in forested regions of eastern Canada in 2024-2025, we initiated the development of regional-scale models tailored for conservation planning in Eastern Canada. While originally focused on priority species identified by the Eastern Habitat Joint Venture (EHJV), the project was expanded based on advisory committee guidance to include 20 additional species representative of eastern boreal bird communities. We adapted BAM's landbird density workflow to be broadly applicable across any Canadian region, incorporating additional habitat change drivers such as forestry roads and insect defoliation (**Research Box 7).** Because national-scale geospatial layers for these variables are unavailable, we compiled and harmonized provincial datasets, with temporal data available for Ontario and Québec. These additions enhance model realism, improve reproducibility through integration with up-to-date federal data sources, and support more robust identification of conservation priorities in landscapes undergoing dynamic ecological change.

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

Research Box 7. Adapting landbird modelling workflows for models of forest landbird distribution

With rapid environmental changes, species distribution models (SDMs) have become increasingly crucial for habitat management and conservation planning, as they explain spatial and temporal variations in species distributions and abundances. For over 20 years, our team—the Boreal Avian Modelling Project (BAM)—has developed national-scale SDMs for ~ 150 landbird species. Those models incorporate a broad set of biophysical covariates to closely reflect ecological reality. However, this covariate set is not regionally specific, which may limit its applicability at a regional scale. Our objectives were to 1) adapt the BAM workflow to develop models to include forestry roads and insect outbreaks, and 2) test the influence of regional variables in the models using two model landbird species: Scarlet Tanager (deciduous associated) and Bay-breasted Warbler (coniferous associated). We found that workflow flexibility allows producing models tailored to different objectives and that accounting for local ecological processes can improve the model precision.

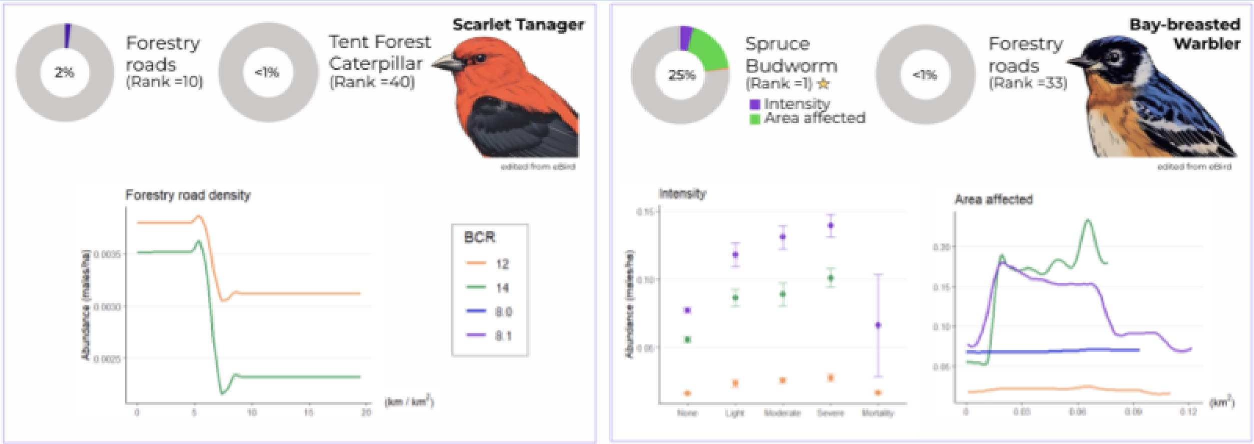


Figure: The influence of forestry road density and insect outbreak predictors on distribution and abundance of two forest landbirds.

Contact: Angela Moreras, ammorerasd@unal.edu.co

Monitoring and sampling

Three Year Summary

BAM has continued to support national-scale monitoring of boreal birds by providing open-source tools, data products, and modelling expertise to improve survey design, data coverage, and accessibility. Central to this work is our ongoing partnership with ECCC on the Boreal Bird Monitoring Program (BBMP), which is implementing the Boreal Optimal Sampling Strategy to address spatial and temporal gaps in bird population data. BAM contributed spatial layers from our landbird density models to guide targeted sampling in underrepresented regions, including Labrador, northern Québec, northern British Columbia, and high-elevation zones. These efforts to improve sampling coverage are improving the accuracy and reliability of the landbird density models, upon which many of BAM's conservation research and tools are b built.

In 2024–2025, BAM partnered with collaborators to advance the field of acoustic classification through two peer-reviewed studies: one describing HawkEars, a high-performance AI classifier for Canadian species, and another reviewing the potential of automated individual identification from acoustic data. These artificial intelligence innovations promise to transform bird monitoring in remote regions by enabling scalable, non-invasive data collection that complements traditional survey methods and continues to improve modelling approaches, particularly for data-sparse taxa.

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. In 2024-2025, Environment and Climate Change Canada (ECCC) continued national implementation of the Boreal Bird Monitoring Program (BBMP) in collaboration with academic, Indigenous, NGO, and provincial partners. Sampling efforts targeted underrepresented regions and habitats—including Labrador, northern Québec, Newfoundland, northern British Columbia, and high-elevation areas—helping to reduce prediction uncertainty in these data-poor landscapes. Processed autonomous recording unit (ARU) and point count data are now accessible through WildTrax and NatureCounts, and are contributing to both BAM's latest modeling efforts and ongoing Breeding Bird Atlases in Saskatchewan, Newfoundland, and Ontario. BAM supported these efforts by providing spatial layers indicating areas of high model extrapolation uncertainty, helping ECCC biologists prioritize sampling for maximum impact.

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

Acoustic classification

With the rapid adoption of autonomous recording units (ARUs) across Canada's boreal forest, advances in acoustic classification have the potential to transform bird monitoring and research by enabling rapid, cost-effective, and scalable analysis of species presence and behaviour across vast and remote landscapes. In 2024-2025, BAM contributed to two peer-reviewed publications showcasing the potential of acoustic classification. The first documented a new artificial intelligence classifier specifically for Canadian bird and amphibian species, HawkEars (Huus et al. 2025), which substantially outperforms existing common classifiers like BirdNET and will be a valuable asset for monitoring Canadian bird species (**Research Box 8**). The second explores and evaluates the potential of automated individual identification (AIID) in acoustic recordings for studying the ecology of acoustic species (Knight et al. 2024). After reviewing nearly 600 studies and the literature in adjacent domains, the article concluded that broadscale implementation of AIID should be soon achievable and will allow biologists to answer important ecological and evolutionary questions with less bias and fewer negative population effects and resources than the current approaches. BAM's future focus for acoustic classification will be on incorporating this new data type into the existing modelling framework for density modelling.

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

Research Box 8. HawkEars: A regional, high-performance avian acoustic classifier

Passive acoustic monitoring is becoming a leading method for studying acoustic wildlife, with neural networks increasingly used to detect species in recordings. Current avian classifiers range from small, species-specific models to broad global models, suggesting a tradeoff between performance and species coverage. We propose that region-specific classifiers offer better performance and introduce HawkEars, a Canadian classifier covering 314 bird and 13 amphibian species. To address the challenge of weakly labeled training data, we developed an embedding-based search method to efficiently generate strong labels. We compared HawkEars to BirdNET and Perch using two datasets focused on community surveys and vocal activity, and found it consistently outperformed both, detecting more species per minute and achieving higher recall at a fixed precision. This improved performance stems from focusing training on a smaller species pool and using high-quality labels. While HawkEars is optimized for Canada and the northern U.S., its open-source framework can be adapted for other regions, offering a scalable tool to improve the effectiveness of passive acoustic monitoring.

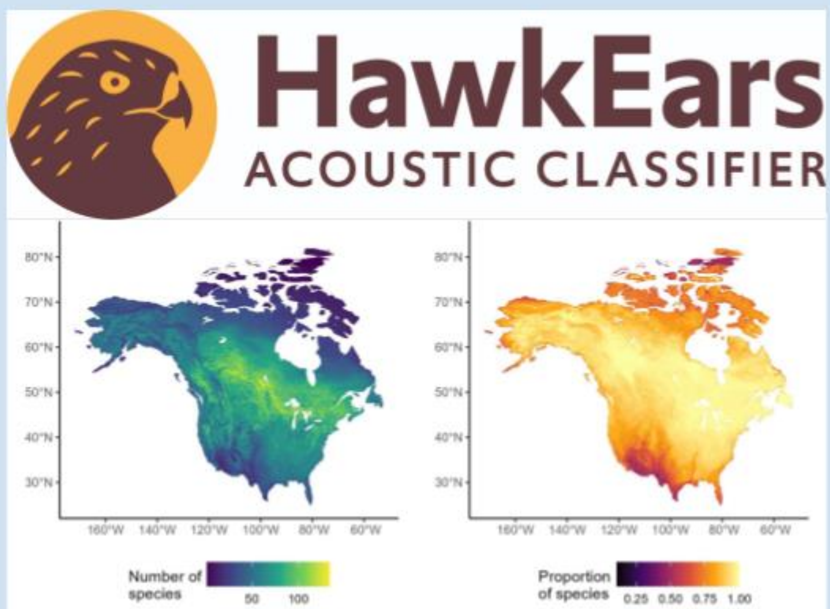


Figure: Spatial distribution of number of breeding bird species (left) and the proportion of total North American breeding bird species available in HawkEars (right).

Huus et al. 2025. https://doi.org/10.1016/j.ecoinf.2025.103122. Contact: Elly Knight, ecknight@ualberta.ca

Knowledge Mobilization

Data products

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.

- 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/.

Three Year Summary

BAM has made significant advancements in developing and delivering spatial data products to support conservation and land-use planning across the boreal forest. Central to this effort is the BAM GeoPortal, which now hosts a growing suite of species-specific distribution, abundance, and habitat suitability products. These include models for boreal landbirds, waterfowl in eastern Canada, and focal species such as Canada Warbler and Pileated Woodpecker.

To improve model accuracy and ecological relevance, we have increasingly integrated advanced remote sensing into our workflows. Collaborations with Planet Labs and academic partners have enabled the use of satellite and LiDAR data to improve habitat characterization—especially for complex forest structure and tree species mixing. These enhancements have strengthened predictions for species like Black-throated Green Warbler and Pileated Woodpecker, the latter of which has benefited from a targeted cavity conservation web application.

Looking forward, BAM is focused on expanding model reproducibility and accessibility. In 2024-2025, we developed a Google Earth Engine (GEE) app for visualizing landbird density predictions across Canada, and launched an R package (BAMexploreR) that allows users to download, explore, and summarize model outputs. We are also translating this functionality into a user-friendly Shiny app to support broader access. These tools were designed in response to user feedback and aim to support the integration of BAM models into conservation workflows.

Through these efforts, BAM continues to prioritize the usability, accessibility, and scientific rigour of our spatial data products, empowering partners to make data-driven decisions for bird conservation and sustainable land management across the boreal region.

Model access tools

In preparation for publication of the version 5 landbird density models, we began development of a series of tools to access and work with the new and existing version 4 models. First, we produced a Google Earth Engine (GEE) application, which will allow users to view the mosaiced models that cover all of Canada and the boreal forest and overlay the models on existing Google imagery or maps. Second, we produced an R package, the BAMexploreR package, which will allow users the ability to download and work with the BAM landbird density models in the program R (**Research Box 9**). There are three general categories of tasks that BAMexploreR provides: 1) download rasters of the model predictions and uncertainty for pre-set regions or custom areas of interest, 2) explore bird species distribution and estimate population size using the downloaded rasters, and 3) explore important predictors of boreal bird abundance and distribution. Finally, we are in the process of translating the R package into a Shiny app that will allow users less familiar with R to undertake the same functionality but with a graphical user interface (GUI). Production of these tools was prompted in part by results from a user survey (see "Data product user survey" below). We hope these tools will allow conservation and land use practitioners to incorporate the BAM landbird density models more easily and seamlessly into their existing workflows and processes.

[**CORE project**. Contact: Mélina Houle or Elly Knight]

Research Box 9. BAMexploreR: model-based distribution, abundance, and habitat associations of boreal birds

The BAMexploreR R package provides tools to access, visualize, and explore data and model outputs from the landbird density models. It supports researchers, partners, and conservation practitioners by streamlining access to BAM's spatial predictions, covariates, and species-specific summaries across Canada's boreal and hemiboreal regions.

The package includes functions to load, map, and analyze outputs from species distribution models, such as predicted abundance, occupancy, or trends. Users can visualize relationships between species responses and environmental variables (e.g., land cover, disturbance, climate), and extract information for specific locations or regions. It integrates seamlessly with spatial R tools like terra and sf, and emphasizes reproducibility by providing access to versioned, standardized datasets. BAMexploreR is particularly useful for exploring model results for custom of areas of interest and seamless integration with R workflows. Developed and maintained by the BAM team, BAMexploreR is open-source and available on GitHub: https://github.com/borealbirds/BAMexploreR. It is designed to be modular, extensible, and aligned with BAM's goals of transparency, collaboration, and applied conservation science.

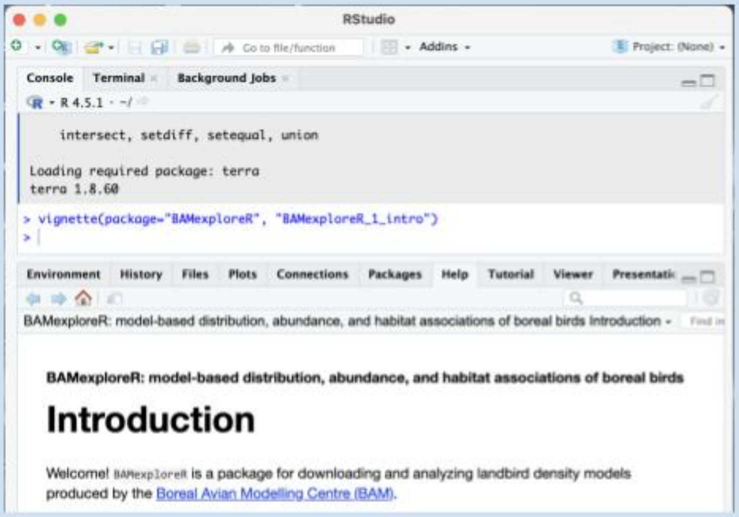


Figure: Github repository page for the BAMexploreR package.

Houle et al. https://github.com/borealbirds/BAMexploreR. Contact: Mélina Houle, houle.melina@gmail.com

Online app to support Pileated Woodpecker cavity conservation

In 2024–2025, significant progress was made in integrating high-resolution remote sensing into species distribution modeling to improve the online app for Pileated Woodpecker cavity conservation. Updated models incorporating 2024 ARU data were validated using newly located nest cavities, and issues related to spatial autocorrelation were resolved to improve model robustness. New methods were developed to characterize cavity-bearing trees using a fusion of LiDAR and multispectral imagery, enabling the extraction of individual tree and crown metrics. These metrics have already been calculated along a proposed pipeline route and will be applied to cavity trees found during the 2025 field season. While the associated web application continues to support field searches and is periodically updated, this year's primary focus was on LiDAR-based method development to enhance predictive accuracy and ecological relevance in habitat modeling.

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

Avian data

Three Year Summary

Perhaps the contribution BAM is best known for, BAM has played a leading role in national efforts to improve the accessibility and usability of bird monitoring data. In 2022-2025, we joined the Canadian Open Avian Data Initiative (CanAvian) and migrated our point count database of over 9 million records to the WildTrax platform. Those records can now be accessed under the Point Count sensor alongside acoustic data, enabling integrated analysis of point count and ARU datasets to build datasets of over 13 million bird records. This transition enhanced data discoverability, interoperability, and open access while respecting contributor agreements. BAM developed and shared harmonization tools to support this migration, helping other partners format their data for inclusion in WildTrax. In total, 17 new point count projects were integrated between 2023 and 2025, adding more than 650,000 additional records, particularly from eastern Canada. In 2024–2025, BAM supported CanAvian's public launch, contributing to a national platform for open bird data and participating in outreach activities including a national webinar. We also revisited and updated sharing agreements with data providers, leading to the release of 18 projects from private to public status. All WildTrax data are now cross-linked with Birds Canada's NatureCounts platform, maximizing accessibility and utility for conservation science and policy.

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 Network for Open Data (CanAvian), which is a collaboration with Birds Canada, ECCC, Alberta Biodiversity Monitoring Institute (ABMI), and WildTrax. In 2024-2025, CanAvian undertook a public launch including a new website and webinar, at which BAM presented our contributions to the initiative.

BAM-managed point count data can be accessed on the WildTrax online platform 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 2024-2025, we continued to revisit data sharing agreements with data partners to increase accessibility, and moved 18 additional projects from private/map-only to public status. We also successfully integrated point count data from 10 new projects into WildTrax, particularly for eastern Canada. We continue collaborating with our partners and others to expand data contribution and facilitate avian conservation and research.

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

Communication and outreach

Three Year Summary

As a collaborative organization, BAM has prioritized effective communication of its science through website updates, collaborative research on knowledge uptake, and user engagement. In 2022–2023, we launched a redesigned bilingual website (borealbirds.ca) to improve accessibility and user experience. Since then, we have continued to enhance content, with a particular focus on the landbird density models and French translation. In 2024–2025, we conducted a bilingual user survey on data product needs and preferences. Insights from the 54 respondents are directly informing the development of new tools and data delivery strategies. Finally, in partnership with Dalhousie University's Westwood Lab, BAM contributed to a communications research project exploring how different audiences engage with scientific tools, using our critical habitat identification framework as a case study. This work aims to strengthen the science-policy interface for species at risk in Canada.

Communications experiment on critical habitat identification framework

Led by Alana Lajoie O'Malley at Dalhousie University's Westwood Lab, this project explores how different stakeholders perceive and prefer communication of policy-relevant science, using the BAM co-developed critical habitat identification framework (Leston et al. 2024) as a case study. The experiment involved a mixed-methods online survey conducted in winter 2024, targeting individuals from federal and provincial governments, NGOs, co-management boards, and community-based organizations. The study investigates how perceptions of usefulness and reliability influence uptake of new scientific knowledge and how communication strategies can be tailored to different audiences. Findings will provide insight into strengthening the science-policy interface for species at risk in Canada and informing more effective knowledge mobilization approaches.

[**CO-PRODUCED project**. Contact: Alana Lajoie-O'Malley]

Updates to the BAM website

We continue to update borealbirds.ca with new content, improve navigability for users and facilitate access to materials, with particular focus in 2024-2025 on highlighting the landbird density models and ensuring thorough translation of materials into French.

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

Data product user survey

Thanks to all 54 respondents to our user base survey on data products! To better understand user needs and improve data delivery, BAM conducted a bilingual user feedback survey focused on current data products and desired features (**Research Box 10**). The results have been greatly informative for informing tool development and future project prioritization and we look forward to sharing those improvements with our users.

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

Research Box 10. Summary from the BAM user base survey on data products

To better understand user needs and improve data delivery, BAM conducted a bilingual user feedback survey in 2024 focused on current data products and desired features. With 54 respondents from government, academia, NGOs, and consulting, the survey highlighted broad satisfaction with BAM products, especially species density maps and habitat suitability layers. Users emphasized the need for clearer documentation, enhanced metadata, additional training materials, and tools like R packages and APIs for programmatic access and customizable downloads.

Table: Top BAM products reported as used in survey respondents' work.

Which BAM product have you been using or are planning to use to support your work? (responses with highest needs)	
Species-specific density maps	55.6%
Current and projected future potential boreal bird densities	53.7%
Population sizes estimates	50.0%
Species-specific habitat suitability maps	42.6%
Point count data harmonization and importing data into WildTrax	37.0%
Species-specific responses to anthropogenic land uses	35.2%
Detectability offsets	29.6%
Statistical scripts and analytical methods	27.8%
QPAD	27.8%
Species-specific critical habitat identification	27.8%
Priority areas for boreal songbird conservation in Canada	22.2%

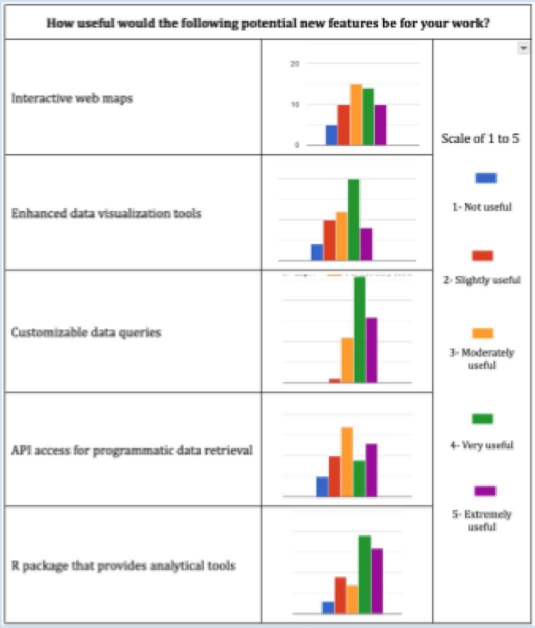


Figure: Top new features requested by survey respondents and degree of usefulness.

Credit: Oussama Bouarkia, Contact: Elly Knight, ecknight@ualberta.ca

Publications and communications 2022-2025

Three Year Summary

Core publications (2022-25)

Publications from BAM Core projects between April 2022 and March 2025

Leston L, Dénes FV, Docherty TDS, Tremblay JA, Boulanger Y, Van Wilgenburg SL, Stralberg D, Sólymos P, Haché S, St. Laurent K, Weeber R, Drolet B, Westwood AR, Hope DD, Ball J, Song SJ, Cumming SG, Bayne SE, Schmiegelow FKA. 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

Stralberg D, Sólymos P, Docherty TDS, Crosby AD, Van Wilgenburg SL, Knight EC, Drake A, Boehm MMA, Haché S, Leston L, Toms JD, Ball JR, Song SJ, Schmiegelow FKA, Cumming SC, Bayne EM. 2025. A generalized modeling framework for spatially extensive species abundance prediction and population estimation. Ecosphere, in press.

Co-produced publications (2022-25)

Publications from BAM Co-produced projects between April 2022 and March 2025

2022

Crosby AD, Leston L, Bayne EM, Sólymos P, Mahon CL, Toms J, Docherty T, Song SJ. 2022. Domains of scale in cumulative effects of energy sector development on boreal birds. Landscape Ecology 38: 3173-3188. doi:10.1007/s10980-023-01779-8.

2023

Binley AD, Edwards BPM, Dansereau G, Knight EC, 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

Edwards BPM, Smith AC, Docherty TDS, Gahbauer MA, Gillespie CR, Grinde AR, Harmer T, Iles DT, Matsuoka SM, Michel NL, Murray A, Niemi GJ, Pasher J, Pavlacky Jr DC, Robinson BG, Ryder TB, Sólymos P, Stralberg D, Zlonis EJ. 2023. Point count offsets for estimating population sizes of north American landbirds. Ibis 165: 482-503. https://doi.org/10.1111/ibi.13169

Leston L, Bayne E, Toms JD, Mahon CL, Crosby A, Sólymos P, Ball J, Song SJ, Schmiegelow FKA, Stralberg D, Docherty TDS. 2023. Comparing alternative methods of modelling cumulative effects of oil and gas footprint on boreal bird abundance. Landscape Ecology 38: 147-168. https://doi.org/10.1007/s10980-022-01531-8

Micheletti T, Haché S, Stralberg D, Stewart FEC, Chubaty AM, Barros C, Bayne EM, Cumming SG, Docherty TDS, Dookie A, Duclos I, Eddy IMS., Gadallah Z, Haas CA, Hodson J, Leblond M, Mahon CL, Schmiegelow F, Tremblay JA, … McIntire EJ. B. 2023. Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. Conservation Science and Practice 5(4): e12908. https://doi.org/10.1111/csp2.12908

2024

Labadie G, Cadieux P, Moreau L, Bognounou F, Thiffault E, Cyr D, Boulanger Y, Stralberg D, Grondin P, Tremblay JA. 2024. Are forest management practices to improve carbon balance compatible with maintaining bird diversity under climate change? A case study in Eastern North America. PLoS Climate 3(4): e0000293. https://doi.org/10.1371/journal.pclm.0000293

MacPherson M, Crosby A, Graff S, Rowse L, Miller D, Raymundo A, Saturno J, Sleep D, Solarik KA, Venier L, Boulanger Y, Fogard D, Hick K, Weber P, Docherty T, Ewert DN, Ginn M, Jacques MJ, Morris DM, Stralberg D, Vezina E, Viana LR, Whitman A, Matula C, Cumming S, Tremblay JA. 2024. A modified co- production framework for improved cross-border collaboration in sustainable forest management and conservation of forest bird populations. The Forestry Chronicle 100(2): 180–193. https://doi.org/10.5558/tfc2024-013

Raymundo A, Micheletti T, Haché S, Stralberg D, Stewart FEC, Tremblay JA, Barros C, Eddy IMS, Chubaty AM, Leblond M, Mahon CL, Van Wilgenburg SL, Bayne EM, Schmiegelow F, Docherty TDS, McIntire EJB, Cumming SG. 2024. Climate-sensitive forecasts of marked short-term and long-term changes in the distributions or abundances of Northwestern boreal landbirds. Climate Change Ecology 7: 100079. https://doi.org/10.1016/j.ecochg.2023.100079

2025

Labadie G, Boulanger Y, Drapeau P, Stralberg D, Tremblay JA. 2025. Projecting bird assemblage responses to climate-driven changes in managed boreal forest landscapes of Québec. Biological Conservation 302: 110956. https://doi.org/10.1016/j.biocon.2024.110956

Lebeuf-Taylor I, Knight E, Bayne E. 2025. Improving bird abundance estimates in harvested forests with retention by limiting detection radius through sound truncation. Ornithological Applications 127(1): duae055. https://doi.org/10.1093/ornithapp/duae055

BAM-informed publications (2022-25)

Publications we're aware of that use BAM data, methods, or expert knowledge, published between April 2022 and March 2025.

2022

Lawley CJM, Mitchell MGE, Stralberg D, Schuster R, McIntire E, Bennett JR. 2022. Mapping Canada's green economic pathways for battery minerals: Balancing prospectivity modelling with conservation and biodiversity values. Earth Science, Systems and Society 2(1). https://doi.org/10.3389/esss.2022.10064

2023

MacPhail AG, Yip DA, Knight EC, Hedley R, Knaggs M, Shonfield J, Upham-Mills E, Bayne EM. 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

2024

Adams CA, Clair CCS, Knight EC, Bayne EM. 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

2025

Knight EC, Carlisle J, Boyce AJ, Bradley D, Cimprich P, Coates S, Dinsmore SJ, Gregory CJ, Jorgensen JG, Kelly JF, Newstead D, Olalla A, Powell LA, Scarpignato AL, Tibbitts TL, Warnock N, Wehtje W, Marra PP, Harrison A-L. 2025. Delineating ecologically distinct groups for annual cycle management of a declining shorebird. Journal of Applied Ecology 62(5): 1152-1165. https://doi.org/10.1111/1365-2664.14885

Knight EC, Rhinehart T, de Zwaan DR, Weldy MJ, Cartwright M, Hawley SH, Larkin JL, Lesmeister D, Bayne EM, Kitzes J. 2025. Individual identification in acoustic recordings. Trends in Ecology & Evolution 39(10): 947-960. https://doi.org/10.1016/j.tree.2024.05.007

Lankau HE, Leston LFV, Bayne EM. 2025. Boreal songbird response to variation in natural seismic line vegetation recovery. Avian Conservation and Ecology 20(2): 5. https://doi.org/10.5751/ACE-02904-200205

Presentations (2022-25)

Presentations given by BAM Team Members between April 2022 and March 2025.

2022

Boulanger Y, Puigdevall JP, Stralberg D, Leblond M, Tremblay JA, St-Laurent M-H, Labadie G, Fortin D. 2022. Using LANDIS to project impacts of climate change and harvest on future wildlife habitats. Presentation to Climate Smart Land Network. Online presentation.

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

Knight EC. 2022. What does a detection mean? Current applications and limitations of using automated recognition in passive acoustic monitoring. BC Association of Professional Biologists AGM. Online presentation.

Knight EC, Brigham M, Edwards B, Harrison A-L, Marra P, Scarpignato A, Smith A, Van Wilgenburg S, Bayne E. 2022. Full-annual cycle conservation of a declining, nocturnal bird: A data integration journey. Canadian Society for Ecology and Evolution and Ecological Society of America Joint Meeting. Montreal, QC. Oral presentation.

Knight EC, Harrison A-L, Marra P, Scarpignato A, Van Wilgenburg S, Bayne E. 2022. Full-annual cycle insights on a declining bird. Global Nightjar Network 2022 Meeting. Online. Oral presentation.

Labadie G, Cadieux P, Thiffault É, Cyr D, Boulanger Y, Stralberg D, Tremblay JA. 2022. Effets des changements climatiques et de l'aménagement forestier sur les communautés d'oiseaux en forêts mixte et boréale du Québec. 15e Colloque annuel du Centre d'étude de la forêt (CEF). Sherbrooke, QC. Oral presentation.

Lane Shaw I, Cumming SG, Raymundo Sanchez, AA, Paradis G, Micheletti T, Barros C, Sólymos P. 2022. Piecewise smoothing: A method of summarising bird population density models for use in forest management planning. Canadian Society for Ecology and Evolution and Ecological Society of America Joint Meeting. Montreal, QC. Poster.

Leston L. 2022. Boosted regression tree models of bird abundance in Nova Scotia. ECCC Community of Practice Group Talk. BAM Species Distribution Modelling Workshop. Online presentation.

Leston L, Bayne EM, Sólymos P, Toms J. 2022. Boosted regression tree models of bird abundance in Nova Scotia. Community Practice Workshop. Online presentation.

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

Raymundo A, Micheletti T, Stewart FEC, Haché S, Stralberg D, Tremblay JA, Barros C, Eddy IMS, Chubaty AM, Leblond M, Mahon CL, Van Wilgenburg SL, Bayne EM, Schmiegelow F, Docherty TDS, McIntire EJB, Cumming SG. 2022. Birds ringing the bell on climate change in the Northern Canadian boreal forest. Society of Canadian Ornithologists. Online Talk.

Tremblay JA, Cadieux P, Labadie G, Boulanger Y, Cyr D, Sólymos P, Stralberg D. 2022. Regional Comparison of the Impacts of Climate Change and Forest Harvesting on Boreal Bird Communities of Canada. Forest Disturbances and Ecosystem Dynamics Symposium. Berchtesgaden, Germany. Poster.

Tremblay JA. 2022. Applying data-driven measures to evaluate and improve the conservation value of managed forests for birds. SFI Conservation Impact Sounding Board Workshop.

2023

Crosby A. 2023. Domains of scale in cumulative effects of energy sector development on boreal birds. Alberta Chapter of The Wildlife Society Annual Meeting. Calgary, AB. Oral presentation.

Knight EC, Sólymos P, Stralberg D, Drake A, Docherty TDS, Crosby AD, Houle M, Leston L, Haché S, Ball J, Bayne EM, Song S, Cumming SG, Schmiegelow F. 2023. An integrated modeling framework for broad-scale spatial prediction and population estimation from varying survey protocols. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Oral presentation.

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

Knight EC, Cumming S. 2023. An integrated modeling framework for broad-scale spatial prediction and population estimation from varying survey protocols. Northern Ontario Bird Modeling Working Group. Online presentation.

Labadie G, Boulanger Y, Tremblay JA, Stralberg D, Drapeau P. 2023. Bird community vulnerability induced by climate change and forest management in the commercial forest of Quebec. The 2023 International Association for Landscape Ecology (IALE) - North American chapter Annual Meeting. Riverside, CA, USA. Oral presentation.

Leston L. 2023a. Power Analysis in Occupancy Models of Acoustic Data from Haida Gwaii, BC, Canada. Pacific Ecology and Evolution Conference. Vancouver, BC. Oral presentation.

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

Leston L, Dénes FV, Docherty TDS, Tremblay JA, Boulanger Y, Van Wilgenburg SL, Stralberg D, Sólymos P, Haché S, St. Laurent K, Weeber R, Drolet B, Westwood AR, Hope DD, Ball J, Song SJ, Cumming SG, Bayne E, Schmiegelow FKA. 2023. 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). Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Oral presentation.

MacPherson M, Crosby A, Rowse L, Graff S, Sleep D, Tremblay JA, Cumming S. 2023. Toward Cross-Border Conservation with Climate Change: Using Co-production to Overcome Ecological Complexity and Jurisdictional Barriers. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Oral presentation.

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

MacPherson M. 2023. Translating management practices into bird population estimates in 50 years.

Moreras A. 2023. Progress on the prioritization (Objective 1.1). EHJV Advisory committee quarterly meeting number 5. Online presentation.

Raymundo A, Micheletti T, Stewart FEC, Haché S, Stralberg D, Tremblay JA, Barros C, Eddy IMS, Chubaty AM, Leblond M, Mahon CL, Van Wilgenburg SL, Bayne EM, Schmiegelow F, Docherty TDS, McIntire EJB, Cumming SG. 2023. Birds ringing the bell on climate change in the Northern Canadian boreal forest. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Oral presentation.

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

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

Tremblay JA, Labadie G, Cadieux P, Thiffault E, Cyr D, Stralberg D, Boulanger Y. 2023. Cumulative impact of climate change and forest management on bird community in mixed and boreal forests in Québec. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Oral presentation.

Tremblay JA. 2023. Spatio-temporal variability of the predicted impacts of climate change on boreal biodiversity. International Boreal Forest Research Association (IBFRA) Conference. Helsinki, Finland. Oral presentation.

2024

Boehm MMA. 2024. Modelling bird populations for Impact Assessments. Impact Assessment Agency (ECCC). Online presentation.

Bouarakia O. 2024. The Boreal Avian Modelling project (BAM): data-driven collaborative science. Partners in Flight - Eastern Working Group and Science Committee Meeting. Online presentation.

Docherty TDS. 2024. Boreal Landbird Data & Tools Update. Prairie Habitat Joint Venture Annual Science Committee Meeting. Winnipeg, MB. Oral presentation.

Houle M. 2024. The Boreal Avian Modelling Project. CanAvian webinar: Introduction to the Canadian Network for Open Avian Data. Online presentation.

Knight EC. 2024. BAM's boreal-wide models of avian density v5. Boreal Partners in Flight Annual Meeting. Online presentation.

Knight EC, Rhinehart T, de Zwaan DR, Weldy MJ, Cartwright M, Hawley SH, Larkin JL, Lesmesiter D, Bayne EM, Kitzes J. 2024. Individual identification in acoustic recordings: Applications and opportunities in ecological research. ABMI Internal Forum. Edmonton, AB.

Knight EC, Rhinehart T, de Zwaan DR, Weldy MJ, Cartwright M, Hawley SH, Larkin JL, Lesmesiter D, Bayne EM, Kitzes J. 2024. 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, AB. Oral presentation.

Knight EC, Edwards B, Yip D, Rhinehart T, Lapp S, Van Wilgenburg S, Iles D, Kitzes J, Bayne EM. 2024. Probability of detection: What can we learn from passive acoustic monitoring? Ecological Society of America. Long Beach, CA. Oral presentation.

Knight EC, Rhinehart T, de Zwaan DR, Weldy MJ, Cartwright M, Hawley SH, Larkin JL, Lesmesiter D, Bayne EM, Kitzes J. 2024. A promising road forward for acoustic individual identification: review and recommendations. Ecological Society of America. Long Beach, CA. Oral presentation.

Lane Shaw I. 2024. Quantifying the birds impacted by the 2023 fire season. Colloque Facultaire FFGG (Faculté de foresterie, de géographie et de géomatique, Université Laval). Quebec, QC. Oral presentation.

Moreras A. 2024 Progress on regional models (Objective 2.1). EHJV Advisory committee quarterly meeting number 6. Online presentation.

Moreras A. 2024. Discussion on Species of interest for regional models. EHJV Advisory committee quarterly meeting number 7. Online presentation.

Varkouhi S, Cumming S, Tremblay JA. 2024. Challenges and innovations in applying a new forest dynamics model to Eastern Canada. 17e Colloque annuel du centre d'Étude de la forêt (CEF). Gatineau, QC. Poster.

Yip DA. 2024. Regional update for British Columbia BCR 4 and 6. Boreal Partners in Flight Annual Meeting. Online presentation.

Yip DA. 2024. Bird monitoring in FNFN restoration areas and integration with ECCC regional monitoring. Fort Nelson First Nation Knowledge Summit. Online presentation.

2025

Bouarakia O. 2025. BAM products and projects. Parks Canada Bird Monitoring Community of Practice. Online presentation.

Boulanger Y, Puigdevall JP, Stralberg D, Leblond M, Tremblay JA, St-Laurent M-H, Labadie G, Drapeau P. 2025. Using forest harvest models to project the impacts of climate change and harvest on wildlife habitats. CFS Seminar. Oral presentation.

Knight EC. 2025. Boreal Avian Modelling Centre: History, Foundational Work, & Current Applications. Biodiversity Pathways Board Meeting. Online presentation.

Knight EC. 2025. The Boreal Avian Modelling Project. MBCMC (Migratory Birds Conservation Managers Committee) meeting. Online presentation.

Knight EC. 2025. The Boreal Avian Modelling Project Discussion. Director General, Canadian Wildlife Service, Environment Canada. Online presentation.

Knight EC. 2025. BAM's boreal-wide models of avian density v5. Northern Ontario Bird Modeling Working Group. Ottawa, ON. Oral presentation.

Leston L, Bayne EM. 2025. Using boreal birds and remotely sensed data as ecological indicators of footprint reclamation for wildlife. Alberta Chapter of the Wildlife Society Annual Meeting. Drumheller, AB. Oral presentation.

Moreras A. 2025. Discussion on Covariates of interest for regional models. EHJV Advisory committee quarterly meeting number 8. Online presentation.

Webinars and workshops (2022-25)

Webinars and workshops organized or co-organized by BAM Team Members, hosted between April 2022 and March 2025

2022

Edwards B, Knight EC. 2022. Importance of detection probability and recent advances in estimation. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON. Symposium.

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

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

2023

Leston L, Knight E. 2023. Detectability offsets to combine survey data from independent boreal bird studies: QPAD workshop. Joint conference of the American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada. London, ON.

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

Stralberg D. 2023. Caribou and Climate Change Workshop. Prince George, BC (hybrid).

Tremblay JA. 2023. Managing for diversity: A call for a better understanding of linkages between forest structure, biodiversity and carbon cycle. International Boreal Forest Research Association (IBFRA) Conference. Helsinki, Finland. Symposium.

2024

Crosby A. 2024. Species occupancy modelling and extensions: Theory and practice. Society of Canadian Ornithologists online workshop series.

Project Management

Structure of the BAM project

The BAM Team

Steering Committee:

- Erin Bayne, Professor, Department of Biological Sciences, University of Alberta. bayne@ualberta.ca
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- Steve Matsuoka, Research wildlife biologist, USGS Alaska Science Centre. smatsuoka@usgs.gov

Future Structure

In 2024-2025, the BAM team initiated conversations about becoming an 'Initiative' under Biodiversity Pathways, a national non-profit organization affiliated with the Alberta Biodiversity Monitoring Institute (ABMI). Biodiversity Pathway's mission of working collaboratively to develop and implement science-based monitoring programs that provide relevant, accessible information to support decision-making is closely aligned with the vision and mission of BAM. Joining BAM with Biodiversity Pathways would provide substantial benefits to both groups in addition to a long history of synergy with the ABMI. We look forward to sharing more news about this new relationship in future annual reports!

Partnerships

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 2024-2025

Natural Resources Canada (NRCan), Canadian Forest Service (CFS) ForSITE program

Natural Resources Canada (NRCan), Canadian Forest Service (CFS) Sustainable Forest Management program

Environment and Climate Change Canada (ECCC), Canadian Wildlife Service

Environment and Climate Change Canada (ECCC), Science and Technology Division

Environment and Climate Change Canada (ECCC), Environmental Damages Fund

Mitacs Accelerate Program

Alberta Biodiversity Monitoring Institute (ABMI)

Forest Resource Improvement Association of Alberta (FRIAA)

Joint Canada-Alberta Oil Sands Monitoring Program (OSM)

The Sustainable Forestry Initiative (SFI)

Petroleum Technology Alliance Canada (PTAC)

Université Laval

University of Alberta

Ducks Unlimited Canada

Nature Conservancy of Canada

Boreal Ecosystems Analysis for Conservation Networks (BEACONs)

G&C Funding summary in 2024-2025

The following section lists projects described in this report that the three-year Grants & Contributions Agreement (G&C) with Environment and Climate Change Canada (ECCC) directly supported. The three-year G&C with ECCC also supported all BAM operational activities in 2024-2025.

Solely funded by G&C

- BAM landbird density models
- Detection probability
- QPAD bug
- Model access tools
- CanAvian and the WildTrax platform
- Updates of the BAM website
- Data product user survey

Co-produced with BAM contributions fully or partially funded by G&C

- Population Estimation
- Northern Ontario Bird Modelling Working Group
- Integrating climate vulnerability into conservation assessments
- Assessing impacts of the 2023 wildfire season on birds
- Ecological framework for assessing and incorporating reclamation success into SDMs and conservation planning
- Classifying forest landbird species into generalized habitat groupings
- Assessing forest degradation using national-scale indicators
- Linkages between habitat change and population patterns
- Boreal Bird Monitoring Program

- Acoustic classification
- Communications experiment on critical habitat identification framework

Funded through other sources leveraged with G&C

- Avian responses to forest disturbances in the Canadian Rockies (funded by FRIAA)
- Impact assessment of forest-associated migratory bird species (funded by ECCC Impact Assessment)
- Live tree retention in harvests as a tool to increase species abundance over time (funded by FRIAA)
- Defining mixedwood forests from a bird's perspective (funded by FRIAA)
- Colonization and persistence dynamics of Black-throated Green Warblers in response to long-term habitat fragmentation (funded by FRIAA)
- Online app to support Pileated Woodpecker cavity conservation (funded by FRIAA and PTAC)

Data partners

Numerous institutions and individuals have provided or facilitated provision of bird and environmental data to the Boreal Avian Modelling Project. Please see the full list on our website at https://borealbirds.ca/about-us/partners-sponsors/.

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Huus J, Kelly KG, Bayne EM, Knight EC. 2025. HawkEars: A regional, high-performance avian acoustic classifier. Ecological Informatics 87: 103122. https://doi.org/10.1016/j.ecoinf.2025.103122.

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Cover photo: Tennessee Warbler (credit Dominic Sherony)

Boreal Avian Modelling Project

Projet de modélisation aviaire boréal