# Estimating population trends for songbirds in Northern Alberta

April 19, 2018

Péter Sólymos[1,2], Erin Bayne[2,3], Judith D. Toms[4]

[1]Alberta Biodiversity Monitoring Institute

[2]Boreal Avian Modelling Project

[3]Department of Biological Sciences, University of Alberta

[4]Environment and Climate Change Canada

## Table of Contents

# Introduction

Spatially and temporally replicated point count surveys, such as the North American Breeding Bird Survey (BBS) (Sauer et al. 2014) remain the 'gold standard' for estimating population trends at the extent of large planning regions and political jurisdictions (Environment Canada 2014). BBS samples points along routes revisited every year. Limitations of BBS has been noted, i.e. geographical sampling bias (Matsuoka et al. 2011), biased representation of land cover types and disturbances (Van Wilgenburg et al. 2015), and point level biases in observed counts (Matsuoka et al. 2011).

Because of these biases, there has been an interest in developing regional monitoring programs (e.g. JOSM, ABMI) that are less reliant of the road network to gain access to sampling sites targeting off-road areas, thus less impacted by the roadside-related biases. In these large-scale programs the times since inception of these regional programs, or the rotation interval does not yet allow the estimation of trend from revisits to the same locations doe to sample size limitations. As an alternative, there is wealth of spatially distributed but not revisited off-road survey locations that has been collected over the past decades. Understanding how these temporally not very well replicated surveys can be utilized for estimating population trends is an important step forward until regional monitoring programs accumulate enough data to allow revisit-based trend estimation.

In this report we used songbird data from Alberta to estimate population trends for 97 songbird species using various statistical techniques. Bird survey data has been collected by ABMI, EC, Bayne Lab, BBS, collated by ABMI and BAM. We investigated how estimates from our data set relate to official BBS trends for the province (Alberta, Bird Conservation Region 6).

# Methods

## Species distribution modeling

We used 83,029 point count survey visits from 25,373 unique survey stations in the Boreal, Foothills, Parklands, and Rocky Mountain natural regions in Alberta, Canada. Survey data were collated from the BBS (46,982 visits), Boreal Avian Modelling Project (25,276 visits; http://www.borealbirds.ca; database version 4), and the Alberta Biodiversity Monitoring Institute (10,771 visits; http://www.abmi.ca). Surveys were conducted between 1997 and 2015. Surveys varied in terms of sampling protocol (duration, area sampled, human observers or recordings interpreted in lab). We used the QPAD approach to account for differences in sampling protocol and nuisance parameters affecting detectability (time of day, time of year, tree cover, habitat composition; Sólymos et al. 2013, Sólymos 2016). We estimated effect size for contrasts between recoding technologies (RiverForks, SoundMeters) in modeling (Ball et al. 2016). Details of the data analyses are explained in Ball et al. 2016, Sólymos et al. 2014, 2015, ABMI 2017.

Local-scale variables were assessed in a 150-m radius of each station. Stand-scale variables were assessed in a 564-m radius (1 km$^2$) of each survey station. Land cover (vegetation type and forest age) was assessed for each survey station using provincial land cover information (ABMI 2013, 2015). Vegetation type included deciduous, mixed wood, white spruce, pine, black spruce, and larch-dominated forest stands, and shrub, grass/herb, swamp, wet grass, and wet shrub cover types. Human footprint was assessed at each survey point based on the year of sampling (interpreted at a 1:5000 scale; Schieck et al. 2014). Footprint type included cultivation, forestry, urban-industrial, hard linear (road and rails), and vegetated soft linear (seismic lines, pipe lines, power lines) features. Latitude, longitude and climate variables and stand-level human footprint amounts were used to improve spatial predictions as described in Ball et al. 2016.

We used data of 93 species (**Table 1**) to build Poisson generalized linear models with a log link. The response variable was the number of birds of a given species counted per survey. The variables were grouped in stages (Null, Local Habitat, Climate, Surrounding Footprint) and were used later to calculate expected bird densities. Model selection procedure was repeated by combining the forward selection process with bootstrap aggregation. Bootstrap replicates were drawn with replacement from each spatio-temporal block to ensure representation of the entire sample distribution. Temporal blocks were set using five-year intervals over the two decades of the study. Spatial blocks were defined based on natural regions (Foothills, Parkland, Rocky Mountain, Boreal). Because of its comparatively large area, the Boreal natural region (including the Canadian Shield) was further subdivided into four quadrants by the 56.5° parallel and the -115.5 meridian. Within spatial units, we sampled survey stations and survey visits within each selected station with replacement, to retain the spatial sampling pattern of the surveys in the bootstrap samples. When more than one visit occurred at the same location in the same year, we randomly selected a single visit for each of the bootstrap iterations. Observations were assumed to be independent, conditional on the value of the predictors. The number of bootstrap iterations was 239, plus the original model fit with all data, for a total of 240 independent runs.

## Trend estimation

Population trends were assessed based on the *year effect* estimate ($\beta$) from the Poisson models jointly estimated with other effects, which we converted to percent annual change ($100 \times [e^{\beta} - 1]$). This estimate reflects change after accounting for all the other (local habitat, climate, and surrounding footprint) effects based on the full data set including both on- and off-road surveys.

To estimate the trend based on off-and on-road surveys, we used the bootstrap smoothed expected density values together with QPAD offsets as known quantities ($\lambda$) in *residual trend* estimation. We fit Poisson log-linear models to the counts using $\lambda$ as offset, and year of survey as a covariate. We estimated the year effect this way while selected a subset of data (e.g. BBS roadside surveys, or non-BBS off-road surveys, or both combined). We repeated the year effect modeling for all 240 bootstrap runs we used in the spatial modeling for each species. We then calculated mean, standard error, median, and 5% and 95% quantile based confidence intervals for the bootstrap distribution. We repeated this for each species and data subsets.

## Exploratory analysis of trend estimates

We compared the following trend estimates:

1. 'Official' route level BBS trend for Alberta BCR 6 from ECCC, long term (**Table 2**);
2. 'Official' route level BBS trend for Alberta BCR 6 from ECCC, short term (**Table 2**);
3. Year effect based percent annual change based on joint modeling;
4. Percent annual change based on residual analysis, on- and off-road data;
5. Percent annual change based on residual analysis, BBS points, roadside surveys only;
6. Percent annual change based on residual analysis, off-road surveys only.

Note that all the estimates in this report other than the route level BBS trends are based on point level data. For residual trend, we compared the effect of how $\lambda$ was defined:

1. No environmental covariates, only QPAD offsets;
2. QPAD offsets, and local land cover;
3. QPAD offsets, local land cover, and climate;
4. QPAD offsets, local land cover, climate and surrounding footprint.

To better understand the relationship between the different trend estimates we calculated proportion of detection (pdet) for each species as the number of >0 counts out of the total number of surveys in the full data set. Roadside affinity for the species was measured by selection index for roads (sroad) estimated via resource selection function in a weighted distribution framework. We also collected information on the species' habitat associations (Forest, Open habitat, Wetlands, Woodlands), feeding behavior (Aerial, Bark/Foliage, Ground foraging), and migratory behavior (Neotropical migrant, Short distance migrant, Resident) from the BNA public website (https://www.allaboutbirds.org/) (**Table 1**).

## Results

The mean percent annual change estimates from bootstrapped joint modeling varied between -12.5% and +115%, mean and median values were very similar, standard errors varied between 0.14% and 5.6% (**Table 3**). There was strong relationship between species' detection rates (**Figure 1**).

The amount of spatial variation (habitat, climate, surrounding footprint) had an effect on the residual percent annual change estimates (**Figure 2**). Complex spatial models resulted in less extreme trends for some species, but variation in terms of percent annual change still remained substantial, in the range of -10% and +10%.

The residual percent annual change estimates after accounting for all the spatial effects varied greatly when comparing results based on different subsets of the data, or in comparison with the short- and long-term route level BBS trend estimates (**Figure 3**).

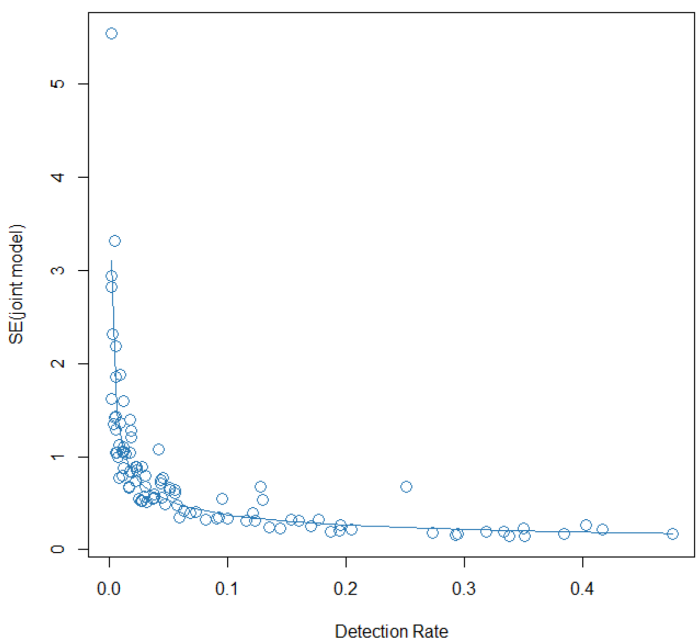


**Figure 1**. Relationship between standard error of trend estimates based on the joint models vs. species' detection rates (pdet in **Table 1**). Fitted line represent a log-log transformed linear relationship, points represent species (*n*=93).

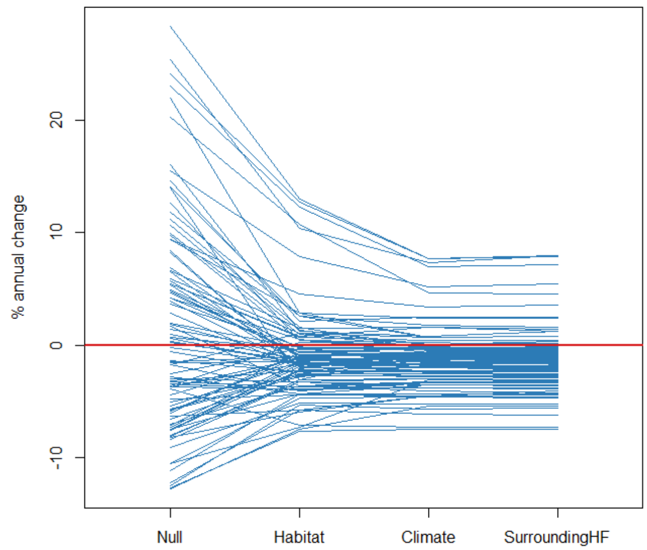


**Figure 2**. Residual trend estimates (on- and off-rad data combined) for 93 bird species after accounting for increasingly complex spatial covariate sets. Each line is a species (*n*=93).

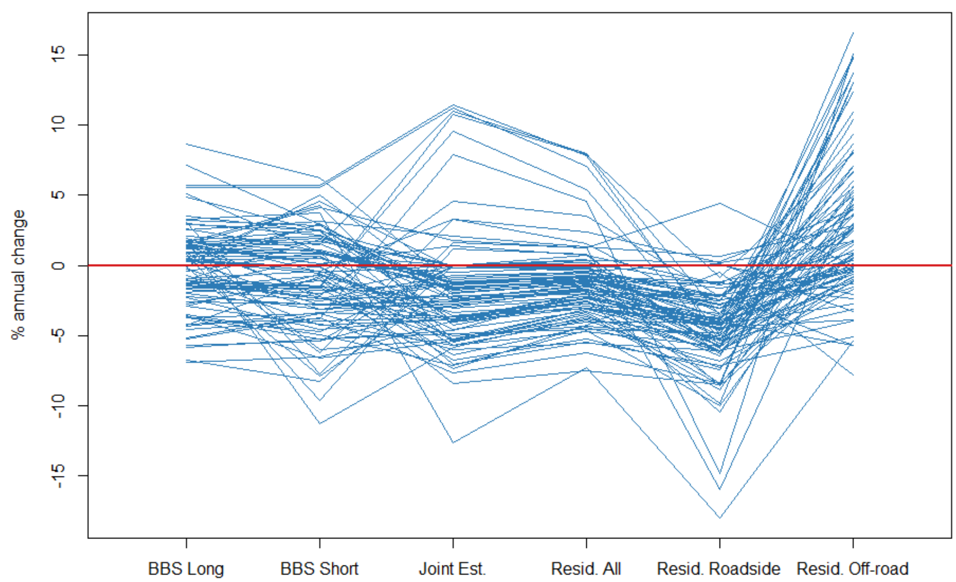


**Figure 3**. Comparing population trend (% annual change) estimates based on different approaches and data subsets (route level BBS, point level joint modeling, point level residual analysis for different data subsets). Each line is a species (*n*=90).

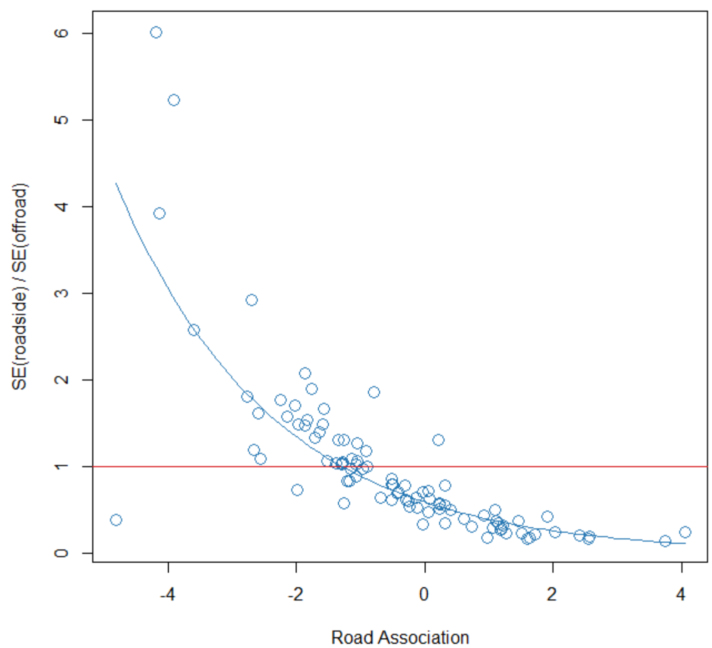


**Figure 4**. Relationship between ratio of standard errors from residual roadside and off-road trend estimates vs. road association (sroad in **Table 1**). Fitted line represent a log-ratio transformed linear relationship, points represent species (*n*=93).

Results in **Figure 3** from the joint modeling were very similar to the combined residual estimates (on- and off-road data), both of these slightly lower and more in the negative side compared to route level BBS estimates for the same species. Residual road side estimates were lowest on average, residual off-road estimates were highest on average.

There was also a relationship between the ratios of standard errors from the on- and off-road subsets of the residual trend estimates and the species' road associations. The relationship (**Figure 4**) indicated that species associated with roads had smaller standard errors for the estimates in the roadside subset, where their detection rates and relative abundance was higher.

Short and long term route level BBS estimates were highly correlated (*r*=0.62). The joint model based and residual trend estimates (on- and off-road combined data) showed highest correlation (*r*=0.99). Residual trend estimates based on roadside data correlated best with short term BBS trend (*r*=0.33). Residual trend estimates based on off-road data usually showed negative correlation with roadside based estimates (**Figure 5**).

Trend estimates by species groups revealed lower (decreasing) trend for aerially feeding species and to some extent for Neotropical migrants. Roadside residual estimates showed similar patterns. Off-road residual estimates showed the opposite: higher (increasing) trend for aerial feeders and Neotropical migrants; stronger positive trends for wetland, open area, and woodland associated species and neutral trends for forest species (**Table 6**).

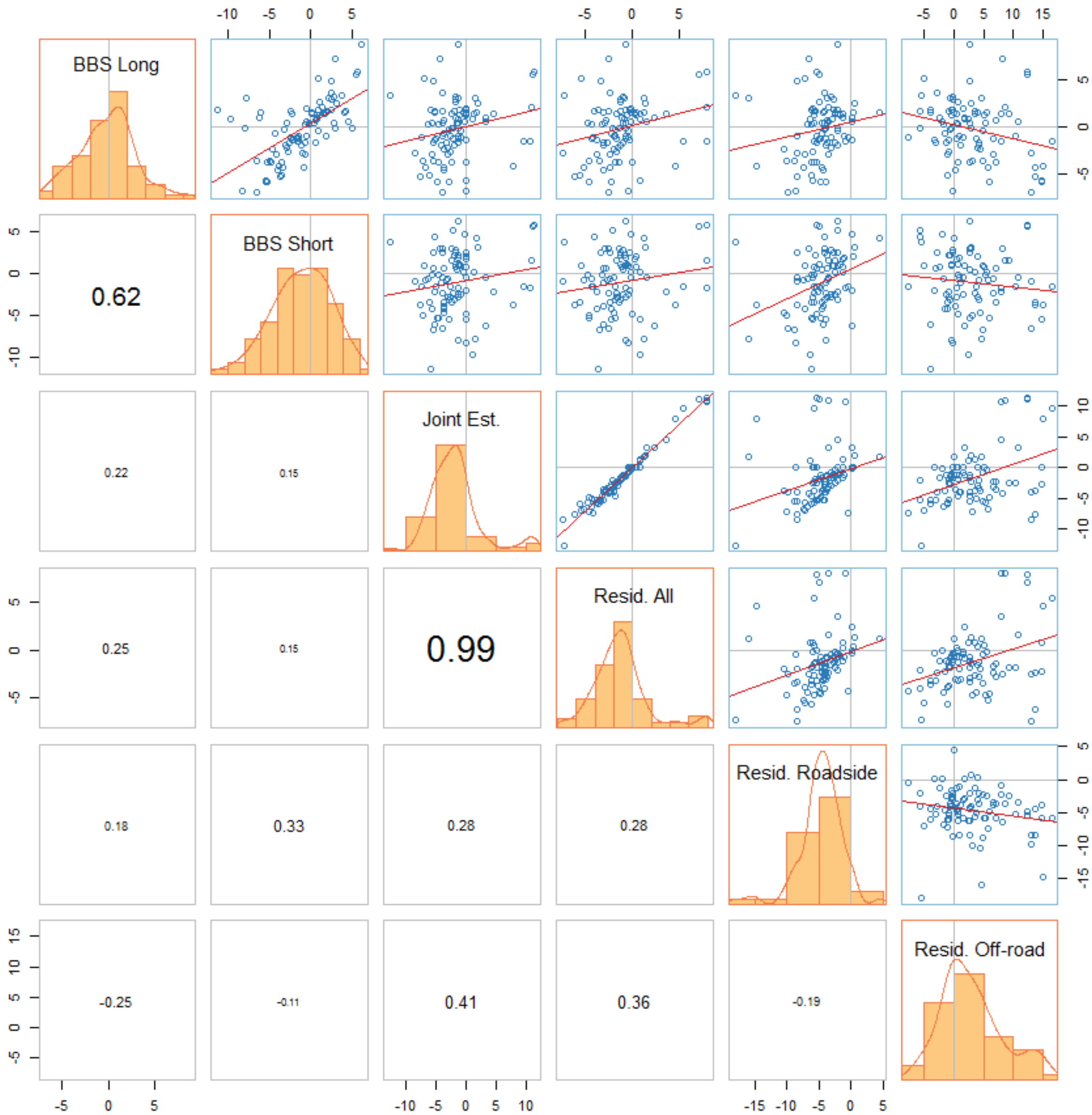


**Figure 5**. Scatterplot matrix showing correlations and univariate and bivariate distributions of the different trend (% annual change) estimates for *n*=90 species. Grey lines indicate 0 trend, red lines are linear 'trend' lines indicating the tendency in the bivariate relationships.

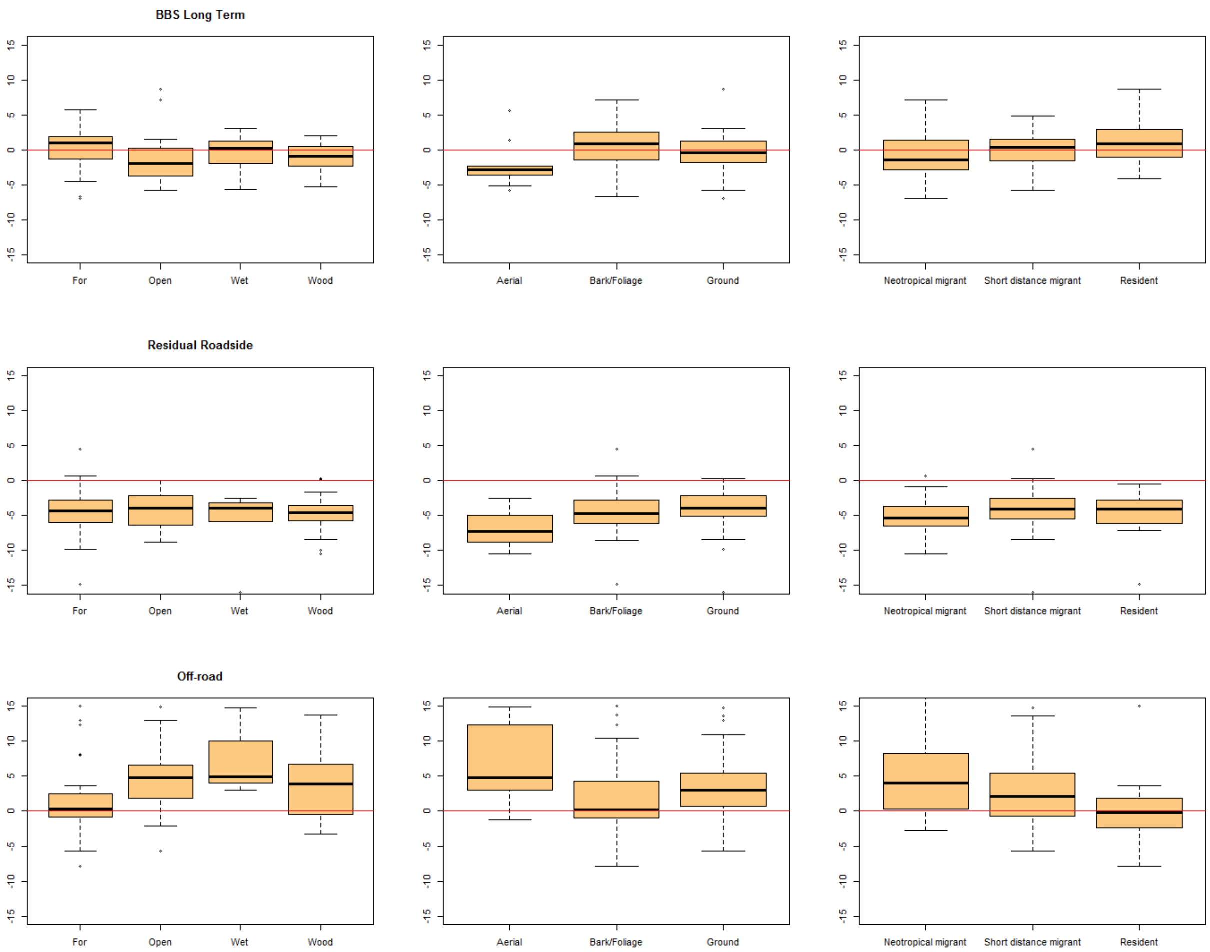


**Figure 6**. Distribution of % annual change (y axis) and life history traits (left: habitat associations; middle: feeding stratum; right: migratory behavior) according to different approaches (top: route level long term BBS trend; middle: residual roadside estimate; bottom: residual off-road estimates).

## Discussion

We found that the trend estimates based on different approaches led to quite different estimates. The short and long term BBS trend estimates based on route level data, and the joint modeling vs. residual based estimates were most correlated with each other. This, at least, indicates that different approaches based on the same data reveal very similar estimates. The difference among the approaches thus is most likely to be traced back to the differences in scale and composition of the input data.

The route level BBS information aggregates point level data of 50 stops per route in each year. This allows the data to be analyzed by a variety of different ways, even with approximate methods (e.g. linear regression) because the prevalence of 0 counts is much less than in usually sparse point/stop level data (a stop is a 3-minutes unlimited radius point count). As opposed to this, point/stop level data has substantially higher levels of 0 counts (usually >90%). This can potentially reduce power to estimate trend, or at least requires larger sample sizes to better estimate expected values. The correlation between route level BBS trend and point level residual trend estimates were moderate ($r$=0.33), but still higher among the other comparisons (**Figure 5**). But the average trend based on point level data was substantially lower (more negative) compared to the route level trends (**Figure 3**).

Another difference is the nature of points that go into the different analyses. In BBS, points are revisited in every year, whereas in most off-road data the number of revisits to the same locations apart from some localized studies is usually 1-2, rarely more. The advantage of revisits is that by conditioning on location one can effectively remove spatial variation due to habitat or biogeographical reasons. In our case, we used spatial distribution models to predict expected abundances as a function of local habitat conditions. This certainly adds to the uncertainty of trend estimates. Higher revisit frequency also allows the estimation of inter-annual variation, which is the 'noise' around the trend. If there are revisits, matching points in space and time helps teasing apart the spatial and inter-annual variation, thus increases our confidence in the trend estimates. In this respect the BBS (roadside) and off-road data not only represent different strata, but opposite ends of possible revisitation strategies.

The other component of the differences is the different strata roadside and off-road surveys sample. The combined data does not represent the two strata in proportion of the availability in the landscape. This alone is not necessarily a problem, unless the trend in the 2 strata are different. In that case there is little simplification that can be made mathematically to estimate the total population trend based on a weighted average of the stratum specific estimates (Appendix B). In this case, because the area of roads and associated habitats is quite small compared to the total extent of the landbase, the true trend is probably mostly driven by the off-road component.

According to a 5% sample of human footprint change in Alberta (Schieck et al. 2014), the percent amount of roads (road surface and verges) in northern Alberta (Boreal, Foothills, and Parkland natural regions) was 1.02% in 1999 and 1.14% in 2014 increasing with a 0.8% annually. Non-road area decreased with a -0.009% annual change. The ratio of road vs. off-road change in the extent of these strata was 1.008 (denoted as $\frac{\Delta_{1p}}{\Delta_{0p}}$ in Appendix B). If population change is driven by changes in road amount, we should expect the on/off-road ratio to be similar to this ~1 value. The mean population trend based ratio (dividing roadside estimates with off-road ones, denoted as $\frac{\Delta_{1\delta}}{1}$ in Appendix B) was 0.93 (90% confidence interval: 0.81 – 1.02, $n$=93 species), which is different from what we would expect based on changes in road area. Also, by controlling for year specific disturbance effects in spatial habitat modelling, we further minimize the effects of footprint driven change.

A mechanism that can contribute to the stratum-specific trend is if e.g. as the population is declining, it would first disappear (or show lowered densities) in suboptimal habitats while still maintaining higher densities in optimal / highly suitable habitats close to carrying capacity. If this is true, we should be able to test this by comparing habitat specific trend estimates, or at least by looking at inter-annual variability by habitats and relate that to known ordering due to habitat suitability. In this on/off road setting, the simplest test would be to see if the population trend ration is correlated with road association (sroad). I found that the correlation between the two variables was -0.01 ($p$=0.93). The detection of this correlation is also complicated by the fact that species preferring roadside habitats shoed more precise estimates along roads while the opposite was true for species mostly avoiding roadsides (**Figure 4**). Thus the uncertainty in these rations is great either way.

Other possible mechanism for the strata specific trend would be e.g. geographic shift in species' ranges relative to road network due to for example climate change. Currently the evidence does not suggest that range shifts are occurring at the southern Boreal, so this mechanism can be ruled out.

Roadside and off-road trend estimates were not only different, but slightly negatively correlated. If we take into account uncertainty and only concentrate on the significant (90% CI) estimates, we find that roadside estimates (point level residual approach) were predominantly negative (80 species out of 81 significant results), and only Yellow-bellied Sapsucker having a significant positive roadside trend. Based on the off-road residual trend, only 15 species showed significant negative trend and 52 showed significant positive trend. There were 46 species where roadside trend was negative and off-road trend was positive, including Olive-sided Flycatcher.

At this point, the biggest challenge is attributing the found discrepancies to different mechanisms, such as: non-representative / biased sampling, lack of adequate revisitation, large variance and 0-problem due to small scale point sampling. Comparing these trend estimates to forthcoming 'revisitation based' point level results might help in getting more refined end certain off-rad trend estimates at regional scales. Two years of revisit information from ABMI data and revisit samples planned for the 2017 field season will be used to quantify revisit based trends for species. The challenge with these forthcoming data will be to account for the variable revisit interval in a meaningful way (e.g. geometric means, or spatio-temporal random effects).

## Acknowledgements

We thank Daiyuan Pan and Diana Stralberg for help in geospatial summaries required for the modeling, and Patricia Fontaine for managing the Boreal Avian Modelling Project database. This research was enabled in part by support provided by WestGrid (http://www.westgrid.ca), Compute Canada Calcul Canada (http://www.computecanada.ca. We acknowledge the Boreal Avian Modelling Project members, avian and biophysical data partners, and funding agencies (including the Joint Oil Sands Monitoring Program and Environment Canada), listed in full at www.borealbirds.ca/index.php/acknowledgements.

## References

Alberta Biodiversity Monitoring Institute (ABMI). 2013. *ABMI human footprint inventory for 2012 conditions (version 3)*. AMBI, University of Alberta, Edmonton, Alberta, Canada. [online] URL: ftp://ftp.public.abmi.ca/GISProduct/HumanFootprint/2012/ABMI_Guide_HF2012_Version3_Public.pdf

Alberta Biodiversity Monitoring Institute (ABMI). 2015. *Alberta backfilled wall-to-wall vegetation layer (version 5) metadata*. AMBI, University of Alberta, Edmonton, Alberta, Canada. [online] URL: http://ftp.public.abmi.ca/species.abmi.ca/geospatial/vegetation/2012_w2w_Backfilled_LayerV5_Metadata_2.docx

Alberta Biodiversity Monitoring Institute (ABMI). 2017. *ABMI Species Website Manual, Version: 2017-03-23.* Alberta Biodiversity Monitoring Institute, Alberta, Canada. [online] URL: http://species.abmi.ca. pp. 27.

Ball, J. R., Sólymos, P., Schmiegelow, F. A. K., Haché, S., Schieck, J., and Bayne, E. M., 2016. Regional habitat needs of a nationally listed species, Canada Warbler *Cardellina canadensis*, in Alberta, Canada. *Avian Conservation and Ecology*, 11(2):10.

Environment Canada. 2014. *North American breeding bird survey—Canadian trends website, data-version 2012*. Environment Canada, Gatineau, Quebec, Canada. [online] URL: http://www.ec.gc.ca/ron-bbs/P004/A001/?lang=e&m=s&r=CAWA&p=-

Matsuoka, S.,P. Solymos, T. Fontaine, E. Bayne. 2011. Roadside surveys of boreal forest birds: how representative are they and how can we improve current sampling? Report to Environment Canada, Canadian Wildlife Service. Edmonton.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2014. *The North American Breeding Bird Survey, results and analysis 1966-2013*. Version 01.30.2015. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. [online] URL: http://www.mbr-pwrc.usgs.gov/bbs/bbs.html

Schieck, J., P. Sólymos, and D. Huggard. 2014. *ABMI science letters: human footprint in Alberta*. AMBI, University of Alberta, Edmonton, Alberta, Canada. [online] URL: http://www.abmi.ca/home/publications/351-400/364.html

Sólymos, P. 2016. *QPAD version 3 documentation*. Technical Report. Boreal Avian Modelling Project, Edmonton, Alberta, Canada. [online] URL: http://www.borealbirds.ca/files/Solymos2016.QPAD_v3_report_2.pdf

Sólymos, P., S. M. Matsuoka, E. M. Bayne, S. R. Lele, P. Fontaine, S. G. Cumming, D. Stralberg, F. K. A. Schmiegelow, and S. J. Song. 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. *Methods in Ecology and Evolution* 4:1047-1058. http://dx.doi.org/10.1111/2041-210X.12106

Sólymos, P., C.L Mahon, P.,Fontaine and E.M.Bayne (2015). Predictive Models for Estimating the Cumulative Effects of Human Development on Migratory Landbirds in the Oil Sands Areas of

Alberta, Joint Oil Sands Monitoring: Cause-Effects Assessment of Oil Sands Activity on Migratory Landbirds, Edmonton, AB. pp. 38.

Sólymos, P., C.L Mahon,and E.M.Bayne (2014). Development of predictive models for migratory landbirds and estimation of cumulative effects of human development in the oil sands areas of Alberta. Technical report, Joint Oil Sands Monitoring: Cause-Effects Assessment of Oil Sands Activity on Migratory Landbirds, Edmonton, AB. pp. 829.

Van Wilgenburg, S. L., E. M. Beck, B. Obermayer, T. Joyce, and B. Weddle. 2015. Biased representation of disturbance rates in the roadside sampling frame in boreal forests: implications for monitoring design. Avian Conservation and Ecology 10(2):5. http://dx.doi.org/10.5751/ACE-00777-100205

Van Wilgenburg, S. L., Sólymos, P., Kardynal, K. J. and Frey, M. D., 2017. Paired sampling as a pragmatic approach toward comparability between point counts conducted by humans versus acoustic recorders. *Avian Conservation and Ecology*, in press.

# Appendices

## Appendix A. Species specific information and estimates

**Table 1**. List of species mentioned in this report with four-letter acronyms, selection index for roads (sroad), proportion of detections (pdet) in the data set, habitat associations (Hab), feeding behavior (Beh), and migratory status (Mig).

| AOU code | English name | Scientific name | sroad | pdet | Hab | Beh | Mig |
|---|---|---|---|---|---|---|---|
| **ALFL** | Alder Flycatcher | *Empidonax alnorum* | -0.12 | 0.123 | Open | Aerial | Neotropical migrant |
| **AMCR** | American Crow | *Corvus brachyrhynchos* | 2.03 | 0.350 | Wood | Ground | Short distance migrant |
| **AMGO** | American Goldfinch | *Spinus tristis* | 1.14 | 0.047 | Wood | Bark/Foliage | Short distance migrant |
| **AMRE** | American Redstart | *Setophaga ruticilla* | -1.71 | 0.056 | For | Bark/Foliage | Neotropical migrant |
| **AMRO** | American Robin | *Turdus migratorius* | 1.21 | 0.338 | Wood | Ground | Short distance migrant |
| **ATTW** | American Three-toed Woodpecker | *Picoides dorsalis* | -1.57 | 0.003 | For | Bark/Foliage | Resident |
| **BAOR** | Baltimore Oriole | *Icterus galbula* | 1.62 | 0.027 | Wood | Bark/Foliage | Neotropical migrant |
| **BARS** | Barn Swallow | *Hirundo rustica* | 2.57 | 0.044 | Open | Aerial | Neotropical migrant |
| **BAWW** | Black-and-white Warbler | *Mniotilta varia* | -1.94 | 0.030 | For | Bark/Foliage | Neotropical migrant |
| **BBMA** | Black-billed Magpie | *Pica hudsonia* | 2.41 | 0.195 | Wood | Ground | Resident |
| **BBWA** | Bay-breasted Warbler | *Setophaga castanea* | -4.19 | 0.018 | For | Bark/Foliage | Neotropical migrant |
| **BBWO** | Black-backed Woodpecker | *Picoides arcticus* | -2.56 | 0.002 | For | Bark/Foliage | Resident |
| **BCCH** | Black-capped Chickadee | *Poecile atricapillus* | 0.23 | 0.073 | For | Bark/Foliage | Resident |
| **BHCO** | Brown-headed Cowbird | *Molothrus ater* | 1.09 | 0.093 | Open | Ground | Short distance migrant |
| **BHVI** | Blue-headed Vireo | *Vireo solitarius* | -1.16 | 0.036 | For | Bark/Foliage | Short distance migrant |
| **BLJA** | Blue Jay | *Cyanocitta cristata* | -0.43 | 0.012 | For | Ground | Short distance migrant |
| **BLPW** | Blackpoll Warbler | *Setophaga striata* | -1.99 | 0.005 | For | Bark/Foliage | Neotropical migrant |
| **BOCH** | Boreal Chickadee | *Poecile hudsonicus* | -1.77 | 0.023 | For | Bark/Foliage | Resident |
| **BRBL** | Brewer's Blackbird | *Euphagus cyanocephalus* | 3.74 | 0.095 | Open | Ground | Short distance migrant |
| **BRCR** | Brown Creeper | *Certhia americana* | -3.91 | 0.018 | For | Bark/Foliage | Short distance migrant |
| **BTNW** | Black-throated Green Warbler | *Setophaga virens* | -4.13 | 0.027 | For | Bark/Foliage | Neotropical migrant |
| **CAWA** | Canada Warbler | *Cardellina canadensis* | -2.60 | 0.017 | For | Bark/Foliage | Neotropical migrant |
| **CCSP** | Clay-colored Sparrow | *Spizella pallida* | 1.18 | 0.350 | Open | Bark/Foliage | Neotropical migrant |
| **CEDW** | Cedar Waxwing | *Bombycilla cedrorum* | 0.31 | 0.051 | Wood | Bark/Foliage | Short distance migrant |
| **CHSP** | Chipping Sparrow | *Spizella passerina* | -0.49 | 0.292 | Wood | Ground | Short distance migrant |
| **CMWA** | Cape May Warbler | *Setophaga tigrina* | -2.77 | 0.017 | For | Bark/Foliage | Neotropical migrant |
| **COGR** | Common Grackle | *Quiscalus quiscula* | 0.93 | 0.004 | Wood | Ground | Short distance migrant |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CONW** | Connecticut Warbler | *Oporornis agilis* | -2.02 | 0.038 | For | Ground | Neotropical migrant |
| **CORA** | Common Raven | *Corvus corax* | -0.04 | 0.121 | Open | Ground | Resident |
| **COYE** | Common Yellowthroat | *Geothlypis trichas* | -0.24 | 0.068 | Open | Bark/Foliage | Neotropical migrant |
| **DEJU** | Dark-eyed Junco | *Junco hyemalis* | -0.52 | 0.135 | For | Ground | Short distance migrant |
| **DOWO** | Downy Woodpecker | *Picoides pubescens* | 0.23 | 0.005 | For | Bark/Foliage | Resident |
| **EAKI** | Eastern Kingbird | *Tyrannus tyrannus* | 1.26 | 0.011 | Open | Aerial | Neotropical migrant |
| **EAPH** | Eastern Phoebe | *Sayornis phoebe* | 2.55 | 0.008 | Wood | Aerial | Short distance migrant |
| **EUST** | European Starling | *Sturnus vulgaris* | 4.05 | 0.251 | Open | Ground | Short distance migrant |
| **EVGR** | Evening Grosbeak | *Coccothraustes vespertinus* | -1.38 | 0.005 | For | Ground | Short distance migrant |
| **FOSP** | Fox Sparrow | *Passerella iliaca* | -1.18 | 0.008 | For | Ground | Short distance migrant |
| **GCKI** | Golden-crowned Kinglet | *Regulus satrapa* | -1.08 | 0.019 | For | Bark/Foliage | Short distance migrant |
| **GRAJ** | Gray Jay | *Perisoreus canadensis* | -1.59 | 0.116 | For | Ground | Resident |
| **GRCA** | Gray Catbird | *Dumetella carolinensis* | 0.73 | 0.005 | Wood | Ground | Short distance migrant |
| **GRYE** | Greater Yellowlegs | *Tringa melanoleuca* | -2.70 | 0.019 | Wet | Ground | Short distance migrant |
| **HAWO** | Hairy Woodpecker | *Picoides villosus* | -0.51 | 0.014 | For | Bark/Foliage | Resident |
| **HETH** | Hermit Thrush | *Catharus guttatus* | -0.98 | 0.160 | Wood | Ground | Short distance migrant |
| **HOWR** | House Wren | *Troglodytes aedon* | 1.72 | 0.187 | Wood | Bark/Foliage | Short distance migrant |
| **KILL** | Killdeer | *Charadrius vociferus* | 1.20 | 0.025 | Open | Ground | Short distance migrant |
| **LCSP** | Le Conte's Sparrow | *Ammodramus leconteii* | -0.68 | 0.056 | Open | Ground | Short distance migrant |
| **LEFL** | Least Flycatcher | *Empidonax minimus* | 0.08 | 0.177 | For | Aerial | Neotropical migrant |
| **LEYE** | Lesser Yellowlegs | *Tringa flavipes* | -0.92 | 0.009 | Wet | Ground | Short distance migrant |
| **LISP** | Lincoln's Sparrow | *Melospiza lincolnii* | -0.26 | 0.154 | Open | Ground | Short distance migrant |
| **MAWA** | Magnolia Warbler | *Setophaga magnolia* | -2.25 | 0.044 | For | Bark/Foliage | Neotropical migrant |
| **MODO** | Mourning Dove | *Zenaida macroura* | 0.98 | 0.008 | Wood | Ground | Short distance migrant |
| **MOWA** | Mourning Warbler | *Geothlypis philadelphia* | -1.84 | 0.057 | For | Bark/Foliage | Neotropical migrant |
| **NOFL** | Northern Flicker | *Colaptes auratus* | 0.05 | 0.038 | Wood | Ground | Short distance migrant |
| **NOWA** | Northern Waterthrush | *Parkesia noveboracensis* | -1.07 | 0.023 | For | Ground | Neotropical migrant |
| **OCWA** | Orange-crowned Warbler | *Oreothlypis celata* | -0.29 | 0.032 | For | Bark/Foliage | Short distance migrant |
| **OSFL** | Olive-sided Flycatcher | *Contopus cooperi* | -1.21 | 0.011 | Wood | Aerial | Neotropical migrant |
| **OVEN** | Ovenbird | *Seiurus aurocapilla* | -2.14 | 0.333 | For | Ground | Neotropical migrant |
| **PAWA** | Palm Warbler | *Setophaga palmarum* | -3.60 | 0.045 | Wood | Ground | Short distance migrant |
| **PHVI** | Philadelphia Vireo | *Vireo philadelphicus* | -1.52 | 0.022 | For | Bark/Foliage | Neotropical migrant |
| **PIGR** | Pine Grosbeak | *Pinicola enucleator* | -0.03 | 0.001 | Wood | Bark/Foliage | Short distance migrant |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **PISI** | Pine Siskin | *Spinus pinus* | 0.22 | 0.128 | Wood | Bark/Foliage | Short distance migrant |
| **PIWO** | Pileated Woodpecker | *Dryocopus pileatus* | -1.31 | 0.012 | For | Bark/Foliage | Resident |
| **PUFI** | Purple Finch | *Carpodacus purpureus* | -0.42 | 0.007 | For | Bark/Foliage | Short distance migrant |
| **RBGR** | Rose-breasted Grosbeak | *Pheucticus ludovicianus* | -1.30 | 0.090 | For | Bark/Foliage | Neotropical migrant |
| **RBNU** | Red-breasted Nuthatch | *Sitta canadensis* | -0.90 | 0.059 | For | Bark/Foliage | Resident |
| **RCKI** | Ruby-crowned Kinglet | *Regulus calendula* | -1.05 | 0.204 | For | Bark/Foliage | Short distance migrant |
| **RECR** | Red Crossbill | *Loxia curvirostra* | -0.31 | 0.005 | For | Bark/Foliage | Short distance migrant |
| **REVI** | Red-eyed Vireo | *Vireo olivaceus* | -0.52 | 0.273 | For | Bark/Foliage | Neotropical migrant |
| **RUBL** | Rusty Blackbird | *Euphagus carolinus* | -1.15 | 0.005 | For | Ground | Short distance migrant |
| **RUGR** | Ruffed Grouse | *Bonasa umbellus* | -1.64 | 0.022 | For | Bark/Foliage | Resident |
| **RWBL** | Red-winged Blackbird | *Agelaius phoeniceus* | 1.45 | 0.403 | Wet | Ground | Short distance migrant |
| **SAVS** | Savannah Sparrow | *Passerculus sandwichensis* | 1.60 | 0.294 | Open | Ground | Short distance migrant |
| **SOSA** | Solitary Sandpiper | *Tringa solitaria* | -1.28 | 0.009 | Wet | Ground | Neotropical migrant |
| **SOSP** | Song Sparrow | *Melospiza melodia* | 1.51 | 0.144 | Wood | Ground | Short distance migrant |
| **SPSA** | Spotted Sandpiper | *Actitis macularius* | 0.31 | 0.012 | Wet | Ground | Neotropical migrant |
| **SWSP** | Swamp Sparrow | *Melospiza georgiana* | -1.26 | 0.030 | Wet | Ground | Short distance migrant |
| **SWTH** | Swainson's Thrush | *Catharus ustulatus* | -1.26 | 0.318 | For | Bark/Foliage | Neotropical migrant |
| **TEWA** | Tennessee Warbler | *Oreothlypis peregrina* | -1.88 | 0.417 | For | Bark/Foliage | Neotropical migrant |
| **TOSO** | Townsend's Solitaire | *Myadestes townsendi* | 3.36 | 0.001 | Wood | Aerial | Short distance migrant |
| **TRES** | Tree Swallow | *Tachycineta bicolor* | 1.91 | 0.129 | Wet | Aerial | Short distance migrant |
| **VATH** | Varied Thrush | *Ixoreus naevius* | 0.05 | 0.029 | For | Ground | Short distance migrant |
| **VEER** | Veery | *Catharus fuscescens* | -0.02 | 0.002 | For | Ground | Neotropical migrant |
| **VESP** | Vesper Sparrow | *Pooecetes gramineus* | 1.06 | 0.099 | Open | Ground | Short distance migrant |
| **WAVI** | Warbling Vireo | *Vireo gilvus* | 0.41 | 0.081 | Wood | Bark/Foliage | Neotropical migrant |
| **WBNU** | White-breasted Nuthatch | *Sitta carolinensis* | 1.11 | 0.003 | For | Bark/Foliage | Resident |
| **WCSP** | White-crowned Sparrow | *Zonotrichia leucophrys* | 2.84 | 0.017 | Open | Ground | Short distance migrant |
| **WETA** | Western Tanager | *Piranga ludoviciana* | -1.97 | 0.044 | For | Bark/Foliage | Neotropical migrant |
| **WEWP** | Western Wood-Pewee | *Contopus sordidulus* | 0.22 | 0.028 | Wood | Aerial | Neotropical migrant |
| **WISN** | Wilson's Snipe | *Gallinago delicata* | -0.13 | 0.170 | Wet | Ground | Short distance migrant |
| **WIWA** | Wilson's Warbler | *Cardellina pusilla* | 0.32 | 0.017 | Open | Bark/Foliage | Neotropical migrant |
| **WIWR** | Winter Wren | *Troglodytes hiemalis* | -4.82 | 0.050 | For | Ground | Short distance migrant |
| **WTSP** | White-throated Sparrow | *Zonotrichia albicollis* | -1.05 | 0.476 | For | Ground | Short distance migrant |
| **WWCR** | White-winged Crossbill | *Loxia leucoptera* | -0.79 | 0.041 | For | Bark/Foliage | Short distance migrant |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **YBFL** | Yellow-bellied Flycatcher | *Empidonax flaviventris* | -2.66 | 0.012 | For | Aerial | Neotropical migrant |
| **YBSA** | Yellow-bellied Sapsucker | *Sphyrapicus varius* | -1.35 | 0.063 | For | Bark/Foliage | Short distance migrant |
| **YEWA** | Yellow Warbler | *Setophaga petechia* | 0.60 | 0.194 | Wood | Bark/Foliage | Neotropical migrant |
| **YRWA** | Yellow-rumped Warbler | *Setophaga coronata* | -1.86 | 0.385 | For | Bark/Foliage | Short distance migrant |

**Table 2**. BBS population trend (percent annual change) estimates in BCR 6 Alberta by ECCC.

| AOU code | Long term Annual trend | Longt erm Lower limit | Long term Upper limit | Short term Annual trend | Short term Lower limit | Short term Upper limit |
|---|---|---|---|---|---|---|
| **ALFL** | -3.58 | -4.74 | -2.35 | -6.59 | -9.54 | -3.64 |
| **AMCR** | 0.38 | -0.28 | 1.03 | -0.10 | -1.83 | 1.39 |
| **AMGO** | -1.41 | -2.79 | 0.06 | -2.19 | -6.19 | 1.80 |
| **AMRE** | -1.71 | -3.77 | 0.45 | -2.49 | -7.55 | 1.65 |
| **AMRO** | 0.46 | -0.14 | 1.06 | 2.91 | 1.27 | 4.57 |
| **ATTW** | -1.09 | -7.40 | 5.64 | -1.55 | -15.20 | 9.41 |
| **BAOR** | -5.25 | -6.67 | -3.80 | -3.73 | -8.37 | 1.28 |
| **BARS** | -2.76 | -4.05 | -1.43 | -0.92 | -4.83 | 3.15 |
| **BAWW** | 1.52 | -1.21 | 4.18 | -2.04 | -9.06 | 3.59 |
| **BBMA** | -1.24 | -2.19 | -0.39 | -1.48 | -3.91 | 0.39 |
| **BBWA** | -1.58 | -8.79 | 5.76 | -1.64 | -19.40 | 15.30 |
| **BBWO** | -4.15 | -12.20 | 4.89 | -3.77 | -16.00 | 12.90 |
| **BCCH** | 0.30 | -1.16 | 1.83 | -0.10 | -3.90 | 3.74 |
| **BHCO** | -0.99 | -2.25 | 0.45 | 1.89 | -1.81 | 6.58 |
| **BHVI** | 3.20 | 1.18 | 5.43 | 2.81 | -1.46 | 7.01 |
| **BLJA** | 0.45 | -0.91 | 1.96 | 0.47 | -2.21 | 3.60 |
| **BLPW** | -1.46 | -5.99 | 3.68 | -1.48 | -12.20 | 10.60 |
| **BOCH** | 3.01 | -0.10 | 6.59 | 2.16 | -5.62 | 10.20 |
| **BRBL** | -5.83 | -7.00 | -4.50 | -5.27 | -7.82 | -1.39 |
| **BRCR** | NA | NA | NA | NA | NA | NA |
| **BTNW** | -6.73 | -10.80 | -2.24 | -8.28 | -19.30 | -1.82 |
| **CAWA** | -3.74 | -7.80 | -0.26 | -4.74 | -15.00 | 2.00 |
| **CCSP** | -2.00 | -2.67 | -1.35 | -3.10 | -4.95 | -1.40 |
| **CEDW** | 1.70 | -0.98 | 4.59 | -2.34 | -8.66 | 4.25 |
| **CHSP** | -0.73 | -1.65 | 0.18 | -4.23 | -6.65 | -1.93 |
| **CMWA** | 5.70 | 0.47 | 11.70 | 5.70 | -1.10 | 13.30 |
| **COGR** | -1.44 | -4.09 | 1.07 | -2.01 | -8.77 | 2.24 |
| **CONW** | 1.65 | -0.23 | 3.65 | 2.11 | -1.23 | 7.45 |
| **CORA** | 8.65 | 6.90 | 11.20 | 6.24 | 2.21 | 9.82 |
| **COYE** | -3.74 | -4.67 | -2.84 | -3.45 | -6.13 | -0.79 |
| **DEJU** | -1.68 | -3.09 | -0.21 | 0.68 | -2.86 | 4.60 |
| **DOWO** | 0.96 | -0.81 | 2.75 | 0.85 | -3.25 | 4.50 |
| **EAKI** | -5.73 | -7.68 | -3.81 | -5.38 | -11.50 | 1.20 |
| **EAPH** | -5.14 | -6.84 | -3.45 | -3.46 | -9.31 | 2.76 |
| **EUST** | -0.09 | -1.62 | 1.55 | 5.07 | 0.40 | 10.50 |
| **EVGR** | 1.42 | -4.72 | 6.92 | -2.15 | -23.20 | 8.21 |
| **FOSP** | -0.93 | -8.25 | 7.44 | -0.44 | -16.00 | 15.90 |
| **GCKI** | 2.59 | -1.01 | 6.51 | 1.04 | -7.59 | 6.77 |
| **GRAJ** | -1.28 | -3.09 | 0.55 | -1.75 | -6.24 | 1.79 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **GRCA** | 1.49 | -1.77 | 3.95 | 1.97 | -4.52 | 7.84 |
| **GRYE** | 3.05 | -4.41 | 11.80 | -7.73 | -24.50 | 8.65 |
| **HAWO** | 0.86 | -0.85 | 2.64 | 0.86 | -2.32 | 4.08 |
| **HETH** | 1.17 | -0.21 | 2.52 | 1.12 | -1.58 | 3.41 |
| **HOWR** | 0.65 | -0.42 | 1.74 | 0.66 | -2.09 | 3.51 |
| **KILL** | -4.27 | -5.51 | -2.93 | -0.80 | -5.10 | 4.40 |
| **LCSP** | -3.68 | -5.50 | -1.65 | -5.25 | -10.70 | 0.05 |
| **LEFL** | -2.89 | -3.77 | -1.98 | -4.19 | -6.77 | -1.67 |
| **LEYE** | -5.71 | -8.03 | -3.42 | -5.41 | -9.02 | -0.02 |
| **LISP** | 1.52 | -0.24 | 3.58 | 0.09 | -3.59 | 3.88 |
| **MAWA** | 0.84 | -3.21 | 4.75 | -9.66 | -18.20 | -0.80 |
| **MODO** | -4.30 | -6.34 | -2.32 | -3.38 | -10.00 | 3.86 |
| **MOWA** | -2.56 | -4.00 | -1.16 | -2.74 | -5.71 | -0.42 |
| **NOFL** | -0.41 | -1.40 | 0.62 | 0.95 | -1.40 | 4.75 |
| **NOWA** | 1.32 | -0.82 | 3.52 | 0.14 | -5.43 | 4.07 |
| **OCWA** | 4.87 | 2.69 | 7.62 | 2.48 | -2.23 | 6.86 |
| **OSFL** | -2.28 | -4.52 | 0.35 | -4.59 | -13.00 | 0.78 |
| **OVEN** | 1.39 | 0.34 | 2.47 | 1.73 | -0.69 | 4.32 |
| **PAWA** | 2.06 | -2.45 | 6.31 | 1.49 | -7.93 | 8.20 |
| **PHVI** | 3.56 | 1.23 | 6.21 | 2.49 | -4.31 | 6.85 |
| **PIGR** | -13.10 | -41.60 | 5.43 | -27.20 | -72.40 | 7.30 |
| **PISI** | 0.32 | -3.27 | 4.25 | -0.59 | -8.94 | 8.22 |
| **PIWO** | 2.89 | 0.84 | 5.14 | 2.54 | -1.68 | 6.04 |
| **PUFI** | 1.65 | -1.14 | 4.72 | 4.30 | -3.12 | 13.30 |
| **RBGR** | 2.51 | 1.14 | 3.74 | 3.18 | 0.32 | 6.68 |
| **RBNU** | 1.78 | -1.19 | 5.13 | -11.30 | -16.10 | -6.33 |
| **RCKI** | 1.52 | -0.56 | 3.98 | -6.01 | -9.93 | -2.03 |
| **RECR** | NA | NA | NA | NA | NA | NA |
| **REVI** | -0.22 | -1.01 | 0.58 | -3.14 | -5.24 | -1.06 |
| **RUBL** | NA | NA | NA | NA | NA | NA |
| **RUGR** | -0.08 | -3.79 | 4.43 | -7.87 | -18.50 | 2.72 |
| **RWBL** | -1.60 | -2.53 | -0.64 | -0.71 | -3.14 | 1.80 |
| **SAVS** | -1.91 | -2.74 | -1.05 | -1.08 | -3.36 | 1.29 |
| **SOSA** | 1.28 | -2.02 | 5.07 | 0.78 | -6.58 | 7.11 |
| **SOSP** | -2.88 | -3.60 | -2.16 | -0.62 | -2.76 | 1.67 |
| **SPSA** | -2.22 | -3.86 | -0.63 | -2.86 | -8.56 | 0.08 |
| **SWSP** | 0.52 | -1.20 | 2.36 | -0.42 | -5.08 | 3.82 |
| **SWTH** | 0.39 | -0.94 | 1.92 | -2.85 | -6.04 | 0.23 |
| **TEWA** | 1.94 | -0.44 | 4.33 | -0.46 | -5.96 | 5.32 |
| **TOSO** | -4.43 | -14.10 | 6.14 | -4.90 | -17.20 | 7.46 |
| **TRES** | 1.33 | 0.30 | 2.37 | 1.53 | -0.37 | 3.79 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **VATH** | -4.54 | -7.97 | -0.90 | -3.95 | -8.48 | 3.34 |
| **VEER** | -6.90 | -11.40 | -2.37 | -6.51 | -21.60 | 10.00 |
| **VESP** | 0.53 | -1.15 | 2.29 | 4.61 | 0.37 | 9.15 |
| **WAVI** | -0.97 | -2.05 | 0.10 | -1.47 | -4.02 | 0.35 |
| **WBNU** | 5.14 | 0.67 | 10.60 | 0.96 | -10.60 | 10.10 |
| **WCSP** | 0.51 | -4.92 | 5.68 | -0.05 | -9.92 | 8.67 |
| **WETA** | 1.80 | -0.25 | 4.12 | 2.46 | -1.28 | 7.60 |
| **WEWP** | -3.53 | -5.07 | -1.95 | -4.93 | -9.34 | -0.54 |
| **WISN** | -0.09 | -1.26 | 1.22 | 3.01 | -0.44 | 6.92 |
| **WIWA** | 7.13 | 3.27 | 12.00 | 2.95 | -7.54 | 10.20 |
| **WIWR** | 0.93 | -3.98 | 5.39 | -6.19 | -18.00 | 3.39 |
| **WTSP** | -1.07 | -1.81 | -0.33 | -2.40 | -4.23 | -0.55 |
| **WWCR** | 3.30 | -2.60 | 10.10 | 3.78 | -8.31 | 21.20 |
| **YBFL** | 5.56 | 0.77 | 11.00 | 5.55 | -2.11 | 14.90 |
| **YBSA** | 1.47 | -0.29 | 3.23 | 4.16 | -0.55 | 9.63 |
| **YEWA** | -1.21 | -2.00 | -0.42 | -2.35 | -4.80 | -0.35 |
| **YRWA** | 1.73 | 0.49 | 3.06 | 0.98 | -2.16 | 3.14 |

**Table 3**. Year effect estimates (percent annual change) from joint log-linear modeling in Northern Alberta. Mean, quantiles (50%=Median, 5% and 95% confidence limits [CL]) and standard errors (SE) based on 240 bootstrap iterations.

| AOU code | Mean | Median | CL 5% | CL 95% | SE |
|---|---|---|---|---|---|
| **ALFL** | -5.41 | -5.43 | -5.90 | -4.87 | 0.31 |
| **AMCR** | -5.70 | -5.70 | -6.06 | -5.32 | 0.23 |
| **AMGO** | -5.26 | -5.24 | -6.08 | -4.53 | 0.48 |
| **AMRE** | -1.19 | -1.20 | -2.18 | 0.00 | 0.64 |
| **AMRO** | -3.98 | -3.99 | -4.19 | -3.76 | 0.14 |
| **ATTW** | -7.18 | -7.33 | -10.67 | -3.54 | 2.32 |
| **BAOR** | -7.63 | -7.68 | -8.44 | -6.67 | 0.52 |
| **BARS** | -8.47 | -8.41 | -9.73 | -7.32 | 0.74 |
| **BAWW** | 2.64 | 2.63 | 1.64 | 3.78 | 0.68 |
| **BBMA** | -5.03 | -5.04 | -5.44 | -4.60 | 0.26 |
| **BBWA** | 10.79 | 10.76 | 8.68 | 13.02 | 1.28 |
| **BBWO** | 7.77 | 7.89 | 0.00 | 16.41 | 5.55 |
| **BCCH** | -4.53 | -4.54 | -5.18 | -3.91 | 0.41 |
| **BHCO** | -1.19 | -1.21 | -1.81 | -0.64 | 0.35 |
| **BHVI** | -1.69 | -1.68 | -2.49 | -0.87 | 0.54 |
| **BLJA** | -1.37 | -1.56 | -2.89 | 0.00 | 1.06 |
| **BLPW** | 9.60 | 9.55 | 6.41 | 12.55 | 1.85 |
| **BOCH** | -1.32 | -1.38 | -2.64 | 0.00 | 0.89 |
| **BRBL** | -4.80 | -4.84 | -5.67 | -3.85 | 0.55 |
| **BRCR** | 4.25 | 4.17 | 2.62 | 5.94 | 1.04 |
| **BTNW** | -0.46 | 0.00 | -2.22 | 0.00 | 0.89 |
| **CAWA** | -0.07 | 0.00 | -1.77 | 1.74 | 0.85 |
| **CCSP** | -1.98 | -1.98 | -2.20 | -1.72 | 0.15 |
| **CEDW** | -3.87 | -3.82 | -4.94 | -2.83 | 0.66 |
| **CHSP** | -3.78 | -3.77 | -4.03 | -3.53 | 0.15 |
| **CMWA** | 11.45 | 11.43 | 9.21 | 13.77 | 1.39 |
| **COGR** | -0.36 | 0.00 | -2.87 | 2.11 | 1.42 |
| **CONW** | -1.88 | -1.93 | -2.85 | -0.99 | 0.60 |
| **CORA** | -1.21 | -1.23 | -1.88 | -0.62 | 0.39 |
| **COYE** | -2.36 | -2.34 | -3.04 | -1.76 | 0.40 |
| **DEJU** | -5.37 | -5.37 | -5.75 | -4.93 | 0.24 |
| **DOWO** | -1.24 | -1.65 | -3.27 | 0.00 | 1.29 |
| **EAKI** | -2.78 | -2.83 | -3.89 | -1.39 | 0.79 |
| **EAPH** | -5.99 | -5.97 | -7.33 | -4.86 | 0.77 |
| **EUST** | -2.19 | -2.17 | -3.36 | -1.02 | 0.67 |
| **EVGR** | 4.48 | 4.56 | 0.00 | 7.27 | 2.19 |
| **FOSP** | -3.97 | -3.90 | -5.74 | -2.22 | 1.12 |

| | | | | | |
|---|---|---|---|---|---|
| **GCKI** | -1.70 | -1.80 | -2.79 | 0.00 | 0.83 |
| **GRAJ** | -1.31 | -1.31 | -1.80 | -0.79 | 0.31 |
| **GRCA** | 0.44 | 0.00 | 0.00 | 2.69 | 1.04 |
| **GRYE** | 1.49 | 1.67 | 0.00 | 3.41 | 1.21 |
| **HAWO** | -1.01 | -1.20 | -2.70 | 0.00 | 1.03 |
| **HETH** | -1.00 | -0.99 | -1.50 | -0.52 | 0.30 |
| **HOWR** | -3.59 | -3.58 | -3.92 | -3.25 | 0.20 |
| **KILL** | -6.79 | -6.79 | -7.62 | -5.90 | 0.54 |
| **LCSP** | -4.63 | -4.65 | -5.69 | -3.71 | 0.61 |
| **LEFL** | -5.64 | -5.66 | -6.08 | -5.08 | 0.32 |
| **LEYE** | 0.91 | 0.00 | -2.08 | 4.34 | 1.88 |
| **LISP** | -0.40 | -0.46 | -0.90 | 0.00 | 0.32 |
| **MAWA** | 1.05 | 1.19 | 0.00 | 2.01 | 0.71 |
| **MODO** | -3.65 | -3.68 | -5.37 | -1.95 | 1.00 |
| **MOWA** | -2.58 | -2.59 | -3.30 | -1.84 | 0.47 |
| **NOFL** | -0.76 | -0.88 | -1.61 | 0.00 | 0.56 |
| **NOWA** | 1.25 | 1.43 | 0.00 | 2.45 | 0.85 |
| **OCWA** | -5.50 | -5.48 | -6.40 | -4.71 | 0.51 |
| **OSFL** | -3.76 | -3.77 | -5.45 | -2.08 | 1.06 |
| **OVEN** | 0.10 | 0.00 | 0.00 | 0.48 | 0.19 |
| **PAWA** | 10.95 | 11.00 | 9.66 | 12.13 | 0.77 |
| **PHVI** | -3.96 | -3.96 | -5.15 | -2.79 | 0.74 |
| **PIGR** | -2.02 | 0.00 | -7.28 | 0.00 | 2.94 |
| **PISI** | -6.37 | -6.40 | -7.36 | -5.18 | 0.68 |
| **PIWO** | -1.54 | -1.76 | -3.13 | 0.00 | 1.10 |
| **PUFI** | -5.29 | -5.29 | -7.04 | -3.55 | 1.04 |
| **RBGR** | 2.10 | 2.07 | 1.53 | 2.68 | 0.34 |
| **RBNU** | -5.80 | -5.84 | -6.38 | -5.24 | 0.34 |
| **RCKI** | -5.21 | -5.22 | -5.58 | -4.88 | 0.21 |
| **RECR** | -2.10 | -1.04 | -7.73 | 3.43 | 3.32 |
| **REVI** | -2.76 | -2.76 | -3.05 | -2.49 | 0.18 |
| **RUBL** | -0.16 | 0.00 | -3.23 | 2.89 | 1.42 |
| **RUGR** | -1.18 | -1.37 | -2.43 | 0.00 | 0.88 |
| **RWBL** | -3.33 | -3.34 | -3.78 | -2.91 | 0.27 |
| **SAVS** | -4.06 | -4.04 | -4.34 | -3.78 | 0.17 |
| **SOSA** | 0.95 | 0.00 | 0.00 | 3.54 | 1.36 |
| **SOSP** | -3.08 | -3.07 | -3.46 | -2.72 | 0.23 |
| **SPSA** | -2.94 | -2.96 | -4.33 | -1.64 | 0.88 |
| **SWSP** | 3.32 | 3.30 | 2.05 | 4.61 | 0.79 |
| **SWTH** | -1.31 | -1.33 | -1.60 | -1.00 | 0.19 |
| **TEWA** | -0.18 | 0.00 | -0.54 | 0.00 | 0.22 |

| | | | | | |
|---|---|---|---|---|---|
| **TOSO** | 0.41 | 0.00 | 0.00 | 4.06 | 1.62 |
| **TRES** | -2.41 | -2.41 | -3.20 | -1.59 | 0.53 |
| **VATH** | -3.66 | -3.63 | -4.61 | -2.84 | 0.56 |
| **VEER** | -3.36 | -3.94 | -7.58 | 0.00 | 2.83 |
| **VESP** | -0.30 | -0.19 | -0.82 | 0.00 | 0.34 |
| **WAVI** | -2.52 | -2.50 | -3.07 | -2.00 | 0.32 |
| **WBNU** | -7.09 | -7.03 | -9.37 | -5.06 | 1.35 |
| **WCSP** | -3.13 | -3.10 | -4.15 | -2.15 | 0.66 |
| **WETA** | -0.34 | 0.00 | -1.43 | 0.00 | 0.55 |
| **WEWP** | -7.15 | -7.17 | -7.96 | -6.23 | 0.52 |
| **WISN** | -2.39 | -2.38 | -2.83 | -2.01 | 0.25 |
| **WIWA** | -4.26 | -4.26 | -5.40 | -3.20 | 0.67 |
| **WIWR** | 3.30 | 3.30 | 2.24 | 4.38 | 0.65 |
| **WTSP** | -0.73 | -0.73 | -0.99 | -0.48 | 0.16 |
| **WWCR** | -12.60 | -12.66 | -14.42 | -10.85 | 1.07 |
| **YBFL** | 11.45 | 11.24 | 9.20 | 14.16 | 1.60 |
| **YBSA** | 1.73 | 1.76 | 1.05 | 2.35 | 0.41 |
| **YEWA** | -2.21 | -2.23 | -2.58 | -1.87 | 0.21 |
| **YRWA** | -1.17 | -1.16 | -1.46 | -0.88 | 0.17 |

**Table 4**. Residual trend (percent annual change) estimates in Northern Alberta after accounting for local habitat, climate and surrounding footprint in spatial models with offsets.

| AOU code | Both Median | Both CL 5% | Both CL 95% | BBS Median | BBS CL 5% | BBS CL 95% | Off-road Median | Off-road CL 5% | Off-road CL 95% |
|---|---|---|---|---|---|---|---|---|---|
| **ALFL** | -3.52 | -3.94 | -3.10 | -8.88 | -9.48 | -8.32 | 4.82 | 3.74 | 5.88 |
| **AMCR** | -4.72 | -5.07 | -4.36 | -5.78 | -6.12 | -5.37 | 5.35 | 3.91 | 7.19 |
| **AMGO** | -3.78 | -4.44 | -3.15 | -5.16 | -6.06 | -4.33 | -0.99 | -3.26 | 1.66 |
| **AMRE** | -1.08 | -1.73 | -0.35 | -2.48 | -3.85 | -1.39 | -1.34 | -2.21 | -0.25 |
| **AMRO** | -2.92 | -3.12 | -2.74 | -4.21 | -4.42 | -3.96 | 2.68 | 1.85 | 3.42 |
| **ATTW** | -4.22 | -6.11 | -1.52 | -0.46 | -6.92 | 4.99 | -7.83 | -11.14 | -4.08 |
| **BAOR** | -6.19 | -7.06 | -5.27 | -8.44 | -9.19 | -7.45 | 13.74 | 8.75 | 18.71 |
| **BARS** | -7.48 | -8.62 | -6.35 | -8.49 | -9.86 | -7.32 | 13.05 | 8.14 | 20.05 |
| **BBMA** | -4.36 | -4.78 | -3.96 | -4.99 | -5.37 | -4.52 | 3.71 | 1.48 | 5.76 |
| **BBWA** | 7.94 | 6.18 | 9.63 | -0.86 | -11.40 | 9.26 | 8.09 | 6.51 | 10.16 |
| **BBWO** | 4.55 | -1.22 | 11.90 | -14.81 | -24.50 | -5.49 | 15.08 | 7.49 | 25.84 |
| **BCCH** | -3.25 | -3.88 | -2.70 | -6.18 | -6.90 | -5.41 | 0.58 | -0.75 | 2.04 |
| **BHCO** | -0.78 | -1.32 | -0.31 | -1.12 | -1.86 | -0.57 | 0.85 | -0.41 | 2.18 |
| **BHVI** | -1.02 | -1.68 | -0.23 | -3.02 | -4.13 | -1.92 | -0.23 | -1.37 | 0.95 |
| **BLJA** | -1.08 | -2.32 | 0.27 | -4.53 | -6.31 | -2.68 | 2.70 | 0.34 | 5.32 |
| **BLPW** | 5.40 | 2.85 | 8.12 | -5.78 | -9.17 | -2.43 | 16.63 | 12.10 | 21.48 |
| **BOCH** | -0.90 | -1.84 | 0.10 | -3.66 | -5.79 | -1.33 | -0.63 | -1.78 | 0.63 |
| **BRBL** | -4.59 | -5.40 | -3.65 | -4.77 | -5.60 | -3.82 | 5.99 | 0.48 | 13.39 |
| **BRCR** | 2.52 | 1.39 | 3.71 | -6.74 | -13.84 | -0.53 | 2.82 | 1.67 | 4.30 |
| **BTNW** | -0.39 | -1.66 | 0.94 | -8.55 | -13.50 | -2.70 | -0.25 | -1.48 | 1.17 |
| **CAWA** | -0.04 | -1.54 | 1.26 | -5.27 | -8.06 | -2.45 | 0.73 | -1.45 | 2.24 |
| **CCSP** | -1.32 | -1.55 | -1.13 | -2.18 | -2.43 | -1.93 | 4.31 | 3.22 | 5.22 |
| **CEDW** | -2.60 | -3.62 | -1.77 | -5.66 | -7.14 | -4.36 | 3.53 | 1.97 | 5.37 |
| **CHSP** | -2.29 | -2.48 | -2.08 | -4.59 | -4.98 | -4.32 | -1.54 | -1.98 | -1.18 |
| **CMWA** | 7.86 | 5.86 | 10.24 | -5.41 | -9.70 | -1.79 | 12.35 | 10.22 | 15.14 |
| **COGR** | -0.38 | -3.02 | 2.06 | 0.15 | -3.37 | 3.02 | -3.28 | -10.40 | 3.82 |
| **CONW** | -1.30 | -2.12 | -0.55 | -5.55 | -7.21 | -3.74 | -0.85 | -1.94 | 0.09 |
| **CORA** | -0.69 | -1.16 | -0.20 | -2.17 | -2.92 | -1.37 | 2.58 | 1.51 | 3.52 |
| **COYE** | -1.37 | -1.93 | -0.85 | -5.77 | -6.53 | -5.12 | 7.09 | 5.86 | 8.55 |
| **DEJU** | -3.15 | -3.46 | -2.80 | -5.31 | -5.74 | -4.73 | -3.09 | -3.66 | -2.44 |
| **DOWO** | -1.15 | -2.64 | 0.22 | -1.25 | -3.09 | 0.90 | -2.35 | -5.52 | 1.27 |
| **EAKI** | -2.20 | -3.29 | -0.99 | -3.86 | -5.14 | -2.55 | 14.88 | 8.79 | 20.57 |
| **EAPH** | -5.58 | -6.88 | -4.50 | -6.10 | -7.41 | -4.98 | -1.20 | -7.63 | 7.54 |
| **EUST** | -2.07 | -3.19 | -0.93 | -2.10 | -3.22 | -0.92 | -5.71 | -9.50 | -1.02 |
| **EVGR** | 3.55 | 1.04 | 6.31 | -2.19 | -6.67 | 2.02 | 8.02 | 4.31 | 12.29 |
| **FOSP** | -2.00 | -3.40 | -0.39 | -8.42 | -11.17 | -6.40 | 0.87 | -1.74 | 3.71 |
| **GCKI** | -1.25 | -2.19 | -0.41 | -4.96 | -6.35 | -3.18 | 0.78 | -0.75 | 2.23 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **GRAJ** | -0.79 | -1.25 | -0.36 | -4.67 | -5.64 | -3.75 | 0.50 | -0.14 | 1.12 |
| **GRCA** | 0.35 | -1.07 | 2.01 | 0.28 | -1.47 | 2.46 | 3.97 | -1.48 | 10.89 |
| **GRYE** | 1.22 | -0.23 | 2.81 | -16.01 | -21.91 | -12.09 | 4.75 | 3.00 | 6.40 |
| **HAWO** | -0.82 | -2.00 | 0.28 | -2.84 | -4.33 | -1.21 | 1.81 | -0.48 | 4.50 |
| **HETH** | -0.59 | -1.00 | -0.25 | -1.60 | -2.19 | -0.99 | -0.39 | -1.00 | 0.25 |
| **HOWR** | -2.78 | -3.11 | -2.46 | -3.76 | -4.10 | -3.44 | 7.04 | 5.59 | 8.47 |
| **KILL** | -5.21 | -6.03 | -4.49 | -7.42 | -8.27 | -6.57 | 5.66 | 2.51 | 8.96 |
| **LCSP** | -1.89 | -2.60 | -1.25 | -6.16 | -7.36 | -5.10 | 2.61 | 0.88 | 4.27 |
| **LEFL** | -3.87 | -4.27 | -3.51 | -7.27 | -7.75 | -6.77 | -1.06 | -1.76 | -0.23 |
| **LEYE** | 0.74 | -1.42 | 2.72 | -5.92 | -10.87 | -0.50 | 14.81 | 10.91 | 20.11 |
| **LISP** | -0.19 | -0.51 | 0.19 | -2.47 | -2.97 | -1.87 | 5.56 | 4.66 | 6.37 |
| **MAWA** | 0.82 | 0.01 | 1.59 | -6.31 | -8.16 | -4.65 | 2.45 | 1.37 | 3.40 |
| **MODO** | -2.35 | -3.69 | -0.89 | -4.45 | -6.17 | -3.01 | 13.68 | 6.71 | 24.69 |
| **MOWA** | -1.72 | -2.28 | -1.01 | -6.05 | -7.41 | -4.73 | -0.77 | -1.47 | 0.16 |
| **NOFL** | -0.47 | -1.00 | 0.24 | -2.19 | -3.04 | -1.40 | 4.96 | 3.44 | 6.50 |
| **NOWA** | 0.75 | -0.08 | 1.54 | -1.35 | -2.71 | 0.10 | 3.62 | 2.07 | 5.30 |
| **OCWA** | -3.37 | -4.11 | -2.68 | -8.50 | -9.49 | -7.63 | 2.76 | 1.19 | 4.45 |
| **OSFL** | -1.98 | -3.18 | -0.65 | -10.48 | -12.50 | -8.49 | 4.37 | 1.98 | 6.64 |
| **OVEN** | 0.18 | -0.09 | 0.46 | -1.36 | -1.90 | -0.77 | 0.38 | 0.00 | 0.79 |
| **PAWA** | 7.95 | 6.81 | 8.96 | -3.59 | -6.65 | -0.19 | 8.65 | 7.62 | 9.79 |
| **PHVI** | -2.40 | -3.37 | -1.50 | -4.16 | -5.63 | -2.69 | -2.78 | -4.26 | -1.58 |
| **PISI** | -4.43 | -5.09 | -3.55 | -6.86 | -8.14 | -5.50 | -1.71 | -2.75 | -0.82 |
| **PIWO** | -1.22 | -2.35 | -0.08 | -2.75 | -4.97 | -1.05 | -0.17 | -2.17 | 1.58 |
| **PUFI** | -4.05 | -5.59 | -2.51 | -4.04 | -6.20 | -2.30 | -5.69 | -8.60 | -2.86 |
| **RBGR** | 1.36 | 0.94 | 1.87 | 0.63 | -0.08 | 1.50 | 2.84 | 2.03 | 3.58 |
| **RBNU** | -3.63 | -4.02 | -3.17 | -6.07 | -6.86 | -5.35 | -3.97 | -4.75 | -3.16 |
| **RCKI** | -3.13 | -3.41 | -2.84 | -4.43 | -4.90 | -3.97 | -3.89 | -4.28 | -3.53 |
| **RECR** | -0.89 | -5.16 | 3.70 | -4.24 | -10.97 | 1.52 | 6.74 | 0.25 | 16.46 |
| **REVI** | -1.81 | -2.07 | -1.57 | -4.11 | -4.48 | -3.69 | -0.64 | -1.11 | -0.19 |
| **RUBL** | 0.13 | -3.12 | 3.26 | -2.11 | -7.28 | 1.84 | 3.31 | -0.28 | 7.38 |
| **RUGR** | -0.69 | -1.63 | 0.12 | -4.02 | -5.48 | -2.10 | -0.45 | -1.57 | 0.76 |
| **RWBL** | -2.71 | -3.07 | -2.31 | -3.77 | -4.25 | -3.30 | 4.14 | 2.96 | 5.67 |
| **SAVS** | -3.08 | -3.38 | -2.83 | -3.96 | -4.26 | -3.70 | 1.11 | -0.46 | 2.88 |
| **SOSA** | 0.43 | -1.08 | 2.25 | -5.83 | -8.28 | -2.40 | 5.19 | 2.46 | 8.26 |
| **SOSP** | -2.36 | -2.74 | -2.02 | -3.42 | -3.78 | -3.04 | 6.62 | 4.97 | 8.26 |
| **SPSA** | -1.57 | -2.66 | -0.49 | -3.04 | -4.63 | -1.79 | 3.99 | 1.40 | 6.74 |
| **SWSP** | 1.55 | 0.70 | 2.56 | -3.42 | -4.54 | -1.99 | 10.93 | 8.73 | 13.42 |
| **SWTH** | -0.78 | -1.01 | -0.52 | -3.67 | -4.09 | -3.17 | 0.48 | 0.14 | 0.87 |
| **TEWA** | -0.17 | -0.43 | 0.09 | -5.88 | -6.40 | -5.27 | 1.46 | 1.10 | 1.84 |
| **TRES** | -1.78 | -2.51 | -1.09 | -2.50 | -3.31 | -1.67 | 9.31 | 7.34 | 11.34 |
| **VATH** | -3.08 | -3.81 | -2.32 | -4.24 | -5.18 | -3.18 | 0.14 | -1.25 | 1.61 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **VEER** | -2.51 | -6.24 | 1.26 | -9.85 | -13.58 | -6.17 | 13.01 | 4.97 | 27.26 |
| **VESP** | -0.11 | -0.47 | 0.24 | 0.05 | -0.43 | 0.51 | -2.09 | -3.86 | -0.58 |
| **WAVI** | -1.86 | -2.40 | -1.42 | -5.34 | -5.98 | -4.77 | 10.41 | 9.31 | 11.73 |
| **WBNU** | -5.45 | -7.42 | -3.18 | -7.12 | -9.47 | -4.83 | -5.10 | -10.62 | 1.19 |
| **WETA** | -0.28 | -1.05 | 0.42 | -2.12 | -3.74 | -0.69 | -0.14 | -1.13 | 0.84 |
| **WEWP** | -4.64 | -5.47 | -3.89 | -9.97 | -11.05 | -8.96 | 3.01 | 1.23 | 5.07 |
| **WISN** | -1.47 | -1.77 | -1.15 | -4.09 | -4.53 | -3.61 | 2.95 | 2.23 | 3.74 |
| **WIWA** | -2.54 | -3.43 | -1.56 | -6.49 | -7.74 | -5.22 | 8.24 | 4.85 | 11.97 |
| **WIWR** | 2.36 | 1.46 | 3.32 | 0.20 | -0.10 | 0.54 | 1.70 | 0.76 | 2.69 |
| **WTSP** | -0.46 | -0.65 | -0.21 | -3.03 | -3.42 | -2.68 | 1.63 | 1.29 | 2.01 |
| **WWCR** | -7.32 | -8.91 | -5.60 | -18.03 | -21.23 | -14.84 | -5.43 | -7.41 | -3.86 |
| **YBFL** | 7.11 | 4.84 | 9.11 | -4.92 | -9.06 | -2.07 | 12.35 | 9.49 | 15.21 |
| **YBSA** | 1.23 | 0.75 | 1.76 | 4.45 | 3.37 | 5.63 | -0.05 | -0.86 | 0.77 |
| **YEWA** | -1.68 | -2.00 | -1.37 | -3.86 | -4.24 | -3.51 | 6.70 | 5.77 | 7.60 |
| **YRWA** | -0.69 | -0.90 | -0.49 | -2.78 | -3.24 | -2.28 | -0.39 | -0.64 | -0.16 |

## Appendix B. Mathematical derivation of stratum specific trend estimation

We define percent annual change as $B = 100\left[\left(\frac{N_{tb}}{N_{ta}}\right)^{\frac{1}{tb-ta}} - 1\right]$. Annual rate of change (R) is related to B as R=1+B/100, where in general $R = N_t/N_{t-1}$. We can write population size in a given stratum as a product of area of the stratum and mean density in the stratum. Let's index roadside stratum by 1 and off-road stratum by 0. Rate of change in roadside stratum them becomes:

$$R_1 = \frac{N_{1t}}{N_{1t-1}} = \frac{p_{1t}A\delta_t D_{0t}}{p_{1t-1}A\delta_{t-1}D_{0t-1}} = \frac{p_{1t}}{p_{1t-1}}\frac{\delta_t}{\delta_{t-1}}\frac{D_{0t}}{D_{0t-1}} = \Delta_{1p}\Delta_{1\delta}\Delta_{0D}$$

Where $p_1$ is the proportion of the roadside stratum, A is the total area (on and off-road combined), $D_0$ is off-road population density, and $D_1 = \delta\ D_0$.

Rate of change in the off-road stratum can be written as:

$$R_0 = \frac{N_{0t}}{N_{0t-1}} = \frac{(1-p_{1t})AD_{0t}}{(1-p_{1t-1})AD_{0t-1}} = \frac{(1-p_{1t})}{(1-p_{1t-1})}\frac{D_{0t}}{D_{0t-1}} = \Delta_{0p}1\Delta_{0D}$$

The two quantities ($R_1$, $R_0$) can be decomposed into 3 multiplicative components:

1. $\Delta_p$: rate of change in the relative area of the strata;
2. $\Delta_\delta$: rate of change in how the roadside stratum trend is different from the off-road trend
3. $\Delta_D$: off-road population trend.

By taking the ratio of the on- and off-rad components, we can evaluate which component is most likely to drive the possible discrepancies:

$$\frac{R_1}{R_0} = \frac{\Delta_{1p}}{\Delta_{0p}}\frac{\Delta_{1\delta}}{1}\frac{\Delta_{0D}}{\Delta_{0D}} = \frac{\Delta_{1p}}{\Delta_{0p}}\frac{\Delta_{1\delta}}{1}$$

The overall population trend estimate follows from the combination of the 2 strata:

$$R = \frac{N_{1t} + N_{0t}}{N_{1t-1} + N_{0t-1}}$$

Which is not the same as the estimate from the combined on- and off-rad data set, but a weighted average of those which is a function of p only if there is not temporal changes in the areas of the strata, and relative differences among strata w.r.t. change are negligible, i.e. $\frac{\Delta_{1p}}{\Delta_{0p}} = 1$ and $\frac{\Delta_{1\delta}}{1} = 1$, which are pretty strong assumptions.