Boreal Avian Modelling Project
Projet de modélisation de l'avifaune boréale

A Report to Environment Canada

Roadside surveys of boreal forest birds: how representative are they and how can we improve current sampling?

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Executive Summary.—The Boreal Avian Modelling (BAM) team examined avian survey point count data collected from across the boreal forest region of Canada to quantify roadside bias in both survey coverage and survey counts by the North American Breeding Bird Survey (BBS), the most important monitoring survey for a wide suite of bird species in the boreal. We compared data from the BBS to data from off-road surveys compiled by the Boreal Avian Modelling Project (BAM) to (1) determine whether gaps in survey coverage by the BBS might be covered by off-road surveys in the region, (2) test for roadside bias in survey counts by comparing data between roadside and off-road surveys, and (3) determine whether the statistical power to detect trends was similar between roadside and off-road surveys given comparable survey effort.

- Survey coverage by the BBS was strongly biased toward sampling southern ecozones which make up 49% of the boreal but received 89% of the BBS surveys. Thus, the ecozones in the northern half of the boreal collectively comprise one of the largest gaps in survey coverage in North America; poorly sampled habitats across the boreal included conifer forests and woodlands, tundra- and lichen-dominated areas, wetlands, and areas with recent burns.
- The patterns of proportional survey coverage by the BBS, in terms of geographic and habitat strata, mirrored the distribution of the road network and the sampling of off-road areas by BAM. Thus the BBS appears to (1) sample geographic areas and habitats in proportion to their availability along the road network and (2) draw from the same sampling frame as the off-road surveys included in BAM (i.e., the road network).
- Opportunities exist to address some of the geographic sampling gaps in the northern boreal in areas serviced by existing roads. We identified 380 areas in the northern boreal with ≥30 km of road network, but with no prior surveys. These areas should be evaluated for future roadside surveys aimed at closing the large continental gap in avian survey coverage. However, complete coverage of sampling gaps will likely require a coordinated, national approach to off-road surveys in the northern boreal.

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- We found significant differences in survey counts for 79% of 85 species between roadside and off-road surveys (roadside bias). Positive roadside bias was more than twice the magnitude of negative roadside bias both in terms of number of species and average effect size. These results are similar to those from small-scale studies in the temperate zone. Extrapolating roadside results to off-road areas may overestimate population sizes for those species that exhibit positive roadside biases.
- Although we controlled for habitat type at the point count location, our results indicated that (1) species showing positive roadside bias are often associated with agricultural areas, clearings, shrub habitats, habitat edges, or human structures and (2) species showing negative bias tend to be associated with mature forests or forest interiors. Controlling for additional habitat covariates at both small (edges, roadside clearings, road width) and landscape scales (amount of agricultural lands) may better control for roadside bias in analyses of BBS data.
- The preponderance of positive roadside bias in our study indicates that detectability may be greater for birds surveyed along roads than off-road areas, possibly because birds can both be seen and heard at greater distances along roadway clearings than in dense vegetation. Additional data collection (in two time and distance intervals) on some roadside surveys would allow us to control for roadside bias in the detection process and thereby permit better integration of roadside and off-road data across the boreal.
- Statistical power to detect declines in avian abundance, and the accuracy and precision of the trend estimates, were positively related to the mean counts for species. Thus, species with positive roadside bias were more effectively monitored for trends on roadside surveys while the opposite was true for species with negative roadside bias. Because more than twice as many species exhibited positive than negative roadside bias, we expect that roadside surveys will be more efficient in detecting population declines than an equivalent survey effort in off-road areas.
- Population declines could be detected with 0.8 power for all nine species evaluated with an annual survey effort equivalent to 60 routes (50 points each). This information may be useful for setting target sample sizes for programs monitoring the population trends of boreal birds.

INTRODUCTION

Estimates of avian population trend (Sauer and Link 2011) and population size (Rich et al. 2004, Rosenberg and Blancher 2005) from the roadside North American Breeding Bird Survey (BBS) have become cornerstones for identifying conservation priorities and setting numerical population goals for landbird species across North America (Rich et al. 2004, Berlanga et al. 2010). Two important assumptions of these analyses are (1) that the BBS samples avian habitats in proportion to their availability across the broader landscape and (2) that roadside counts of birds are equivalent to counts of bird populations in roadless areas (Rosenberg and Blancher 2005, Thogmartin et al. 2006. Thogmartin 2010). Understanding the extent of these roadside biases are important not only for guiding the allocation of additional surveys (Bart et al. 2004, Dunn et al. 2005), but also for devising computational methods to account for bias when analyzing BBS data (Lawler and O'Conner 2004, Thogmartin et al. 2006, Sauer and Link 2011).

An extreme case of proportional habitat sampling bias by the BBS likely occurs over the majority of North America's boreal forest due to the region's sparse and uneven road network (Bystrak 1981, Bart et al. 2004, Rosenberg and Blancher 2005, Thogmartin et al. 2006). Violations of proportional habitat sampling across this vast region may arise for two reasons, neither of which has been explicitly tested. First, roads are not randomly distributed across the boreal and tend to be concentrated in the southern part of the region. Thus, the entire road network is not likely representative of the habitats across the region with habitats found predominately in the northern boreal being under sampled, and those in the southern boreal being over sampled. Assessing habitats bisected by the road network in relation to habitat availability across the boreal will help identify which habitats we can be conceivably sampled by the BBS and which will require sampling in roadless areas (Dunn et al. 2005). Second, the BBS may not sample habitats in relationship to their availability within the boreal road network due to sparse sampling compared to BBS sampling in temperate areas (Bart et al. 2004). Understanding where these gaps in habitat coverage occur will help prioritize where additional BBS surveys could be established to better meet national mandates for monitoring migratory birds.

The second way that roadsides can influence counts of birds is through their effect on bird behaviour, bird detectability, and habitat quality. For example, Western Meadowlarks are counted more often at survey points along roads due to their tendency to sing from fence posts (Rotenberry and Knick 1995). Similarly, there is a propensity of habitat edges along roadsides (Harris and Haskell 2007) and bird attracted to edges may be counted more frequently along roadside than off-road areas (Hutto et al. 1995). Roadsides also have large open areas which may increase detectability since birds can be seen and heard at greater distances across open space than through dense vegetation. Also, forest fragments in converted landscape along roads may act as population sinks that have reduced bird densities compared to unfragmented forests away from roads. Although comparisons between counts from roadside and nearby off-road surveys have been examined in the temperate zone, these studies have been limited in geographic scope and have not controlled for the effects of habitat when conducting the paired comparisons. Thus, broader-scale study is needed, both to understand the prevalence of roadside bias in BBS survey counts, and to determine whether accounting for the effects of habitat can help control for roadside bias in analyses of BBS data.

Finally, the primary goal of the BBS is to estimate population trends, yet statistical power to detect declines at spatial scales finer than the continental scale are often low because the number of routes can be quite small at the regional scale (Bart et al. 2004). Statistical power to detect trends of landbirds across the boreal has not been evaluated but is needed both to determine whether the current survey effort is adequate and to quantify how many additional surveys are needed to meet monitoring goals for detecting declines of magnitudes that warrant conservation action. Many researchers have recognized the clear limitations that the sparse boreal road network imposes upon BBS sampling and have therefore recommended complementing the BBS with off-road surveys to improve regional survey coverage (Dunn et al. 2005). Therefore, it would be helpful to determine how many surveys in off-road areas would be required to complement monitoring by the BBS.

In this study we assessed data from BBS surveys conducted across the boreal forest region of Canada to determine levels of bias in the survey and to explore ways to improve sampling by incorporating additional roadside and off-road surveys. Specifically, we first examined both the road network and the locations of BBS surveys to determine whether each sampled geographic strata and habitats in proportion to their availability at different spatial scales across boreal Canada. We also conducted similar analyses using locations of off-road surveys from across the boreal and compiled as part of the Boreal Avian Modelling (BAM) Project (Cumming et al. 2010a). We then highlighted gaps in BBS coverage relative to geographic locations and habitats and assessed whether these gaps (1) reflected biases inherent in the distribution of roads, (2) were accounted for by off-road surveys compiled by BAM, and (3) could be filled by additional roadside surveys. Next, we compared survey counts of birds between roadside surveys and off-road surveys compiled by BAM to test for roadside bias in the survey counts of 85 species. As part of this analysis we controlled for the effects of habitat to better isolate the roadside effect on the counts. Finally, we examine the data from the BBS and BAM for nine species and ran simulations to determine the number of roadside versus off-road surveys that are required to have 80% power to detect a 50% decline in population size over a 20 year period, the general standard for the landbird monitoring (Bart et al. 2004).

METHODS

Data analyzed

Avian datasets.—We analyzed point count data collected from throughout the boreal forest region of Canada (Table 1). We emphasized those data collected as part of the BBS as this is the broadest-scale and longest-standing monitoring program for boreal birds. Our analysis included data from BBS routes conducted from 1996–2009 in all provinces and territories, except Nunavut. We restricted our analysis to this time frame when the point level count data were available from the BBS national office.

We also analyzed data from off-road avian surveys that were conducted across boreal Canada from 1992–2010 and were compiled as part of the Boreal Avian Modelling (BAM) Project (Cumming et al. 2010a). We used all of the BAM and the BBS locations when testing for geographic and habitat gaps in sampling. We placed 400-m radius buffers around each BBS and BAM survey point to represent the geographic areas and habitats sampled by these surveys. When buffers overlapped between adjacent points for a given survey, we combined them into a single polygon. In our comparisons of avian counts between roadside versus off-road surveys, we used on-road data from the BBS (3-min duration counts) and the Ontario Breeding Bird Atlas (5-min, atlas) and off-road surveys of 3-min or 5-min compiled by BAM. For habitats, we used the habitat type intersected by the point as the data from the 400-m buffers were not available when we conducted these analyses. For each bird species analyzed in this report, we include the common name, the scientific name, and the AOU code in the Appendix.

Spatial data on roads, habitats, and geographic strata.—We examined BBS and BAM sampling relative to spatial data layers on roads, habitats, and geographic strata. For the location of roads, we used the National Road Network 2.0 (Natural Resources Canada 2007). We acknowledge that finer-scale information on the locations of roads were likely available at the provincial level, but we did not have access to these data layers at the time of this analysis. We placed 400-m wide buffers around roads to define the geographic areas and habitats associated with roads. When buffers from adjacent roads overlapped, we combined them into a single polygon for analysis.

For habitats, we used the land cover classes defined by the 250-m resolution Land Cover Map of Canada 2005 (Latifovic et al. 2008) and reclassified from 39 to 17 cover types by Cumming et al. (2010a). For our analysis, we collapsed the cover types further into nine classes: conifer forests and woodlands (conifer); deciduous forests and woodlands (deciduous); mixed forests and woodlands (mixed); bogs, fens, wetlands, and riparian areas (wetlands); open herbaceous and grass habitats (herbaceous/grass); tundra, non-vascular, rock, and snow (tundra / lichen / rock); recent burns (burns); agricultural lands (agricultural); and urban areas (urban). This aggregation ensured that adequate numbers of survey points existed in each category. We had considering using the land cover classes defined at a 25-m resolution by the Earth Observation for Sustainable Development (EOSD), but we found the classification to have inconsistencies at provincial borders and to lack complete coverage over our planning area. Thus, we did not use this landcover classification in our analyses.

For geographic strata, we used the National Ecological Framework for Canada (hereinafter ecological framework) which organizes ecological units into a nested spatial hierarchy based on geomorphology, hydrology, soils, climate, and vegetation. We examined our data relative to geographic stratifications of decreasing spatial extent: ecozones (n = 8) and ecoregions (n = 106) and ecodistrict (n =

580 (Ecological Stratification Working Group 1995). The global stratum was the boreal which encompassed the eight boreal ecozones.

Distribution of roadside surveys relative to geographic strata, habitats, and the road network

General approach.—We compiled the data on total road length, numbers of BBS and off-road surveys, and habitats within a grid of 10-km x 10-km blocks across the boreal (*n* = 60,621 blocks). We then examined the distribution of both BBS sampling and the boreal road network relative to larger geographic stratifications (ecoregion and ecozone) to identify geographic gaps in survey coverage. In general, we identified sampling gaps using a selection index (index) which we calculated as the difference between proportional sampling and proportion availability among geographic or habitat strata. We conducted these analyses for BBS, BAM, and the road network to assess bias among these different samples. This provided a better perspective of sampling gaps in the BBS and indicated whether they (1) might be adequately covered by existing surveys in off-road surveys included in BAM or (2) could be filled by establishing new BBS routes in geographic areas or habitats with high proportional coverage by roads.

We present selection indices at large spatial scales first (boreal forest or ecozone) to emphasize large-scale gaps in sampling. We then present selection indices at the ecoregional level to identify more specifically where the sampling gaps occur within ecozones. When the value of the selection index was less than zero, we interpreted this as a proportional gap in sampling which we further classified as large (≤ -0.1), moderate (-0.1 to -0.05), or small (-0.05 to 0) in magnitude. We present the gaps in this manner to help emphasize where surveys are most needed. When the selection index was greater than or equal to zero, we interpreted this as proportional sampling coverage. Although large values of the selection index indicate proportional oversampling in strict technical terms, we do not view the index values in this way. We simply view habitats and geographic areas with positive index values as lower priorities for future sampling when compared to strata with negative index values (gaps). We used this general approach to address questions related to the distribution of BBS surveys.

Question 1: How can we improve spatial coverage of the BBS across the boreal?—Our goal was to examine BBS sampling relative to geographic strata to identify spatial gaps in sampling. We used the general selection index approach described above and identified geographic gaps in sampling among boreal ecozones across Canada (large-scale gaps) and among ecoregions within each of these ecozones (small-scale gaps).

Questions 2 and 3: *Does BBS sampling or the road network encounter habitats in proportion to availability*? —To answer this question we used the general selection index approach outlined above and examined habitats associated with BBS sampling and the road network relative to habitats availability across the landscape. We did this at the scale of the boreal forest to identify large-scale gaps in habitat sampling and within each ecozone to identify smaller-scale gaps in habitat sampling. For each question, we also compared the direction and magnitude of bias in sampling between the road network and the BBS. When the magnitude and direction of bias were similar, we took this as evidence that the BBS generally sampled geographic areas or habitats in proportion to their availability along the road network.

We then examined the geographic sampling gaps (identified above) in relation to the 10-km x 10-km blocks across the boreal. We then highlighted the 10-km x 10-km blocks that possessed three characteristics: (1) within a geographic gap in BBS sampling, (2) ≥30 km of road existed in the block, and (3) no prior BBS or BAM surveys. We considered these blocks to be potential priorities (priority blocks) for future roadside surveys. We ranked the priority blocks (priorities 1—4) relative to whether they were located in an ecozone and/or ecoregion identified as a sampling gap (Table 2).

Finally, we compiled the data for each 10-km x 10-km blocks across the boreal including: (1) the ecozone and ecoregion that the block is located in, (2) the number of BBS and BAM sampling points in the block, (3) the number of years of BBS sampling, (4) the area of each habitat class (ha), and (5) our priority ranking for future sampling. We provide this information in an Access database and an accompanying GIS shapefile of the grid of 10-km x 10-km blocks.

Roadside bias in avian survey counts

General approach.—We used the three avian data sets (BBS, BAM, atlas) and tested for a roadside effect on the mean number of detections per survey point using a generalized linear mixed model (GLMM) with Poisson error and log-link function. We ran separate analysis for 85 species using Program R and the glmer function in package 'lme4' (Bates et al. 2011). We treated the point count station as the unit of sampling and the number of detections at a survey point (count) as the dependent variable. We tested for a fixed-categorical effect of roadside controlled for the fixed-categorical effect of habitat (eight classes), the fixed-categorical effect of count duration (3 min versus 5 min), and the categorical-random effect of ecodistrict. The latter was included to account for spatial and temporal non-independence in the data and for differences in bird counts caused by covariates not in the model. We treated ecodistrict as a normal random variable with mean zero and certain variance on the linear predictor scale. We assumed that there were no interactions among the covariates for roadside, habitat, and count duration.

Question 4: Which species show positive, neutral or negative roadside bias?— For each species we obtained the maximum likelihood estimates and associated standard errors for the intercept, roadside effect, count duration, each of the habitat classes (minus the withheld reference class) as well as the variance of the random intercept. We quantified roadside bias using the coefficient for the roadside effect and its 95% asymptotic Wald confidence interval (CI). This coefficient represents the difference between the expected counts of roadside versus off-road surveys (log scale) controlled for the other variables in the model. We considered the roadside bias to be positive or negative based on the sign of coefficient when it had a 95% CI that did not overlap zero. When the 95% CI of the coefficient overlapped zero, then we considered roadside bias to be neutral.

Power to detect trends in avian abundance

General approach.—We ran a series of simulations to quantify the number of roadside and off-road surveys required to detect a 50% population decline in population size over a 20-year period with power of 0.8, using 2-tailed tests and a type I error rate (α) of 0.1. We used the parameter estimates in the models of roadside bias for each species to calculate baseline levels in abundance (log-scale) and then determine the annual abundances leading to a linear decline of 50% over 20 years. We also used our models of roadside bias in survey counts to balance sample sizes for roadside and off-road surveys by (1) calculating the fitted values of abundance for each survey location (log scale) and then (2) resampling the fitted abundance values with replacement to ensure that we maintained representation of habitat types, count durations, and ecodistricts between original and simulated data. The annual rate of change in abundance (trend) was expressed as the difference between future and current log abundances per year, which we calculated as [log(0.5) – log(1)] / 20 years = -0.0347 (Humbert et al. 2009). We subtracted this yearly rate from the baseline values of abundance and then repeated this in subsequent time steps over 20 years to create the trend. We then simulated observations for each species in each year for the 20-year period based on Poisson random numbers with mean calculated as the exponent of the log-based trend in abundance (equation above). We repeated this 100 times for each combination of species, survey type (roadside versus off-road), and sample size. We calculated the trend from the simulated data using a simplified version of the route-regression technique (Thomas and Martin 1994, Sauer and Link 2011) where a single route included 50 sampling locations. However, we defined a route as a cluster of observations rather than contiguous survey locations which allowed us to make the comparison between BBS and BAM. We did not include spatial dependence explicitly in our models and simulations. We fitted Poisson GLMs to simulated location-specific counts using year as an independent covariate. Other covariates were not specified, thus variation in the counts due to these unaccounted covariates contributed to our models as noise and thereby made the power-analysis more realistic. For each route, we used Poisson regression to estimate both the slope of the counts across the 20 years and the associated variance of the slope parameter. We then calculated the overall trend among routes as the average of the route-level slopes each weighted by the inverse of the route-level variance in the slope parameter. We calculated 90% CI (corresponding to α = 0.1) around the average slope, our estimate of the average annual rate of change in log abundance (trend).

Simulating the data for these analyses was quite time consuming and this constrained the number of species and sampling scenarios that we could run. The simulations that we ran were therefore relatively simple scenarios which we can refine in the future.

Question 5: How does statistical power relate to sample size and roadside bias?—We used sample sizes up to 25,000 survey locations (500 routes) in our separate simulations of roadside versus off-road surveys. We ran our simulations of statistical power on nine species: Olive-sided Flycatcher, Alder Flycatcher, American Robin, Bay-breasted Warbler, Blackpoll Warbler, Canada Warbler, Ovenbird, Clay-colored Sparrow, and Song Sparrow. We selected these species based on conservation relevance and variation in both abundance and the magnitude and direction of roadside bias in their counts. Statistical power was calculated as the number of simulations where the 90% CI of the trend did not contain zero (null hypothesis of no change is rejected), divided by 100, the number of replicate simulations. We expected that power would generally increase with sample size and that this increase would be more rapid for roadside versus off-road surveys for species with positive roadside bias in their survey counts. We expected the opposite to occur for species with negative roadside bias in survey counts. This was because higher counts help to estimate the slope parameter with greater precision using Poisson regression.

Question 6: How does the precision and accuracy of the estimated trends relate to sample size and roadside bias?—Our power analyses quantify whether we are able to detect a decline in abundance for a given species relative to sample size. However, this does not tell us how accurate or precise the resulting estimates of trend are. We therefore inspected the estimates of trend for bias by plotting the yearly trend estimates and 90% CI as a function of the number of routes surveys based on an average of 100 replicate simulation runs. We considered the estimates to be more accurate the closer they were to the true rate of change, -0.0347. We considered the estimate to be more precise the narrower the confidence interval was. We expected the accuracy and precision of the trend estimates to improve with increasing sample size both in terms of the number of routes and the average number of birds counted on a route. For the latter, we expected that accuracy and precision would generally be better for common species and for roadside versus off-road surveys when the species exhibited positive roadside bias.

RESULTS

Distribution of roadside surveys relative to geographic strata, habitats, and the road network

Geographic gaps in sampling across boreal Canada.—At the scale of the Canadian boreal forest, proportional gaps in sampling by the BBS (index < 0) occurred in all five of the northern ecozones which encompass 51% of boreal Canada (Figs. 1a and 2). This included the Taiga Shield (large sampling gap), Taiga Plains and Hudson Plains (medium gaps), and Boreal Cordillera and Taiga Cordillera (small gaps; Fig. 1 and 2). BBS sampling exceeded proportional availability (index > 0) and therefore had good proportional coverage in the three southern ecozones including, in increasing order of magnitude, the Boreal Plains, Atlantic Maritime, and Boreal Shield (Fig. 1a). The vast majority of BBS sampling was in these three ecoregions (89% of BBS samples) which constitute 49% of boreal Canada.

The overall geographic distribution of sampling by both BBS and BAM was largely proportional to the road network. For example, the direction of bias was concordant between BBS and the road network for all eight ecozones and concordant between BBS and BAM for seven of eight ecozones. Furthermore, sampling gaps were of similar magnitude between BBS and roads for four of five ecozones. The lone exception was the Boreal Cordillera where the gap in sampling was small for the BBS versus moderate for the road network. Sampling gaps were also of similar magnitude between BBS and BAM for three of five ecozones. Taiga Shield and Taiga Plains exhibited the two largest sampling gaps in both the BBS and BAM; additional sampling in these areas would go the farthest in balancing sampling across the boreal region. Compared to BAM, the gaps in BBS sampling were smaller for the Boreal Cordillera (small versus moderate) and larger for the Hudson Plains (moderate versus small; Fig. 1a).

Geographic gaps in sampling within boreal ecozones.—Among the 106 ecoregions, only 40 had an index value ≥ 0 and might therefore be considered to have proportional coverage by the BBS within ecozones. The remaining 66 ecoregions exhibited proportional sampling gaps of large (seven ecoregions), moderate (14), and small magnitude (45) within ecozones (Figs. 1b–i, 3). Five of the eight boreal ecozones contained at least one large ecoregional gap in proportional sampling. This included three ecoregions within the Taiga Shield and one ecoregion within each of the Boreal Plains, Taiga Cordillera, Boreal Cordillera, and Hudson Plains (Figs. 1c, f, g, h, i). Two of these poorly sampled ecoregions within the Boreal Plains and Taiga Cordillera were proportionally covered by BAM data (index > 0). The other five ecoregional gaps of large size for the BBS were also gaps in BAM sampling (four large, one small) and therefore particularly deficient in overall sampling for boreal birds. Three of these ecoregions in the Taiga Shield, Boreal Cordillera, and Hudson Plains also had large gaps in the road network. These ecoregions will likely require off-road surveys to improve their survey coverage. The other two ecoregions that had large gaps in BBS and BAM were in the Taiga Shield and were small to moderate gaps in the road network. These areas may be better prospects for additional BBS routes (Fig. 1c).

Habitat gaps in sampling across boreal Canada.—The BBS has proportional gaps in sampling (index < 0) in four of 10 general habitat classes, including: conifer forests (large sampling gap), tundra / non-vascular / rocky habitats (moderate gap), bogs and wetlands (small gap), and recent burns (small gap). Conversely, the selection index was ≥ 0 for BBS sampling in increasing order of magnitude from open herb / grass, mixed forest, agricultural, and deciduous forest. Proportional sampling of habitats by the BBS largely mirrored those of both the road network and sampling by BAM; all sampling gaps by the BBS were matched in direction and magnitude by gaps in both the road network and BAM. Thus, both BBS and BAM appear to sample habitats in proportion to their availability along the road network. The primary exceptions were that the selection index was positive in open herb / grass and agricultural areas for the BBS and the road network, while these habitats were small sampling gaps by BAM (Fig. 4a).

Habitat gaps in sampling within boreal ecozones.—The large-scale gaps in habitat sampling by the BBS were often apparent within individual ecozones (Fig. 4b–i). The large boreal gap in sampling conifers was a large sampling gap within the Taiga Plains, Boreal Shield, and Boreal Plains (Figs. 4b, d, f). Within the Taiga Plains, the gap in conifer coverage was larger for the BBS than the road network, indicating that there may be additional roads that could be surveyed to narrow this gap in BBS sampling (Fig. 4b). The large boreal gap in sampling tundra / non-vascular / rocky habitats by the BBS was also a large gap within the Taiga Shield and the Boreal and Taiga Cordilleras (Figs. 4c, g, i). These gaps were matched by large habitat gaps by the road network indicating that off-road surveys may be needed. This gap in BBS sampling in the Taiga Cordillera may be offset in part by BAM which had proportional coverage of this habitat type.

Within ecozones, the direction of bias in habitat sampling was concordant between the BBS and the road network in 91% of cases. This indicated that the BBS typically sampled habitats in proportion to their availability along the road network within each ecozone. However, the direction of bias was concordant between the BBS and BAM in only 65% of cases within ecozones. Lack of concordance in bias was particularly problematic within ecozone with large disparities between numbers of BBS and BAM sampling points, such as in the Atlantic Maritime and Hudson Plains (Table 1; Figs. 4e, i).

Identifying areas with roads where new roadside surveys would fill gaps in sampling.—A total of 1,135 10-km x 10-km blocks out of the 60,621 blocks across the boreal could be considered priority blocks for future roadside surveys because they met our criteria of (1) being located within a geographic sampling gap, (2) having ≥30 km or road, and (3) having no prior sampling by the BBS or BAM (Table 3, Fig. 5). Among these priority blocks, 380 were located in ecozones that were geographic gaps in sampling (large-scale gaps). Sixty of these blocks were given a priority ranks of 1 (highest priority), 66 blocks a priority rank of 2, and 254 blocks a priority rank of 3. Among these high priority blocks, 40% were in the Taiga Plains, 34% were in the Boreal Cordillera, 19% were in the Taiga Shield, and 4% were in each of the Hudson Plains and Taiga Cordillera. Thus, opportunities to add additional road-based surveys in these four poorly-sampled ecozones are quite limited.

A total of 755 priority blocks received a lower priority rank of 4 because they were located in small-scale gaps within ecozones that were overall well covered by the BBS. Among these blocks, 69% were in the Boreal Plains, 18% in the Boreal Shield, and 13% in the Atlantic Maritime (Table 3, Fig. 5). Surveys allocated to a subset of these blocks will help achieve geographic balance in BBS sampling within these ecozones.

Evaluating the 1,135 priority blocks relative to the identified gaps in habitat sampling may further help prioritize which blocks should be sampled by future roadside surveys. For example, 68% of the priority block of ranks 1–3 contained above average amounts of habitats that are gaps in sampling either across the boreal (large-scale) or within the priority block's ecozone (smaller scale). Thus, these blocks might be given highest consideration for sampling as they would help fill both geographic and habitat gaps in sampling.

Roadside bias in avian survey counts

We found evidence for significant roadside bias in avian survey counts for 79% of the 85 species we evaluated. More than twice as many species were estimated to have positive roadside bias in their counts (n = 49 species) than negative roadside bias (n = 19 species). In addition to the greater number of species, the average effect size was more than twice as large for species with positive roadside bias ($\overline{\beta}$ = 0.99 ± 0.13 [SE]; range = 0.07–4.33) than species with negative roadside bias ($\overline{\beta}$ = -0.41 ± 0.07; range = -0.94 – -0.05; Fig. 6).

Our models assessing roadside bias also provide information on avian counts relative to habitats and count duration. For example, our models can be used to evaluate the average counts of species relative to the general habitat types. Such information might be helpful in identifying habitats that support an abundance of species of concern (Fig. 7). For example, average counts of threatened Canada Warblers were highest in deciduous and mixed forest; counts of threatened Olive-sided Flycatchers were highest in recent burns (Fig. 7). The model results on the effects of count duration are also of interest, particularly for 10 species (12% of species) with a significant positive effect because our models indicated that the average counts are higher for a 3-min survey than a 5-min survey. This indicates that the effect of count duration is not well accounted for in these 10 species as count duration appears to be confounded by survey type (roadside versus off-road). The remaining 88% of species either had higher average counts during the 5-min period (55 species) or similar counts in the 3- and 5-min surveys (20 species). For these species, the effects of count duration appear to be better controlled for in our models.

Power to detect trends in avian abundance

Statistical power to detect declines in abundance.—Statistical power to detect declines in abundance reached 1.0 with few routes (<20 or often <10 routes needed) for the more common species: Alder Flycatcher, American Robin, Ovenbird, Clay-colored Sparrow, and Song Sparrow (Fig. 8). It took larger numbers of routes in our simulations (20–100 routes) before statistical power converged to 1.0 for rare species: Olive-sided Flycatcher, Bay-breasted Warbler, Blackpoll Warbler, and Canada Warbler. Roadside surveys resulted in higher power to detect declines for species with positive roadside bias: Alder Flycatcher, American Robin, Clay-colored Sparrow, and Song Sparrow. Off-road surveys resulted in higher power to detect declines for species with negative roadside bias: Olive-sided Flycatcher, Bay-breasted Warbler, Canada Warbler, and Ovenbird. The number of routes necessary to reach a power of

0.8 reflected these differences in abundance and roadside bias. A survey effort of 60 routes was sufficient to reach this monitoring goal collectively for the nine species given current simulation settings (Fig. 8).

Bias in trend estimation.—Accuracy and precision of the trend estimates rapidly improved with increases in the number of routes included in our simulations. The trend estimates had smaller bias and greater accuracy for the more common species: American Robin, Ovenbird, and Song Sparrow (Fig. 8). For rare species, trend estimates had higher bias and poorer accuracy: Olive-sided Flycatcher, Blackpoll Warbler, and Canada Warbler. Species with positive roadside bias had more accurate and precise trend estimates when sampled by roadside surveys (American Robin, Blackpoll Warbler, Clay-colored Sparrow, and Song Sparrow), while species with negative roadside bias tended to have more accurate and precise trend estimates when sampled by off-road surveys (Bay-breasted Warbler). For other species, the difference between roadside versus off-road samples was not pronounced with respect to accuracy and precision: Alder Flycatcher, Canada Warbler, and Ovenbird (Fig. 8).

DISCUSSION

Our study provides the first broad assessment of bias in avian surveys conducted across boreal Canada as part of the North American Breeding Bird Survey. This analysis was possible because the BAM project has assembled a large database of avian point count survey data surveys collected from across boreal Canada from numerous researchers, and because BAM has helped georeference the BBS stop locations. Our results often confirmed the general patterns in bias in sample allocation and roadside survey counts found in studies in the temperate U.S. (Hanowski and Niemi 1995, Hutto et al. 1995, Keller and Fuller 1995, Rotenberry and Knick 1995, Lawler and O'Connor 2004). However, we were at times surprised by the magnitude and prevalence of these biases which tended to be more extreme in the boreal. For example 89% of the BBS surveys were allocated to the southern 49% of boreal Canada, thereby leading to an extreme case of disproportional sampling by the BBS both in terms of geographic and habitat strata. In terms of survey counts, we found evidence of significant roadside biases for 79% of the 85 species we evaluated. Such biases can limit how BBS survey data are used to generated inferences when the biases are not controlled. However, these biases do provide some benefits. For example, we found that the positive bias in the counts actually increased the statistical power, precision, and accuracy in estimating population trends.

Understanding these biases will clearly help us devise ways to advance our understanding of boreal birds through the allocation of new surveys in poorly sampled areas (a design-based approach) and the development of correction factors that minimize the influence of these biases when estimating abundance or population trends (a model-based approach). In addition to measuring biases in the BBS, we also provide results which may help with moving forward on each of these fronts. We do caution our readers that our analyses and results are preliminary. We emphasize that the BBS data has not yet been completed incorporated into the Boreal Avian Modelling Project databases.

However, the BAM team is well-positioned to conduct additional, detailed analyses that will more completely address these issues. We very much welcome the feedback from ornithologists from programs such as the BBS, Canadian Breeding Bird Atlases, and Environment Canada's Landbird Committee about how we might improve upon these analyses to make the results more useful to their programs.

Distribution of roadside surveys relative to geographic strata, habitats, and the road network

Sampling by the BBS was clearly biased with the northern 51% of the boreal zone constituting a vast gap in sampling which has only received 11% of the BBS surveys in boreal Canada. Within boreal ecozones, we found that 20% of ecoregions constituted moderate to large gaps in BBS sampling. In general, our results are similar to those found in the U.S. but of greater magnitude and prevalence. In the U.S., high elevation and arid regions were generally under sampled and gaps in geographic coverage within states were generally rare and restricted to a few states with overall poor sampling. Such gaps in coverage in the U.S. are controlled for in analyses of trend using a model-based approach (Lawler and O'Connor 2004, Sauer and Link 2011), whereas in the boreal region, data from northern areas are excluded from continental analyses of trends due to the magnitude of the sampling gap (Bystrak 1981, Bart et al. 2004, Dunn et al. 2005). The gaps in sampling by the BBS across the boreal were clearly due to a paucity of roads in the north as the BBS sampled geographic areas and habitats in proportion to their availability along the boreal road network both at large and smaller spatial scales. This bias in sampling was generally not compensated for by the current distribution of off-road avian surveys across the boreal zone. The biases in sampling by the BBS and BAM mirrored one another and as well as the distribution of roads both across boreal Canada (large scale) and within ecozones with reasonable survey effort (small scale). Thus off-road surveys as practiced to date appear to be drawing from the same sampling frame as the BBS—a sample frame defined by the road network.

Clear gaps in sampling exist relative to habitats. Conifer forests and woodlands constituted the largest gap; tundra, lichen, and rock dominated areas were a medium gap; and recent burns and wetlands formed smaller gaps in habitat sampling. However, careful thought and discussion is needed to determine how we should proceed to fill habitat gaps in sampling for at least two reasons. First, in terms of monitoring, stratifying survey effort relative to habitats is potentially problematic in areas with frequent and large-scale disturbances, such as the boreal forest. Monitoring programs that allocate surveys to fixed locations that are surveyed year after year (e.g., BBS) may therefore choose not to allocate sampling relative to the current distribution of habitats, since the sampling frame will change through time when disturbances occur. For these reasons the BBS program has instead chosen to allocate sampling relative to more stable strata (physiographic region) in order to minimize this problem of a shifting sampling frame.

However, our results indicated that geographic gaps in sampling by the BBS were often associated with habitat gaps in sampling. Thus, focusing future allocation of BBS to geographic areas with deficient sampling may help satisfy in part habitat gaps in sampling. When this approach is not adequate, then other programs, such as the Breeding Bird Atlases, might be used to fill important gaps in habitat sampling.

Second, conifer forests and woodlands constituted the largest sampling gap identified in our analysis but this general habitat type covered 41% of the boreal region. Clearly, we should not chose to sample conifer habitats proportional to their availability at the expense of achieving sufficient sampling of other habitats, such as wetlands and riparian areas, which are known to be rich in avian diversity and abundance. Thus, some programs may find it necessary to undersample some super-abundant habitat types to achieve a target number of surveys in all habitat types within their planning area. We do acknowledge that our habitat classification was rather crude and that it may mask sampling biases of particular conifer forest types, such as mature spruce (*Picea* spp.) forests with merchantable timber, which we expect to be oversampled by BAM. Thus our analyses could be refined by using the full suite of 39 land cover classes included in the Land Cover Classification of Canada (Latifovic et al. 2008) or by analyzing forest inventory data compiled across Canada which will soon be available to our program (Cumming et al. 2010a,b).

Clearly more survey effort is needed in the northern reaches of boreal Canada before we can gain a region-wide perspective into the status and trends of North America's boreal birds. This is key given that data from the BBS already indicate that a wide suite of migratory bird species that breed primarily in the boreal forest are among the steepest declining species in North America, including Horned Grebe (*Podiceps auritus*, -2.5% population decline per year), Lesser Scaup (*Aythya affinis*, -3%), Lesser Yellowlegs (*Tringa flavipes*, -4.9%), Olive-sided Flycatcher (-3.6%), Blackpoll Warbler (-6.3%), Canada Warbler (-2.2%), and Rusty Blackbird (-6.3%, Sauer and Link 2011). Additional monitoring surveys in the northern boreal will help differentiate whether such declines are symptomatic of region-wide declines, northward shifts in avian distribution related to climate change, or responses to the widespread conversion of habitats in the southern boreal, the regional currently sampled by the BBS and contributing to the estimated trends listed above.

Some new survey locations proposed for the northern boreal are serviced by existing roads. We provide a list of 380 locations in northern ecozones that have more than 30 km of roads, but, to our knowledge, lack BBS and off-road surveys. The majority of these locations (68%) include above-average amounts of habitats that are poorly sampled by the BBS. These should be evaluated for suitability for future road-side surveys conducted as part of the BBS, Breeding Bird Atlases, or other regional survey and monitoring programs, as sampling these areas will help fill large geographic gaps in survey coverage.

In our analysis used GIS data from the National Road Network 2.0 (Natural Resources Canada 2007); however, more refined GIS layers on the location and types of roads may be quite useful in finding additional areas for roadside surveys.

However, most of the northern boreal that has been poorly sampled by avian surveys lacks roads. While the Breeding Bird Atlases in Canada are now beginning to conduct off-road surveys in these northern areas, a national approach and additional funding may be needed to more systematically address this continental gap in avian monitoring (Dunn et al. 2005; C. Machtans, personal communication).

Roadside bias in avian survey counts

We found roadside bias in survey counts to be quite prevalent across the boreal with 79% of 85 species showing significant roadside bias. Positive roadside bias was more than twice as large in prevalence and average effect size as negative roadside bias. In general, our results followed the patterns found in smaller scale studies conducted in the temperate U.S. However, we found many more species with significant bias, likely due to our much larger sample size of surveys. Comparing our results to these small-scale studies which used a matched-pairs design (Hanowski and Niemi 1995, Hutto et al. 1995, Keller and Fuller 1995), we found concordance in both the significance and direction of bias for 24 species (Table 4) and discordance among only three species. Thus, our model-based approach of controlling for landcover type and spatial units appears to provide comparable results to design-based studies using matching pairs of roadside and off-road surveys. The preponderance of roadside bias that we found indicates that care should be taken when extrapolating results of roadside survey counts beyond the road network, which may lead to an overestimation of population size since most species exhibit positive roadside bias in their counts.

When all relevant factors are controlled for, we expect that roadside bias will only reflect behavioral responses of a species to the presence of road (attraction) or differences in detectability along roads compared to off-road areas. We controlled for the effects of the landcover type at each point count station in our analyses in an attempt to isolate roadside bias in this manner. Some species are known to nest on structures, such as Eastern Phoebe and Barn Swallow, which might explain the particularly large positive roadside bias in counts in these species. Birds may also be detected by observers at further distances by both sight and sound across open spaces compared to dense vegetation. This may explain in part why the majority of species exhibited positive roadside bias in their counts. Currently we do not have information from roadside surveys to estimate detection rates which would be useful for more effectively controlling for roadside bias and thereby allow a more seamlessly combining of roadside and off-road survey data to estimate population sizes and trends. To be able to account for detectability bias along roads, ideally we would have data from matched roadside versus off-road surveys collected in multiple distance bands (e.g. 0–50 m, > 50 m) and time intervals (e.g., 0–3 min, 3–5 min). If such data were collected by Breeding Bird Atlases in Canada or other studies, then we would be able to resolve detectability issues related to roadside point counts. The counts relative to multiple distance intervals would help in measuring differences in the effective detection distances between on versus off road surveys (Buckland et al. 2001). The multiple time intervals would help us understand whether differences in singing rate exist between on- versus off-road surveys (Farnsworth et al. 2002). Multiple time intervals would also help to control more effectively for the effects of count duration (3-min versus 5-min count) between roadside and off-road surveys which was not well accounted in the 12% of the species where our models predicted a higher count during a 3-min survey than an 5-min survey.

As with other studies (Hanowski and Niemi 1995, Hutto et al. 1995, Keller and Fuller 1995) we found (1) higher counts along roads for bird species associated with shrubs, clearings, forest edges, and agricultural areas (e.g., American Robin. American Crow, Song Sparrow, and Brown-headed Cowbird) and (2) lower counts along roads for species associated with forest interior habitats or mature and lowland forests (e.g., Boreal Chickadee, Golden-crowned Kinglet, Bay-breasted Warbler, and Ovenbird). These patterns provide some insight into the species-habitat relationships that possibly contributed to roadside biases in the counts. However, they also emphasize instances where roadside bias may not have been well controlled for in our models due to the presence of unaccounted habitat covariates. We used land cover classes intersected by the survey point in our analysis, which describes the habitat in a 250-m x 250-m pixel. Yet avian abundance can be related to smaller scale habitats along roads or large-scale habitats surrounding the point count station at the landscape level. For example, accounting for habitat edges and narrow right-of-way roadside clearings may be helpful important when controlling for roadside bias (Harris and Haskell 2007). Furthermore, roadside bias has been found to be more prevalent along wider roads (Hutto et al. 1995). At larger spatial scales, we might expect bird counts in forest patches to be different in landscapes dominated by forested versus agricultural lands. Since roads are often in human-modified landscapes with sparse forest cover, bird counts on road might encounter low densities of forest species due to either a lower extent of available habitats or the presence of fragmentation effects on populations. We can use existing spatial data on landcover to extend our current models to include landscape-level habitats. We are not aware of spatial data on habitats that will allow us to identify small-scale habitat patches along roads, but information on the class of the road may help control for the effects of road width.

Power to detect trends in avian abundance

We found that roadside bias in survey counts also affects the statistical power to detect declines in avian abundance as well as the accuracy and precision of the trend estimates. In general, higher counts of birds resulted in both smaller sample size requirements and greater accuracy and precision in when estimating declines in avian abundance. Thus, when survey effort was equivalent between roadside versus off-road survey, the direction of roadside bias determined which type of survey was more effective in detecting the simulated population trend. Negative roadside bias resulted in higher counts in off-road surveys and therefore more effective monitoring in off-road areas. The opposite held for species with positive roadside bias. Because more than twice as many species show positive versus negative roadside bias, we expect that roadside surveys should be more efficient in detecting declines than an equivalent survey effort away from roads. However, such trends may not be representative of the large landscape if the trend analyses do not adequately account for biases in survey coverage such as outlined earlier.

Relatively small numbers of survey routes ($n \leq 60$ routes) were required to detect a 50% decline in abundance over 20 years with 80% power at $\alpha = 0.1$. This information can be used to set target samples sizes for monitoring. Our power analysis was based on annual surveys over 20 years. However, biennial surveys have been found to have similar statistical power to detect declines as annual surveys in temperate areas (Bart et al. 2004). Thus, an annual survey effort of 60 routes (50 points each) per year might be divided evenly between odd and even years which could potentially cut in half the annual survey costs with little loss in statistical power to detect declines. This may be an important consideration for the off-road surveys which generally require more effort to obtain an equivalent sample as the BBS. Related to this, we made the assumption in our simulations that off-road samples are collected in clusters with 50 nearby points which constituted a ‘route’ in our analyses. This was done to compare power between roadside and off-road surveys of comparable effort. However, we acknowledge that only 10–15 points can be sampled in a morning of off-road surveys while 50 points are the standard number visited in a morning of BBS surveys. Thus, off-road surveys will require approximately 5-times the effort to acquire the same samples size as the BBS. This does not include the higher costs of travelling to off-road areas. If the cluster size is decreased from 50 in the off-road surveys, then the statistical power to detect a decline will also decrease. We recommend that future analyses of statistical power of monitoring programs for boreal birds explore how to optimize monitoring surveys relative to the tradeoffs among number of routes, number of points within routes, the temporal frequency of repeating surveys (e.g., annual versus biennial), and the five-fold disparity in costs of on versus off-road surveys. Such simulations might provide more realistic scenarios of conducting monitoring surveys in on versus off-road areas.

We do emphasis that unlike the BBS, the off-road surveys compiled by BAM were neither conducted using a common protocol nor shared the goal of monitor the long-term population trends of birds across the boreal. Thus, the temporal replication of BAM surveys tends to be quite low, the survey methods are variable, and the sampling haphazard among contributing studies (Cumming et al. 2010a). Thus analyzing these data for population trends using design-based approaches will not be feasible and hierarchical models may provide more flexible model-based approaches for pooling information across space and time (Humbert et al. 2009; but see also Link and Sauer 2011 for hierarchical models for BBS).

However, even within this context the BAM data may be too sparse longitudinally for robust analyses of population trends at regional spatial scales.

Conclusions

We commend the Canadian BBS program for blanketing the boreal road network with surveys which proportionally sample the geographic areas and habitats bisected by the road network across boreal Canada. However, the road network remains sparsely developed in the northern 51% of boreal Canada, the region poorly sampled by both the BBS and off-road surveys compiled by BAM. This region therefore constitutes one of the largest monitoring gaps in landbird survey coverage in North America (Dunn et al. 2005). Narrowing this gap by adding additional roadside and off-road surveys will be difficult and expensive and will likely require the development of a national strategy and new funding sources to meet the challenge. Opportunities for additional roadside surveys across this remote region are limited, but we have identified 380 areas where new roadside surveys would help fill geographic and habitat gaps in sampling.

In addition to bias in survey coverage, we also found a preponderance of positive survey bias in the counts of birds during roadside surveys. Thus, in addition to improving survey coverage, it will be helpful to better understand the sources of this bias in survey counts to effectively control for it in future analyses of species distribution, abundance, and population trend. In particular, the collection of ancillary data to estimate detection probabilities during both roadside and off-road surveys would help determine what proportion of this bias is due to greater detectability of birds along roads versus off-road areas. Further work is also needed to determine whether we can more effectively account for roadside bias through the use of more complex model-based approaches than we have used in this report. In particular, we feel that controlling for landscape-scale habitats, the amount of habitat edges, and the width of roads may be the next steps for developing model-based approaches to better control for roadside bias.

The positive roadside bias in not without its merits, as we have found that the larger numbers of birds counted along roadsides often leads to greater efficiency in detecting declines in abundance. Given that most species exhibited positive roadside bias in their count, then roadside surveys will generally be more efficient than off-road surveys in detecting declines. However, for the minority of species with negative roadside bias in counts, off-road surveys will have greater statistical power to detect declines in their populations. In general, on and off-road surveys required fairly similar amounts of survey effort to have adequate 0.8 power to detect declines ($n \leq 60$ routes of 50 points each). This information will be useful to help set target sampling sizes in poorly monitored areas.

Finally, the analyses presented in the report are only now possible as we finalize the incorporation of the BBS data into the databases developed by the Boreal Avian Modelling Project. Most of the avian point count data from across boreal Canada now reside within a single centralized repository. Thus the analyses presented in this report can be quickly revised with input from the ornithological community across boreal Canada. Because the BAM Project is now expanding to include avian point count data from across the entire North American boreal forest region, future iterations of our analyses will also include data from boreal regions across North America.

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Table 1. Number of point count locations by a) ecozone and b) habitat that were analyzed in this report. Data are from roadside avian counts conducted between 1996–2009 as part of the North American Breeding Bird Survey (BBS, *n* = 26,912 points) and off-road surveys conducted from 1992–2010 and compiled by the Boreal Avian Modelling Project (BAM, *n* = 51,082).

Strata	BBS	BAM
a) Ecozones		
Taiga Plains	554	2,551
Taiga Shield	304	197
Boreal Shield	14,132	30,502
Atlantic Maritime	5,139	704
Boreal Plains	4,426	14,384
Taiga Cordillera	315	349
Boreal Cordillera	1,877	671
Hudson Plains	165	1,724
Total	26,912	51,082
b) Habitats[1]		
Conifer	4,823	11,670
Deciduous	9,368	19,138
Mixed	4,541	11,726
Bog / Fen / Wetland / Riparian	1,568	2,127
Open Herb / Grass	2,771	2,970
Tundra / Lichen / Rock / Snow	465	685
Agricultural	3,054	1,902
Burns	217	829
Urban	105	34

[1] Habitats within 400-m radius buffers around survey points were analyzed for habitat sampling in this report. However, we include here the habitats intersected by the survey points to provide a general measure of sample size.

Table 2. Sampling priorities for establishing new survey routes for the North American Breeding Bird Survey (BBS) in boreal forest region of Canada. Priorities of 1–4 were assigned to 10-km x 10-km sampling blocks that (1) were in an ecozone or ecoregion identified as a sampling gap, (2) included ≥30 km of road, and (3) had no prior sampling by the BBS or off-road surveys compiled as part of the Boreal Avian Modelling Project.

Priority level	Ecozone gaps	Ecoregion gaps
1	Gap (Index < 0)	Moderate to large gap (Index < -0.05)
2	Gap (Index < 0)	Small gap (-0.05 < Index < 0)
3	Gap (Index < 0)	Sampled proportionally or oversampled (Index ≥ 0)
4	Sampled proportionally (Index ≥ 0)	Moderate to large gap (Index < -0.05)
0	Sampled proportionally (Index ≥ 0)	Small gap of sampled proportionally (Index > -0.05)

Table 3. Numbers of priority blocks with road access and no prior avian surveys by ecozone and priority level. See Table 2 for definitions of priority levels.

Ecozone	Priority level	Number of blocks
Taiga Plains	1	4
	2	30
	3	114
Taiga Shield	1	23
	2	5
	3	44
Boreal Shield	4	139
Atlantic Maritime	4	94
Boreal Plains	4	522
Taiga Cordillera	1	1
	2	6
	3	7
Boreal Cordillera	1	29
	2	25
	3	77
Hudson Plains	1	3
	2	0
	3	12

Table 4. Bird species showing concordance in the significance and direction of road-side bias in survey counts between boreal Canada (this study) and small-scale studies in the temperate zone[1].

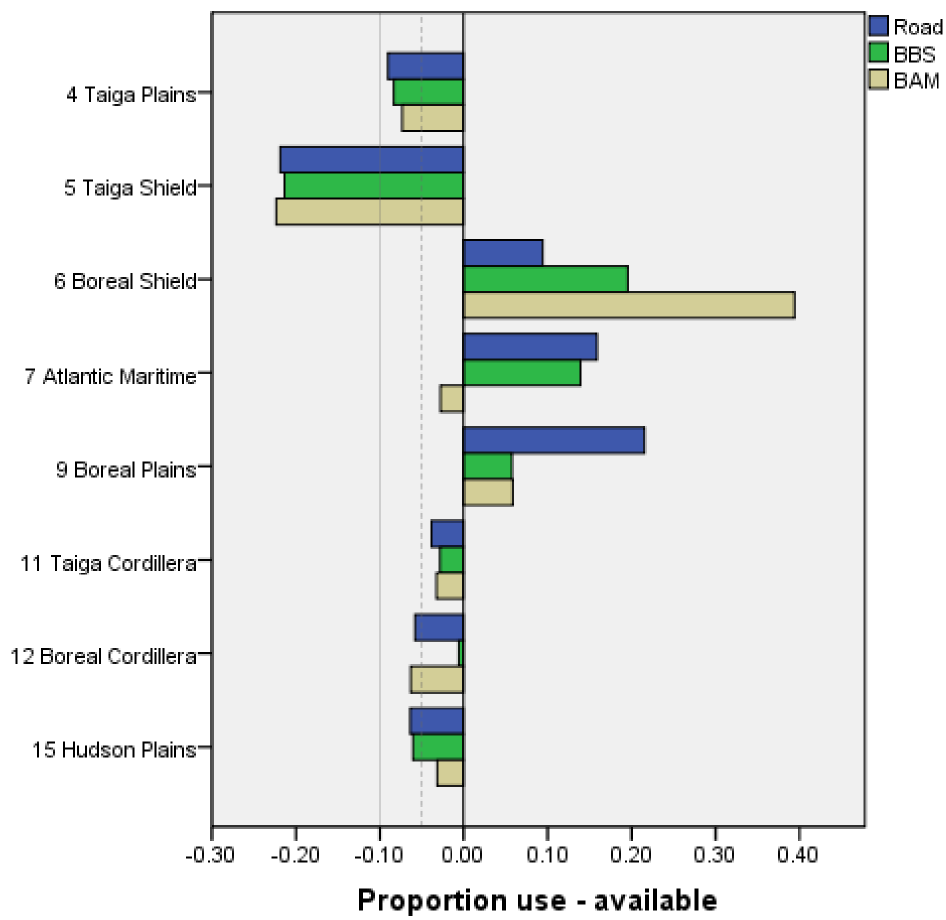
Species	Roadside bias[2]	Species	Roadside bias[2]
Eastern Phoebe	+	Common Yellowthroat	+
American Goldfinch	+	Chipping Sparrow	+
Brown-headed Cowbird	+	Mourning Warbler	+
Red-winged Blackbird	+	Veery	+
Eastern Kingbird	+	Chestnut-sided Warbler	+
Warbling Vireo	+	Wilson's Warbler	+
American Crow	+	Red-eyed Vireo	+
Song Sparrow	+	Blue Jay	+
American Robin	+	Ovenbird	–
Cedar Waxwing	+	Yellow-bellied Flycatcher	–
Yellow Warbler	+	Connecticut Warbler	–
Common Raven	+	Golden-crowned Kinglet	–

[1] Studies in the temperate zone included Hutto et al. (1995), Hanowski and Niemi (1995), and Keller and Fuller (1995).

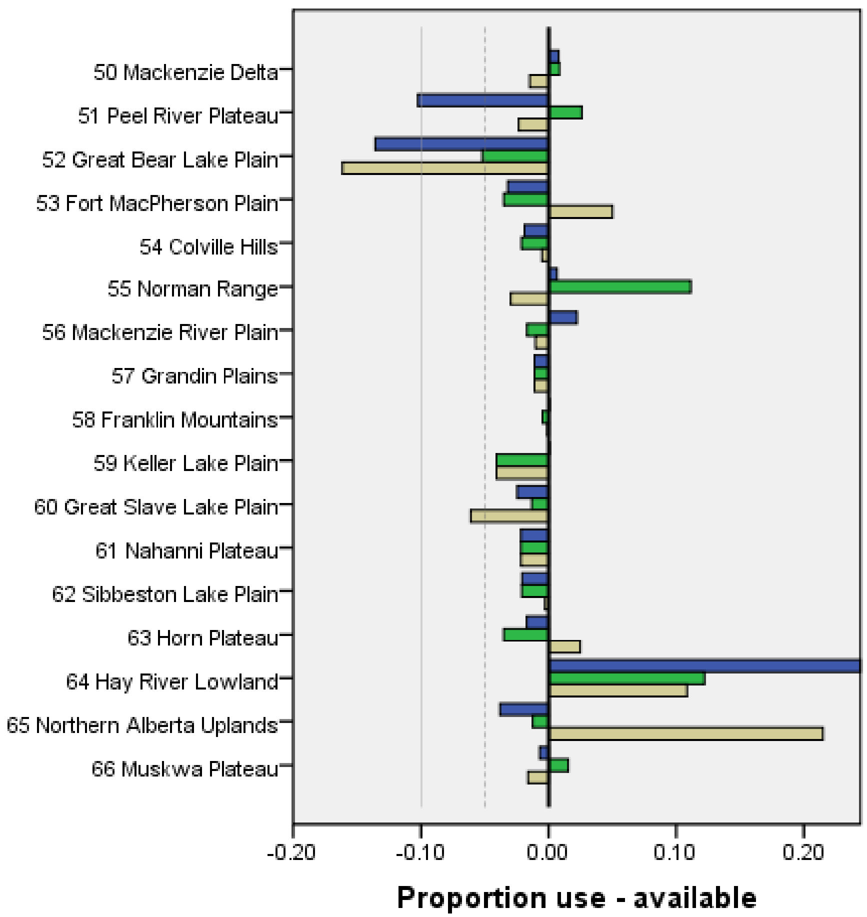
[2] Positive roadside bias (+) is indicated when the average number of individuals encountered per point count location was higher for surveys along roadsides than surveys conducted in off-road areas. The opposite holds for species with negative roadside bias (–). Species are ordered relative to decreasing values of roadside bias across the boreal (see Fig. 6).

Figure 1. Bias in the geographic coverage of roadside avian surveys conducted as part of the North American Breeding Bird Survey (BBS) and off-road avian surveys compiled by the Boreal Avian Modelling Project (BAM). We also present bias in the geographic coverage by the road network (Roads) to emphasize where spatial patterns in surveys closely follow those of roads. Bars represent sampling bias calculated as the difference in proportion sampling (use) and proportional availability (available). We consider gaps in coverage large when values of bars were ≤ -0.1 (gray line), moderate when values ranged from -0.1 to -0.05 (dashed line), and small when values ranged from -0.05 to 0. Results are presented for coverage bias among eight ecozones across boreal Canada and (a) among ecoregions within each of the eight boreal ecozones (b–i).

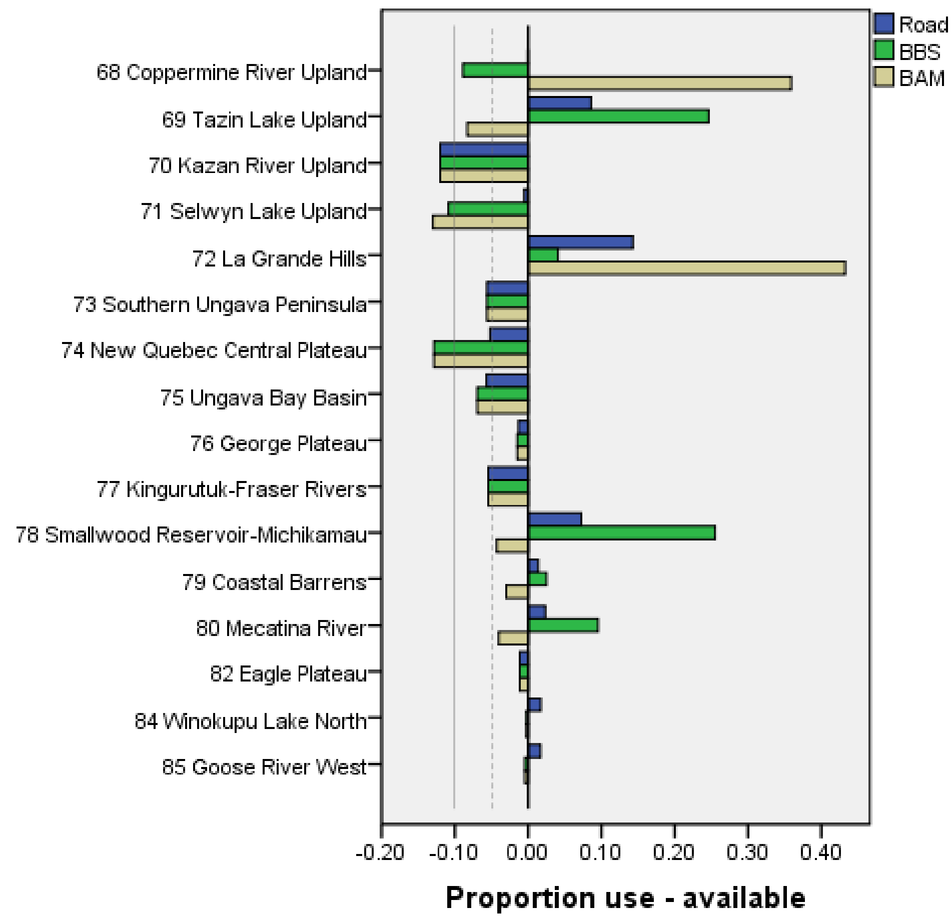
a. Coverage bias among boreal ecozones.



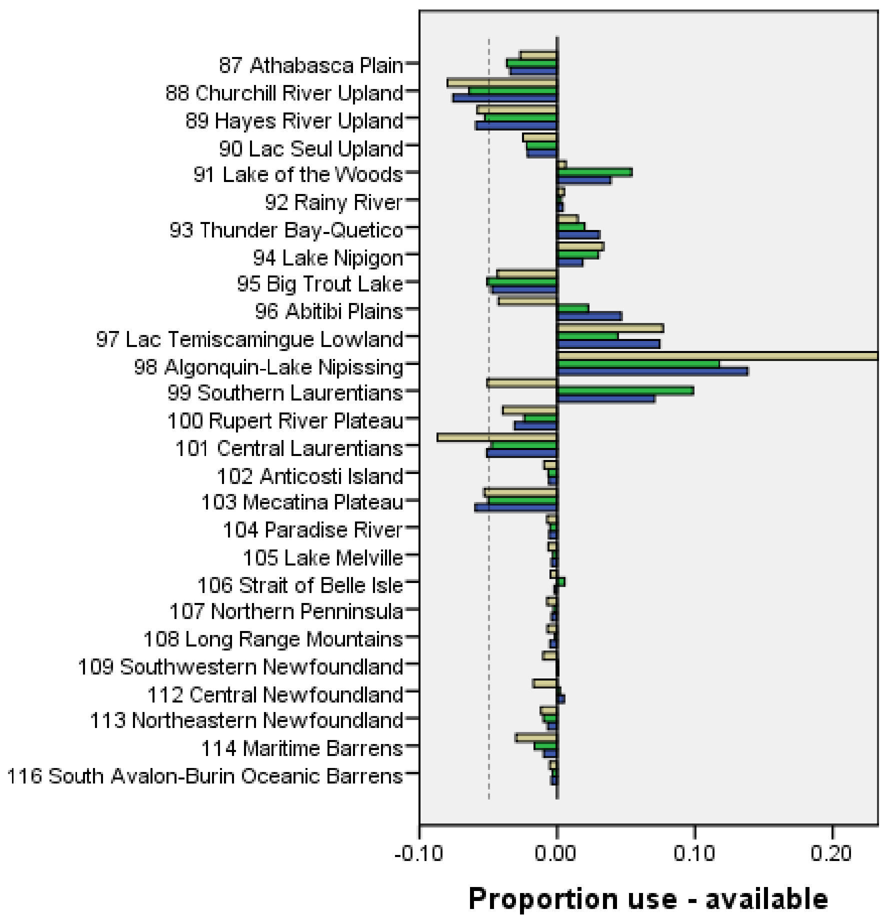
b. Coverage bias among ecoregions within the Taiga Plains ecozone.



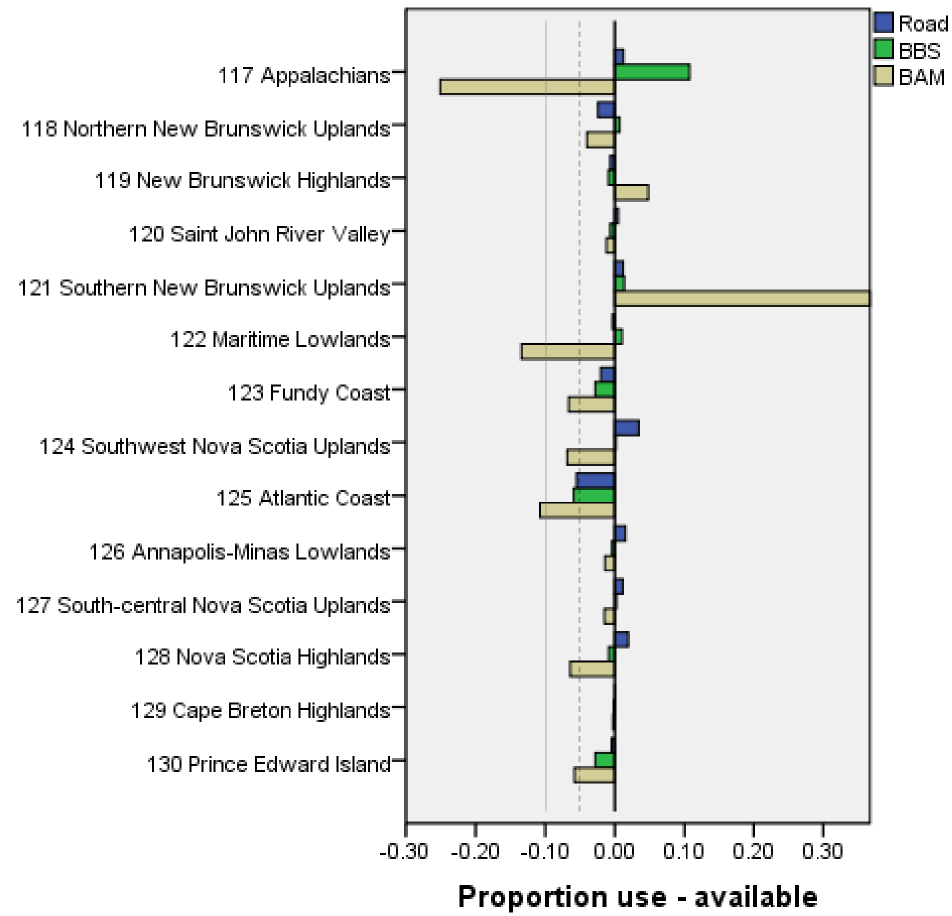
c. Coverage bias among ecoregions within the Taiga Shield ecozone.



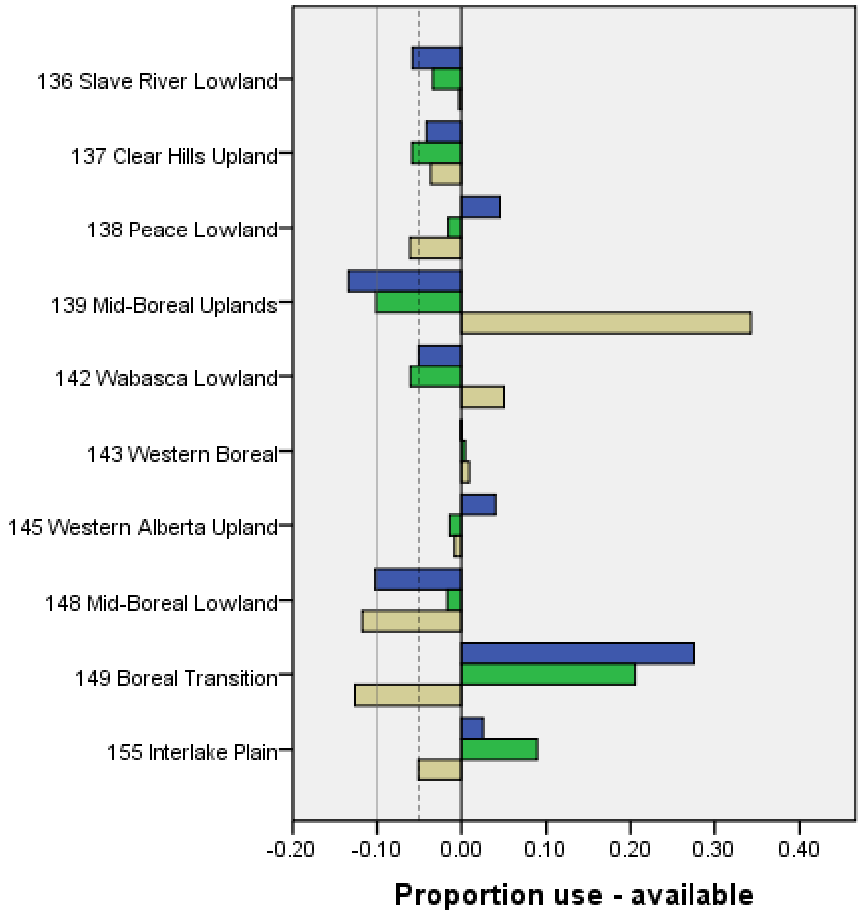
d. Coverage bias among ecoregions within the Boreal Shield ecozone.



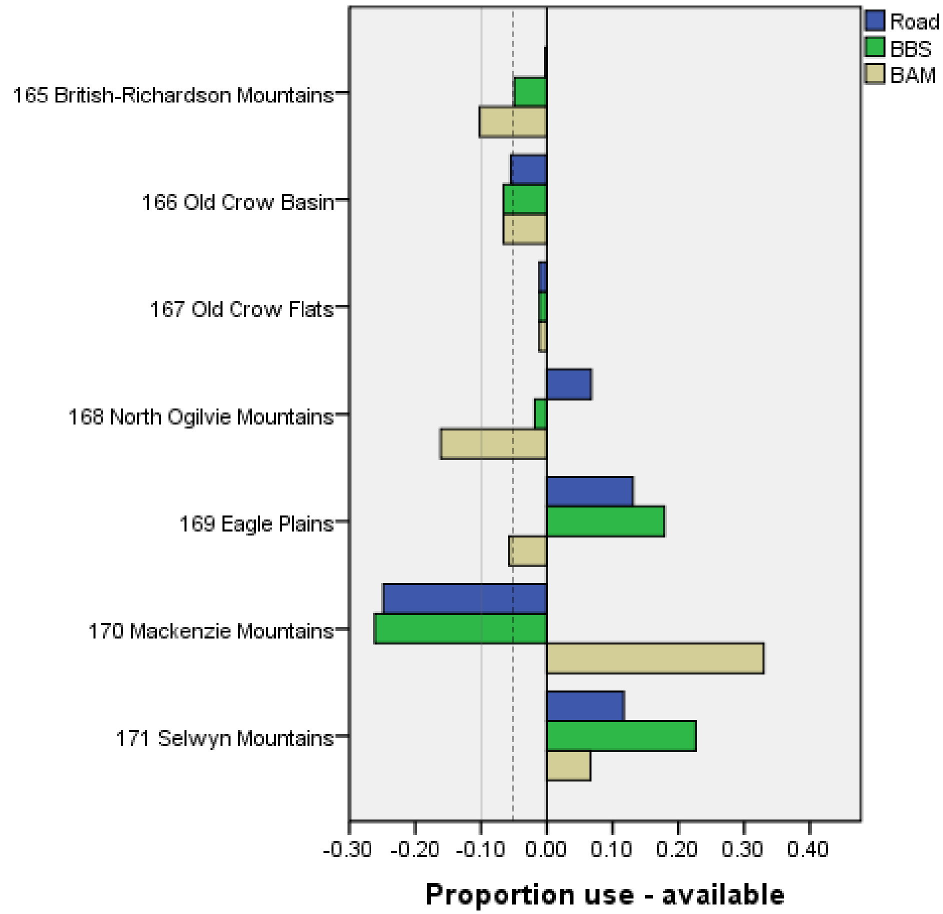
e. Coverage bias among ecoregions within the Atlantic Maritime ecozone.



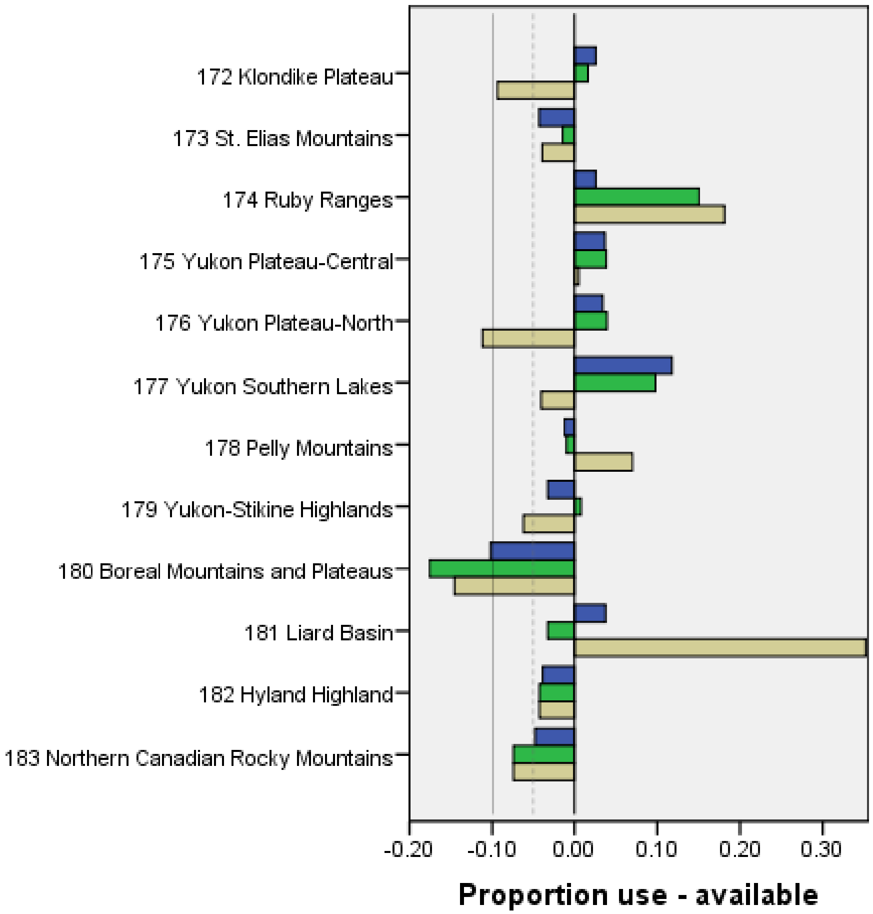
f. Coverage bias among ecoregions within the Boreal Plains ecozone.



g. Coverage bias among ecoregions within the Taiga Cordillera ecozone.



h. Coverage bias among ecoregions within the Boreal Cordillera ecozone.



i. Coverage bias among ecoregions within the Hudson Plains ecozone.

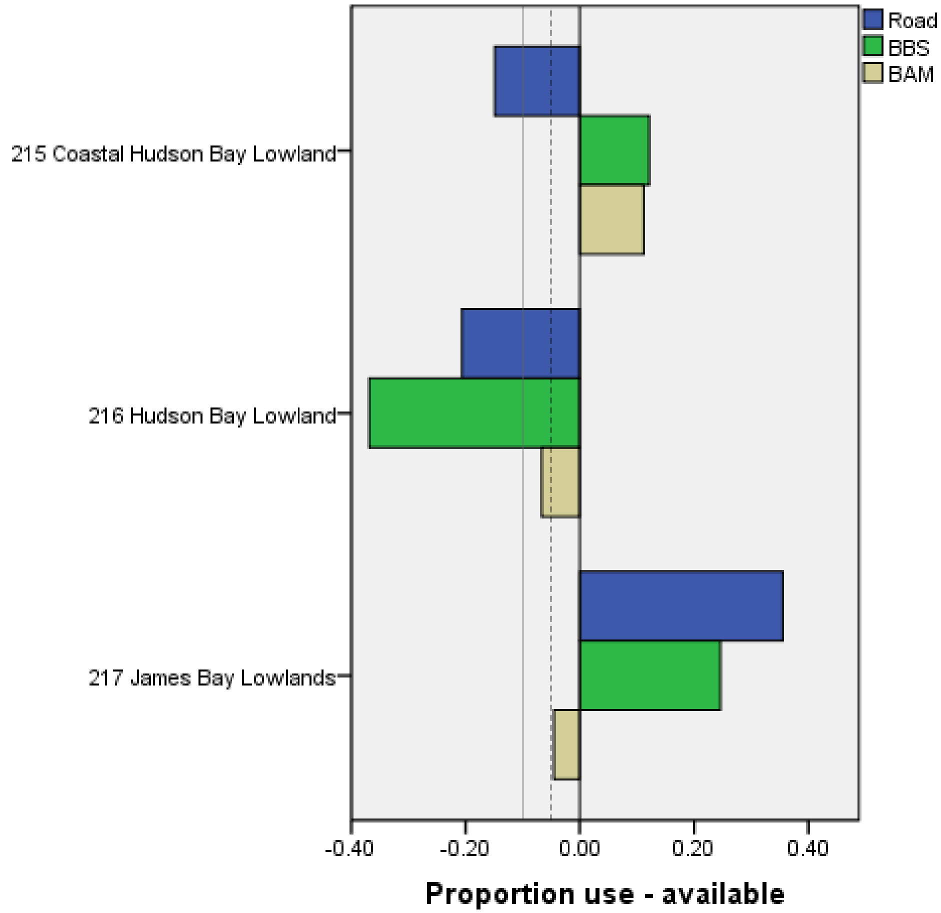


Figure 2. Ecozone gaps in survey coverage by the North American Breeding Bird Survey across boreal Canada. Gaps were identifyed based on selection indices (Fig. 1a).

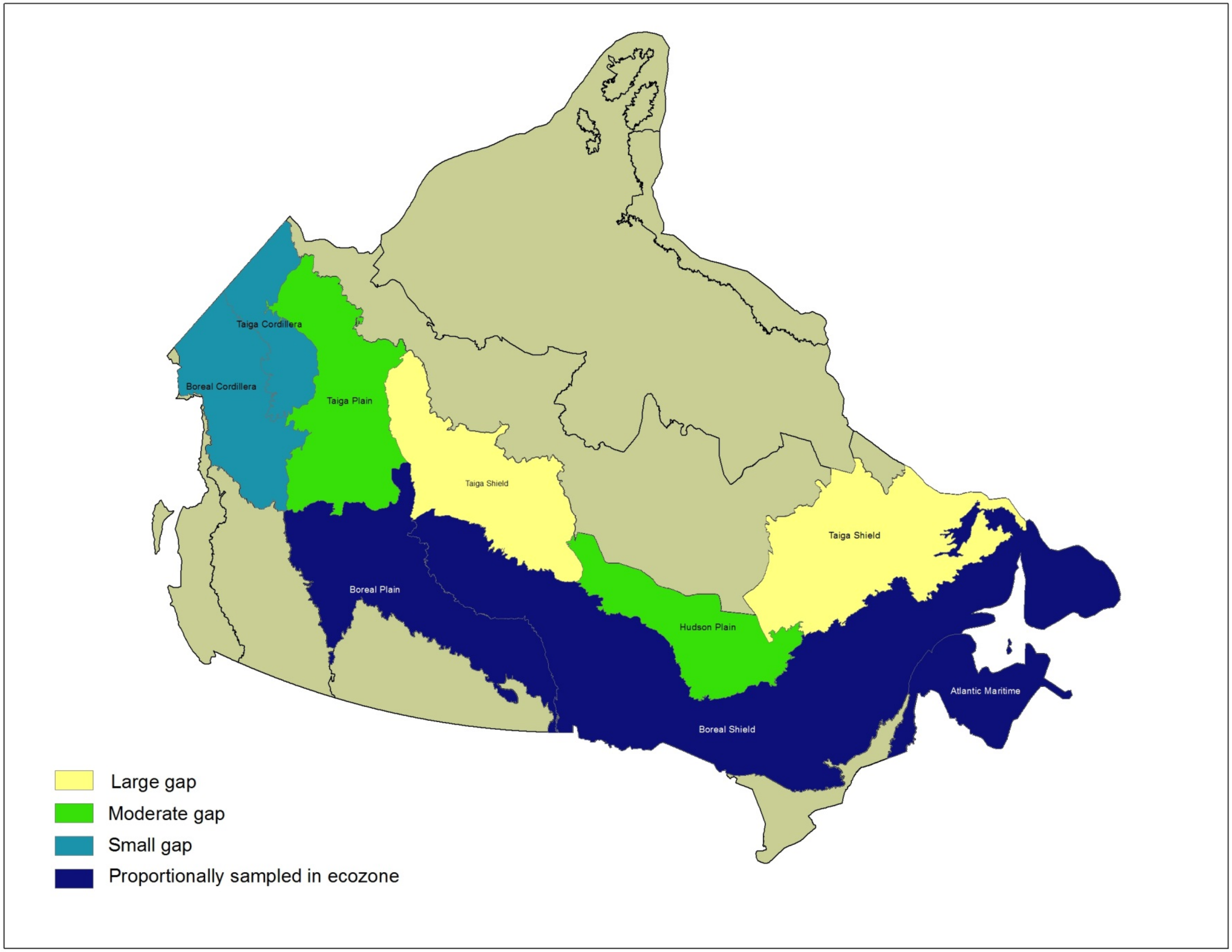


Figure 3. Ecoregional gaps in survey coverage by the North American Breeding Bird Survey within each of eight ecozones across boreal Canada. Gaps were identifyed based on selection indices presented in Figures 1a–i.

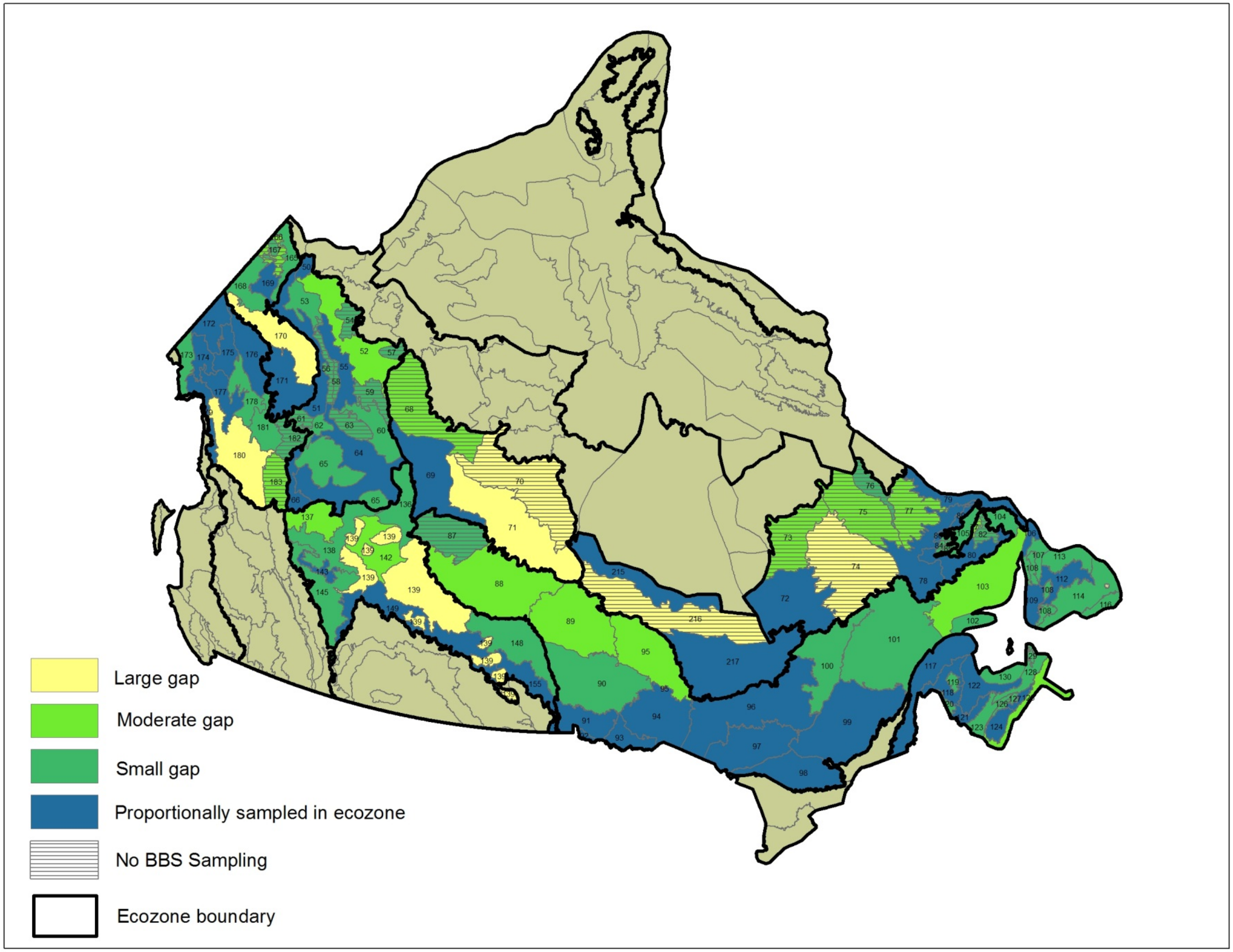
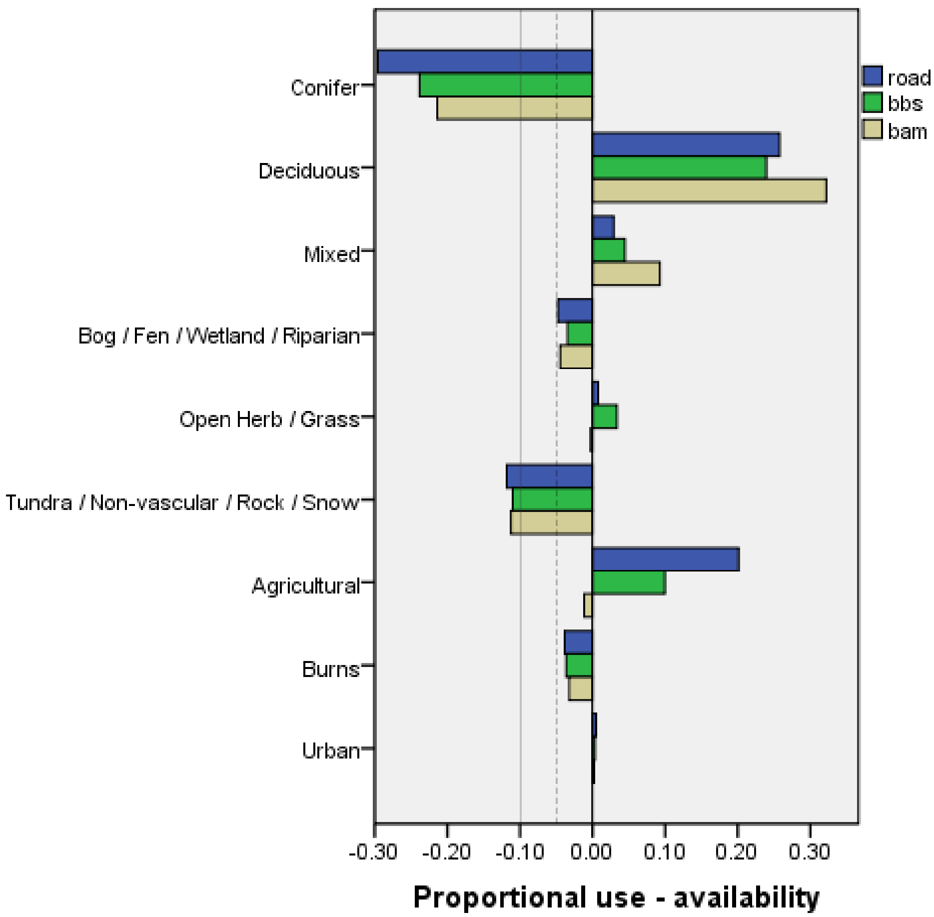
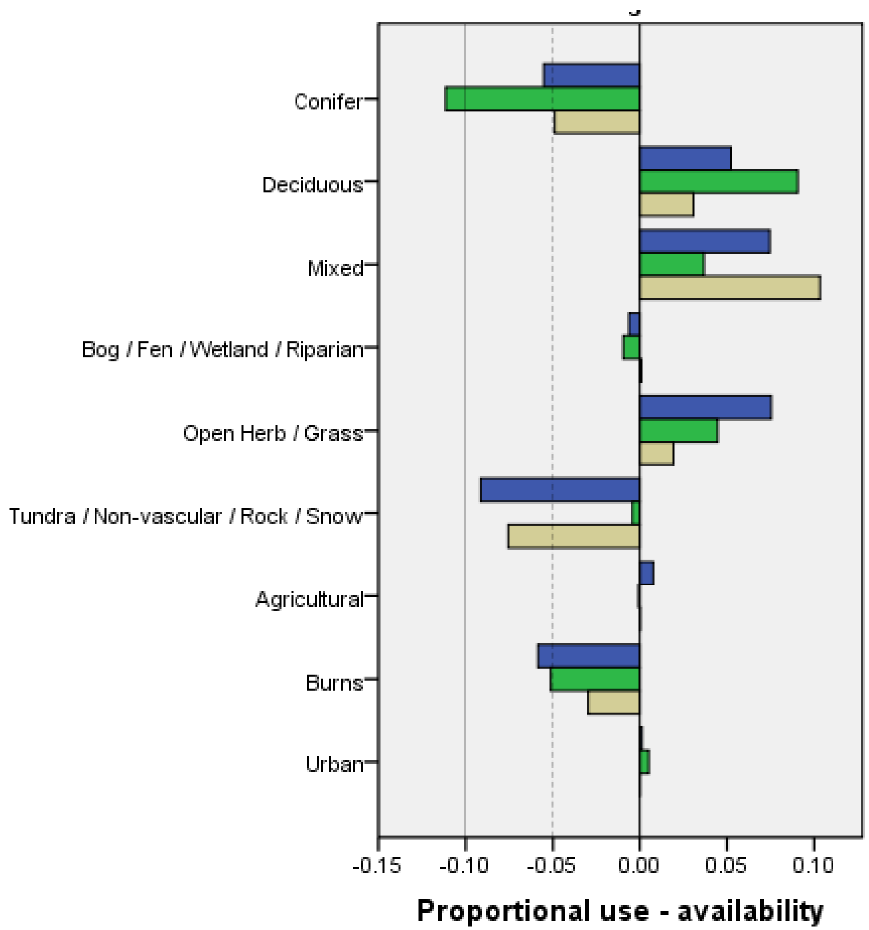


Figure 4. Bias in habitat coverage of roadside avian surveys conducted as part of the North American Breeding Bird Survey (BBS) and off-road avian surveys compiled by the Boreal Avian Modelling Project (BAM). We also present bias in the habitat coverage of the road network (roads) to emphasize where patterns bias in surveys closely follows that of roads. Bars represent sampling bias calculated as the difference in proportion sampling (use) and proportional availability (available). We consider gaps in coverage large when values of bars were ≤ -0.1 (gray line), moderate when values ranged from -0.1 to -0.05 (dashed line), and small when values ranged from -0.05 to 0.0. Results are presented for coverage bias in habitats (a) across the boreal and (b) within each of the eight boreal ecozones (b–i).

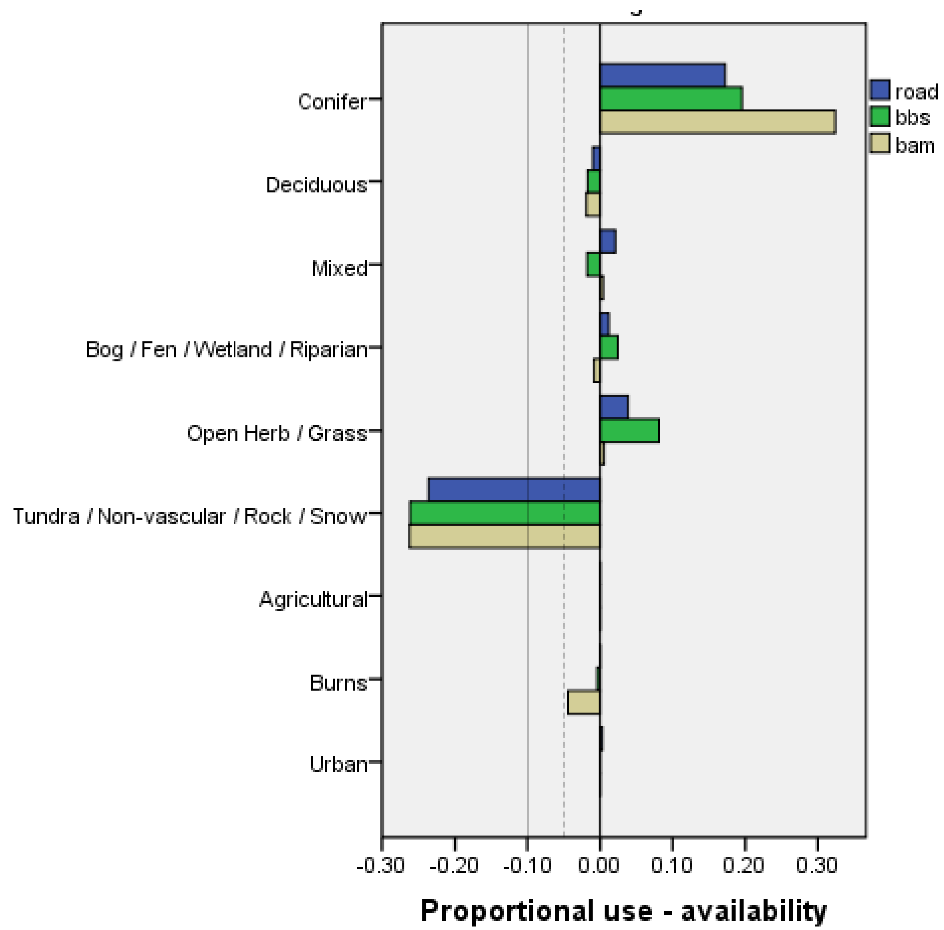
a. Bias in habitat coverage across boreal Canada.



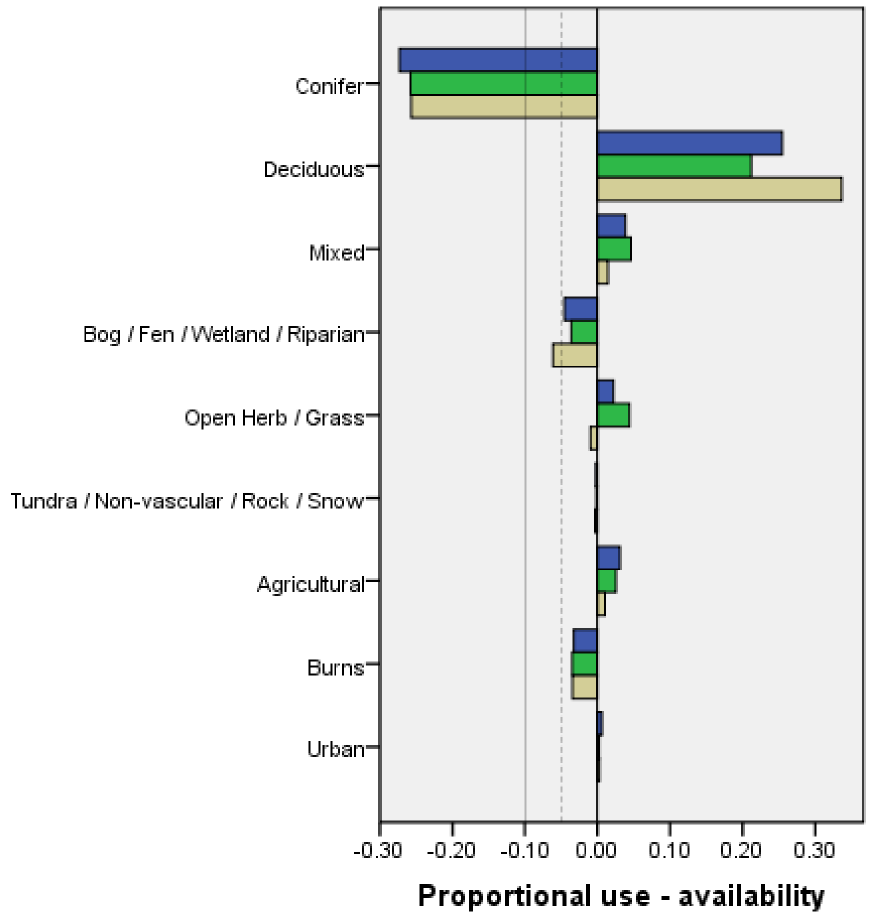
b. Habitat bias in coverage within the Taiga Plains ecozone.



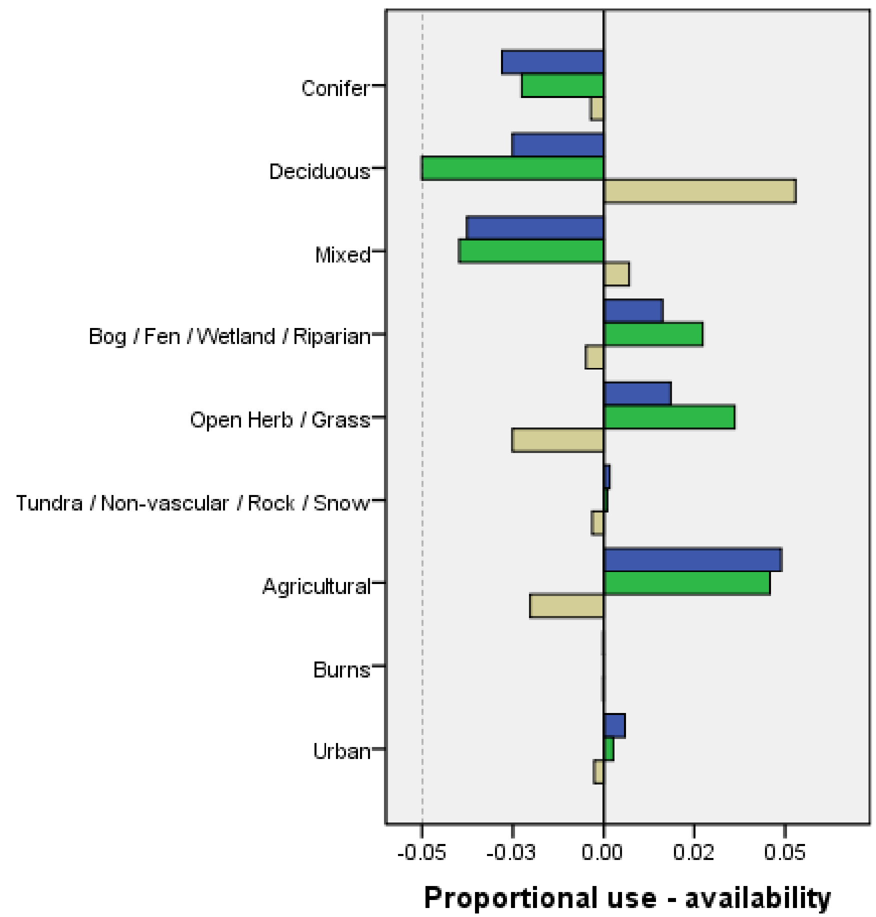
c. Habitat bias in coverage within the Taiga Shield ecozone.



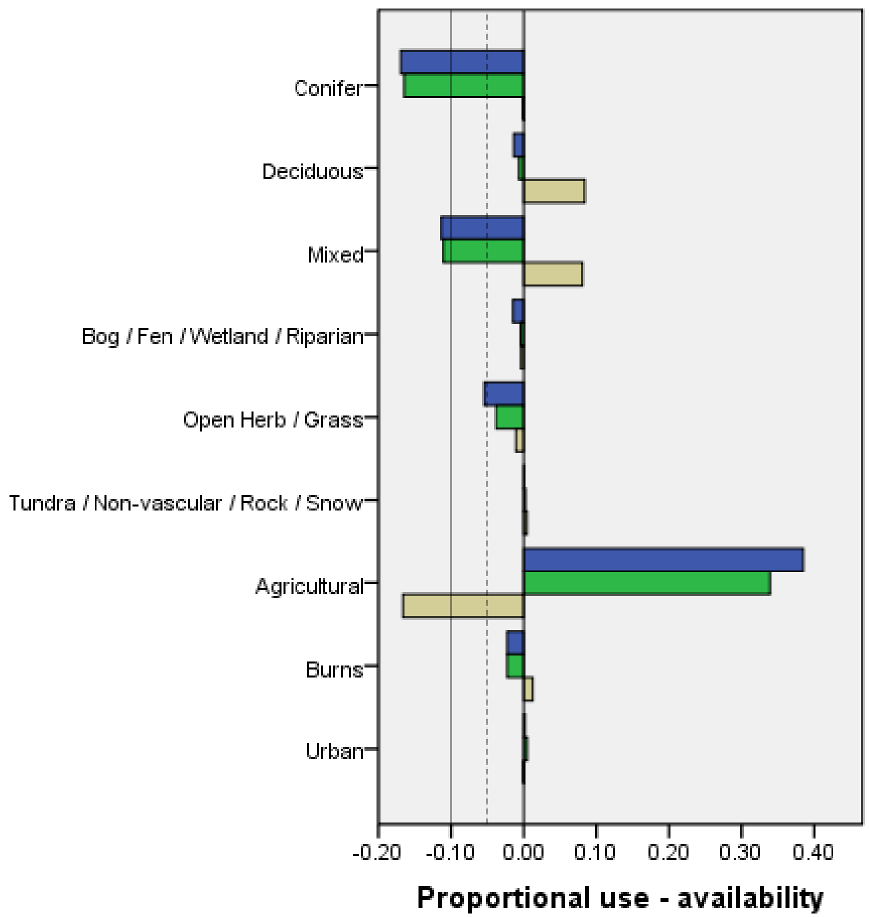
d. Habitat bias in coverage within the Boreal Shield ecozone.



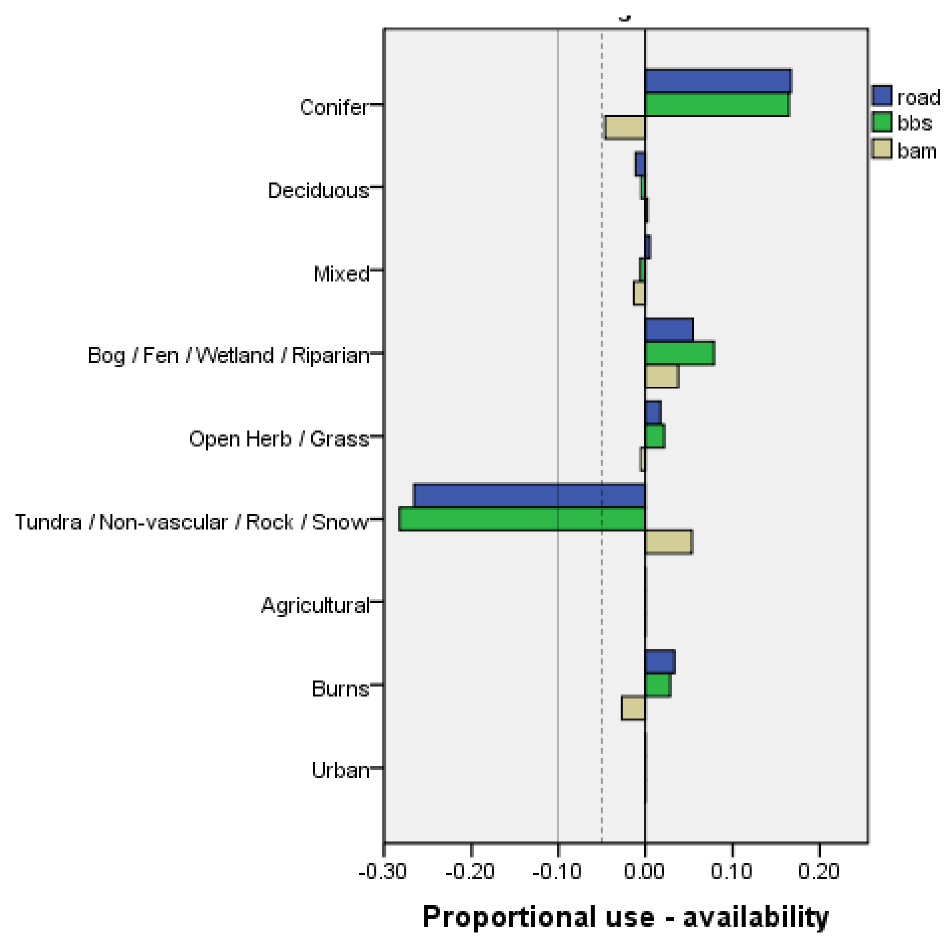
e. Coverage bias in coverage within the Atlantic Maritime ecozone.



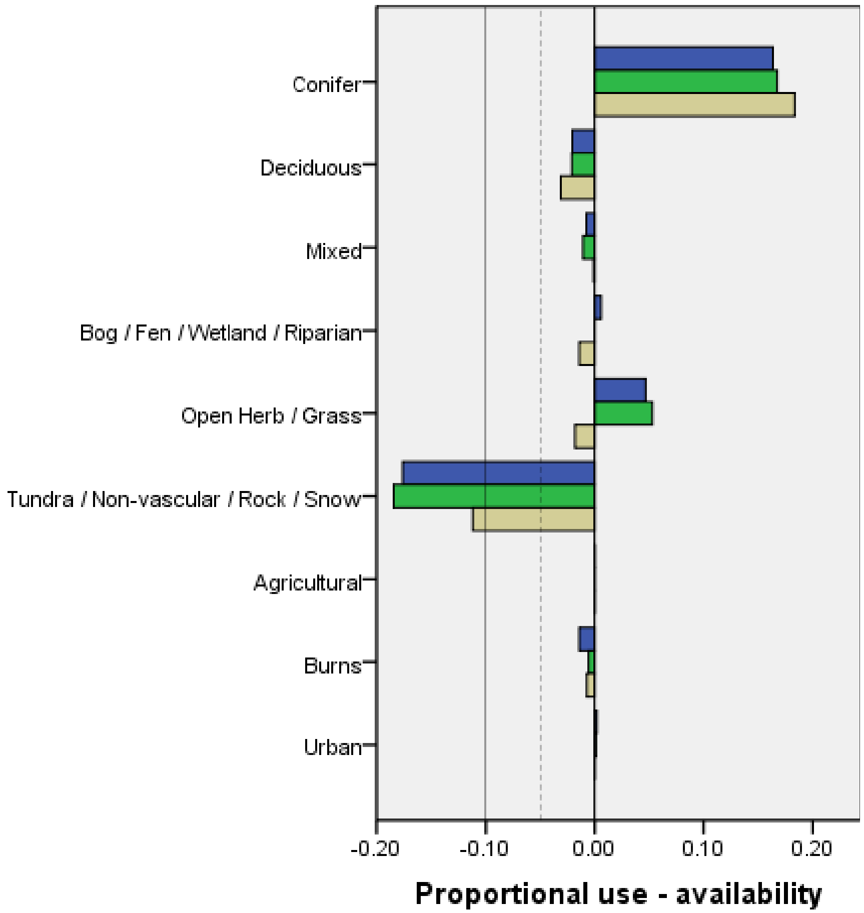
f. Habitat bias in coverage within the Boreal Plains ecozone.



g. Habitat bias in coverage within the Taiga Cordillera ecozone.



h. Habitat bias in coverage within the Boreal Cordillera ecozone.



i. Habitat bias in coverage within the Hudson Plains ecozone.

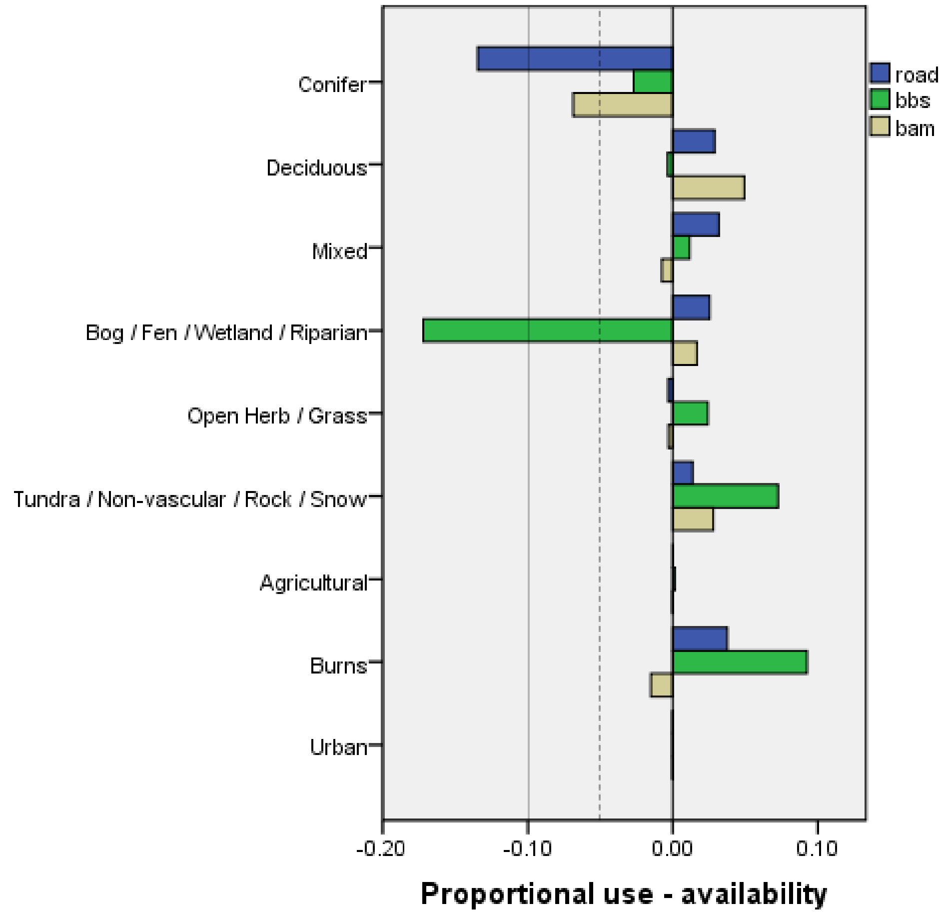


Figure 5. Priority blocks (10-km x 10-km, *n* = 1,135) that could be evaluted for future roadside surveys in boreal Canada. Priority blocks were identified in geographic sampling gaps (Figs. 1–4), had ≥30 km of roads, and did not include BBS or BAM surveys. Higher priority rankings (1–3, with 1 the highest priority) were given to blocks in ecozones that were sampling gaps at the transboreal level (Fig. 1, *n* = 380 blocks).

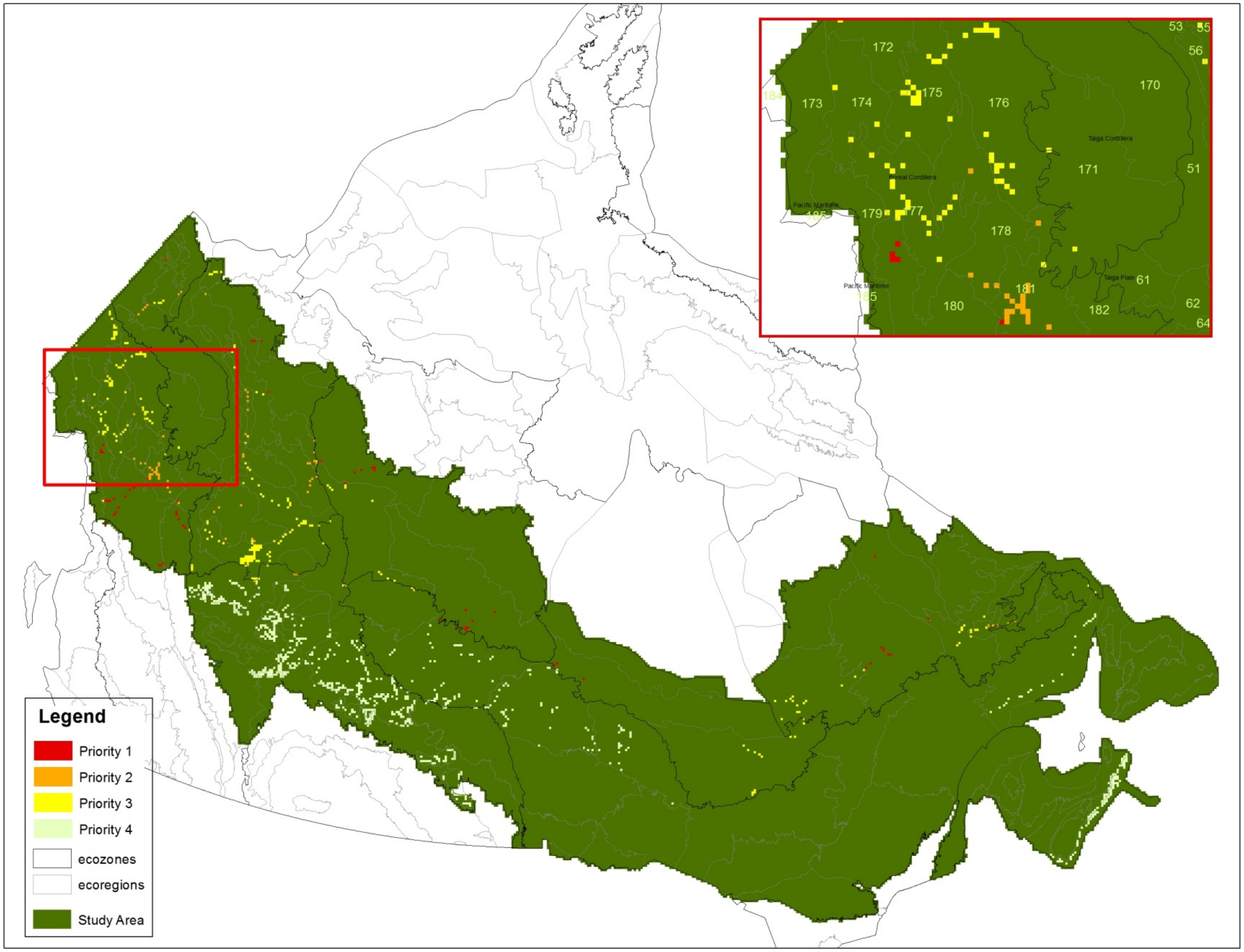


Figure 6. Roadside bias in avian survey estimated for 84 species using species-specific generalized linear mixed models (BWWA omitted because it was an outlier). Filled circles indicate species with significant roadside bias (95% CI does not contain zero); open circles indicate species with non-significant roadside bias (95% CI overlaps zero). The size of the circles corresponds to relative number of detections among the species. Small number of detections usually coincides with wide confidence intervals. We include the AOU code for the species analyzed; the corresponding common and scientific names are included in the Appendix.

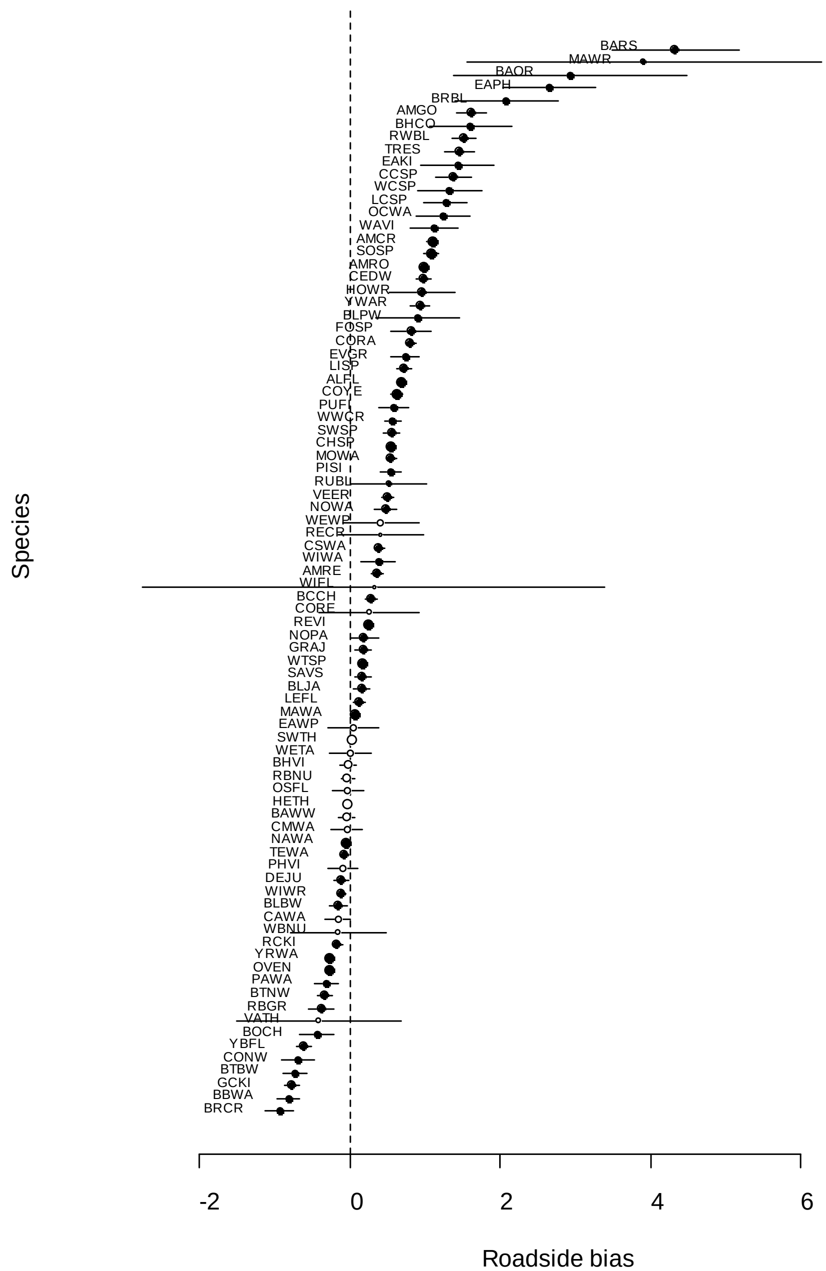


Figure 7. Expected abundance (birds per survey point) for selected species in different habitat categories based on mixed model estimates and 3-min duration point counts during on- and off-road surveys in boreal Canada. Species include Canada Warbler (CAWA), Olive-sided Flycatcher (OSFL), Blackpoll Warbler (BLPW), and Bay-breasted Warbler (BBWA). Habitat categories are conifer forest and woodlands (lcc1), deciduous forest and woodland (lcc2), mixed forest and woodlands (lcc3), wetlands (lcc4), open-non forested habitats (lcc5), recent burns (lcc6), agricultural lands (lcc7), and urban landscapes (lcc99).

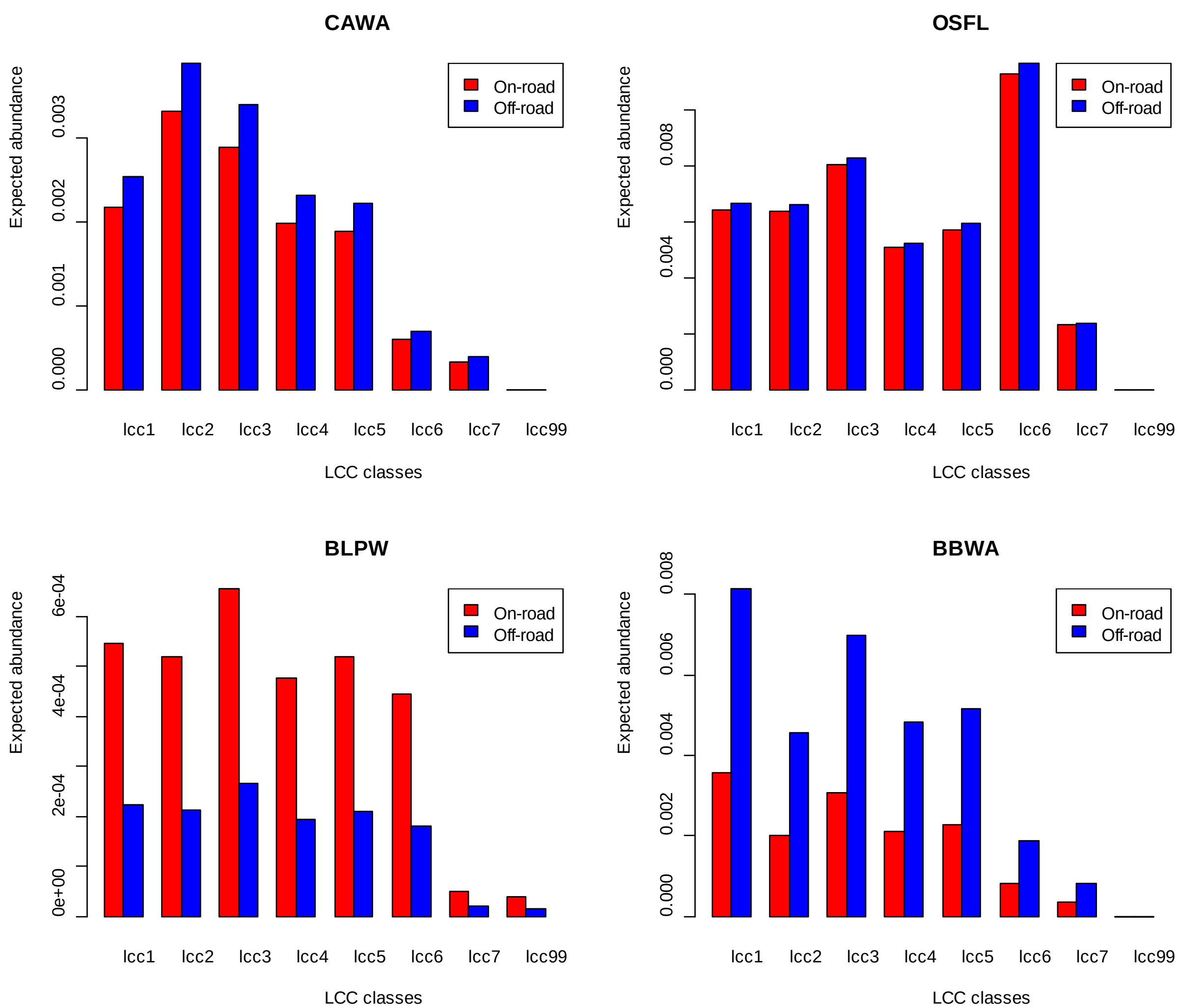
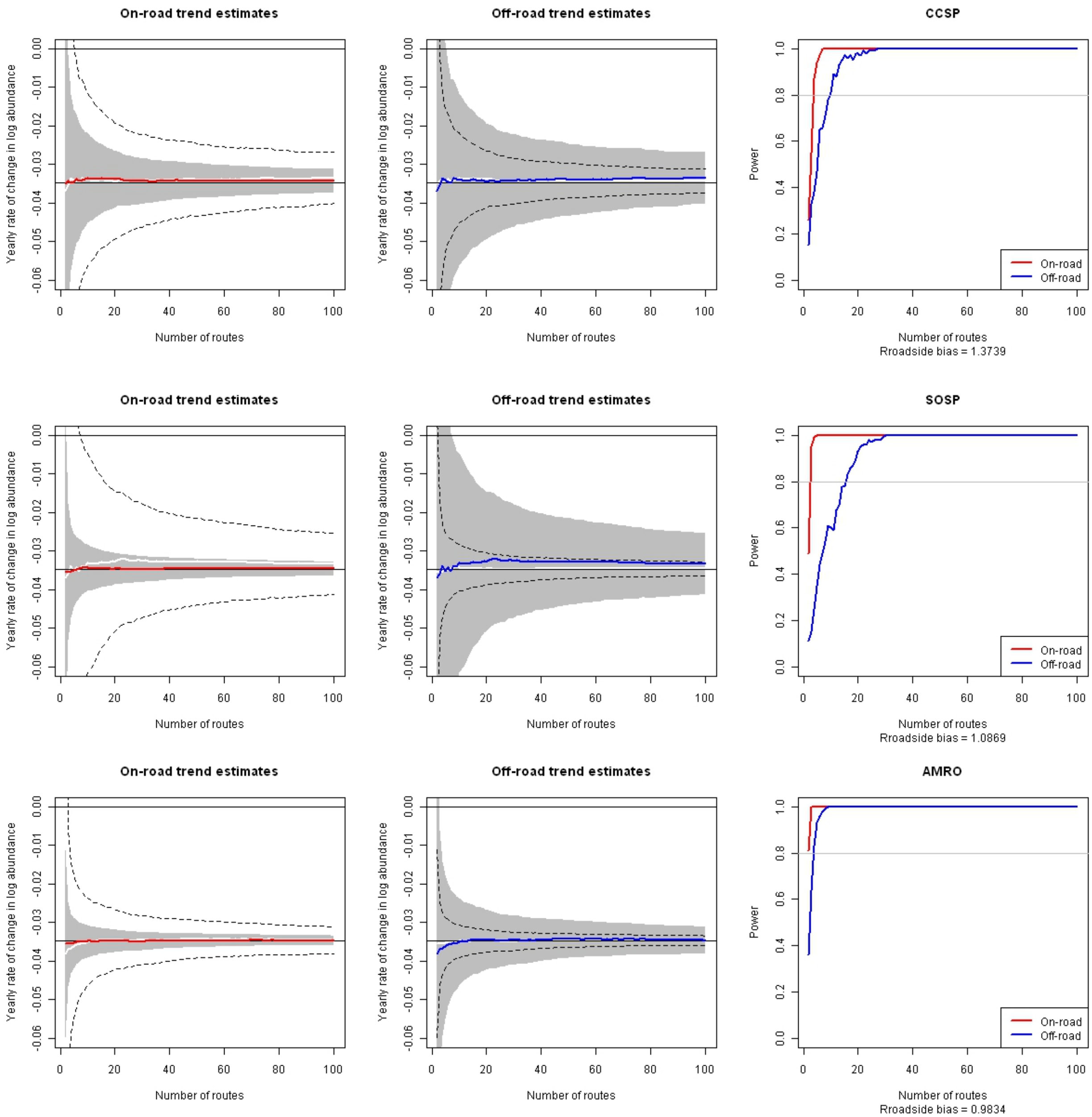
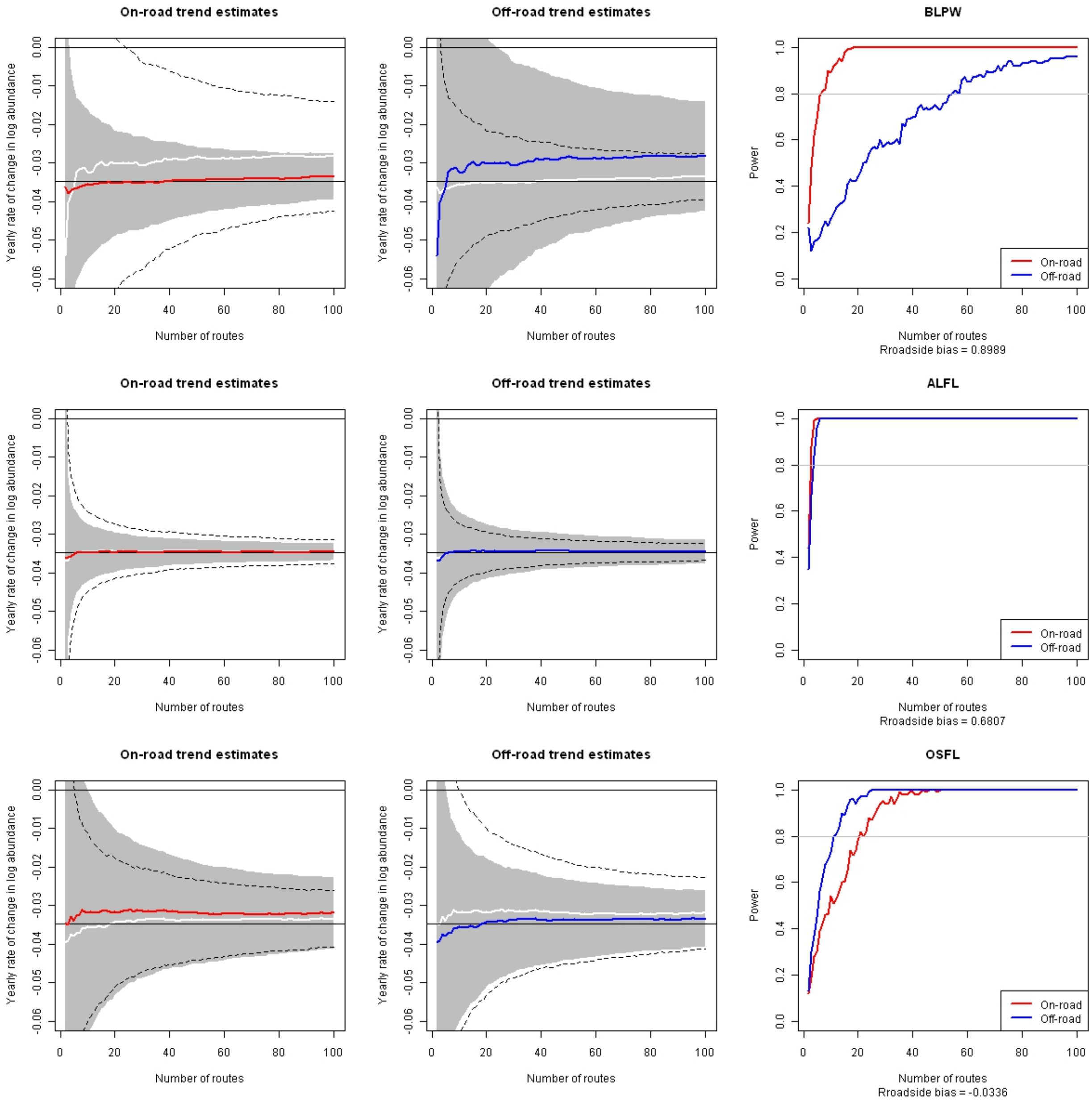
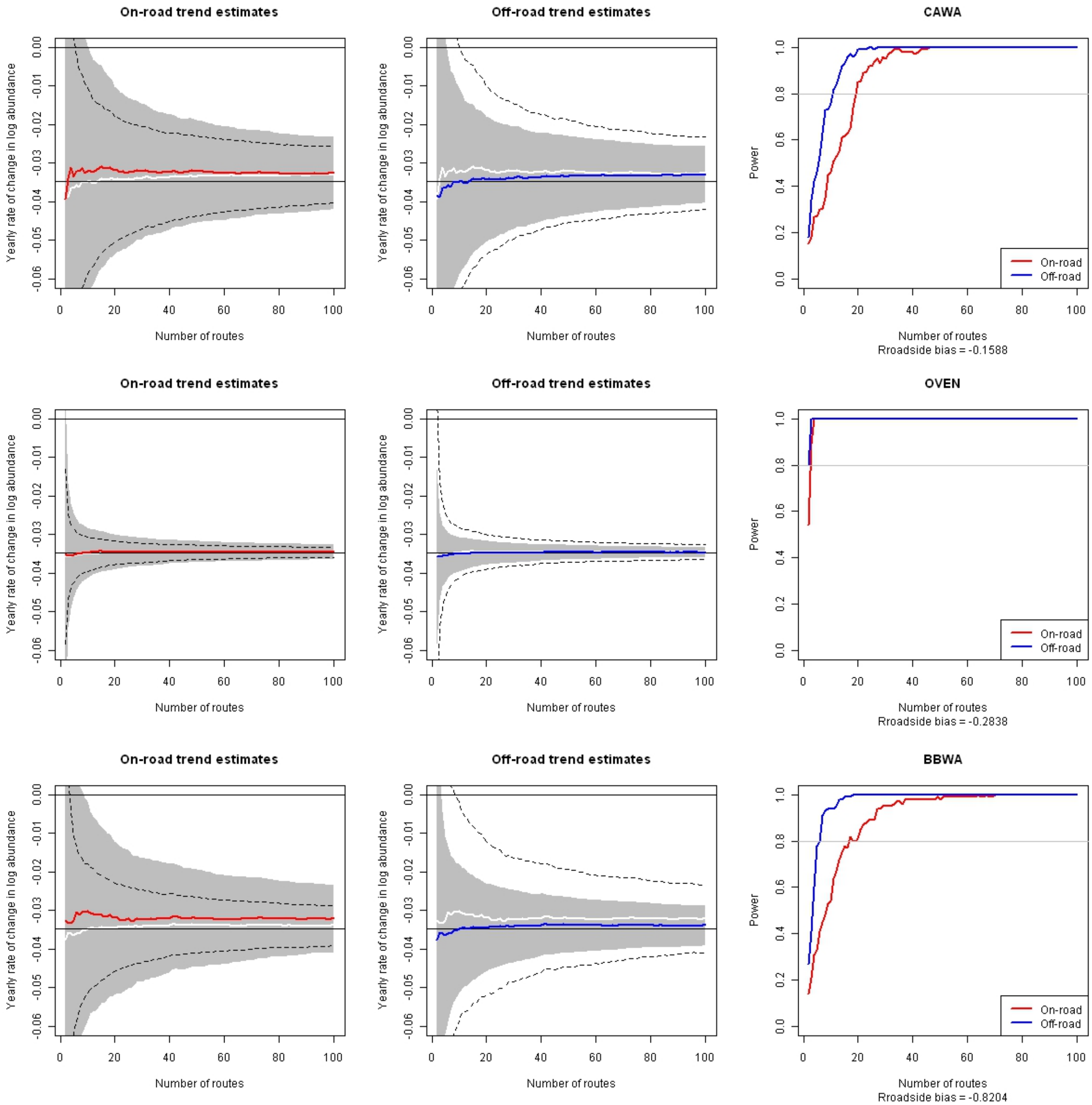


Figure 8. Bias, precision, and statistical power in estimating population trends for on-versus off-road surveys as functions of sample size for nine selected species. Sample size is expressed as number of routes with 50 survey points each. The panels show estimated trends and 90% CI for on-road surveys (left panel) and off-road surveys (middle panel) and statistical power to detect declines in abundance (right panel). Red lines are for on-road surveys, blue lines are for off-road surveys. In the left and middle panels, 0 (no trend) and -0.0347 (true trend) are indicated as horizontal lines; white line and scattered lines indicate the corresponding values in the opposite panels (roadside vs. off-road) as visual aids. The 0.8 power in the right panel also indicated.




On-road trend estimates
Off-road trend estimates
BLPW
Yearly rate of change in log abundance
Power
Number of routes
On-road
Off-road
Rroadside bias = 0.8989
On-road trend estimates
Off-road trend estimates
ALFL
Rroadside bias = 0.6807
On-road trend estimates
Off-road trend estimates
OSFL
Rroadside bias = -0.0336


On-road trend estimates
Off-road trend estimates
CAWA
Yearly rate of change in log abundance
Number of routes
Power
On-road
Off-road
Roadside bias = -0.1588
OVEN
Roadside bias = -0.2838
BBWA
Roadside bias = -0.8204

Appendix. The common names, scientific names, and species codes for the bird species analyzed in this report.

Common name	Scientific name	Code
Alder Flycatcher	*Empidonax alnorum*	ALFL
American Crow	*Corvus brachyrhynchos*	AMCR
American Goldfinch	*Carduelis tristis*	AMGO
American Redstart	*Setophaga ruticilla*	AMRE
American Robin	*Turdus migratorius*	AMRO
Baltimore Oriole	*Icterus galbula*	BAOR
Barn Swallow	*Hirundo rustica*	BARS
Black-and-white Warbler	*Mniotilta varia*	BAWW
Bay-breasted Warbler	*Dendroica castanea*	BBWA
Black-capped Chickadee	*Poecile atricapillus*	BCCH
Brown-headed Cowbird	*Molothrus ater*	BHCO
Blue-headed Vireo	*Vireo solitarius*	BHVI
Blackburnian Warbler	*Dendroica fusca*	BLBW
Blue Jay	*Cyanocitta cristata*	BLJA
Blackpoll Warbler	*Dendroica striata*	BLPW
Boreal Chickadee	*Poecile hudsonica*	BOCH
Brewer's Blackbird	*Euphagus cyanocephalus*	BRBL
Brown Creeper	*Certhia americana*	BRCR
Black-throated Blue Warbler	*Dendroica caerulescens*	BTBW
Black-throated Green Warbler	*Dendroica virens*	BTNW
Blue-winged Warbler	*Vermivora pinus*	BWWA
Canada Warbler	*Wilsonia canadensis*	CAWA
Clay-colored Sparrow	*Spizella pallida*	CCSP
Cedar Waxwing	*Bombycilla cedrorum*	CEDW
Chipping Sparrow	*Spizella passerina*	CHSP
Cape May Warbler	*Dendroica tigrina*	CMWA
Connecticut Warbler	*Oporornis agilis*	CONW
Common Raven	*Corvus corax*	CORA
Common Redpoll	*Carduelis flammea*	CORE
Common Yellowthroat	*Geothlypis trichas*	COYE
Chestnut-sided Warbler	*Dendroica pensylvanica*	CSWA
Dark-eyed Junco	*Junco hyemalis*	DEJU
Eastern Kingbird	*Tyrannus tyrannus*	EAKI
Eastern Phoebe	*Sayornis phoebe*	EAPH
Eastern Wood-Pewee	*Contopus virens*	EAWP
Evening Grosbeak	*Coccothraustes vespertinus*	EVGR
Fox Sparrow	*Passerella iliaca*	FOSP
Golden-crowned Kinglet	*Regulus satrapa*	GCKI
Gray Jay	*Perisoreus canadensis*	GRAJ
Hermit Thrush	*Catharus guttatus*	HETH
House Wren	*Troglodytes aedon*	HOWR
Le Conte's Sparrow	*Ammodramus leconteii*	LCSP
Least Flycatcher	*Empidonax minimus*	LEFL
Lincoln's Sparrow	*Melospiza lincolnii*	LISP
Magnolia Warbler	*Dendroica magnolia*	MAWA

Common name	Scientific name	Code
Marsh Wren	*Cistothorus palustris*	MAWR
Mourning Warbler	*Oporornis philadelphia*	MOWA
Nashville Warbler	*Vermivora ruficapilla*	NAWA
Northern Parula	*Parula americana*	NOPA
Northern Waterthrush	*Seiurus noveboracensis*	NOWA
Orange-crowned Warbler	*Vermivora celata*	OCWA
Olive-sided Flycatcher	*Contopus cooperi*	OSFL
Ovenbird	*Seiurus aurocapilla*	OVEN
Palm Warbler	*Dendroica palmarum*	PAWA
Philadelphia Vireo	*Vireo philadelphicus*	PHVI
Pine Siskin	*Carduelis pinus*	PISI
Purple Finch	*Carpodacus purpureus*	PUFI
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	RBGR
Red-breasted Nuthatch	*Sitta canadensis*	RBNU
Ruby-crowned Kinglet	*Regulus calendula*	RCKI
Red Crossbill	*Loxia curvirostra*	RECR
Red-eyed Vireo	*Vireo olivaceus*	REVI
Rusty Blackbird	*Euphagus carolinus*	RUBL
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL
Savannah Sparrow	*Passerculus sandwichensis*	SAVS
Song Sparrow	*Melospiza melodia*	SOSP
Swamp Sparrow	*Melospiza georgiana*	SWSP
Swainson's Thrush	*Catharus ustulatus*	SWTH
Tennessee Warbler	*Vermivora peregrina*	TEWA
Tree Swallow	*Tachycineta bicolor*	TRES
Varied Thrush	*Ixoreus naevius*	VATH
Veery	*Catharus fuscescens*	VEER
Warbling Vireo	*Vireo gilvus*	WAVI
White-breasted Nuthatch	*Sitta carolinensis*	WBNU
White-crowned Sparrow	*Zonotrichia leucophrys*	WCSP
Western Tanager	*Piranga ludoviciana*	WETA
Western Wood-Pewee	*Contopus sordidulus*	WEWP
Willow Flycatcher	*Empidonax traillii*	WIFL
Wilson's Warbler	*Wilsonia pusilla*	WIWA
Winter Wren	*Troglodytes troglodytes*	WIWR
White-throated Sparrow	*Zonotrichia albicollis*	WTSP
White-winged Crossbill	*Loxia leucoptera*	WWCR
Yellow-bellied Flycatcher	*Empidonax flaviventris*	YBFL
Yellow-rumped Warbler	*Dendroica coronata*	YRWA
Yellow Warbler	*Dendroica petechia*	YWAR