# ANNUAL REPORT

April 2021 - MARCH 2022

BOREAL AVIAN MODELLING PROJECT

PROJET DE MODÉLISATION AVIAIRE BORÉAL

# Highlights from 2021–2022

The Boreal Avian Modelling Project (BAM) is a collaborative group of academic researchers, government scientists, project staff, postdoctoral fellows, and graduate students. We conduct collaborative research in avian ecology and conservation and produce information and data products to fill information gaps and support evidence-based decision-making. We collaborate with a wide range of partners, including federal and provincial governments, academia, industry, Indigenous Peoples and communities, and non-governmental organizations (NGOs). Highlights from our research and knowledge mobilization activities in 2021-2022 are listed below.

## Research & Monitoring

### Population Status and Trends

- Development of version 4.1 of BAM's landbird density estimates for the entire boreal/hemiboreal region of North America is underway and will improve the reproducibility of our workflow and incorporate annual landcover and climate covariates to support analyses of trends. ▶ page 9
- BAM is contributing to a large collaborative project called NA-POPS generating detectability offsets for all species of landbirds in North America to improve estimates of population size. ▶ page 11

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

- A synthesis of our conceptual and analytical framework to support the identification of critical habitat for wide-ranging species comparing Canada Warbler and Wood Thrush is underway. ▶ page 12

### Habitat Selection

- A study predicting bird response to harvesting demonstrates that species distribution model performance improves with remotely sensed covariates over models built using only forest resource inventory data. ▶ page 14

### Detecting and Attributing Land-use and Climate Change Impacts on Boreal Birds

#### *Climate change impacts*

- Two projects evaluate the regional impacts of climate change and forest management on boreal bird abundance and recommend regionally-specific measures for the conservation of boreal birds. ▶ page 16

#### *Energy sector impacts and cumulative effects*

- Two projects evaluate methods for assessing cumulative effects by evaluating the influence of spatial scale and by comparing alternative cumulative effects models. ▶ page 18
- Predictive habitat models, using a reproducible methodology, evaluate the response of landbirds to cumulative effects within the proposed Ring of Fire development area in northern Ontario. ▶ page 19

#### *Forestry Impacts*

- Data-driven risk matrices and a new workflow were developed to support harvest planning decisions regarding incidental take of migratory birds in Alberta and British Columbia. ▶ page 20
- A new project is developing and evaluating methods to optimise for both sustainable harvests and sustainable bird populations in forest management planning. ▶ page 20
- A comparison and synthesis of methods to measure conservation value of forest certification for forest bird populations in Canada. ▶ page 21
- Develop a new project to evaluate the value and resilience of certified forests for eastern forest birds in a changing climate. ▶ page 21

- A collaborative cross-border initiative with the American Bird Conservancy and Sustainable Forestry Initiative (SFI) supports the identification of opportunities and challenges for forest management to benefit bird populations. ▶ page 21

### *Projecting impacts of landscape and climate change*

- Two projects evaluate future climate change impacts on boreal caribou and landbirds in the Northwest Territories to support land-use and conservation planning. ▶ page 23
- Forecastable versions of the BAM National Models developed for the western boreal are being integrated into a broader modelling framework for Environment and Climate Change Canada's (ECCC) Western Boreal Initiative looking at co-benefits of conservation of Species at Risk, migratory birds and carbon in western Canada. ▶ page 24
- A new project is evaluating the future impacts of climate change on the predicted abundance of 75 landbird species in the Northwest Territories. ▶ page 22

## Conservation Planning for Boreal Birds

- Potential co-benefits for boreal forest landbirds as a result of conservation opportunities for caribou were identified across the boreal forest of Canada using BAM's spatial prioritization framework. ▶ page 25
- Identified priority areas to support the conservation of forest birds and wetland birds in the Prairie Habitat Joint Venture-Western Boreal Forest Implementation Plan. ▶ page 25
- Initiated a project with the Eastern Habitat Joint Venture to identify habitat-relationships and priority areas for forest bird conservation in Canada's six eastern provinces. ▶ page 25

## Monitoring and Sampling

- ECCC's Boreal Optimal Sampling Strategy (BOSS) is using BAM detectability offsets and density maps in conjunction with pilot sampling to test design efficiency and sampling bias and determine national sample size requirements to meet Boreal Monitoring Strategy (BMS) objectives. ▶ page 26
- ECCC partners have been working with BAM and the Alberta Biodiversity Monitoring Institute to facilitate the addition of ECCC acoustic data and historic point counts to WildTrax. ▶ page 26

# Knowledge Mobilization

## Data and Data Product Development

The results and outputs of many BAM research projects are synthesized into data products, which we make publicly available to support the conservation and management of boreal birds. More details about our data and data products can be found on page 27 or visit https://borealbirds.ca/explore-our-data/.

- Data products currently available include:
  - Bird **data and methods** to support data standardization
  - **Density and population size estimates** for over 160 landbird and waterfowl species
  - Model-predicted **species distribution and habitat suitability** maps for 94 boreal bird species
  - **Habitat and landcover associations** for 143 landbird species across Canada
  - Maps of **future landbird and waterfowl densities** and **climate change refugia** across Canada
  - **Conservation planning** and **habitat management tools** and data products
- The BAM point count database has been uploaded to WildTrax.ca. Datasets will be openly available to the extent that sharing agreements with data partners permit. To date, the point count data on WildTrax contains approximately 1.9 million observations from 208,000 unique locations across the boreal and hemiboreal region of North America including major datasets from Breeding Bird Atlases, Canadian Wildlife Service's (CWS) regional offices, and provincial governments. ▶ page 28
- Automation of the BAM data standardization process is underway to facilitate the integration and upload of new point count data that will support transparent and reproducible research data management. ▶ page 29

- The BAM GeoPortal was developed and launched as an online platform to facilitate the discovery and accessibility of BAM's spatially referenced data products (https://borealbirds.ca/explore-our-data/). ▶ page 27
- BAM is improving the discovery, accessibility, integration and use of bird data in Canada as a member of the Canadian Network for Open Avian Data (CanAvian), which is a collaboration with Birds Canada, ECCC, Alberta Biodiversity Monitoring Institute (ABMI), and WildTrax. ▶ page 29

### Application of Results through Collaborations

- BAM contributed to more than 30 collaborative efforts to facilitate boreal bird conservation and management.
- BAM data products, methods and results have been applied by partners to support conservation and management efforts related to monitoring design, threats assessment and management planning, priority areas assessment, and species at risk planning.
- A comprehensive list of collaborative projects and applications is included on page 31.

### Communications

- The BAM website (borealbirds.ca) has been updated and translated into French highlighting data products and conservation partnerships. ▶ page 34.
- BAM co-produced 20 peer-reviewed publications since January 2019. ▶ page 34
- BAM research and conservation efforts were highlighted in more than 42 talks at international or regional conferences, targeted workshops, webinars, and collaborative meetings since January 2019. ▶ page 34

## Project Management

- We wish the best of luck to Péter Sólymos who has moved onto a new opportunity. We thank him for his many years of innovative contributions to the BAM project.
- We are pleased to have two new members on our Steering Committee: Diana Stralberg (Natural Resources Canada) and Jeff Ball (ECCC). We look forward to working with them on our leadership team.
- We say farewell to Fiona Schmiegelow and Samantha Song who are transitioning out as Steering Committee members in 2021-2022. We wish to express our deep appreciation to Fiona and Samantha who not only co-founded BAM, but also contributed years of leadership and scientific direction to BAM. We look forward to our continued collaboration with them.

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## Project Team & Technical Committee

| | |
|---|---|
| Erin Bayne, U.Alberta | Steering Committee |
| Steve Cumming, U.Laval | Steering Committee |
| Jeff Ball, ECCC | Steering Committee |
| Diana Stralberg, NRCan | Steering Committee |
| Fiona Schmiegelow, U.Alberta | Steering Committee |
| Samantha Song, ECCC | Steering Committee |
| Hana Ambury, U.Alberta | Research Assistant |
| Teegan Docherty, U.Alberta | Coordinating Scientist |
| Péter Sólymos, U.Alberta | Statistical Ecologist |
| Mélina Houle, U.Laval | Database Manager |
| Hedwig Lankau, U.Alberta | Database Manager |
| Andy Crosby, U.Alberta | Post-doctoral Fellow |
| Lionel Leston, U.Alberta | Post-doctoral Fellow |
| Maggie MacPherson, U.Laval | Research Associate |
| Brendan Casey, U.Alberta | PhD Student |
| Isolde Lane Shaw, U.Laval | PhD Student |
| Ana Raymundo, U.Laval | PhD Student |
| Samuel Haché, ECCC | Contributing Scientist |
| Lisa Mahon, ECCC | Contributing Scientist |
| Steve Matsuoka, USGS | Contributing Scientist |
| Judith Toms, ECCC | Contributing Scientist |
| Junior A. Tremblay, ECCC | Contributing Scientist |
| Steve Van Wilgenburg, ECCC | Contributing Scientist |

# About Us

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

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

## Our Vision

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

## Our Mission

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

## Our Objectives

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

## Our Structure

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

Project execution is facilitated by a dedicated team of staff, post-doctoral fellows, and graduate students. Contributing Scientists provide expert advice and are involved in co-production of relevant science. The collaborative nature of the project is further highlighted by the many individuals who have provided project assistance and support over the years. To learn more about our team visit page 39.

## Recognizing Collaborations

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

**CORE project:** A project addressing BAM's core mandate, led from inception to completion by BAM Team Members

**CO-PRODUCED project:** A project jointly produced between BAM and external collaborator(s). These are often conceptualized outside of BAM before BAM involvement is solicited. BAM involvement could include intellectual contribution to project goals, data provision, analysis, and interpretation of results.

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

**Learn more at borealbirds.ca**

## Proposed Major Activities for April 2019–March 2022

In April 2019, we proposed projects in three parallel but interconnected domains: 1) Research & Monitoring, 2) Communications, Collaborations, and Implementation, and 3) Data and Data Products, with several projects in each domain. Within these three domains we identified the following major activities:

Research & Monitoring

- Population Status & Trends
- Species at Risk
- Habitat Selection
- Climate Change
- Projecting Impacts of Landscape Change
- Conservation Planning
- Monitoring & Sampling

Communications, Collaborations, and Implementation

- Communication
- Application of Results through Collaborations

Data and Data Products

- Data Products
- BAM Databases

Summaries of progress on these activities and others since April 2019 are provided below with a focus on reporting results of the third and final year of the 2019-2022 agreement. Detailed reports of results during years 2019-2020 and 2020-2021 are contained in the respective annual reports found here (https://borealbirds.ca/our-work/annual-reports/).

# Research & Monitoring

BAM's research and monitoring activities provide the scientific foundation for the conservation and management of boreal birds by providing the best available information and by advancing the theoretical foundations and methods of boreal bird conservation. BAM collaborative research projects are designed to address conservation priorities in Canada and inform conservation planning.

Here we describe progress on our research projects from April 2021–March 2022.

## Population Status and Trends

**Summary:** BAM produces reliable information on boreal bird distributions, abundances, trends, and habitat associations to support evidence-based decision-making in migratory bird management and conservation across North America. We have made significant progress in developing a generalized analytical approach to model species density at high resolution and broad spatial extents. We continue to evaluate and refine our spatially-explicit approach to estimate population sizes (Sólymos et al 2020) and to improve methods to estimate population trends and habitat associations. We continue to advance methods to integrate and analyse broad, heterogeneous data to estimate avian population size through collaborations with partners such as ECCC and Partners in Flight (PIF). Since 2019, BAM projects achieved: (1) Canada-wide density estimates for 143 landbird and 18 waterfowl species, (2) a revised trend estimation procedure, (3) a comparison of our spatially explicit models and the PIF approach to estimate population sizes, and (4) contributions to a collaboration to develop point count offsets for North American landbirds (see Appendix 1 for a full list of 2019-2022 projects).

In 2021-2022, we focused on producing annual, pixel-level estimates of density across Canada and regions of the USA to support trend estimation. We also improved our workflow automation to more easily scale, reproduce, and run density models to provide partners with current and robust estimates of status and trends for birds in their region of interest. We continued to collaborate on NA-POPS, an ECCC-led project to produce point count offsets for population sizes of North American landbirds.

### BAM National Density Models Version 4.0 AND 4.1

BAM has developed a generalized analytical approach to model species densities in relation to environmental covariates. In 2020, we produced the BAM National density models version 4.0 (Boreal Avian Modelling 2020). We used the BAM database (data between 1990 and 2018) and built models for bird species based on data from non-arctic portions of Canada. To date, these models provide the first Canada-wide density estimates of terrestrial bird species and address detection heterogeneity (Solymos et al 2013). Compared to previous models for the boreal region of Canada that included 80 species (Stralberg et al 2015), version 4.0 developed models for 143 species and used a modular modelling approach to capture regional differences in habitat associations (Crosby et al 2019). We modelled density independently in 16 regional sub-units (portions of BCRs separated by provincial boundaries) using predictors including tree species biomass, stand age, topography, land use, and climate (Figure 1). We used machine learning to allow for variable interactions and non-linear responses while avoiding time-consuming species-by-species parameterization. We applied cross-validation to avoid overfitting and bootstrap resampling to estimate uncertainty associated with our density estimates. To explore our density models v4.0 visit https://borealbirds.github.io/

In 2021-2022, we worked to fill data gaps in the territories, British Columbia, and the northern U.S. states for the next version of our models (version 4.1; anticipate completion in 2022), which will cover the entire boreal/hemiboreal region of North America (~1990-2022). We also obtained annual climate and updated landcover datasets for data attribution and modelling. This will allow version 4.1 to develop annual, pixel-level estimates that can then be used to estimate trends for a variety of different geographies and time periods. These models will allow us to identify the factors affecting changes in bird populations across their breeding habitat. Recently, we have focused on improving the automation and modularity of the modelling workflow to more easily scale, reproduce, and re-run density models with regionally specific inputs. These improvements will allow us to provide partners with current and robust estimates of status and trends for landbirds in their region of interest. [**CORE project**. Contact: Diana Stralberg and Mélina Houle]

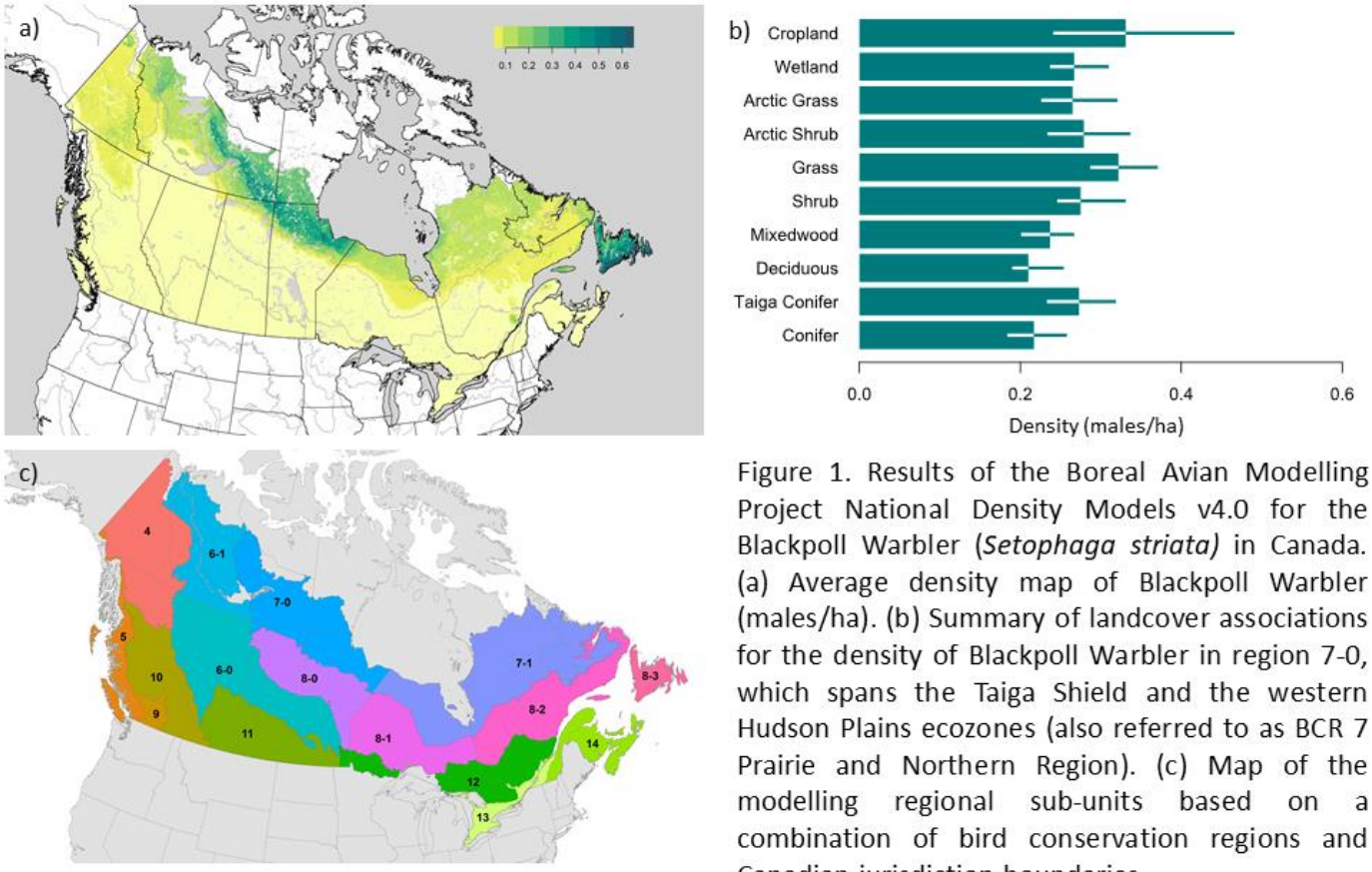


Figure 1. Results of the Boreal Avian Modelling Project National Density Models v4.0 for the Blackpoll Warbler (*Setophaga striata)* in Canada. (a) Average density map of Blackpoll Warbler (males/ha). (b) Summary of landcover associations for the density of Blackpoll Warbler in region 7-0, which spans the Taiga Shield and the western Hudson Plains ecozones (also referred to as BCR 7 Prairie and Northern Region). (c) Map of the modelling regional sub-units based on a combination of bird conservation regions and Canadian jurisdiction boundaries.

## Predicting spatiotemporal abundance of breeding waterfowl across Canada

The aim of this project was to develop predictive statistical models for mapping the abundance and distribution of waterfowl species across Canada and to assess potential effects of climate change on abundance. This research, led by Antoine Adde (a former PhD student with Steve Cumming), refined the previous generation of national waterfowl models developed by Barker et al. (2014). In 2020, a review was published in Écoscience that summarized environmental variables known to affect breeding duck distribution and abundance in northern North America (Adde et al 2020a). Following this review, we used spatial-temporal mixed-effects models to estimate the density of 18 waterfowl species in relation to habitat characteristics, while accounting for both spatial autocorrelation and the serial-autocorrelation inherent in the repeated measurements (Adde et al 2020b). The models were used to generate updated predictions of species density at national extent. A third step of this work assessed the potential effects of climate change on the breeding abundance of 12 common waterfowl species in

Eastern Canada. Species-specific projections indicated potential declines in the abundance of 5 species, including large declines for Barrow's Goldeneye, a boreal cavity nester and a species at risk (Special Concern; eastern population) (Adde et al 2020c). This work continued an 11-year collaboration between Steve Cumming and Marcel Darveau of Ducks Unlimited Canada and benefitted from an NSERC Strategic Partnership Grant and an Ouranos-MITACS (IT12104) internship. A version of these models are being used for the Western Boreal Initiative (page 24) and these models will be used in an upcoming project to support the EHJV (page 25). These models are available on the BAM GeoPortal. [**CO-PRODUCED project**. Contact: Steve Cumming]

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

BAM is a collaborator on a project, called NA-POPS, that builds on our foundational work to develop methods to integrate heterogeneous datasets and generate detectability offsets to support analyses of avian density. This project expands on BAM's work by generating offsets for a number of key field conditions (i.e., road-side, off-road, open habitat, and closed habitat). This large collaborative effort has a goal to generate open-source detectability offsets for all species of landbirds in North America. Currently, this project has generated offsets for 351 species. NA-POPS has compiled a large point count dataset, which includes BAM data, representing a broad array of species, environments, and methods from across North America. The offsets generated by this work will support improved model-based, continent-wide population status and trends estimates. This work has recently been submitted as a manuscript for publication. NA-POPS is led by Brandon Edwards, a PhD student at Carleton University, and is a collaboration among numerous partners, including the ECCC, Natural Resources Canada (NRCan), Bird Conservancy of the Rockies, Klamath Bird Observatory, USGS, the National Audubon Society, PIF, and the Avian Knowledge Network. To learn more, visit the NA-POPS website. [**CO-PRODUCED project**. Contact: Diana Stralberg and Teegan Docherty]

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

**Summary:** Identifying the location and amount of critical habitat needed by a species is an important step in planning recovery strategies for species at risk (SAR). BAM's research, implementable analytical approaches, and data products support recovery planning and the identification of critical habitat. Over the past three years, BAM has partnered with ECCC to inform critical habitat identification through the development of a conceptual and analytical framework that provides a systematic approach to inform the identification of critical habitat based on current and future habitat conditions for wide-ranging SAR in Canada.

In 2021-2022, BAM completed steps to test and synthesize our conceptual and analytical framework for the identification of critical habitat using Canada Warbler (*Cardellina canadensis*) as a case study. We continued to provide support for the application of the analytical framework to identify critical habitat for Wood Thrush (*Hylocichla mustelina*). We are in the midst of completing a manuscript that demonstrates this framework using Canada Warbler and Wood Thrush as case studies.

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

BAM has developed a conceptual and analytical framework to guide the identification of critical habitat (CH) for wide-ranging boreal bird species to support their recovery. This framework provides a systematic approach to inform the identification of critical habitat based on current and future habitat conditions. To address rangewide differences in a species' habitat requirements, this approach independently assesses abundance and habitat relationships across multiple units (hereafter 'management units'). The four steps of the framework include: 1) review species' distribution and life history, 2) delineate management units, 3) assess current and future potential habitat and population size, and 4) spatial implementation of CH identification (see Research Box 1 for details on methods and results). To date, we have applied the analytical framework to two migratory forest songbird species: Canada Warbler (*Cardellina canadensis*) and Wood Thrush (*Hylocichla mustelina*). This project is a collaboration with ECCC and is currently being written as a manuscript to be submitted for publication in 2022. [**CORE project**. Contact: Lionel Leston, Teegan Docherty & Junior A. Tremblay]

**Box 1. A framework to support the identification of critical habitat for wide-ranging boreal bird species at risk**

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

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

Conservation planning exercises suggest a small proportion of available land contains sufficient critical habitat to maintain current populations of Canada Warbler in Nova Scotia and Wood Thrush in eastern Canada, but that there will be insufficient habitat under all evaluated future scenarios to maintain the current Alberta population of Canada Warbler. This framework provides a systematic approach to inform the identification of critical habitat based on current and future habitat conditions for wide-ranging species at risk in Canada.

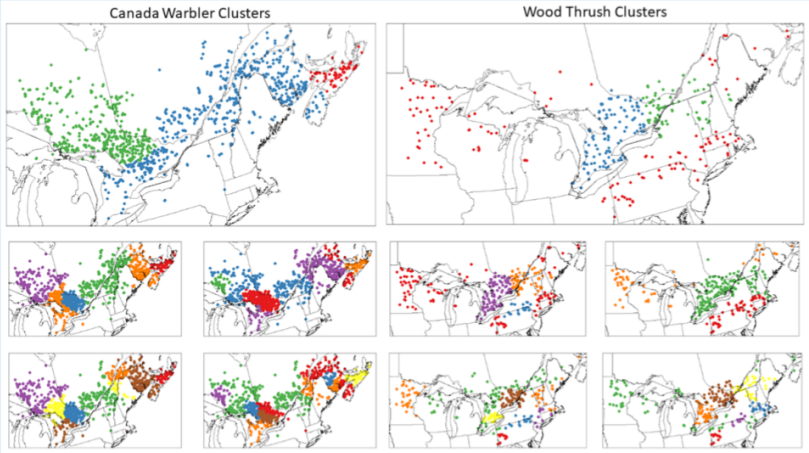


**Figure.** Cluster analysis results from multiple geographically weighted (GW) models run for Canada Warbler (left 5 plots) and Wood Thrush (right 5 plots), using different sample datasets in eastern Canada and adjacent American states. Point counts were assigned to one of 3, 5, or 7 clusters based on values of the GW model coefficients at each point count. Across different cluster analyses and sample data sets for Canada Warbler, point counts in northern Nova Scotia were separated from other clusters, but there were no stable clusters across the Wood Thrush analysis.

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

## Habitat Selection

**Summary:** Understanding habitat selection is an important step in predicting species distribution and can enhance ecological forecasting and conservation planning. Over the last three years, BAM has explored large-scale spatial variation in habitat selection across breeding ranges, as well as finer-scale habitat modelling via advanced remote sensing products. We demonstrated that range-wide differential habitat selection (DHS) in boreal songbirds influences estimates of population size and distribution (Crosby et al 2019) and began to develop explanatory models of DHS to better predict changes to bird populations in changing landscapes.

In 2021-2022, we advanced methods to quantify habitat selection to better predict changes to bird populations in changing landscapes. In addition, we continued work to evaluate and compare the use of remote sensing tools and the Common Attribute Schema for Forest Resource Inventories to improve species distribution models for birds.

### Using remote sensing tools to improve species distribution models for birds: a case study in harvested forests of Alberta.

We are evaluating and comparing the suitability of (1) LiDAR-derived vegetation structure and cover metrics, (2) spectral change metrics from Earth observation satellites, and (3) forest resource inventory (FRI) data from Common Attribute Schema for Forest Resource Inventories (CASFRI, page 27) for modeling the species-habitat relationships of birds in the boreal. As a test case, in 2021-2022 we used covariates from these sources, along with point count and acoustics monitoring data, to predict bird response to harvesting in Alberta. We compared the relative contribution of differently sourced covariates in models predicting within-block diversity and the abundance of twenty species associated with different foraging and nesting strata. Results suggest that model performance improves by integrating LiDAR and Landsat spectral change covariates over models built using FRI data alone. In addition, of our initial set of thirty candidate variables, spectral estimates of harvest severity and time since disturbance contributed the most to explaining variation in community and species abundance models (see Research Box 2 for more details on methods and results). The dominant disturbance regimes in Alberta are common to boreal forests globally. So, while data availability limited the size of our study area, the value of LiDAR and satellite imagery for modelling habitat selection should be generalizable to boreal forests elsewhere. This project is led by Brendan Casey (PhD Student with Erin Bayne, University of Alberta). This project benefits from an NSERC Strategic Partnership Grant and is a collaboration with the Alberta Department of Agriculture and Forestry, the Bioacoustic Unit at the University of Alberta, and the Boreal Ecosystem Recovery and Assessment (BERA) project. [**CO-PRODUCED project**. Contact: Brendan Casey]

**Box 2. Remote sensing tools to improve species distribution models for birds in Alberta**

To effectively manage avian populations, it is important to understand the stand level conditions that contribute to changes in distribution and abundance. Remote sensing tools can help, but costs and availability have historically limited their adoption in ecological research. Now, provincial scale remote sensing products, cloud-based computing platforms like Google Earth Engine, and long-term bird monitoring data provide opportunities to model species-habitat relationships using novel remote sensing metrics over large spatial extents.

We explored the viability of using LiDAR and Landsat time-series to predict avian response to harvesting. Expanding covariates beyond discrete harvest severity classes included in forest resource inventories (FRIs) to those derived directly from remote sensing may reveal subtle relationships between the structure of harvest residuals and bird communities. We gathered human and ARU point-count data from forestry harvest blocks across 50,190 km$^2$ of the Central Mixedwood natural subregion of northern Alberta. For all sampled harvests, we calculated disturbance and recovery metrics from a Landsat time series of normalized burn ratio (NBR) using the LandTrendr algorithm. We used linear and generalized linear mixed models to evaluate the power of forest resource inventories, LiDAR, and NBR recovery metrics to predict bird abundance and community response to harvesting.

We found that LiDAR-derived height and complexity metrics and spectral measures of harvest severity are more predictive of abundance and diversity than the discrete harvest severity classes often used to model birds. Of our initial set of thirty candidate variables, spectral estimates of harvest severity and time since disturbance contributed the most to community and abundance models (see Figure). Supplementing forest resource inventory data with LiDAR and Landsat time-series can improve the accuracy of bird models while avoiding the costs of boots-on-the-ground vegetation surveys.

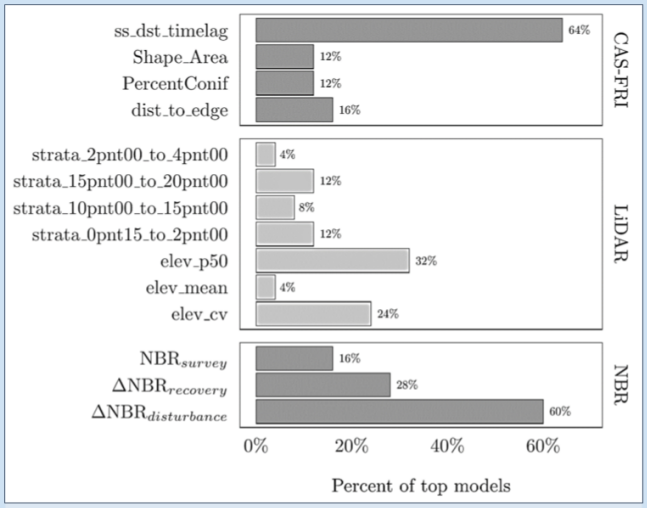


**Figure.** The frequency of metrics in top models. Years post harvest (ss_dst_timelag) and spectral disturbance derived from a time series of normalized burn ratio ($\Delta NBR_{disturbance}$) occurred more often in top models and contributed more to explained model variance than all other predictors.

*Work in progress. Contact: Brendan Casey; email:bgcasey@ualberta.ca*

## Functional response models to quantify habitat selection while accounting for habitat availability in the surrounding region

BAM is developing explanatory models of differential habitat selection (DHS) to better predict changes to bird populations in changing landscapes. This work builds on a BAM project that demonstrated DHS for boreal songbird species among regions of Canada (Crosby et al 2019). These new models account for the way differences in habitat availability and species density interact to affect population size and distribution, known as a functional response. By accounting for landscape-scale relationships between species density and habitat amount, these can avoid potentially important underestimation of the population consequences of habitat-selective disturbances such as forest management. In 2020-2021, we finalized the database to calculate landscape-scale habitat suitability using the Common Attribute Schema for Forest Resource Inventories (CASFRI) database (page 27). In 2021-2022, we explored the potential for developing these models within a Poisson point process framework. It is possible this framework would allow us to exploit Poisson additivity, similar to its use in fire modeling. In this formulation point-level predictions are conditional on both patch- and landscape-scale factors, but are simply additive within landscapes. This increases the generality of the models in forecasting applications of the effects of land-use, land cover, and climate change. This project benefited from an NSERC Strategic Partnership Grant. [**CORE project**. Contact: Andrew Crosby or Steve Cumming].

# Detecting and Attributing Land-use and Climate Change Impacts on Boreal Birds

BAM uses modelling and simulation to evaluate drivers of change and quantify impacts of industrial activities on past and future migratory bird populations to inform land-use planning and management. The outcomes of these research projects inform and refine regional, national and continental scale population & trend estimates and provide methods, tools, and recommendations to support impact assessment, cumulative effects, land-use planning, and management for migratory birds and their habitats. The projects within the theme 'Detecting and Attributing Land-use and Climate Change Impacts on Boreal Birds" are organized into four sub-themes: (1) Climate Change Impacts; (2) Energy & Mining Impacts and Cumulative Effects; (3) Forestry Impacts; and (4) Projecting Impacts of Landscape Change.

## Climate Change Impacts

**Summary:** BAM's research continues to advance our understanding of the effects of climate change on boreal bird populations and their forest habitats, document broad-scale climate-related changes in distribution and abundance and inform climate-smart conservation planning. Over the last three years, BAM co-produced projects to assess: (1) the potential effects of climate change on the breeding abundance of waterfowl species in Eastern Canada; (2) regional impacts of climate change and forest harvesting on boreal bird populations; and (3) Canada-wide historical changes in boreal bird abundance and distribution (see Appendix 1 for a full list of our 2019-2022 Climate Change Projects).

In 2021-2022, we continued to co-produce projects that assess the regional impacts of climate change and forest harvesting on landbird populations. We also revised our large-scale density modelling approach to generate annual density predictions for each species and region (page 9). This will allow us to compare trends and near-term projections to identify when and where climate models fail or succeed in anticipating future change. Additional projects with a climate change focus can be found in the theme: Projecting Impacts of Landscape Change (page 22).

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

Since 2019, BAM has been contributing to two projects in collaboration with ECCC and NRCan, to evaluate and compare the regional effects of climate change and forest management strategies on bird communities. The first project evaluates the effects of forest management and climate change on bird communities in two contrasting forests in Québec. The objective of this project is to evaluate the cumulative effects of timber harvest, climate change, and natural disturbance on forest composition, net $CO_2$ sequestration, and bird community composition and abundance. This project makes recommendations for management practices that may support bird communities and was funded by the Ministère des Forêts, de la Faune et des Parcs of Québec. The second project evaluates and compares the effects of climate change and forest harvest on boreal bird communities in Alberta and Québec. We use the LANDIS-II forest landscape model to project the impacts of climate change and forest harvesting on boreal bird abundance. Our results show that climate change and forest harvesting may impact species differently across their range, and regionally specific management measures should be implemented to ensure adequate conservation of climate-sensitive species. [**CO-PRODUCED project**. Contact: Junior A. Tremblay]

## Energy Impacts and Cumulative Effects

**Summary:** Effective management strategies and conservation planning require an understanding of the individual and cumulative impacts of multiple stressors on boreal bird populations. BAM's research has advanced our understanding of the effects of development by the energy and mining sector on boreal birds within a cumulative impacts framework and has improved our ability to attribute impacts of these and other sectors on bird populations at local and landscape scales. Over the last three years BAM projects have evaluated: (1) analytical approaches to support cumulative effects assessments; (2) homogenization of avian communities in response to oil sands development; (3) the attribution of impacts of various oil sands stressors on bird populations; and (4) the effects of chromium mining on bird populations (see Appendix 1 for a full list of projects).

In 2021-2022, BAM advanced efforts to assess the potential effects of chromium mining on bird densities and distributions in the Ring of Fire region, Ontario. We contributed to advancements in cumulative effects analyses via two studies. First, we compared two alternative approaches to cumulative effects assessment: zone-of-impact and dose-response models. Second, we developed a novel multi-scale modeling framework to directly compare effects of total human footprint, individual footprint types, and interactions among footprint types on different bird species across spatial scales.

### Comparing zone of impact to dose-response models when assessing cumulative effects of energy sector development

Wildlife conservation in landscapes undergoing industrial development requires an understanding of species' responses to combined or cumulative effects of multiple human footprints. We compared two alternative approaches to cumulative effects assessment: (i) zone-of-impact, where the distance from different disturbance features is assessed and buffers drawn around disturbances are used to assess changes in habitat quality; and, (ii) dose-response, where the percentage of the footprint in different categories is modelled. This study found that zone-of-impact models tend to explain more variation than dose response models using the same dataset; however, the general direction of responses by bird species is similar. We also compared population estimates of 48 boreal songbird and woodpecker species in simulated landscapes predicted from dose-response and zone-of-impact models (see Research Box 4 for more details on methods and results). This project is a collaboration with ABMI and was funded by the Oil Sands Monitoring (OSM). [**CO-PRODUCED project**. Contact: Lionel Leston & Erin Bayne]

**Box 4. Cumulative Effects Methods Comparison**

Oil and gas activity is increasing in the western boreal forest of North America. To manage the cumulative effects of this industry, a better quantification of footprint effects on boreal forest wildlife is needed. We used point-count surveys to evaluate how well dose-response and zone-of-impact models predicted the abundance of 48 bird species using the amounts of, compared with distances to, seismic lines, pipelines, well sites, roads, and energy facilities in Alberta, Canada.

We developed models for each species, evaluating the best functional forms (linear, non-linear) for different footprint effects. We then predicted how the different model structures influenced estimates of regional population size for each species. Nonlinear functional forms of footprint amount or distance were better at predicting abundance than linear forms. Species associated with older upland coniferous forests were more likely to decrease with higher footprint amount and closer proximity to footprint. Zone-of-impact models had better model fit than dose-response models for 47 of 48 species using AIC and 42 of 48 species using cross-validation, but both model types produced similar population estimates.

Although zone-of-impact models had better model fit than dose-response models, both kinds of models are useful for assessing cumulative effects on wildlife and the mechanisms causing change. Zone-of-impact models provide evidence of positive or negative edge effects that can be used in developing management buffers, while dose-response models provide important information on how functional changes in bird habitat with oil and gas footprint should be quantified.

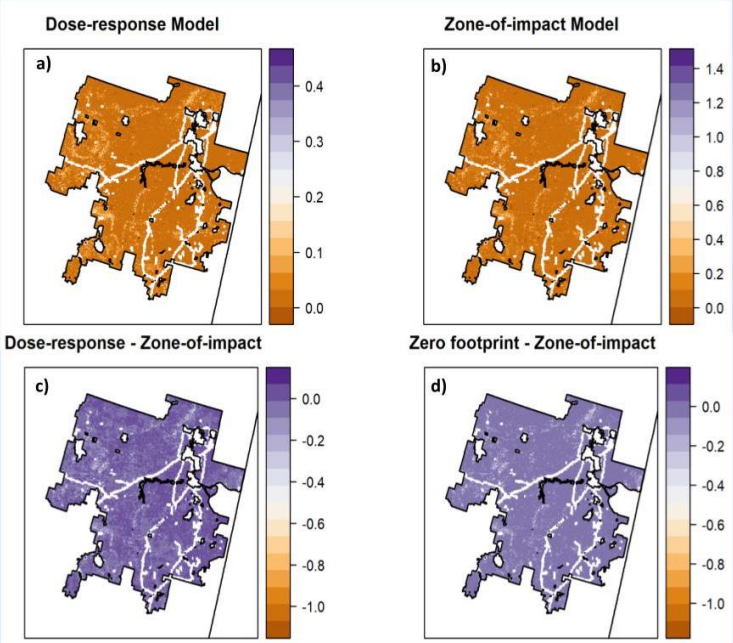


Figure. Density (#males/ha) distribution maps from models predicting effects of oil and gas footprint on Canada Warbler. (a) Predicted density based on footprint amounts within 150 m of points (dose-response model); (b) density based on distances to footprint (zone-of-impact model); (c) differences in density predicted from from dose-response model vs. zone-of-impact model; and (d) differences in density predicted from habitat (zero-footprint model) vs. zone-of-impact model. On average, zone-of-impact model predicted lower densities of Canada Warbler than the dose-response and habitat models for this species.

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

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

Scale domains are regions of the scale spectrum over which ecological patterns remain steady, while transitions between domains are marked by high variability or unpredictability (Wiens 1989). Emergent ecological patterns can differ markedly among scale domains, meaning different conclusions can be drawn from the same analysis conducted at different scales. As a result, investigations of the cumulative effects of environmental variables on habitat selection and species distributions should occur across multiple scales. The objective of this project is to understand the spatial scales at which cumulative effects of human footprint should be considered for different bird species in Alberta. At local scales, birds are likely responding directly to habitat alteration by a one or two types of human footprint. As scale increases, the probability of multiple human disturbance types interacting to affect bird distributions increases. In 2021-2022, we developed a novel modeling framework that allowed us to directly compare effects of total human footprint, individual footprint types, and interactions among footprint types across 5 spatial scales. We found evidence of domains of scale in passerine responses to energy sector development (see Research Box 3 for more details on Methods and Results). We have summarized these results in a report submitted to the OSM Program, with a planned manuscript submission in 2022. This data was collected over multiple projects in NE Alberta and received additional support from two NSERC Collaborative Research and Development Grants and the OSM. [**CO-PRODUCED project**. Contact: Andrew Crosby and Lionel Leston]

**Box 3. Hierarchical, multi-scale modeling framework reveals evidence for domains of scale in cumulative effects of development on boreal bird distributions**

Many forested areas of the globe formerly considered intact, such as Canada's boreal forest, are undergoing increased industrial development. At large spatial extents, this development creates multiple individual human footprint (HF) disturbances that can interact across space and time, resulting in cumulative effects on ecosystem patterns and processes. Effective regulation of industrial development requires understanding cumulative effects on biodiversity. However, species may exhibit scale-dependent responses to disturbance, leading to uncertainty in our understanding of cumulative effects.

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

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

Our results provide evidence for domains of scale in bird species responses to energy sector development, reflecting local scale habitat selection and landscape scale distributional effects. Limiting the cumulative area of disturbance within a given management unit is the most likely path towards conserving bird populations in this region. Examining patterns across multiple spatial scales is critical to understand the cumulative effect of disturbance on ecological communities. The sampling design and modeling approach we developed provides researchers with a greatly improved framework for estimating multi-scale cumulative effects of environmental stressors on wildlife populations and biodiversity.

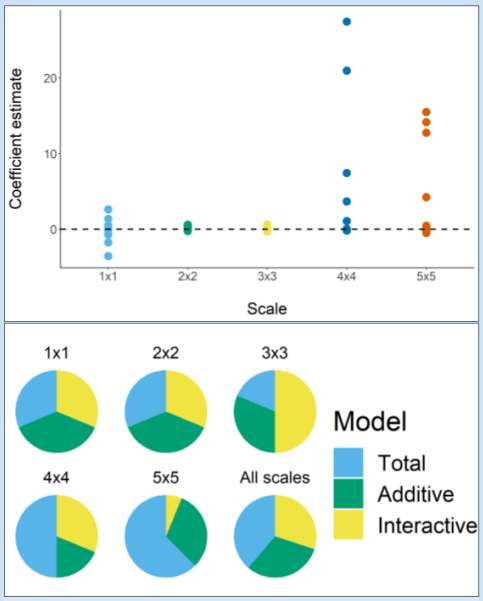


**Figure:** Plots showing coefficient estimates of the effect of total human footprint across species and scales (top), and the proportion of species for which each of three model types received the highest model weight among sixteen bird species at five spatial scales.

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

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

BAM developed predictive species distribution models for birds within northern Ontario to understand the potential effects of developing new chromium mines on bird communities within the proposed Ring of Fire development area. The objective of this project is to develop regional species distribution models of breeding landbirds in Ontario's Far North that can be integrated with outputs from landscape simulation models (e.g, SpaDES R package) to forecast the potential effects of proposed industrial development on bird populations. In 2020-2021, we assembled point count and geospatial data for building the predictive models and fit Boosted Regression Tree (BRT) models. We also began to develop SpaDES (spatially explicit simulation framework; Chubaty & McIntire 2019) modules for fitting generalized linear models (GLM) to bird data and predicting densities to future simulated landscapes. In 2021-2022, to facilitate reproducibility, the spatial predictor layers, point count data, and the R scripts were encapsulated into two annotated R projects. We fit BRT models for 62 species, created bird density maps, and calculated habitat-specific densities based on the Ontario land cover classifications. We combined these maps with Partners in Flight regional conservation scores to map potential hotspots for bird conservation within the Ring of Fire region. This work was summarized in a report (Crosby et al 2022) and is a partnership with ECCC and the SpaDES development group at the Canadian Forest Service's (CFS) Pacific Forestry Centre. [**CO-PRODUCED project**. Contact: Andrew Crosby, Lionel Leston or Erin Bayne]

## Forestry Impacts

**Summary:** BAM's research aims to improve our understanding of how forest management and harvest practices impact bird populations at local, regional, and national scales. This work is focused on the co-production of actionable science with local forest industry, government, and community partners. Our research activities include projects that identify and attribute the historic, current and future effects of forest harvest, certification, and management decisions on bird populations. Over the last three years, our Forestry Impacts research: (1) quantified bird population responses to simulated harvest plans and caribou conservation (Leston et al 2020); (2) provided tools to support harvest planning; (3) evaluated the impacts of fragmentation, residual retention and forestry practices on bird populations; (4) evaluated the conservation value of forest certification on bird populations and (5) developed new collaborations with forestry partners to inform forest management practices that benefit bird populations (see Appendix 1 for a full list of Forestry Impacts projects).

In 2021-2022, we continued to improve: (1) science-based spatial tools to support harvest planning; (2) methods to optimize for sustainable harvests and bird populations; and (3) metrics to measure conservation value of forest certification across Canada. We also initiated a new project that evaluates the value and resilience of SFI certified forests for eastern forest birds in a climate change context. This project integrates an ongoing collaboration with SFI and the American Bird Conservancy (ABC) to co-produce actionable science and develop a cross-border initiative for bird conservation on managed forest lands in BCR 12.

### Alberta and British Columbia Risk Matrices: Supporting harvest planning decisions

BAM is supporting forest companies to manage their risk of incidental take by providing science-based decision-making tools based on abundance, conservation priority and uncertainty. Risk of incidental take is used to inform operational planning of harvest and is usually based on expert biologist opinions. Before 2019, BAM used point count data to assess if risk of incidental take based on expert opinion was positively and strongly correlated with observed total bird abundance within forest stands in BC and Alberta. We ran gap analyses to assess point count representation in different forest stands and developed bird models and workflows to estimate total bird density and inform risk in Alberta and BC. This project benefited from a Mitacs Accelerate grant and collaborations with the Council of Forest Industries of BC (COFI), the Forest Resource Improvement Association of Alberta (FRIAA), and the ABMI. [**CO-PRODUCED project**. Contact: Lionel Leston]

### Optimising for sustainable harvests and bird populations in forest management planning

This project aims to develop and evaluate methods to integrate bird conservation objectives into forestry optimisation models that are used for strategic and operational planning. In 2021-2022, we evaluated a method called 'post-hoc binning' that produces categories of bird density outcomes based on the BAM national density models (version 4.0, page 9) for a given study area and set of stand type and age classes. In 2022-2023, the output of these models (bird density predictions by landscape category) will be incorporated into forestry optimisation models to evaluate and compare the harvesting constraints required to achieve different bird density objectives. This will establish an efficient workflow for determining area-specific strategies to combine forest harvesting with bird conservation. This project is led by Isolde Lane Shaw, a PhD student with Steve Cumming at Université Laval. This work is a partnership with the Western Boreal Initiative (page 24), the SpaDES development group at the Pacific Forestry Centre (CFS), and ECCC, and benefited from funding from CWS Northern Region. [**CO-PRODUCED project**. Contact: Isolde Lane Shaw]

## Conservation Value of Forest Certification for Birds Differs Among Bird Conservation Regions

BAM evaluated the conservation value of forest certification based on the contribution of certified forest lands to regional avian species richness relative to the non-certified lands. The objectives of this project were to: (i) map species richness, community composition, and bird diversity at different scales across Canada; (ii) quantify the contribution of managed forests to bird species diversity; and (iii) quantify the contributions of different forest ecosystem types (e.g., deciduous, conifer, mixed) to breeding bird diversity at local and regional scales. We found that species richness was higher on certified forestlands in all BCRs, while rarity was higher on certified forestlands in BCR 8 and 14. In 2021-22, we developed a plan in collaboration with forestry partners to synthesize these results with previous research on the conservation value of forest certification (Barker & Schmiegelow 2018; https://prvernier.shinyapps.io/consvalue/) to draw direct comparisons among measures of conservation value and develop a robust discussion of what these measures mean in terms of forest certification and bird conservation. The goal of this comparison is to improve conservation outcomes for birds from sustainable forest management. This work is a collaboration with the BEACONS project. [**CO-PRODUCED project**. Contact: Andrew Crosby]

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

Understanding how species respond to changes in current and future ecological conditions is important for developing best management practices (BMPs) for biodiversity conservation in sustainably managed forests. Developing BMPs that are both robust and adaptive to potential climate and landscape changes requires reliable rangewide estimates of future species distributions and landscape conditions. The goals of this project are to:

1. Develop and implement a bi-national collaborative framework for developing and sharing science-based knowledge about the effects of forest management on birds;
2. Assemble spatial data representing forest inventory and management practices in and out of certified forest lands;
3. Evaluate the impacts of past and present forest management on bird populations in certified vs. non-certified forests; and
4. Simulate the potential impacts of future forest management on bird populations in certified vs. non-certified forests under potential climate change scenarios.

BAM has collaborated with SFI and the ABC since 2019 to develop a cross-border initiative for bird conservation on managed forest lands in the Upper Great Lakes region of BCR 12. In June 2020, we hosted a webinar to engage stakeholders, which resulted in a working group of representatives from ECCC, US Forest Service, National Council for Air and Stream Improvement, Inc. (NCASI), Forestland Group, and Wisconsin Department of Natural Resources. This working group is planning an in-person workshop for autumn 2022 that will support Goal 1. This project is a collaboration with partners from ABC, SFI, ECCC, NRCan, Resolute Forestry Products, Quebec SFI Implementation Committee, and many more. Funding is provided by an SFI Conservation Grant awarded to BAM in December 2021. [**CO-PRODUCED project**. Contact: Teegan Docherty, Junior A. Tremblay, Andrew Crosby, & Steve Cumming]

# Projecting Impacts of Landscape Change

**Summary:** BAM continues to co-produce research that uses spatial simulation models to enhance our understanding of the past and future impacts of climate and landscape change on boreal bird populations, including species at risk. From 2019-2022, BAM co-produced projects that evaluated: (1) the potential future effects of anthropogenic disturbances on boreal birds; (2) the projected effects of habitat and climate change on caribou resource selection and landbird abundances; and (3) the backcasted and projected effects of forest management strategies on avian abundance (see Appendix 1 for a full list of projects).

In 2021-2022, BAM co-produced three projects in the BCR 6 portion of the Northwest Territories that aimed to: (1) understand the pathways by which climate change influences boreal landbird distributions; (2) evaluate whether caribou function as an umbrella species for the conservation of boreal landbirds; and (3) evaluate the future impacts of climate change on boreal landbirds. We continue to contribute to this initiative, which has grown into a larger collaborative project called the Western Boreal Initiative that aims to inform multispecies conservation and protected area planning under current and future climate scenarios.

## Interpreting predicted avian responses to climate change in the Northwest Territories

The distribution and abundance of birds are predicted to shift as the climate gets warmer (Cumming et al., 2014; Stralberg et al., 2015). High-latitude ecosystems, such as the boreal forest, are already experiencing significant temperature changes. Understanding how bird populations respond to climate change is important for conservation and land-use planning. Ana Raymundo (Ph.D. student with Steve Cumming and Eliot McIntire) is evaluating the future impacts of climate change on the avian community in the Northwest Territories. For this project, we are using density models for 75 boreal landbird species, which include both climate and landscape predictor variables, to quantify the temporal and spatial variation in predicted abundances among three contrasting global climate models (GCMs) under Representative Concentration Pathway (RCP) 8.5 (a high global emission scenario). The spatio-temporal changes in abundance were estimated in the short term (2011-2031) and the long term (2011-2091). A preliminary set of 'winner' and 'loser' species has been identified for each GCM and time frame (see Research Box 5 for more details on methods and results). [**CO-PRODUCED project**. Contact: Ana Raymundo]

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

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

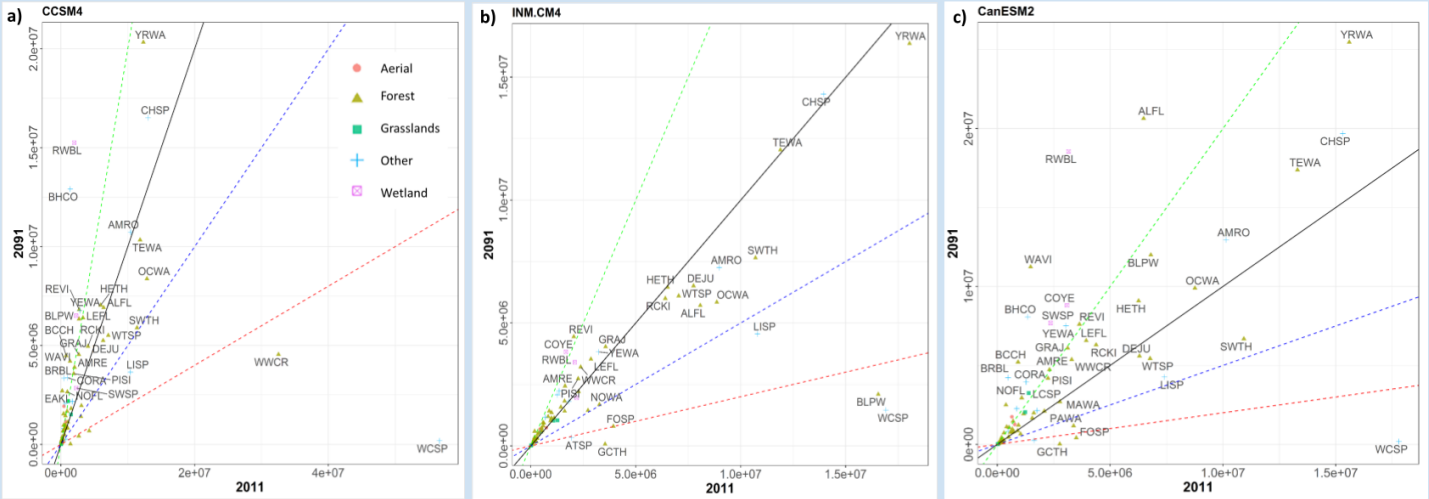


**Figure.** Long term change between current and future predicted bird species abundances under three GCMs: (a) CCSM4, (b) INM-CM4 and (c) CanESM2. The black line represents 1:1 relationship; the green, blue and red lines are proportional change relationships (slope = 2.0, 0.2 and 0.5, respectively)

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

## Understanding Climate Change Effects on Boreal Landbirds in the Northwest Territories, Canada

BAM collaborated on a project to understand the pathways by which climate change influences boreal landbird distributions and abundance in the BCR 6 portion of the Northwest Territories. We simulated two climate-sensitive metrics, forest growth and wildfire, and built two sets of regional landbird models (n = 64) using boosted regression trees (BRT) that varied based on the inclusion of different climate variables. This project demonstrated that most of the predicted differences in net area of occupancy across models were attributed to direct climate effects rather than simulated vegetation change, despite a similar relative importance of vegetation and climate variables in landbird models. Our results were published in the special issue 'Using landscape simulation models to help balance conflicting goals in changing forests' in Frontiers in Ecology and Evolution (Micheletti et al 2021). This project is a collaboration that includes CFS' Pacific Forestry Centre and Northern Forestry Centre, Université Laval, ECCC, and the NWT Department of Environment and Natural Resources. This project benefited from additional funding from CWS Northern Region [**CO-PRODUCED project**. Contact: Tati Micheletti, Samuel Haché, Diana Stralberg and Steve Cumming].

## The Umbrella Concept: An Application to Boreal Caribou and Landbirds in the Northwest Territories, Canada

BAM is collaborating on a project to identify present and future hotspots for conservation, and to test the concept that boreal caribou serve as an effective umbrella for conserving landbird populations in the Northwest Territories. We used caribou resource selection models and landbird density models in the spatially explicit simulation tool SpaDES (Chubaty & McIntire 2019) to evaluate the efficacy of the boreal caribou as an umbrella for 75 boreal landbird species across different scales of space and time, and three future climate scenarios. This project has recently been submitted for publication. This project is a collaboration that includes CFS' Pacific Forestry Centre and Northern Forestry Centre, Université Laval, ECCC, and the NWT Department of Environment

and Natural Resources. This project benefited from additional funding from CWS Northern Region. [**CO-PRODUCED project**. Contact: Tati Micheletti, Samuel Haché, Diana Stralberg and Steve Cumming]

## The Western Boreal Initiative (WBI)

In 2021-2022, BAM continued to contribute to a large collaborative project, now called the WBI, that builds upon the modelling framework developed for BCR 6 portion of the Northwest Territories. The objectives are: (i) improve existing SpaDES modules; (ii) develop new modules (e.g., waterfowl, carbon sequestration, insect outbreaks, permafrost dynamics, etc.); and (iii) apply the framework to the entire Western Boreal region. An important component of the WBI is our formal collaboration with Indigenous partners that will determine the best approach to braid ways of knowing (i.e., Traditional Knowledge and Western Science) as it relates to habitat use of boreal caribou. BAM contributed updated versions of their national landbird and waterfowl density models that included a reduced number of predictors suited to forecasting future distribution and abundance (visit BAM's GitHub page to learn more about these models). These bird models are being used to inform multispecies conservation and protected area planning under current and future climate scenarios. This project is a collaboration with ECCC, NRCan, Université Laval, University of British Columbia, Dalhousie University (DAL), Dene Nation, and the NWT Department of Environment and Natural Resources and benefited from additional funding from ECCC. [**CO-PRODUCED project**. Contact: Samuel Haché, Tati Micheletti, and Steve Cumming]

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

# Conservation Planning for Boreal Birds

**Summary:** BAM continues to facilitate the application of our knowledge and tools in a robust conservation planning framework to support ECCC and partners in delivering conservation for boreal birds directly or through co-benefits with other programs. From 2019 to 2022, we leveraged our spatially-explicit density estimates, data products, tools and collaborations to support climate-informed, multi-species conservation planning, including advancing projects related to: (1) habitat joint ventures, (2) key biodiversity area identification, (3) evaluations of biodiversity surrogates, and (4) the Pan-Canadian approach to transforming species at risk conservation in Canada (see Appendix 1 for a full list of projects).

In 2021-2022, we continued to enhance BAM's close collaboration and contributions to large-scale conservation planning efforts with the BEACONs (Boreal Ecosystems Analysis for Conservation Networks) Project and ECCC. We evaluated the potential conservation co-benefits for boreal caribou and landbirds across the Canadian boreal forest. We also contributed to the Prairie Habitat Joint Venture's (PHJV) Western Boreal Implementation plan through the identification of priority areas for habitat conservation action to benefit landbirds. We built on knowledge developed for the PHJV and began a 3-year project to support the Eastern Habitat Joint Venture (EHJV) to develop forest bird-habitat models and identify priority areas for habitat conservation in eastern Canada.

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

The new Pan-Canadian Approach to transforming Species at Risk Conservation in Canada shifts from a single species approach to one that focuses on multi-species objectives. Within this approach, conservation efforts will focus on shared priorities and identifying co-benefits for biodiversity and ecosystems. The aim of this BAM project is to test the extent to which conservation directed at boreal caribou (Rangifer tarandus caribou) provides co-benefits for bird populations across the entire boreal region of Canada. We first evaluated the overlap between caribou ranges and bird populations across the boreal. We then identified priority areas for avian conservation in the boreal region based on avian density and assessed the extent to which these areas would be included in the protection of the caribou ranges. Priority areas were identified using the Zonation software package and density rasters for 138 bird species (see page 9) and a set of conservation objectives for landbirds inside and outside the caribou ranges. This project is currently being drafted into a manuscript that will be submitted for publication in 2022. This project was an ECCC Experimentation Works Project and is a collaboration with ECCC, DAL and BEACONS. [**CORE project**. Contact: Teegan Docherty]

## Supporting Habitat Joint Ventures: identifying co-benefits for landbirds and waterfowl using multi-species conservation planning

Over the last 2 years, BAM has supported the Prairie Habitat Joint Venture's (PHJV) Western Boreal Forest (WBF) with conservation planning. We identified areas of high conservation value for landbirds within the WBF region to assess the potential for co-benefits from habitat conservation initiatives directed at waterfowl. Priority areas were identified using Zonation software based on a set of conservation objectives for (a) forest-associated species and (b) wetland-associated species (~100 species total; see page 9). This work is a contribution to the updated PHJV Implementation Plan for the WBF and is a collaboration with ECCC and Ducks Unlimited Canada (DUC).

BAM will leverage methods developed to identify priority areas for the PHJV, BAM's national-scale avian density models (page 9), and a multi-species conservation planning framework developed by BAM (Stralberg et al. 2018) to advance a new project for the Eastern Habitat Joint Venture (EHJV). In 2022, we started a 3-year project to develop and deliver on EHJV objectives to identify: 1) linkages between habitat change and population patterns of forest birds in Canada's six eastern provinces; and 2) priority areas for habitat conservation and restoration.

This project is a collaboration with ECCC and Laval University and received funding from ECCC, DUC, and the Nature Conservancy of Canada (NCC). [**CO-PRODUCED project**. Contact: Teegan Docherty]

## Monitoring and Sampling

**Summary:** BAM continues to support ongoing improvements of monitoring programs and status assessments for migratory birds, including SAR, by identifying data gaps in species coverage and supporting existing federal and provincial monitoring efforts. We provide open-source tools and resources, including our national scale density models (page 9), to support monitoring and sampling across North America. Since 2019, we have continued to improve methodologies and develop resources, such as training workshops, R packages, and data products, to support sampling design and the analysis of point count data (see Appendix 1 for a full list of projects).

In 2021-2022, we continued to provide tools and information products to support ECCC's Boreal Monitoring Strategy and partnered with ECCC to facilitate the upload of autonomous recording unit (ARU) and point count data to WildTrax to support open data.

### Boreal Monitoring Strategy

ECCC has continued to implement and refine the Boreal Monitoring Strategy (BMS) with aid of data, products and tools provided by BAM. Recent analyses have used BAM tools and offsets to optimize clustered sampling where ARUs are to be used as the primary sampling tool. In addition, one component of the BMS involves integration of migration count data into national trend estimation, and ECCC staff (D. Iles et al.) have developed and tested Bayesian models that integrate migration counts, data on migratory connectivity, and strata specific estimates of population size from BAM density models to estimate species trends. In 2021-2022, work continued on the precision analysis framework informed by BAM density models (page 9) and will be used for refining sample size targets as more field data come available. ECCC has also developed a preliminary Bayesian species distribution model using QPAD offsets applied to BMS and breeding bird atlas data and has validated the models against spatially explicit simulations based on BAM density maps. Finally, ECCC staff involved in the BMS have worked with BAM, ABMI and Bioacoustic Unit (BU) staff to add ECCC acoustic data and historic point counts to WildTrax as part of our efforts to meet open data standards. [**INFORMED project**. Contact: Steve Van Wilgenburg]

# Knowledge Mobilization

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

## Data Products

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

In 2021-2022, we launched the BAM GeoPortal, which is a spatially referenced platform to facilitate the discovery of and access to our data products. The BAM GeoPortal is available in French and English. We also continued to support and use the Common Attribute Schema for Forest Resource Inventories (CASFRI).

### BAM GeoPortal: spatially-referenced data product distribution platform

To facilitate the discovery and accessibility of BAM's data products we have developed and launched an online platform to host our many spatially referenced data products. The BAM GeoPortal, which is an application to manage spatially referenced resources, will serve to showcase BAM's data products to the public and to share commonly used data products within the team. The BAM GeoPortal lists metadata of methods, results, and data products created by BAM and has a search function to support discovery. The BAM GeoPortal is available in French and English and can be accessed via the 'Explore Our Data' section on the BAM website. In 2022, we will continue to add BAM data products to this portal. [**CORE project**. Contact: Mélina Houle]

### Planet Data Supports Integrated Research Programs in the Boreal Forest

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

### CASFRI: Common Attribute Schema for Forest Resource Inventories

CASFRI is a compilation of Canada's digital forest resource inventory (FRI) datasets, standardized into a large PostGIS database. The newest version, CASFRI 5.0, was supported by a substantial three-year contract between NRCan and Steve Cumming (Universite Laval). CASFRI 5.0 has inventories from two time periods for large parts of Canada, and will continue to incorporate new and old datasets as they become available. The goal is to incorporate as much of the history of Canada's FRI as possible, dating from the earliest of digital inventories in the late 1980s to the present day. CASFRI is a comprehensive, reliable, error-corrected, and maintainable source of spatially enabled forest inventory data and supports a number of past and present BAM projects, including habitat selection projects (page 14), forest certification projects (page 21) and a new project to support the EHJV (page 25). [**INFORMED project**. Contact: Steve Cumming & Mélina Houle]

## Avian Data

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

In 2021-2022, we continued to collaborate with ABMI, the Bioacoustic Unit, and WildTrax to launch the point count sensor on WildTrax.ca, an online platform that now hosts our human point count database. We uploaded approximately 140 datasets to WildTrax and worked with data partners to support the sharing of their data. We continued to collaborate with partners from ECCC, Birds Canada, and ABMI to advance avian data accessibility as part of the Canadian Open Avian Data Initiative. Lastly, we developed a workflow and methods to automate the translation of point count data into the BAM and WildTrax data structure.

### BAM Avian Database update: Migration to the WildTrax Platform

To increase discoverability and accessibility to the BAM database, we have collaborated with ABMI to develop an online point count data platform to host our data securely. Point count data is now available via the 'point count sensor' on WildTrax.ca. To date, the majority of the BAM point count database has been uploaded to WildTrax, which includes 140 datasets, approximately 1.9 million observations from 208,000 unique locations (see Figure 6). These datasets can be discovered on WildTrax.ca in the point count sensor. Datasets will be made publicly available to the extent that data sharing agreements permit and we continue to work with data partners to update their data sharing preferences on WildTrax. We also continue to work with partners to receive, standardize and upload new datasets. Visit WildTrax.ca to explore this point count data. This work is a collaboration with ABMI, the Bioacoustic Unit, and WildTrax. [**CORE project**. Contact: Teegan Docherty, Mélina Houle & Erin Bayne]

Figure 2. Map of the location and number of point count surveys currently discoverable on WildTrax

## Open Data Initiative

The effort to improve access to the BAM database is part of a larger Open Data Initiative in Canada to develop a wider network that connects avian data portals and partners. BAM is a founding member of the Canadian Network for Open Avian Data (CanAvian), which is a collaboration with Birds Canada, ECCC, ABMI, and WildTrax, that supports the discovery, accessibility, integration and use of bird data in Canada. CanAvian has a mission to improve accessibility and increase use of avian data and information in Canada by enhancing data sharing, networking, and collaboration. In 2021–2022, we designed a website to introduce CanAvian and facilitate data discovery within the network. We will continue to collaborate with these and other partners to ensure alignment with the larger vision for open data. [**CORE project**. Contact: Teegan Docherty & Erin Bayne]

## Automating the standardization of avian point count data

BAM has undertaken work to improve the reproducibility of our computing workflows to support the documentation and transparency of our research data management. In 2019, we started to use automated techniques and scripting languages (program R) to standardize BBS data into the BAM database structure. The translation workflow to standardize the BBS data was developed into an R package (BBS2BAM) and is available on the borealbirds Github repository under BAMTools. This work allowed us to organize and document the standardization steps and structure the data for transparency and reproducibility. Now that we have moved forward to integrate human point count data into WildTrax, all new data acquisition by BAM follows the standardization workflow. In 2021-2022, we used this workflow to standardize 5 new, large datasets and uploaded them to WildTrax. We focused on datasets where geographic coverage improvements had the most impact for version 4.1 of the BAM National Models (page 9). [**CORE project**. Contact: Mélina Houle]

## Automating point count and acoustic data integration

The BAM point count data does not have the same data structure as data transcribed from ARUs. To facilitate the integration of ARU data and human point count data, we developed a process to automate the download of ARU data into the BAM point count data structure that exists within WildTrax. This new feature became available on WildTrax in 2021 and reconciles differences in attributes between data structures using specific translation rules. [**CORE project**. Contact: Mélina Houle]

## Training Workshop for the Analysis of Heterogeneous Point Count Data

In 2021, Péter Sólymos in partnership with BIOS$^2$ delivered an in-depth workshop on the "Analysis of point-count data in the presence of variable survey methodologies and detection error". This workshop was wattended by over 55 registered participants from multiple countries, organizations and industries. The workshop explores the theory, technical implementation, and relevant assumptions of BAM's QPAD approach, which is a method to develop statistical correction factors to account for variation in detectability and survey protocols when integrating datasets. Video recordings and materials from the workshop are available online as a self-taught course or as reference material (borealbirds.github.io/qpad-workshop/). Additional information about the QPAD method can be found on our website or in the QPAD book. [**CORE project**. Contact: Péter Sólymos

# Collaborations & Applications of BAM Results

Multi-sector collaborative partnerships are important for achieving science-informed conservation and policy. BAM collaborates with conservation practitioners and decision-makers to co-create, co-produce, transfer, and exchange research and information. Between 2019 and 2022, BAM collaborated with partners to co-produce research and shared research findings, methods, data products and information to support knowledge users.

## Boreal Bird Density, Population Status & Trends

- BAM's national-scale density models, population estimates and methods have been used by and/or integrated into various initiatives, including ECCC's Boreal Monitoring Strategy for migratory birds (page 26), **ECCC**'s Western Boreal Initiative (page 24), Habitat Joint Ventures (page 25), COSEWIC assessment & status reports (COSEWIC 2020), proposed recovery strategies and management plans (ECCC 2021; ECCC 2022), management plan, estimates of biotic intactness for the Key Biodiversity Areas Criterion C initiative (**WCS Canada**/**McGill University**), and the WildTrax species tag checker tool (**ABMI**), ECCC's density models for prairie landbirds, and more.
- BAM continues to contribute to discussions within **Partners in Flight** (PIF) regarding population estimation as well as a broader adoption of the BAM's point count offsets approach (QPAD) by PIF for population estimation.
- Waterfowl abundance models, co-produced with Louis Imbeau (**Université du Québec en Abitibi-Témiscamingue**) and Marcel Darveau (**Ducks Unlimited Canada**), were integrated into the Western Boreal Initiative (page 24) and Habitat Joint Ventures (page 25).
- BAM is contributing to a project called NA-POPS to generate detectability offsets for all species of landbirds in North America; which is a collaboration among many partners, including the **ECCC**, **NRCan**, **Bird Conservancy of the Rockies, Klamath Bird Observatory, USGS, the National Audubon Society, Partners in Flight Science Committee** (**PIF**), and the **Avian Knowledge Network** (page 11).

## Species at risk

- BAM continues to provide tools and analyses to support **ECCC**'s efforts to identify critical habitat for wide-ranging species at risk, for Canada Warbler and Wood Thrush (page 12).

## Habitat selection, availability and needs

- A project examining the use of remotely sensed data such as LiDAR and **CASFRI** in species distribution models is a collaboration with **the Alberta Department of Agriculture and Forestry**, **the Bioacoustic Unit at the University of Alberta**, and **the Boreal Ecosystem Recovery and Assessment** (**BERA**) **project** (page 14).

## Detecting & Attributing Land-use and Climate Change Impacts

### *Climate Change Impacts*

- Two projects that compare regional impacts of climate change and forest management on boreal birds are collaborations with **ECCC**, the **Ministère des Forêts, de la Faune et des Parcs of Québec**, and **NRCan** (page 23).
- BAM continues to contribute to a new committee with **PIF**, **Audubon**, and **ECCC** to add a climate-change vulnerability component to the PIF Avian Conservation Assessment Database (ACAD).

### *Energy & Mining Impacts and Cumulative Effects*

- BAM is partnering with **ECCC** and the SpaDES development group at the **Pacific Forestry Centre** (**NRCan**) to apply predictive habitat models for birds as part of an environmental assessment in the Ring of Fire region, Ontario (page 19).
- Two projects that evaluate and develop methods for cumulative effects assessment support the **Oil Sands Monitoring** (**OSM**) **Program** and are collaborations with the **ABMI** and **ECCC** (page 18).

- BAM partnered with **ABMI** and **ECCC** to develop models that separate the cumulative impacts of multiple sectors on boreal birds and attribute these impacts to specific sectors. Results for over 100 species are hosted on the ABMI's Biodiversity Browser.

### *Forestry Impact*

- Data-driven risk matrix tools developed by BAM for Alberta and British Columbia are collaborations with the **Alberta Forest Products Association**, **Forest Resource Improvement Association of Alberta** (**FRIAA**), **the Council of Forest Industries** (**COFI**), and the **ABMI** (page 20).
- A project to develop and evaluate methods to integrate bird conservation objectives with forest management planning is a collaboration with **ECCC**, the **Western Boreal Initiative** and the **Pacific Forestry Centre** (**CFS**).
- A project to evaluate the conservation value of forest certification across BCRs is a collaboration with the **BEACONS Project**, the **Sustainable Forestry Initiative (SFI**), **Al-Pac**, **Fuse Consulting Ltd**., and **fRI Research** (page 21).
- Over the past 3 years, BAM has developed a cross-border initiative with the **American Bird Conservancy** (**ABC**) and **SFI** to identify opportunities for forest management to benefit bird populations. This work includes numerous partners via a recently formed working group **ECCC**, **US Forest Service**, **National Council for Air and Stream Improvement, Inc.** (**NCASI**), **Forestland Group**, **Wisconsin Department of Natural Resources**. This project is integrated into a larger project to evaluate the value and resilience of SFI forests and is a collaboration with partners from **ECCC**, **NRCan**, **Resolute Forestry Products**, **Quebec SFI Implementation Committee**, **BEACONS**, and many more (page 21).
- BAM completed and published work in 2020 in collaboration with **Alberta-Pacific Forest Industries Inc. (Al-Pac**) and the **ABMI** to understand the potential impacts of caribou-specific harvest management plans on avian populations.

### *Projecting Impacts of Landscape Change*

- Two projects to assess the effects of climate change and caribou's potential as an umbrella species for landbird conservation in the Northwest Territories are collaborations that include **CFS' Pacific Forestry Centre** and **Northern Forestry Centre**, **Université Laval**, **ECCC**, and the **NWT Department of Environment and Natural Resources**.
- The Western Boreal Initiative is a collaboration with **ECCC**, **Université Laval**, **UBC**, **DAL**, **CFS**, **Dene Nation**, and **the NWT Department of Environment and Natural Resources.**

## Conservation Planning for Boreal Birds

- **A project that identifies co-benefits for boreal caribou and landbirds across the boreal forest is an ECCC Experimentation Works Project and is a collaboration with ECCC**, **DAL, NRCan** and **BEACONS**.
- Work to support the PHJV and a new project to support the EHJV are collaborations with **ECCC**, **Laval University**, **DUC**, and **NCC**. In addition, BAM methods have guided analyses to support the PHJV Prairie Parklands science and planning in collaboration with **ECCC**.
- In collaboration with **WCS** and **BEACONS** we developed a new biotic intactness (BI) index for forest songbirds as a criterion to support the identification of Key Biodiversity Areas in Canada.

## Landbird monitoring and sampling design

- BAM continues to support **ECCC** with the Boreal Monitoring Strategy. This project uses BAM data, offsets and density maps in conjunction with BMS sampling to test design efficiency and sampling bias (page 26).
- BAM is supporting the design of monitoring using ARUs to sample for Pileated Woodpecker in Québec in collaboration with the **SFI Québec Implementation Committee** and **ECCC** and including partners from **Groupe Rémabec**, **Resolute Forest Products**, **Interfor, Kenauk Canada**.
- BAM team members are contributing to planning and support of the third **Ontario Breeding Bird Atlas** via involvement in committees and working groups.

- A point count analysis workshop delivered by Péter Sólymos with **BIOS²**, which explored BAM's statistical approach to integrate heterogeneous datasets, was attended by over 55 participants from multiple countries, organizations and industries (page 30).

## Data and Data Products

- BAM is collaborating with **ECCC**, **Birds Canada**, **ABMI**, and the **BU** to develop the **Canadian Network for Open Avian Data** (**CanAvian**), which is a network to connect avian data portals and partners in Canada (page 29).
- In collaboration with **ABMI** and the **BU**, the BAM database has been uploaded to **WildTrax**—an online platform for storing, managing, and sharing biological data. Datasets will be made available to the extent that data sharing agreements permit (page 28).
- BAM has been partnering with **ECCC** staff, **ABMI** and **BU** staff to ensure that ECCC's acoustic data and historic point counts are being added to **WildTrax** as part of ECCC's efforts to meet open data standards.
- BAM continues to work with partners to solicit, standardize and upload new and historical point count datasets to support research data management and data sharing in Canada.

## Communications

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

### Updates and Translation of the BAM Website

Over the past three years, BAM has worked to improve and translate our website to increase the accessibility and dissemination of BAM's research, data products and information. In 2020-2021, we developed new pages for our projects and data products to provide easy access. We also initiated French translation of materials to re-establish the bilingual nature of our website. In 2021-2022, we completed the French translation of our website. The current version of our website can be viewed at https://borealbirds.ca/ [Contact: Teegan Docherty & Hana Ambury]

## Outreach & Publications

We communicate BAM research via webinars, publications in peer-reviewed journals, presentations, and reports. From January 2019 through March 2022, BAM led or significantly contributed to 20 papers in peer-reviewed journals, gave over 42 talks, poster, or workshop presentations, and organized 7 workshops and webinars.

### BAM Publications

### BAM Core Publications

*Publications from BAM Core projects between January 2019 and March 2022.*


Crosby, A.D., Bayne, E.M., Cumming, S.G., Schmiegelow, F.K.A., Dénes, F.V., Tremblay, J.A., 2019. Differential habitat selection in boreal songbirds influences estimates of population size and distribution. Divers Distrib 25, 1941– 1953. https://doi.org/10.1111/ddi.12991.

Sólymos, P., Toms, J.D., Matsuoka, S.M., Cumming, S.G., Barker, N.K.S., Thogmartin, W.E., Stralberg, D., Crosby, A.D., Dénes, F.V., Haché, S., Mahon, C.L., Schmiegelow, F.K.A., Bayne, E.M., 2020. Lessons learned from comparing spatially explicit models and the Partners in Flight approach to estimate population sizes of boreal birds in Alberta, Canada. The Condor 122. https://doi.org/10.1093/condor/duaa007


### BAM Co-produced Publications

*Publications from BAM Co-produced projects between January 2019 and March 2022.*


Adde, A., Darveau, M., Barker, N., Cumming, S., 2020. Predicting spatiotemporal abundance of breeding waterfowl across Canada: A Bayesian hierarchical modelling approach. Divers Distrib ddi.13129. https://doi.org/10.1111/ddi.13129

Adde, A., Darveau, M., Barker, N., Imbeau, L., Cumming, S., 2020. Environmental covariates for modelling the distribution and abundance of breeding ducks in northern North America: a review. Écoscience 1–20. https://doi.org/10.1080/11956860.2020.1802933

Adde, A., Stralberg, D., Logan, T., Lepage, C., Cumming, S., Darveau, M., 2020. Projected effects of climate change on the distribution and abundance of breeding waterfowl in Eastern Canada. Climatic Change. https://doi.org/10.1007/s10584-020-02829-9

Cadieux, P., Boulanger, Y., Cyr, P. D., Taylor, A. R., Price, D. T., Stralberg, D., Sólymos, P., Tremblay, J. A. 2020. Projected effects of climate change on boreal bird community accentuated by anthropogenic disturbances in western boreal forest, Canada. Divers Distrib 26, 668- 682. https://doi.org/10.1111/ddi.13057

Leston, L., Bayne, E., Dzus, E., Sólymos, P., Moore, T., Andison, D., Cheyne, D., Carlson, M., 2020. Quantifying Long-Term Bird Population Responses to Simulated Harvest Plans and Cumulative Effects of Disturbance. Front Ecol Evol. 8, 252. https://doi.org/10.3389/fevo.2020.00252

Micheletti, T., Stewart, FEC, Cumming, SG, Haché, S., Stralberg, D., Tremblay, JA, Barros, C., Eddy, IMS, Chubaty, AM, Leblond, M., Pankratz, RF, Mahon, CL, Van Wilgenburg, SL, Bayne, EM, Schmiegelow, F., McIntire, EJB, 2021. Assessing

Pathways of Climate Change Effects in SpaDES: An Application to Boreal Landbirds of Northwest Territories Canada. Forehead. School. Evol. 9, 679673. https://doi.org/10.3389/fevo.2021.679673

Stralberg, D., Berteaux, D., Drever, R., Drever, M.C., Naujokaitis-Lewis, I., Schmiegelow, F.K.A., Tremblay, J.A., 2019. Conservation planning for boreal birds in a changing climate: A framework for action. Avian Conserv Ecol 14(1):13. https://doi.org/10.5751/ACE-01363-140113

Tremblay, J. A., Y. Boulanger, P. Cadieux, D. Cyr, A. R. Taylor, D. T. Price, D. Stralberg, and P. Sólymos. 2020. Projected effects of climate change on boreal bird community accentuated by anthropogenic disturbances in western boreal forest, Canada. Diversity and Distributions. https://doi.org/10.1111/ddi.13057

Westwood, A.R., Stacier, C., Sólymos, P., Haché, S., Fontaine, T., Bayne, E.M., Mazerolle, D., 2019. Estimating the conservation value of protected areas in Maritime Canada for two species at risk: the Olive-sided Flycatcher (Contopus cooperi) and Canada Warbler (Cardellina canadensis). Avian Conserv Ecol 14(1): 16. https://doi.org/10.5751/ACE-01359-14011

Westwood, A.R., Lambert, J.D., Reitsma, L.R., Stralberg, D., 2020. Prioritizing Areas for Land Conservation and Forest Management Planning for the Threatened Canada Warbler (*Cardellina canadensis*) in the Atlantic Northern Forest of Canada. Diversity 12, 61. https://doi.org/10.3390/d12020061

Westwood, A.R., Barker, N.K., Grant, S., Amos, A.L., Camfield, A.F., Cooper, K.L., Dénes, F.V., Jean-Gagnon, F., McBlane, L., Schmiegelow, F.K.A., Simpson, J.I., Slattery, S.M., Sleep, D.J.H., Sliwa, S., Wells, J.V., Whitaker, D.M., 2020. Toward actionable, coproduced research on boreal birds focused on building respectful partnerships. ACE 15, art26. https://doi.org/10.5751/ACE-01589-150126

Westwood AR, Lambert JD, Reitsma LR, Stralberg D. 2020. Prioritizing areas for land conservation and forest management planning for the threatened Canada warbler (*Cardellina Canadensis*) in the Atlantic northern forest of Canada. Diversity 12.

## BAM Informed Publications

*Publications we're aware of that use BAM data, methods, or expert knowledge, published between January 2019 and March 2022.*

Matsuoka, S., J. Hagelin, M. Smith, T. Paragi, A. Sesser, and M. Ingle. 2019. Pathways for avian science, conservation, and management in boreal Alaska. Avian Conservation and Ecology 14. doi: 10.5751/ACE-01347-140115.

Roy, C., Michel, N.L., Handel, C.M., Van Wilgenburg, S.L., Burkhalter, J.C., Gurney, K.E.B., Messmer, D.J., Princé, K., Rushing, C.S., Saracco, J.F., Schuster, R., Smith, A.C., Smith, P.A., Sólymos, P., Venier, L.A., Zuckerberg, B., 2019. Monitoring boreal avian populations: how can we estimate trends and trajectories from noisy data? Avian Conserv Ecol 14. https://doi.org/10.5751/ACE-01397-140208

Van Wilgenburg, S. L., Mahon, C. L.,Campbell, G., McLeod, L., Campbell, M., Evans, D., Easton, W., Francis, C. M., Haché, S., Machtans, C. S., Mader, C., Pankratz, R. F., Russell, R., Smith, A. C., Thomas, P., Toms, J. D., and Tremblay, J. A., 2020. A cost efficient spatially balanced hierarchical sampling design for monitoring boreal birds incorporating access costs and habitat stratification. PLoS ONE. https://doi.org/10.1371/journal.pone.0234494

Westwood, A.R., Barker, N.K., Grant, S., Amos, A.L., Camfield, A.F., Cooper, K.L., Dénes, F.V., Jean-Gagnon, F., McBlane, L., Schmiegelow, F.K.A., Simpson, J.I., Slattery, S.M., Sleep, D.J.H., Sliwa, S., Wells, J.V., Whitaker, D.M., 2020. Toward actionable, coproduced research on boreal birds focused on building respectful partnerships. ACE 15, art26. https://doi.org/10.5751/ACE-01589-150126

Wilson, R.E., Matsuoka, S.M., Powell, L.L., Johnson, J.A., Demarest, D.W., Stralberg, D., Sonsthagen, S.A., 2021. Implications of Historical and Contemporary Processes on Genetic Differentiation of a Declining Boreal Songbird: The Rusty Blackbird. Diversity 13, 103. https://doi.org/10.3390/d13030103

Yip, D. A., Knight, E. C., Haave-Audet, E., Wilson, S. J., Charchuk, C., Scott, C. D., Sólymos, P., and Bayne, E. M., 2019. Sound level measurements from audio recordings provide objective distance estimates for distance sampling wildlife populations. Remote Sensing in Ecology and Conservation. https://doi.org/10.1002/rse2.118

## BAM Technical Reports

*Reports describing BAM core and co-produced projects that were not peer-reviewed, completed between January 2019 and March 2022.*

Boreal Avian Modelling Project. (2020), Boreal Avian Modelling Project Annual Report - April 2019-March 2020, BAM Annual Report, Boreal Avian Modelling Project, University of Alberta, Edmonton, AB, Canada, available at: https://doi.org/10.5281/zenodo.4041713

Boreal Avian Modelling Project. (2019). Annual Report - April 2018-March 2019. Boreal Avian Modelling Project, University of Alberta, Edmonton, AB, Canada. https://doi.org/10.5281/zenodo.2925165

Boreal Avian Modelling Project. (2021), Boreal Avian Modelling Project Annual Report - April 2020-March 2021, BAM Annual Report, Boreal Avian Modelling Project, University of Alberta, Edmonton, AB, Canada, available at: https://doi.org/10.5281/zenodo.4041713

Micheletti, T., Stewart, F., McIntire, E.J.B., Eddy, I., Barros, C., Marchal, J., Stralberg, D., et al. (2019), Simulation Effects of Climate Change on Fire Regime: Implications for Boreal Caribou and Landbird Communities in the Northwest Territories, Technical Report.

## Presentations

*Presentations given by BAM Team Members between January 2019 and March 2022.*

BAM Team. (2019), "Boreal Avian Modelling (BAM) Project Overview", Talk presented at the Open Data Workshop for Avian Data in Canada, Edmonton, AB, Canada, 24 April.

Barker, N.K.S. (2019), "Application of models to date", Talk presented at the NSERC CRD Birds and Forestry Meeting, Edmonton, AB, Canada, 23 January.

Barker, N.K.S. (2019), "BAM Highlights: Conservation value of SFI-certified lands for Boreal Birds", Talk presented at the Meeting for SFI Grant Project Launch, Washington, DC, USA, 8 April.

Barker, N.K.S. and Williams, E. (2019), "Meeting in the Middle: Potential avenues for pan-American bird conservation", Talk presented at the SFI Conservation Impact Sounding Board, Washington, DC, USA, 9 April.

Bayne, E.M. (2019), "Boreal Avian Modelling (BAM) Project Overview", Talk presented at the Open Data Workshop for Avian Data in Canada, Edmonton, AB, Canada, 24 April.

Crosby, A.D. and Bayne, E.M. (2019), "Boreal Avian Modelling Project: Addressing Critical Knowledge Gaps Challenging the Management and Conservation of Boreal Birds in Canada", Talk presented at the SFI Annual Conference, 22 October.

Crosby, A.D. (2019), "Incorporating Regional Variation into Habitat Models with Functional Responses", Talk presented at the 37th Meeting of the Society of Canadian Ornithologists, Québec City, QC, Canada, 27 April.

Crosby, A.D. (2019), "Science for the Future of Boreal BIrds: Defining the Scientific Challenges", Talk presented at the 37th Meeting of the Society of Canadian Ornithologists, Québec City, QC, Canada, 27 April.

Crosby, A. (2020) "BAM-ABC-SFI Cross-border Bird Conservation Initiative", Presented at the Partners in Flight Easter Working Group Annual Meeting, 06 October.

Denés, F.V. (2019), "Identification of critical habitat for wide-ranging migratory birds: a conceptual model towards achieving self-sustaining populations", Talk presented at the Schedule of Studies Advisory Committee Meeting, Ottawa, ON, Canada, 27 February.

Docherty, T. (2020), "Boreal Avian Modelling Project: data sharing and open science", Talk presented at the Joint 28th Boreal Partners in Flight & 26th Alaska Shorebird Group Annual Meeting (on-line), 14 December.

Haché, S., Micheletti, T., Stralberg, D., Cumming, S.G., McIntire, E.J.B., Tremblay, J.A., Leblond, M., et al. (2019), "Simulating the Effects of Climate on Fire Regime & Vegetation: Implications for Woodland Caribou & Boreal Landbird Communities", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 26 June.

Haché, S. (2020), "Overview of the Western Boreal Initiative", Talk presented at the Joint 28th Boreal Partners in Flight & 26th Alaska Shorebird Group Annual Meeting (on-line), 14 December.

Knight, E.C., Harrison, A., Scarpignato, A.L., Van Wilgenburg, S.L., Bayne, E.M. and Marra, P.P. (2019), "Conservation Implications of a Migratory Network for the Common Nighthawk", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 26 June.

Leston, L., Bayne, E.M. and Schmiegelow, F.K.A. (2019), "Long-term monitoring of boreal bird community at Calling Lake Alberta, 1993-2018 and counting", Talk presented at the Western Canada Bird Banding Conference, Edmonton, AB, Canada, 29 March.

Leston, L., Bayne, E.M. and Schmiegelow, F.K.A. (2019), "Long-term monitoring of changes in harvest area, weather, and insect outbreaks on boreal birds", Talk presented at the Alberta Chapter of the Wildlife Society AGM, Canmore, AB, 22 March.

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Sólymos, P. (2019), "Analysis of Point-count Data in the Presence of Variable Survey Methodologies and Detection Error", Workshop presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 25 June.

Sólymos, P. (2019), "Data integration and current models", Talk presented at the NSERC CRD Birds and Forestry Meeting, Edmonton, AB, Canada, 23 January.

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Sólymos, P., Matsuoka, S.M., Van Wilgenburg, S.L., Stralberg, D., Cumming, S.G. and Bayne, E.M. (2019), "What Can We Do with Survey Design Specific Biases in Point-Count Data? Integrating Roadside Surveys and New Technologies", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 28 June.

Stehelin, T.E. and Schmiegelow, F.K.A. (2019), "Predicting present and future distribution and abundance of Olivesided Flycatcher and Western Wood-pewee in northwestern North America using climate and landcover",Talk presented at the Biodiversity Forum, Whitehorse, YT, Canada, 2 March.

Stralberg, D., Berteaux, D., Drever, M.C., Naujokaitis-Lewis, I., Schmiegelow, F.K.A. and Tremblay, J.A. (2019), "Conservation Planning for Boreal Birds in a Changing Climate: A Framework for Action", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 26 June.

Stralberg, D., Barker, N.K.S., Bayne, E.M., Berteaux, D., Camfield, A.F., Carlson, M., Cumming, S.G., et al. (2019), "Conservation planning for boreal birds in a changing climate", Talk presented at the Annual Partners in Flight Science Meeting, Ottawa, ON, Canada, 9 July.

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Stralberg, D. and P. Sólymos (2020). "New spatial abundance models inform distribution, population, and trends for forest birds in Canada." Webinar presented for Partners in Flight and the ECCC Landbird Technical Committee, 8 October. https://www.youtube.com/watch?v=Z1js0MWs4z8Stralberg, D. (2020), "Data and metrics for vulnerability assessment and conservation planning in a changing climate", Talk presented at the NWT Protected Areas and Climate Change, 25 March.

Toms, J.D. and Carpenter, T.M. (2019), "Community-level Response to Cumulative Effects of Forestry and Energy Development", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 26 June.

Toms, J.D. and Carpenter, T.M. (2019), "Assessing the cumulative impacts of resource development on landbirds in northern Alberta", Talk presented at the Society of Canadian Ornithologists' Meeting, Quebec City, QC.

Toms, J.D., Sólymos, P., Stralberg, D., Barker, N.K.S., Micheletti, T., Leston, L., Haché, S., et al. (2019), "Conservation of Boreal Birds: Status, Trends, and Data Gaps", Talk presented at the American Ornithological Society Annual Meeting, Anchorage, AK, USA, 26 June.

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Tremblay, J.A., Y. Boulanger, P. Cadieux, D. Cyr, D. Price, P. Solymos, D. Stralberg, and A. Taylor. 2020. A synthesis of climate change impacts on boreal bird communities in boreal managed forests of Canada. Landbird Technical Committee. Virtuel.17 novembre 2020.

Tremblay, J.A., Bayne, E.M., and Cuming S.G. "Boreal Avian Modelling (BAM) Project", Talk presented at the Quebec SFI Implementation Committee, 3 December.

Tremblay, J.A., Y. Boulanger, P. Cadieux, D. Cyr, D. Price, P. Solymos, D. Stralberg, and A. Taylor. 2020. Synthèse des impacts du changement climatique sur les communautés d'oiseaux boréaux dans les paysages aménagés du Canada. Séminaire de l'Institut de recherche sur les forêts (IRF) de l'Université du Québec en Abitibi-Témiscamingue (UQAT), Rouyn-Noranda, Canada. 30 janvier 2020. Invited Seminar.

Stralberg, D., P. Solymos, J. A. Tremblay, P. Cadieux, Y. Boulanger, F. K. A. Schmiegelow, E. M. Bayne, S. G. Cumming, S. Matsuoka, D. Berteaux, C. R. Drever, M. Drever, I. Naujokaitis-Lewis, C. Carroll, S. E. Nielsen, and C. Wilsey (2021). "Conservation and management of boreal birds in a changing climate: What do we expect, what have we observed, and what do we do about it?" Alberta Chapter of The Wildlife Society conference (online), 25 March. https://youtu.be/u2fop1P_FBU

Leston, L., Bayne, E., Solymos, P., Tremblay, J. et al. (2021). "Habitat On The Move: Using species distribution models and landscape simulation to project and manage for future Canada Warbler populations". Alberta Chapter of The Wildlife Society conference (online), 26 March. https://youtu.be/IB-PanUY40U

## Webinars and Workshops

*Webinars and workshops organized or co-organized by BAM, hosted between January 2019 and March 2022.*

BAM Team. (2021), "The Boreal Avian Modelling Project", BAM Webinar to the Landbird Technical Committee (online), 16 April.

Barker, N.K.S. and Bayne, E.M. (2019), "Open Data Workshop for Avian Data in Canada", Workshop, Edmonton, AB, Canada, 24-25 April.

Crosby, A. (2020), "Introduction to the Boreal Avian Modelling Project", presentation as part of the BAM-ABC-SFI Cross-border Bird Conservation Initiative webinar, 03 June.

"NSERC CRD Birds and Forestry Meeting". (2019), Workshop, University of Alberta, Edmonton, AB, Canada, 25 January, Organized by Erin Bayne.

Solymos, P. (2021), "Analysis of point-count data in the presence of variable survey methodologies and detection error" originally developed for BIOS2 held on March 16, 18, 23, 25, 2021 https://peter.solymos.org/qpad-workshop/land

McIntire, E., Haché, S., Micheletti, T. et al. (2021). "Western Boreal Initiative: year-end workshop". Workshop (online), 26 April.

Stralberg, D. and Sólymos, P. (2020), "New spatial abundance models inform distribution, population, and trends for forest birds in Canada.", Webinar presented at International Scientific Committee of Partners in Flight, 8 October.

# Project Management

## The Structure of the BAM Project

### The BAM Team

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

### Project Team

**Steering Committee**

- Erin Bayne, University of Alberta
- Steve Cumming, Université Laval
- Jeff Ball, Environment & Climate Change Canada
- Fiona Schmiegelow, University of Alberta
- Samantha Song, University of Alberta
- Diana Stralberg, Natural Resources Canada

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### Support Team

Many additional people provide time and expertise to BAM project activities. This year, we would like to recognize the contributions of the following individuals:

- Trish Fontaine (University of Alberta): project, data management & administrative support
- Veronica Aponte (CWS): BBS data support
- Denis Lepage, Danielle Ethier and Catherine Jardine (Bird Studies Canada): Atlas data support
- Nash Goonewardena, Christie Nohos, Sandy Doerr (University of Alberta): Technical and administrative support
- Brad Grier: website design, programming, and support

## Partnerships

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

### Funding Partners

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

#### Founding organizations and funders

Environment & Climate Change Canada University of Alberta BEACONs

#### Financial support to BAM in 2021-2022

- Alberta Pacific Forest Industries Inc. (Al-Pac)
- Boreal Ecosystems Analysis for Conservation Networks (BEACONs)
- Canadian Forest Products Ltd. (Canfor)
- Council of Forest Industries (COFI)
- Environment & Climate Change Canada (ECCC), Canadian Wildlife Service
- Environment & Climate Change Canada, Science and Technology Division
- Mitacs Accelerate Program
- Natural Sciences and Engineering Research Council of Canada (NSERC)
- Oil Sands Monitoring (OSM) Program
- Ouranos Consortium
- Sustainable Forestry Initiative (SFI)
- Université Laval
- University of Alberta

#### Financial support for CASFRI

- ECCC
- GEOIDE Network
- Canada Foundation for Innovation
- NSERC Discovery Grant
- NRCan
- Sustainable Forest Management Network
- Nature Conservancy

## Data Partners

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

### Avian Data

*Institutions:*

Acadia University
Alaska Bird Observatory
Alaska Natural Heritage Program
Alaska Science Center
Alberta Biodiversity Monitoring Institute
Alberta Pacific Forest Industries Inc.
AMEC Earth & Environmental
AREVA Resources Canada Inc.
Avian Knowledge Network
AXYS Environmental Consulting Ltd.
BC Hydro
Bighorn Wildlife Technologies Ltd.
Birds Canada
Canadian Natural Resources Ltd.
Canadian Forest Products Ltd.
Daishowa Marubeni International Ltd
Devon Canada
Environment and Climate Change Canada
Fish & Wildlife Compensation Program
Golder Associates Ltd.
Government of British Columbia
Government of Saskatchewan
Government of Yukon
Hinton Wood Products
Hydro-Québec Équipement
Interfor
Kluane Ecosystem Monitoring Project
Komex International Ltd.
Louisiana Pacific Canada Ltd.
Manitoba Breeding Bird Atlas
Manitoba Hydro
Manitoba Model Forest Inc.
Manning Diversified Forest Products Ltd.
Maritimes Breeding Bird Atlas
Matrix Solutions Inc.
MEG Energy Corp.
Mirkwood Ecological Consultants Ltd.
The Nature Conservancy
Northeast Temperate Network
Ontario Ministry of Natural Resources
OPTI Canada Inc.
PanCanadian Petroleum Limited
Parks Canada
Petro Canada
Pope & Talbot Ltd.
Principal Wildlife Resource Consulting
Regroupement Québec Oiseaux
Rio Alto Resources Int'l Inc.
Shell Canada Ltd.
STRIX Ecologic al Consulting
Suncor Energy Inc.
Tembec Industries Inc.
Tolko Industries Ltd.
U.S. Army
U.S. Fish and Wildlife Service
U.S. Geological Survey, Alaska Science Center
U.S. National Park Service
Université de Moncton
Université du Québec à Montréal
Université du Québec en Abitibi Témiscamingue
Université Laval
University of Alaska, Fairbanks
University of Alberta
University of British Columbia
University of Guelph
University of New Brunswick
University of Northern British Columbia
URSUS Ecosystem Management Ltd.
Vermont Center for Ecostudies
West Fraser Timber Co. Ltd.
Weyerhaeuser Company Ltd.
Wildlife Resource Consulting Services MB Inc.

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M. Cadman
D. Collister
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A. Desrochers
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S. Haché
R. Hall
C. Handel
S. Hannon
B. Harrison
C. Harwood
J. Herbers
K. Hobson
M-A. Hudson
L. Imbeau
P. Johnstone
V. Keenan
K. Koch
M. Laker
S. Lapointe
R. Latifovic
R. Lauzon
M. Leblanc
L. Ledrew
J. Lemaitre
D. Lepage
K. Lewis
B. MacCallum
P. MacDonell
C. Machtans
K. Martin
S. Mason
C. McIntyre
M. McGovern
D. McKenney
L. Morgantini
J. Morton
G. Niemi
T. Nudds
P. Papadol
M. Phinney
D. Phoenix
D. Pinaud
D. Player
D. Price
R. Rempel
A. Rosaasen
S. Running
R. Russell
C. Savignac
J. Schieck
F. Schmiegelow
D. Shaw
P. Sinclair
A. Smith
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K. Sowl
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D. Swanson
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P. Taylor
S. Van Wilgenburg
P. Vernier
M-A. Villard
D. Whitaker
T. Wild
J. Witiw
S. Wyshynski
M. Yaremko

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

Natural Resources, Pacific Wildlife Foundation, Prince Edward Island Department of Natural Resources, Regroupement Québec Oiseaux

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

## Biophysical Data

*Institutions:*

BirdLife International & NatureServe; Global Land Cover Facility; Natural Resources Canada - Canada Centre for Remote Sensing & Canadian Forest Service; Numerical Terradynamic Simulation Group at the University of Montana.

*Common Attribute Schema for Forest Resource Inventory (CASFRI):*

Alberta Pacific Forest Industries Inc.
Blue Ridge Lumber
Buchanan Forest Products
Canadian Forest Products Ltd.
Cenovus Energy Inc.
Daishowa Marubeni International Ltd.
Forsite Consultants, Ltd.
Government of Alberta
Government of British Columbia
Government of Canada
Government of Manitoba
Government of New Brunswick
Government of Newfoundland & Labrador
Government of Nova Scotia
Government of Ontario
Government of PEI
Government of Saskatchewan
Government of the Northwest Territories
Gouvernement du Québec
Louisiana Pacific Canada Ltd.
Millar Western Forest Products Ltd.
Mistik Management Ltd.
Parks Canada
Tembec Industries Inc.
Tolko Industries Ltd.
West Fraser Timber Co. Ltd.
Weyerhaeuser Company Ltd.
Yukon Government

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Leston 2022. MODELING FRAMEWORK TO SUPPORT CRITICAL HABITAT IDENTIFICATION FOR THE WOOD THRUSH IN CANADA. Detailed Technical Methods and Results (EC Contract No. – N°de contrat EC3000713776). Technical Report.

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# Appendix 1: List of Research & Monitoring Projects 2019-2022

| Project | Type of BAM Project | Years | Outputs |
|---|---|---|---|
| ***Theme 1: Population Status & Trends*** | | | |
| BAM National Density Models Version 4.1 | Core | 2021 - present | |
| BAM National Density Models Version 4.0 | Core | 2017 - 2020 | Boreal Avian Modelling Project, 2020 |
| Predicting spatiotemporal abundance of breeding waterfowl across Canada | Co-produced | 2018 - 2020 | Adde et al 2020a & Adde et al 2020b |
| Revising our trend estimation procedure | Core | 2019 - present | |
| NA-POPS | Co-produced | 2020 - present | Edwards et al *In review* |
| Comparing spatially explicit models (PIX) and the Partners in Flight (PIF) approach to estimate population sizes of boreal birds in Alberta, Canada | Core | 2017 - 2020 | Solymos et al 2020 |
| ***Theme 2: Species at Risk Status, Recovery Planning, and Multi-species Management*** | | | |
| Critical habitat identification for the recovery of wide-ranging boreal species at risk in Canada: a case study with the Canada Warbler | Core | 2017 - 2021 | Leston et al. *In prep* |
| Critical habitat identification for the recovery of wide-ranging boreal species at risk in Canada: a case study with the Wood Thrush | Informed | 2020 - 2021 | Leston 2022 |
| A Standard Operating Procedure to Inform the Identification of Critical Habitat Under the Species at Risk Act | Informed | 2019 - 2020 | |
| ***Theme 3: Habitat Selection*** | | | |
| Can new remote sensing tools improve species distribution models for birds in Alberta? | Co-produced | 2018 - 2022 | Casey et al *In Review* |
| Functional response models to quantify habitat selection while accounting for habitat availability in the surrounding region | Core | 2019 - present | |
| Differential habitat selection | Core | 2017-2020 | Crosby et al 2019 |
| ***Theme 4: Detecting and Attributing Land-use and Climate Change Impacts on Boreal Birds*** | | | |
| ***Climate Change*** | | | |
| Projected effects of climate change on the distribution and abundance of breeding waterfowl in Eastern Canada | Co-produced | 2019-2020 | Adde et al 2020c |
| Cumulative impact of climate change and forest management on bird community in two contrasting forests in Eastern North America | Co-produced | 2019 - present | |
| A regional comparison of the impacts of climate change and forest harvesting on boreal bird communities of Canada | Co-produced | 2020 - present | |
| Avian responses to climate-mediated landscape changes in Bird Conservation Region 4 | Co-produced | 2018 - 2020 | |

| | | | |
|---|---|---|---|
| Historical changes in boreal bird abundance and distribution | Core | 2019 - present | |
| Conservation and management of boreal birds in a changing climate: What do we expect, what have we observed, what do we do about it? | Co-produced | 2019 - 2020 | Workshop/symposium |
| Western Wood-Pewee and Olive-sided Flycatcher in northwestern North America | Co-produced | 2018 - 2020 | Stehelin 2020 |
| Phenological investigation between insect prey and two species of aerial insectivorous bird | Co-produced | 2018 - 2020 | Stehelin 2020 |
| ***Energy & Mining Impacts and Cumulative Effects*** | | | |
| Biotic Homogenization | Informed | 2019 - present | |
| Attribution of impacts to different sectors at local and landscape scales | Co-produced | 2019 - present | |
| Environmental assessment of effects of chromium mining on bird populations in the Ring of Fire region, Ontario | Co-produced | 2020 - present | Crosby et al 2022a |
| Hierarchical, multi-scale modeling framework reveals evidence for domains of scale in cumulative effects of energy sector development on boreal birds | Co-produced | 2020 - present | Crosby et al *in review* |
| Comparing zone of impact to dose-response models when assessing cumulative effects of energy sector development | Co-produced | 2020 - present | Leston et al *in print* |
| Trends in wetland birds in Alberta's oilsands (2013-2019) | Co-produced | 2020 - present | |
| Partitioning impacts of various Oil Sands Region stressors on the Ovenbird | Co-produced | 2019 - 2020 | Solymos et al 2020 |
| Forest Resource Improvement Association of Alberta (FRIAA) – Managing Alberta's forest birds through multi-scale forestry planning. | Co-produced | | |
| ***Forestry Impacts*** | | | |
| Quantifying Long-Term Bird Population Responses to Simulated Harvest Plans and Cumulative Effects of Disturbance | Co-produced | 2017 - 2020 | Leston et al 2020 |
| AB Risk Matrix: Supporting harvest planning decisions regarding risk of incidental take | Co-produced | 2018 - present | |
| BC Risk Matrix: Supporting harvest planning decisions regarding risk of incidental take | Co-produced | 2018 - present | |
| Impacts of residual tree retention on birds | Co-produced | 2018 - present | |
| Calling Lake - Temporal response of birds to variables within a long-term fragmentation experiment | Informed | 2018 - present | |
| Conservation Value of Forest Certification Differs Among Bird Conservation Regions | Co-produced | 2019 - present | Crosby & Bayne 2020 |
| Cross-border collaboration between BAM, American Bird Conservancy, and Sustainable Forestry Initiative for bird conservation on managed forest lands | Co-produced | 2019 - present | Webinar |
| Value and resilience of SFI forests for eastern forest birds in a changing climate | Co-produced | 2022 - present | |
| ***Projecting Impacts of Landscape Change*** | | | |

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|---|---|---|---|
| Hindcasting the net effect of forest harvesting on the abundance of boreal songbirds: 1985-2011 | Co-produced | 2019 - present | |
| Using landscape simulations to forecast caribou resource selection and population growth and landbird abundances under climate change | Co-produced | 2018 - 2021 | Micheletti et al 2021 |
| Assessing the Umbrella Concept: An Application to Boreal Landbirds in the Northwest Territories Canada | Co-produced | 2020 - present | Micheletti et al *in review* |
| The Western Boreal Initiative | Co-produced | 2020 - present | |
| Interpreting predicted avian responses to climate change in the Northwest Territories | Co-produced | 2021 - present | |
| Historical range of variation as a strategy to identify forest management practices to conserve avian populations | Co-produced | 2019 - present | |
| Optimising for sustainable harvests and bird populations in forest management planning | Co-produced | 2019 - present | |
| Effects of anthropogenic disturbances on boreal birds at national extent | Core | 2016 - 2020 | |
| ***Theme 5: Conservation Planning for Boreal Birds*** | | | |
| Identifying co-benefits for boreal caribou and landbirds across the boreal forest of Canada. | Core | 2020 - present | Docherty et al. *In prep* |
| Developing indices of biotic intactness as a criterion to identify Key Biodiversity Areas in Canada | Co-produced | 2020 - present | Technical Report |
| Prairie Habitat Joint Venture: identifying priority areas for landbirds using multi-species conservation planning | Co-produced | 2020 - 2021 | |
| Eastern Habitat Joint Venture: modelling species-habitat relations and population distributions to support conservation and restoration planning for forest birds in Eastern Canada | Co-produced | 2022 - present | |
| Evaluating the Effectiveness of Biodiversity Surrogates for Conservation Planning in the Boreal Region of Canada | Co-produced | 2020 - 2021 | |
| Prioritizing Areas for Land Conservation and Forest Management Planning for the Threatened Canada Warbler in the Atlantic Northern Forest | Co-produced | 2017 - 2020 | Westwood et al 2020 |
| Supporting land-use planning by the Lac Seul First Nation for Species at Risk | Co-produced | 2018 - 2020 | Denes 2019a |
| Supporting the Pathway to Canada's Target 1 in the Moose Cree First Nation Homelands: Avian ecological representation of the North French River Watershed | Co-produced | 2017 - 2020 | Denes 2019b |
| ***Theme 6: Monitoring and Sampling*** | | | |
| Boreal Monitoring Strategy | Informed | 2017 - present | Van Wilgenburg et al 2020 |
| Training Workshop for the Analysis of Heterogeneous Point Count Data | Core | 2020 - 2021 | borealbirds.github.io/qpad-workshop/ |
| Methods and products to support survey design | Core | 2019 - 2020 | bSims package |

# Boreal Avian Modelling Project

## Annual Report April 2021 - March 2022

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### Suggested reference format

Boreal Avian Modelling Project. 2022. Annual Report - April 2021-March 2022. Boreal Avian Modelling Project, University of Alberta, Edmonton, AB, Canada.

Boreal Avian Modelling Project

Projet de modélisation aviaire boréal

**COVER PHOTO:**

Chestnut-sided Warbler: Yousif Attia (CC)

**www.borealbirds.ca**