Analyses to support critical habitat identification for Canada Warbler, Olive-sided Flycatcher, and Common Nighthawk (Project K4B20-13-0367)

FINAL REPORT 1

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Report Overview

Defining critical habitat is required to inform recovery strategies for species at risk. High density areas tend to have the highest per unit area reproductive output. Hence, these areas are often assumed to be the most important to protect if populations are to recover. In this study, the Boreal Avian Modelling (BAM) project provided analyses to support Environment Canada in its effort to identify critical habitat for three Neotropical migratory birds (Canada Warbler, *Cardellina canadensis*; Olive-sided Flycatcher, *Contopus cooperi*; and Common Nighthawk, *Chordeiles minor*). Specifically, BAM used the best information available (i.e. avian point count and biophysical data) to: 1) generate habitat models identifying the biophysical attributes characterizing areas of low and high densities; 2) estimate population size at multiple spatial scales under various assumptions; 3) map predicted density estimates and uncertainty across Canada; and 4) provide a Schedule of Studies identifying important gaps in data availability and the limitations of current models.

Information from over 1.5 million avian point count surveys were used with land cover, disturbance, topography, climate, and spatio-temporal variables to generate 9 model subsets that explained the variation in abundance of the three focal species across Canada. We used different model subsets to account for different spatial extents and co-linearity among variables. Poisson log-linear regression models were produced using a branching hierarchy model building process and bootstrap procedures to account for model uncertainty.

Density of male Canada Warblers was higher eastern Canada and in mixedwood and deciduous stands with tall trees and closed canopy. There was a 50-60% decline in relative abundance of territorial males from 1997 to 2013. Density was lower in areas with high proportion of agricultural and human developments within a 16 km^2 area of survey points. Alternatively, landscapes with a higher proportion of mixedwood and deciduous stands supported higher densities. Estimated Canadian population size across the monitoring period was 11 million birds with the highest proportion being in Ontario, Quebec, and Alberta.

Density of male Olive-sided Flycatchers was higher in conifer stands, recent burns, shrubby areas, and western Canada. There tended to be higher a density in stands with taller trees. There was no significant evidence of a temporal trend in relative abundance of territorial males from 1997 to 2013. Landscapes (i.e. 16 km^2) supporting higher densities included high proportions of conifer and mixedwood stands, shrubby and wet areas and water bodies. Estimated Canadian population size across the monitoring period was 9.2 million birds with the highest proportions of the Canadian population being in Quebec and British Columbia.

There was some evidence that shrubby areas, human development, and western Canada supported higher densities of male Common Nighthawks. Relative abundance declined by 70-80% from 1997 to 2013. Highly suitable landscapes were comprised of many land cover types (i.e. shrub and grassy areas, conifer stands, and, to a lesser extent, urban development, barren ground, and wet areas). The number of individuals in Canada was estimated at 270,000 with the highest proportions predicted to occur in Alberta, British Columbia, and Saskatchewan.

Model validation suggested that our habitat models had very good predictive and discriminatory power. This was determined based on agreement among bootstrap predictions and measures of goodness of fit for model subsets based on random samples of observation. We also compared our population estimates to those derived from data and methods used by Partners in Flight. This exercise highlighted important discrepancies in population size estimates when using different analytical approaches and including off-road surveys. Although our habitat models were derived from the best available information, we provided a detailed list of future studies required to address remaining gaps in the breeding ecology and habitat modelling of these species.

1.0 Introduction

Under the *Species at Risk Act* (1994), Environment Canada has the mandate to complete a recovery strategy within one year of a species being listed as endangered or two years if listed as threatened or extirpated (Government of Canada 2014a). Such a strategy requires identifying the critical habitat for these species based on the best available information. Specifically, critical habitat is defined as: "habitat that is necessary for the survival or recovery of a listed wildlife species" (Government of Canada 2014a). Identifying habitat conditions that support the highest densities of individuals is a fundamental component of addressing this question. Setting aside areas with high densities is assumed to have the greatest long-term potential to stop the decline of species that are limited by the amount of breeding habitat remaining. High density areas also tend to have the highest per unit area reproductive output (Skagen and Yackel Adams 2010; Haché et al. 2013). Thus, identifying areas with high density and producing the greatest among of young, is key to defining critical habitat.

Environment Canada is currently developing recovery strategies for three boreal birds (Canada Warbler, *Cardellina canadensis,* hereafter CAWA; Olive-sided Flycatcher, *Contopus cooperi*, hereafter OSFL; and Common Nighthawk, *Chordeiles minor*, hereafter CONI). According to the Bird Breeding Survey (BBS), CAWA declined by 2.9% annually in Canada between 1970 and 2012 (ranging from a 0.3% increase to 5.4% decrease annually among provinces/territories; Environment Canada 2014). Over the same period, similar patterns have been observed for OSFL (3.4% annual decline nationally and declines ranging from 1.6% to 5.7% annually among provinces/territories) and CONI (3.6% annual decline nationally and declines ranging from 1.8% to 11.9% annually among provinces/territories). However, the overall reliability of these estimates is low to medium. While BBS data can be used to generate habitat models, there are issues with BBS derived estimates of habitat suitability that include: 1) most of the boreal forest where these species are known to breed is poorly sampled; and 2) point counts are systematically being conducted along roads which may be selected or avoided by certain species. Hence, it is important to combine BBS data with other sources of bird abundance data to cover the Canadian breeding range of each focal species and to statistically account for a potential roadside survey bias (Matsuoka et al. 2011; Wellicome et al. 2014).

Since 2003, the Boreal Avian Modelling (BAM) project has been compiling boreal and hemiboreal avian point count data from Canada and the United States (Cumming et al. 2010, http://www.borealbirds.ca/; Figure 1). Data contributors have included BBS, Breeding Bird Atlases, university researchers, government scientists, and industrial partners. BAM has worked to convert these datasets that vary in point count methodology to a standard that allows quantitative density estimates to be created across Canada for hundreds of passerine species (Solymos et al. 2013). This comprehensive database is the single largest dataset on passerine birds in Canada. For the current contract, BAM had the mandate to use the best information available (i.e. avian point count and biophysical data) to address four main objectives:

1) generate habitat models identifying the biophysical attributes characterizing areas of low and high densities of CAWA, OSFL, and CONI;

2) use density estimates generated from the habitat models to estimate population size for each focal species at multiple spatial scales (i.e. Canada, province/territory, BCR, and BCR within provinces/territories);

3) map predicted density estimates and uncertainty for each focal species across Canada;

4) provide a Schedule of Studies identifying important gaps in data availability and key limitations of the data and resulting models and derived predictions.

2.0 Methods

2.1 Focal Species

All three species considered in this report are neotropical migratory birds for which little information is available on their migration and wintering habitat requirements. Recent reviews of their breeding ecology have been provided by The Birds of North America Online (Reitsma et al. 2010; Brigham et al. 2011; Altman and Sallabanks 2012). From a subset of the data used in this report and covariates at larger spatial resolutions, Cumming et al. (2103) recently quantified the relative importance of climate and vegetation variables for several songbird species including CAWA and OSFL. Similarly, Stralberg et al. (in press) quantified the relative importance of bioclimatic, land use, and topographic variables for these species and many other forest songbirds. In both studies, models with climate variables explained most of the variation in abundance for both focal species at continental scales.

The CAWA forages mostly on invertebrates and builds an open nest on the forest floor. Breeding habitat has been shown to vary across the species' range (reviewed by Reitsma et al. 2010). In the southern part of its range, CAWA seems to prefer montane areas with a thick understory comprised of *Rododendron* sp.. In the central portion of its range, it would reach higher densities in forested wetlands and swamps. In northern areas of the boreal forest, trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) stands on more rugged terrain would support higher densities (see also Ball et al. 2013). The effects of habitat fragmentation and alteration remain unclear with studies reporting contrasting results. Cumming et al. (2013) and Stralberg et al. (in press) have shown that variation in CAWA abundance was best explained by the number of growing degree days (> 5°C and < 0°C). Although to a lesser extent, mean differences between the warmest and coldest monthly temperatures (climate), mean normalised difference vegetation index (NDVI), mean leaf area index (LAI; vegetation), compound topographic index, and the proportion of water bodies in 4-km grid cell (topographic) were also good predictors of variation in CAWA abundance. According to Nature Serve, the Canadian breeding range of CAWA covers about 2,184,400 km^2 (http://www.natureserve. org/; Figure 2). This species is thought to be absent from Newfoundland (but see http://www.ebird.org/) and Nunavut, with relatively few observations in the Yukon, British Columbia, and Prince Edward Island (Table 1).

The OSFL is an aerial insectivore associated with open coniferous forests (< 40% canopy closure) comprised of mature trees and snags (reviewed by Altman and Sallabanks 2012). This species also reaches higher abundance in mature coniferous forests near edges (e.g. open water, clearcut, farmland, and town). Hence, highly fragmented late-seral forests are purported to be optimal habitat for OSFL. There is evidence suggesting that human disturbances (e.g. forestry activities) would support higher densities than natural disturbances (e.g. burns), but higher nesting success has been documented in burns (Robertson and Hutto 2007). According to Cumming et al. (2013) and Stralberg et al. (in press), variation in OSFL abundance across the continent was best explained by the mean and standard deviation of the mean maximum monthly temperature and to a lower extent by mean precipitation, number of degree days (> 5°C), climate moisture index, difference between mean warm month and cold month temperatures (climate) and LAI (vegetation). The Canadian breeding range for this species covers about 5,175,600 km^2 (http://www.natureserve.org/; Figure 3) including every Canadian province and territory except Nunavut (Table 1).

Lastly, the CONI is an aerial insectivore associated with open habitat (reviewed by Brigham et al. 2011). This species is more active at dawn and dusk and nests in a broad range of habitats (e.g. recently burned or logged forests, prairies, sand dunes, and beaches). It also nests on flat gravel roof tops in urban and rural areas and is often seen foraging near light posts. Proximity to water bodies has also been shown to be a good predictor of the presence of this species (Ng 2009). In Canada, the breeding range of the CONI covers about 4,722,400 km^2 (http://www.natureserve.org/; Figure 4). It can be found in all Canadian provinces and territories except Newfoundland (but see http://www.ebird.org/) and Nunavut (Table 1).

2.2 Point Count Data

BAM manages a dataset of over 1.5 million records of avian point counts conducted between 1990 and 2013 from more than 125,000 locations across North America. Also included in this database are data from large-scale and long-term monitoring projects such as the Bird Breeding Survey (57,000 avian point counts), provincial Breeding Bird Atlases, and Calling Lake (1993-present; Schmiegelow et al. 1997) and Fort Liard projects (1998-present; Machtans et al 2014; Figure 1). From this dataset, at least one CAWA has been detected at 4,749 locations across Canada and USA (Figure 2), while OSFL has been detected at 7,529 (Figure 3) and CONI at 1,788 (Figure 4) locations (Table 1).

2.3 Spatial Covariates

For each avian point count location, spatial covariates were extracted (point level data extraction) from a series of biophysical data layers. Variables used to generate the habitat models were divided into four categories: land cover, disturbance, topography, and climate:

2.3.1 Land Cover

Information on vegetation class was available through the 2005 North American Land Change Monitoring System (NALCMS; MODIS data; 250 m spatial resolution; Commission for Environmental Cooperation 2014; Appendix 1), Land Classification Cover Map of Canada 2005 (LCCMC; MODIS data; 250 m spatial resolution; Natural Resources Canada 2014a; Appendix 2), Earth Observation for Sustainable Development of Forests (2000; EOSDF; Landsat data; 25 m spatial resolution; Wulder et al. 2008; Appendix 3), and Common Attribute Schema from Canada's Forest Resource Inventories (CASFRI; ~ 150 m spatial resolution; Cumming et al. 2010; Appendix 4). CASFRI also provided information on canopy height and forest cover. For the three other land cover maps covering larger spatial extents, information on canopy height and forest cover was available from the Global Map of Forest Canopy Height (2005; GMFCH; satellite-based LiDAR; 1 km spatial resolution; Oak Ridge National Laboratory 2014; Simard et al. 2011; Appendix 5) and the Global Percent Tree Cover Map (2000-2001; GPTC; MODIS data; 500 m spatial resolution; Hansen et al. 2003; Appendix 6), respectively. For each of the four land cover layers (NALCMS, LCCMC, EOSDF, and CASFRI), we created dummy variables (0 - 1) for different forested/non-forested land cover classes (Deciduous, Mixedwood, and Non-forest). These dummy variables were used as interaction terms combined with canopy height to determine whether the relationship between bird abundance and forest stand type was influenced by canopy height. Specific land cover variables from each spatial data layer used in the species-specific habitat models (see *2.4 Habitat models*) are summarized in Table 2.

2.3.2 Disturbances

In addition to land cover information, CASFRI (Cumming et al. 2010) provided information about forestry activities (presence/absence of clearcuts; ≤ 10 years between year of sampling and year since the most recent harvesting). Complementary information on anthropogenic disturbances over a broader spatial extent was available from the 2008-2011 Boreal Ecosystem Anthropogenic Disturbance Layers (BEAD; 1 km spatial resolution; Landsat-5 imagery; Government of Canada 2014b; Pasher et al. 2013; Appendix 7). Information on the presence and absence of fire (≤ 10 years between year of sampling and year since the most recent fire) was available for Canada (Canadian Wildland Database Fire Information System (CWDFIS); Natural Resources Canada 2014b) and United States (Monitoring Trends in Burn Severity (MTBS) 2014; 30 m image resolution). We also determined the proportion of agriculture and urban development (AgrDev) within 4 km × 4 km cells using the NALCMS layer. Variables from the disturbance layers considered in the species-specific habitat models (see *2.4 Habitat models*) are summarized in Table 3.

2.3.3 Topography

We generated a topographic wetness index (TWI) across Canada based on a composite 3 arc second (90-m) Global Land Survey Digital Elevation Model (GLSDEM) provided by the Global Land Cover Facility (2014). The portion of the GLSDEM product that we used is comprised of data from the Canadian Digital Elevation Dataset (CDED) above 60 degrees north latitude and the Shuttle Radar Topography Mission (SRTM) below 60 degrees. The TWI was calculated as the log of the catchment area (km) divided by the tangent of the slope of a cell (Moore et al. 1993). We used SAGA-GIS and the RSAGA package, version 0.93-6 (Brenning 2013), to calculate a version of TWI based on a modified catchment area calculation. TWI values could only be positive and higher values represented wetter areas. We also calculated the slope (radian; SLOPE) using a second-order polynomial interpolation method (Zevenbergen and Thorne 1987) and the RSAGA package. Using the NALCMS layer, we determined the proportion of wet areas (Wet) and wet areas and water bodies (WetWater) within 4 km × 4 km cells surrounding each avian point count location. Variables from the topography layers considered in the species-specific habitat models (see *2.4 Habitat models*) are summarized in Table 4.

2.3.4 Climate

Monthly climate and weather normals (average climatic and weather conditions per location; 1960-1999) have been interpolated at a 4 km resolution by PRISM (Daly et al., 2002) and WorldClim (Hijmans et al., 2005). All climate data can be retrieved from Dr. Andreas Hamann's personal website (www.ualberta.ca/~ahamann/data/climatena.html). Climate covariates used to build species-specific habitat models (see *2.4. Habitat models*) are summarized in Table 5. Climate data were incorporated in habitat models and their underlying density estimates. At large spatial extents like those considered here, climate is often a better predictor of bird abundance by explaining species distributions. However, our priority was to determine how local scale variables (e.g. catchment area and stand), like vegetation type and disturbances, influence bird density. Hence, climate entered our models much later in our hierarchical model building approach.

2.4 Habitat Models

2.4.1 Model Subsets and Building Process

Poisson log-linear regressions were used to generate four types of habitat models (i.e. model sets) explaining variation in abundance of the three focal species. Model A used products that were North American in scope (Canada and USA; e.g. NALCMS), model B had products available across Canada (e.g. LCCMC), model C combined information available for Canadian forests (e.g. EOSDF), and model D covered the forested area of Canada under management agreements with forestry companies (e.g. CASFRI; Tables 2-5; Appendices 1-7). The four different model sets used different variables (i.e. biophysical attributes) as availability differed among spatial extents and were produced for each focal species. The goal was to determine how the inclusion of additional detail as the spatial extent decreases influenced prediction accuracy of the habitat models.

We were also interested in exploring whether there was evidence for spatial variation in habitat association (i.e. differential habitat selection). We tested for differential habitat selection by creating interactions between forest attributes and spatial variables using BCR as a categorical predictor. We did not include climate variables and BCR in the same model sets owing to co-linearity. Hence, each model set was divided in two subsets: one including climate variables (Climate models) and the other with BCR as a categorical predictor (BCR models). We also considered differential habitat selection in the Climate models by using an interaction between the same forest attributes and the East-West divide, west of -98° longitude (0-1; hereafter EA_WE).

Our land cover covariates allowed accounting mainly for local variation in vegetation type (see *2.3.1 Land Cover*). However, it is known that larger scale vegetation attributes (e.g. patch size and configuration) can influence bird abundance. Thus, we also determined high suitability land cover classes based on predicted point level densities and land cover information from the NALCMS layer. High suitability land cover types were used to calculate the proportion of suitable habitat in a 4 km grid cell around each point count survey. We used the Lorenz-tangent approach to determine the threshold for delineating high suitability land cover classes. First, we fit a model with land cover types as categorical predictors. This model was used to predict expected density ("fit") values for each observation used. Fit values were then sorted from the smallest to largest. The cumulative sum of sorted fit values represented a strictly monotonically increasing convex function (i.e. Lorenz-curve; Appendix 8). We determined the value of the sorted (not cumulated) density value (λ_J) that corresponded to the point in the Lorenz-curve where the slope is 1 (tangent). This point corresponds to the Youden statistic (Youden 1950) which is the maximum difference between the Lorenz-curve and the diagonal. The maximum difference is located at the tangent. A land cover class was defined as highly suitable when expected density was equal or higher than the threshold (λ_J). By converting densities to occupancy probabilities (1-exp(-density * area)), the Youden index and the corresponding threshold lead to an optimal separation that balances sensitivity and specificity related to the ROC curve (Schisterman et al. 2005). We refer to suitable habitat (i.e. combination of land cover classes) for a given species as the Intrinsic Patch (hereafter IP). Given that Intrinsic Patch was only available for the NALCMS layer, we divided the climate models subset for this layer with (Climate-Landscape models) and without (Climate models) landscape information. The model subsets with landscape information were also the only ones that included AgrDev, Wet, and WetWater. The model subset without landscape information allowed better comparisons among model types (A-D).

In summary, we had four model types (A-D) divided in 8 model subsets (BCR and Climate models) and model set A was further divided in a Landscape-Climate model subset for a total of 9 models per species. A detailed description of all variables considered in the 9 models subsets is available from Appendices 9-17.

For each model subset, we used a "branching" forward stepwise variable selection approach (or branching hierarchy model building process) with bootstrapping. This approach allows minimizing bias in predictions. Prior to analyses, appropriate transformations were applied to variables with unsuitable distributions (Table 6). For the Climate model subsets, we used a 10-stage branching hierarchy model building procedure to evaluate the importance of: 1) land cover variables and their forms (numerical covariates; linear, quadratic, etc.); 2) roadside bias (0-1; off-roadside surveys vs. BBS and other known roadside surveys); 3) topographic variables; 4) spatial variation (EA_WE); 5) disturbances; 6-9) climate variables (models including moisture, temperature, extreme weather, and precipitation variables were analyzed separately); and 10) temporal variation (year was used as numerical [centered at 2000; YR] and categorical [1997-2001, 2002-2006, and 2007-2013; YR5] to allow for nonlinear year effects) in predicting bird abundance (Appendices 9-12). The model set including landscape covariates from the NALCMS layer (Climate-Landscape model) had an additional stage to include Intrinsic Patch (Appendix 13). The temporal component of our modelling exercise (stage 10) has to be interpreted with caution. Although we understand the spatial structure in the dataset, further analyses of its spatio-temporal structure is warranted. We used a blocking approach in the bootstrap runs where ~5 year intervals were combined with spatial units (as described below). Based on this approach, the database is considered "spatio-temporally balanced" (i.e. there are no regions with major temporal gaps) and this is required to avoid confounding effects of spatial and temporal variation. In other words, there is no evidence that more impact studies were conducted in specific years for a given region which would have resulted in unreliable negative trends. However, this could only be based on a crude assessment.

The total number of variables for the Climate and Climate-Landscape model subsets varied between 50-64 candidate variables depending on the number of variables available at each spatial scale (Appendices 9-13). A bootstrap procedure was generated 200 times in an iterative bootstrap approach using consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) to determine how often a particular predictor variable was selected (Burnham and Anderson 2001). This approach, also known as 'bagging' (Breiman 1996), reduces variance in the predictions and helps avoid overfitting the data. The top ranked variable in a given stage was fixed and added to variables in the subsequent stage. The resampling scheme went as follows:

1) For each sampling location, we selected visit 1 for point counts with multiple visits within a same year;

2) Used bootstrap blocks (merged BCR and YR5) to repeat the subsampling within each block;

3) In each block, we counted the number of surveys within each 10 × 10 km grid cell;

4) We selected a maximum of 5 random surveys from each grid cell (fewer if total <5);

5) The resampling was repeated 200 times to get quantile-based bootstrap inference.

Similar branching hierarchy model building process and bootstrap procedures were used to create the BCR model subsets. Owing to scarce data, we could only use eight BCR (5, 6, 8, 9, 19, 12, 13, and 14) and had to pool data from BCR 1, 2, and 4 into "Alaska"; 3 and 7 into "Arctic"; 11, 17, and 22 into "Prairies"; and 22, 23, 24, 26, 28, 29, and 30 into "EastUS". We used a four-stage branching hierarchy model building procedure to evaluate the importance of: 1) land cover variables and their forms (numerical covariates; linear, quadratic, etc.); 2) roadside bias; 3) topographic variables; and 4) spatial variation in predicting bird abundance. Models for each BCR model subset had 12 variables (Appendices 14-17). The same bootstrap procedure and resampling scheme has been used for these model subsets.

The BAM avian dataset consists of heterogeneous sampling protocols. Consequently, the analytical approach suggested by Solymos et al. (2013) was used to control for the effects of survey protocols on detectability. This approach accounts for time of day and time of year when surveys were done and the duration and radius of point count surveys. This was achieved by combining species-specific offsets and habitat models to estimate densities of territorial males (/ha) for each species. These offsets included species' signing rate and habitat-specific effective detection radius over which a species can be detected (see Solymos et al. 2013 and Matsuoka et al. 2012 for details). From each of the 200 bootstrap predictions, we reported median density as it is more robust to outliers than the mean. It is important to note that "density estimates" for CONI should be considered as relative abundance because the offsets used assume that CONI are territorial. This may not be true as little is known about where CONI are detected relative to where they nest and/or defend territories (if they do).

We used a large computer network known as Westgrid (https://www.westgrid.ca/) allowing the numerous computational steps to be done in a timely manner.

2.4.2 Model Uncertainty and Validation

By using bootstrap procedures and creating the various model forms, we provided multiple measures of model validation and prediction uncertainty. Model uncertainty was represented as a variable selection path along the stages of the modeling approach described above. Model validation was performed to determine whether our models allowed us to answer our main question: what biophysical attributes are supporting larger densities of the three focal species? Such an assessment was done using a visualization of the goodness of fit approach. We measured the goodness of fit of our models by comparing a count with expected density * exp(offset) to account for detectability and survey protocol because difference in sampling protocol alone can have important effects on observed counts. Visualization of the goodness of fit of each model subset was presented using a ranking plots approach based on 10000 random samples of observations. These ranking plots allowed determination of the predictive power of point density estimates, while using random samples allowed validating our models. Scale and location shifts across bootstrap-based predictions were evaluated by the overall concordance correlation coefficient (OCCC; measured deviation from 45° line through origin, i.e. perfect agreement between two measures) based on Lin (1989, 2000) and Barnhart et al. (2002). We reported the OCCC, overall precision (OPREC; measured of how far each observation deviated from the best fit line), and overall accuracy (OACCU; measured how far the best line deviates from the 45° line). This approach is comparable to a test of parametric assumptions about the residual error (e.g. χ^2). We did not calculate AUC/ROC metrics because we were not looking for an optimal threshold.

2.5 Population Sizes and Spatial Predictions of Density

To estimate population size, we extracted point level habitat data (i.e. biophysical attributes) from equally spaced points (1 km apart) across the Canadian range of each focal species (Table 7). Then, using our habitat models, we scaled density estimates from ha to km^2 and obtained population size estimates for each focal species by summing density estimates ($/km^2$) from all points within their Canadian breeding range (i.e. density estimates for each point were assigned to a corresponding 1 km × 1 km cell generated from the point grid). We had to make the assumption that values for biophysical attributes extracted from each point represented values of these attributes within its corresponding 1 km × 1 km cell. This approach had to be used because the spatial extent of the study precluded estimation or mapping at higher resolution.

Canadian population size estimates for each species were generated using predictions from the Climate-Landscape model subset (NALCMS). We report population size estimates across Canada and by BCR, Province/Territory, and BCR within Province/Territory. For each species, we produced high resolution digital predictive map (1 km spatial resolution) of density and coefficient of variation (prediction standard deviation scaled by point prediction). Note that predicted values were generated irrespective of year. Hence, estimated population size represented mean values across the monitored period (1997-2013).

Given the uncertainty regarding the northern limit of the species breeding ranges, we mapped density and provided coefficients of variation for entire Canadian boreal forest. Numerous detections of CAWA in the BAM database lie well outside the Nature Serve distribution map. However, we provided population size estimates based on reported Canadian breeding ranges (i.e. Nature Serve maps) to allow meaningful comparisons with population size estimates reported by Partners and Flight (http://www.rmbo.org/pif_db/laped/about.aspx; Rosenberg and Blancher 2005). These results allow comparisons to be made from the different analytical approaches and datasets being used. PIF's approach assumes that BBS data randomly samples the range of these species which is unlikely to be true. The approach BAM uses accounts for non-random sampling with respect to vegetation type (Solymos et al. 2013). Detailed descriptions of other important differences between the two analytical approaches are provided below.

Lastly, we generated population size estimates over the spatial extent covered by CASFRI using the four BCR and Climate model subsets (i.e. CASFRI, EOSDF, LLCMC, and NALCMS) and the Climate-Landscape model subset (NALCMS; total of 9 population size estimates per species). The objective was to explore consistency in predicted values among models using different land cover data, but the same spatial extent, as a mean of modelling avian density recognizing that all GIS layers have errors in classification.

3.0 Results

3.1 Canada Warbler

Selection paths of variable selection for each CAWA model subset and variable selection frequencies are available from Figures 5, 6, and 11 and Appendices 9-17, respectively. Results from the branching hierarchy model building process for the 9 model subsets are reported in Table 8. Variables consistently selected among model subsets were considered the most important predictors of variation in abundance of the three focal species (Table 9). For the Climate and BCR model subsets, a variable had to have the highest selection frequency within a given stage for at least two or more model type (A-D; NALCMS, LCCMC, EOSDF, and CASFRI) to be considered among the most important variables (Table 9). The top ranked variables from the climate-landscape model subset were systematically considered important because this model was only conducted at one spatial extent (NALCMS).

Land cover, forest cover, canopy height, and temperature difference (warmest month vs. coldest month) were the best predictors along with Intrinsic Patch, survey type (roadside vs. off-road surveys) and spatio-temporal (BCR, EA_WE, and year) effects. Specifically, densities were generally higher in mixedwood and deciduous stands, in eastern Canada (Figure 12) and stands with tall trees (Figure 13) and dense cover. Roadside surveys systematically underestimated density of male CAWA (Figure 14) and important declines (50-60%) in relative abundance over time were reported from models at all spatial extents (Figure 15). There was a negative effect of the proportion of agriculture and human development within 16 km^2 and a positive effect of the proportion of Intrinsic Patch on CAWA density (Climate-Landscape model; Appendix 22). Mixedwood and deciduous stands corresponded to highly suitable CAWA habitat (i.e. Intrinsic Patch; Figure 16). Coefficients and standard errors for all the parameters considered in each model subset can be retrieved from Appendices 18-26.

Based on our analytical approach, Canada could support ca. 5,500,000 male CAWA (population size of ca. 11,000,000 birds). Approximately 80% of the breeding population would be found in BCR 6, 8, and 12 or Ontario, Quebec, and Alberta (Table 10; see also Figure 25A).

3.2 Olive-sided Flycatcher

Selection paths of variable selection for each OSFL model subset and variable selection frequencies are available from Figures 7, 8, and 11 and Appendices 9-17, respectively (see Table 8 for the results from the branching hierarchy model building process for each model subset). Variables consistently considered important in predicting variation in OSFL among the Climate and BCR model subsets included land cover, canopy height, topographic wetness index, linear disturbance, recent fire, and five climatic variables (climate moisture index, temperature difference, potential evapotranspiration, degree days above 5 °C, and mean summer precipitation; Table 9). There was also an important bias related to roadside surveys, while East-West divide and BCR were also good predictors.

Density of male OSFL was higher in conifer stands, recently burned and shrubby areas, and in western Canada (Figure 17). Density also tended to be higher in stands with taller trees (Figure 18). Topographic wetness index and, somewhat surprisingly, linear disturbances had negative effects on OSFL density (Appendices 18-26). There was a positive roadside bias (3 out of 4 model subsets) indicating that roadside surveys overestimated OSFL density (Figure 19). The proportion of wet areas and water bodies (WetWater) within 16 km^2 (Climate-Landscape model subset) had a negative effect on OSFL density, whereas density increased with the proportion of Intrinsic Patch (Appendix 22). High suitable OSFL habitat (i.e. Intrinsic Patch) included conifer and mixedwood stands and shrubby and wet areas (Wet; Figure 20). Coefficients and standard errors for all the parameters considered in each model subset can be retrieved from Appendices 18-26.

The Canadian population of Olive-side Flycatcher would be comprised of ca. 4,600,000 breeding males (population size of ca. 9,200,000 birds). Approximately 60% of the breeding population would be in the BCR 4, 8, and 10, while Quebec and British Columbia would support more than 50% of the breeding population (Table 11; see also Figure 26A).

3.3 Common Nighthawk

Selection paths of variable selection for each CONI model subset and variable selection frequencies are available from Figures 9, 10, and 11 and Appendices 9-17, respectively (see Table 8 for the results from the branching hierarchy model building process for each model subset). Land cover, climate moisture index for June/July/August, survey type, East-West divide, Intrinsic Patch, and year were variables consistently important in predicting variation in CONI among the Climate and BCR model subsets (Table 9). However, there was inconsistency among model subsets regarding the land cover classes supporting highest densities of CONI. Two subsets showed no effect of land cover (EOSDF and CASFRI), whereas shrubby areas (NALMCS) and human development (LCCMC) would support higher CONI densities according to the two other model subsets (Figure 21). Density of male CONI was consistently higher in western Canada (Figure 21). Roadside surveys consistently overestimated CONI density (Figure 22) and there was an important negative effect of year (70-80% decline) on the relative abundance of CONI (Figure 23). When considering landscape composition within 16 km^2 (Climate-Landscape model subset), there was only a positive effect of Intrinsic Patch (Appendix 22). High suitable CONI habitat (i.e. Intrinsic Patch) included shrub and grassy areas, conifer stands and, to a lesser extent, urban development, barren ground, and wet areas (Figure 24). Coefficients and standard errors for all the parameters considered in each model subset can be retrieved from Appendices 18-26.

Based on our analytical approach, Canada would support ca. 135,000 male CONI (population size of ca. 270,000 birds). About 58% of the breeding population would be found in the BCR 6, 8, and 10 or 70% the population would breed in Alberta, British Columbia, Ontario, and Saskatchewan (Table 12; see also Figure 27A).

3.4 Variation in population size estimates

There were important discrepancies between our population size estimates and those reported from Partners in Flight (PIF) based on BBS surveys (PIF(BBS)) for the same regions. We estimated that Canada would support ca. 3.7 times more CAWA than PIF(BBS) estimates (Tables 10 and 13). The difference was even greater for the OSFL where we reported an estimated population sizes ca. 10.3 times larger than PIF(BBS) estimates (Tables 11 and 13). However, the opposite pattern was observed for the CONI with PIF(BBS) population size estimates ca. 3.3 times larger than ours (Tables 12 and 13).

As described in detail in section 4.4, the major reason for these differences is BAM's use of the statistical concept of Effective Detection Radius (EDR) versus that used by PIF which is a concept called Maximum Detection Distance (MDD). These two concepts are very different and can create different areas over which bird point count numbers are divided to generate density estimates. Which approach is "more" correct is debatable. From a theoretical statistical perspective, the EDR approach should be more accurate.

In Tables 10-12, we also provided population estimates using MDD from PIF (rather than EDR), but based on the BAM dataset (PIF(BAM)). Population estimates based on PIF(BAM) was still 1.3 and 1.6 times more than PIF(BBS) estimates for CAWA and OSFL, respectively, whereas PIF(BBS) estimates for CONI was 22.3 times larger than the PIF(BAM) estimates (Tables 10-12). This indicates that differences in population estimates between BAM and PIF are not solely caused by differences in statistical methodology, but also because of differences in the dataset being used.

When comparing population size estimates from the 4 model sets (i.e. NALCMS, LCCMC, EOSDF, and CASFRI) and 3 model subsets (i.e. Climate, BCR, and Climate-Landscape) over the CASFRI extent (total of 9 population size estimates), we generally had similar values among models for each focal species (Table 14). In other words, population estimates were not strongly influenced by how land cover was stratified. Estimates were more consistent for OSFL with values ranging from 2.3 - 3.2 million birds. Both CAWA (5.3 - 7.2 million) and CONI (57,000 - 98,000) showed larger variation, but the difference among species was consistent among model subsets (i.e. population size estimates were always larger for CAWA than CONI). Also, there was no evidence that a given land cover layer generated a systematic bias in population size estimates (Table 14).

3.5 Model and prediction uncertainty

Correlation coefficients among bootstrap predictions within each model subset were all > 0.75 (Appendix 27) suggesting good agreement among bootstrap predictions and, therefore, that our models had good predictive power. Predicted densities for CAWA in Alberta, Manitoba, and northern Ontario had the highest coefficients of variation (i.e. prediction uncertainty; Figure 25B). For OSFL, higher coefficients of variation were reported in Alberta, Saskatchewan, and Manitoba (Figure 26B). Among the three focal species, the

CONI had the highest correlation coefficients. Larger prediction uncertainty (coefficient of variation > 0.25) was reported across the country (Figure 27B). Note that for all focal species, relatively high densities are predicted beyond the northern limit of the documented breeding ranges and such finding is particularly interesting given the uncertainty regarding the northern limit of these breeding ranges (Figures 25a-27a).

Measurements of goodness of fit for each model subset generally showed a good discriminatory power of the bootstrap based median predictions with regards to the observed counts, i.e. our models could separate counts = 0 from those > 0 and there was higher counts of 1 (Appendix 28-34). Hence, predicted density was a good indicator of habitat suitability and the most highly suitable areas were more likely to host the largest proportion of the breeding population.

4.0 Discussion

Identifying critical habitat is an important step required in the process of creating recovery strategies for species at risk. We used the largest avian point count dataset and the best biophysical information available over a large enough spatial extent to generate habitat models that will help support identification or partial identification of critical habitat for Canada Warbler, Olive-sided Flycatcher, and Common Nighthawk in Canada. We suggest that biophysical attributes supporting higher bird density should be considered as important habitat and management plans should have for objective to increase the availability of these attributes to stop population declines and provide opportunities for species to recover.

4.1 Canada Warbler

Higher densities of territorial males were systematically reported in deciduous and mixedwood stands with tall trees. Tree height can to some extent be used as a proxy for stand age and other studies have reported higher density in older stands, especially in western Canada (Reitsma et al. 2010; Ball et al. 2013). In addition to tree height, canopy cover also had a positive effect on bird density. Further studies are required to better understand the processes underlying this relationship because the opposite pattern has also been reported in other studies (reviewed by Reitsma et al. 2010). Given that deciduous and mixedwood stands supported higher densities both at the local and landscape scales (16 km^2), they should be considered as important habitat, especially older stands.

Interestingly, tree height was not significant when generated from the CASFRI layer. One reason might be the difference in spatial resolution (i.e. 150 m vector-based vs. 1 km raster-based layer) between tree height layers. Also, the CASFRI layer provided information only for forested areas, while the GMFCH layer also provided tree height estimates in non-forested areas (e.g. wetland and agricultural landscapes). Human disturbances would also influence CAWA density. The proportion of agricultural and human developments over a 16 km^2 had a negative effect on CAWA density. This was expected as these activities result in loss of trees which are required by this species. However, linear features and forestry activities were not important predictors of variation in bird density. Although previous studies did not provide consistent patterns regarding effects of forestry on this species (Reitsma et al. 2010), there are concerns in Alberta given positive relationships reported between CAWA density and stand age (Ball et al. 2013). Surprisingly, there was little evidence of an effect of topographic wetness index on density. In Alberta, smaller proportions of wet areas and smaller point-level compound topographic index values supported higher density of CAWA (Ball et al. 2013), while in eastern Canada, this species has been associated with wet areas (Reitsma et al. 2010). Furthermore, the absence of East-West divide (EA_WE) × land cover and EA_WE × forest cover interaction effects provides little evidence for differential habitat selection in this species across Canada (but see Reitsma et al. 2010). There was also no evidence of differential habitat selection for the two other focal species.

Our results suggest that between 1997 and 2013, CAWA would have declined by 50-60% across Canada. Such a decline is greater than the one reported during this period by the Bird Breeding Survey (ca. 30%; Environment Canada 2014). However, our modelling approach does not allow determining the underlying factor(s) responsible for the estimated decline (e.g. habitat loss or alteration on the breeding grounds, at migratory stopovers, and/or on the wintering grounds). The majority of CAWA are likely breeding in Ontario and Quebec with a considerable proportion of individuals in Alberta and in the Maritimes. Conservation plans likely should focus on these areas although there is a need to explore potential management plans that would allow increasing population size in other provinces as well (e.g. Saskatchewan and Manitoba).

4.2 Olive-sided Flycatcher

Conifer stands and especially those with taller trees systematically supported higher densities of OSFL. Shrubby areas and recent burns also supported higher densities. At a landscape scale (16 km^2), high proportions of conifer and mixedwood stands, and shrubby and wet areas supported higher densities. Taken together, these results provide further evidence of that mature conifer stands within patchy landscapes influenced by natural disturbances represent important habitat for OSFL (Robertson and Hutto 2007; Altman and Sallabanks 2012). The importance of wet areas remain unclear as there was a positive effect on density at a landscape scale, but areas of low topographic wetness index supported higher local densities. Many studies have reported high densities near bogs and beaver dams (Altman and Sallabanks 2012). There was some evidence for a positive effect of clearcuts on density, but future studies are required to understand their effects on population dynamics because results from Robertson and Hutto (2007) suggest that they might act as ecological traps. Although clearcuts may support high density, there was consistent negative effect of linear features on OSFL. This negative effect of linear features was unexpected given that this species is strongly associated with fragmented landscapes and that we reported a positive roadside bias. Future studies should try to better understand the mechanisms underlying this negative response.

Unlike the Breeding Bird Survey (ca. 30% decline; Environment Canada 2014), we found no evidence for a decline in OSFL density across Canada between 1997 and 2013. British Columbia and Quebec would support most (ca. 50%) OSFL breeding in Canada.

4.3 Common Nighthawk

Based on different model subsets, shrubby areas and human developments would have positive effects on CONI density. The positive effect of human developments was expected given that the species uses human infrastructures for nesting (gravel roof of buildings) and foraging (light posts; Brigham et al. 2011). However, we also found evidence of a positive effect of shrubby areas using the available GIS layers. Although the species is associated with open habitat, it tends to use barren ground in recent clearcuts and burns and sand dunes as nesting substrate. While barren ground was included in these model subsets, this habitat class supported lower densities than shrubby areas. Whether this reflects some type of error in GIS classification or a previously unobserved habitat association warrants future research. Results from two model sets showed no effect of land cover type. Hence, the lack of agreement among model sets supports findings from other studies suggesting that the species would use a broad range of habitat types (Brigham et al. 2011). It is also important to consider that standard avian point count surveys tend to result in low detectability of CONI. Indeed, the lower number of CONI detections available in the BAM dataset might have prevented us from finding important habitat relationships (see also Schedule of Studies) That said, landscapes (16 km^2) with higher proportions of conifer stands, shrubby, grassy, and wet areas, barren ground, and urban development would support higher CONI density. Studies in northern Alberta regularly detect CONI in open and shrubby fen habitat (E. Bayne, personal communication).

The Bird Breeding Survey reports a decline of about 30% in Canadian population size since 1997 (Environment Canada 2014). Again, our modelling approach does not allow determining the underlying factor(s) responsible for the estimated decline. However, our results suggest that this decline would be closer to 70-80%. Higher abundances have been estimated for Alberta, British Columbia, Ontario, and Saskatchewan. Future studies should have for objective to characterize the biophysical attributes of these high density areas. Such information would allow identifying important habitat for this species and informing conservation plans aiming to increase population size elsewhere in the Canadian breeding range.

4.4 Different analytical approaches to estimate bird population size

There were important discrepancies between our population size estimates and those reported by Partners in Flight for the same regions (Bias Observed; Table 13). Our estimates were a lot larger than those from PIF for two species (CAWA and OSFL), whereas the opposite pattern was observed for CONI. There are three main reasons why estimates differ considerably among the two approaches:

1) PIF estimator uses BBS data which are all roadside counts (Y_{ROAD}). A large portion of BAM's dataset is comprised of off-road surveys (ca. 60%). This allowed us to account for roadside bias in our modeling approach for counts from roadside surveys and estimate expected value for off-road counts (Y) (Table 17).

2) PIF derived a time adjustment (T) that accounts for relative difference with respect to the timing of surveys. This adjustment is relative to the maximum count observed and not a model based probability. An analogous measure of availability is the inverse of the probability of singing within 3 minutes survey interval ($1/p_{3;}$ BBS surveys are based on three minutes point count) based on the singing rate approach described by Solymos et al. (2013). This signing rate approach was used in our modelling approach.

3) PIF derived a maximum detection distance (MDD) to use in correcting for unknown sampling area (unlimited radius) of BBS point counts as $1/(\pi MDD^2) = 1/MDA$ (i.e. maximum detection area). Our estimator accounts for distance related detectability and the unknown area of sampling by using effective detection radius (EDR; see Matsuoka et al. 2012 and Solymos et al. 2013 for details). The area correction analogous to the PIF approach is therefore $1/(\pi EDR^2) = 1/EDA$, where EDA is the effective detection area.

Based on these differences, we would expect that the bias (BAM/PIF(BBS)) equals the product of the road, time and area specific biases, because:

$$BAM = A * Y * (1/p_3) * (1/EDA) \text{ and } PIF(BBS) = A * Y_{ROAD} * T * (1/MDA)$$

The area of the region (A) cancels out, thus:

$$(BAM/PIF(BBS)) = (Y/Y_{ROAD}) * ((1/p_3)/T) * ((1/EDA)/(1/MDA))$$

which are the component of the bias reported in Table 13. We compared this expected bias and its component to the observed bias based on dividing the actual values from our estimation (Median_BAM) and PIF estimate (PIF(BBS); Table 13).

Two components of this bias (road and time related) are much smaller and the direction of the bias was inconsistent across the species. For example CAWA are avoiding roads, while OSFL and CONI would prefer roads (Table 13). In contrast, the relative magnitude of the "area bias" was consistently high across the three species, which indicates that the maximum detection distance (PIF) versus effective detection radius (BAM) assumption is the main driver of the discrepancies found between BAM and PIF(BBS) estimates.

We suggest that the higher density estimates derived from our models for CAWA and OSFL than those from PIF even when both used the MDD approach is caused primarily by BAM's more complete sampling of the boreal forest and the use of off-road surveys. Further work is required to understand why differences in population size estimates for CONI between BAM and PIF follow a different pattern than the one observed for the two other focal species.

See our proposed Schedule of Studies for a detailed list of limitations regarding our modelling approach and knowledge gaps pertaining to the identification of critical habitat of the three focal species.

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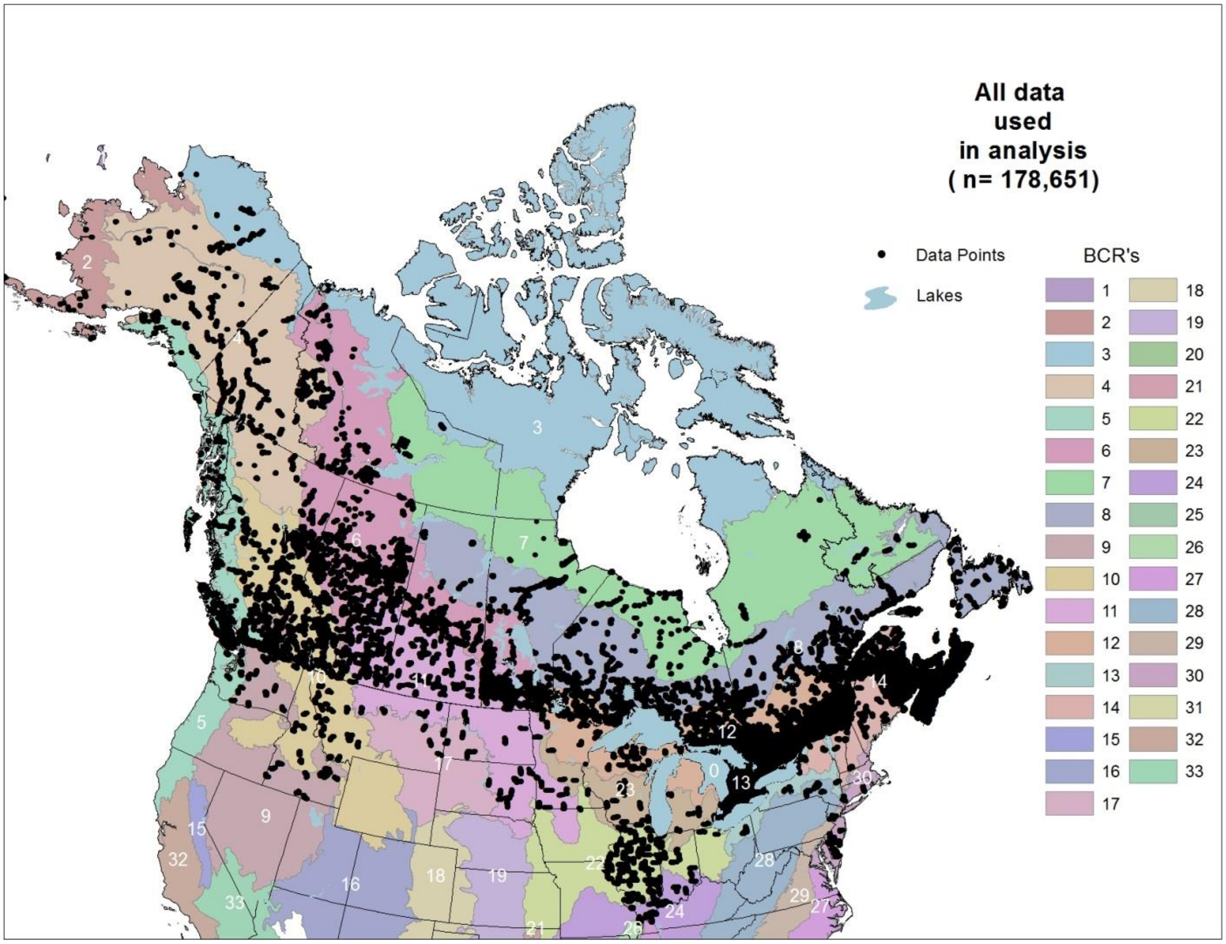


Figure 1. Location of all avian point counts from the Boreal Avian Modelling project. Abundance data from these locations have been used to generate bird habitat models for the three focal species.

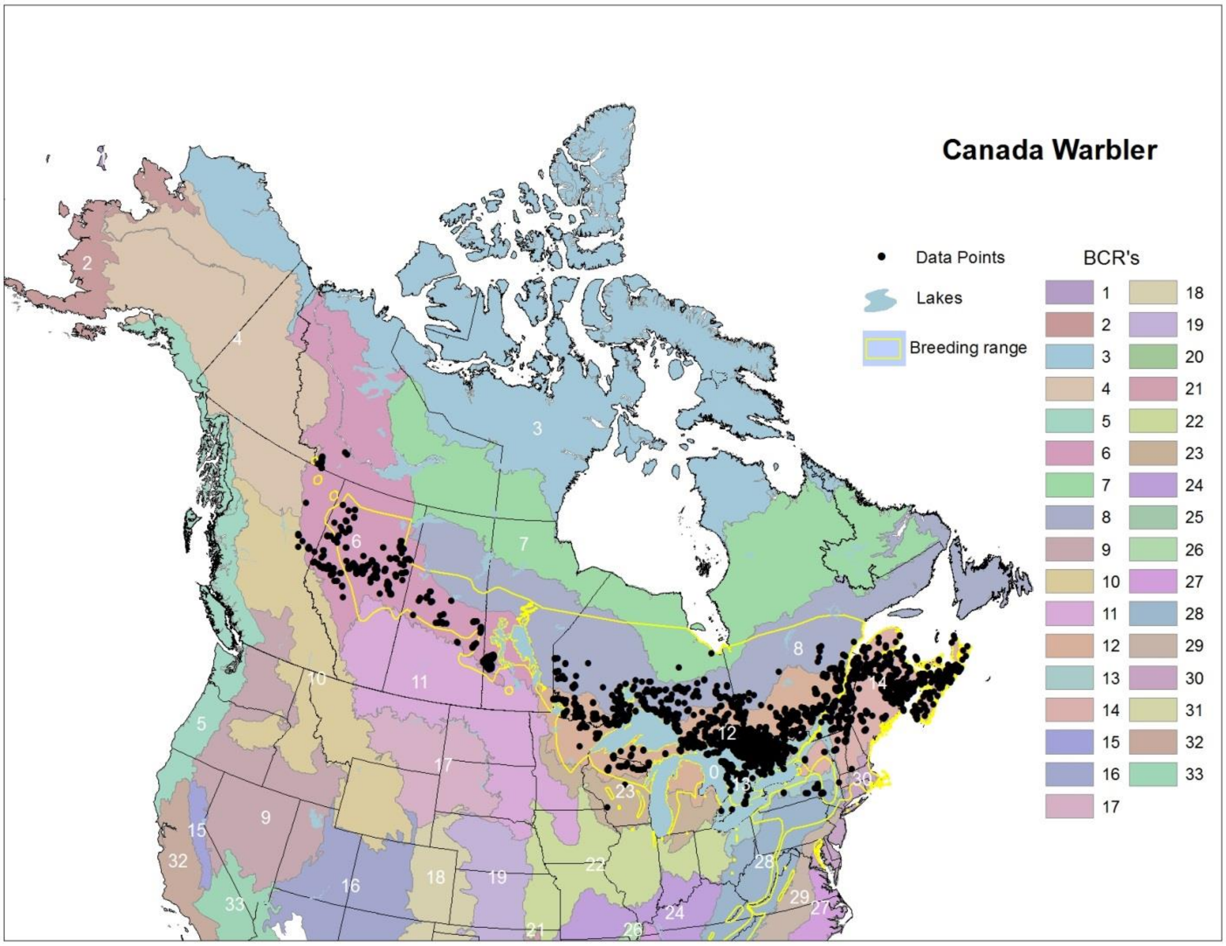


Figure 2. Location of all Canada Warbler (*Cardellina Canadensis*) detections available from the Boreal Avian Modelling project. In yellow is the breeding range of the species according to Nature Serve (http://www.natureserve).

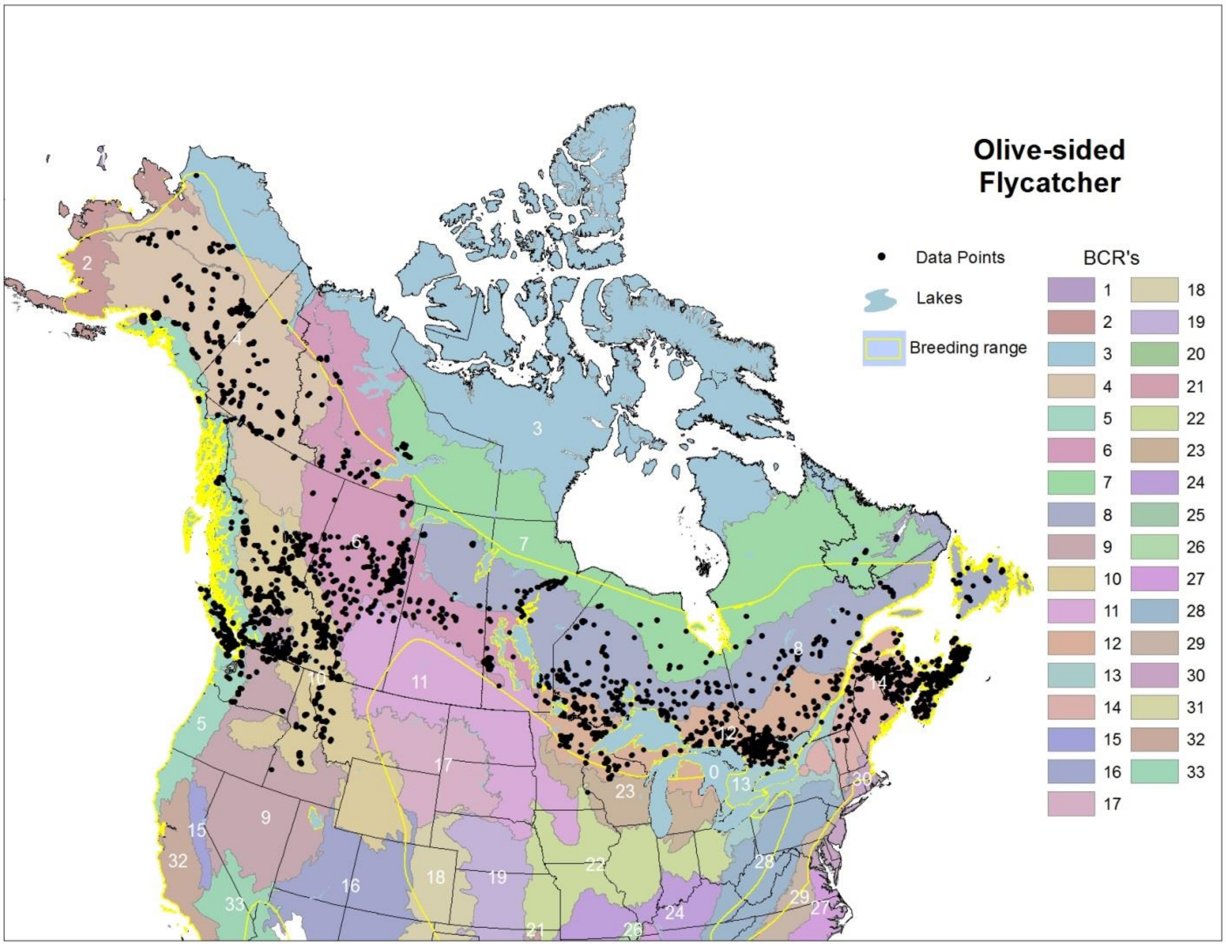


Figure 3. Location of all Olive-sided Flycatcher (*Contopus cooperi*) detections available from the Boreal Avian Modelling project. In yellow is the breeding range of the species according to Nature Serve (http://www.natureserve).

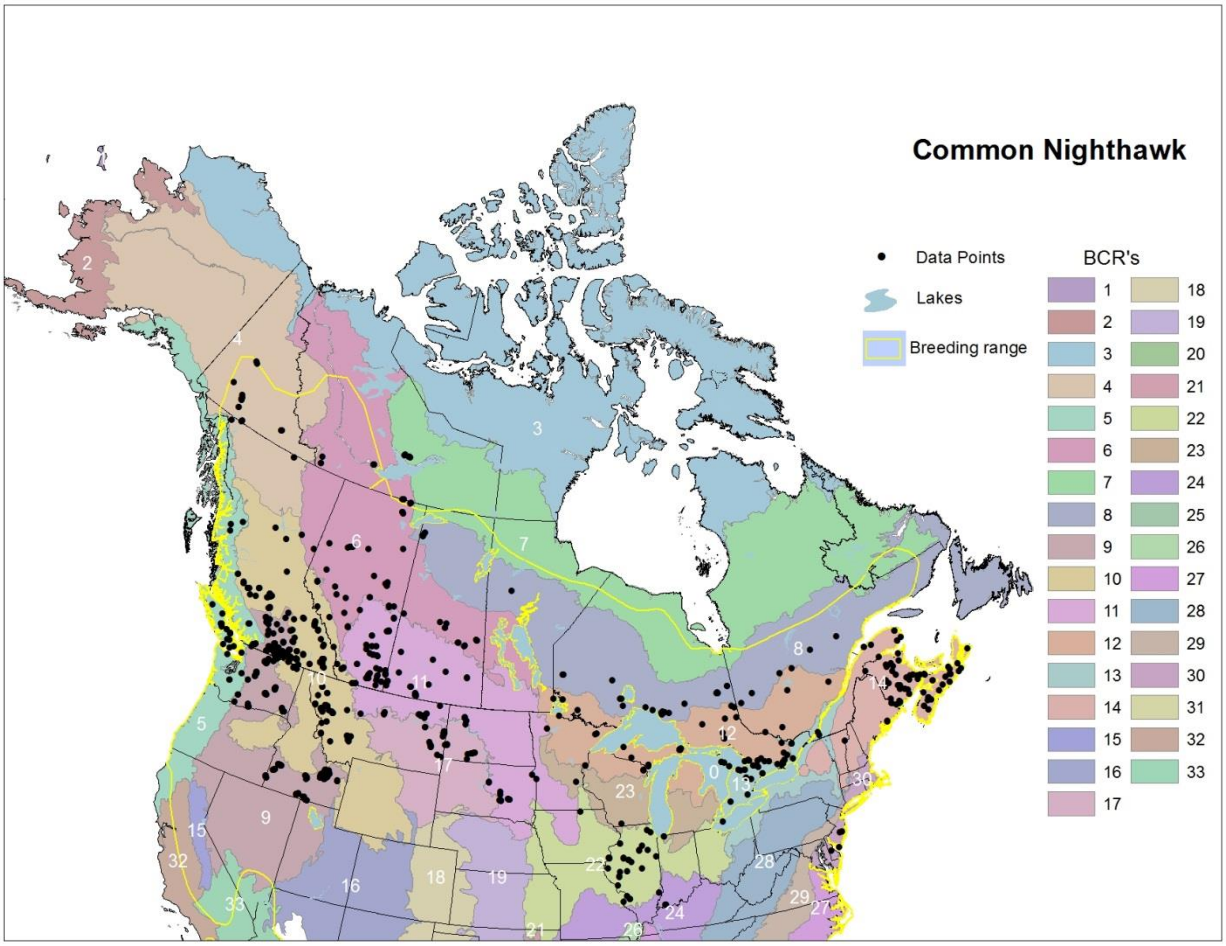


Figure 4. Location of all Common Nighthawk (*Chordeiles minor*) detections available from the Boreal Avian Modelling project. In yellow is the breeding range of the species according to Nature Serve (http://www.natureserve).

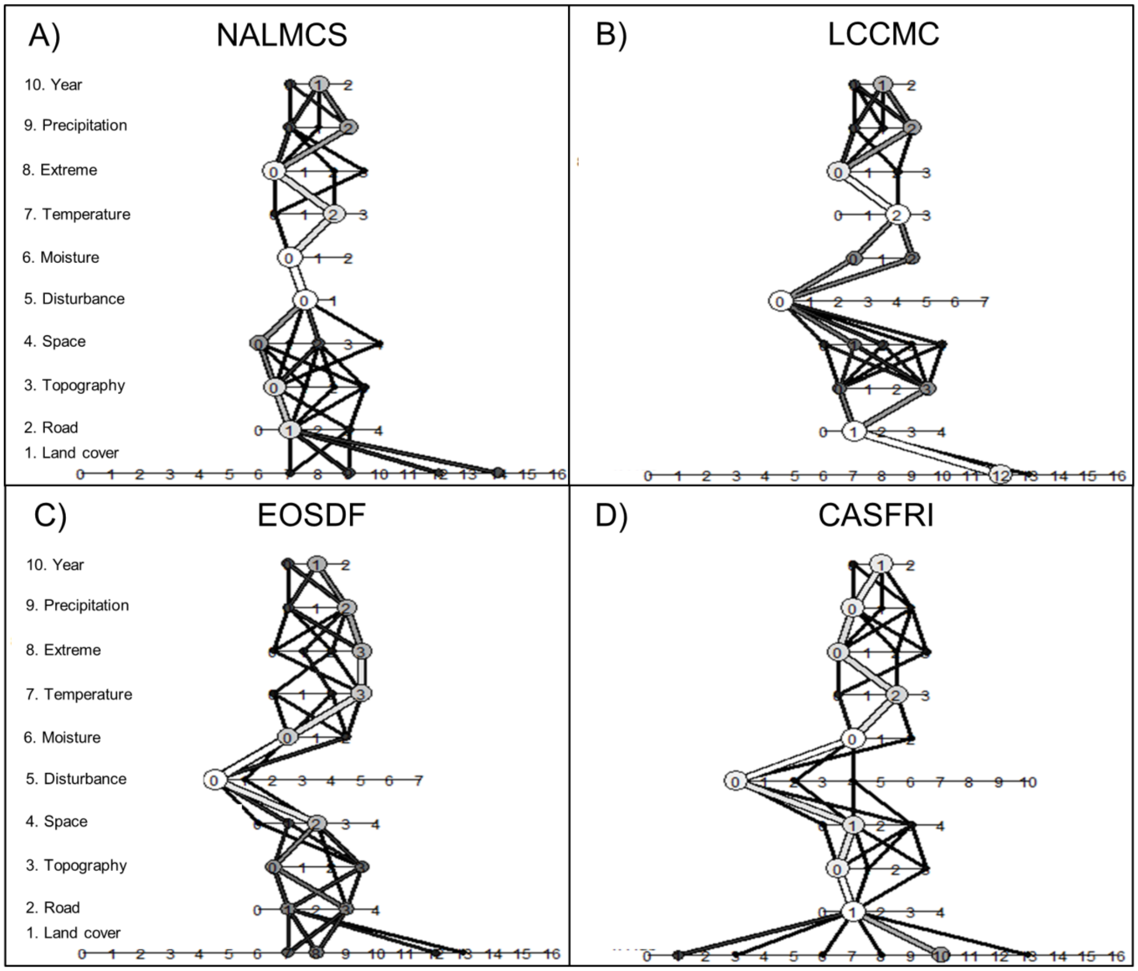


Figure 5. Selection paths of variables best explaining variation in abundance of Canada Warbler across Canada based on the branching hierarchy model building process. Results for the four Climate model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 9-12 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 9-12).

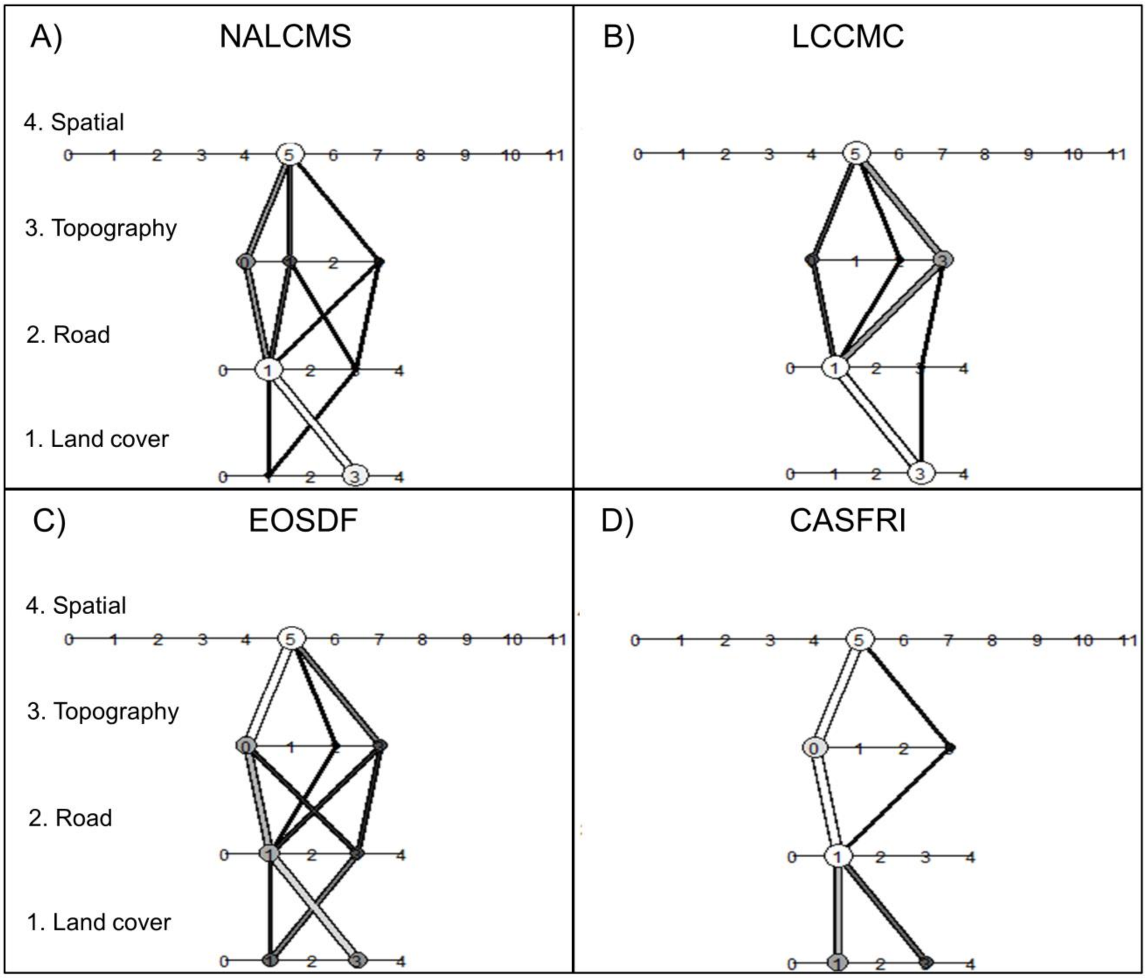


Figure 6. Selection paths of variables best explaining variation in abundance of Canada Warbler across Canada based on the branching hierarchy model building process. Results for the four BCR model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 14-17 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 14-17).

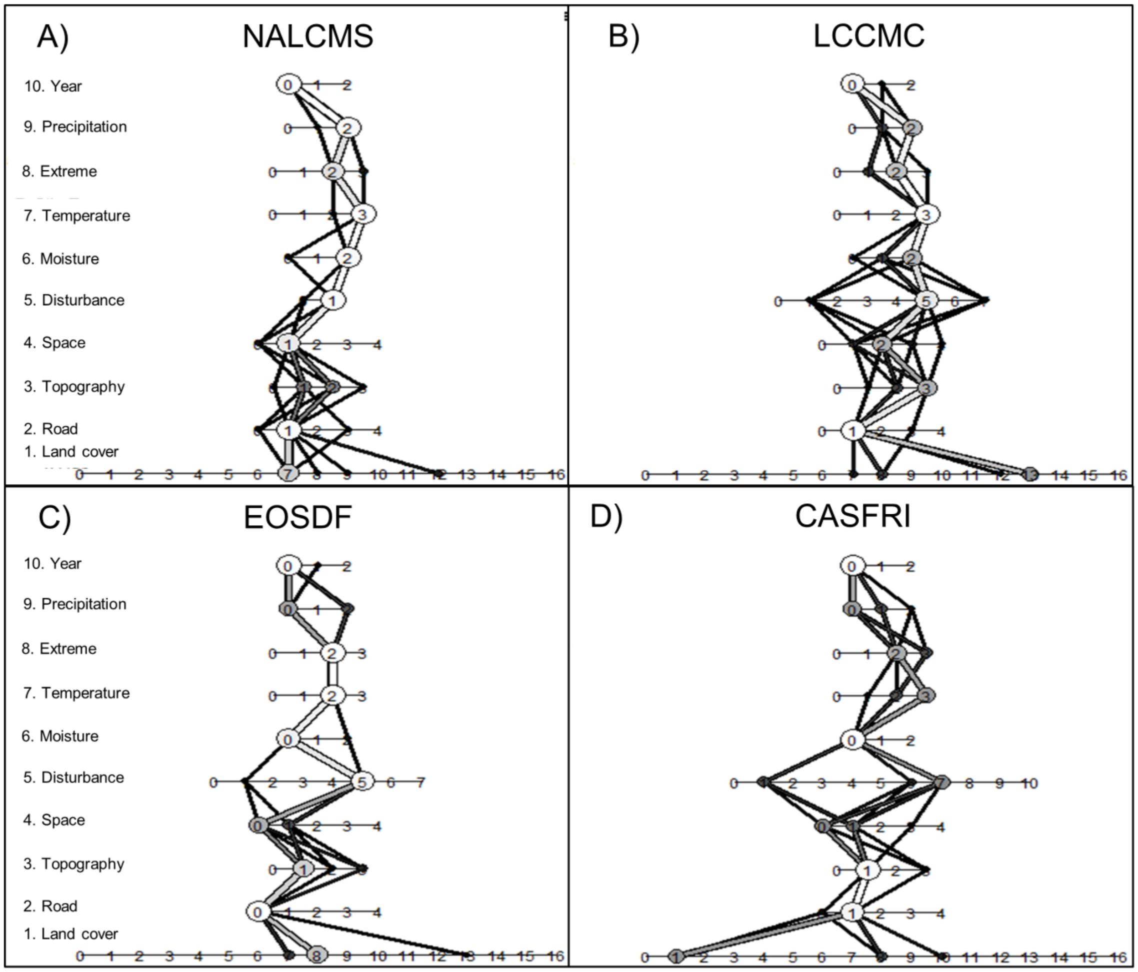


Figure 7. Selection paths of variables best explaining variation in abundance of Olive-sided Flycatcher across Canada based on the branching hierarchy model building process. Results for the four Climate model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 9-12 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 9-12).

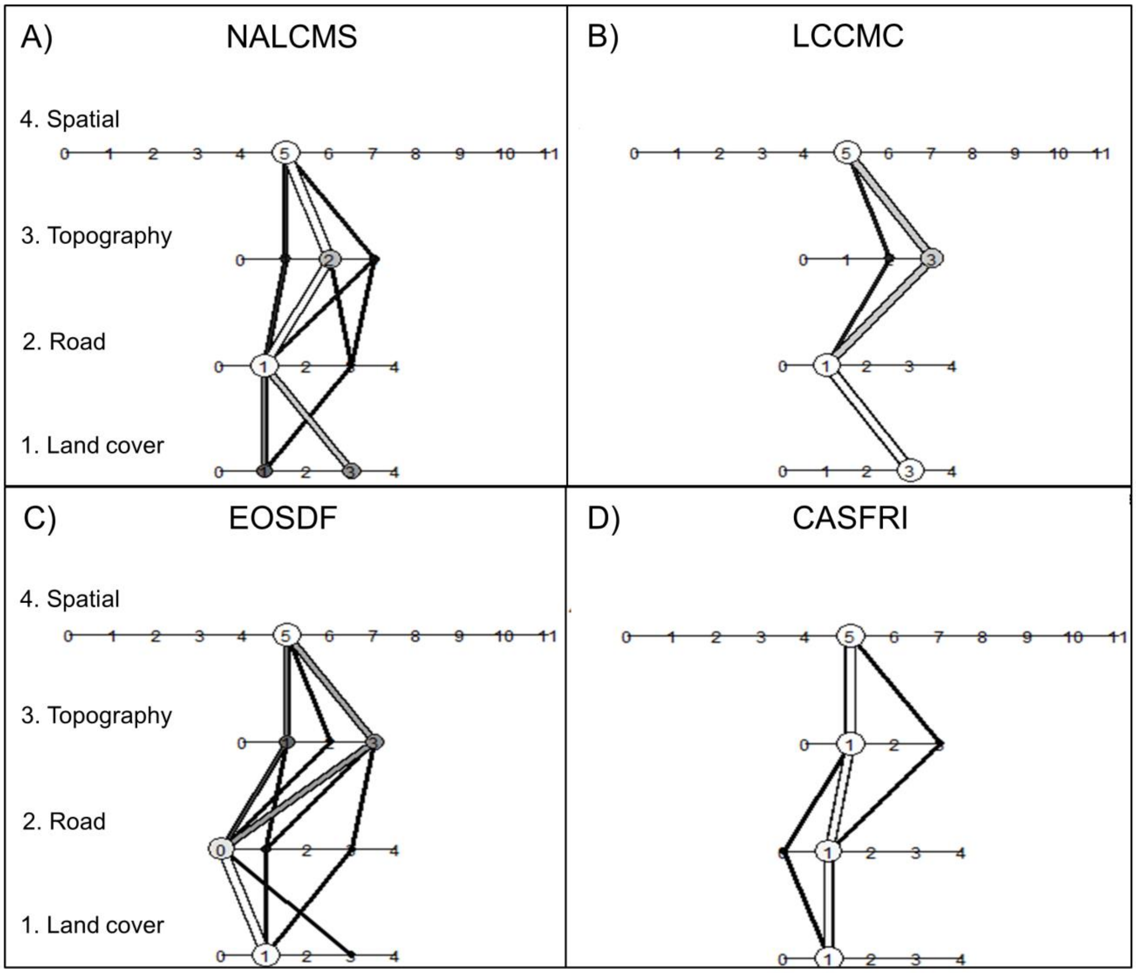


Figure 8. Selection paths of variables best explaining variation in abundance of Olive-sided Flycatcher across Canada based on the branching hierarchy model building process. Results for the four BCR model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 14-17 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 14-17).

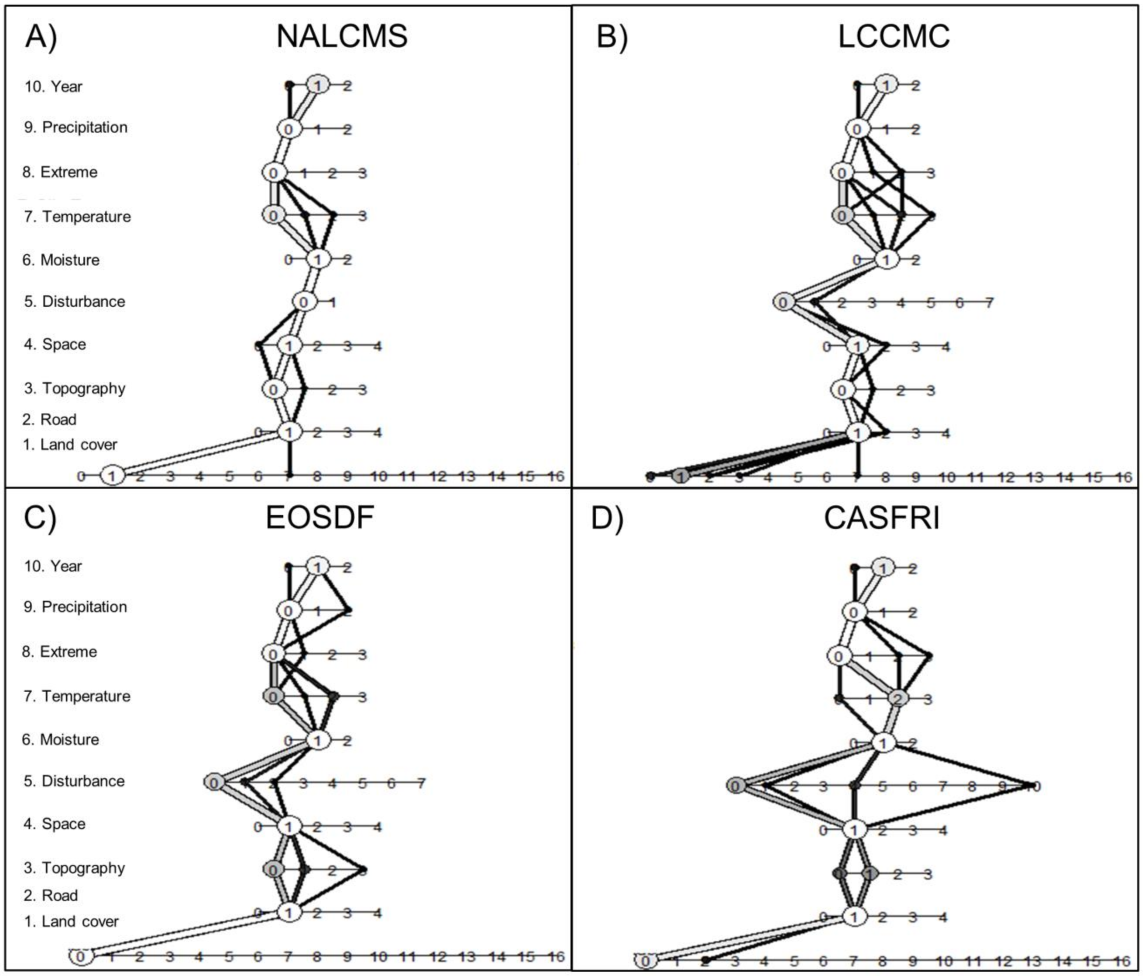


Figure 9. Selection paths of variables best explaining variation in abundance of Common nighthawk across Canada based on the branching hierarchy model building process. Results for the four Climate model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 9-12 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 9-12).

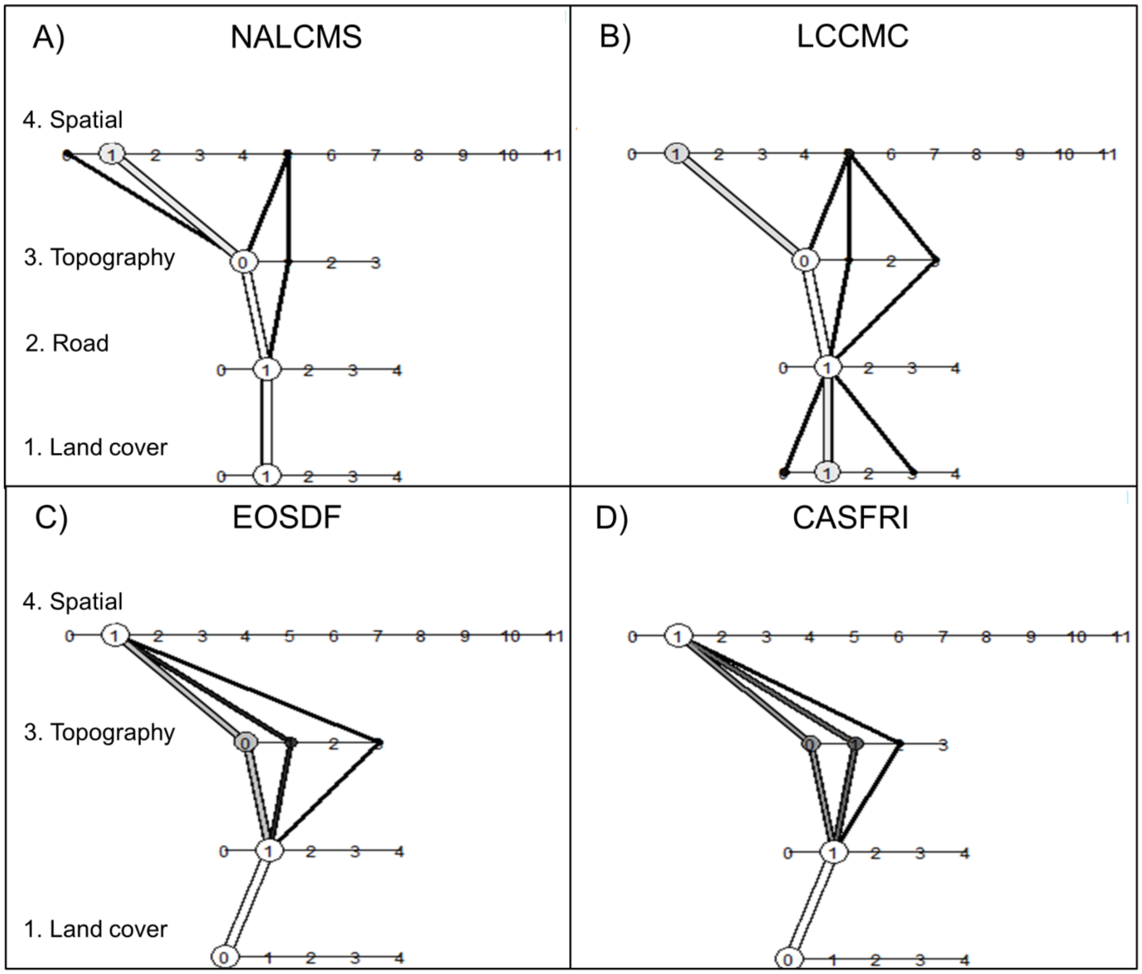


Figure 10. Selection paths of variables best explaining variation in abundance of Common nighthawk across Canada based on the branching hierarchy model building process. Results for the four BCR model subsets represent selection frequencies from 200 bootstrap iterations. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendices 14-17 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendices 14-17).

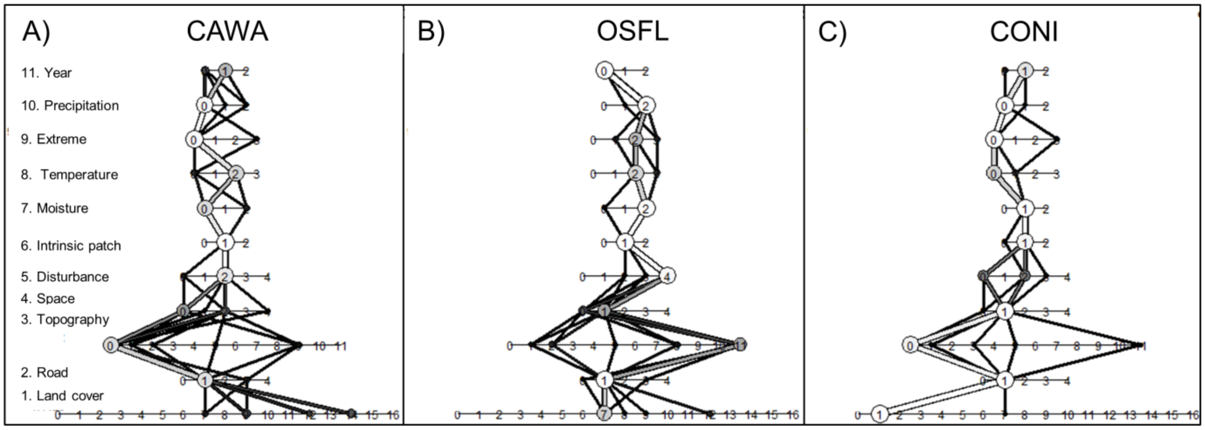


Figure 11. Selection paths of variables best explaining variation in abundance of the three focal species across Canada based on the branching hierarchy model building process. Results represent selection frequencies from 200 bootstrap iterations at each stage leading to the Climate-Landscape model subsets. Horizontal lines are the stages of the branching hierarchy model building process (numbers are the covariate types; see Appendix 13 for details). Size and shade of circles are proportional to selection frequencies (larger and lighter represents higher selection frequencies; idem for thicker and lighter lines; Appendix 13).

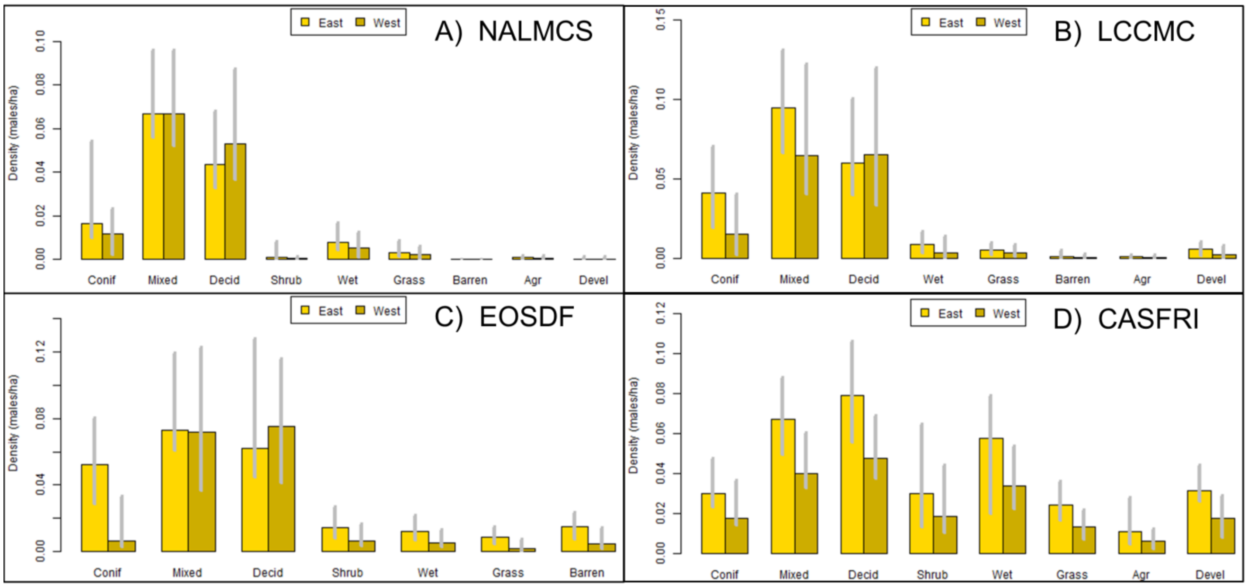


Figure 12. Median CAWA density estimates (± 95% C.I.) as a function of land cover classes and eastern and western Canada. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI). Note that categories available only for one spatial extent (i.e. Burn, LCCMC, and Riparian, CASFRI) are not presented in this figure (see Appendices 18-26 for effect sizes).

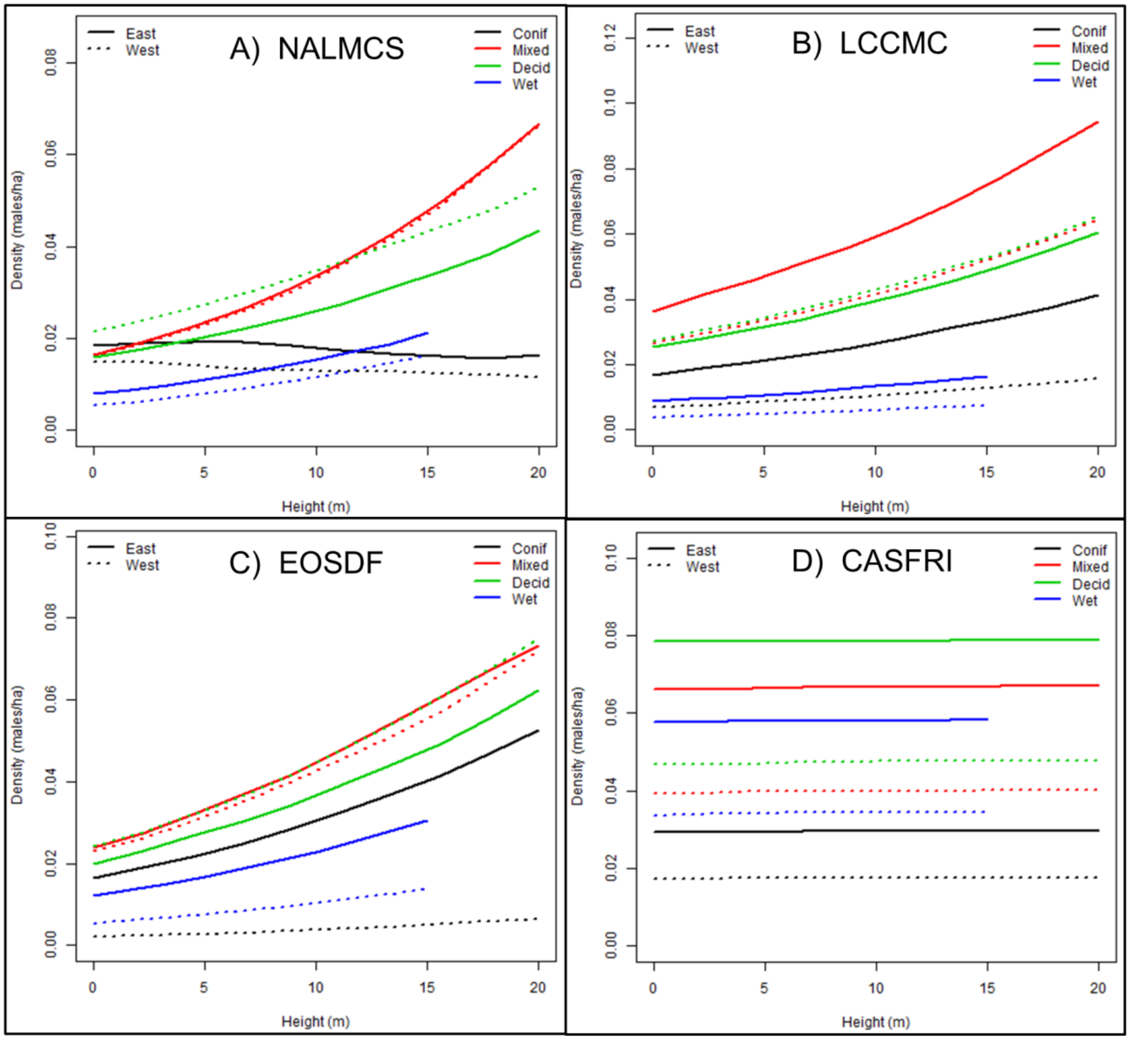


Figure 13. Median CAWA density estimates as a function of canopy height, land cover classes, and eastern and western Canada. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

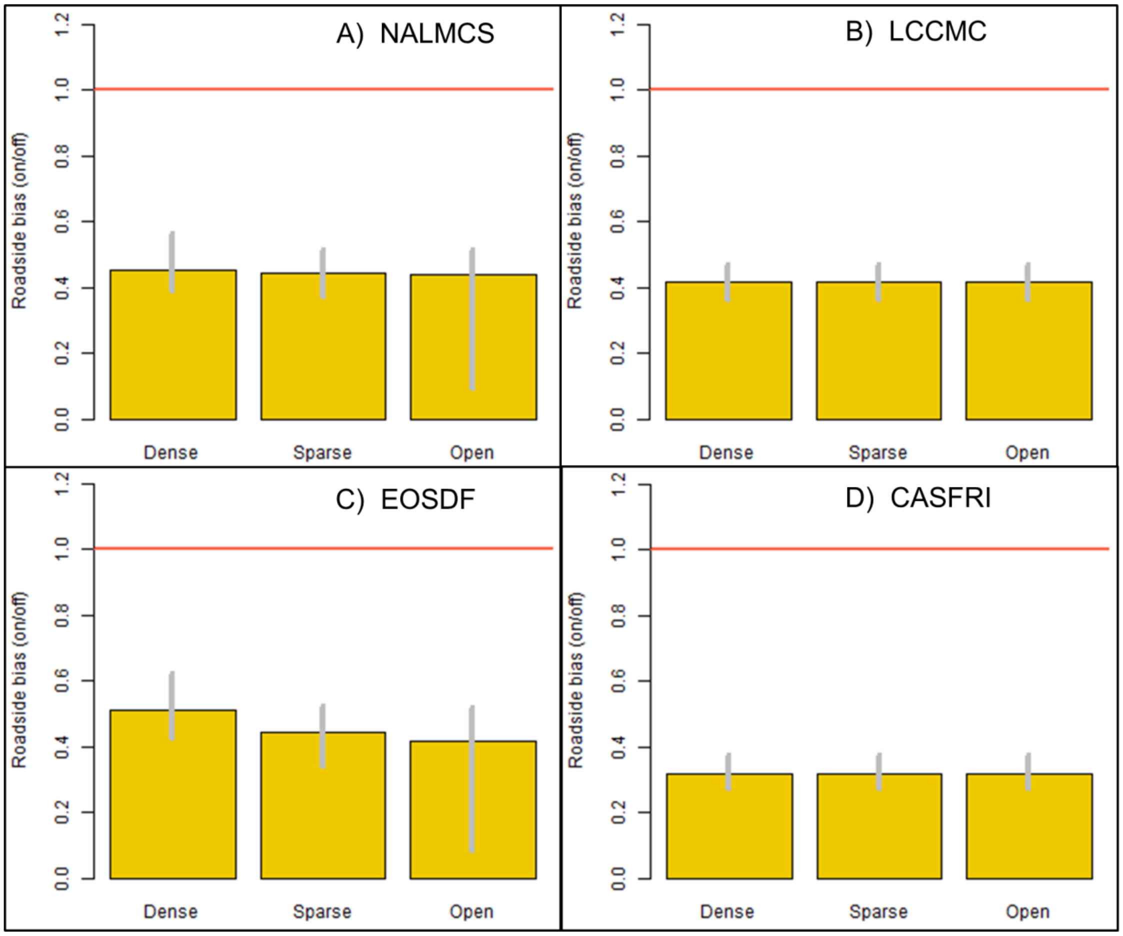


Figure 14. Median roadside bias (± 95% C.I.) in CAWA density estimates as a function of forest cover. Values below the red line represent negative roadside bias (i.e. roadside surveys underestimate CAWA density). Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

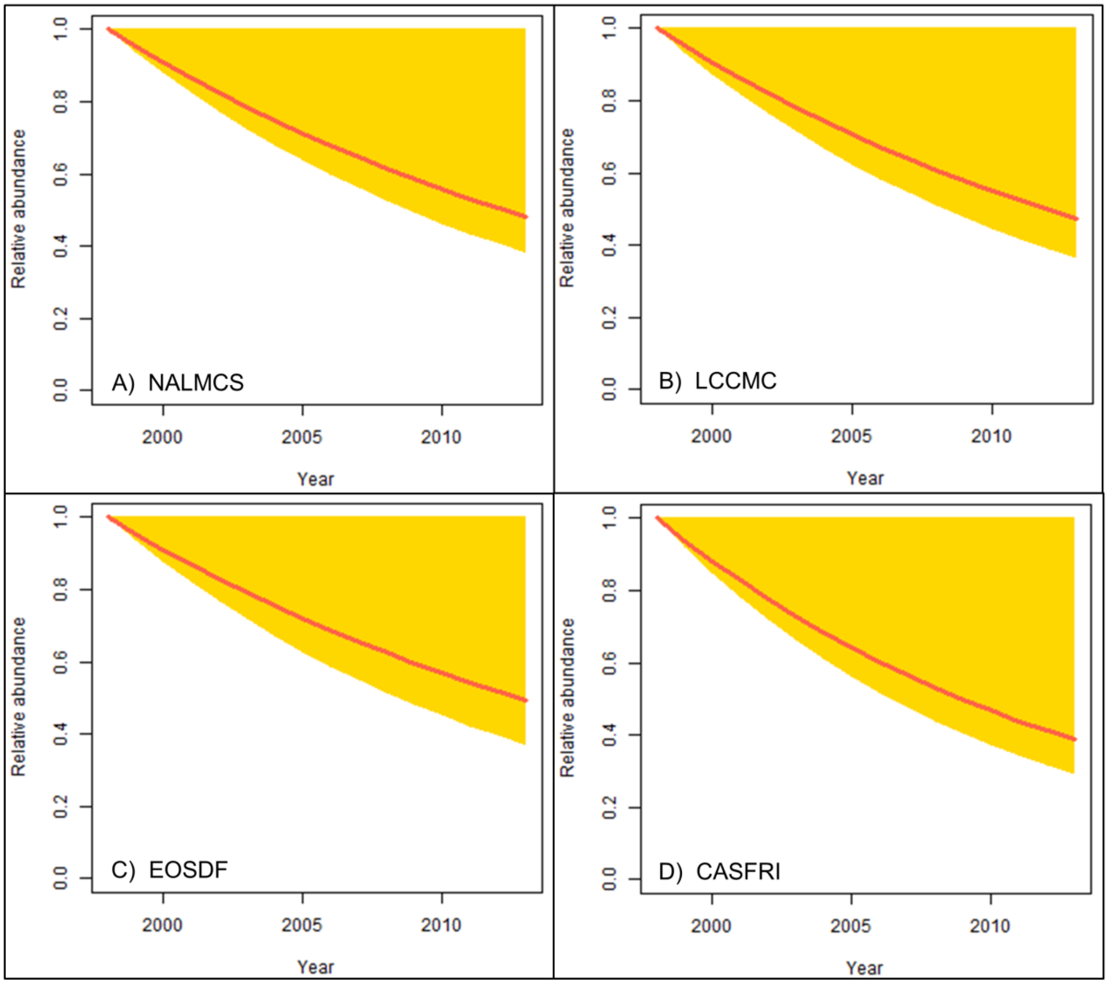


Figure 15. Median CAWA density estimates as a function of year. The yellow area represents 95% C.I. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

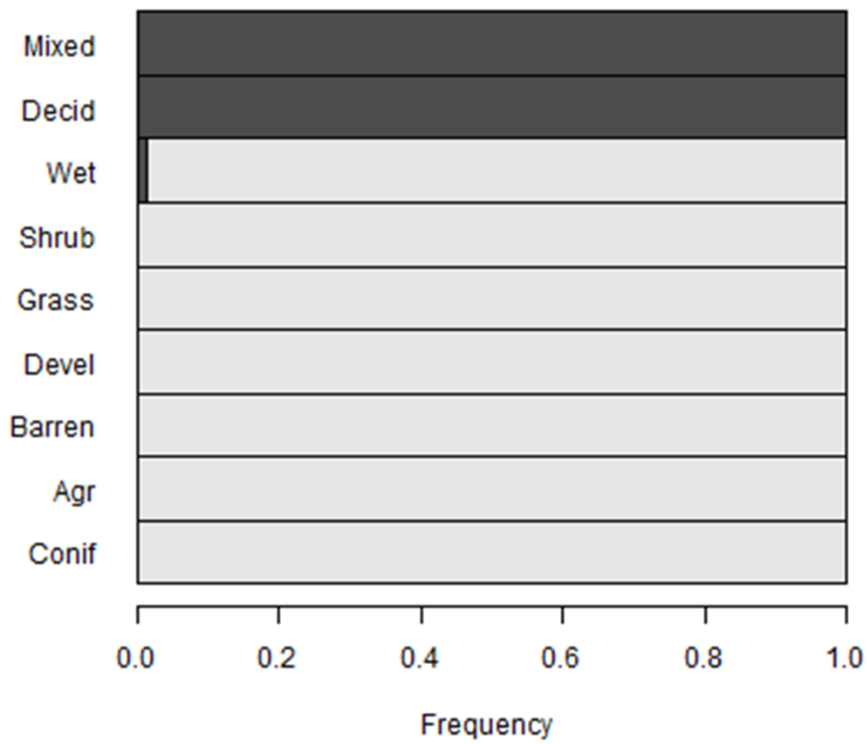


Figure 16. Frequency that a land cover class (NALCMS) was selected as part of the high suitability CAWA habitat (16 km^2; dark grey) based on Lorenz-tangent. These results were generated from the Climate-Landscape model subset (NALCMS).

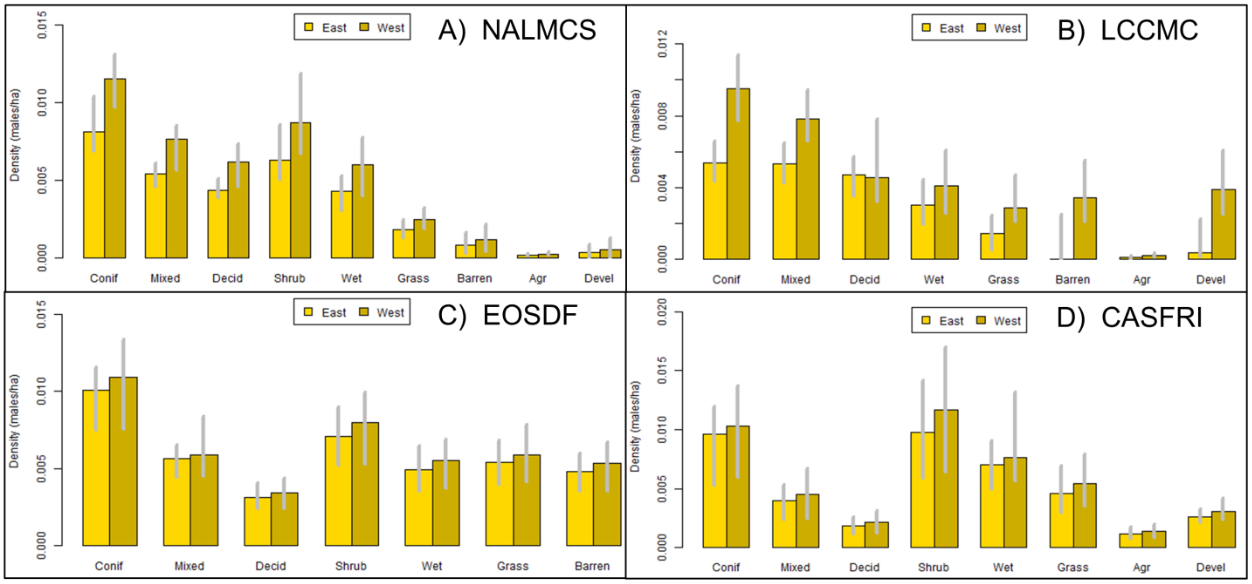


Figure 17. Median OSFL density estimates (± 95% C.I.) as a function of land cover classes and eastern and western Canada. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI). Note that categories available only for one spatial extent (i.e. Burn, LCCMC, and Riparian, CASFRI) are not presented in this figure (see Appendices 18-26 for effect sizes).

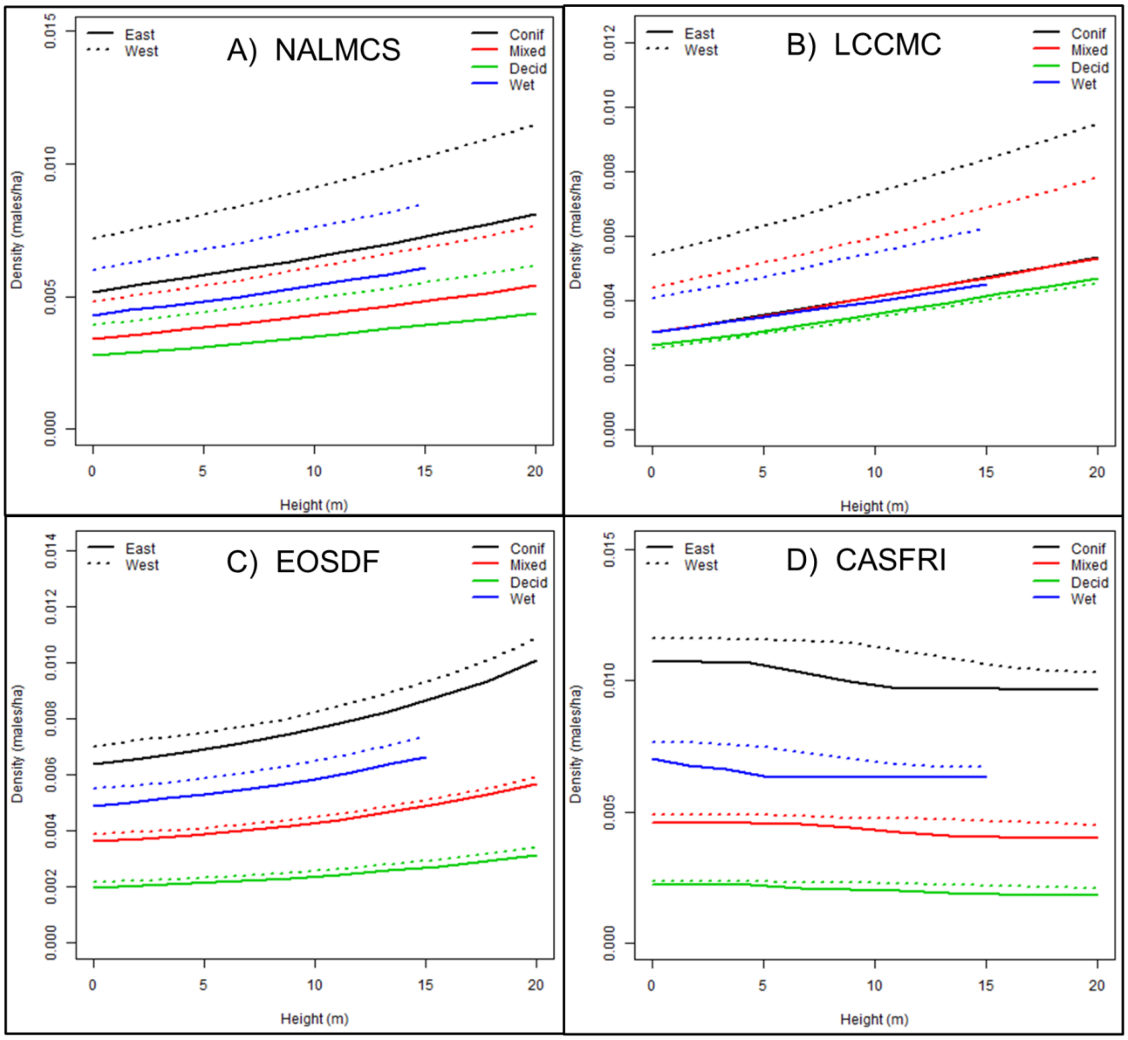


Figure 18. Median OSFL density estimates as a function of canopy height, land cover classes, and eastern and western Canada. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

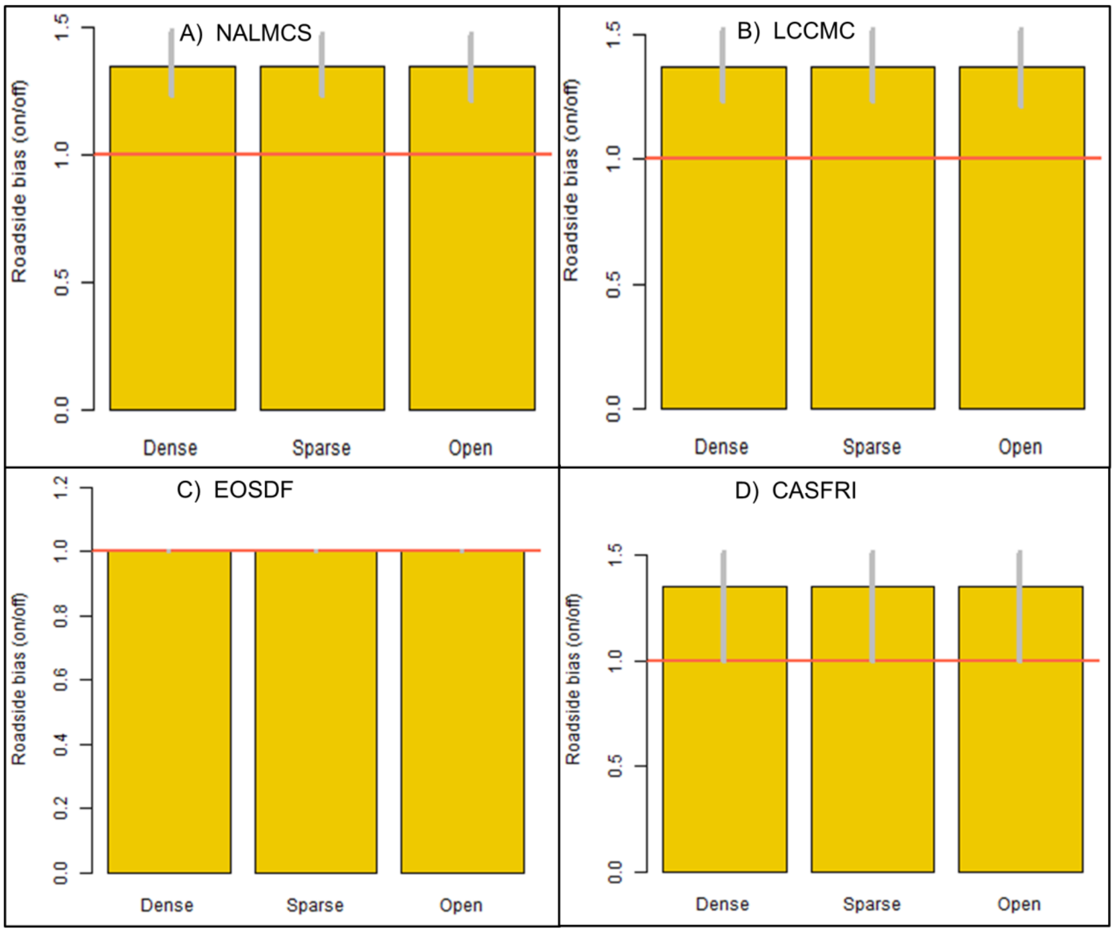


Figure 19. Median roadside bias (± 95% C.I.) in OSFL density estimates as a function of forest cover. Values of 1 (red line) represent no bias and those above 1 indicate positive roadside bias (i.e. roadside surveys overestimate OSFL density). Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

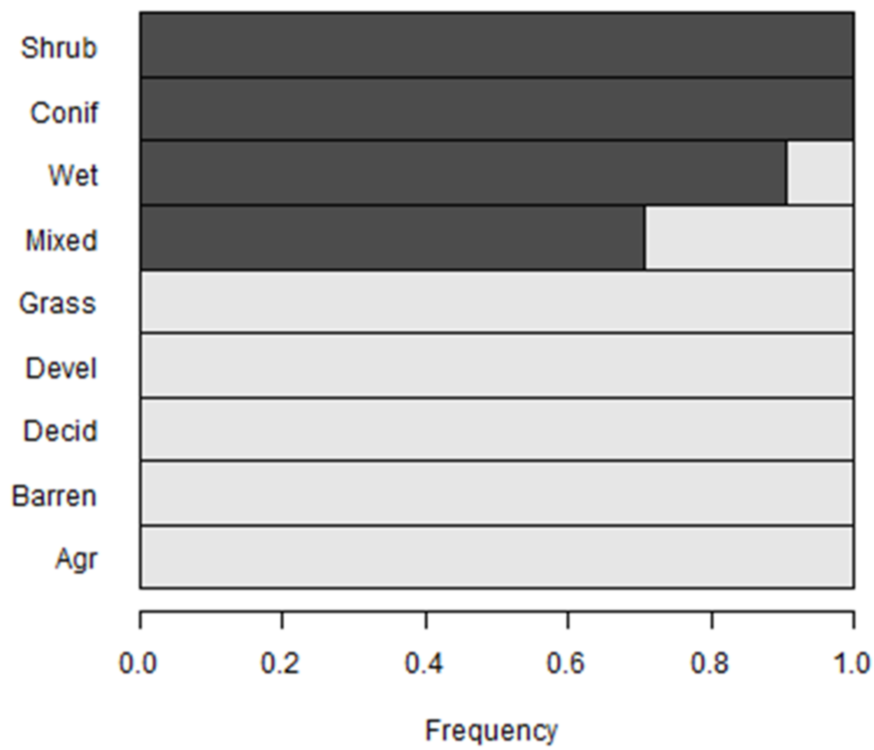


Figure 20. Frequency that a land cover class (NALCMS) was selected as part of the high suitability OSFL habitat (16 km^2; dark grey) based on Lorenz-tangent. These results were generated from the Climate-Landscape model subset (NALCMS).

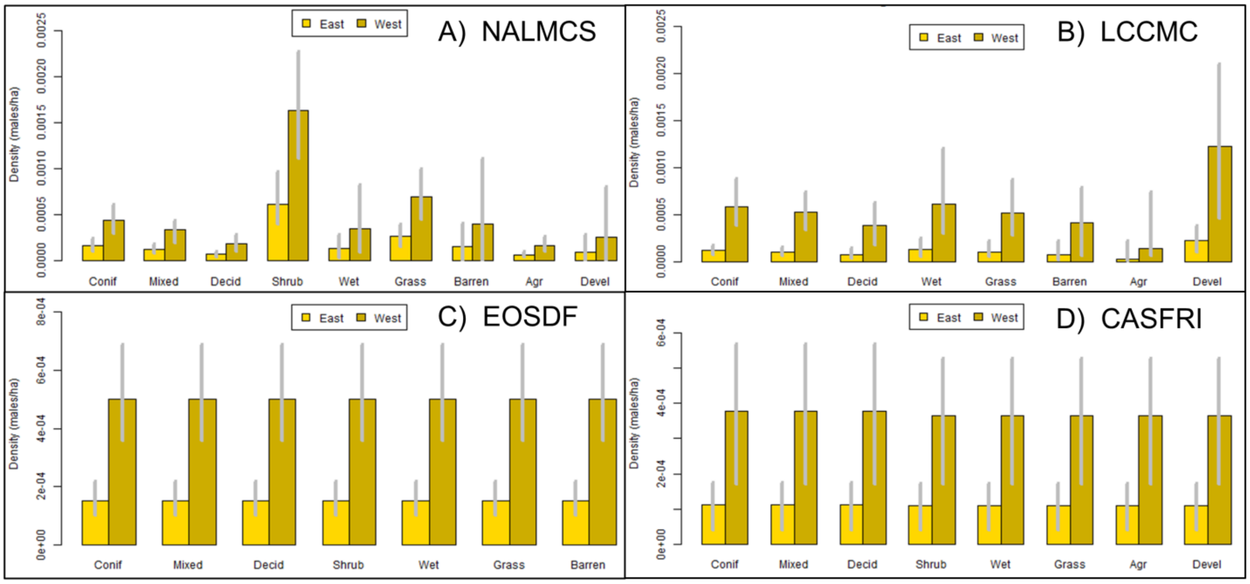


Figure 21. Median CONI density estimates (± 95% C.I.) as a function of land cover classes and eastern and western Canada. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI). Note that categories available only for one spatial extent (i.e. Burn, LCCMC, and Riparian, CASFRI) are not presented in this figure (see Appendices 18-26 for effect sizes).

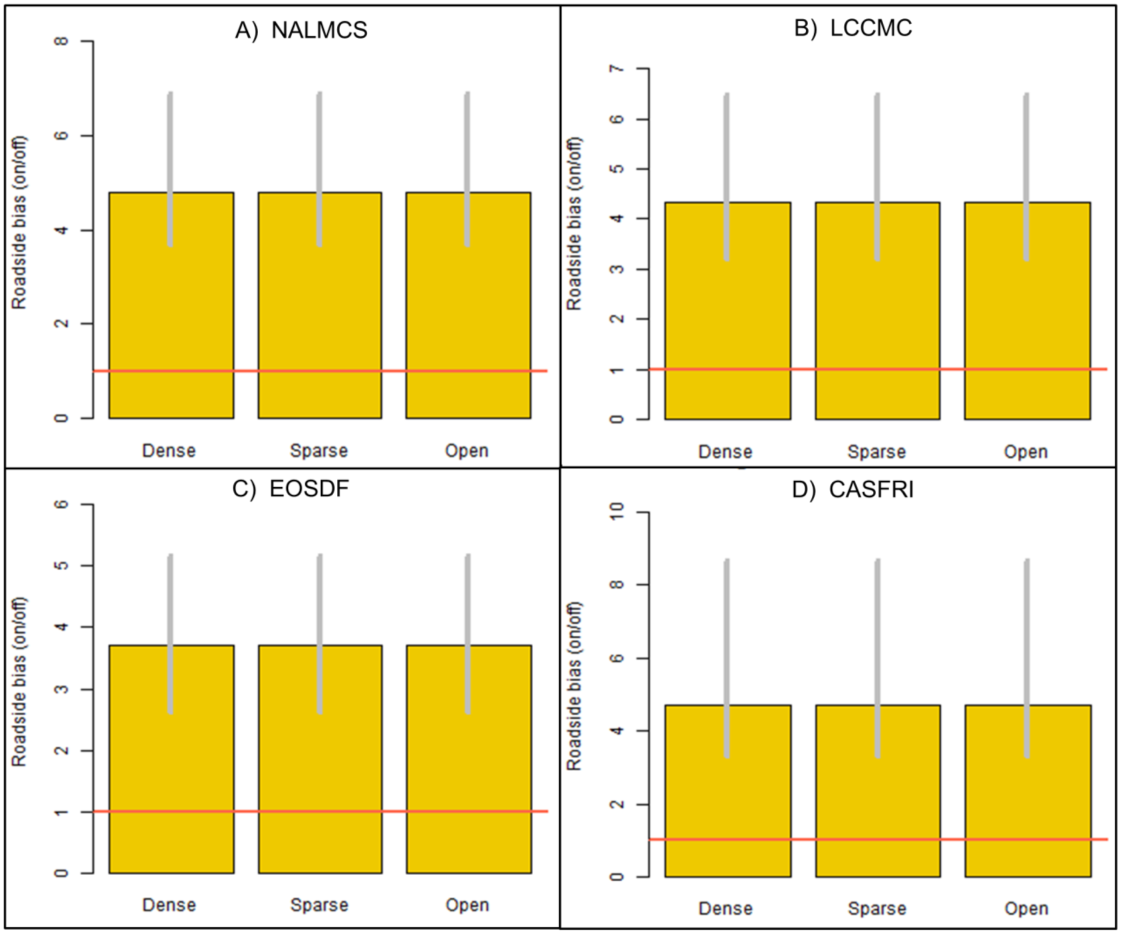


Figure 22. Median roadside bias (± 95% C.I.) in CONI density estimates as a function of forest cover. Values of 1 (red line) represent no bias and those above 1 indicate positive roadside bias (i.e. roadside surveys overestimate CONI density). Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

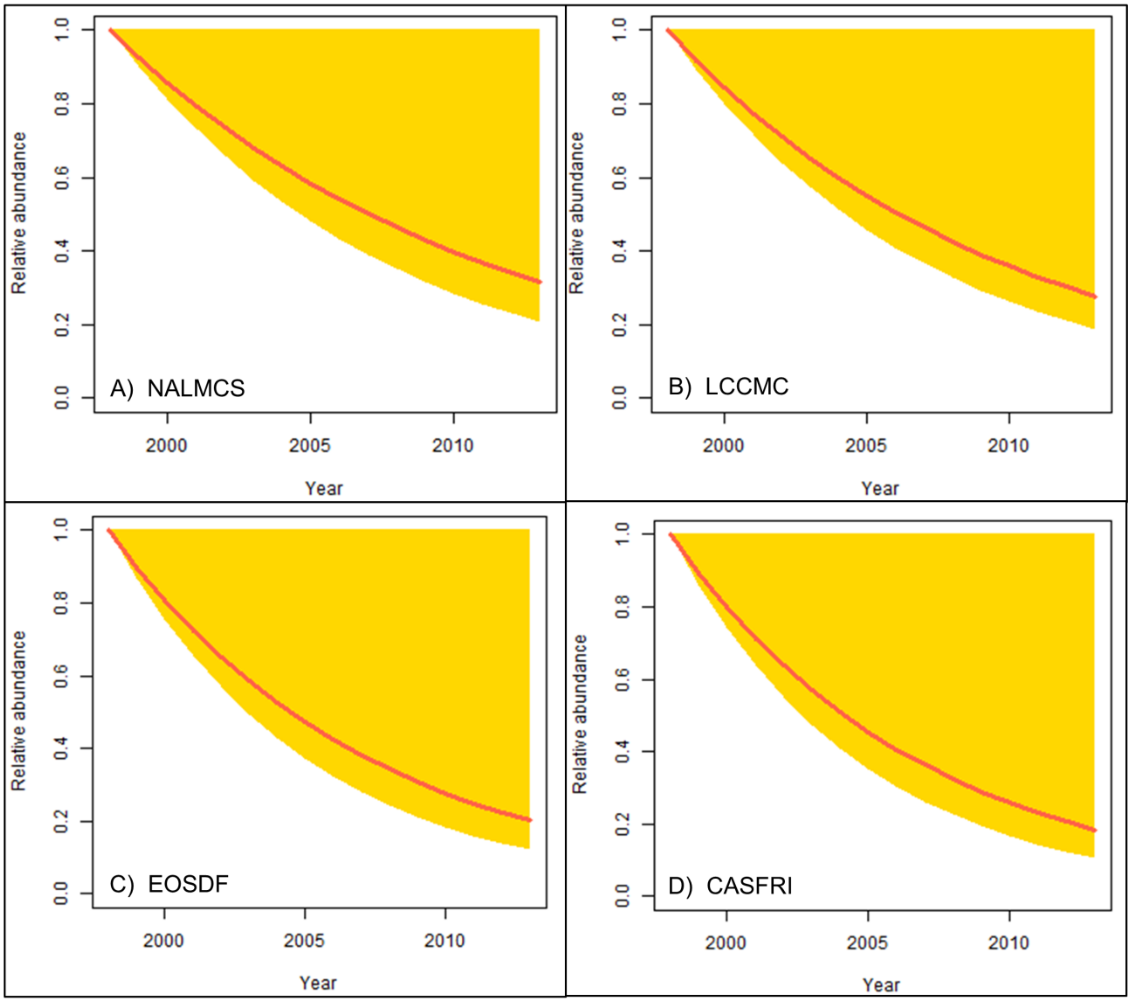


Figure 23. Median CONI density estimates as a function of year. The yellow area represents 95% C.I. Estimates were derived from the Climate model subsets and four spatial extents (NALCMS, LCCMC, EOSDF, and CASFRI).

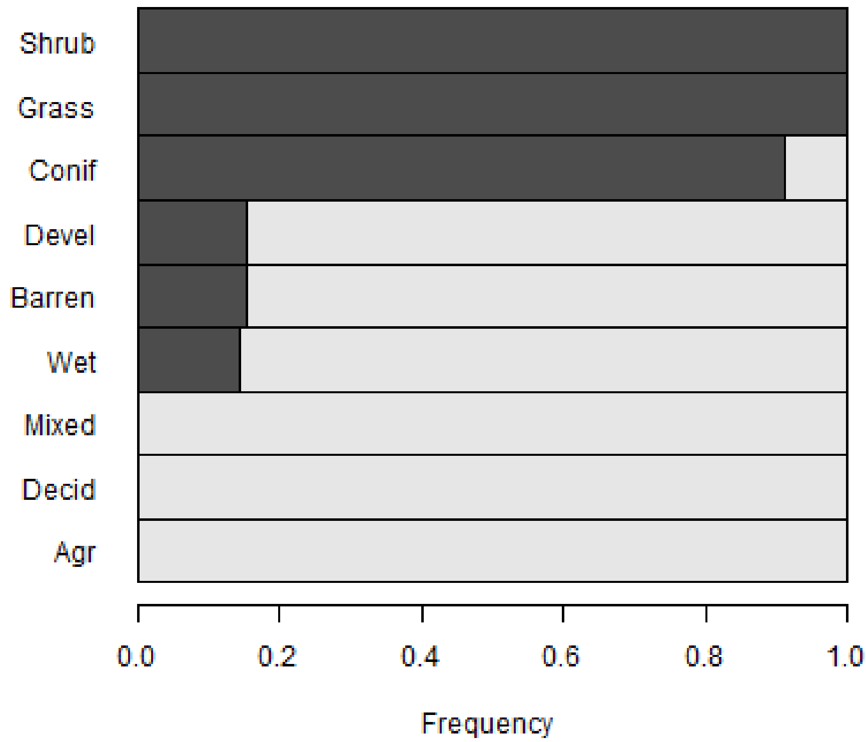
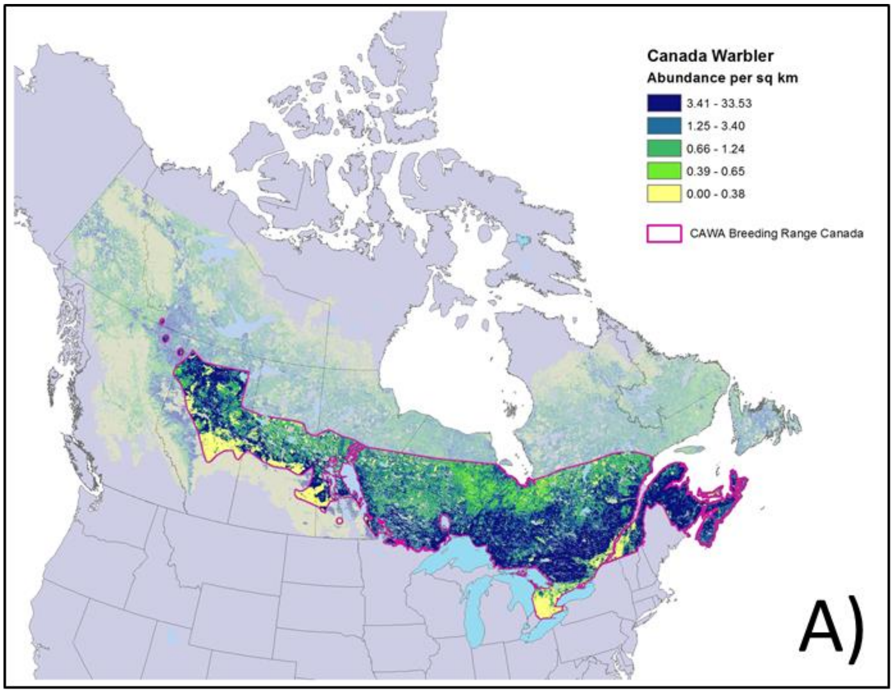


Figure 24. Frequency that a land cover class (NALCMS) was selected as part of the high suitability CONI habitat (16 km^2; dark grey) based on Lorenz-tangent. These results were generated from the Climate-Landscape model subset (NALCMS).



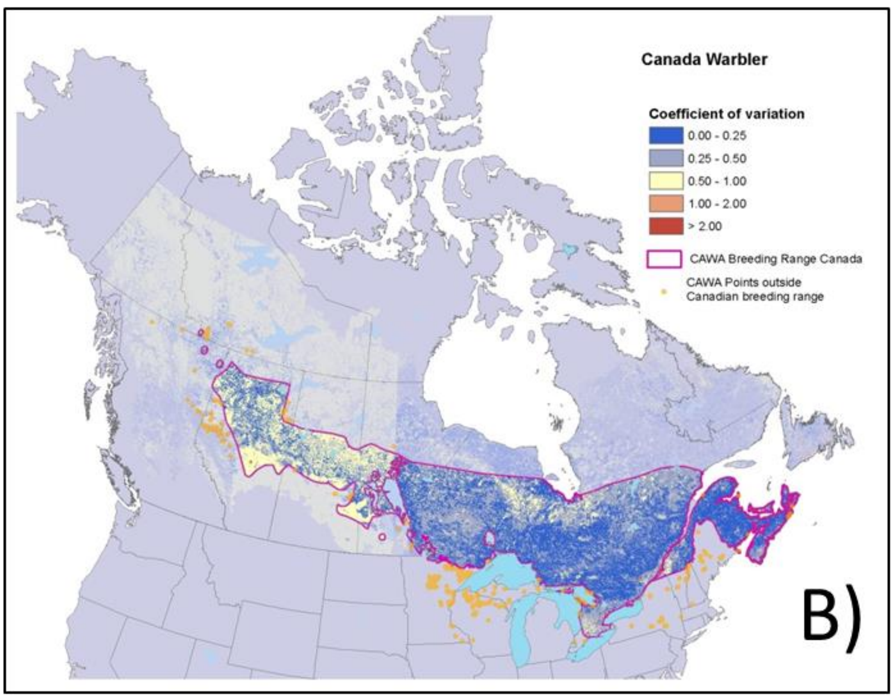


Figure 25. Predicted abundance (/km^2; A) and related coefficient of variation (B) for CAWA across its Canadian breeding range (in purple) according to Nature Serve (http://www.natureserve). The range of predicted abundance values (and corresponding colors) is presented as percentages of the total population (i.e. 0-5, 5-10, 10-25, 25-50, and 50-100%). For example, the area in yellow would support 5% of the total population and the area in dark blue would support 50% of the total population. Shaded area represents predicted values across the

Canadian boreal forest. Note that percentages of total population size refer to predicted values across the Canadian boreal forest. In orange, are sampling locations from BAM database where the species was detected beyond the Canadian breeding range. Values from these locations were also used to generate the bird habitat models. Values were generated from the Climate-Landscape model subset.

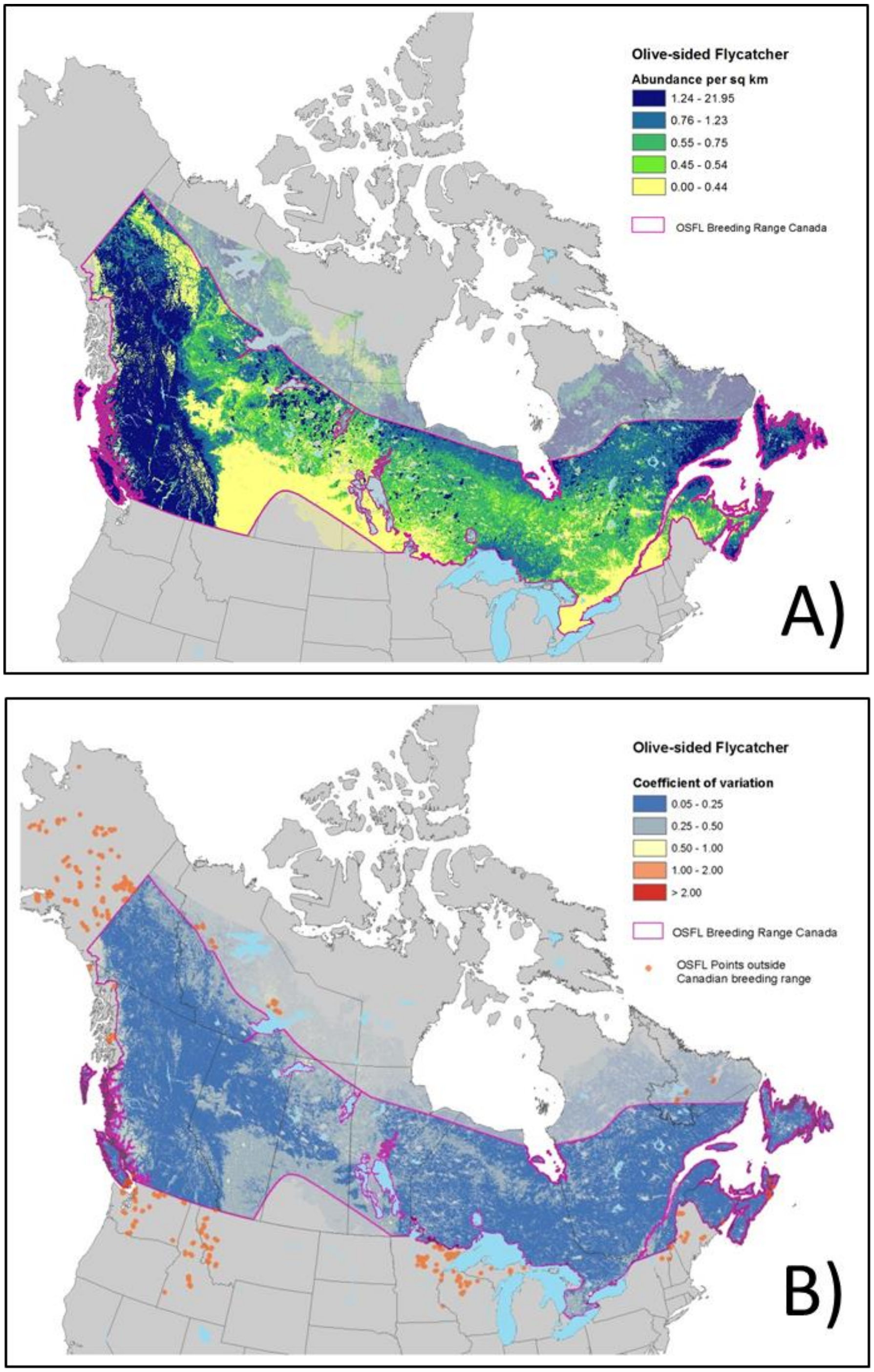
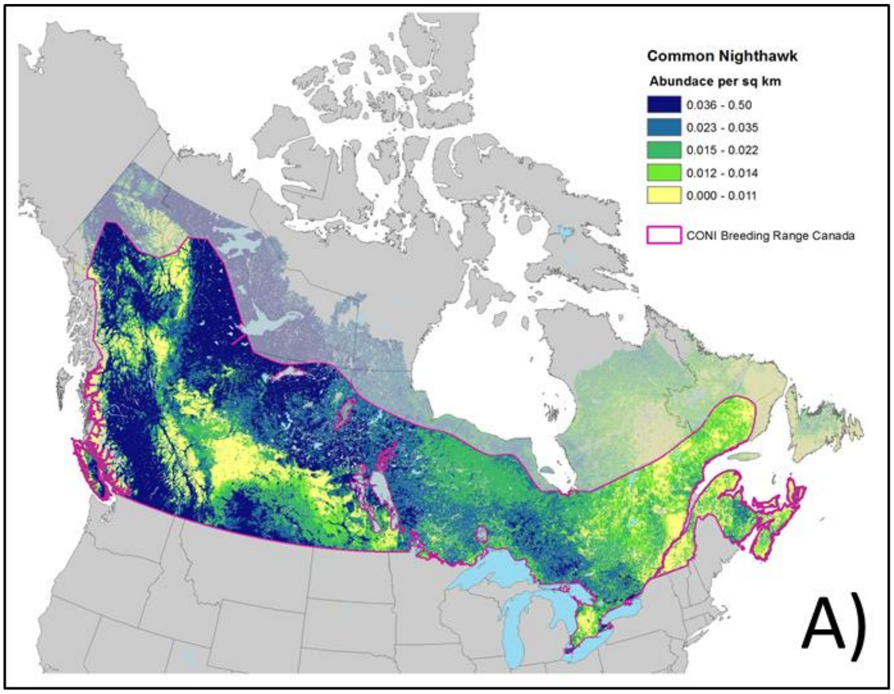


Figure 26. Predicted abundance (/km^2; A) and related coefficient of variation (B) for OSFL across its Canadian breeding range (in purple) according to Nature Serve (http://www.natureserve). The range of predicted abundance values (and corresponding colors) is presented as percentages of the total population (i.e. 0-5, 5-10, 10-25, 25-50, and 50-100%). For example, the area in yellow would support 5% of the total population and the area in dark blue would support 50% of the total population. Shaded area represents predicted values across the

Canadian boreal forest. Note that percentages of total population size refer to predicted values across the Canadian boreal forest. In orange, are sampling locations from BAM database where the species was detected beyond the Canadian breeding range. Values from these locations were also used to generate the bird habitat models. Values were generated from the Climate-Landscape model subset.



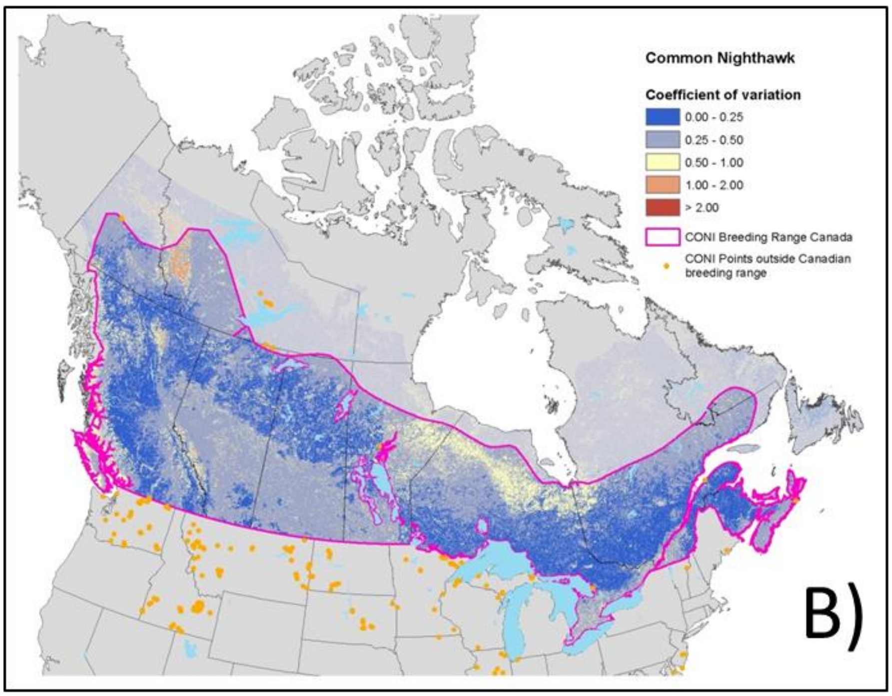


Figure 27. Predicted abundance (/km^2; A) and related coefficient of variation (B) for CONI across its Canadian breeding range (in purple) according to Nature Serve (http://www.natureserve). The range of predicted abundance values (and corresponding colors) is presented as percentages of the total population (i.e. 0-5, 5-10, 10-25, 25-50, and 50-100%). For example, the area in yellow would support 5% of the total population and the area in dark blue would support 50% of the total population. Shaded area represents predicted values across the

Canadian boreal forest. Note that percentages of total population size refer to predicted values across the Canadian boreal forest. In orange, are sampling locations from BAM database where the species was detected beyond the Canadian breeding range. Values from these locations were also used to generate the bird habitat models. Values were generated from the Climate-Landscape model subset.

Table 1. Number of sampling locations with at least one individual detected for each focal species by Province, BCR, and in Canada and USA.

BCR	Province/Territory	CAWA	OSFL	CONI
4	BC	0	15	3
4	NT	0	1	0
4	YT	0	515	20
5	BC	0	423	41
6	AB	463	363	45
6	BC	8	41	3
6	MB	408	46	0
6	NT	290	38	14
6	SK	76	20	23
7	NL	0	14	0
7	NT	0	15	8
7	ON	3	30	0
8	ON	410	77	24
8	NL	0	77	0
8	QC	47	100	4
8	SK	0	24	5
9	BC	0	346	164
10	AB	0	259	10
10	BC	1	1130	242
11	AB	0	17	81
11	MB	5	1	0
11	SK	0	0	28
12	ON	1150	537	41
12	QC	335	155	6

13	ON	170	16	53
13	QC	48	1	2
14	NB	427	293	45
14	NS	257	525	47
14	PE	9	20	0
14	QC	167	56	8
Canada		**4474**	**5421**	**918**
USA		**275**	**2108**	**870**
Total		**4749**	**7529**	**1788**

Table 2. Land cover variables used to generate bird habitat models.

Variable	Description	Spatial resolution	Spatial extent	Source
LC_NALCMS	Conifer, Deciduous, Mixedwood, Agriculture, Grass, Barren ground, Shrub, Wet, or Urban development	250 m	CAN/USA	NALCMS[1]
LC_LCCMC	Conifer, Deciduous, Mixedwood, Agriculture, Barren ground, Burn, Grass, Urban development, or Wet	250 m	CAN	LCCMC[2]
LC_EOSDF	Conifer, Deciduous, Mixedwood, Barren ground, Grass, Shrub, or Wet	25 m	Canadian forests	EOSDF[3]
LC_FRI	Conifer, Deciduous, Mixedwood, Agriculture, Grass, Riparian, Shrub, Urban development, or Wet	150 m	Canadian forests managed by forestry companies[1]	CASFRI[4]
HEIGHT_FRI	Canopy height (m)	150 m	Canadian forests managed by forestry companies[1]	CASFRI[4]
FC_FRI	Forest cover (open < 25%, sparse = 25-60%, and dense > 60%)	150 m	Canadian forests managed by forestry companies[1]	CASFRI[4]
HEIGHT	Canopy height (m)	1 km	CAN/USA	GMFCH[5]
FC	Forest cover (open < 25%, sparse = 25-60%, and dense > 60%)	500 m	CAN/USA	GPTC[6]
Decid	Dummy variable (Deciduous stand)	250 m	CAN/USA	NALCMS[1], LCCMC[2], EOSDF[3], and

				CASFRI[4]
Mixed	Dummy variable (Mixedwood stand)	250 m	CAN/USA	NALCMS[1], LCCMC[2], EOSDF[3], and CASFRI[4]
Nonforest	Dummy variable (Non-forested stand)	250 m	CAN/USA	NALCMS[1], LCCMC[2], EOSDF[3], and CASFRI[4]

[1] North American Land Cover Monitoring System (Commission for Environmental Cooperation 2014).

[2] Land classification cover map of Canada 2005 (Natural Resource Canada 2014a).

[3] Earth Observation for Sustainable Development of Forests layer (Wulder et al. 2008).

[4] Common Attribute Schema from Canada's Forest Resource Inventories (Cumming et al. 2010).

[5] Global Map of Forest Canopy Height (Simard et al 2011; Oak Ridge National Laboratory 2014).

[6] Global Percent Tree Cover (Hansen et al. 2003).

Table 3. Disturbance variables used to generate bird habitat models.

Variable	Description	Spatial resolution	Spatial extent	Source
CC	Clearcut (0-1: ≤ 10 years between year of sampling and year since the most recent harvesting)	150 m	Canadian forests managed by forestry companies[1]	CASFRI[1]
LD	Density of linear disturbances (km/km^2; airstrips, dams, pipelines, powerlines, railways, roads, and seismic exploration lines)	1 km	Boreal forest[2]	BEAD[2]
PD	Total polygonal disturbances (%; agriculture, cutblocks, mines, oil and gas infrastructure, reservoirs, settlements, and well sites)	1 km	Boreal forest[2]	BEAD[2]
BURN	Burn (0-1: ≤ 10 years between year of sampling and year of since most recent fire)	30 m	CAN/USA	CWDFIS[3] MTBS[4]
AgrDev	Proportion of agriculture/ urban development within a 4 km × 4 km	250 m	CAN/USA	NALCMS[5]

[1] Common Attribute Schema from Canada's Forest Resource Inventories (Cumming et al. 2010).

[2] Boreal ecosystem anthropogenic disturbance layers (Pasher et al. 2013; Government of Canada 2014b).

[3] Canadian Wildland Database Fire Information System (Natural Resources Canada 2014b).

[4] Monitoring Trends in Burn Severity 2014.

[5] North American Land Cover Monitoring System (Commission for Environmental Cooperation 2014).

Table 4. Topographic variables used to generate bird habitat models.

Variable	Description	Spatial resolution	Spatial extent	Source
TWI	Topographic wetness index	90 m	CAN/USA	GLSDEM[1]
SLOPE	Slope (radian)	90 m	CAN/USA	GLSDEM [1]
WET	Proportion of wet areas within 4 km × 4 km cells	250 m	CAN/USA	NALCMS[2]
WetWater	Proportion of wet areas and water bodies within 4 km × 4 km cells	250 m	CAN/USA	NALCMS[2]

[1] Variables generated from the Global Land Survey Digital Elevation Model (Global Land Cover Facility 2014).

[2] North American Land Cover Monitoring System (Commission for Environmental Cooperation 2014).

Table 5. Climate variables used to generate bird habitat models. The spatial resolution was 4 km and data was extracted for all avian point counts in the dataset (Canada and USA). All climate data can be retrieved from Dr. Andreas Hamann's personal website (www.ualberta.ca/~ahamann/data/ climatena.html).

Covariate	Description
MAP	Mean annual precipitation (mm)
MSP	Mean summer (May-Sep) precipitation (mm)
DD0	Degree days below 0 °C
DD5	Degree days above 5 °C
EMT	Extreme minimum temperature (°C)
PET	Potential evapotranspiration (cm)[1]
MAT	Mean annual temperature (mm)
TD	Temperature difference (mean temperature of the warmest month - mean temperature of the coldest month; °C)
CMI	Climate moisture index (precipitation – potential evapotranspiration; mm)[1]
CMIJJA	Climate moisture index for June/July/August (mm)[1]

[1] Calculated using Hogg's (1997) modified Penman-Monteith method.

Table 6. Transformations applied to variables with unsuitable distributions. "x_i" represents a value for a given variable.

Variable	Transformation
TWI[1]	$(x_i - 8)/2$
SLOPE[1]	$\mathrm{sqrt}(x_i)$
LD[2]	$\log(x_i + 1)$
HEIGHT[3]	$x_i/50$
CMIJJA[4]	$x_i/50$
CMI[4]	$x_i/50$
MAT[4]	$x_i/100$
TD[4]	$(x_i - 300)/100$
PET[4]	$(x_i - 500)/400$
DD0[4]	$(x_i - 1000)/1000$
DD5[4]	$(x_i - 1600)/1000$
EMT[4]	$(x_i + 400)/100$
MAP[4]	$\log(x_i/100) - 2$
MSP[4]	$(x_i - 400)/200$

[1] Variables generated from Global Land Survey Digital Elevation Models (Global Land Cover Facility 2014).

[2] Boreal ecosystem anthropogenic disturbance layers (Pasher et al. 2013; Government of Canada 2014b).

[3] Global Map of Forest Canopy Height (Oak Ridge National Laboratory 2014; Simard et al. 2011).

[4] Climate variables can be retrieved from Dr. Andreas Hamann's personal website (www.ualberta.ca/~ahamann/data/ climatena.html).

Table 7. Number of points (1 km apart) generated within the breeding range of each species (http://www.natureserve.org/) used for predicting species-species density across Canada and by Canadian BCR, province/territory, and Canadian BCR by province/territory.

BCR	Province/Territory	CAWA	CONI	OSFL
3	YT	0	0	1137
4	BC	0	179080	186518
4	NT	180	50228	81662
4	YT	315	183604	382492
5	BC	0	174902	197558
5	YT	0	0	4106
6	AB	251311	425086	428181
6	BC	6349	103727	103727
6	MB	66267	84981	84980
6	NT	385	212660	207355
6	SK	127912	167922	167922
6	YT	327	745	7022
7	AB	48	5705	8441
7	MB	0	46818	62478
7	NL	0	31101	38292
7	NT	0	1961	20248
7	NU	0	0	3398
7	ON	136072	173456	224481
7	QC	14050	19272	158484
7	SK	0	34069	21415
8	AB	0	4686	4686
8	MB	117496	217381	217357

8	NL	0	3673	110361
8	ON	407506	420602	420571
8	QC	263690	352499	442863
8	SK	41685	166429	166411
9	BC	0	59347	59347
10	AB	0	52705	52705
10	BC	0	372858	372858
11	AB	18092	147581	144016
11	MB	5557	68669	36118
11	SK	8602	238547	56081
12	MB	10125	14833	14834
12	ON	201641	201955	201918
12	QC	174872	175008	174886
13	ON	75141	85800	70628
13	QC	28324	28812	28731
14	NB	74138	74143	74141
14	NS	55814	55814	55815
14	PE	5869	5869	5869
14	QC	67533	67450	67794
Total		**2159301**	**4710068**	**5167887**

Table 8. Top ranked variables explaining variation in abundance for the three focal species based on the different model subsets and spatial extent (total of 27 model subsets). Models represent the top rank variable from each stage of the model building process. See Figures 5 - 11 for model uncertainty (i.e. variable selection paths resulting from the model building process).

Species	Variable set	Spatial extent	Top ranked model
CAWA	Climate	CASFRI	Count ~ LC + FC_FRI + ROAD + EA_WE + TD + YR
		LCCMC	Count ~ LC + HEIGHT + FC + ROAD + TWI + SLOPE + EA_WE + TD + MSP + YR
		EOSDF	Count ~ LC + HEIGHT + $HEIGHT^2$ + ROAD + EA_WE + EA_WE × LC + PET + EMT + MSP + YR
		NALCMS	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest + ROAD + TD + MSP + YR
	BCR	CASFRI	Count ~ LC + ROAD + BCR
		LCCMC	Count ~ LC + FC + ROAD + TWI + SLOPE + BCR
		EOSDF	Count ~ LC + FC + ROAD + BCR
		NALCMS	Count ~ LC + FC + ROAD + BCR
	Climate-Landscape	NALCMS	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest + ROAD + AgrDev + IP + TD + YR
OSFL	Climate	CASFRI	Count ~ LC + ROAD + TWI + LD + CC + PET + DD5
		LCCMC	Count ~ LC + HEIGHT + $HEIGHT^2$ + FC + ROAD + TWI + SLOPE + EA_WE + EA_WE × LC + LD + BURN + CMI + PET + DD5 + MSP

		EOSDF	Count ~ LC + HEIGHT + $HEIGHT^2$ + TWI + LD + BURN + TD + DD5
		NALCMS	Count ~ LC + HEIGHT + ROAD + TWI + EA_WE + BURN + CMI + PET + DD5 + MSP
	BCR	CASFRI	Count ~ LC + ROAD + TWI + BCR
		LCCMC	Count ~ LC + FC + ROAD + TWI + SLOPE + BCR
		EOSDF	Count ~ LC + BCR + TWI + SLOPE + BCR
		NALCMS	Count ~ LC + FC + ROAD + TWI + TWI^2 + BCR
	Climate-Landscape	NALCMS	Count ~ LC + HEIGHT + ROAD + SLOPE + WetWater + EA_WE + BURN + AgrDev + IP + CMI + TD + DD5 + MSP
CONI	Climate	CASFRI	Count ~ ROAD + TWI + EA_WE + CMIJJA + TD + YR
		LCCMC	Count ~ LC + ROAD + EA_WE + CMIJJA + YR
		EOSDF	Count ~ ROAD + EA_WE + CMIJJA + YR
		NALCMS	Count ~ LC + ROAD + EA_WE + CMIJJA + YR
	BCR	CASFRI	Count ~ ROAD + EA_WE
		LCCMC	Count ~ LC + ROAD + EA_WE
		EOSDF	Count ~ ROAD + EA_WE
		NALCMS	Count ~ LC + ROAD + EA_WE
	Climate-Landscape	NALCMS	Count ~ LC + ROAD + EA_WE + IP + CMIJJA + YR

Table 9. Top ranked variables for each model subset (Climate, BCR, and Climate-Landscape) best explaining variation in abundance of CAWA, OSFL, and CONI across Canada. There were four Climate and four BCR model subsets (NALCMS, LCCMC, EOSDF, and CASFRI). Only reported are covariates that were selected as the top ranked variables at a stage for at least 2 of the 4 model subsets (Climate and BCR subsets). The Climate-Landscape set only had variables from one spatial extent (NALCMS; i.e. presented are variables from the best ranked model; see Appendices 9-17 for details). N/A represents stages that were not included in the 4-stage bootstrap procedure used for the BCR model subsets and "." indicates when the top ranked variable was the null (i.e. top ranked variables from the previous stage).

Stage	CAWA			OSFL			CONI		
	Climate	BCR	Climate-Landscape	Climate	BCR	Climate-Landscape	Climate	BCR	Climate-Landscape
1) Land cover	LC FC HEIGHT	LC FC	LC FC HEIGHT Decid[1] Mixed[1] Nonforest[1]	LC HEIGHT HEIGHT[2]	LC	LC HEIGHT	LC	LC	LC
2) Road	ROAD	ROAD	ROAD	ROAD	ROAD	ROAD	ROAD	ROAD	ROAD
3) Topography	.	.	.	TWI	.	SLOPE WetWater	.	.	.
4) Space	EA_WE	BCR	.	EA_WE	BCR	EA_WE	EA_WE	EA_WE	EA_WE
5) Disturbance	.	N/A	AgrDev	LD	N/A	BURN	.	N/A	.

				BURN		AgrDev			
6) Intrinsic Patch	N/A	N/A	IP	N/A	N/A	IP	N/A.	N/A	IP
7) Moisture	.	N/A	.	CMI	N/A	CMI	CMIJJA	N/A	CMIJJA
8) Temperature	TD	N/A	TD	TD PET	N/A	TD	.	N/A	.
9) Extreme	.	N/A	.	DD5	N/A	DD5	.	N/A	.
10) Precipitation	.	N/A	.	MSP	N/A	MSP	.	N/A	.
11) Year	YR	N/A	YR	.	N/A	.	YR	N/A	YR

Table 10. Estimated abundance of male CAWA (± 95% C.I.) across Canada and by BCR, Province/Territories, and BCR by Province/Territories. Predictions were derived from the Climate-Landscape model subset (NALCMS) and for the species Canadian breeding range according to Nature Serve (http://www.natureserve). Also reported is percentage of males in the different regions, estimates provided by Partners in Flight (PIF(BBS); number of breeding males), and estimates derived from PIF analytical approach using BAM dataset (PIF(BAM)). BCR 3 and 7 were pooled into "Arctic" and 11, 17, and 22 into "Prairies" for the habitat models.

Region	Median	Lower 95% C.I.	Upper 95% C.I.	%	PIF(BBS)	PIF(BAM)
Canada	5537807	4989073	6112450		1515575	1993611
4	965	860	1290	0.0	0	347
6	1132269	980759	1286971	20.6	318426	407617
8	1672922	1455968	1988014	30.5	828981	602252
12	1686394	1532308	1919274	30.7	249318	607102
13	77905	60226	101067	1.4	6818	28046
14	733137	646113	883315	13.4	95193	263929
Arctic	177285	136704	246875	3.2	16428	63823
Prairie	6703	4349	10976	0.1	410	2413
Alberta	689020	599540	785578	12.5	82676	248047
British Columbia	15729	12083	18640	0.3	0	5662
Manitoba	391358	323849	475446	7.1	176557	140889
New Brunswick	320275	280956	372132	5.8	50930	115299
Northwest Territories	1898	1697	2334	<0.1	8689	683
Nova Scotia	142771	117462	224946	2.6	22442	51398
Ontario	2046391	1838928	2310141	37.2	754293	736701
Prince Edward Island	3512	2531	5466	0.1	698	1264
Quebec	1581386	1424725	1880092	28.8	235326	569299
Saskatchewan	300632	248792	351905	5.5	183965	108227

Yukon	1338	1152	1643	<0.1	0	482
4/Northwest Territories	456	397	628	0.0	0	164
4/Yukon	514	442	689	0.0	0	185
6/Alberta	687089	596944	783419	12.5	82664	247352
6/British Columbia	15729	12083	18640	0.3	0	5662
6/Manitoba	162431	134380	214880	3.0	73929	58475
6/Northwest Territories	1434	1276	1744	0.0	8689	516
6/Saskatchewan	269079	231025	311700	4.9	153145	96868
6/Yukon	821	700	976	0.0	0	296
8/Manitoba	191480	152031	229617	3.5	101850	68933
8/Ontario	927901	812214	1093013	16.9	580937	334044
8/Quebec	529616	440375	668085	9.7	115374	190662
8/Saskatchewan	30963	13761	41479	0.6	30820	11147
12/Manitoba	30516	22851	38176	0.6	368	10986
12/Ontario	886608	809142	980885	16.2	153593	319179
12/Quebec	755236	684975	930658	13.8	95358	271885
13/Ontario	55866	42972	72041	1.0	4159	20112
13/Quebec	22626	16520	29698	0.4	2658	8145
14/New Brunswick	320275	280956	372132	5.8	50930	115299
14/Nova Scotia	142771	117462	224946	2.6	22442	51398
14/Prince Edward Island	3512	2531	5466	0.1	698	1264
14/Quebec	261787	232734	299457	4.8	21123	94243
Arctic/Alberta	88	62	115	0.0	12	32
Arctic/Ontario	165417	126852	227758	3.0	15604	59550
Arctic/Quebec	12190	9291	18731	0.2	813	4388
Prairies/Alberta	1980	981	3917	0.0	0	713
Prairies/Manitoba	3421	2571	5127	0.1	410	1231

Prairies/Saskatchewan	1218	643	2248	0.0	0	439

Table 11. Estimated abundance of male OSFL (± 95% C.I.) across Canada and by BCR, Province/Territories, and BCR by Province/Territories. Predictions were derived from the Climate-Landscape model subset (NALCMS) and for the species Canadian breeding range according to Nature Serve (http://www.natureserve). Also reported is percentage of males in the different regions, estimates provided by Partners in Flight (PIF(BBS); number of breeding males), and estimates derived from PIF analytical approach using BAM dataset (PIF(BAM)). BCR 3 and 7 were pooled into "Arctic" and 11, 17, and 22 into "Prairies" for the habitat models.

Region	Median	Lower 95% C.I.	Upper 95% C.I.	%	PIF(BBS)	PIF(BAM)
Canada	4636263	4187490	5117736		437711	713907
4	874868	787572	977028	19.0	103046	139979
5	338427	258729	411613	7.3	21713	54148
6	593532	504684	757971	12.9	47062	94965
8	1017023	883325	1234516	22.0	76453	162724
9	143157	106283	172434	3.1	6880	22905
10	828354	600964	960335	18.0	79007	132537
12	205600	176949	228828	4.5	11522	32896
13	9294	7476	12435	0.2	50	1487
14	123062	103491	140214	2.7	11872	19690
Arctic[1]	471453	368157	584776	10.2	79687	75432
Prairie	9023	5758	12615	0.2	421	1444
Alberta	337699	284526	407953	7.3	17644	54032
British Columbia	1690495	1369762	1941852	36.7	133815	270479
Manitoba	218078	182531	311088	4.7	44840	34893
New Brunswick	39887	33107	44686	0.9	2910	6382
Newfoundland	158870	118448	203153	3.4	8381	25419
Northwest Territories	226792	191967	334209	4.9	52291	36287
Nova Scotia	40014	30867	46557	0.9	5421	6402

Nunavut	2847	2101	3556	0.1	7953	456
Ontario	541378	449428	628115	11.8	35804	86620
Prince Edward Island	933	687	1207	0.0	228	149
Quebec	669108	557108	771561	14.5	26350	107057
Saskatchewan	205227	165439	347312	4.5	32815	32836
Yukon	475022	424668	560980	10.3	69259	76004
4/British Columbia	360897	293227	416597	7.8	23415	57744
4/Northwest Territories	46261	36397	58321	1.0	13387	7402
4/Yukon	466206	416516	545987	10.1	66244	74593
5/British Columbia	338417	258707	411601	7.4	21164	54147
5/Yukon	14	4	104	0.0	549	2
6/Alberta	256232	212811	317318	5.6	14268	40997
6/British Columbia	82859	69709	101226	1.8	6018	13257
6/Manitoba	23270	17440	36981	0.5	6879	3723
6/Northwest Territories	159677	136914	249378	3.5	14202	25548
6/Saskatchewan	60017	48798	86521	1.3	3262	9603
6/Yukon	7919	6676	12576	0.2	2434	1267
8/Alberta	4288	3161	7341	0.1	148	686
8/Manitoba	128968	105561	189810	2.8	29707	20635
8/Newfoundland	122864	85878	157045	2.7	5631	19658
8/Ontario	260031	216426	307575	5.6	4965	41605
8/Quebec	378601	313764	451023	8.2	13443	60576
8/Saskatchewan	121547	93477	215310	2.6	22558	19447
9/British Columbia	143157	106283	172434	3.1	6880	22905
10/Alberta	61956	45388	75109	1.3	2668	9913
10/British Columbia	766318	553252	885254	16.6	76339	122611
12/Manitoba	4399	3754	5411	0.1	1451	704

12/Ontario	106336	91135	119439	2.3	7368	17014
12/Quebec	93784	81373	105516	2.0	2702	15006
13/Ontario	7104	5667	9799	0.2	35	1137
13/Quebec	2199	1797	2717	0.0	15	352
14/New Brunswick	39887	33107	44686	0.9	2910	6382
14/Nova Scotia	40014	30867	46557	0.9	5421	6402
14/Prince Edward Island	933	687	1207	0.0	228	149
14/Quebec	42759	36613	49525	0.9	3313	6841
Arctic/Alberta	6692	5641	13385	0.1	287	1071
Arctic/Manitoba	61787	44057	80499	1.3	6655	9886
Arctic/Newfoundland	38727	30065	48905	0.8	2750	6196
Arctic/Northwest Territories	19328	16259	39402	0.4	24702	3093
Arctic/Nunavut	2847	2101	3556	0.1	7953	456
Arctic/Ontario	166494	116005	220022	3.6	23436	26639
Arctic/Quebec	149430	116649	179534	3.2	6876	23909
Arctic/Saskatchewan	21889	16784	47337	0.5	6995	3502
Arctic/Yukon	1151	920	2216	0.0	33	184
Prairies/Alberta	6432	4076	9061	0.1	274	1029
Prairies/Manitoba	1591	966	2177	0.0	147	255
Prairies/Saskatchewan	1015	589	1549	0.0	0	162

[1] Abundance is the sum of estimated values from BCR 3 and 7. Given that >99% of the individuals would originate from BCR 3, we only provided ±95 % C.I. from estimates of that BCR.

Table 12. Estimated abundance of male CONI (± 95% C.I.) across Canada and by BCR, Province/Territories, and BCR by Province/Territories. Predictions were derived from the Climate-Landscape model subset (NALCMS) and for the species Canadian breeding range according to Nature Serve (http://www.natureserve). Also reported is percentage of males in the different regions, estimates provided by Partners in Flight (PIF(BBS); number of breeding males) estimates, and estimates derived from PIF analytical approach using BAM dataset (PIF(BAM)). BCR 3 and 7 were pooled into "Arctic" and 11, 17, and 22 into "Prairies" for the habitat models.

Region	Median	Lower 95% C.I.	Upper 95% C.I.	%	PIF(BBS)	PIF(BAM)
Canada	134745	97326	177252		433624	19457
4	12777	7792	18244	9.5	7391	1789
5	3264	2139	7019	2.4	27504	457
6	33750	24213	45795	25.1	95654	4725
8	25720	15448	34642	19.2	74371	3601
9	6359	4179	8930	4.7	19248	890
10	18992	12717	26864	14.1	139865	2659
12	7420	5215	9885	5.5	5079	1039
13	1805	1123	2637	1.3	2620	253
14	2493	1768	3497	1.9	11487	349
Arctic	7123	3282	11304	5.3	30306	997
Prairie	14518	9229	21001	10.8	20098	2032
Alberta	19876	14352	26568	14.8	27418	2783
British Columbia	36494	24859	51001	27.2	185764	5109
Manitoba	11544	6839	16146	8.6	47900	1616
New Brunswick	1157	823	1600	0.9	4506	162
Newfoundland	381	192	602	0.3	0	53
Northwest Territories	12157	5975	16735	9.1	65032	1702
Nova Scotia	570	396	967	0.4	5657	80

Ontario	19299	12000	26993	14.4	6025	2702
Prince Edward Island	43	28	65	0.0	15461	6
Quebec	7848	5537	10722	5.8	0	1099
Saskatchewan	17723	12571	25675	13.2	6953	2481
Yukon	7178	4124	10507	5.3	62853	1005
4/British Columbia	4951	3433	6971	3.7	0	693
4/Northwest Territories	661	275	1320	0.5	1353	93
4/Yukon	7166	4114	10491	5.4	6038	1003
5/British Columbia	3264	2139	7019	2.4	27504	457
6/Alberta	12278	8747	16612	9.2	19421	1719
6/British Columbia	3333	2413	4478	2.5	0	467
6/Manitoba	2331	1627	3287	1.7	10687	326
6/Northwest Territories	11452	5614	15791	8.6	44963	1603
6/Saskatchewan	4563	3185	6236	3.4	20566	639
6/Yukon	12	9	17	0.0	16	2
8/Alberta	220	145	305	0.2	202	31
8/Manitoba	6401	3280	9380	4.8	34141	896
8/Newfoundland	42	22	66	0.0	0	6
8/Ontario	9225	5390	12940	6.9	9405	1291
8/Quebec	4098	2581	5981	3.1	4698	574
8/Saskatchewan	5430	3588	7749	4.1	25925	760
9/British Columbia	6359	4179	8930	4.7	19248	890
10/Alberta	761	499	1145	0.6	853	107
10/British Columbia	18227	12227	25850	13.6	139012	2552
12/Manitoba	363	245	520	0.3	712	51
12/Ontario	4674	3301	6350	3.5	3627	654
12/Quebec	2363	1631	3147	1.8	740	331

13/Ontario	1557	963	2275	1.2	2429	218
13/Quebec	250	157	382	0.2	191	35
14/New Brunswick	1157	823	1600	0.9	4506	162
14/Nova Scotia	570	396	967	0.4	5657	80
14/Prince Edward Island	43	28	65	0.0	0	6
14/Quebec	713	501	976	0.5	1324	100
Arctic/Alberta	321	190	453	0.2	265	45
Arctic/Manitoba	1206	498	1815	0.9	0	169
Arctic/Newfoundland	339	170	535	0.3	0	47
Arctic/Northwest Territories	63	28	93	0.0	18716	9
Arctic/Nunavut[1]	0	N/A	N/A	0.0	6025	0
Arctic/Ontario	3616	1714	7063	2.7	0	506
Arctic/Quebec	311	152	531	0.2	0	44
Arctic/Saskatchewan	1206	604	1767	0.9	5300	169
Prairie/Alberta	6268	4135	9240	4.7	6676	877
Prairie/Manitoba	1226	758	1865	0.9	2360	172
Prairie/Saskatchewan	6884	4260	10692	5.1	11062	964

[1] BAM did not generate an abundance estimate for Artic/Nunavut because it was beyond the extent its Canadian breeding range according the Nature Serve (http://www.natureserve). However, estimates are available for this region from Partner's in Flight.

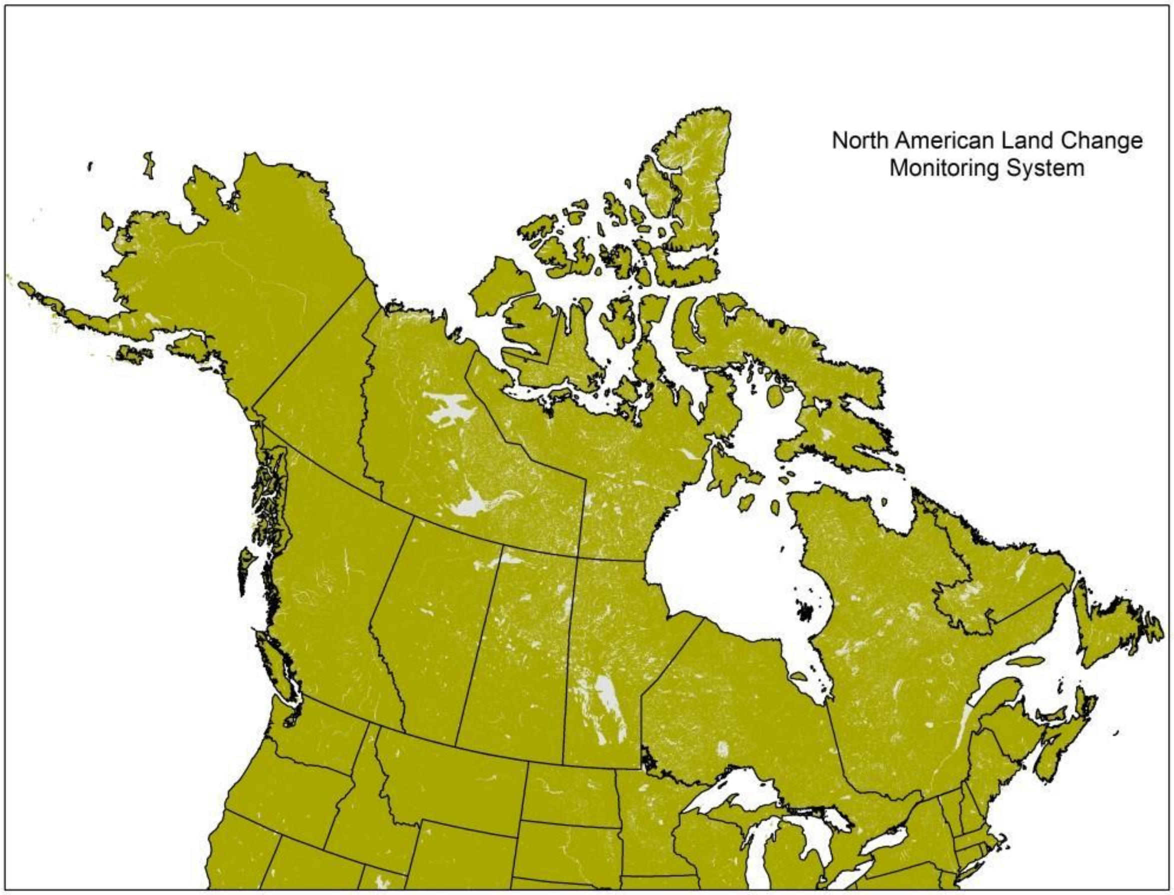
Table 13. BAM population estimates (± 95% C.I.) across Canada for each focal species based on the Climate-Landscape model subsets (NALCMS). Also reported are PIF population estimates for Canada and biases related to two both analytical approaches.

	CAWA	OSFL	CONI
Median_BAM	5537807	4636263	134745
Lower 95% C.I.	4989073	4187490	97326
Upper 95% C.I.	6112450	5117736	177252
PIF(BBS)	1500000	450000	450000
Bias Observed	3.69	10.30	0.15
Bias expected	8.98	7.84	0.26
Bias road	2.45	0.74	0.20
Bias time	1.28	1.46	0.19
Bias area	2.86	7.22	6.93

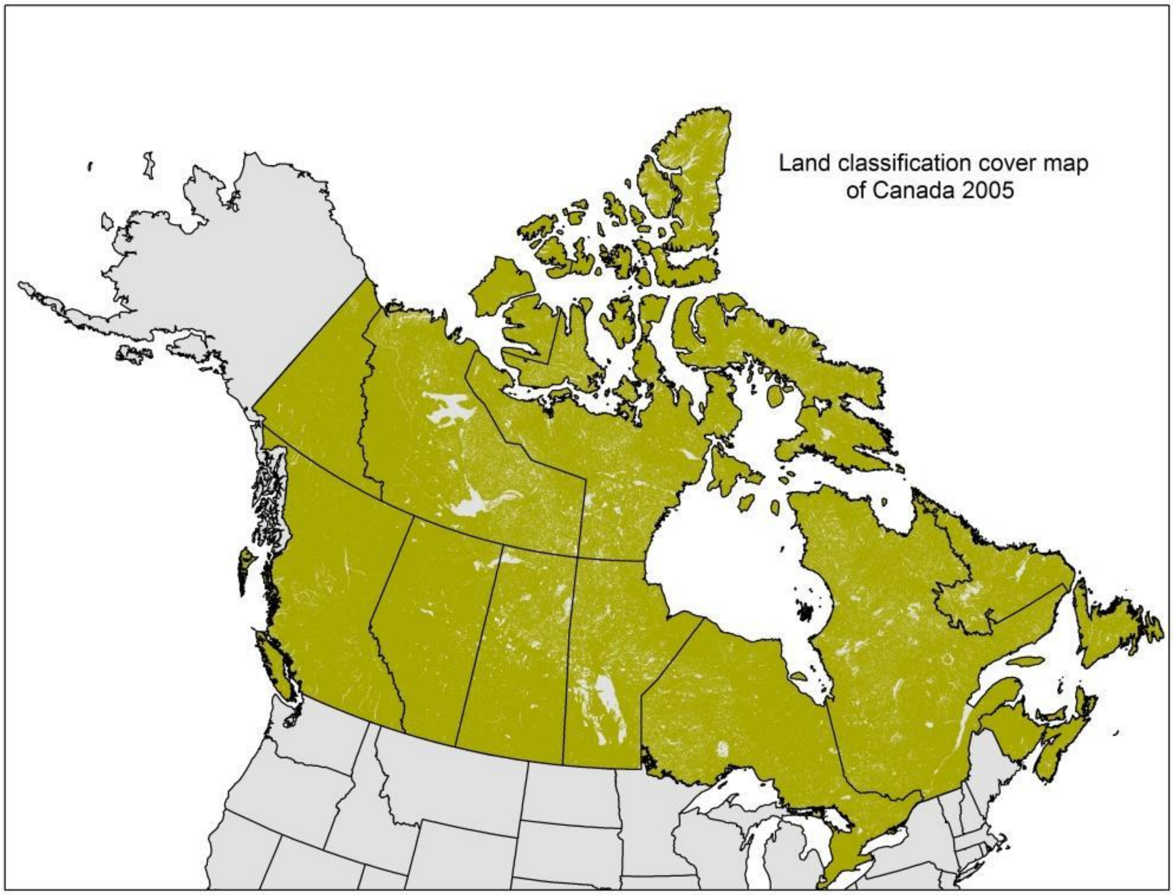
Table 14. Population size estimates (± 95% C.I.) for each focal species over the CAFRI spatial extent. Estimates have been generated from the 9 model subsets.

Species	Model subset	Model set (Spatial extent)	Median	Lower 95% C.I.	Upper 95% C.I.
CAWA	Climate	CASFRI	5352994	4091238	9356208
		LCCMC	6073054	5657052	6469724
		EOSDF	5859821	5239475	6554658
		NALCMS	5970078	5401261	6716486
	BCR	CASFRI	7219440	4255245	7902146
		LCCMC	5834360	5458442	6242436
		EOSDF	5645543	5300058	6200612
		NALCMS	5882575	5441988	6327283
	Climate-Landscape	NALCMS	5487006	5061253	6096802
OSFL	Climate	CASFRI	2335538	1787484	3353185
		LCCMC	2552322	2313258	2777465
		EOSDF	2637380	2519169	2825637
		NALCMS	2446487	2241612	2708318
	BCR	CASFRI	3208162	2834322	3530307
		LCCMC	2883048	2654796	3189333
		EOSDF	2469791	2328285	2791611
		NALCMS	2967103	2716260	3249330
	Climate-Landscape	NALCMS	2619911	2355271	2885652
CONI	Climate	CASFRI	57164	28488	83938
		LCCMC	81060	56424	110488
		EOSDF	88744	67918	118398
		NALCMS	80014	58952	105062
	BCR	CASFRI	88089	51915	131416

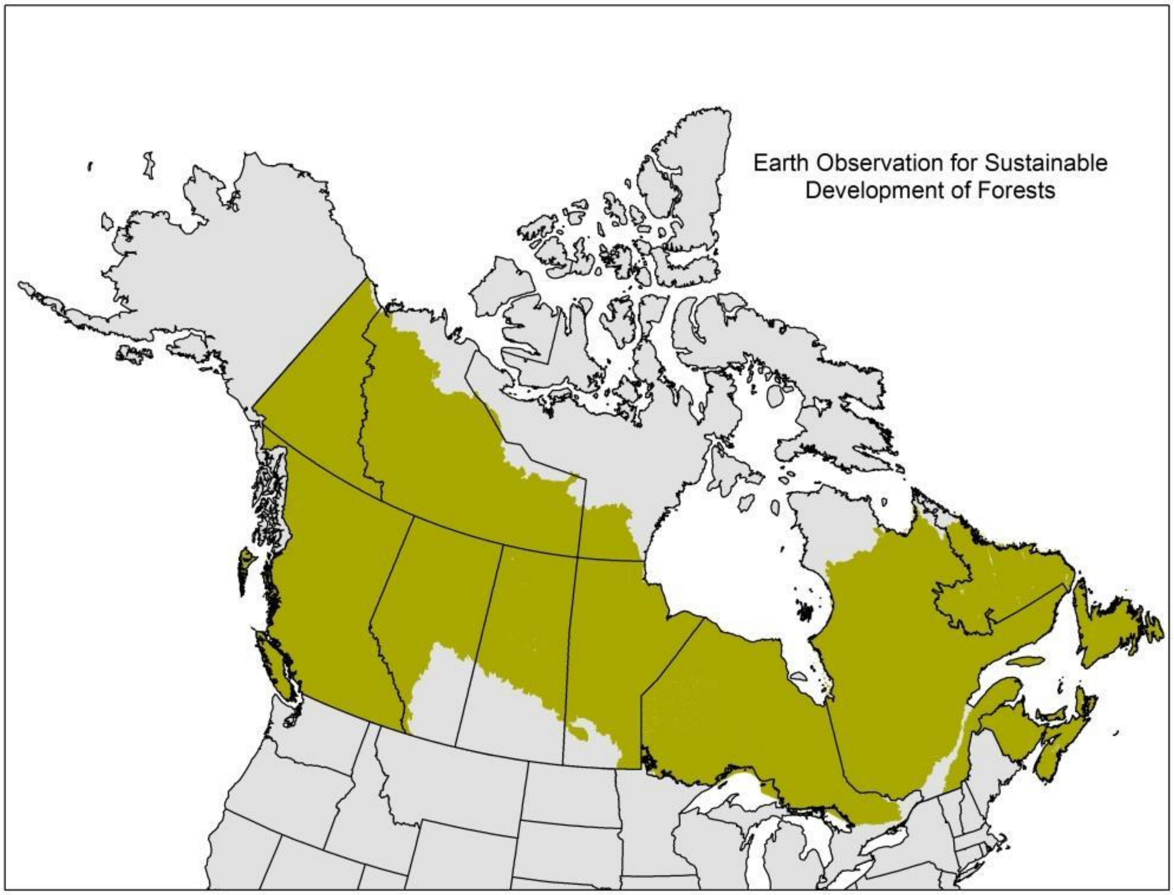
		LCCMC	93599	65851	126842
		EOSDF	98125	69318	127841
		NALCMS	90201	65588	124093
	Climate-Landscape	NALCMS	81315	59457	108205



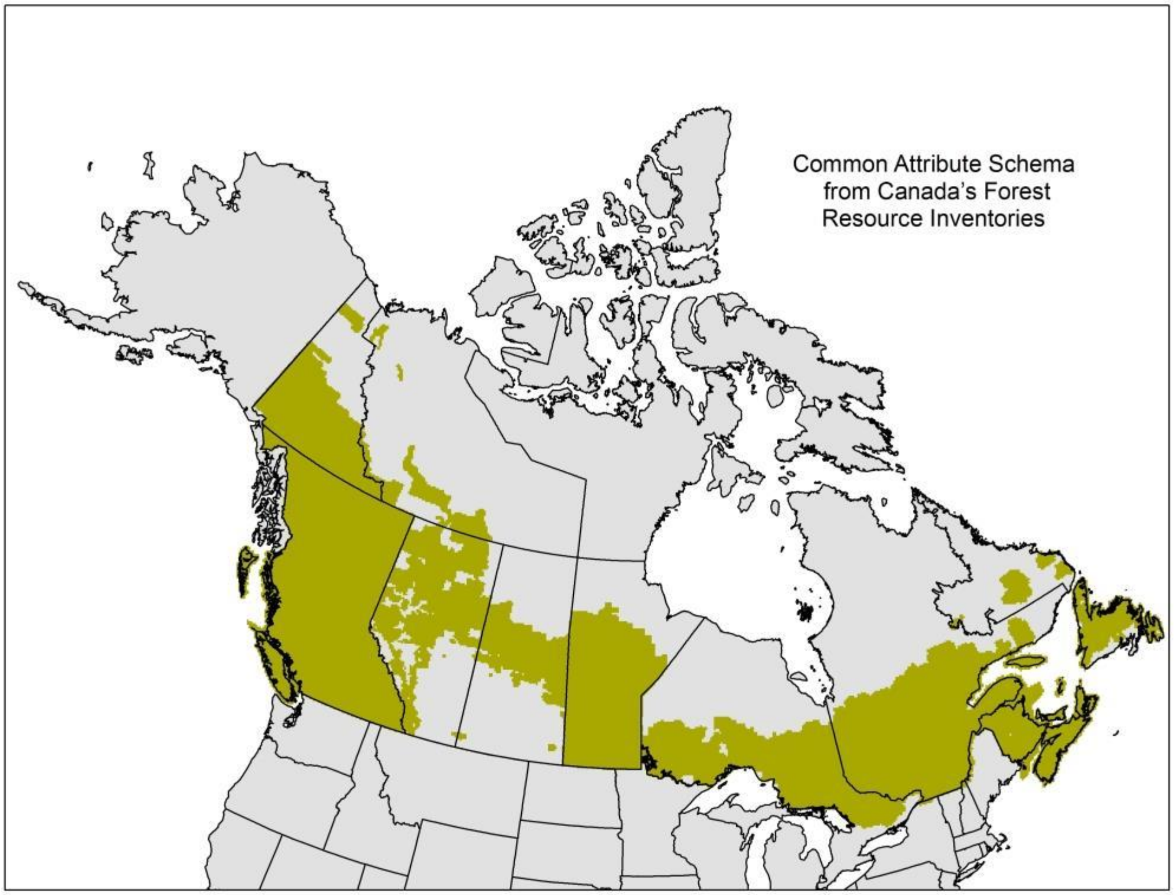
Appendix 1. Spatial extent covered by the North American Land Change Monitoring System (NALCMS) map. The climate layers and the Wildland Database Fire Information System (CWDFIS) and United States Monitoring Trends in Burn Severity (MTBS) maps covered the same spatial extent. The topographic wetness index (TWI) and Slope layers were available between the 40th - 66th parallels (or degree latitudes).



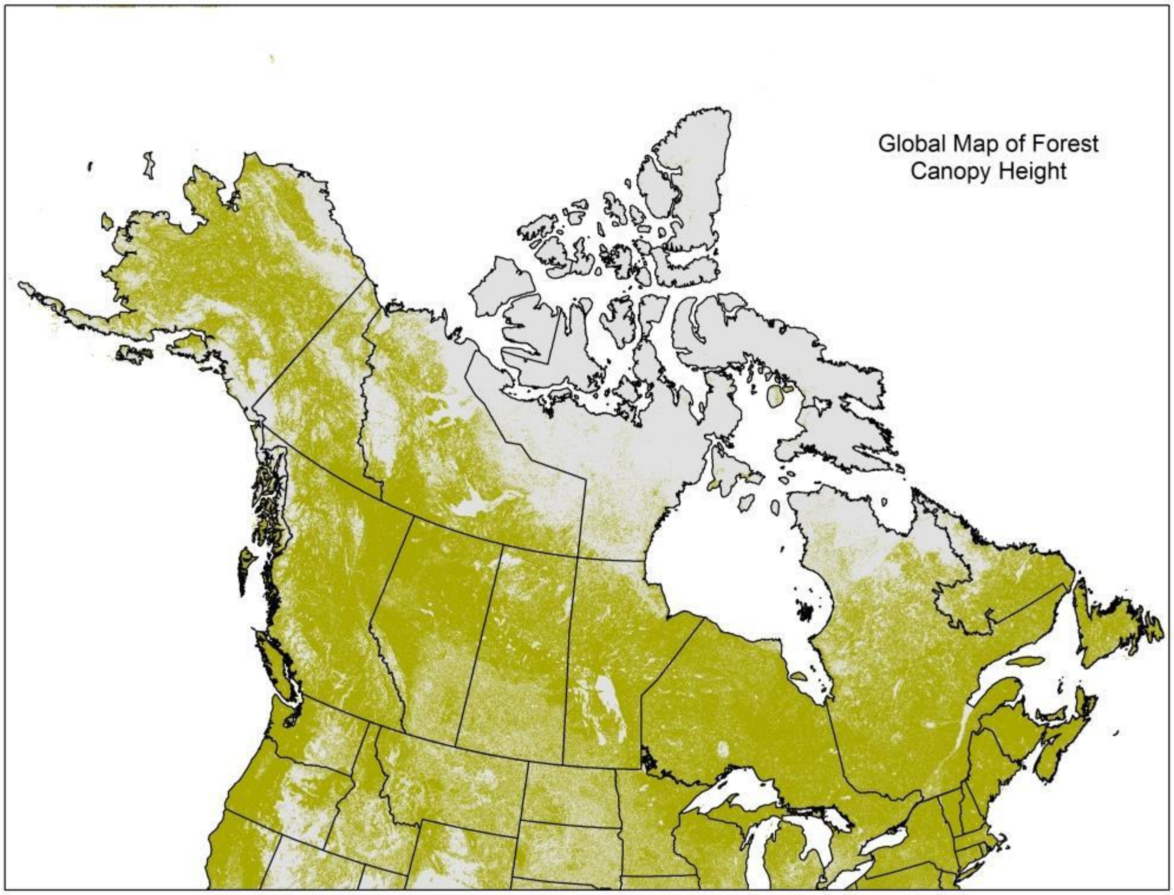
Appendix 2. Spatial extent covered by the Land Classification Cover Map of Canada 2005 (LCCMC).



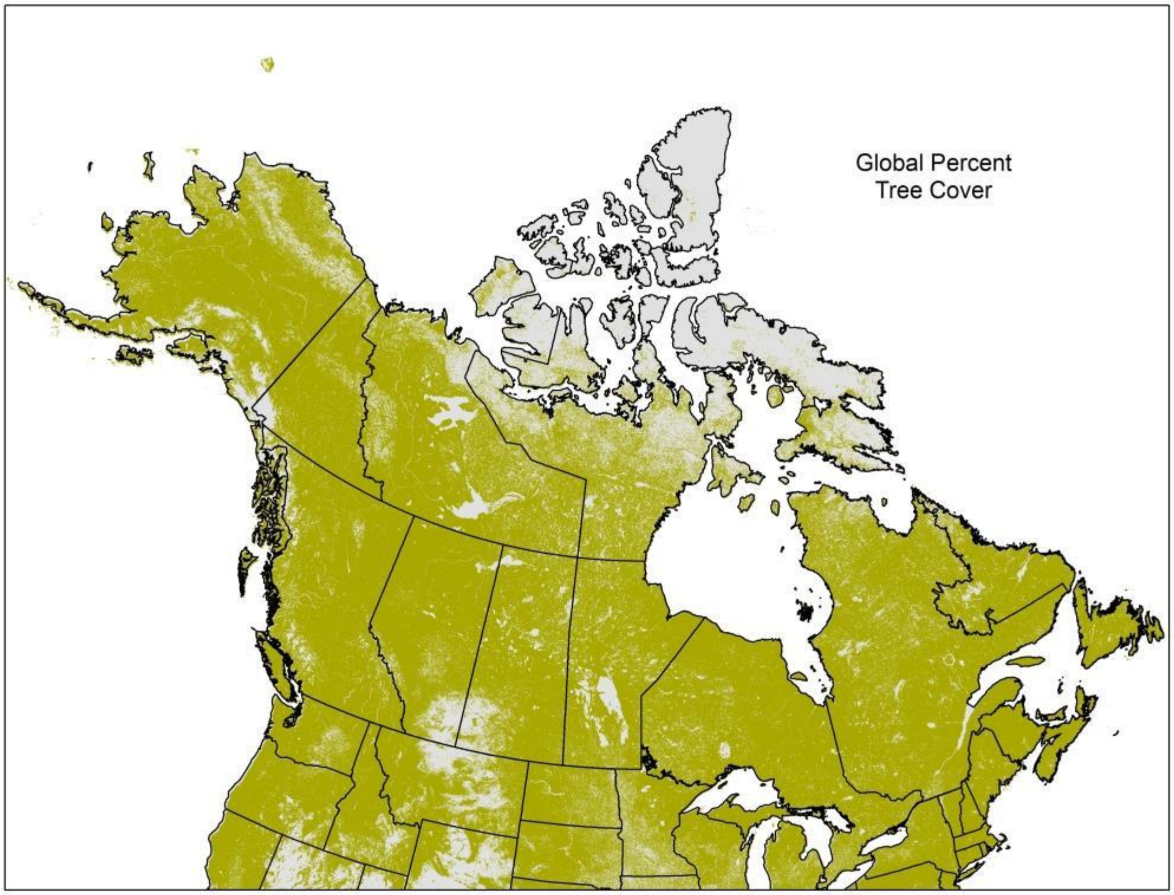
Appendix 3. Spatial extent covered by the Earth Observation for Sustainable Development of Forests (EOSDF) map.



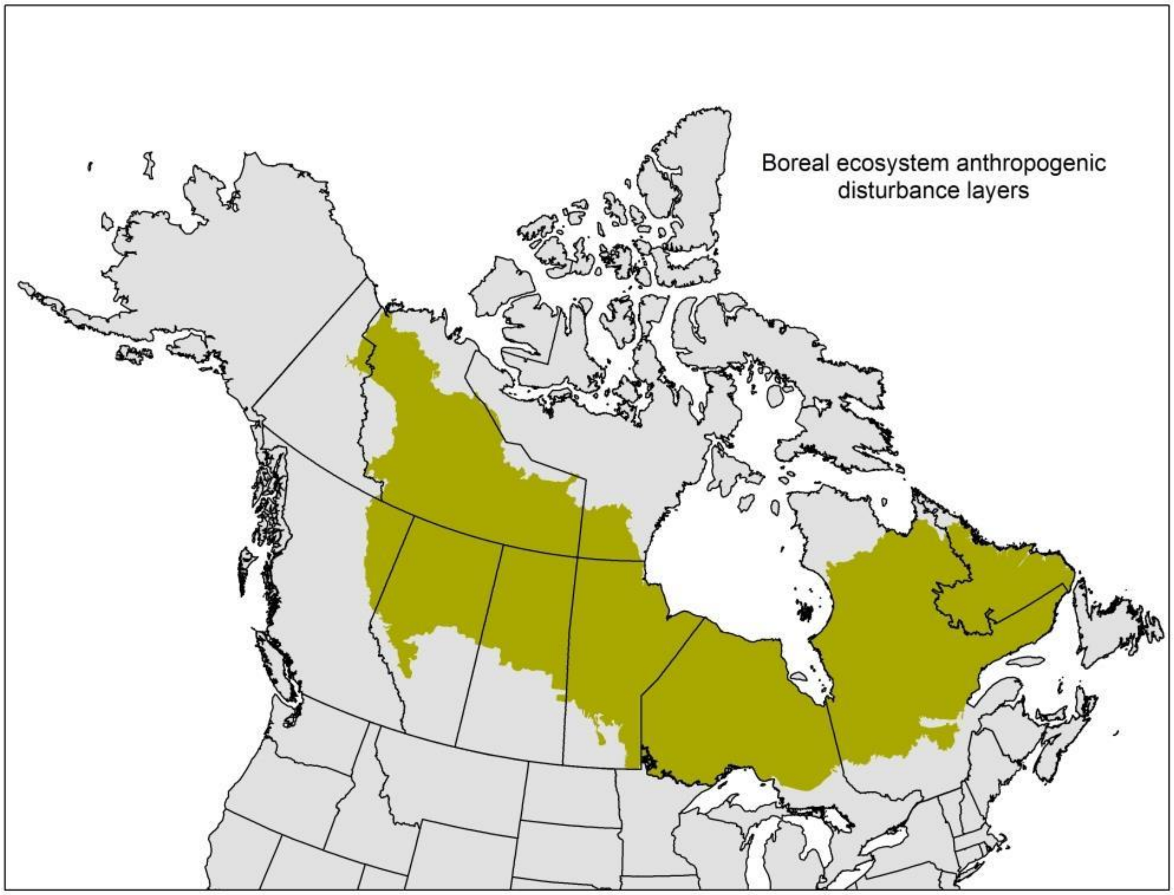
Appendix 4. Spatial extent covered by the Common Attribute Schema from Canada's Forest Resource Inventories (CASFRI) map.



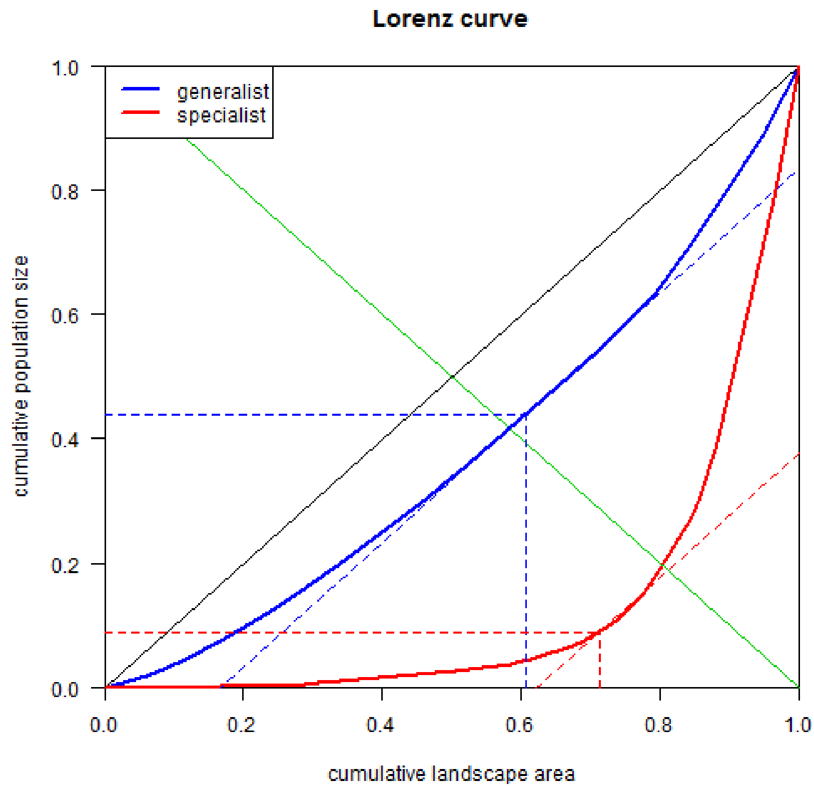
Appendix 5. Spatial extent covered by the Global Map of Forest Canopy Height (GMFCH).



Appendix 6. Spatial extent covered by the Global Percent Tree Cover (GPTC) map.



Appendix 7. Spatial extent covered by the Boreal Ecosystem Anthropogenic (BEAD) layers.



Appendix 8. Generalized Lorenz-curves indicating thresholds (broken lines) based on the tangent for species considered habitat generalist and habitat specialist. Species-specific thresholds corresponding to the point (broken lines) in the Lorenz-curve where the slope is 1 (tangent; Youden statistic) was used to determine the suitable habitat considered as Intrinsic Patch.

Appendix 9. All covariates available over the spatial extent of the North American Land Change Monitoring System (NALCMS) map used to generate a "Climate model" (10-stage bootstrap procedure) for each focal species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land Cover	Count ~ NULL	0	0	0
1.1 – Land Cover	Count ~ LC	0	0	***1***
1.2 – Land Cover	Count ~ HEIGHT	0	0	0
1.3 – Land Cover	Count ~ HEIGHT + $HEIGHT^2$	0	0	0
1.4 – Land Cover	Count ~ FC	0	0	0
1.5 – Land Cover	Count ~ FC + HEIGHT	0	0	0
1.6 – Land Cover	Count ~ FC + HEIGHT + $HEIGHT^2$	0	0	0
1.7 – Land Cover	Count ~ LC + HEIGHT	0.13	***0.81***	0
1.8 – Land Cover	Count ~ LC + HEIGHT + $HEIGHT^2$	0	0.02	0
1.9 – Land Cover	Count ~ LC + HEIGHT + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0.32	0.03	0
1.10 – Land Cover	Count ~ LC + FC	0	0	0
1.11 – Land Cover	Count ~ LC + FC + LC × FC	0	0	0
1.12 – Land Cover	Count ~ LC + HEIGHT + FC	0.22	0.14	0
1.13 – Land Cover	Count ~ LC + HEIGHT + $HEIGHT^2$ + FC	0	0	0
1.14 – Land Cover	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	***0.33***	0	0
1.15 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC	0	0	0
1.16 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0

2.0 – Road	Count ~ NULL	0	0.01	0
2.1 – Road	Count ~ ROAD	***0.88***	***0.99***	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0.12	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	***0.87***	0	***0.99***
3.1 – Topography	Count ~ TWI	0.04	***0.47***	0.01
3.2 – Topography	Count ~ TWI + TWI^2	0	0.52	0
3.3 – Topography	Count ~ TWI + SLOPE	0.09	0.01	0
4.0 – Space	Count ~ NULL	***0.60***	0.08	0.01
4.1 – Space	Count ~ EA_WE	0.02	***0.92***	***0.99***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0.38	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × CFC	0	0	0
4.4 – Space	Count + EA_WE + EA_WE × LC + EA_WE × CFC	0	0	0
5.0 – Disturbance	Count ~ NULL	***1***	0.02	***1***
5.3 – Disturbance	Count ~ BURN	0	***0.98***	0
6.0 – Moisture	Count ~ NULL	***1***	0.03	0
6.1 – Moisture	Count ~ CMIJJA	0	0	***1***
6.2 – Moisture	Count ~ CMI	0	***0.97***	0
7.0 – Temperature	Count ~ NULL	0.12	0	***0.91***
7.1 – Temperature	Count ~ MAT	0	0	0.09
7.2 – Temperature	Count ~ TD	***0.89***	0	0
7.3 – Temperature	Count ~ PET	0	***1***	0

8.0 – Extreme	Count ~ NULL	***0.96***	0	***1***
8.1 – Extreme	Count ~ DD0	0	0	0
8.2 – Extreme	Count ~ DD5	0	***0.89***	0
8.3 – Extreme	Count ~ EMT	0.04	0.11	0
9.0 – Precipitation	Count ~ NULL	0.34	0	***1***
9.1 – Precipitation	Count ~ MAP	0.01	0.02	0
9.2 – Precipitation	Count ~ MSP	***0.65***	***0.98***	0
10.0 – Year	Count ~ NULL	0.25	***1***	0.09
10.1 – Year	Count ~ YR	***0.75***	0	***0.91***
10.2 – Year	Count ~ YR5	0	0	0

Appendix 10. All covariates available over the spatial extent of the Land classification cover map of Canada 2005 (LCCMC) used to generate a "Climate model" (10-stage bootstrap procedure) for each focal species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land Cover	Count ~ NULL	0	0	0.19
1.1 – Land Cover	Count ~ LC	0	0	***0.64***
1.2 – Land Cover	Count ~ HEIGHT	0	0	0.04
1.3 – Land Cover	Count ~ HEIGHT + $HEIGHT^2$	0	0	0.05
1.4 – Land Cover	Count ~ FC	0	0	0
1.5 – Land Cover	Count ~ FC + HEIGHT	0	0	0
1.6 – Land Cover	Count ~ FC + HEIGHT + $HEIGHT^2$	0	0	0
1.7 – Land Cover	Count ~ LC + HEIGHT	0	0.11	0.08
1.8 – Land Cover	Count ~ LC + HEIGHT + $HEIGHT^2$	0	0.26	0
1.9 – Land Cover	Count ~ LC + HEIGHT + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0
1.10 – Land Cover	Count ~ LC + FC	0	0	0
1.11 – Land Cover	Count ~ LC + FC + LC × FC	0	0	0
1.12 – Land Cover	Count ~ LC + HEIGHT + FC	***0.93***	0.04	0
1.13 – Land Cover	Count ~ LC + HEIGHT + $HEIGHT^2$ + FC	0.07	***0.59***	0
1.14 – Land Cover	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0
1.15 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC	0	0	0
1.16 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0

2.0 – Road	Count ~ NULL	0	0	0
2.1 – Road	Count ~ ROAD	***1***	***0.99***	***0.98***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0.02
2.3 – Road	Count ~ ROAD + ROAD × FC	0	0.01	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	0.43	0	***0.99***
3.1 – Topography	Count ~ TWI	0	0.02	0.01
3.2 – Topography	Count ~ TWI + TWI^2	0	0.28	0
3.3 – Topography	Count ~ TWI + SLOPE	***0.57***	***0.70***	0
4.0 – Space	Count ~ NULL	0.16	0	0
4.1 – Space	Count ~ EA_WE	***0.42***	0.20	***0.97***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0.24	***0.70***	0.03
4.3 – Space	Count ~ EA_WE + EA_WE × CFC	0.02	0.09	0
4.4 – Space	Count + EA_WE + EA_WE × LC + EA_WE × CFC	0.16	0.01	0
5.0 – Disturbance	Count ~ NULL	***1***	0	***0.89***
5.1 – Disturbance	Count ~ LD	0	0.05	0.11
5.2 – Disturbance	Count ~ PD	0	0	0
5.3 – Disturbance	Count ~ BURN	0	0	0
5.4 – Disturbance	Count ~ LD + PD	0	0	0
5.5 – Disturbance	Count ~ LD + BURN	0	***0.92***	0
5.6 – Disturbance	Count ~ BURN + PD	0	0	0
5.7 – Disturbance	Count ~ LD + BURN + PD	0	0.03	0
6.0 – Moisture	Count ~ NULL	***0.54***	0	0
6.1 – Moisture	Count ~ CMIJJA	0	0.27	***1***
6.2 – Moisture	Count ~ CMI	0.46	***0.73***	0
7.0 – Temperature	Count ~ NULL	0	0	***0.83***

7.1 – Temperature	Count ~ MAT	0	0	0
7.2 – Temperature	Count ~ TD	***1***	0	0.17
7.3 – Temperature	Count ~ PET	0	***1***	0
8.0 – Extreme	Count ~ NULL	***0.91***	0	***0.97***
8.1 – Extreme	Count ~ DD0	0	0.23	0
8.2 – Extreme	Count ~ DD5	0.09	***0.77***	0.03
8.3 – Extreme	Count ~ EMT	0	0	0
9.0 – Precipitation	Count ~ NULL	0.27	0	***1***
9.1 – Precipitation	Count ~ MAP	0.09	0.27	0
9.2 – Precipitation	Count ~ MSP	***0.64***	***0.73***	0
10.0 – Year	Count ~ NULL	0.29	***0.97***	0.07
10.1 – Year	Count ~ YR	***0.71***	0.03	***0.93***
10.2 – Year	Count ~ YR5	0	0	0

Appendix 11. All covariates available over the spatial extent of the Earth Observation for Sustainable Development of Forests (EOSDF) map used to generate a "Climate model" (10-stage bootstrap procedure) for each focal species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land Cover	Count ~ NULL	0	0	***1***
1.1 – Land Cover	Count ~ LC	0	0	0
1.2 – Land Cover	Count ~ HEIGHT	0	0	0
1.3 – Land Cover	Count ~ HEIGHT + HEIGHT^2	0	0	0
1.4 – Land Cover	Count ~ FC	0	0	0
1.5 – Land Cover	Count ~ FC + HEIGHT	0	0	0
1.6 – Land Cover	Count ~ FC + HEIGHT + HEIGHT^2	0	0	0
1.7 – Land Cover	Count ~ LC + HEIGHT	0.38	0.23	0
1.8 – Land Cover	Count ~ LC + HEIGHT + HEIGHT^2	***0.46***	***0.77***	0
1.9 – Land Cover	Count ~ LC + HEIGHT + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0
1.10 – Land Cover	Count ~ LC + FC	0	0	0
1.11 – Land Cover	Count ~ LC + FC + LC × FC	0	0	0
1.12 – Land Cover	Count ~ LC + HEIGHT + FC	0.12	0	0
1.13 – Land Cover	Count ~ LC + HEIGHT + HEIGHT^2 + FC	0.04	0	0
1.14 – Land Cover	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0
1.15 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC	0	0	0
1.16 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0

2.0 – Road	Count ~ NULL	0	***1***	0
2.1 – Road	Count ~ ROAD	***0.51***	0	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0.49	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	***0.59***	0	***0.75***
3.1 – Topography	Count ~ TWI	0	***0.82***	0.25
3.2 – Topography	Count ~ TWI + TWI^2	0.01	0.02	0
3.3 – Topography	Count ~ TWI + SLOPE	0.4	0.16	0
4.0 – Space	Count ~ NULL	0	***0.70***	0
4.1 – Space	Count ~ EA_WE	0.27	0.30	***1***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	***0.73***	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × CFC	0	0	0
4.4 – Space	Count + EA_WE + EA_WE × LC + EA_WE × CFC	0	0	0
5.0 – Disturbance	Count ~ NULL	***1***	0	***0.82***
5.1 – Disturbance	Count ~ LD	0	0.03	0.18
5.2 – Disturbance	Count ~ PD	0	0	0
5.3 – Disturbance	Count ~ BURN	0	0	0
5.4 – Disturbance	Count ~ LD + PD	0	0	0
5.5 – Disturbance	Count ~ LD + BURN	0	***0.97***	0
5.6 – Disturbance	Count ~ BURN + PD	0	0	0
5.7 – Disturbance	Count ~ LD + BURN + PD	0	0	0
6.0 – Moisture	Count ~ NULL	***0.80***	***0.94***	0
6.1 – Moisture	Count ~ CMIJJA	0	0	***1***
6.2 – Moisture	Count ~ CMI	0.20	0.06	0

7.0 – Temperature	Count ~ NULL	0.09	0	***0.76***
7.1 – Temperature	Count ~ MAT	0	0	0
7.2 – Temperature	Count ~ TD	0.12	***1***	0.24
7.3 – Temperature	Count ~ PET	***0.79***	0	0
8.0 – Extreme	Count ~ NULL	0.06	0	***0.97***
8.1 – Extreme	Count ~ DD0	0.12	0	0.03
8.2 – Extreme	Count ~ DD5	0.11	***1***	0
8.3 – Extreme	Count ~ EMT	***0.71***	0	0
9.0 – Precipitation	Count ~ NULL	0.28	***0.65***	***1***
9.1 – Precipitation	Count ~ MAP	0	0	0
9.2 – Precipitation	Count ~ MSP	***0.72***	0.35	0
10.0 – Year	Count ~ NULL	0.31	***1***	0.04
10.1 – Year	Count ~ YR	***0.69***	0	***0.96***
10.2 – Year	Count ~ YR5	0	0	0

Appendix 12. All covariates available over the spatial extent of the Common Attribute Schema from Canada's Forest Resource Inventories (CASFRI) map used to generate a "Climate model" (10-stage bootstrap procedure) for each species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land Cover	Count ~ NULL	0	0	***0.91***
1.1 – Land Cover	Count ~ LC	0.28	***0.60***	0
1.2 – Land Cover	Count ~ HEIGHT_FRI	0	0	0.09
1.3 – Land Cover	Count ~ HEIGHT_FRI + HEIGHT_FRI^2	0.01	0	0
1.4 – Land Cover	Count ~ FC_FRI	0	0	0
1.5 – Land Cover	Count ~ FC_FRI + HEIGHT_FRI	0	0	0
1.6 – Land Cover	Count ~ FC_FRI + HEIGHT_FRI + HEIGHT_FRI^2	0.02	0	0
1.7 – Land Cover	Count ~ LC + HEIGHT_FRI	0	0	0
1.8 – Land Cover	Count ~ LC + HEIGHT_FRI + HEIGHT_FRI^2	0	0.28	0
1.9 – Land Cover	Count ~ LC + HEIGHT_FRI + HEIGHT_FRI × Decid + HEIGHT_FRI × Mixed + HEIGHT_FRI × Nonforest	0	0	0
1.10 – Land Cover	Count ~ LC + FC_FRI	***0.65***	0.12	0
1.11 – Land Cover	Count ~ LC + FC_FRI + LC × FC_FRI	0	0	0
1.12 – Land Cover	Count ~ LC + HEIGHT_FRI + FC_FRI	0	0	0
1.13 – Land Cover	Count ~ LC + HEIGHT_FRI + HEIGHT_FRI 2 + FC_FRI	0.04	0	0
1.14 – Land Cover	Count ~ LC + HEIGHT_FRI + FC_FRI + HEIGHT_FRI × Decid + HEIGHT_FRI × Mixed + HEIGHT_FRI × Nonforest	0	0	0
1.15 – Land Cover	Count ~ LC + HEIGHT_FRI + FC_FRI +	0	0	0

	LC × FC_FRI			
1.16 – Land Cover	Count ~ LC + HEIGHT_FRI + FC_FRI + LC × FC_FRI + HEIGHT_FRI × Decid + HEIGHT_FRI × Mixed + HEIGHT_FRI × Nonforest	0	0	0
2.0 – Road	Count ~ NULL	0	0.04	0
2.1 – Road	Count ~ ROAD	***1***	***0.96***	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC_FRI	0	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC_FRI	0	0	0
3.0 – Topography	Count ~ NULL	***0.94***	0	0.42
3.1 – Topography	Count ~ TWI	0.01	***0.98***	***0.58***
3.2 – Topography	Count ~ TWI + TWI^2	0	0	0
3.3 – Topography	Count ~ TWI + SLOPE	0.05	0.02	0
4.0 – Space	Count ~ NULL	0	***0.55***	0
4.1 – Space	Count ~ EA_WE	***0.89***	0.44	***1***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × FC_FRI	0.11	0.01	0
4.4 – Space	Count + EA_WE + EA_WE × LC + EA_WE × FC_FRI	0	0	0
5.0 – Disturbance	Count ~ NULL	***0.95***	0	***0.72***
5.1 – Disturbance	Count ~ LD	0	0.31	0.01
5.2 – Disturbance	Count ~ PD	0.03	0	0
5.3 – Disturbance	Count ~ BURN	0	0	0
5.4 – Disturbance	Count ~ CC	0.02	0	0.27
5.5 – Disturbance	Count ~ LD + PD	0	0	0
5.6 – Disturbance	Count ~ LD + BURN	0	0.14	0
5.7 – Disturbance	Count ~ LD + CC	0	***0.55***	0

5.8 – Disturbance	Count ~ BURN + PD	0	0	0
5.9 – Disturbance	Count ~ BURN + CC	0	0	0
5.10 – Disturbance	Count ~ PD + CC	0	0	0
6.0 – Moisture	Count ~ NULL	***1***	***1***	0
6.1 – Moisture	Count ~ CMIJJA	0	0	***1***
6.2 – Moisture	Count ~ CMI	0	0	0
7.0 – Temperature	Count ~ NULL	0.15	0	0.18
7.1 – Temperature	Count ~ MAT	0	0.05	0
7.2 – Temperature	Count ~ TD	***0.85***	0.35	***0.82***
7.3 – Temperature	Count ~ PET	0	***0.60***	0
8.0 – Extreme	Count ~ NULL	***0.87***	0	***0.99***
8.1 – Extreme	Count ~ DD0	0	0	0
8.2 – Extreme	Count ~ DD5	0.04	***0.68***	0.01
8.3 – Extreme	Count ~ EMT	0.09	0.32	0
9.0 – Precipitation	Count ~ NULL	***0.93***	***0.63***	***1***
9.1 – Precipitation	Count ~ MAP	0	0.32	0
9.2 – Precipitation	Count ~ MSP	0.07	0.05	0
10.0 – Year	Count ~ NULL	0.08	**1**	0.08
10.1 – Year	Count ~ YR	***0.92***	0	***0.92***
10.2 – Year	Count ~ YR5	0	0	0

Appendix 13. All covariates covering the spatial extent of the North American Land Change Monitoring System (NALCMS) map used to generate a "Climate-Landscape model" (11-stage bootstrap procedure) for each species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. This model subset included information on landscape composition. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land Cover	Count ~ NULL	0	0	0
1.1 – Land Cover	Count ~ LC	0	0	***1***
1.2 – Land Cover	Count ~ HEIGHT	0	0	0
1.3 – Land Cover	Count ~ HEIGHT + HEIGHT^2	0	0	0
1.4 – Land Cover	Count ~ FC	0	0	0
1.5 – Land Cover	Count ~ FC + HEIGHT	0	0	0
1.6 – Land Cover	Count ~ FC + HEIGHT + HEIGHT^2	0	0	0
1.7 – Land Cover	Count ~ LC + HEIGHT	0.13	***0.81***	0
1.8 – Land Cover	Count ~ LC + HEIGHT + HEIGHT^2	0	0.02	0
1.9 – Land Cover	Count ~ LC + HEIGHT + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0.32	0.03	0
1.10 – Land Cover	Count ~ LC + FC	0	0	0
1.11 – Land Cover	Count ~ LC + FC + LC × FC	0	0	0
1.12 –Land Cover	Count ~ LC + HEIGHT + FC	0.22	0.14	0
1.13 – Land Cover	Count ~ LC + HEIGHT + HEIGHT^2 + FC	0	0	0
1.14 – Land Cover	Count ~ LC + HEIGHT + FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	***0.33***	0	0
1.15 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC	0	0	0
1.16 – Land Cover	Count ~ LC + HEIGHT + FC + LC × FC + HEIGHT × Decid + HEIGHT × Mixed + HEIGHT × Nonforest	0	0	0

2.0 – Road	Count ~ NULL	0	0.01	0
2.1 – Road	Count ~ ROAD	***0.88***	***0.99***	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0.12	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	***0.87***	0	***0.94***
3.1 – Topography	Count ~ TWI	0.04	0.07	0.01
3.2 – Topography	Count ~ TWI + TWI^2	0	0.17	0
3.3 – Topography	Count ~ Wet	0	0	0.01
3.4 – Topography	Count ~ Wet + Wet^2	0	0	0
3.5 – Topography	Count ~ WetWater	0	0	0.04
3.6 – Topography	Count ~ WetWater + $WetWater^2$	0	0	0
3.7 – Topography	Count ~ TWI + Wet	0	0	0
3.8 – Topography	Count ~ TWI + WetWater	0	0.10	0
3.9 – Topography	Count ~ TWI + SLOPE	0.09	0	0
3.10 – Topography	Count ~ SLOPE + Wet	0	0	0
3.11 – Topography	Count ~ SLOPE + WetWater	0	***0.66***	0
4.0 – Space	Count ~ NULL	***0.60***	0.35	0.01
4.1 – Space	Count ~ EA_WE	0.02	***0.65***	***0.99***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0.38	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × CFC	0	0	0
4.4 – Space	Count + EA_WE + EA_WE × LC + EA_WE × CFC	0	0	0
5.0 – Disturbance	Count ~ NULL	0.09	0	***0.49***
5.1 – Disturbance	Count ~ BURN	0	0	0
5.2 – Disturbance	Count ~ AgrDev	***0.91***	0.02	0.47
5.3 – Disturbance	Count ~ AgrDev + $AgrDev^2$	0	0.01	0.04

5.4 – Disturbance	Count ~ BURN + AgrDev	0	***0.97***	0
6.0 – Landscape	Count ~ NULL	0	0	0.04
6.1 – Landscape	Count ~ IP	***1***	***1***	***0.96***
6.2 – Landscape	Count ~ IP + IP^2	0	0	0
7.0 – Moisture	Count ~ NULL	***0.86***	0.01	0
7.1 – Moisture	Count ~ CMIJJA	0	0	***1***
7.2 – Moisture	Count ~ CMI	0.14	***0.99***	0
8.0 – Temperature	Count ~ NULL	0.16	0	***0.82***
8.1 – Temperature	Count ~ MAT	0	0	0.18
8.2 – Temperature	Count ~ TD	***0.84***	***0.84***	0
8.3 – Temperature	Count ~ PET	0	0.16	0
9.0 – Extreme	Count ~ NULL	***0.98***	0	***1***
9.1 – Extreme	Count ~ DD0	0	0.12	0
9.2 – Extreme	Count ~ DD5	0	***0.73***	0
9.3 – Extreme	Count ~ EMT	0.02	0.15	0
10.0 – Precipitation	Count ~ NULL	***0.97***	0	***0.99***
10.1 – Precipitation	Count ~ MAP	0.01	0	0.01
10.2 – Precipitation	Count ~ MSP	0.02	***1***	0
11.0 – Year	Count ~ NULL	0.28	***1***	0.11
11.1 – Year	Count ~ YR	***0.72***	0	***0.89***
11.2 – Year	Count ~ YR5	0	0	0

Appendix 14. All covariates available over the spatial extent of the North American Land Change Monitoring System (NALCMS) map used to generate a "BCR model" (4-stage bootstrap procedure) for each focal species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land cover	Count ~ NULL	0	0	0
1.1 – Land cover	Count ~ LC	0.06	0.41	***1***
1.2 – Land cover	Count ~ FC	0	0	0
1.3 – Land cover	Count ~ LC + FC	***0.94***	***0.59***	0
1.4 – Land cover	Count ~ LC + FC + LC × FC	0	0	0
2.0 – Road	Count ~ NULL	0	0	0
2.1 – Road	Count ~ ROAD	***0.98***	***1***	***0.98***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0.02	0	0.02
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	***0.56***	0	***1***
3.1 – Topography	Count ~ TWI	0.34	0.17	0
3.2 – Topography	Count ~ TWI + TWI^2	0	***0.74***	0
3.3 – Topography	Count ~ TWI + SLOPE	0.1	0.09	0
4.0 – Space	Count ~ NULL	0	0	0.03
4.1 – Space	Count ~ EA_WE	0	0	***0.92***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × FC	0	0	0
4.4 – Space	Count ~ EA_WE + EA_WE × LC + EA_WE × FC	0	0	0

4.5 – Space	Count ~ BCR	***1***	***1***	0.05
4.6 – Space	Count ~ BCR + EA_WE × LC	0	0	0
4.7 – Space	Count ~ BCR + EA_WE × FC	0	0	0
4.8 – Space	Count ~ BCR + EA_WE × LC + EA_WE × FC	0	0	0
4.9 – Space	Count ~ BCR + BCR × FC	0	0	0
4.10 – Space	Count ~ BCR + BCR × LC	0	0	0
4.11 – Space	Count ~ BCR + BCR × LC + BCR × FC	0	0	0

Appendix 15. All covariates available over the spatial extent of the Land classification cover map of Canada 2005 (LCCMC) used to generate a "BCR models" (4-stage bootstrap procedure) for each focal species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land cover	Count ~ NULL	0	0	0.09
1.1 – Land cover	Count ~ LC	0	0	***0.91***
1.2 – Land cover	Count ~ FC	0	0	0
1.3 – Land cover	Count ~ LC + FC	***1***	***1***	0
1.4 – Land cover	Count ~ LC + FC + LC × FC	0	0	0
2.0 – Road	Count ~ NULL	0	0	0
2.1 – Road	Count ~ ROAD	***1***	***1***	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	0.36	0	***0.99***
3.1 – Topography	Count ~ TWI	0	0	0.01
3.2 – Topography	Count ~ TWI + TWI^2	0	0.19	0
3.3 – Topography	Count ~ TWI + SLOPE	***0.64***	***0.81***	0
4.0 – Space	Count ~ NULL	0	0	0
4.1 – Space	Count ~ EA_WE	0	0	***0.86***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × FC	0	0	0
4.4 – Space	Count ~ EA_WE + EA_WE × LC + EA_WE × FC	0	0	0

4.5 – Space	Count ~ BCR	***1***	***1***	0.14
4.6 – Space	Count ~ BCR + EA_WE × LC	0	0	0
4.7 – Space	Count ~ BCR + EA_WE × FC	0	0	0
4.8 – Space	Count ~ BCR + EA_WE × LC + EA_WE × FC	0	0	0
4.9 – Space	Count ~ BCR + BCR × FC	0	0	0
4.10 – Space	Count ~ BCR + BCR × LC	0	0	0
4.11 – Space	Count ~ BCR + BCR × LC + BCR × FC	0	0	0

Appendix 16. All covariates available over the spatial extent of the Earth Observation for Sustainable Development of Forests (EOSDF) map used to generate a "BCR model" (4-stage bootstrap procedure) for each species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land cover	Count ~ NULL	0	0	***1***
1.1 – Land cover	Count ~ LC	0.44	***0.99***	0
1.2 – Land cover	Count ~ FC	0	0	0
1.3 – Land cover	Count ~ LC + FC	***0.56***	0.01	0
1.4 – Land cover	Count ~ LC + FC + LC × FC	0	0	0
2.0 – Road	Count ~ NULL	0	***0.90***	0
2.1 – Road	Count ~ ROAD	***0.67***	0.10	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC	0.33	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC	0	0	0
3.0 – Topography	Count ~ NULL	***0.66***	0	***0.76***
3.1 – Topography	Count ~ TWI	0	0.41	0.24
3.2 – Topography	Count ~ TWI + TWI^2	0.01	0.02	0
3.3 – Topography	Count ~ TWI + SLOPE	0.33	***0.57***	0
4.0 – Space	Count ~ NULL	0	0	0
4.1 – Space	Count ~ EA_WE	0	0	***1***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × FC	0	0	0
4.4 – Space	Count ~ EA_WE + EA_WE × LC + EA_WE × FC	0	0	0

4.5 – Space	Count ~ BCR	***1***	***1***	0
4.6 – Space	Count ~ BCR + EA_WE × LC	0	0	0
4.7 – Space	Count ~ BCR + EA_WE × FC	0	0	0
4.8 – Space	Count ~ BCR + EA_WE × LC + EA_WE × FC	0	0	0
4.9 – Space	Count ~ BCR + BCR × FC	0	0	0
4.10 – Space	Count ~ BCR + BCR × LC	0	0	0
4.11 – Space	Count ~ BCR + BCR × LC + BCR × FC	0	0	0

Appendix 17. All covariates available over the spatial extent of the Common Attribute Schema from Canada's Forest Resource Inventories (CASFRI) map used to generate a "BCR model" (4-stage bootstrap procedure) for each species. Selection frequencies from the 200 bootstrap iterations for each variable within each stage are reported for the three focal species. For each iteration, a variable was selected based on the lowest value of the consistent AIC (CAIC = 0.5 AIC + 0.5 BIC) among competing variables. The parameter coefficients of the top ranked variable of a given stage were fixed and included to models in the subsequent stage.

Covariate type	Model	CAWA	OSFL	CONI
1.0 – Land cover	Count ~ NULL	0	0	**1**
1.1 – Land cover	Count ~ LC	***0.63***	***1***	0
1.2 – Land cover	Count ~ FC_FRI	0	0	0
1.3 – Land cover	Count ~ LC + FC_FRI	0.37	0	0
1.4 – Land cover	Count ~ LC + FC_FRI + LC × FC_FRI	0	0	0
2.0 – Road	Count ~ NULL	0	0.03	0
2.1 – Road	Count ~ ROAD	***1***	***0.97***	***1***
2.2 – Road	Count ~ ROAD + ROAD × LC	0	0	0
2.3 – Road	Count ~ ROAD + ROAD × FC_FRI	0	0	0
2.4 – Road	Count ~ ROAD + ROAD × LC + ROAD × FC_FRI	0	0	0
3.0 – Topography	Count ~ NULL	***0.88***	0	***0.60***
3.1 – Topography	Count ~ TWI	0	***0.99***	0.40
3.2 – Topography	Count ~ TWI + TWI^2	0	0	0
3.3 – Topography	Count ~ TWI + SLOPE	0.12	0.01	0
4.0 – Space	Count ~ NULL	0	0	0
4.1 – Space	Count ~ EA_WE	0	0	***1***
4.2 – Space	Count ~ EA_WE + EA_WE × LC	0	0	0
4.3 – Space	Count ~ EA_WE + EA_WE × FC_FRI	0	0	0
4.4 – Space	Count ~ EA_WE + EA_WE × LC + EA_WE × FC_FRI	0	0	0

4.5 – Space	Count ~ BCR	***1***	***1***	0
4.6 – Space	Count ~ BCR + EA_WE × LC	0	0	0
4.7 – Space	Count ~ BCR + EA_WE × FC_FRI	0	0	0
4.8 – Space	Count ~ BCR + EA_WE × LC + EA_WE × FC_FRI	0	0	0
4.9 – Space	Count ~ BCR + BCR × FC_FRI	0	0	0
4.10 – Space	Count ~ BCR + BCR × LC	0	0	0
4.11 – Space	Count ~ BCR + BCR × LC + BCR × FC_FRI	0	0	0

Appendix 18. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the Climate model subsets (NALCMS) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-4.72	0.55	-6.00	0.21	-7.94	0.24
Agr	-2.59	0.69	-2.33	0.27	-1.55	0.21
Barren ground	-14.00	1.21	-1.76	1.27	-2.49	4.60
Decid	0.05	0.42	-0.13	0.11	-0.98	0.24
Development	-11.53	4.82	-3.12	3.79	-2.48	3.99
Grass	-0.91	0.58	-0.59	0.16	-0.47	0.21
Mixed	-0.05	0.54	-0.06	0.12	-0.26	0.22
Shrub	-2.66	2.55	0.20	0.10	0.11	0.21
Wet	-0.67	0.54	-0.09	0.13	-0.21	0.57
Height	1.31	1.44	1.27	0.17	-0.01	0.09
$Height^2$	0	N/A	-0.03	0.16	0	N/A
CFC (Sparse)	0.35	0.34	0.08	0.20	0	N/A
CFC (Dense)	0.47	0.45	0.08	0.22	0	N/A
Road	-0.80	0.46	0.27	0.06	1.16	0.19
TWI	-0.07	0.19	-0.12	0.07	0.01	0.02
TWI^2	0.01	0.01	0.04	0.04	0	N/A
Slope	-0.15	0.54	-0.01	0.01	0	N/A
West	-0.94	1.22	-0.39	0.22	0.17	0.20
Burn	0	N/A	0.96	0.18	0	N/A
CMI	0	N/A	0.40	0.10	0	N/A

CMIJJA	0	N/A	0	N/A	-3.80	0.40
MAT	0	N/A	0	N/A	0.09	0.29
TD	0.53	0.22	0.01	0.04	0.01	0.05
PET	0	N/A	0.40	0.73	0	N/A
DD0	0	N/A	0	N/A	0	N/A
DD5	0.01	0.04	-1.40	0.54	0	N/A
EMT	-0.02	0.08	0.03	0.08	0	N/A
MAP	0.02	0.13	0.01	0.06	0	N/A
MSP	0.31	0.23	-0.79	0.16	0	N/A
Year	-0.04	0.02	0	N/A	-0.07	0.03
Height × Decid	1.52	1.36	-0.03	0.15	0	N/A
Height × Mixed	2.71	2.13	-0.05	0.31	0	N/A
Height × Nonforest	2.53	2.06	0.04	0.21	0	N/A
ROAD × FC (Sparse)	0.15	0.42	0.01	0.03	0	N/A
ROAD × FC (Dense)	0.20	0.54	0.01	0.04	0	N/A
Agr × Road	0	N/A	0	N/A	0	N/A
Barren ground × Road	0	N/A	0	N/A	0	N/A
Decid × Road	0	N/A	0	N/A	0	N/A
Development × Road	0	N/A	0	N/A	0	N/A
Grass × Road	0	N/A	0	N/A	0	N/A
Mixed × Road	0	N/A	0	N/A	0	N/A
Shrub × Road	0	N/A	0	N/A	0	N/A
Wet × Road	0	N/A	0	N/A	0	N/A
Agr × Ea_We	-0.20	3.17	0	N/A	0	N/A
Barren ground × Ea_We	0.99	1.29	0	N/A	0	N/A
Decid × Ea_We	1.22	1.57	0	N/A	0	N/A
Development × Ea_We	0.08	3.37	0	N/A	0	N/A

Grass × Ea_We	-0.20	2.25	0	N/A	0	N/A
Mixed × Ea_We	0.94	1.22	0	N/A	0	N/A
Shrub × Ea_We	-1.68	4.51	0	N/A	0	N/A
Wet × Ea_We	0.22	1.48	0	N/A	0	N/A
Ea_We × FC (Sparse)	-0.01	0.12	0	N/A	0	N/A
Ea_We × FC (Dense)	-0.01	0.15	0	N/A	0	N/A

Appendix 19. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the Climate model subsets (LCCMC) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-5.50	0.38	-6.57	0.40	-8.15	0.30
Agr	-1.52	0.46	-3.10	2.53	-1.36	0.89
Barren ground	-4.80	6.06	-9.12	5.51	-0.66	1.44
Burn	-5.82	6.50	1.28	0.52	0.51	0.36
Decid	0.57	0.39	0.17	0.16	-0.44	0.32
Development	-0.10	0.20	-0.60	0.57	-0.85	0.57
Grass	0.15	0.20	-0.07	0.17	-0.45	0.36
Mixed	0.84	0.28	0.24	0.12	-0.08	0.19
Wet	-0.39	0.34	-0.20	0.20	0.08	0.38
Height	2.95	0.38	2.21	0.60	0.08	0.27
$Height^2$	-0.03	0.45	-2.06	1.03	-0.01	0.32
FC (Sparse)	0.77	0.28	0.45	0.41	0	N/A
FC (Dense)	1.00	0.32	0.48	0.44	0	N/A
Road	-0.61	0.09	0.21	0.07	1.13	0.27
TWI	-0.33	0.29	-0.20	0.09	-0.01	0.06
TWI^2	0	N/A	0.02	0.03	0	N/A
Slope	-1.00	1.00	-0.48	0.38	0	N/A
West	-0.60	0.87	-0.03	0.38	0.21	0.23
LD	0	N/A	-0.80	0.13	-0.16	0.45
PD	0	N/A	0.02	0.13	0	N/A

Burn	0	N/A	0.90	0.26	0	N/A
CMI	-0.18	0.24	0.36	0.22	0	N/A
CMIJJA	0	N/A	-0.89	1.47	-4.87	0.60
MAT	0	N/A	0	N/A	0.01	0.09
TD	0.71	0.18	0	N/A	-0.09	0.21
PET	0	N/A	-0.35	1.81	-0.01	0.19
DD0	0	N/A	-0.06	0.12	-0.01	0.02
DD5	0.03	0.11	-1.41	0.80	-0.02	0.15
EMT	0	N/A	0.01	0.01	0	N/A
MAP	0.23	0.70	0.21	0.35	0	N/A
MSP	0.43	0.35	-0.65	0.40	0	N/A
Year	-0.04	0.02	0.01	0.01	-0.08	0.03
Height × Decid	0	N/A	0	N/A	0	N/A
Height × Mixed	0	N/A	0	N/A	0	N/A
Height × NonForest	0	N/A	0	N/A	0	N/A
Road × FC (Sparse)	0	N/A	0.01	0.05	0	N/A
Road × FC (Dense)	0	N/A	0.01	0.06	0	N/A
Agr × Road	0	N/A	0	N/A	-0.05	0.32
Barren ground × Road	0	N/A	0	N/A	-0.01	0.06
Burn × Road	0	N/A	0	N/A	0.01	0.04
Decid × Road	0	N/A	0	N/A	-0.02	0.17
Development × Road	0	N/A	0	N/A	-0.03	0.20
Grass × Road	0	N/A	0	N/A	-0.01	0.11
Mixed × Road	0	N/A	0	N/A	-0.01	0.02
Wet × Road	0	N/A	0	N/A	0.01	0.06
Agr × Ea_We	-0.50	3.16	0.98	2.55	-0.06	0.32
Barren ground × Ea_We	-0.67	6.47	8.68	5.58	-0.09	0.98

Burn × Ea_We	-1.44	6.12	-1.17	0.79	0.03	0.16
Decid × Ea_We	1.09	1.37	-0.44	0.32	-0.02	0.13
Development × Ea_We	-4.41	6.13	0.97	0.65	-0.04	0.19
Grass × Ea_We	0.35	0.52	0.01	0.16	-0.02	0.13
Mixed × Ea_We	0.76	0.96	-0.21	0.18	-0.01	0.03
Wet × Ea_We	-2.29	5.15	-0.10	0.27	0.01	0.04
Ea_We × FC (Sparse)	-0.21	0.46	-0.07	0.26	0	N/A
Ea_We × FC (Dense)	-0.30	0.65	-0.08	0.29	0	N/A

Appendix 20. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the Climate model subsets (EOSDF) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-3.60	0.35	-5.33	0.11	-7.98	0.26
Barren ground	-0.12	0.18	-0.16	0.07	0	N/A
Decid	0.11	0.38	-0.78	0.11	0	N/A
Grass	-0.75	0.17	-0.02	0.08	0	N/A
Mixed	0.25	0.23	-0.16	0.08	0	N/A
Shrub	-0.13	0.26	0.09	0.07	0	N/A
Wet	-0.22	0.19	-0.10	0.10	0	N/A
Height	2.58	0.80	1.36	0.38	0	N/A
$Height^2$	-0.75	1.34	-0.21	0.70	0	N/A
FC (Sparse)	0.06	0.15	0.01	0.06	0	N/A
FC (Dense)	0.09	0.21	0.01	0.06	0	N/A
Road	-1.28	0.71	0	N/A	0.98	0.24
TWI	-0.17	0.21	-0.12	0.05	-0.06	0.13
TWI^2	-0.01	0.03	0.01	0.01	0	N/A
Slope	-0.60	0.85	-0.08	0.19	0.01	0.09
West	-1.50	1.00	-0.17	0.26	-0.09	0.23
LD	-0.01	0.04	-0.54	0.11	-0.24	0.55
PD	0	N/A	0	N/A	-0.02	0.28
Burn	0	N/A	1.17	0.25	0	N/A
CMI	-0.10	0.25	0.01	0.05	0	N/A

CMIJJA	0	N/A	0	N/A	-5.84	0.75
MAT	0	N/A	0	N/A	0.01	0.14
TD	0.26	0.70	-0.57	0.08	-0.17	0.32
PET	1.58	0.96	0	N/A	0	N/A
DD0	-0.18	0.48	0	N/A	-0.02	0.12
DD5	0.12	0.36	-1.01	0.14	0	N/A
EMT	-0.43	0.29	0	N/A	0	N/A
MAP	0	N/A	0	N/A	0	N/A
MSP	0.55	0.42	-0.14	0.21	0.01	0.11
Year	-0.04	0.02	0.01	0.01	-0.10	0.03
Height × Decid	0	N/A	0	N/A	0	N/A
Height × Mixed	0	N/A	0	N/A	0	N/A
Height × NonForest	0	N/A	0	N/A	0	N/A
ROAD × FC (Sparse)	0.59	0.64	0	N/A	0	N/A
ROAD × FC (Dense)	0.75	0.79	0	N/A	0	N/A
Barren ground × Road	0	N/A	0	N/A	0	N/A
Decid × Road	0	N/A	0	N/A	0	N/A
Grass × Road	0	N/A	0	N/A	0	N/A
Mixed × Road	0	N/A	0	N/A	0	N/A
Shrub × Road	0	N/A	0	N/A	0	N/A
Wet × Road	0	N/A	0	N/A	0	N/A
Barren ground × Ea_We	0.75	0.57	0	N/A	0	N/A
Decid × Ea_We	1.90	1.18	0	N/A	0	N/A
Grass × Ea_We	0.15	1.04	0	N/A	0	N/A
Mixed × Ea_We	1.65	1.04	0	N/A	0	N/A
Shrub × Ea_We	1.18	0.79	0	N/A	0	N/A
Wet × Ea_We	0.88	0.64	0	N/A	0	N/A

Ea_We × FC (Sparse)	0	N/A	0	N/A	0	N/A
Ea_We × FC (Dense)	0	N/A	0	N/A	0	N/A

Appendix 21. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the Climate model subsets (CASFRI) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-3.45	0.18	-4.39	0.42	-8.08	0.42
Agr	-1.00	0.41	-2.58	0.40	0	N/A
Decid	0.96	0.19	-1.71	0.46	0	N/A
Development	0.13	0.16	-1.69	0.37	0	N/A
Grass	-0.09	0.22	-1.43	0.38	0	N/A
Mixed	0.73	0.16	-0.55	0.10	0	N/A
Riparian	-5.35	6.08	-7.70	5.57	0	N/A
Shrub	0.16	0.35	-0.70	0.41	0	N/A
Wet	0.62	0.17	-0.62	0.28	0	N/A
Height_FRI	0.28	1.03	-1.21	1.94	0.02	0.28
$Height\_FRI^2$	-0.32	1.22	1.28	2.05	0	N/A
FC_FRI (Sparse)	-0.10	0.29	-0.04	0.10	0	N/A
FC_FR (Dense)	0.02	0.13	-0.08	0.22	0	N/A
Road	-0.90	0.10	0.06	0.07	1.22	0.33
TWI	-0.04	0.15	-0.09	0.07	-0.04	0.11
TWI^2	0	N/A	0	N/A	0	N/A
Slope	-0.08	0.35	-0.01	0.03	0	N/A
West	-0.58	0.25	-0.15	0.20	-0.38	0.24
LD	0	N/A	-1.11	0.20	-0.01	0.16
PD	-0.04	0.22	0	N/A	-0.06	0.89

Burn	0	N/A	0.13	0.33	0	N/A
CC	0.01	0.06	0.51	0.48	-0.22	0.38
CMI	-0.01	0.07	0	N/A	0	N/A
CMIJJA	0	N/A	0	N/A	-5.65	0.50
MAT	0	N/A	0.05	0.23	0	N/A
TD	0.36	0.18	-0.37	0.52	-0.74	0.37
PET	0	N/A	1.37	1.18	0	N/A
DD0	0	N/A	0	N/A	0	N/A
DD5	0.02	0.11	-1.66	1.21	-0.01	0.09
EMT	-0.04	0.13	-0.29	0.43	-0.01	0.06
MAP	0.01	0.19	0.13	0.19	0	N/A
MSP	0.04	0.14	-0.02	0.07	0	N/A
Year	-0.06	0.02	0	N/A	-0.11	0.04
Height × Decid	0	N/A	0	N/A	0	N/A
Height × Mixed	0	N/A	0	N/A	0	N/A
Height × NonForest	0	N/A	0	N/A	0	N/A
Road × FC_FRI (Sparse)	0	N/A	0	N/A	0	N/A
Road × FC_FRI (Dense)	0	N/A	0	N/A	0	N/A
Agr × Road	0	N/A	0	N/A	0	N/A
Decid × Road	0	N/A	0	N/A	0	N/A
Development × Road	0	N/A	0	N/A	0	N/A
Grass × Road	0	N/A	0	N/A	0	N/A
Mixed × Road	0	N/A	0	N/A	0	N/A
Riparian × Road	0	N/A	0	N/A	0	N/A
Shrub × Road	0	N/A	0	N/A	0	N/A
Wet × Road	0	N/A	0	N/A	0	N/A
Agr × Ea_We	0	N/A	0	N/A	0	N/A

Decid × Ea_We	0	N/A	0	N/A	0	N/A
Development × Ea_We	0	N/A	0	N/A	0	N/A
Grass × Ea_We	0	N/A	0	N/A	0	N/A
Mixed × Ea_We	0	N/A	0	N/A	0	N/A
Riparian × Ea_We	0	N/A	0	N/A	0	N/A
Shrub × Ea_We	0	N/A	0	N/A	0	N/A
Wet × Ea_We	0	N/A	0	N/A	0	N/A
FC_FRI (Sparse) × Ea_We	0.17	0.51	-0.01	0.03	0	N/A
FC_FRI (Dense) × Ea_We	0.12	0.35	-0.01	0.07	0	N/A

Appendix 22. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the Climate-Landscape model subsets (NALCMS) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-5.22	0.46	-6.17	0.32	-8.29	0.34
Agr	-2.17	0.57	-0.68	0.26	-0.54	0.54
Barren ground	-13.36	1.05	-1.37	1.25	-2.24	4.67
Decid	-0.82	0.35	0.21	0.09	-0.62	0.26
Development	-11.22	4.82	-2.45	4.02	-1.78	4.02
Grass	-0.88	0.43	-0.26	0.14	-0.23	0.25
Mixed	-0.78	0.44	0.05	0.12	0.01	0.26
Shrub	-2.47	2.46	0.10	0.12	0.13	0.20
Wet	-0.66	0.41	0.12	0.14	0.03	0.55
Height	0.56	1.07	0.63	0.19	-0.01	0.10
$Height^2$	0	N/A	-0.03	0.19	0	N/A
FC (Sparse)	0.18	0.21	0.07	0.17	0	N/A
FC (Dense)	0.28	0.28	0.06	0.15	0	N/A
Road	-0.73	0.36	0.16	0.08	1.13	0.19
TWI	-0.06	0.15	-0.01	0.05	0.01	0.03
TWI^2	-0.01	0.01	0.02	0.04	0	N/A
Wet	0	N/A	0	N/A	-0.02	0.27
WetWater	0.01	0.05	-0.63	0.48	-0.05	0.26
Slope	-0.04	0.22	-0.02	0.25	-0.01	0.14
West	-0.72	0.94	-0.27	0.24	0.05	0.25

Burn	0	N/A	1.00	0.21	0	N/A
AgrDev	-0.72	0.59	-2.55	0.67	-0.95	1.10
AgrDev^2	0	N/A	0.05	0.44	-0.16	0.80
IP	2.58	0.23	1.01	0.23	0.68	0.45
CMI	-0.01	0.06	0.21	0.07	0	N/A
CMIJJA	0	N/A	0	N/A	-3.56	0.58
MAT	0	N/A	0	N/A	0.22	0.50
TD	0.41	0.20	-0.55	0.39	0	N/A
PET	0	N/A	-0.21	0.51	0	N/A
DD0	0	N/A	0.11	0.29	0	N/A
DD5	0	N/A	-0.73	0.46	0	N/A
EMT	-0.01	0.07	0.04	0.10	-0.01	0.06
MAP	0.02	0.14	0.01	0.07	-0.01	0.11
MSP	0.01	0.08	-0.57	0.12	0	N/A
Year	-0.04	0.02	0	N/A	-0.07	0.03
Height × Decid	1.07	1.01	-0.03	0.15	0	N/A
Height × Mixed	2.08	1.61	-0.05	0.28	0	N/A
Height × NonForest	1.72	1.51	0.04	0.21	0	N/A
Road × FC (Sparse)	0.11	0.32	0.01	0.02	0	N/A
Road × FC (Dense)	0.15	0.42	0.01	0.03	0	N/A
Agr × Road	0	N/A	0	N/A	0	N/A
Barren ground × Road	0	N/A	0	N/A	0	N/A
Decid × Road	0	N/A	0	N/A	0	N/A
Development × Road	0	N/A	0	N/A	0	N/A
Grass × Road	0	N/A	0	N/A	0	N/A
Mixed × Road	0	N/A	0	N/A	0	N/A
Shrub × Road	0	N/A	0	N/A	0	N/A

Wet × Road	0	N/A	0	N/A	0	N/A
Agr × Ea_We	-0.27	3.16	0	N/A	0	N/A
Barren ground × Ea_We	0.66	0.87	0	N/A	0	N/A
Decid × Ea_We	1.06	1.37	0	N/A	0	N/A
Development × Ea_We	-0.03	3.35	0	N/A	0	N/A
Grass × Ea_We	-0.23	2.24	0	N/A	0	N/A
Mixed × Ea_We	0.82	1.06	0	N/A	0	N/A
Shrub × Ea_We	-1.61	4.47	0	N/A	0	N/A
Wet × Ea_We	0.13	1.46	0	N/A	0	N/A
Ea_We × FC (Sparse)	-0.01	0.09	0	N/A	0	N/A
Ea_We × FC (Dense)	-0.01	0.12	0	N/A	0	N/A

Appendix 23. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the BCR model subsets (NALCMS) at the last stage of the model building process (i.e. Year; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-17.46	5.46	-3.88	0.22	-8.56	0.47
Agr	-1.75	0.38	-1.63	0.23	-0.92	0.35
Barren ground	-15.03	0.29	-2.11	1.25	-1.90	4.44
Decid	0.45	0.10	-0.11	0.07	-0.87	0.28
Development	-14.06	4.06	-4.08	4.25	-1.86	4.15
Grass	-0.18	0.18	-0.55	0.11	0.45	0.22
Mixed	0.68	0.09	-0.05	0.07	-0.31	0.25
Shrub	-1.73	1.46	-0.02	0.09	1.30	0.18
Wet	-0.11	0.19	-0.05	0.11	-0.20	0.57
FC (Sparse)	0.11	0.16	0.30	0.26	0	N/A
FC (Dense)	0.21	0.16	0.26	0.22	0	N/A
Road	-0.76	0.14	-0.19	0.08	1.55	0.22
TWI	-0.17	0.20	0.01	0.05	0.01	0.05
TWI^2	0	N/A	0.08	0.05	0	N/A
Slope	0.07	0.25	-0.02	0.07	0	N/A
West	0	N/A	0	N/A	0.87	0.28
BCR5	-3.18	5.35	-0.02	0.06	-0.05	0.23
BCR6	13.68	5.45	-1.94	0.12	-0.08	0.38
BCR8	13.17	5.46	-1.02	0.09	-0.08	0.39
BCR9	-2.58	5.34	-0.12	0.07	0.04	0.17

BCR12	13.80	5.46	-1.70	0.11	-0.08	0.38
BCR13	12.15	5.47	-4.68	0.51	-0.13	0.62
BCR14	13.66	5.46	-0.78	0.07	-0.06	0.29
BCR_Alaska	-2.98	5.34	-0.21	0.09	-0.11	0.51
BCR_Arctic	-0.93	7.69	-1.48	0.19	-0.22	1.50
BCR_Prairie	8.87	6.92	-6.02	3.95	-0.07	0.32
ROAD × FC (Sparse)	0.02	0.12	0.01	0.06	0	N/A
ROAD × FC (Dense)	0.02	0.13	0.01	0.07	0	N/A

Appendix 24. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the BCR model subsets (LCCMC) at the last stage of the model building process (i.e. Space; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-16.44	6.17	-4.03	0.13	-8.60	0.90
Agr	-1.67	0.44	-1.36	0.26	-1.41	0.57
Barren ground	-4.34	6.02	-0.68	0.21	-0.95	2.35
Burn	-7.61	7.28	1.21	0.14	0.58	0.29
Decid	0.53	0.11	0.07	0.07	-0.46	0.26
Development	0.35	0.17	-0.09	0.07	0.67	0.25
Grass	-0.06	0.16	-0.02	0.08	-0.25	0.25
Mixed	0.80	0.09	0.15	0.06	-0.12	0.22
Wet	-0.59	0.38	-0.36	0.15	-0.05	0.45
FC (Sparse)	0.11	0.15	0.48	0.07	-0.01	0.04
FC (Dense)	0.19	0.16	0.42	0.07	-0.01	0.02
Road	-0.76	0.17	-0.17	0.06	1.42	0.28
TWI	-0.10	0.11	-0.13	0.09	0.01	0.02
TWI^2	-0.01	0.01	0.02	0.05	0	N/A
Slope	0.91	0.84	-0.33	0.29	-0.01	0.09
West	0	N/A	0	N/A	1.33	0.55
BCR5	-4.64	5.82	-0.05	0.07	-0.23	0.59
BCR6	12.44	6.16	-2.08	0.13	-0.24	0.61
BCR8	11.96	6.17	-1.14	0.08	-0.29	0.74
BCR9	-4.41	5.82	-0.11	0.07	0.09	0.23

BCR12	12.53	6.17	-1.84	0.10	-0.32	0.79
BCR13	10.79	6.18	-4.93	0.52	-0.37	0.93
BCR14	12.40	6.16	-0.90	0.07	-0.22	0.56
BCR_Alaska	-4.36	5.82	-0.12	0.08	-0.35	0.88
BCR_Arctic	-1.33	8.00	-1.19	0.15	-1.23	3.86
BCR_Prairie	7.54	7.56	-5.77	3.06	-0.20	0.49
Road × FC (Sparse)	0.01	0.15	0	N/A	0	N/A
Road × FC (Dense)	0.01	0.15	0	N/A	0	N/A

Appendix 25. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the BCR model subsets (EOSDF) at the last stage of the model building process (i.e. Space; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-16.64	6.14	-3.71	0.16	-8.80	0.20
Barren ground	0.02	0.12	-0.29	0.06	0	N/A
Decid	0.69	0.10	-0.63	0.11	0	N/A
Grass	-0.48	0.15	-0.07	0.07	0	N/A
Mixed	0.70	0.09	-0.17	0.08	0	N/A
Shrub	0.13	0.14	0.04	0.07	0	N/A
Wet	-0.28	0.16	0.04	0.10	0	N/A
FC (Sparse)	0.17	0.18	0.01	0.08	0	N/A
FC (Dense)	0.25	0.24	0.01	0.07	0	N/A
Road	-1.14	0.65	-0.02	0.07	1.30	0.18
TWI	-0.03	0.07	-0.22	0.09	-0.09	0.17
TWI^2	0.01	0.01	0.01	0.01	0	N/A
Slope	0.57	0.85	-0.42	0.40	0.01	0.14
West	0	N/A	0	N/A	1.21	0.16
BCR5	-4.01	5.64	-0.09	0.07	0	N/A
BCR6	12.74	6.13	-1.96	0.13	0	N/A
BCR8	12.28	6.12	-0.89	0.11	0	N/A
BCR9	-3.93	5.64	-0.01	0.08	0	N/A
BCR12	12.91	6.12	-1.48	0.11	0	N/A
BCR13	11.80	6.10	-3.43	0.26	0	N/A

BCR14	12.95	6.12	-0.73	0.08	0	N/A
BCR_Alaska	-3.90	5.65	-0.51	0.11	0	N/A
BCR_Arctic	-1.29	8.18	-1.02	0.16	0	N/A
BCR_Prairie	6.78	10.25	-9.84	5.43	0	N/A
Road × FC (Sparse)	0.40	0.60	0.01	0.02	0	N/A
Road × FC (Dense)	0.50	0.73	0.01	0.03	0	N/A

Appendix 26. Coefficient and standard error (Coef. ± SE) for each variable used to explain variation in CAWA, OSFL, and CONI density across Canada. Presented are values from the BCR model subsets (CASFRI) at the last stage of the model building process (i.e. Space; see Table 8 for variables selected in final models). Variables with a selection frequency of 0 have coefficient = 0 and SE = N/A. For categorical variables, values are relative to the mean of a reference category for each variable.

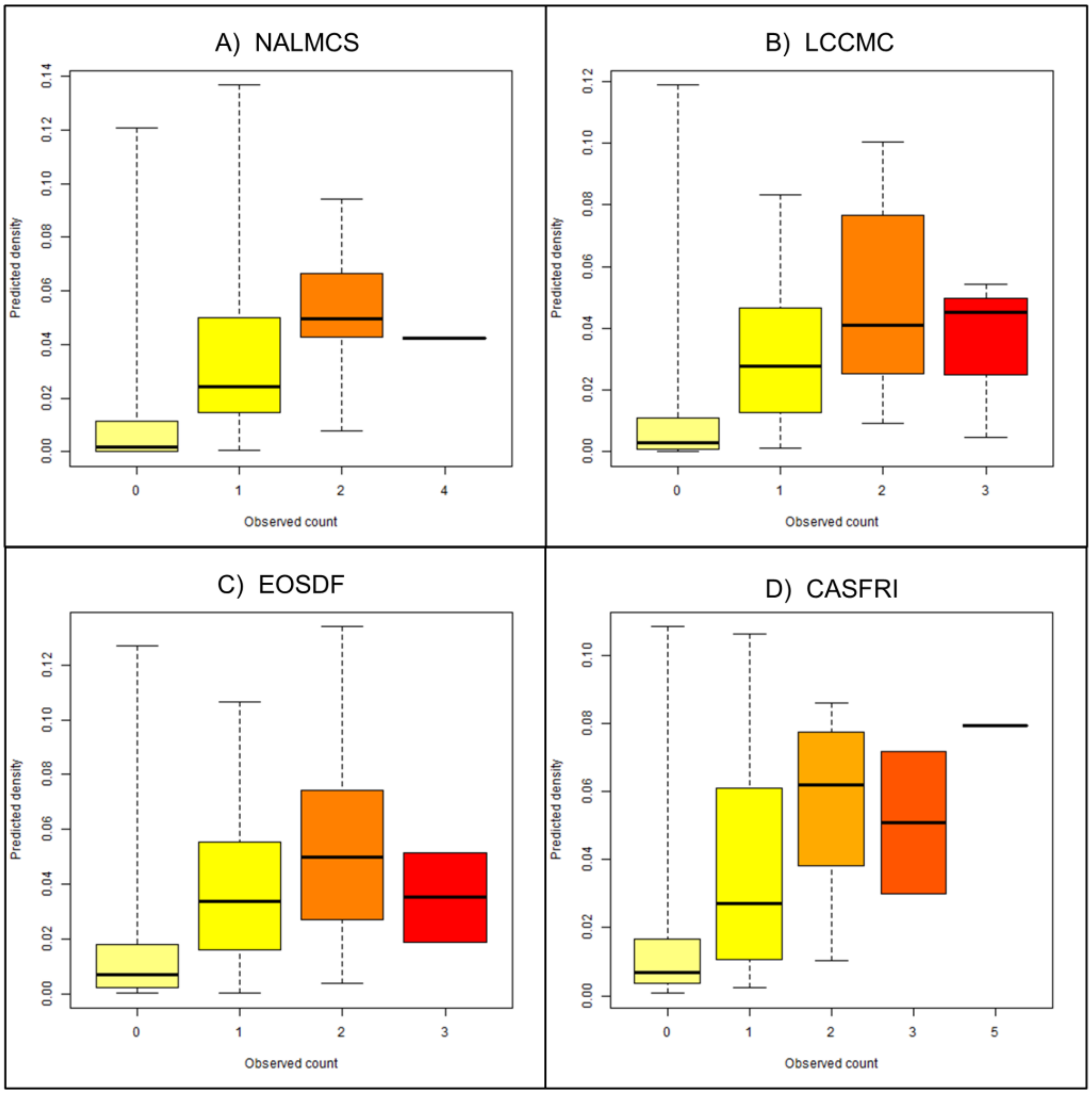
	CAWA		OSFL		CONI	
Variable	**Coef.**	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
(Intercept)	-19.65	0.50	-3.36	0.09	-8.98	0.29
Agr	-1.29	0.38	-1.86	0.21	0	N/A
Decid	0.57	0.09	-1.18	0.11	0	N/A
Development	-0.36	0.12	-1.03	0.08	0	N/A
Grass	-0.27	0.19	-0.70	0.20	0	N/A
Mixed	0.54	0.08	-0.59	0.09	0	N/A
Riparian	-8.46	8.21	-9.52	6.93	0	N/A
Shrub	-0.09	0.35	0.13	0.18	0	N/A
Wet	0.25	0.11	-0.12	0.11	0	N/A
FC_FRI (Sparse)	-0.04	0.07	0	N/A	0	N/A
FC_FRI (Dense)	-0.10	0.14	0	N/A	0	N/A
Road	-0.78	0.07	-0.23	0.07	1.45	0.24
TWI	-0.01	0.04	-0.03	0.04	-0.17	0.21
TWI^2	0	N/A	0	N/A	0.01	0.03
Slope	0.19	0.52	-0.01	0.01	0	N/A
West	0	N/A	0	N/A	1.23	0.18
BCR5	-0.12	0.02	-1.18	0.16	0	N/A
BCR6	16.31	0.45	-1.91	0.13	0	N/A
BCR8	15.93	0.44	-1.22	0.10	0	N/A

BCR9	0.10	0.04	-0.01	0.08	0	N/A
BCR12	16.44	0.44	-1.27	0.11	0	N/A
BCR13	15.06	0.54	-3.73	0.34	0	N/A
BCR14	16.49	0.43	-0.60	0.07	0	N/A
BCR_Alaska	0.01	0.07	-0.12	0.09	0	N/A
BCR_Arctic	0	N/A	0	N/A	0	N/A
BCR_Prairie	11.31	4.98	-12.33	5.30	0	N/A
ROAD × FC_FRI (Sparse)	0	N/A	0	N/A	0	N/A
ROAD × FC_FRI (Dense)	0	N/A	0	N/A	0	N/A

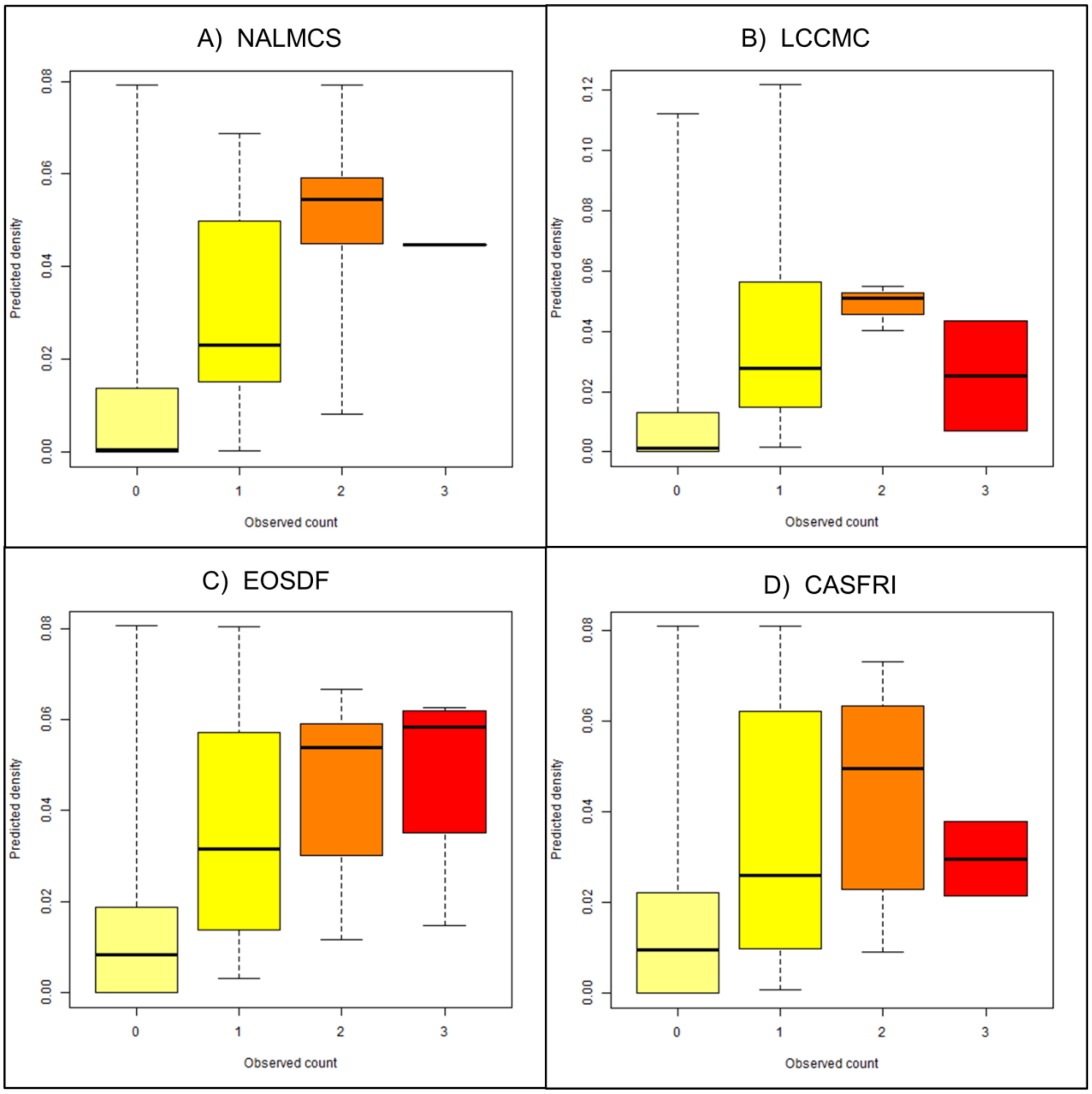
Appendix 27. Overall concordance correlation coefficients (OCCC; measured deviation from 45° line through origin, i.e. perfect agreement between two measures), overall precision (OPREC; measured of how far each observation deviated from the best fit line), and overall accuracy (OACCU; measured how far the best line deviates from the 45° line) for each model subsets. OCCC allowed evaluating scale and location shifts across 200 bootstrap based predictions for each model subset and exploring prediction uncertainty.

Species	Variable set	Spatial extent	OCCC	OPREC	OACCU
CAWA	Climate	CASFRI	0.9455	0.9512	0.9940
		LCCMC	0.9296	0.9330	0.9964
		EOSDF	0.9038	0.9105	0.9926
		NALCMS	0.9265	0.9301	0.9961
	BCR	CASFRI	0.9710	0.9733	0.9976
		LCCMC	0.9737	0.9755	0.9982
		EOSDF	0.9617	0.9646	0.9971
		NALCMS	0.9757	0.9774	0.9982
	Climate-Landscape	NALCMS	0.8294	0.8795	0.9430
OSFL	Climate	CASFRI	0.9098	0.9126	0.9969
		LCCMC	0.9250	0.9281	0.9966
		EOSDF	0.9496	0.9538	0.9956
		NALCMS	0.9543	0.9562	0.9980
	BCR	CASFRI	0.9850	0.9865	0.9985
		LCCMC	0.9834	0.9845	0.9989
		EOSDF	0.9776	0.9799	0.9976
		NALCMS	0.9740	0.9750	0.9990
	Climate-Landscape	NALCMS	0.8762	0.9418	0.9304
CONI	Climate	CASFRI	0.9075	0.9319	0.9738

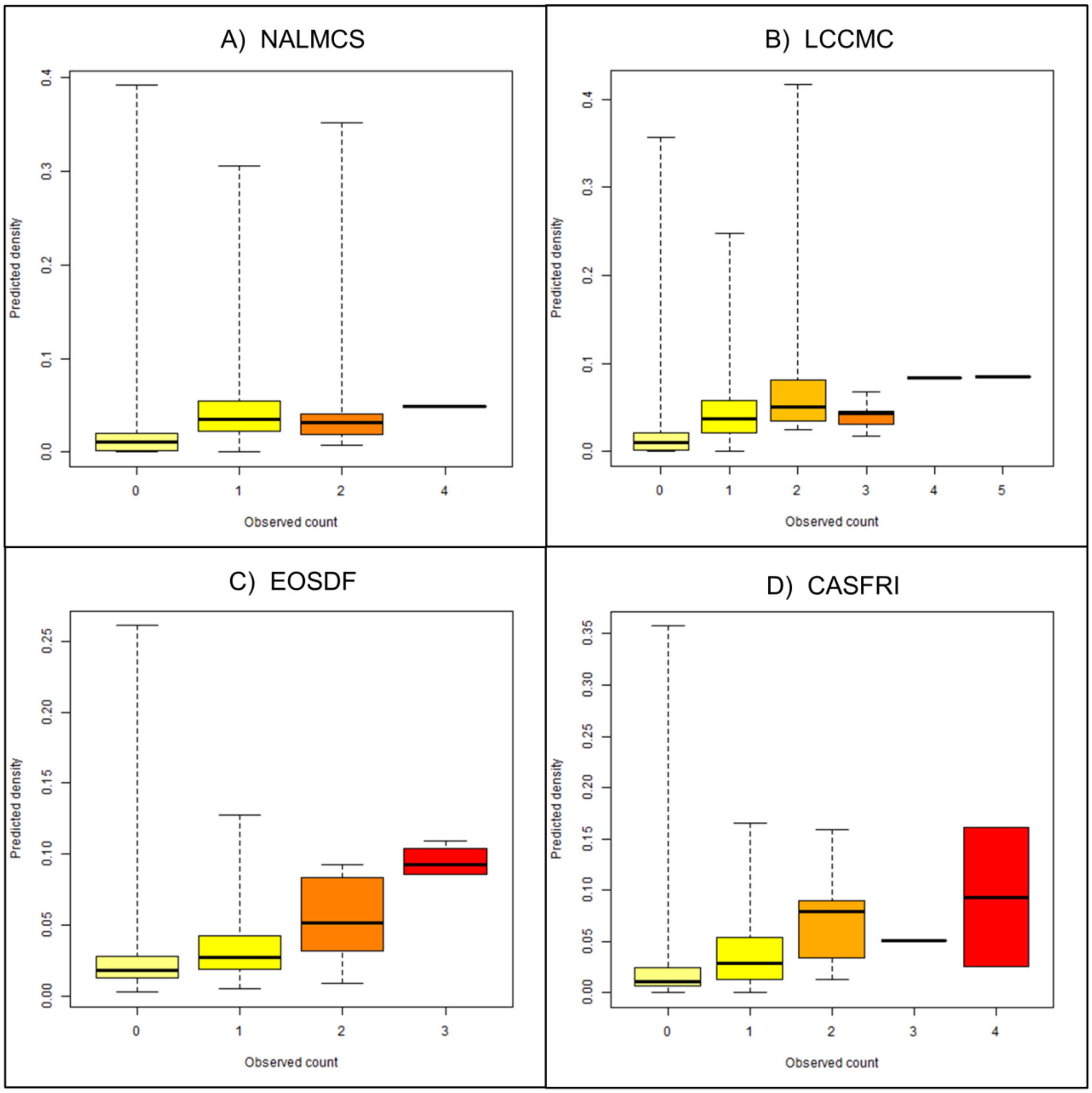
		LCCMC	0.9455	0.9611	0.9838
		EOSDF	0.9358	0.9571	0.9777
		NALCMS	0.9665	0.9768	0.9895
	BCR	CASFRI	0.9148	0.9457	0.9673
		LCCMC	0.8265	0.8622	0.9585
		EOSDF	0.9286	0.9566	0.9708
		NALCMS	0.9273	0.9469	0.9793
	Climate-Landscape	NALCMS	0.7680	0.9467	0.8112



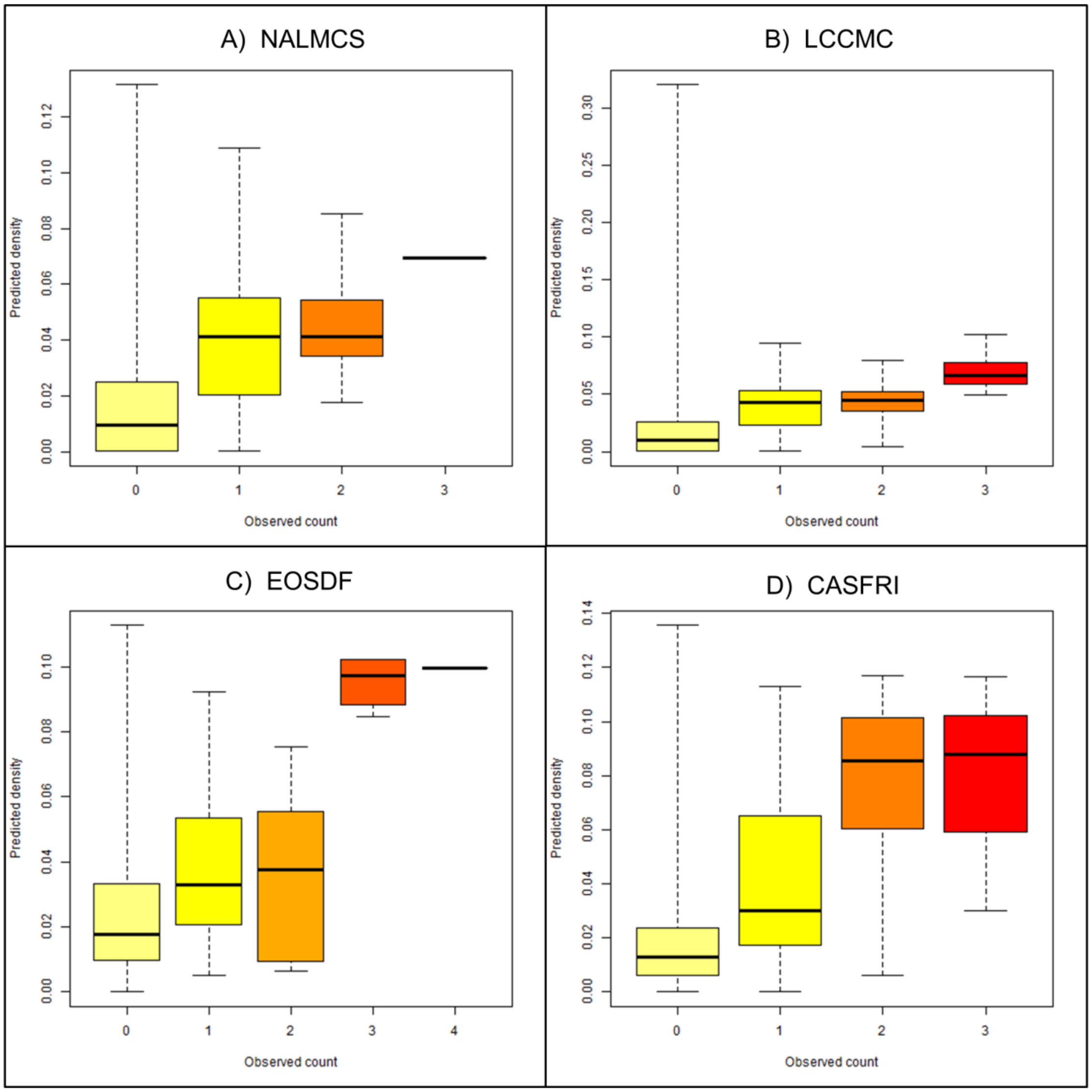
Appendix 28. Goodness of fit measurements for the four Climate model subsets explaining variation in CAWA density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



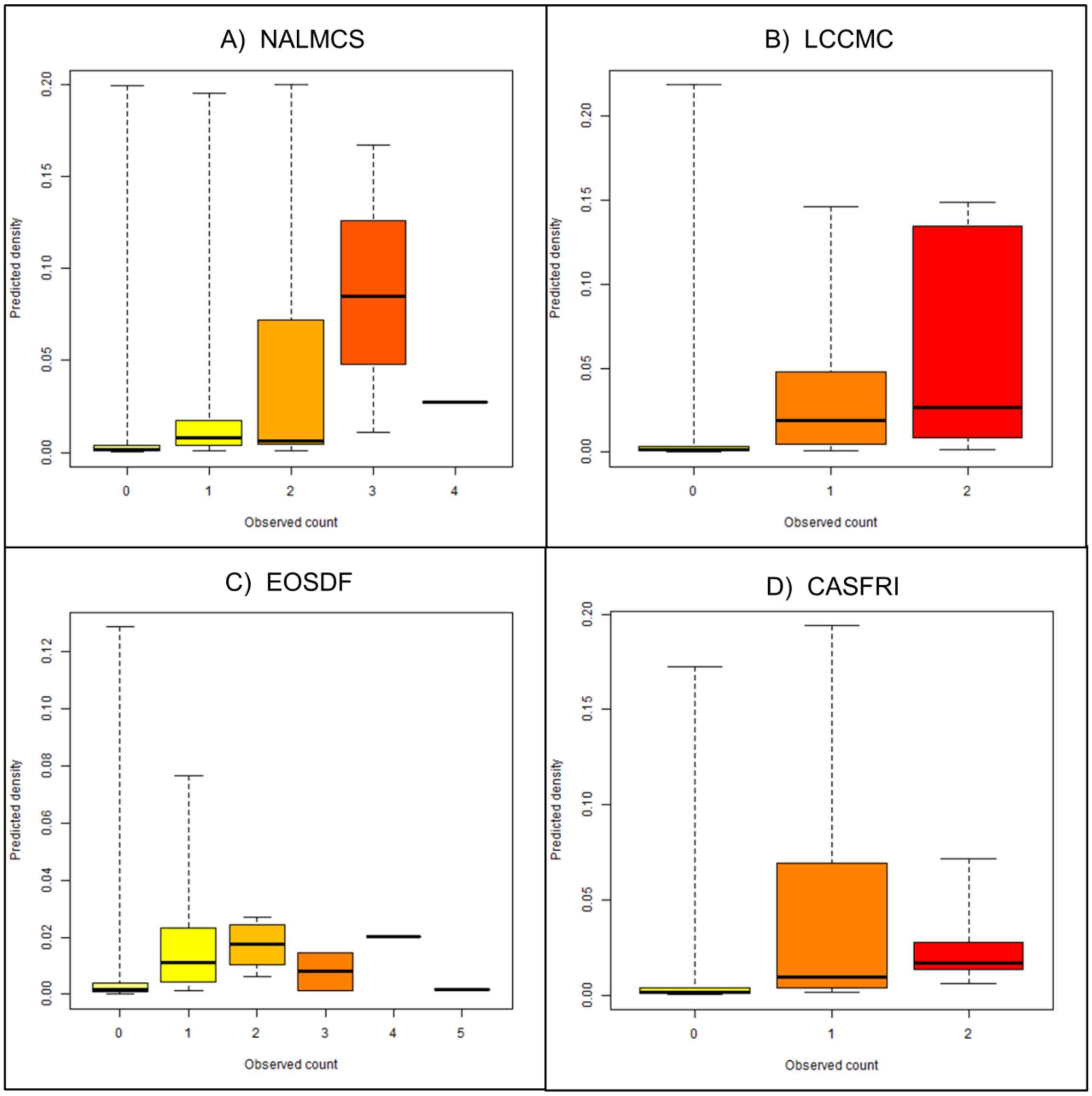
Appendix 29. Goodness of fit measurements for the four BCR model subsets explaining variation in CAWA density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



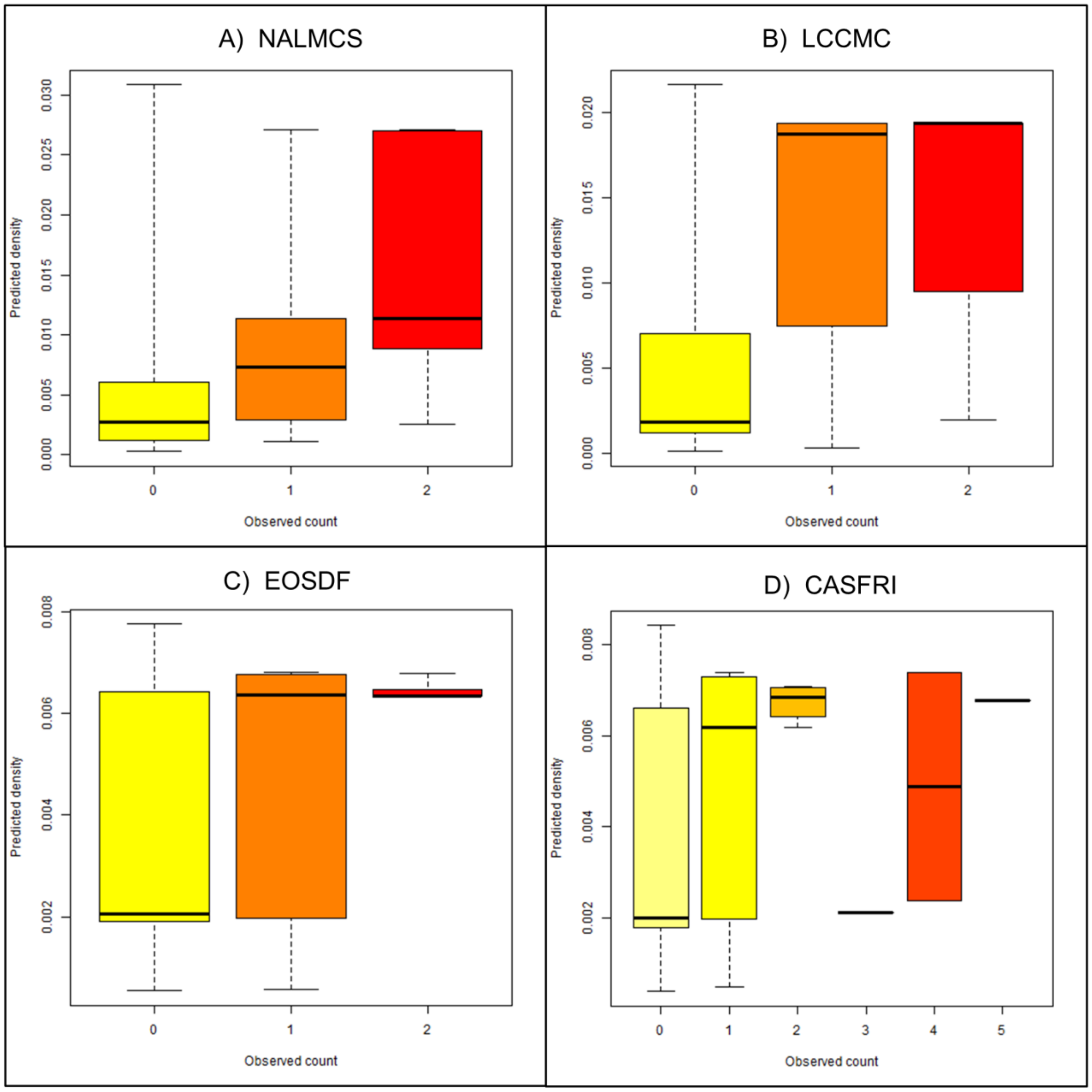
Appendix 30. Goodness of fit measurements for the four Climate model subsets explaining variation in OSFL density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



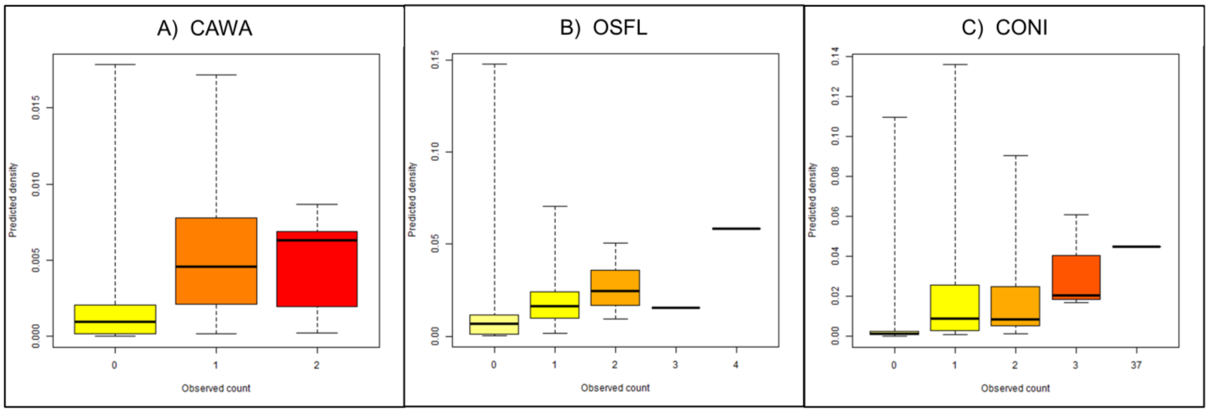
Appendix 31. Goodness of fit measurements for the four BCR model subsets explaining variation in OSFL density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



Appendix 32. Goodness of fit measurements for the four Climate model subsets explaining variation in CONI density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



Appendix 33. Goodness of fit measurements for the four BCR model subsets explaining variation in CONI density based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of >1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).



Appendix 34. Goodness of fit measurements for the Climate-Landscape model subset explaining variation in density for the three focal species based on count frequencies from 10000 random samples of observations. Models could separate counts = 0 from those > 0 and there was higher counts of 1 (vs. counts of 0) suggesting that they properly fit the data. The different colours represent different abundance values from point count stations (Observed count).

Analyses to support critical habitat identification for Canada Warbler, Olive-sided Flycatcher, and Common Nighthawk (Project K4B20-13-0367)

FINAL REPORT 2

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http://www.borealbirds.ca

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Table 1. Proposed Schedule of Studies identifying limitations regarding our modelling approach and knowledge gaps pertaining to the identification of critical habitat for Canada Warbler (*Cardellina Canadensis*; CAWA), Olive-sided Flycatcher (*Contopus cooperi*; OSFL), and Common Nighthawk (*Chordeiles minor*; CONI).

Description of Activity	**Rationale**
Gaps in avian and biophysical data	
1) CONI: Improve detection models for CONI to calibrate data for years where only standard point count data are available. Data from autonomous recording units (ARUs) could be used to provide the required data for those new detection models. Alternatively, data could be available from standard point counts conducted at dawn and dusk.	- CONI are hard to detect using standard point count surveys and low detectability results in large uncertainty in density estimates; - Compared to other bird species, the Boreal Avian Modelling (BAM) project currently has few detections of CONI although it has a large Canadian breeding range; - ARUs allow detection of species that are active at dawn and dusk such as CONI and are being used in many regions across the country; - Current models based on point count surveys conducted just after sunrise might substantially underestimate population size.
2) All focal species: Increase targeted sampling effort in areas of data availability or high prediction uncertainty.	- There are important gaps in the BAM dataset (e.g. territories, Northern Manitoba, Northern Saskatchewan, Northern Quebec, and Newfoundland; Figure 1) and adding point count data from these regions would generate more accurate habitat models for BCR 7 and the northern portion of BCR 8; - Estimates of model prediction errors should be used to inform efficient sampling design.
3) All focal species: Continue working toward standardizing all point count and biophysical data available across Canada.	- Only by standardizing all point count and biophysical data available across Canada would the best information be available to generate habitat models and estimate population size for these focal species

	across the country.
4) <u>All focal species</u>: Compare reproductive success of individuals in areas with the highest vs. lowest predicted densities.	- An important assumption in this report is that density is a good indicator of habitat quality. Hence, comparing reproductive success of individuals in areas with the highest vs. lowest predicted densities would be important to consider when developing the Recovery Strategies.
5) <u>All focal species</u>: Determine whether all available habitat is being used.	- Important habitat in this report is identified based on the assumption that important habitat is saturated (i.e. important habitat is occupied and unoccupied habitat is considered not important). However, factors limiting population size may occur outside of the breeding range and unused important habitat might be available across Canada. Our analytic approach does not allow identification of unused important habitat; - Simulation studies show that for old-forest associated species, the natural disturbance regime coupled with modest dispersal limitation can easily reduce population size below 50% of carrying capacity, because areas of high quality habitat are not immediately filled. Forest harvesting and other anthropogenic disturbances compound this effect; - Further development of these models is required for identification and management of the spatial structure of important habitat at regional and national extents.
Analytical approach	
6) Habitat models should account for years for which biophysical data are available.	- Current models are derived from biophysical data ranging from 2000 to 2011 and the implications of using some relatively old (10-15 years) compared to more recent land cover data remain unclear; - Recent products tend to provide better

	spatial resolutions and are presumably more reliable, but studies are required to better understand how temporal variation in the quality of biophysical data influences model predictions. This is especially important for habitat models that are being used to explore temporal variation in population sizes.
7) <u>All focal species</u>: Validate model predictions by conducting point counts in areas with the highest uncertainty and comparing observed to predicted bird densities (i.e. prediction error).	- Model validation is a critical process required prior to implementing predictions from habitat models in conservation planning.
8) <u>All focal species</u>: Covariates at finer spatial resolutions across Canada should be used to generate habitat models as they become available.	- Some covariates used in this report were available at a relatively coarse spatial resolution (250 - 500 m) and such information at a finer spatial resolution might provide more accurate predictions; - Fine-scale resolution would be especially important for wet areas and initiatives such as the Wet Areas Mapping[1] will allow identifying more precisely the availability of important habitat for each focal species when/if it becomes available nationally.
9) <u>All focal species</u>: Predictions of bird abundance should be generated at a finer spatial scale.	- Owing to computation time and power, point level predictions were generated at a 1 km resolution. Because some disturbances (e.g. harvesting) take place over smaller areas, we recommend that predictions are being conducted at a finer spatial scale (e.g. 250 m) to determine how it influences population size estimates.
10) <u>All focal species</u>: Generate bird habitat models and predictions considering potential effects of landscape composition and structure.	- Landscape characteristics were only available from the NALCMS layer (i.e. proportion of high suitability land cover types within 4 km) to the test for an effect of landscape composition on bird abundance; - All other covariates in this report only

	included point level information; - The amount, quality, and configuration of habitat are all known to be important predictors of bird abundance and covariates allowing to characterize such relationships at multiple spatial scales would further our understanding of Critical Habitat for each focal species.
11) All focal species: Model spatio-temporal variation in important habitat in response to climate change and land-use change from forestry, energy sector, and other spatially extensive processes.	- For each species, climate covariates have been identified as important predictors of abundance; - Climatic projections for the next century are available[3]; - Combining bird habitat and climatic models would be important to produce adaptive conservation strategies considering spatio-temporal variation in Critical Habitat; - Changes in population sizes can result from activities occurring on the breeding grounds, at migratory stopovers or on the wintering grounds. Understanding the factors limiting population sizes throughout the entire life cycle of migratory birds is important to inform sound conservation planning.
12) All focal species: Conduct a more robust test of Maximum Detection Distance used by Partners in Flight vs. Effective Detection Radius (EDR) method used by BAM.	- Knowing the maximum detection distance of a species is critical to estimate population size based on point count surveys; - To reach this goal, it is important to conduct playback experiments and account for the ability of humans to hear the playback.
13) All focal species: Summarize information provided by the 9 model subsets generated for each focal species in a single population size estimate per species using a model weighting	- As part of this report, we generated 9 model subsets per species. Although our measures of Goodness of Fit suggest that they are good models, we are not recommending the use of one model subset

approach.	over another; - Single population size could be generated for each focal species by "weighting" cell-level abundance predicted from each model subset as a function of their respective coefficient of variation (i.e. accounting for prediction uncertainty); - One population size estimate for each species could integrate all the information currently available (covariates) at different spatial scales; - Such information would provide a better summary of the current understanding of the habitat being used by the three focal species and facilitate identification of critical habitat and inform conservation planning.
14) <u>All focal species</u>: Improve our analytical approach to better quantify temporal variation in population size estimates derived from the BAM dataset and identify factors explaining the estimated population trends.	- Models that take into account the spatio-temporal dependence structure of the data require that data are missing from the location specific time series. - We need to better understand how a spatially extensive, but temporally sparse dataset such as BAM, combined with locally available trend data (Calling Lake, Fort Liard) and BBS can be used in time series analysis. - It is also important to know how results from BAM dataset compare to year effects derived from a spatial model where year effect is a predictor without being part of the dependence structure. This will provide a better understanding of the current discrepancy between the estimated population trends based on BAM dataset and analytical approach and those reported by BBS.
15) <u>All focal species</u>: Improve our analytical approach to better quantify differential habitat selection for	- Observed abundance depends on both habitat selection and habitat availability. Differences in availability of habitats across the species range can shape differential use even if there is no difference in habitat

each focal species using the BAM dataset.	selection; - One approach that could be used is to generate an index of relative selection (RS) which compares selection in a given habitat category based on the density models with random selection (P. Solymos, unpublished data).

[1] See the Government of Alberta (http://esrd.alberta.ca/forms-maps-services/ maps/ resource-data-product-catalogue/hydrological.aspx) and Forest Watershed Research Center, University of New Brunswick (http://watershed.for.unb.ca/).

[2] http://www.natureserve.org/.

[3] GCM: downscaled GCM data portal (http://test.ccafs-climate.org/).