ANNUAL REPORT

April 2020 - MARCH 2021

BOREAL AVIAN MODELLING PROJECT

PROJET DE MODÉLISATION AVIAIRE BORÉAL

Highlights from 2020–2021

BAM conducts collaborative research in avian ecology and conservation and develops data products to support research and management of boreal birds. We partner with federal and provincial governments, academia, industry, Indigenous Peoples and communities, and non-governmental organizations (NGOs) with interests in the development and application of science to support bird conservation and management.

Research & Monitoring

Population Status and Trends

- New national-scale landbird density estimates (version 4.0), population sizes and habitat associations are available for 143 species. ▶ page 10
- Development of version 4.1 of landbird density estimates is underway to incorporate annual landcover and climate covariates to support analyses of trends. ▶ page 10
- New national-scale waterfowl density models are available for 18 species. ▶ page 11
- BAM is contributing to a large collaborative project called NA-POPS to improve estimates of population size for all species of landbirds in North America by generating detectability offsets. ▶ page 11

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

- Identification of critical habitat for Canada Warbler and Wood Thrush using BAM's conceptual and analytical framework. ▶ page 12 & 13

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

Climate change impacts

- New projected distributions and abundance of 12 waterfowl species in Eastern Canada were produced using a climate envelope modelling approach. ▶ page 15
- A project describing the cumulative impacts of climate change and forest management on two contrasting forests in Québec makes recommendations for mitigation strategies to support avian conservation and carbon sequestration. ▶ page 16
- A comparison of boreal bird communities in Alberta and Québec finds that climate change and forest harvesting may impact species differently across their range and recommends regional-specific measures for conservation of climate-sensitive bird species. ▶ page 17
- Preliminary analyses to obtain trend estimates using our generalized national modelling approach. ▶ page 18

Energy & mining sector impacts and cumulative effects

- Predictive habitat models evaluate the response of birds to cumulative effects within the proposed Ring of Fire development area in northern Ontario. ▶ page 19
- Two projects evaluate methods to support cumulative effects assessment by comparing 3 types of cumulative effects models and evaluating the impact of spatial scale on cumulative effects assessment. ▶ page 19 &21
- Declining trends from 2013-2019 were detected for multiple bird species in wetland habitats across the oilsands region of Alberta. ▶ page 20

Forestry Impacts

- Projected bird abundances were not adversely affected by differences in caribou conservation harvest plans, but species associated with older forests decline with increasing cumulative effects in Alberta. ▶ page 20

- Data-driven risk matrices were developed to support harvest planning decisions regarding incidental take of migratory birds in Alberta and British Columbia. ▶ page 21
- A new analysis provides the foundations for understanding how forest certification can affect the conservation of forest birds in Canada. ▶ page 22
- A new cross-border collaboration and working group was established to identify opportunities and challenges for forest management to benefit bird populations. ▶ page 23

Projecting impacts of landscape change

- Predicted changes in boreal bird distributions in the Bird Conservation Region (BCR) 6 portion of NWT are largely attributed to direct climate effects. ▶ page 24
- Forecastable versions of the BAM National Models are being integrated into a broader modelling framework for the ECCC's Western Boreal Initiative looking at co-benefits of conservation of Species at Risk, migratory birds and carbon in western Canada. ▶ page 25

Conservation Planning for Boreal Birds

- Potential co-benefits for boreal caribou and landbird conservation are being identified across the boreal forest of Canada. ▶ page 27
- New indices of biotic intactness for songbirds have been developed as a criterion to identify Key Biodiversity Areas in Canada. ▶ page 27
- The degree of overlap between areas of high conservation value for landbirds and waterfowl has been evaluated across the western boreal forest to support the Prairie Habitat Joint Venture Implementation Plan. ▶ page 28
- BAM has co-produced work to evaluate biodiversity surrogacy within a conservation planning framework in the boreal region of Canada. ▶ page 28

Monitoring and Sampling

- The Boreal Monitoring Strategy (BMS) is using BAM density maps in conjunction with pilot sampling and BAM offsets to test design efficiency and sampling bias and determine national sample size requirements to meet BMS objectives. ▶ page 29

Data and Data Product Development

The results and outputs of many of BAM's research projects are summarized into data products, which we make publicly available to support and facilitate conservation and management of boreal birds. More details about our data and data products can be found on page 31 or visit https://borealbirds.ualberta.ca/maps-data/.

- Data products currently available include:
  - Bird **data and methods** to support data standardization and integration
  - **Densities and population sizes** 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
- BAM's updated Avian Database (version 6.0) has a new, efficient structure and now contains point count data from over 170 projects at more than 250,000 locations across North America ▶ page 32.
- The BAM database is going online on WildTrax! ▶ page 32.
- BAM is working towards improved access to avian data in Canada in partnership with the ABMI, Bird Studies Canada (BSC), and ECCC ▶ page 34.

Communications, Collaborations and Implementation

Application of Results through Collaborations

BAM contributed to more than 35 collaborative efforts to facilitate boreal bird conservation and management, involving non-governmental organizations, provincial and federal government agencies, Indigenous Peoples, industry, and academic institutions. A comprehensive list of collaborative projects is included on page 5.

BAM results have been applied by partners to facilitate and support conservation and management efforts related to monitoring design, threats assessment and management planning, priority areas assessment, and species at risk planning.

Communications

- BAM has a newly updated website highlighting data products and conservation partnerships. The French version is forthcoming in 2021-22 ▶ page 35.
- BAM co-produced 10 peer-reviewed publications since January 2020 ▶ page 35
- BAM research and conservation efforts were highlighted in more than 17 talks at international or regional conferences, targeted workshops, webinars, and collaborative meetings since January 2020 ▶ page 36

Project Management

- BAM wishes the best of luck to Diana Stralberg in her new role as a Climate Change Research Scientist with the Canadian Forest Service and in her continued role as a BAM Contributing Scientist.
- Congratulations to Antoine Adde for successfully defending his PhD!

Collaborations & Applications of BAM Results

Collaborations with conservation practitioners and decision-makers are one of the main ways in which BAM's work can support and inform boreal bird conservation. In 2020–2021, BAM continued to provide research findings, methods, and data products to support and inform conservation and management initiatives through collaborations and partnerships.

Boreal Bird Density, Population Status & Trends

- BAM's national-scale density models and population estimates have been used and integrated into various initiatives, including the **Environment and Climate Change Canada's** (**ECCC**) Boreal Monitoring Strategy for migratory birds (page 29), Key Biodiversity Areas Criterion C initiative (page 27), ECCC's Western Boreal Initiative (page 25), the Prairie Habitat Joint Venture (page 28), the proposed recovery strategy for bank swallow (ECCC 2021) and more.
- BAM continued contributions to discussions within **Partners in Flight (PIF)** regarding population estimation leading to collaborations with **ECCC** on population/trend 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** [**DUC**]), are being integrated into the Western Boreal Initiative (page 25) and the Prairie Habitat Joint Venture (page 28).
- BAM is collaborating on 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 **ECCC**, **NRCAN**, **PIF Science Committee**, and more (page 11). (page 11).

Species at risk and conservation planning

- BAM continues to support **ECCC** efforts to develop a standardized approach to identify critical habitat for wide-ranging species at risk, using Canada warbler as a test species (page 12).
- BAM is collaborating with **ECCC** to support work to identify critical habitat for Wood Thrush (page 12).

Habitat selection, availability and needs

- A project examining the use of LiDAR in species distribution models is a collaboration with the **Alberta Agriculture and Forestry** (page 14).

Detecting & Attributing Land-use and Climate Change Impacts

Climate Change Impacts

- A project that compares the effects of climate change and forest management on two forest bird communities in Québec is a collaboration with **ECCC** and **Ministère des Forêts, de la Faune et des Parcs of Québec** (page 17)
- Efforts to forecast the impacts of climate change and forest harvesting on regional bird communities in Alberta and Québec is a collaboration with the **NRCAN** and **ECCC** (page 18)
- BAM is contributing to a new committee with **Partners in Flight (PIF), Audubon**, and **ECCC** to add a climate-change vulnerability component to the PIF Avian Conservation Assessment Database (ACAD).

Energy & Mining Sector Impacts and Cumulative Effects

- BAM is partnering with **ECCC** and the **SpaDES** development group at the **Pacific Forestry Centre** (**NRCAN**) to develop predictive habitat models for birds in northern Ontario as part of an environmental assessment in the Ring of Fire region (page 20).

Forestry Impacts

- BAM completed and published work in collaboration with **Alberta-Pacific Forest Industries Inc. (Al-Pac)** and the **Alberta Biodiversity Monitoring Unit** (**ABMI)** to understand the potential impacts of caribou-specific harvest management plans on avian populations (page 21).
- A data-driven risk matrix tool was developed by BAM, in collaboration with the **Alberta Forest Products Association**, **Forest Resource Improvement Association of Alberta** (**FRIAA**), and the **ABMI,** to evaluate avian abundance and support harvest planning decisions in Alberta (page 21). BAM is also collaborating

with the **Council of Forest Industries** (**COFI**) and **ABMI** to develop similar methods and tools in British Columbia (page 21).

- BAM is co-producing work with the **Bioacoustic Unit (BU)** at the University of Alberta and **ABMI** to evaluate the impacts of residual tree retention in Alberta (page 22).
- Our project to evaluate the conservation value of forest certification across BCRs is a collaboration with the **Sustainable Forestry Initiative** (**SFI**), **Al-Pac**, **Fuse Consulting Ltd.**, and **fRI Research** (page 22).
- BAM developed a new 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 (page 24).

Projecting Impacts of Landscape Change

- Our hindcasting effort to understand the historical impacts of forest management on bird populations is a collaboration with **NRCAN** (page 25).
- A collaboration with **Université Laval**, **NRCAN**, **ECCC**, and the **NWT Department of Environment and Natural Resources** (**NWT ENR**) is evaluating the effects of climate change on boreal landbird distributions in the BCR 6 portion of the Northwest Territories (page 25).
- BAM is contributing to a highly collaborative project called the Western Boreal Initiative that includes partners from **Université Laval**, **UBC**, **Dalhousie University (DAL)**, **NRCAN**, **ECCC**, **Dene Nation**, and the **NWT ENR** (page 26).

Conservation Planning for Boreal Birds

- BAM is co-producing work to identify potential co-benefits for boreal caribou and landbirds across the boreal region in collaboration with **ECCC, NRCAN, DAL** and **BEACONS**. (page 27)
- 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. (page 27).
- BAM has identified priority areas for landbird conservation in the Western Boreal Forest (WBF) to support the Prairie Habitat Joint Venture (PHJV) Implementation Plan for the WBF in collaboration with **ECCC** and **DUC** (page 28). In addition, BAM methods have guided analyses to support the PHJV Prairie Parklands science and planning in collaboration with **ECCC**.

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 pilot BMS sampling to test design efficiency and sampling bias (page 29).
- A point count analysis workshop delivered by Péter Sólymos with **BIOS2**, which explored BAM's statistical approach to integrate heterogeneous datasets (e.g., data with variable survey methods and detection error), was attended by over 55 participants from multiple countries, organizations and industries (page 30).
- BAM team members are contributing to planning and support of the third **Ontario Breeding Bird Atlas** via involvement in committees and working groups.

Data and Data Products

- BAM is collaborating with **ECCC**, **Birds Canada**, **ABMI**, and the **BU** to develop the Canadian Network for Open Avian Data, which is a network to connect avian data portals and partners in Canada (page 32).
- In collaboration with **ABMI** and the **BU**, the BAM database will now be hosted on **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 32).
- **WildTrax** is integrating BAM tools such as automating ARU data download into the BAM data structure, as well as automating the calculation of detectability offsets (page 34).

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Steve Cumming, U.Laval	Steering Committee
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About Us

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 History

The Boreal Avian Modelling Project (BAM) was initiated in 2004 to address knowledge gaps associated with the management and conservation of boreal birds in North America.

BAM is built on the foundation of boreal bird data. The BAM database was created by collating and harmonizing avian data from the Breeding Bird Survey, Breeding Bird Atlases, and individual research, monitoring, and inventory efforts conducted across the Canadian and US boreal and hemi-boreal region.

BAM is working to develop rigorous analytical model-based approaches to support the conservation of the boreal forest region and the bird populations and communities that depend upon it. We have developed specialized statistical approaches to harmonize these datasets by correcting for survey methodology and species detectability to estimate density.

BAM models have a myriad of applications: they allow us to draw relationships between birds and their environment (e.g. vegetation, climate, disturbance) from regional to national scales, to predict their response to changes through time and across geographic areas, to explain population trends, to determine which habitats are important and why, to design monitoring efficiently and effectively, to assess how management decisions made now may affect birds in the future...just to name a few.

Our Structure

The BAM Project Team is comprised 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.

A National Technical Committee of boreal bird researchers from across North American facilitates data sharing and project collaboration. The collaborative nature of the project is further highlighted by the many individuals who have provided project assistance and support over the years.

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

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 2020–March 2021.

Population Status and Trends

Summary: Reliable and accurate estimation of species' population size, trend and distribution is important for informing status assessment, recovery actions, and conservation planning. BAM is committed to developing approaches to estimate the density, distribution, and trends of boreal birds using heterogeneous datasets. In recent years, we have made significant progress developing a generalized analytical approach to model species density at ecosystem and national scales.

In 2020–2021, we launched a new set of national-scale data products (version 4.0) including density maps and population estimates for 143 landbird species. We published research and data products predicting the abundance of breeding waterfowl across Canada. We also began contributing to a large collaborative effort, led by CWS, to produce point count offsets to support population sizes of North America landbirds.

BAM National Density Models Version 4.0 AND 4.1

BAM has produced Canada-wide estimates of species' density, population sizes, habitat associations, and distributions for 143 landbird species. We used the BAM database and developed a generalized analytical approach to model species densities in relation to environmental covariates. In 2020-21, we focused on summarizing and distributing products based on these new density models (version 4.0). In addition to 1-km^2 raster products, we published a summary report, tutorial, standardized map products, habitat-specific density estimates, summaries of covariate importance, and model diagnostics on https://borealbirds.github.io. In October 2020, we presented a joint webinar to Partners in Flight and the ECCC Landbird Technical Committee that summarized methods, results, and data products. The webinar was also recorded, distributed on Twitter, and posted on our website.

We also generated 250-m predictions (2011 snapshot) for each of 143 species, 32 bootstrap replicates, and 19 Canadian geographic units. This large volume of data is now available for download by request. For one bootstrap replicate, we also generated annual predictions at 1-km^2, which have been used to develop preliminary pixel-level trend estimates (see page 18). However, we plan to wait for the next version of the models, which will incorporate annual landcover and climate covariates, to analyze and publish trend estimates.

Finally, we focused on filling data gaps in the Yukon, British Columbia, and New England U.S. states for the next version of our models (version 4.1), which will cover the entire boreal/hemiboreal region of North America. We also obtained annual climate and landcover datasets for data attribution and modelling. [**CORE project**. Contact: Diana Stralberg and Péter Sólymos]

Predicting spatiotemporal abundance of breeding waterfowl across Canada

The aim of this project was to refine the previous generation of national waterfowl models developed by Barker et al. (2014) and to develop predictive statistical models for mapping the abundance and distribution of waterfowl species across Canada. In 2020, a review was published in Écoscience that summarized environmental variables known to affect breeding duck distribution and abundance in northern North America. Following this review, work was conducted to model the spatio-temporal abundance of 18 waterfowl species at a pan-Canadian level and was published in *Diversity & Distributions* in August 2020. This research was led by Antoine Adde (BAM PhD student with Marcel Darveau and Steve Cumming, Université Laval). This work continues the 11-year collaboration between Steve Cumming and Marcel Darveau of Ducks Unlimited Canada and benefits from an NSERC Strategic Partnership Grant. Antoine successfully defended his PhD in October 2020. Congratulations Antoine! [**CO-PRODUCED project**. Contact: Antoine Adde]

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

BAM is contributing to a large collaborative effort to generate detectability offsets for all species of landbirds in North America. This project, called NA-POPS, builds on BAM's foundational work to develop detectability offsets and methods to integrate heterogeneous datasets. NA-POPS has compiled a large point count dataset representing a broad array of species, environments, and methods from across North America (see Research Box 1). 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). The offsets generated by this work will support improved model-based, continent-wide population estimates and estimates of population trends. NA-POPS is a collaboration among numerous partners, including the Canadian Wildlife Service (CWS), Canadian Forest Service (CFS), Partners in Flight Science Committee (PIF), and more. [**CO-PRODUCED project**. Contact: Péter Sólymos and Diana Stralberg]

Box 1. NA-POPS: Point-count Offsets for Population Sizes of North America landbirds

The goal of this collaborative project is to generate open-source detectability offsets for all species of landbirds in North America. This project advances BAM's foundational work to develop offsets and will allow the quantitative integration of observations from different programs and field protocols. This project has compiled many existing datasets of point counts that allow for distance sampling and/or removal-model based estimates of detectability. To date, approximately 300 datasets have been compiled, which has allowed for the generation of detectability functions for more than 350 species of landbirds.

Key components of this project include: 1) data acquisition and standardization, 2) derivation of covariates to be used to model cue rate and effective detection radius (see Figure), 3) the estimation of detectability functions and offsets for individual species and regions, and 4) development of a software infrastructure used to curate the data, generate model runs, and host results.

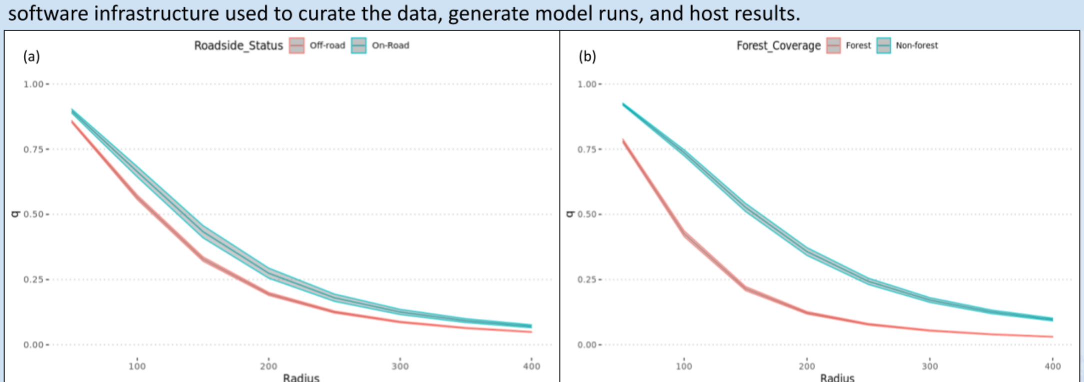

Figure. Lines show the conditional probability that a bird is perceived, provided it gives a cue (q), modelled by survey radius for Wood Thrush for (a) roadside status (on- vs. off-road) and (b) forest coverage (forest vs. non-forest). NA-POPS considers 5 candidate models for deriving cue rate (q) and effective detection radius (EDR) that model different combinations of roadside status and forest coverage.

Work in progress. Contact: Péter Sólymos; solymos@ualberta.ca

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. Over the past few years, BAM has partnered with ECCC to test and apply a critical habitat (CH) identification framework. This framework was developed by BAM as a tool to support the identification of CH for wide-ranging threatened species in Canada.

In 2020–2021, we completed steps to apply this framework using Canada Warbler (*Cardellina canadensis*) as a case study. We also contributed to a project that is applying this conceptual framework to identify critical habitat for Wood Thrush (*Hylocichla mustelina*).

Critical habitat identification for the recovery of wide-ranging boreal species at risk in Canada: a case study with the Canada Warbler

BAM developed a conceptual and analytical framework to guide the identification of critical habitat (CH) for wide-ranging boreal species to support their recovery. This framework was developed using Canada Warbler (*Cardellina canadensis*) as a case study. The conceptual framework is a four-step process for identifying the locations and amount of area required to maintain as habitat for a specific population size of species at risk in Canada, based on predicted current and future densities of a species. The four steps of the framework include: 1) review species' distribution and life history, 2) delineate management units, 3) assess population risk, and 4) spatial implementation of CH identification (see research box 2 for details on methods and results). This project is a collaboration with ECCC. [**CORE project**. Contact: Lionel Leston and Francisco Dénes]

Critical habitat identification for the recovery of wide-ranging boreal species at risk in Canada: a case study with the Wood Thrush

This project is applying the four steps of BAM's conceptual and analytical framework to identify critical habitat (CH) to Wood Thrush (*Hylocichla mustelina*). In step 1, we reviewed life history and distribution of Wood Thrush to identify potential spatial variables for predicting abundance and distribution. In step 2, we performed geographically weighted regression followed by cluster analysis on geographically weighted regression model coefficients from a subset of these predictors to determine if Wood Thrush responds differently to the same environmental features in different parts of its range. A single management unit was identified for the regional models. This project is a collaboration with ECCC. [**INFORMED project**. Contact: Lionel Leston]

Box 2. Critical habitat identification for the recovery of wide-ranging boreal species at risk in Canada: a case study with the Canada Warbler

This study implements BAM's conceptual framework for critical habitat (CH) identification for Canada Warbler (*Cardellina canadensis*). The four steps of the framework are: 1) review life history and distribution of Canada Warbler; 2) identify one or more management region; 3) develop regional models of current abundance and assess population risk to Canada Warbler based on how its population changes in response to simulated future change in habitat based on land use, natural disturbance and climate change; and 4) spatially implement CH identification (i.e., prioritize locations according to their importance as current or future CH).

First, we reviewed the distribution and life history of Canada Warbler to identify potential spatial variables for modelling abundance and distribution. Second, we ran geographically weighted regression models on a subset of predictors to determine if separate regional models should be run in distinct management zones within the Canadian breeding range of this species. We identified and ran separate models for northern Nova Scotia and Alberta, based on Canada Warbler responding differently to the same habitat features in different parts of its range. Third, we ran regional models (boosted regression trees) in each management zone (i.e., northern Nova Scotia & Alberta) to predict Canada Warbler density and population size under current and future vegetation. At the same time, land use scenarios under different amounts of harvest and climate change were run in Landis. Population trajectories and population risk were determined for Canada Warbler based on both BBS trends and Landis outputs. Fourth, we used raster overlay analysis in ZONATION software to spatially implement Canada Warbler CH identification. Spatial implementation was based on where Canada Warbler was most abundant currently and in 2100 AD under the worst-case Landis scenarios for northern Nova Scotia and northeastern Alberta. We generated combined LANDIS/BBS trends of Canada Warbler from 2000-2100 in both regions and used conservation planning software (Zonation) to identify how much critical habitat (and where) would have to be protected to maintain the current population (achieve the 95% lower confidence interval estimate of current population abundance).

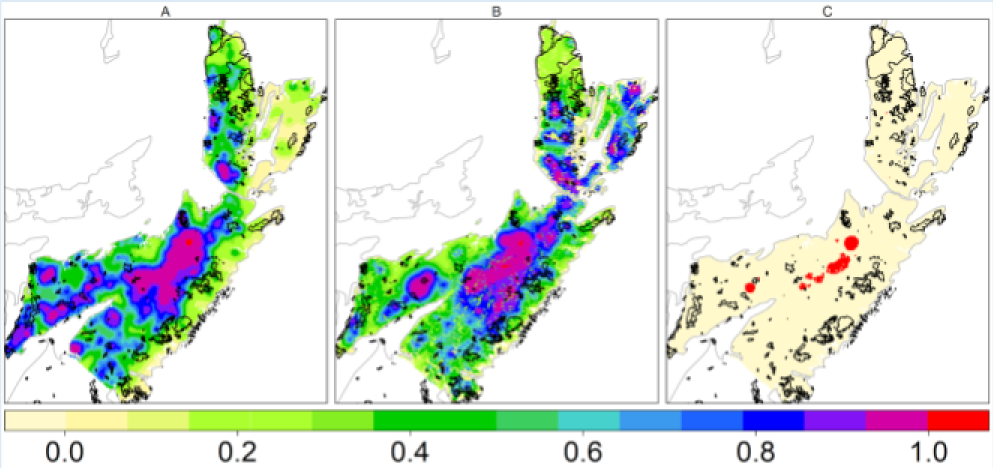

Figure. Maps of northern Nova Scotia produced in ZONATION showing what land (250-m pixels) to prioritize as Canada Warbler critical habitat based on: (A) current Canada Warbler distribution in 2019, and (B) current + future distribution under the worst-case Landis population projection in 2100. For panels A & B, highest Zonation ranks are in red; lowest ranks are in yellow. Panel C: red = habitat required to maintain current Canada Warbler population in 2019 (up to the 95 % lower confidence interval limit of the population estimate), under the worst-case population projection in panel B. Current protected areas (national & provincial parks and reserves) are displayed in black.

Regional model results demonstrate that Canada Warbler prefers wet coniferous forest habitat in eastern Canada and very old deciduous and upland forest in western Canada (Alberta), suggesting that it should be managed differently in western and eastern Canada. Both increasing harvest and increased global warming are projected to reduce habitat for this species in both management regions; however, harvest and global warming are offset by regenerating and aging forests providing more habitat over time. Annual population trends (2000-2100) varied from -1 to -1.5 % across 9 Landis scenarios in Alberta and from 0.2 to 0.8% across 18 Landis scenarios in Nova Scotia. The least positive trend in Nova Scotia was associated with highest harvest rates and warmest future climate, while the most negative trend in Alberta was associated with moderate harvest rates and warmest future climate. ZONATION conservation planning scenarios that overlay current and worst-case future predicted abundance are being used to identify the locations to prioritize for protection or management as Canada Warbler CH in both regions (see Figure).

Work in progress. Contact: Francisco Denes; voroesd@ualberta.ca or Lionel Leston; leston@ualberta.ca

Habitat Selection

Summary: Understanding habitat requirements and how they vary across species' ranges is an important step in predicting species distribution and can improve ecological forecasting and conservation planning. Recently, BAM has begun to explore large-scale spatial variation in habitat selection across breeding ranges, as well as finer-scale habitat modelling via advanced remote sensing products.

In 2020–2021, we continued to develop models to quantify differential habitat selection and evaluated the suitability of LiDAR-derived predictors for modelling species-habitat relationships.

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. These models account for the way differences in habitat availability and species density interact to affect population size and distribution, known as a functional response. In 2020-2021, we finalized the database to calculate landscape-scale habitat suitability using the Common Attribute Schema for Forest Resource Inventories (CASFRI) database. This project benefits from an NSERC Strategic Partnership Grant. [**CORE project**. Contact: Andrew Crosby]

Can new remote sensing tools improve species distribution models for birds in Alberta?

We are evaluating the suitability of high-precision, LiDAR-derived predictors for modelling the species-habitat relationships of birds. Objectives are: (1) identify differential strength of LiDAR covariates in Species Distribution Models; (2) test the influence of time lag between LiDAR acquisitions and bird surveys on model robustness; and (3) compare the suitability of LiDAR-derived metrics against covariates derived from CASFRI. We have supplemented ARUs deployed by the Bayne Lab with point count data from BAM's avian database. LiDAR was flown by the Government of Alberta between 2008 and 2010 and the Boreal Ecosystem Recovery and Assessment (BERA) project in 2017. In 2020, we summarized 34 LiDAR metrics associated with canopy closure, vegetation height, and vertical vegetation density around each point count/ARU location. 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. [**CO-PRODUCED project**. Contact: Brendan Casey]

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

Climate Change Impacts

Summary: BAM conducts research to improve our understanding of the current and projected effects of climate change on boreal bird populations and their forest habitats, to document broad-scale climate-related changes in distribution and abundance, and to inform conservation planning. This work is focused primarily on developing spatial models for the purposes of forecasting and vulnerability assessment, but also for evaluating historical climate-related changes.

In 2020–2021, we evaluated the projected effects of climate change on waterfowl abundance and climate suitability indices for 12 waterfowl species. We evaluated and compared the cumulative effects of climate change and forest management in bird communities from contrasting forests and regions. Finally, we estimated historical changes in landbird abundance and compared these trend estimates with future climate-change projections.

Projected effects of climate change on the distribution and abundance of breeding waterfowl in Eastern Canada

This project assessed the potential effects of climate change on the breeding abundance of 12 common waterfowl species in Eastern Canada. From the projected abundances, we computed climate suitability indices that accounted for potential temporal mismatches between climate change and the biota, as well as the expected velocity of climate change (see Research Box 3 for more details on methods and results). Species-specific projections indicated potential declines in the abundance of 5 species, including large declines for Barrow's Goldeneye, a species at risk and boreal cavity nester. This work was published in *Climatic Change* in August 2020. This project was led by Antoine Adde (former BAM PhD student with Marcel Darveau and Steve Cumming, Université Laval) and benefitted from an Ouranos-MITACS (IT12104) internship. [**CO-PRODUCED project**. Contact: Antoine Adde]

Box 3. Projected effects of climate change on the distribution and abundance of breeding waterfowl in Eastern Canada

As breeding areas are becoming warmer and wetter, climatic changes are likely to affect the distributions of millions of waterfowl in Eastern Canada. The objective of this study was to assess the potential effects of climate change on the breeding abundance of 12 common waterfowl species, by using a climate envelope modeling approach.

Our response variables were species counts on 317 helicopter plots (25 km^2) averaged over 22 years (1996–2017). We applied a covariate selection procedure to select the best subset of a panel of 170 climate covariates for each species, which we then used to fit quantile regression forest models. Climate change projections were applied to the waterfowl models to infer 2011–2100 abundances. From the projected abundances, we computed climate suitability indices that accounted for potential temporal mismatches between climate change and the biota, as well as the expected velocity of climate change.

On average, with a maximum of 4 covariates per model, the variance explained was 41% for out-of-bag predictions. Overall, the magnitude of absolute projected changes peaked under the "high" greenhouse gas concentration trajectory (RCP8.5) and at the end of the century (2071–2100). Species-specific projections indicated that climate change would potentially increase the abundance and core distributions of 7/12 species, whereas 5/12 species would experience a decrease. In particular, large decreases were projected for Barrow's goldeneye, an imperiled boreal cavity nester.

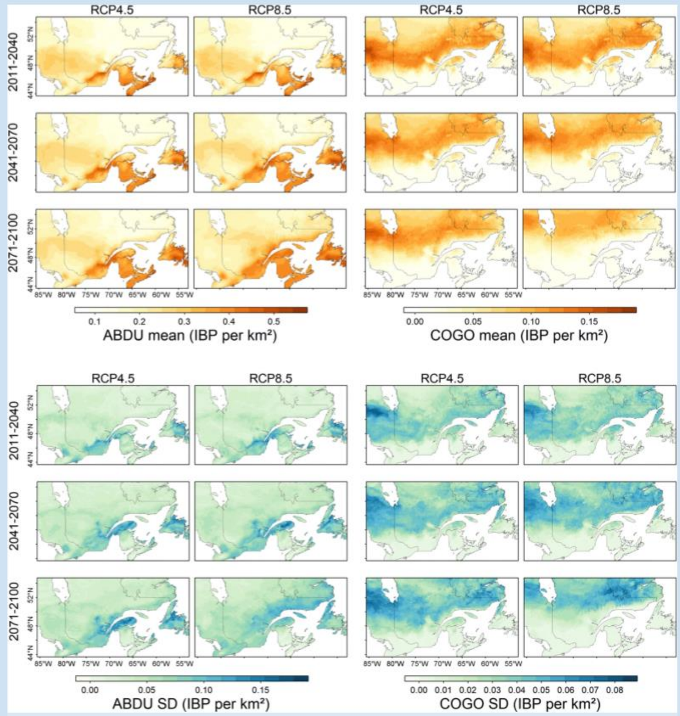

Figure. Maps of projected indicated breeding pairs (IBP) for American black duck (ABDU) and common goldeneye (COGO) summarized for three 30-year periods under the "low" (RCP4.5) and "high" (RCP8.5) greenhouse gas concentration trajectories. Top: projected mean IBP averaged for the 27 global climate models considered in this study. Bottom: standard deviation (SD)

doi.org/10.1007/s10584-020-02829-9. Contact: Antoine Adde; antoine.adde.1@ulaval.ca

Cumulative impact of climate change and forest management on bird communities in two contrasting forests in Eastern Canada

This project evaluated the combined effects of climate change and management strategies on two contrasting forests in Québec: (1) the Montmorency Forest, representative of boreal forest on public land, and (2) the Hereford Forest, representative of temperate forest on private land. The objective was to evaluate the cumulative effects of climate change, timber harvest, and natural disturbance on forest composition, net CO2 sequestration, and bird community composition and abundance. We simulated three climate scenarios and four harvest scenarios, which included business-as-usual scenarios and scenarios representing reductions and increases in harvest. Based on our results, climate change is likely to have a major impact on forest landscapes, both in boreal and temperate forests, with larger effects in the medium and long term and under a high climate warming scenario. Key forest species of the Québec forestry sector, such as balsam fir, white spruce and sugar maple, will be negatively affected by climate warming. This decline would likely benefit intolerant hardwood species and American beech. Lengthening harvest rotations and increasing the area dedicated to partial cuts and conservation may help maintain softwood species in boreal landscapes and high-value hardwoods in temperate landscapes. These practices would also support a diversity of wildlife habitats, including bird communities adapted to closed, mature, and overmature forests (see Research Box 4 for more details on methods and results). Such mitigation practices may also provide a net sequestration of carbon from business as usual and a cooling effect on the climate system. This project was funded by the Ministère des Forêts, de la Faune et des Parcs of Québec and the final report was delivered in August 2020. [**CO-PRODUCED project**. Contact: Junior A. Tremblay]

Box 4. Cumulative impact of climate change and forest management on bird communities in contrasting forests in Eastern North America

The temperate forests provide essential habitat for many bird species that regularly breed, overwinter, reside year-round or routinely migrate through this region (Rich et al. 2004). The northward range expansions of breeding birds inhabiting this region have already been reported because of climate change (Hitch and Leberg 2007). Many bird species associated with broadleaf trees or shrubs and/or mixed conifer-broadleaf forests are expected to gain habitat within the boreal forest in the future (Wells et al. 2018). The objective of this study is to project bird community change according to three climatic scenarios and evaluate how forest management scenarios may mitigate these impacts in two contrasting forest landscapes in northeastern America, the boreal (i.e., Montmorency) and the temperate (i.e., Hereford) forests. More specifically, our objectives are to (i) predict change in bird community according to anthropogenic forcing and ii) forest management scenarios; (iii) compare these impacts on bird community between temperate and boreal forests. We used the LANDIS-II forest landscape model to simulate climate change and forest management scenarios in (1) the boreal Montmorency Forest and (2) the temperate Hereford Forest.

The climate-driven ecological process (i.e., climate-dependent) had more significant projected influences on the Hereford than the Montmorency forest bird community. In Hereford forest, the impact of the climate-dependent driver had the most important projected influences on all bird communities associated with coniferous and mature mixedwood forest stands. Contrastingly, bird species associated with mature and young coniferous forests were the most sensitive to the effect of climate change (respectively 97 ± 0 and 96 ± 2 %). In Montmorency forest, no bird community was most influenced by the climate-driven ecological process, while eight bird communities (all except community associated with closed deciduous forest stands) were sensitive to forest harvesting scenarios.

Projections for 2100 under RCP 8.5		Percentage change under harvesting scenario (%)				Drivers of change (%)	
Cover type and forest age	Location	No Harvest	Conservation	Reference	Intensive	Climate change	Harvest
Generalist	HF	-1 ± 5	16 ± 16	11 ± 12	19 ± 21	44 ± 20	35 ± 17
Young Deciduous		6 ± 15	17 ± 22	14 ± 21	19 ± 23	49 ± 36	42 ± 32
Closed deciduous		10 ± 22	4 ± 27	-1 ± 28	3 ± 30	40 ± 39	48 ± 33
Mature deciduous		2 ± 7	-23 ± 6	-20 ± 5	-29 ± 8	40 ± 4	48 ± 15
Young mixedwood		-1 ± 7	-4 ± 14	-5 ± 13	-5 ± 19	37 ± 36	23 ± 24
Closed mixedwood		2 ± 23	-15 ± 19	-16 ± 17	-20 ± 18	50 ± 36	44 ± 35
Mature mixedwood		3 ± 34	-9 ± 14	-9 ± 12	-11 ± 14	58 ± 46	16 ± 23
Young coniferous		-18 ± 6	-22 ± 6	-21 ± 6	-21 ± 6	96 ± 2	2 ± 1
Closed coniferous		-3 ± 25	-13 ± 27	-14 ± 23	-18 ± 23	59 ± 45	30 ± 34
Mature coniferous[a]		-30	-35	-35	-36	97	0
Generalist	MF	-4 ± 7	4 ± 7	13 ± 12	16 ± 13	23 ± 19	68 ± 24
Young Deciduous		3 ± 28	4 ± 11	7 ± 15	5 ± 23	21 ± 23	73 ± 29
Closed deciduous		6 ± 23	7 ± 10	13 ± 9	13 ± 11	40 ± 10	54 ± 8
Young mixedwood		-11 ± 21	-3 ± 13	8 ± 16	12 ± 13	36 ± 24	62 ± 24
Closed mixedwood		6 ± 12	4 ± 6	7 ± 12	3 ± 13	26 ± 28	57 ± 31
Mature mixedwood		78 ± 87	17 ± 15	-8 ± 12	-20 ± 7	4 ± 2	91 ± 10
Young coniferous		-21 ± 23	-11 ± 12	6 ± 5	4 ± 17	6 ± 5	81 ± 11
Closed coniferous		3 ± 12	2 ± 9	5 ± 9	-1 ± 13	24 ± 35	54 ± 35
Mature coniferous		16 ± 24	-1 ± 12	-7 ± 17	-8 ± 14	29 ± 24	54 ± 29

Table. Percentage change of abundance of birds associated with forest cover type and age under RCP 8.5 at year 2100 relative to the change simulated under baseline climate for Hereford forest (HF) and Montmorency forest (MF). The relative contribution of drivers of change are also presented (climate dependent and forest harvest) as values of ω2.

Work in progress. Contact: Junior A. Tremblay junior.tremblay@canada.ca

A regional comparison of the impacts of climate change and forest harvesting on boreal bird communities of Canada

In this study, we used the LANDIS-II forest landscape model to project the impacts of climate change and forest harvesting on boreal bird communities in two Canadian provinces (Alberta and Québec). We found that both forest harvesting and climate-related drivers are projected to have significant impacts on bird communities in both regions, with changes projected to occur sooner and more drastically in western regions than in eastern regions of the Canadian boreal forest. With climate change, declines are projected for old forest-associated bird species in both regions, especially in conifer-dominated habitats, and a greater increase of bird species associated with early stages of forest succession and treeless habitats in western regions. Our results also show that climate change and forest harvesting may impact species differently across their range, and regionally specific measures should be implemented to ensure adequate conservation of climate-sensitive species. This project is a collaboration with ECCC & NRCAN [**CO-PRODUCED project**. Contact: Junior A. Tremblay]

Box 5. A regional comparison of the impacts of climate change and forest harvesting on boreal bird communities of Canada

Projected environmental changes of unprecedented speed and amplitude pose a substantial threat to boreal forest health (Gauthier et al. 2015). Both forest harvesting and climate-related drivers are projected to have great impacts on boreal bird communities (Cadieux et al. 2020). However, the impacts of climate change are not expected to be similar and consistent throughout boreal regions (Price et al. 2013).

In this study, we use LANDIS-II, a forest landscape model, to project the impacts of climate change and forest harvesting on boreal bird communities in two Canadian boreal regions (Northeastern Alberta and Central Québec).

As reported in previous studies (Boulanger et al. 2017, Stralberg et al. 2018), our results predicted wildfire to be the main driver of change in both regions. Fire will act as a catalyst for forest change (Stralberg et al. 2018, Cadieux et al. 2020) and will consequently alter the boreal bird community through changes in habitat. In western and eastern regions respectively, 18 and 17 forest-associated bird species are projected to decline in population abundance by more than 25% by 2100 under the RCP 8.5 with baseline harvesting (see Figure).

Our study also highlights the important role of forest management when projecting climate-driven changes in future bird populations, accentuating the effects of climate change, either positive or negative.

Although our study suggests similar impacts on bird communities in eastern and western boreal regions, the magnitude of change is not the same, and species are not evenly impacted in both regions. Our results showed that climate change and forest harvesting may impact species differently across their range. Thus, regionally-specific measures should be implemented to ensure adequate conservation of climate-sensitive species.

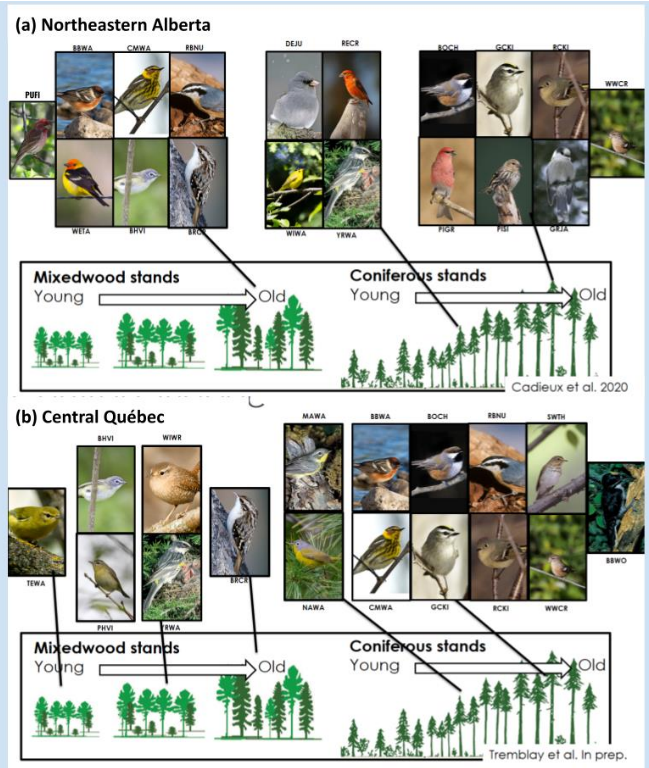

Figure. Species sensitive to climate change in both simulated regions: (a) western region (from Cadieux et al. 2020); (b) eastern region (from Tremblay et al. in prep.). Species are those that are declining >25% according to climate-sensitive drivers (either fire or tree growth) under RCP 8.5 and the current harvest scenario at 2100.

Work in progress. Contact: Junior A. Tremblay junior.tremblay@canada.ca

Comparing historical trends in boreal bird abundance to future climate change projections

In 2020-2021, we conducted a preliminary evaluation of pixel-level (1km^2) trend estimates generated as a product of our generalized national modelling approach (page 10). Our most recent models contain a year effect and temporally matched vegetation inputs (pre- and post-2005), allowing us to generate annual density predictions for each species and region. Based on these annual predictions we fit linear trend models at the pixel level and mapped pixel-level trends for the period 1996-2016. These values can then be averaged across any area to obtain regional 20-year trend estimates.

Using the well-surveyed Alberta portion of BCR 6 as a case study, we first compared BAM model-based trends to BBS-based trends. We then compared both sets of trend estimates with two sets of future climate-change projections for Alberta: bioclimatic model projections from Stralberg et al. (2015), and landscape simulation model projections for the ALPAC region (Cadieux 2020). BAM and BBS trends were not well correlated, indicating that BBS-based trends are likely inadequate for species that are not well-represented by southerly roadside surveys. Furthermore, relationships between BAM trends and future (both mid-century and end-of-century) climate-change projections were also not correlated, suggesting the predominance of factors other than climate change influencing historical trends. However, the strongest positive relationship was between BAM trends and mid-century landscape simulation model projections. We presume that the general lack of correspondence is due to the fact that climate-change effects on landbirds may primarily occur through abrupt changes in vegetation states, which require disturbance. We will continue to compare trends and near-term projections to identify when and where climate models fail or succeed in anticipating future change. [**CORE project**. Contact: Diana Stralberg]

Energy & Mining Impacts and Cumulative Effects

Summary: Effective management and conservation of boreal birds and their landscapes requires an understanding of the combined effect of past, present and potential future anthropogenic and natural disturbances. BAM's research examines the effects of energy sector development on boreal birds at multiple scales and within a cumulative effects framework. BAM's work continues to evaluate methodological approaches to advance cumulative effects assessment.

In 2020–2021, BAM collaborated on a project to evaluate the potential effects of developing new chromium mines within the proposed Ring of Fire development area. In addition, we evaluated cumulative effects using multiple approaches and across multiple scales and using multiple approaches. Lastly, we evaluated trends in wetland birds in Alberta's oilsands.

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

BAM is developing predictive habitat models for birds within northern Ontario. The objective of this project is to understand the potential effects of developing new chromium mines within the proposed Ring of Fire development area on avian species. In 2020-2021, we assembled point count and geospatial data for building the predictive models and fit Boosted Regression Tree models. We also began to develop SpaDES modules for fitting generalized linear models (GLM) to bird data and predicting densities to future simulated landscapes. This project is a partnership with ECCC and the SpaDES development group at the Pacific Forestry Centre (CFS). [**CO-PRODUCED project**. Contact: Andrew Crosby, Lionel Leston or Péter Sólymos]

Interactive effects of human footprint on bird populations in Alberta across multiple spatial scales

The objective of this project is to understand the spatial scales at which interactive effects of human footprint should be considered for different bird species in Alberta. In 2020-2021, we used bird, environmental, and human footprint data from fifteen large sampling grids in the boreal region of Alberta to develop models that estimate the single, additive, and interactive effects of different human footprint types on bird occupancy rates at five different spatial scales. We have summarized these results into a report. This data was collected over multiple projects in NE Alberta and received additional support from two NSERC Collaborative Research and Development Grants and Oil Sands Monitoring (OSM). [**CO-PRODUCED project**. Contact: Andrew Crosby and Lionel Leston]

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

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 84 boreal songbird and woodpecker species in simulated landscapes predicted from dose-response and zone-of-impact models. While there were minor percentage differences in populations (<1 %) for most species, zone-of-impact models predicted larger Brown-headed Cowbird populations (69% more), as well as smaller populations of at least two declining or at-risk species (Rusty Blackbird, Black-throated Green Warbler). Results suggest that zone-of-impact models may be better at providing early warnings about important changes in the abundance of boreal birds. [**CO-PRODUCED project**. Contact: Lionel Leston & Erin Bayne]

Trends in wetland birds in Alberta's oilsands (2013-2019)

Temporal trends of birds in graminoid fen and marsh meadow habitats in different areas of the oilsands region of Alberta were assessed from 2013-2019. Wilson's Snipe, Yellow Rail, Rusty Blackbirds, Palm Warbler, and Solitary Sandpiper were species that showed significant declines in the mineable vs non-mineable region, as well as patterns of change that differed as a function of distance to the mine edge. These results demonstrate that change has occurred for a number of species, including species at risk. [**CO-PRODUCED project**. Contact: Erin Bayne]

Forestry Impacts

Summary: BAM is investigating the current and projected effects of forestry sector activities on birds. Our research evaluates the conservation value of forest management and certification and develops tools to support forest planning. BAM's forestry research includes highly effective and wide-ranging collaborations with the forestry sector, government agencies and organizations.

In 2020–2021, we published work on the long-term responses of bird populations to simulated harvest practices. We developed analytical tools to support harvest planning for nesting forest birds. We also evaluated the effects of residual retention and forest certification on bird communities. Lastly, we established a large, cross-border initiative to identify opportunities and challenges for forest management to benefit bird populations.

Quantifying long-term bird population responses to simulated harvest plans and cumulative effects of disturbance

As interest in caribou conservation continues to increase, there is growing interest in understanding potential trade-offs or co-benefits with other species. In 2020-21, we completed work to estimate possible impacts on boreal bird populations resulting from various harvest management options in the Al-Pac forest management unit in north-eastern Alberta. Using the *cure4insect* decision support tool (Sólymos, 2018), we applied avian habitat models to the landscapes simulated under different timber supply scenarios, including a caribou conservation scenario, to anticipate bird population response (see Research Box 6 for more details on methods and results). We extended this work further using a custom-built ALCES Online simulator to explore impacts of fire and energy—in addition to forest harvest—for the caribou conservation scenario. We projected how population sizes of 20 boreal songbird and woodpecker species would respond to differences in harvest locations, energy sector development, and either increases or cessation of forest fires. In general, species associated with older forests declined with increasing cumulative effects of harvest, fire, and energy sector footprint but were not adversely affected by differences in harvest plans meant to accommodate caribou conservation. This research was published in Frontiers in Ecology and Evolution in July 2020 (DOI: 10.3389/fevo.2020.00252) and benefited from additional support and collaboration from Al-Pac, ABMI and an Accelerate grant from Mitacs. [**CO-PRODUCED project**. Contact: Lionel Leston]

Box 6. Quantifying Long-Term Bird Population Responses to Simulated Harvest Plans and Cumulative Effects of Disturbance

We used two land use simulators, Patchworks and ALCES Online, to project what forest age structure would look like in the Al-Pac Forest Management Area over 50 years, under different amounts and locations of disturbances (harvest, fire, energy sector development) in Alberta. The harvest plans compared in Patchworks differed only in that harvest in one plan (caribou conservation scenario) was deferred for the first 20 years for stands embedded within habitats used by woodland caribou. After 20 years, the same stands were eligible for harvest as in the plan where harvest was not deferred. Simulated fire and energy sector footprint were overlaid on the caribou conservation scenario harvest areas in ALCES Online under different land use scenarios (see Figure). Bird models developed by the Alberta Biodiversity Modelling Institute, BAM, and Environment and Climate Change Canada were then used to predict abundance of 20 bird species based on the type and age of forest at different locations in each Patchworks and ALCES Online scenario.

Caribou conservation within harvest plans did not adversely affect populations of bird species examined. Species associated with older forests (e.g., Bay-breasted Warbler, Boreal Chickadee, Brown Creeper, see Figure) had less habitat over time as total footprint increased. Black-backed Woodpecker increased with fire.

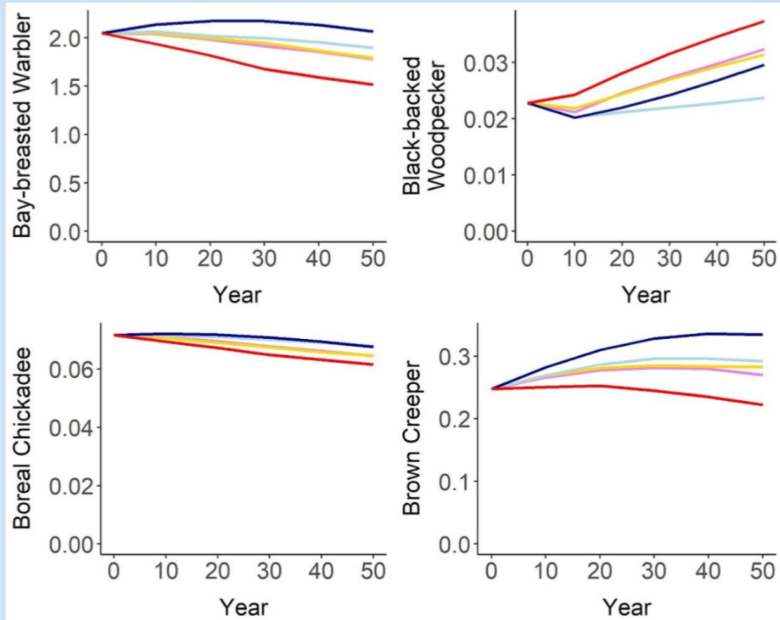

Figure. Predicted abundance of 4 boreal bird species over time (year 0–50, where year 0 = 2016) in the Al-Pac Forest Management Area (FMA). Scenarios: dark blue=harvest only, no energy or fire; light blue=harvest+energy, no fire; yellow=harvest, energy, current fire; pink = harvest, energy, seismic line revegetation, current fire; red=harvest, energy, 2x current fire, no seismic line revegetation).

DOI: 10.3389/fevo.2020.00252. Contact: Lionel Leston; leston@ualberta.ca

AB Risk Matrix: Supporting harvest planning decisions

BAM is collaborating with the forestry industry to translate predictions of individual forest bird species abundance into GIS-based decision support tools that field operators can use to schedule harvest. We organized R scripts that 1) take attributes (e.g., forest age class, stand type, forest stand latitude and longitude) from a vegetation inventory shapefile compiled by FORSITE Consultants Ltd., 2) use those attributes to predict individual species densities within forest stands from ABMI bird models, 3) calculate total densities of birds, 4) rank stands from 1 to 6 based on total densities, and 5) generate hybrid ranks from expert-based and data-driven ranks. We incorporated these R scripts into an R project, and we are developing decision tools to schedule stands for harvest. This project benefited from a Mitacs Accelerate grant and is a collaboration with FRIAA and ABMI. [**CO-PRODUCED project**. Contact: Lionel Leston]

BC Risk Matrix: Supporting harvest planning decisions

Building on the data-driven risk matrix tool used for existing bird abundance models within Alberta, we developed analyses of birds in British Columbia's forests. We generated initial models based on local-scale (<150 m) forest age, forest height, species composition, biogeoclimatic (BEC) zone and subzone, and elevation for nearly 120 forest bird species in BC. We used individual species density predictions to generate predicted total bird densities within individual forest stands and summarized individual species densities and total density by forest age class, forest height class, dominant tree species and BEC zone. This project benefited from support from the Council of Forest Industries in BC (COFI) and ABMI. [**CO-PRODUCED project**. Contact: Lionel Leston]

Impacts of residual tree retention on birds

This project uses historical point count data, acoustics monitoring tools, LIDAR, and multispectral satellite imagery to explore the effects of harvest residuals on bird communities. The project objectives are: (i) To quantify the influence of harvesting on birds; (ii) to examine the post-harvest structural conditions that drive community response; and, (iii) to compare the predictive power of spatial covariates. We surveyed bird communities using autonomous recording units (ARUs) in harvest blocks across northern Alberta and gathered supplemental acoustic and point count data from BAM. Airborne LiDAR and Landsat normalized burn ratio (NBR) were used to characterize the vertical structure and spectral recovery of harvest blocks. This project benefits from an NSERC Strategic Partnership Grant and is a collaboration with the Bioacoustic Unit at the University of Alberta and the ABMI. [**CO-PRODUCED project**. Contact: Brendan Casey]

Conservation Value of Forest Certification 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 contribution at different scales across Canada; (ii) quantify the contribution of managed forests to bird species diversity; and (iii) quantify the contributions of different forest types to breeding bird diversity at local and regional scales. We developed community occupancy/abundance models of boreal forest birds and calculated the contribution of the bird community at each sampling point to species richness of the BCR in which the point occurred (see research box 7 for methods and results). 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 2020-2021, we developed predictive maps of species richness, community composition, diversity contribution, uncertainty across four BCRs in Canada: Atlantic Northern Forest (BCR 14), Boreal Hardwood Transition (BCR 12), Boreal Softwood Shield (BCR 8), and Boreal Taiga Plains (BCR 6). This project is a collaboration with the SFI, Alberta-Pacific Forest Industries Inc., Fuse Consulting Ltd., and fRI Research. [**CO-PRODUCED project**. Contact: Andrew Crosby]

Box 7. Conservation value of certified forestlands

Conserving the diversity of boreal forest birds is a daunting task, and one of the major challenges is that many at-risk species have differing (and sometimes opposing) habit requirements. As such, conservation planning must focus on maintaining the mosaic of habitat types and ages across the landscape that supports the full range of species - often referred to as a course filter management approach. In this effort, it is important to understand the relative contributions of different areas and habitat types to regional diversity so that they can be prioritized for conservation.

One of the primary goals of sustainable forestry certification is the conservation of biological diversity. Conservation value (CV) generally refers to determining which areas contribute the most to meeting conservation goals. Alternatively, CV can be seen as a measurement of how effective management systems are in meeting conservation goals. Our objective was to evaluate CV of sustainable forestry certification through conservation of bird species diversity on forestlands in Canada. We estimated bird community composition at sampling plots across four Bird Conservation Regions (BCR) in Canada, and compared species richness, relative species rarity, and contribution to regional bird species diversity (diversity contribution) between certified and uncertified forestlands in each BCR.

We found that species richness was higher on certified forestlands in all BCRs, while rarity was higher on certified forestlands in two of the BCRs (Atlantic Northern Forest and Boreal Softwood Shield). Higher species rarity led to a greater diversity contribution, and indicated the existence of less common habitat types, suggesting areas with higher diversity contribution were less representative of overall forest conditions in these two BCRs (see Figure). Higher species richness on certified forestlands suggests greater diversity of habitat conditions around sampled plots, which is generally considered positive for conservation of biological diversity. Our analysis provides the basis for understanding how management can affect conservation of forest birds in Canada, and will help us develop tools and management recommendations for managers to increase the biodiversity conservation value of managed forests.

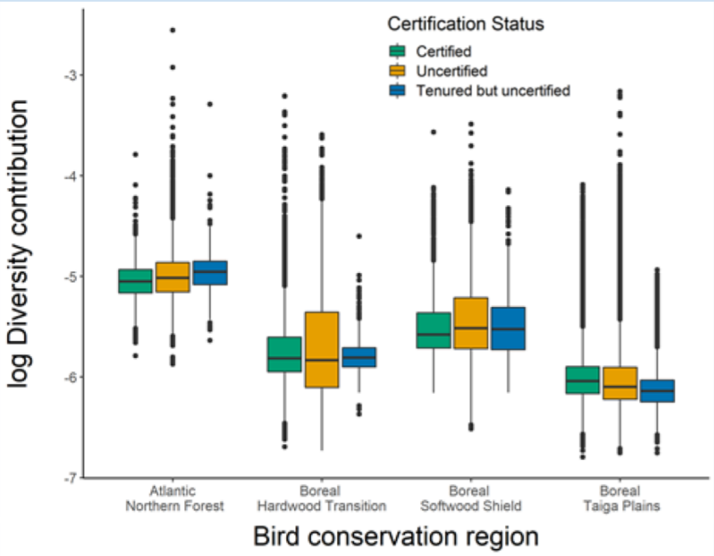

Figure. Boxplots of avian diversity contribution values among certified forestlands, uncertified forestlands, and tenured but uncertified forest within four Bird Conservation Regions in Canada.

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

Cross-border collaboration between BAM, American Bird Conservancy (ABC), and Sustainable Forestry Initiative (SFI) for bird conservation on managed forest lands

In 2020-2021, BAM collaborated with SFI and ABC to develop a cross-border initiative for bird conservation on managed forest lands in the Upper Great Lakes region of BCR 12 (Boreal Hardwood Transition). The project is focused on the co-production of actionable science with local forest industry, government, and community partners to identify opportunities and challenges for forest management to benefit bird populations. We held an informational webinar in June 2020 to engage local stakeholders, and from there formed a working group of interested partners to develop the project and ensure full partner involvement at all levels. In February 2021, we held an initial working group meeting, which included representatives from ECCC, US Forest Service, National Council for Air and Stream Improvement, Inc. (NCASI), Forestland Group, Wisconsin Department of Natural Resources. Additional members are welcome! In 2021-2022, we will continue to meet with the working group with the goal of holding an in-person workshop when circumstances permit and submitting a joint funding proposal to support the research. [**CO-PRODUCED project**. Contact: Andrew Crosby]

Projecting Impacts of Landscape Change

Summary: BAM applies predictive species abundance models to simulated landscapes that are likely to result from climate change, disturbance regimes, and management actions in order to estimate and manage for future changes and risks to avian populations.

In 2020–2021, we conducted multiple simulation projects to better understand the projected effects of forest management strategies on past, present and potential future bird populations. BAM is collaborating on a project to forecast caribou resource selection and population growth and landbird abundances under climate change in the Northwest Territories. This project led to a large collaborative initiative that is working to combine species models (e.g., boreal caribou, landbirds and waterfowl) and simulations of future landscape conditions to ultimately inform the identification of priority places in the Western Boreal Forest.

Hindcasting the net effect of forest harvesting on the abundance of boreal songbirds: 1985-2015

This project predicts the effects of forest harvesting on landbird abundance from 1985 to 2015 across the boreal region. The effects of harvest over 30 years were examined at four spatial scales: (1) site (30-m resolution pixel centered on the point count location), (2) local (100-m radius around the point count, disregarding the point count), (3) neighborhood (500-m radius, disregarding the centered 100-m annulus), and (4) landscape (1000-m radius, disregarding the 500-m annulus). We integrated disturbance information at multiple scales into one model using a hierarchical Bayesian model structure. This project is a collaboration with the CFS. [**CO-PRODUCED project**. Contact: Tati Micheletti]

Using landscape simulations to forecast caribou resource selection and population growth and landbird abundances under climate change

BAM is co-producing work to simulate landbird abundances, caribou resource selection and population growth under climate change. In 2020-2021, we updated both caribou RSF and population growth models with the newest models available and have simulated forest growth and wildfire that are climate sensitive. We also built two sets of regionalized landbird models (n = 64), that were fit using boosted regression trees (BRT). These models vary based on the inclusion or exclusion of climate variables. This work has been submitted as a manuscript to the special issue '*Using landscape simulation models to help balance conflicting goals in changing forests*' in Frontiers in Ecology and Evolution. In this manuscript, we attempt to understand the pathways by which climate change influence boreal landbird distributions in the BCR 6 portion of the Northwest Territories using a simulation experiment (see research box 8 for more details on methods and results).

In addition to this manuscript, we are currently working on an approach to identify hotspots for conservation and to test the umbrella concept with boreal caribou and landbirds in the present and future. For this work, we are using a third set of the bird models, which include both climate and landscape variables. This project is a collaboration with Université Laval, CFS, 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, and Steve Cumming]

Box 8. Teasing apart the pathways of climate change effects on boreal landbird distributions in Northwestern Canada using SpaDES

Climate can influence species through different pathways: indirectly via changes in their habitat, or directly (e.g., by pushing them outside of their climate niche). We present a simulation experiment for a 50 million ha study area in Northwest Territories, Canada, in which we contrast climate-sensitive and non-climate sensitive models for i) tree growth and non-disturbance mortality, ii) wildfire and iii) landbird distribution. We found that most of the predicted changes in species distribution were attributed to direct climate effects (climate niche and unmodelled habitat changes) in spite of a similar relative importance of vegetation and climate variables in the landbird models. This suggests that hybrid approaches using both statistical models and landscape simulation tools could improve wildlife forecasts when major future uncoupling of vegetation and climate is anticipated, and lays methodological groundwork for ecological adaptive management using the new platform SpaDES, which allows for iterative forecasting, mixing of modeling paradigms, and tightening connections between data, parameterization, and simulation.

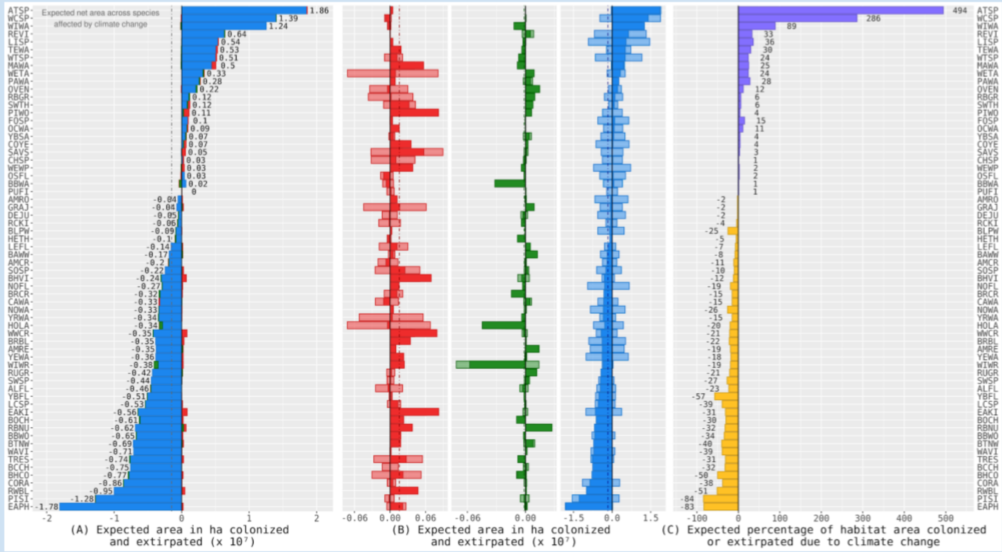

Figure. Direct and indirect effects of climate change on the distributions of 64 landbird species. Effects are measured as the absolute or relative differences in pixel occupancy between 2011 to 2100 (probabilities calculated over replicates) between paired climate-sensitive and non-climate sensitive models. Left to right, (A) the net direct effects and indirect effects (via forest change and fire). Net effects are total areas colonised minus total areas of extirpation; (B) mean expected areas gained (colonisation) and lost (extirpation) for each species due to direct (blue) and indirect effects of climate (green via forest change, red via fire), where the full color depicts the net effect of each of these pathways; and (C) the proportional net change in species' occupancies, measured as the area of colonisation minus the area of extirpation due to the net effects of climate, divided by the area occupied in 2011, with net declines shown in yellow and net gains in purple.

Work submitted. Contact: Tati Micheletti; tati.micheletti@gmail.com

The Western Boreal Initiative (WBI)

This was year 1 of a 2-year project that aims to build upon the modelling framework developed for the previous project based in the BCR 6 portion of the Northwest Territories. It does so by: (i) improving existing SpaDES modules; (ii) developing new modules (e.g., waterfowl, carbon sequestration, insect outbreaks, permafrost dynamics, etc.); and (iii) applying the framework to the entire Western Boreal region. Another important component of the WBI is our formal collaboration with Indigenous partners to determine the best approach to braid ways of knowing (i.e., Traditional Knowledge and Western Science) as it relates to habitat use of boreal caribou. This will hopefully help set the stage to apply this comprehensive way of knowing to other taxa and ecological processes. For this project, we are aiming to use a forecastable version of the BAM national-scale density models to forecast boreal bird distributions. We are currently working on a manuscript describing solutions space (i.e., trade-off functions) when combining carbon sequestration, landbirds, and timber harvesting. This project is a collaboration with Université Laval, UBC, DAL, CFS, ECCC, Dene Nation, and the NWT Department of Environment and Natural Resources and benefited from additional funding from CWS. [**CO-PRODUCED project**. Contact: Samuel Haché, Tati Micheletti, and Steve Cumming]

Box 9. The Western Boreal Initiative

The Pan-Canadian Approach (PCA) to Transforming Species at Risk (SAR) Conservation in Canada is a national framework to focus our collaborative and collective work to protect SAR using multi-species and ecosystem-based approaches and maximize multi-species and biodiversity conservation on shared priorities species, places, and sectors. To support this initiative, CWS-Northern Region is leading a research program that will combine a suite of models for priority species (boreal caribou) and other important ecological indicators (other SAR, migratory birds, and carbon sequestration), and simulations of future landscape conditions in responses to natural (i.e. wildfire and insect outbreaks) and anthropogenic (i.e., forestry, energy, urban development) disturbances, and climate change across the western boreal forest from 2011 to 2100.

The Western Boreal project represents an ambitious spatial expansion and diversification of forest values from our pilot project in Northwest Territories (Micheletti et al. 2019; Stewart et al. in prep). Using a foundational and predictive system for geospatial simulation—the SpaDES family of R packages (McIntire et al. in review; Chubaty and McIntire 2019), this approach facilitates findable, accessible, interoperable and reusable science, paramount for conducting landscape modeling and prediction in ecology (Dietze et al. 2018; Stall et al. 2019). It also allows for diverse models generated from previously siloed areas of expertise to be integrated into a continuous, adaptable and reusable workflow, directly conducting a cumulative effects analysis over large spatial extents.

To help support this initiative, species abundance models for a range of priority species need to be developed and/or implemented as SpaDES-compatible modules to be included in a broader modelling framework (Micheletti et al. 2019) across the Western Boreal region. This modelling framework will allow for continuous flexibility and updating as policies and regulations change, and as data and models improve.

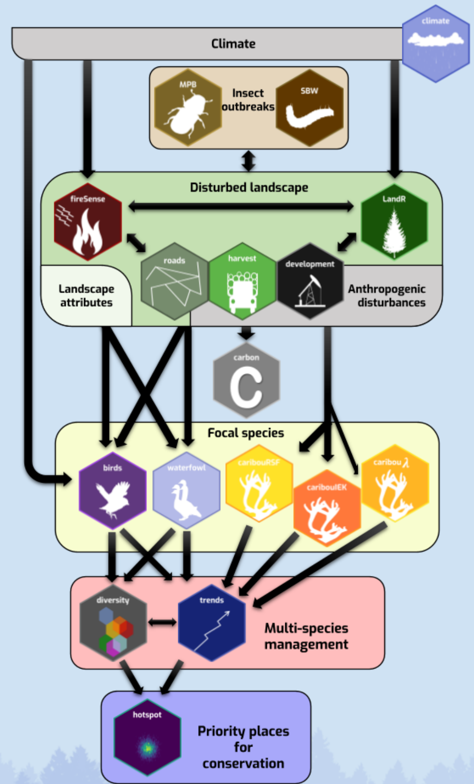

Figure 1. Scheme depicting the modular components of the Western Boreal Initiative.

Work in progress. Contact: Tati Micheletti; tati.micheletti@gmail.com

Optimising for sustainable harvests and bird populations in forest management planning

BAM is evaluating different approaches to incorporating bird conservation in optimisation problems for forest management planning. While this research is focused on study regions in Québec and British Columbia, the models that are developed will be readily reproducible across the Canadian boreal forest. This project uses the BAM national-scale density models (see page 10) and spatial simulation models built in SpaDES to experiment with different harvesting constraints designed to benefit bird conservation while optimising sustainable harvest volumes. In 2020-2021, a method was developed for predicting bird species' density for each of a specified set of cover type and age classes, alongside a method for reclassifying habitat data into suitable cover type and age classes. This project is led by Isolde Lane Shaw, a PhD student with Steve Cumming at Université Laval. This work benefits from an NSERC Strategic Partnership Grant. [**CO-PRODUCED project**. Contact: Isolde Lane Shaw]

Historical range of variation as a strategy to identify forest management practices to conserve avian populations

This project is forecasting the effects of alternative forest management strategies on avian abundance in three regions of the Canadian boreal forest: Québec, Ontario, and Alberta. The Historical Range of Variation (HRV) in the landscape is being quantified through simulation experiments of vegetation dynamics and wildfire in SpaDES. Avian HRV will be derived by converting the simulated forest maps into maps of abundance of selected bird species. Harvesting SpaDES module and scenarios will be developed and added to the landscape simulations to forecast the consequences of alternative forest management strategies. This work is led by Ana Raymundo a PhD student with Steve Cumming at Université Laval and Eliot McIntire, Pacific Forestry Centre (NRCAN). [**CO-PRODUCED project**. Contact: Ana Raymundo]

Conservation Planning for Boreal Birds

Summary: One of BAM's primary goals is to inform conservation planning efforts by identifying and evaluating priority wildlife areas and protected areas. The creation of spatially explicit avian density and distribution information supports spatial prioritization analyses, protected area planning, and multi-species conservation.

In 2020–2021, we collaborated with research partners and organizations to inform multi-species conservation planning, identify priority areas for avian conservation, develop indices of biotic intactness, and evaluate the effectiveness of biological surrogacy for conservation planning.

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 conservation to one that focuses on multi-species conservation. Within this approach, conservation efforts will focus on shared priorities and identifying co-benefits for biodiversity and ecosystems. The aim of this project is to test the extent to which conservation directed at boreal caribou (*Rangifer tarandus caribou*) functions as an umbrella for the conservation of bird species living within the Canadian boreal forest. First, we evaluated the overlap between caribou ranges and bird populations across the boreal region. Second, we identified priority areas for avian conservation in the boreal region based on avian density and assessed how much these areas would benefit from the protection of the caribou ranges. We conducted prioritizations using the Zonation software package (v4.0) and avian density rasters for 138 species (see page 10). We identified areas of high conservation value based on a set of conservation objectives for landbirds inside and outside the caribou ranges. This is an ECCC Experimentation Works Project and is a collaboration between BAM, ECCC and BEACONS. [**CORE project**. Contact: Teegan Docherty]

Developing indices of biotic intactness as a criterion to identify Key Biodiversity Areas in Canada

The International Union for the Conservation of Nature (IUCN) has established several criteria for identifying Key Biodiversity Areas (KBAs), including criterion C that is intended to identify sites that contribute significantly to the global persistence of intact ecological communities. The Wildlife Conservation Society (WCS) Canada, which is leading the identification of KBAs in Canada, recruited BAM and BEACONs members to develop and apply an index to identify regions of high ecological integrity based on biotic indicators.

Working closely with BEACONs, we developed a new biotic intactness index for forest songbirds that is based entirely on BAM national model predictions, human footprint mapping, and hydrologic units. The biotic intactness index can be applied at national or ecoregional scales to compare the density of forest-associated species in a region to its predicted reference density in that region if there were no human footprint. Our approach consisted of five broad steps:

1. We created a common scale and common format GIS database using ecoregions, watersheds, human footprint, and species density maps.
2. We modelled the relationship between bird density and human footprint (stratified by ecoregions) for forest-associated songbird species.
3. Models were used to estimate species-specific reference density (i.e., density where footprint = 0).
4. A species intactness index was developed for each species and applied to map areas from low (0) to high (1) intactness.

5. Species intactness maps were combined to create biotic intactness maps for the forest-associated species group.

Results have been written up as a report to be finalized by Summer 2021. WCS Canada is in the process of developing a system to combine the various abiotic and biotic Criterion C indices into a unified system for KBA identification. This project is a BAM collaboration with WCS and BEACONS. [**CO-PRODUCED project**. Contact: Diana Stralberg & Péter Sólymos]

Prairie Habitat Joint Venture: identifying co-benefits for landbirds and waterfowl across the Western Boreal Forest using multi-species conservation planning

BAM has developed conservation planning work to support the Prairie Habitat Joint Venture's (PHJV) aims to conserve core waterfowl habitat in the Western Boreal Forest (WBF) while providing co-benefits for other bird species. We identified areas of high conservation value for landbirds within the WBF region to assess the potential for co-benefits from habitat implementation directed at waterfowl conservation. Priority areas were identified based on a set of conservation objectives for (a) forest-associated species and (b) wetland-associated species. BAM's avian density rasters (see page 10)—for approximately 100 species—were used in prioritization analyses using the Zonation software (version 4.0). 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). [**CO-PRODUCED project**. Contact: Teegan Docherty & Jeff Ball]

Evaluating the Effectiveness of Biodiversity Surrogates for Conservation Planning in the Boreal Region of Canada

BAM has co-produced work to evaluate surrogacy within a conservation planning framework in the boreal region of Canada. This study aims to evaluate if protected area networks that are representative of environmental features are also representative of biodiversity, specifically boreal caribou, songbird assemblages, and waterfowl guilds. Here, surrogates are a set of environmental features that we expect to conserve broader biodiversity when represented in a reserve network: (1) gross primary productivity, (2) climate moisture index, (3) land cover, and (4) lake edge density. A draft manuscript of this work has been written and will be submitted for publication in 2021. This project is a collaboration with and led by BEACONS. [**CO-PRODUCED project**. Contact: Diana Stralberg & Fiona Schmiegelow]

Monitoring and Sampling

Summary: BAM continues to support the design of monitoring and sampling programs for boreal birds, including the development of a Boreal Monitoring Strategy (BMS), an effort to monitor the status, trends and distribution of boreal forest birds at a national scale. This strategy is being led by ECCC and involves several BAM Contributing Scientists.

In 2020–2021, BAM continued to support the BMS by providing data, density maps, detectability offsets and expertise as needed. BAM Statistical Ecologist Péter Sólymos delivered a workshop on the analysis of point-count data and BAM methods to continue to support the use of BAM methods and data products.

Boreal Optimal Sampling Strategy

BAM continues to support ECCC's Boreal Avian Monitoring Strategy by providing data, data products, and expertise as needed. In 2020-21, a framework was developed to determine which legacy and iconic data can be incorporated into the design of the monitoring program for migratory birds without inducing bias. This monitoring design will: (1) reduce costs by incorporating data from other ongoing surveys, and (2) incorporate resurveys of historical survey locations to extend assessments of population change over a longer time period. The framework is being applied for 2021 BMS survey design in several regions.

ECCC staff have also been using BAM density maps in conjunction with pilot BMS sampling and BAM offsets to test design efficiency and sampling bias as well as develop a precision analysis framework to determine national sample size requirements to meet BMS objectives of monitoring population abundance, distribution and trends (see Figure 1). [**INFORMED project**. Contact: Steve Van Wilgenburg]

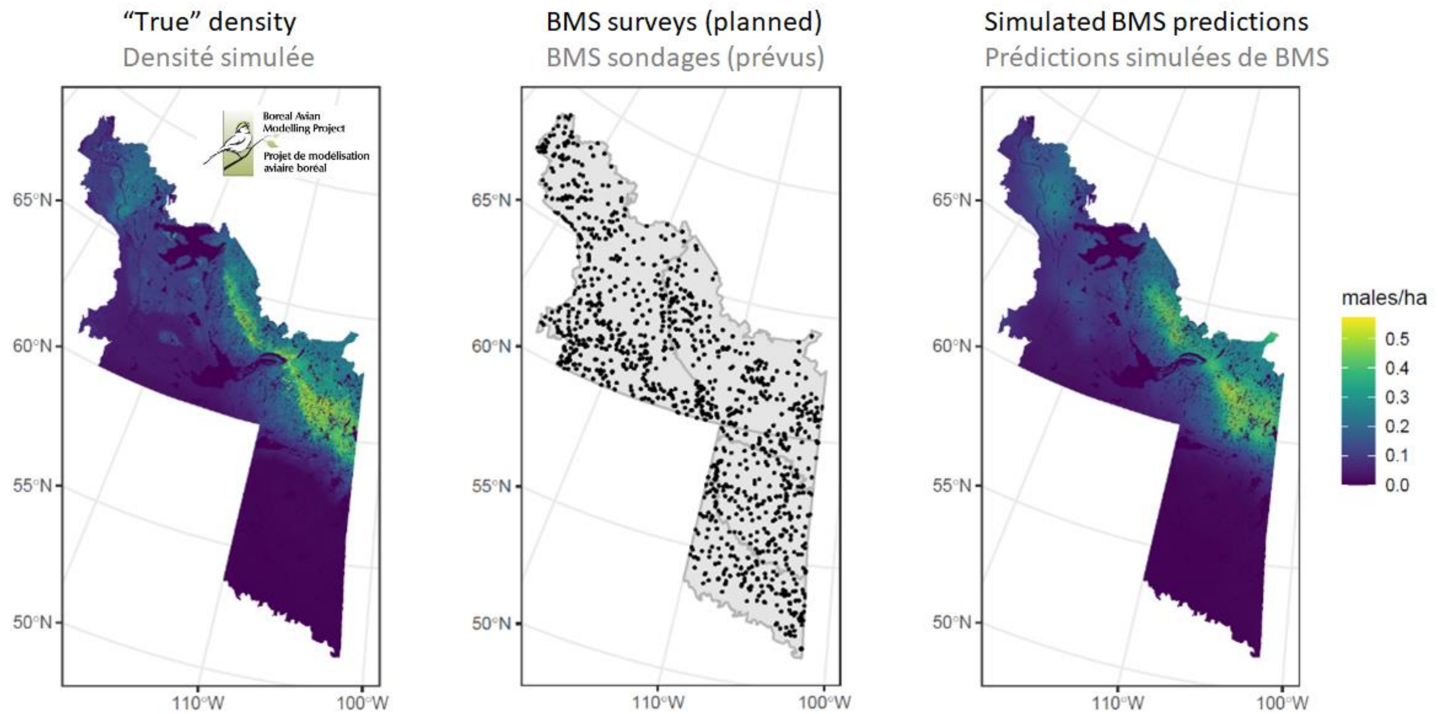

Figure 1. Simulation based test of the BMS sampling scheme to recover described patterns of distribution and abundance for Blackpoll warbler (*Setophaga striata*). Zero-inflated Poisson counts were simulated with means estimated from sampling BAM density maps at planned sampling locations and a simple spatial smooth count model applied to predict densities at "un-sampled" locations. Courtesy D. Iles (ECCC).

Training Workshop for the Analysis of Heterogeneous Point Count Data

A 4-day workshop was delivered by Péter Sólymos on the "Analysis of point-count data in the presence of variable survey methodologies and detection error" to BIOS² fellows in March 2021. BIOS² is a community of early career researchers who are exploring and applying modern-day computational and quantitative techniques to address the challenges of biodiversity sciences. The workshop explored 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. It was attended by over 55 registered participants from multiple countries, organizations and industries. Video recordings and materials from the workshop are available at: https://borealbirds.ualberta.ca/data-harmonization/

Data and Data Products

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.

In 2020–2021, we have developed new data products and updated the BAM website where they are made available. We have also continued to develop our new data product distribution platform—the GeoNetwork.

Summary and inventory of BAM's data products

In 2020–2021, BAM has made a number of new data products available, which include the Canada-wide landbird density estimates (see page 10), as well as current and future waterfowl densities (see page 11 & page 15). The data products that are currently available from BAM include regional and Canada-wide density estimates for 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 visit https://borealbirds.ualberta.ca/maps-data/ to explore the available data products or contact BAM at bamp@ualberta.ca for more information. [**CORE project**. Contact: Teegan Docherty].

GeoNetwork: BAM's data product distribution platform

BAM is developing an online platform to host our many data products and to facilitate the accessibility, discovery and download of these products. The BAM GeoNetwork, which is an application to manage spatially referenced resources, will serve to showcase the BAM data products to the public and to share commonly used data products within the team. In 2020-21, we finished developing a set of custom tags that will function to catalogue our data products and will be used internally as keywords by the online platform. We also surveyed BAM data users on their data product needs and added data to the online platform in response to those needs. [**CORE project**. Contact: Mélina Houle]

CASFRI: Common Attribute Schema for Forest Resource Inventories

CASFRI is a compilation of Canada's digital forest resource inventory (FRI) datasets, standardised into a large PostGIS database. CASFRI is currently being used in several BAM projects, including habitat selection research (page 14). Thanks to a substantial three-year contract between NRCAN and Steve Cumming's lab at Laval, work has been undertaken to completely revise and correct the FRI data assimilation and processing stages, re-implementing the entire workflow as a suite of table-driven PostGIS queries. The entire system is now far more maintainable and robust than the original versions developed since 2010. A major design change has been the introduction of multi-temporality. CASFRI now has inventories from two time periods for large parts of Canada, and the methodology is well-developed to incorporate new datasets as they are produced, or older historical FRI datasets as they can be found. 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. The new completed version, CASFRI 5.0, will continue to support BAM projects with a comprehensive, reliable, error-corrected, and maintainable source of spatially enabled forest inventory data. [**INFORMED project**. Contact: Steve Cumming]

Avian Data

Summary: Since 2004 BAM has collected and harmonized data from over 180 different projects into a large database containing over 10 million bird records from the boreal and hemi-boreal regions of North America. Enhanced accessibility and sharing of this database with our partners and data users is one of BAM's key priorities and represents an important opportunity to facilitate avian conservation.

In 2020–2021, we collaborated with ABMI and WildTrax to develop an online platform to host our human point count database. 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 methods and tools to automate the translation of the Breeding Bird Survey data and ARU data into the BAM data structure.

BAM Avian Database update: version 6.0

In 2020-21, we updated and launched the BAM database version 6.0, which includes new datasets, updated Breeding Bird Survey (BBS) data and a new database structure. The updates to the SQL database structure made it more efficient to store data and easier to move legacy BAM data to WildTrax (see page 32). This new structure was developed by Hedwig Lankau, the BAM database manager, in consultation with BAM scientists and data partners.

We added data from multiple projects in the northeastern USA, updated one long-term project, and integrated several Breeding Bird Atlases. We also removed all of the BBS data in our database and then used a new automated approach to download and add all available BBS data (see page 33). This was done to standardize the way we integrate BBS data and to update the historical BBS data in our database. The new data includes:

- Contributing scientists' data from Yukon Territory, Northwest Territories and Saskatchewan.
- Surveys from northern Ontario
- BBS data up to 2019 (>6,500,000 observations)

[**CORE project**. Contact: Hedwig Lankau]

Open Data Initiative

BAM believes that enhanced data sharing will facilitate collaborative science and accelerate avian conservation and research. It is BAM's goal to increase accessibility to the point count data compiled and harmonized by BAM, while honouring the agreements of data contributors, in order to support rigorous, evidence-based, transparent research in Canada and elsewhere. As a first step, we have collaborated with ABMI to develop an online platform to host our data securely on WildTrax (see next project). Secondly, as part of an Open Data Initiative for avian data in Canada, we are collaborating with Birds Canada, ECCC, ABMI, and WildTrax to develop a wider network to connect avian data portals and partner. This network will allow the BAM database to be connected to a network of data portals and providers. In 2020–2021, we will be working with data partners to revisit and re-negotiate data-sharing agreements. We will also continue to collaborate with these and other partners to ensure alignment with the larger vision for open data. [**CORE project**. Contact: Erin Bayne and Teegan Docherty]

BAM to WildTrax

The BAM point count database is being migrated online to be hosted on WildTrax. We have been collaborating with the WildTrax team to create the structure and platform to store point count data within the WildTrax database. BAM chose to work with WildTrax to host our data for a number of reasons, including: (i) it is capable of hosting our unique data structure; (ii) it will facilitate data upload and discovery; (iii) it provides long-term data security and storage; (iv) it supports a range of data access options (e.g., private, open, etc.) to support the individual data sharing needs of our data partners; and (v) it will support the integration of point-count data with other types of avian data (e.g., ARU data, see page 34). WildTrax provides many services and tools that will support data users and BAM's collaborations. These include the R package WildRTrax, tools to download and integrate multiple data types in the BAM data structure, methods for automating and applying BAM's statistical offsets, and more. The first online version of the point count sensor on WildTrax was released on March 24, 2021, as part of WildTrax Phase 4, and the first public data sets were uploaded by March 31, 2021 (Figure 2). Upgrades to the online point count system will be part of WildTrax Phase 5. This work is a collaboration with ABMI, BU, and WildTrax. [**CORE project**. Contact: Hedwig Lankau]

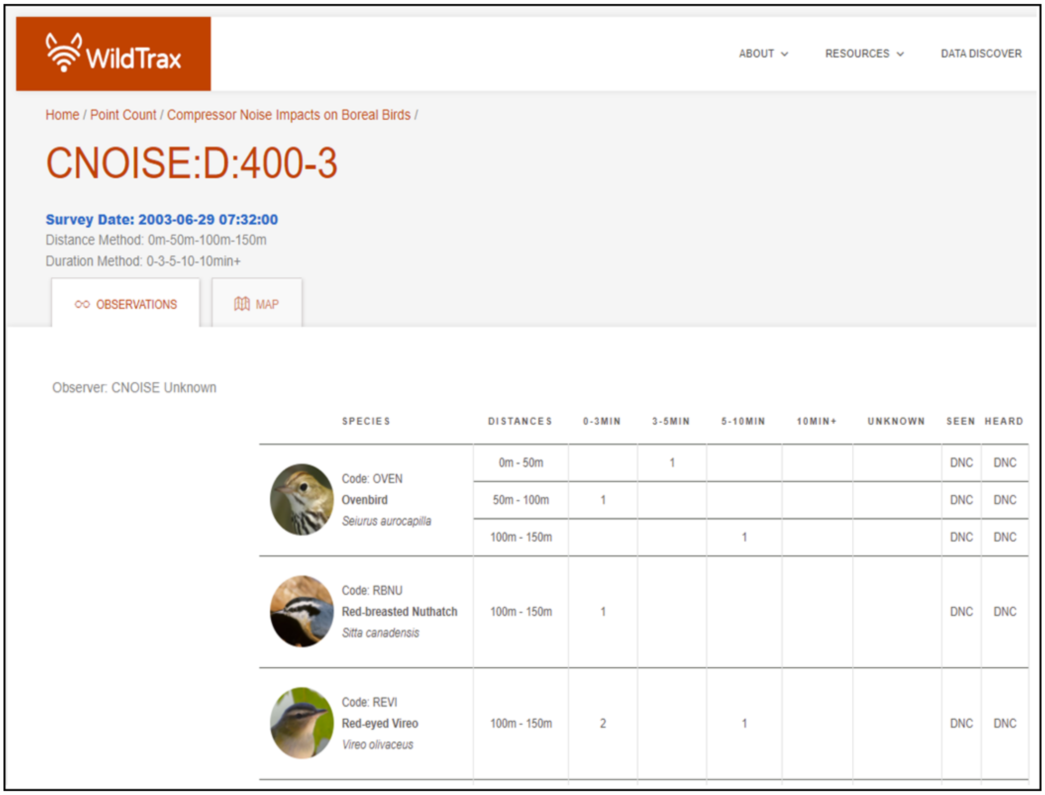

Figure 2. Image of point count data on the WildTrax platform designed to host the BAM database. This platform was designed to support the BAM data structure, which includes distance and time information for all observations. Visit WildTrax.ca to learn more and explore the data.

Automating the translation of Breeding Bird Survey data

The Breeding Bird Survey (BBS) data spans more than 50 years and provides important information for estimating bird population trends, relative abundance, and species richness at the regional and continental scale. However, prior to being integrated into the BAM database, the BBS data needs to be standardized into the BAM data structure. In 2019–2020, we began the development of an R package called BBS2BAM to automate this process from download. In 2020–2021, we tested and validated the R package using sample and previous non-automated output. We standardized the latest version of BBS data (2020 Release) using the package. The package is now available on the borealbirds Github repository under BAMTools. In early 2021–2022, we will explore the possibility of including the BBS2BAM package in the already existing WildRTrax package to support data users outside of BAM. [**CORE project**. Contact: Mélina Houle]

Automating point count and acoustic data integration

In 2020-2021, the BAM point count database migrated to the WildTrax data platform to ease accessibility. The WildTrax data platform is an online platform for processing and sharing avian point count and data collected by environmental sensors, such as ARUs and remote cameras. However, the BAM point count data does not have the same data structure as data transcribed from ARUs or remote cameras. To facilitate the integration of ARU data and human point count data, we have developed a process to automate the download of ARU data into the BAM point count data structure. This new feature, which will be available on WildTrax in 2021, will reconcile differences in attributes between data structures using specific translation rules. We are now in the process of defining these translation rules based on ARU data transcription methodologies, which will continue in early 2021-22. [**CORE project**. Contact: Mélina Houle]

Communications, Collaborations, and Implementation

Communications

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

Updates and Translation of the BAM Website

In 2020-2021, BAM conducted significant updates and restructuring of our website to facilitate the discovery, communication, and sharing of our work and data products. Specifically, we developed new pages for our projects and data products to provide easy access and initiated French translation of materials to re-establish the bilingual nature of our website. We anticipate a fully bilingual site will again be available in 2021. Updates to our website will continue in 2021-22. The current version of our website can be viewed here: https://borealbirds.ca/ [Contact: Teegan Docherty]

Outreach & Publications

We communicate BAM research via webinars, publications in peer-reviewed journals, presentations, and reports. From January 2020 through March 2021, BAM led or significantly contributed to 10 papers in peer-reviewed journals, gave over 13 talks, poster, or workshop presentations, and organized 5 workshops and webinars.

BAM Publications

BAM Core Publications

Publications from BAM Core projects between January 2020 and March 2021.

2020 – January - December

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

2021 – January – March

No BAM Core Publications were published in January through March 2021.

BAM Co-produced Publications

Publications from BAM Co-produced projects between January 2020 and March 2021.

2020 – January - December

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

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

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., 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

2021 – January - March

No BAM Co-Produced Publications were published in January through March 2021.

BAM Informed Publications

Publications we're aware of that use BAM data, methods, or expert knowledge, published between January 2020 and March 2021.

2020 – January - December

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

2021 – January - March

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

BAM Technical Reports

Reports describing BAM core and co-produced projects that were not peer-reviewed, completed between January 2020 and March 2021.

2020 – January - December

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

2021 – January - March

No BAM Technical Reports were published in January through March 2021.

Presentations

Presentations given by BAM Team Members between January 2020 and March 2021.

2020 – January - December

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

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. (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.

Stralberg, 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.

Stralberg, D. (2020), "Identifying boreal forest refugia from climate change: a framework and conservation planning applications," Talk presented at NACCB, 30 July (on-line). Part of co-organized session called: "Innovative Approaches for Identifying and Managing Climate-change Refugia"

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.

Tremblay, J.A., Y. Boulanger, D. Cyr, A.R. Taylor, P. Solymos, and D. Stralberg. 2020. A Regional Comparison of the Impacts of Climate Change and Forest Harvesting on Boreal Bird Communities of Canada. Conférence virtuelle International Research Network on Cold Forests. Virtuel. 2 novembre 2020.

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. Climate Change and Birds #BOUsci20 - British Ornithological Union. Virtuel. 24 novembre 2020.

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.

2021 – January - March

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 2020 and March 2021.

2020 – January - December

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.

McIntire, E., Haché, S., Micheletti, T. et al. (2020). “Western Boreal Initiative: annual workshop”. Workshop (online), 9 December.

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.

2021 – January - March

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

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.

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
- Fiona Schmiegelow, University of Alberta
- Samantha Song, Environment & Climate Change Canada

Project Staff: BAM wishes good luck to Diana Stralberg in her new role!

- Hana Ambury, Research Assistant, part-time. ambury@ualberta.ca
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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:

- Connie Downes, Marie-Anne Hudson, and Kate Campbell (CWS): BBS data support
- Nash Goonewardena, Ian Paine, Michael Abley, Christie Nohos, Andrea Gougeon, Marina Offengenden, Marilyn Johnson (University of Alberta): Technical and administrative support
- Paul Morrill, Genevieve Beaulieu, Brad Grier: website design, programming, and support
- Denis Lepage and Catherine Jardine (Bird Studies Canada): Atlas data support
- Brendan Ward (Conservation Biology Institute): Data Basin support
- Laura Garland (University of Alberta): Data management 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 2020-2021

- Alberta Forest Products Association (AFPA) (West Fraser Timber Co. Ltd)
- 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
- Wilburforce Foundation

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.
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Rio Alto Resources Int'l Inc.
Shell Canada Ltd.
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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
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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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R. Eccles
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D. Swanson
S. Swanson
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.
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Daishowa Marubeni International Ltd.
Forsite Consultants, Ltd.
Government of Alberta
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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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Boreal Avian Modelling Project

Annual Report April 2020 - March 2021

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Suggested reference format

Boreal Avian Modelling Project. 2021. Annual Report - April 2020-March 2021. Boreal Avian Modelling Project, University of Alberta, Edmonton, AB, Canada.

Boreal Avian Modelling Project

Projet de modélisation aviaire boréal

COVER PHOTOS:

Rusty Blackbird: Yousif Attia (CC)

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