



Westwood, A. R., C. Staicer, P. Sölymos, S. Haché, T. Fontaine, E. Bayne, and D. Mazerolle. 2019. Estimating the conservation value of protected areas in Maritime Canada for two species at risk: the Olive-sided Flycatcher (*Contopus cooperi*) and Canada Warbler (*Cardellina canadensis*). *Avian Conservation and Ecology* 14(1):16. <https://doi.org/10.5751/ACE-01359-140116>  
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Research Paper, part of a Special Feature on Conservation of Boreal Birds

## Estimating the conservation value of protected areas in Maritime Canada for two species at risk: the Olive-sided Flycatcher (*Contopus cooperi*) and Canada Warbler (*Cardellina canadensis*)

Alana R. Westwood<sup>1,2</sup>, Cindy Staicer<sup>3</sup>, Péter Sölymos<sup>1,4,5</sup>, Samuel Haché<sup>6</sup>, Trish Fontaine<sup>7</sup>, Erin M. Bayne<sup>8</sup> and Dan Mazerolle<sup>9</sup>

<sup>1</sup>Boreal Avian Modelling Project, Edmonton, Alberta, Canada, <sup>2</sup>Dalhousie University, Halifax, Nova Scotia, Canada,

<sup>3</sup>Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada, <sup>4</sup>Alberta Biodiversity Monitoring Institute, Edmonton, Alberta, <sup>5</sup>Department of Biological Sciences, University of Alberta, Edmonton, Alberta, <sup>6</sup>Canadian Wildlife Service, Environment and Climate Change Canada, Yellowknife, Northwest Territories, Canada, <sup>7</sup>Department of Renewable Resources, University of Alberta, Alberta, Canada, <sup>8</sup>Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada, <sup>9</sup>Canadian Forest Service, Natural Resources Canada

**ABSTRACT.** The Olive-sided Flycatcher (*Contopus cooperi*) and Canada Warbler (*Cardellina canadensis*) are threatened landbirds in Canada and parts of the U.S. Both species are subjects of recent conservation and management interest. Protected areas are a key tool for managing populations of species at risk, and Canadian national parks may serve as important refuges in an increasingly fragmented landscape. However, the potential role that Canadian national parks may play in the recovery of these species is unclear. We used the Boreal Avian Modelling Project point count database to build Poisson log-linear models using forward stepwise variable selection to predict population density and distribution of these two threatened species in four national parks in Maritime Canada. We also predicted population density in areas of equivalent size in the same ecoregions outside the parks for comparison. Because forested wetlands, a key habitat for these species in this region, are difficult to represent with available spatial data, we tested the effectiveness of different remote sensing products. We tested GIS layers based on aerial photography wetlands (WETLANDS), depth to water table (WETNESS), and WETNESS as interacted with forest cover from aerial photography (WETxFOR). The best-performing models for the Olive-sided Flycatcher used WETxFOR, whereas WETNESS performed best for the Canada Warbler. Anthropogenic disturbance and proximity to roads had a negative effect on predicted density for both species. Protected areas showed slightly higher Olive-sided Flycatcher population densities than nearby areas, but not so for the Canada Warbler. Our results provide the first population density and population size estimates for these species in these parks, and novel information on the impacts of anthropogenic disturbance on predicted population density. These results can inform conservation and management in this region and our approach can be replicated in other regions to support ongoing recovery efforts.

## Évaluation de la valeur de conservation d'aires protégées dans les Maritimes, Canada, pour deux espèces en péril : le Moucherolle à côtés olive (*Contopus cooperi*) et la Paruline du Canada (*Cardellina canadensis*)

**RÉSUMÉ.** Le Moucherolle à côtés olive (*Contopus cooperi*) et la Paruline du Canada (*Cardellina canadensis*) sont des oiseaux terrestres menacés au Canada et dans certaines parties des États-Unis. Ces deux espèces font depuis peu l'objet d'un intérêt de conservation et de gestion. Les aires protégées représentent des outils stratégiques pour gérer les populations d'oiseaux en péril, et les parcs nationaux canadiens serviront peut-être d'importants refuges dans la foulée de la fragmentation grandissante du paysage. Toutefois, le rôle potentiel que les parcs nationaux canadiens pourraient jouer dans le rétablissement de ces espèces est incertain. À partir des points d'écoute de la base de données du Projet de modélisation de l'avifaune boréale, nous avons conçu des modèles log-linéaires de Poisson et sélectionné les variables au moyen de régression multiple ascendante pour prédire la densité et la répartition de ces deux espèces menacées dans quatre parcs nationaux dans les Maritimes, Canada. Nous avons aussi prédit la densité dans des aires de taille équivalente dans les mêmes écorégions, mais hors des parcs, à des fins de comparaison. En raison de la difficulté à représenter les milieux humides forestiers, un habitat clé pour ces espèces dans cette région, à partir des données spatiales disponibles, nous avons testé l'efficacité de différents produits de télédétection. Nous avons testé des couches SIG fondées sur des photographies aériennes de milieux humides (WETLANDS), des chartes de profondeur d'eau (WETNESS), et l'interaction de WETNESS avec le couvert forestier déterminé à partir de photographies aériennes (WETxFOR). Les meilleurs modèles pour le Moucherolle à côtés olive ont été créés à partir de WETxFOR, tandis que WETNESS s'est avéré le meilleur pour la Paruline du Canada. Les perturbations d'origine anthropique et la proximité des routes ont eu des effets négatifs sur les densités prédites pour les deux espèces. Les aires protégées hébergeaient des densités de moucherolles sensiblement plus élevées que les aires environnantes, mais ce n'était pas le cas pour la Paruline du Canada. Nos résultats sont les premiers à chiffrer les densités et la taille des populations pour ces espèces dans

ces parcs. Ils présentent également de l'information inédite quant aux impacts des perturbations d'origine anthropique sur les densités prédites de population. Ces résultats peuvent être utilisés pour orienter la conservation et la gestion dans cette région, et notre approche peut être reproduite dans d'autres régions pour appuyer les efforts de rétablissement en cours.

**Key Words:** *Canada Warbler*; *conservation*; *Olive-sided Flycatcher*; *parks and protected areas*; *species at risk*; *species distribution models*

## INTRODUCTION

The Olive-sided Flycatcher (*Contopus cooperi*) and the Canada Warbler (*Cardellina canadensis*) are migratory songbirds with large breeding ranges that co-occur east of the Rocky Mountains (Reitsma et al. 2010, Altman and Sallabanks 2012). Both species are listed as nationally threatened in Canada as a result of ongoing steep population declines. Decline severity is higher in the eastern portion of the range, including the Canadian Maritime provinces of New Brunswick and Nova Scotia (GC 2002, ECCC 2017). Both have been subjects of recent conservation and management interest through groups such as the Canada Warbler International Conservation (CWICI 2016) and research efforts (e.g., de Lima Pereira 2016, Haberski et al. 2016, Hunt et al. 2017, Céspedes and Bayly 2018; A. R. Westwood, D. Lambert, L. Reitsma, and D. Stralberg, *unpublished manuscript*).

On the eastern portion of their range, these species occur in forested wetlands (Hallworth et al. 2008a, Becker et al. 2012, Westwood 2016). Also termed “treed swamps,” forested wetlands are characterized by a treed canopy atop peatland or mineral wetland, with a water table at or near the surface (NWWG 1997). The Olive-sided Flycatcher uses edges of predominantly coniferous forests alongside wetlands and gaps created by recent burns or clearcuts (Altman and Sallabanks 2012). The Canada Warbler uses forested wetlands and wet, shrubby mixedwood forests (Reitsma et al. 2010). A field study in southwestern Nova Scotia found both species mainly on forested wetland sites on organic soils (Westwood 2016).

Throughout their breeding ranges, the Canada Warbler and Olive-sided Flycatcher have experienced historical and ongoing pressures from the forestry sector (CCFM 2019). These activities tend to decrease the availability of forested wetlands and mixedwood forests (Mosseler et al. 2003, Amos-Binks et al. 2010, Berry et al. 2018) and increase landscape fragmentation (Betts et al. 2003). The impacts of anthropogenic disturbance on populations of these species is not fully known (EC 2015, 2016). Although both species will breed in postharvest areas, their population density seems to be related to the type of forest management applied, with higher density and productivity in partial and patch cuts than in clearcuts (Preston and Harestad 2007, Robertson and Hutto 2007, Spies et al. 2007, Hallworth et al. 2008a, Ball et al. 2016, Hunt et al. 2017). There is also some evidence of detrimental effects of road networks on density of these species (Miller 1999, Matsuoka et al. 2011, Haché et al. 2014).

Protected areas, regularly identified as key tools for managing species at risk (Guisan et al. 2013), can serve as important refuges for biodiversity (Deguise and Kerr 2006). In Canada, national parks are administered by Parks Canada, whose mandate also includes ensuring the ecological integrity of its lands and the protection and management of species at risk (Parks Canada 2011). Species within national parks experience disturbance from

road expansion, recreation, and other managed uses, but are largely unimpacted by timber harvest and resource extraction, or they are managed at levels considerably lower than in nonprotected landscapes (GC 2017). However, the efficacy of parks and other protected areas (e.g., privately protected areas, wildlife management areas) to meet their conservation and management-related objectives remains largely unknown (Leverington et al. 2010). Two key factors limit our ability to evaluate how effectively parks protect species at risk: (1) a lack of information on species population density and distribution; and (2) limited high-resolution information on the impacts of anthropogenic disturbance.

## Modeling species associated with wet forest habitats

Species distribution models (SDMs) encompass a suite of tools used to predict the distribution of a species based on species-habitat relationships, and resulting maps of predicted estimates are widely used to guide protected areas planning and monitor effectiveness to achieve conservation targets (Sanderson et al. 2002, Elith and Leathwick 2009, Franklin 2009, Veloz et al. 2015, Lecours 2017).

Although landcover is often the main explanatory covariate used for regional SDMs (e.g., Bustamante and Seoane 2004, Bellis et al. 2008, Atamian et al. 2010), topological and hydrological variables related to wetness may predict distribution equally well or even better than vegetation cover for some bird species (Barker et al. 2014), including the Olive-sided Flycatcher and Canada Warbler (Bale 2017). However, remote sensing products of vegetation cover tend to provide limited temporal replication, which is a concern when modeling habitat association of birds breeding in these dynamic landscapes (but see Hansen et al. 2013). Because hydrological variables are less prone to frequent disturbance effects than vegetation cover, they could be a particularly important tool to improve model accuracy for species associated with forested wetlands. High-quality remote sensing data classifying forested wetlands are scarce (but see Kreakie et al. 2012) and for regions in which they are available, accuracy can be highly variable because of the ephemeral nature of many types of wetland (Gómez-Rodríguez et al. 2008, Skagen et al. 2008). To our knowledge, the accuracy of available data products that can be used to identify forested wetlands in the Canadian Maritimes has not previously been tested in the context of SDMs.

To inform management of populations of these focal species in national parks, it is necessary to make accurate predictions while simultaneously achieving a resolution precise enough for management planning. The resolution of SDMs should ideally be determined by the size of forest stands in the region, the scale of habitat selection for the target organism, and the scale of management units (Sirkiä et al. 2012, Aguirre-Gutiérrez et al. 2013, Pradervand et al. 2014). In practice, most SDMs are constructed to reflect the resolution of available data layers

(predictions can only be as fine as the coarsest layer of the input data) or limited computing power (Franklin 2009).

For these species in Canada, there are two national-scale SDMs that predict population density at a resolution of 1 km x 1 km (Haché et al. 2014, Stralberg et al. 2015a). There are two regional scale SDMs, with one predicting population density in Alberta at 1 km x 1 km resolution (Canada Warbler only; Ball et al. 2016) and one predicting species occurrence in Nova Scotia at 150 m x 150 m resolution (Bale 2017). Although these are valuable for understanding provincial and national habitat associations and distributions, they are either (1) too coarse for management planning within national parks, or (2) lack complete coverage of maritime parks.

Our objectives were to (1) develop high-resolution (250 m x 250 m) SDMs predicting the population density of the Olive-sided Flycatcher and the Canada Warbler in four maritime national parks (Kouchibouguac, Fundy, Cape Breton Highlands, and Kejimikujik) and equally sized areas in the same ecoregions outside of these parks; (2) compare prediction accuracy of models using different products available to delineate wet forested stands (photo-interpreted wetlands, depth to water table, and the interaction between water table and forest cover); (3) evaluate the effects of anthropogenic disturbance on density estimates; and (4) compare population density estimates inside versus outside national parks.

## METHODS

### Study area

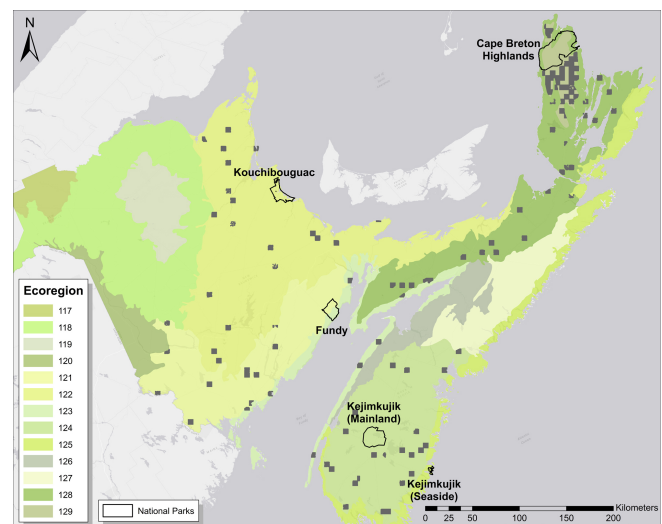
Of the total land base of Nova Scotia and New Brunswick, 7.9% is within protected areas including national, provincial, and privately protected lands (Vankerham 2015), 19% of which comprise the four national parks under consideration (Kouchibouguac, Fundy, Cape Breton Highlands, and Kejimikujik; Fig. 1). These parks are within in the Atlantic Maritime Ecozone, characterized by proximity to the Atlantic Ocean, creating a cool and moist climate (ESWG 1995). Prince Edward Island and part of the province of Québec are included in this ecozone, but they were excluded from our analysis because of a lack of available data layers. Atlantic maritime forests are predominantly composed of mixedwood stands of hemiboreal conifers and deciduous species, with the most common species being red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*). Black spruce (*Picea mariana*), white birch (*Betula papyrifera*), and other boreal tree species are less common (ESWG 1995). Nonforested areas in this region tend to comprise a patchwork of urbanization and agriculture, as well as coastal and highland environments (ESWG 1995). The four parks have a coastal component except Kejimikujik. A total of 7 ecoregions overlap these national parks (ESWG 1995; Fig. 1).

### Avian dataset

The Boreal Avian Modelling Project (BAM) has compiled avian point count data in the boreal and hemiboreal regions of Canada and the U.S. (Barker et al. 2015). The BAM dataset contains data from over 1 million avian point count surveys conducted between 1990 and 2016 at over 250,000 locations (Barker et al. 2017). It

includes data from long-term projects such as provincial breeding bird atlases (Bird Studies Canada 2017), the North American Breeding Bird Survey (USGS and ECCC 2018), and contributions from universities, governments, and industrial partners. These different projects used a wide range of sampling protocols, so data are harmonized through the application of statistical offsets to convert count data into density estimates (Barker et al. 2015). Specifically, avian data are standardized to control for the effects of survey protocols on detectability of each species, based on time of day, time of year, duration and radius of survey, and surrounding landcover types (Matsuoka et al. 2012, Sólymos et al. 2013, 2018). These standardized avian population density data have been used to predict range dynamics of passerines (Stralberg et al. 2017), climate change impacts on passerines (Stralberg et al. 2015a, b), regional population trends for species occurring in spruce-fir forests (Ralston et al. 2015), and Canada Warbler habitat needs in Alberta (Ball et al. 2016).

**Fig. 1.** Ecoregions of New Brunswick and Nova Scotia. Gray squares show randomly selected nonpark replicates used for comparison with the corresponding national park within the same ecoregion. Data source: CGDI National Frameworks Data.



In our study area, the BAM project included 15,021 locations in which point counts were conducted between 1996 and 2013. Olive-sided Flycatchers and Canada Warblers were detected at 801 and 658 locations, respectively (Appendix 1). To reflect local-level habitat attributes (hereafter “local buffer”), a different radius was used for each species. For the Canada Warbler, a 50 m radius (0.79 ha) was delineated around each point count location to reflect average territory size ( $\leq 1$  ha; Reitsma et al. 2010) and detection radius (60 m; Matsuoka et al. 2012). For the Olive-sided Flycatcher, a 100 m radius (3.14 ha) was used to reflect immediate habitat area around the nest, and larger detection radius for this species (123 m; Matsuoka et al. 2012). A larger buffer of 250 m radius (19.6 ha; hereafter “territory buffer”) was created to capture habitat attributes within the territory of the Olive-sided Flycatcher (10-45 ha; Altman and Sallabanks 2012) and the often

clustered territories (or neighborhoods) of Canada Warblers resulting from conspecific attraction (Hunt et al. 2017, Reitsma et al. 2018).

### Spatial covariates

Spatial covariates were extracted at all point count locations (both presence and absence) using ESRI ArcGIS 10.2.2 (Esri 2014), PostGIS (Ramsey et al. 2011), R (R Core Team 2015), and/or Geospatial Modelling Environment (Beyer 2012). All GIS layers were projected in NAD83 (Canadian Spatial Reference System; Seely 2011, Government New Brunswick 2015, NRCAN 2019). A total of 20 covariates were extracted from 19 remote sensing products (Appendix 2), with vector data having a minimum mapping unit of < 50 m, and cell size of raster data ranging from 10 m x 10 m to 90 m x 90 m. The minimum resolution available for model predictions was 90 m x 90 m, but because of computational limitations, all data layers were standardized to 250 m x 250 m resolution for model predictions

### Wetness

Three model subsets were used to test the effects of different methods used for delineating wet areas that could support forested wetlands, including (1) wetlands layers (WETLANDS), (2) depth to water table (WETNESS), and (3) WETNESS x forest cover (WETxFOR). For the WETLANDS subset, we used wetland layers classified from aerial photography in both provinces (minimum mapping unit < 30 m) harmonized into five classes (tree, shrub, graminoid, aquatic, and water/exposed) based on the Canadian Wetlands Classification System (Warner and Rubec 1997; Appendix 2). The dominant wetland class type was extracted for each buffer.

For the WETNESS and WETxFOR subset, we used wet areas mapping (10 m resolution; Murphy et al. 2007, FWRC 2012) to measure average depth to water table (DTW) at both buffer sizes around each point count location. Depth to water table is a cartographic index derived from digital elevation models (Murphy et al. 2007). When compared with similar indices calculated using different algorithms (e.g., topographic wetness index, soil water index), DTW is more closely related to soil and vegetation type than the commonly used terrain wetness index, which is a function of elevation (Murphy et al. 2007, 2009, White et al. 2012) and performs better when used for modeling distribution of streams (White et al. 2012) and landbird species (Bale 2017). The DTW predicts small wetlands (i.e., < 1 ha) that are usually not visible in aerial photographs (Murphy et al. 2007) and delineates wet areas under vegetation cover more accurately (White et al. 2012). We considered  $DTW \leq 1$  m to be areas which may support forested wetlands because these values correspond to field-measured depth to water table in forested wetlands (FWRC 2012). Other extracted covariates included the proportion of  $DTW \leq 1$  m and standard deviation of DTW within the territory buffer.

### Landcover and structure

Forest cover information was derived from the Common Attribute Schema for Forest Resource Inventories (CASFRI; minimum mapping unit < 50 m; Cumming et al. 2010, Cosco 2011), which combines provincial forest resource inventory databases into a comprehensive classification of attributes present across jurisdictions. From CASFRI, we extracted tree species

composition (primary and secondary) and mean and standard deviation of canopy height and canopy closure within local and territory buffers. Percent tree species cover was converted into area (m<sup>2</sup>) covered within both local and territory buffers. Tree species were also reclassified to genus (see <https://github.com/borealbirds> for model code).

### Landscape complexity and disturbance

Mean landscape complexity was estimated for each territory buffer using a layer from Anderson et al. (2012), which estimates landscape complexity at three values (above average, average, or below average) based on combinations of three values: topography, elevation range, and moisture gradients. Landscape complexity was characterized as an index of the number and diversity of microsites available. The data layer was available at 90 m resolution.

Disturbance information was acquired from both the CASFRI and Human Footprint (HF) mapping (90 m resolution; Woolmer et al. 2008). Using CASFRI, we calculated the proportion of territory buffer affected by each of the following disturbance types: clearcuts, partial cuts, burns, slides, windfalls, and unspecified disturbances. This information did not include time since disturbance. The HF is an index of disturbance from 1-100 based on standardized measures of human population density, land transformation, accessibility, and electrical infrastructure (Sanderson et al. 2002). We calculated average HF index within each territory buffer. Distance to the nearest road (m) was calculated for each point count location using the National Road Network (GC and NRCAN 2015).

### Landscape connectedness and protected areas

We calculated the mean index of landscape connectedness for each territory buffer based on a layer from Anderson and Clark (2012), who measured landscape connectedness at 90 m resolution as a continuous index based on the contiguity of cover types among what they considered natural ecosystems types. Finally, all point counts were intersected with park and protected area maps (including federal, provincial, and municipal protected areas), and classified as being on unprotected or protected lands.

### Models

Rather than using a presence-absence species distribution modeling approach (Franklin 2009), we instead used count data to estimate population density. We used Poisson log-linear models to relate bird counts at locations to values of covariates at those locations. We used a model-building process based on a forward stepwise variable selection approach (also used in Haché et al. 2014, Ball et al. 2016, and Bayne et al. 2016). This method enters a set of competing covariates in stages to predict population density, and once the leading covariate is chosen at a given stage, it is entered into the next stage to compete against another set of covariates from which one is selected. This is repeated until the final stage is reached. This hierarchical model selection minimizes multicollinearity because all the covariates that were highly correlated ( $r > 0.7$ ) entered the model at the same stage and only one of these covariates could be included in the final model.

We evaluated relative importance of covariates nested within eight stages based on a priori assumptions about the habitat selection of each species. We assumed that habitat selection-driven decisions at the regional scale were most related to proximate

**Table 1.** Model subsets and descriptions of covariates used in stages one and two of hierarchical Poisson log-linear models of Olive-sided Flycatcher and Canada Warbler density. All covariates were measured at either the local (L) buffer size (50 m for Canada Warbler, 100 m for Olive-sided Flycatcher), or the territory (T) buffer size (250 m for both species). Note: CASFRI = Common Attribute Schema for Forest Resource Inventories, DTW = depth to water table.

Model Stage	Subset A: WETLANDS	Subset B: WETNESS	Subset C: WETxFOR
1. Wetness	1.0 Null	1.0 Null	1-2.0 Null
	1.1 Dominant wetland type (WET_TYPE (L))	1.1 Proportion of area with DTW classified “wet” ( $\leq 1$ m) (DTW_PROP (L))	1-2.1 Tree species coverage (CASFRI) x proportion of area with DTW classified “wet” ( $\leq 1$ m) (CASFRIxDTW_PROP (L))
	1.2 Perimeter of wetland + stream length (WET_LENGTH (T))	1.2 Proportion with DTW classified “wet” ( $\leq 1$ m) (DTW_PROP (T))	1-2.2 Tree species coverage (CASFRI) x proportion of area with DTW classified “wet” ( $\leq 1$ m) (CASFRIxDTW_PROP (T))
	1.3 Proportion wetland (WET_PROP (T))	1.3 Standard deviation of DTW (DTW_STDEV (T))	
2. Forest Cover	2.0 Null	2.0 Null	
	2.1 Tree species coverage (CASFRI (L))	2.1 Tree species coverage (CASFRI (L))	
	2.2 -Tree species coverage (CASFRI (T))	2.2 -Tree species coverage (CASFRI (T))	

factors (e.g., tree species, nest site availability, insect availability) and least related to ultimate factors (e.g., landscape composition, protection status of a site). Recognizing the importance of both types of factors, we ordered the following eight stages from proximate to ultimate covariates: (1) wetness; (2) forest cover; (3) forest structure; (4) landscape complexity; (5) anthropogenic disturbance; (6) distance from roads; (7) landscape connectivity; and (8) protection status. Stages one and two were merged for the WETxFOR subset, whereas variables in stage two remained the same for the two other model subsets (Table 1). For each model subset, covariates in stages three-eight were the same (Table 2). Consistent Akaike’s information criterion (AIC; CAIC = 0.5 AIC + 0.5 BIC, where AIC = Akaike’s information criterion, CAIC = consistent Akaike’s information criterion, and BIC = Bayesian information criterion) was used as our information criterion (Bozdogan 1987, Taper 2004).

We also evaluated models by calculating the coefficient of variation of population density estimates, as well as two goodness of fit measures: (1) area under the operating curve (AUC; Bradley 1997), a commonly used statistic that provides a measure of the likelihood that a randomly selected population density count has a higher suitability score than a randomly selected absence, and (2) directly comparing estimated mean population density with observed counts at our point count locations.

We used a bootstrap aggregation approach (Breiman 1996, Efron and Tibshirani 1998, Efron 2014), whereby the stage-wise model-building process was repeated 240 times using bootstrapped runs of the data, with each bootstrap run randomly selecting 70% of the data. For each covariate, we reported the selection frequency based on that number of iterations (Burnham and Anderson 2002). The most frequently selected covariate at each stage (which could also include no covariate, i.e., null covariate) was carried over to the following stage and the process was repeated for all eight stages to produce a final model.

We present the selection frequency of the model terms divided by the number of bootstrap runs as a measure of variable importance (Appendix 3). We do not provide effect sizes because those would inaccurately represent the bootstrap averaging process (for example, when a term was not selected). Instead, we present

marginal effect plots to capture how the different discrete and continuous covariates in our models affect bird density (Appendix 4). These plots show average change in the response averaged over all possible values of other covariates in the model (Avgar et al. 2017).

**Table 2.** Model subsets and descriptions of covariates used in stages three to eight of hierarchical Poisson log-linear models of Olive-sided Flycatcher and Canada Warbler density. All covariates were measured at either the local (L) buffer size (50 m for Canada Warbler, 100 m for Olive-sided Flycatcher) or the territory (T) buffer size (250 m for both species). Note: CASFRI = Common Attribute Schema for Forest Resource Inventories.

Model Stage	All subsets (WETLANDS, WETNESS, WETxFOR)
3. Forest Structure	3.0 Null
	3.1 Mean canopy closure (CANCL_AV (L))
	3.2 Mean canopy closure (CANCL_AV (T))
	3.3 Standard deviation of canopy closure (CANCL_STD (L))
	3.4 Standard deviation of canopy closure (CANCL_STD (T))
	3.5 Mean canopy height (HT_AV (L))
4. Land-scape Complexity	3.6 Standard deviation of canopy height (HT_STD (T))
	4.0 Null
5. Disturbance	4.1 Mean landscape complexity (COMPLEXITY (T))
	5.0 Null
6. Road Distance	5.1 Leading CASFRI disturbances (CASFRI_DIST (T))
	5.2 Mean human footprint index (FOOTPRINT (T))
	6.0 Null
7. Landscape Connectivity	6.1 Distance from road (ROAD (L))
	7.0 Null
8. Protection Status	7.1 Mean connectivity index (CONNECT (T))
	8.0 Null
	8.1 Protected/unprotected (PROTECT (L))

Prediction uncertainty (precision) was mapped as coefficient of variation derived from the standard error of the bootstrap predictions divided by the mean of the bootstrap predictions at any prediction point (240 runs). This process resulted in six SDMs (three subsets per species). Subsets were compared by examining frequency selection of covariates and consistent AIC. Model accuracy was assessed based on a graphical comparison of observed counts vs. expected values from bootstrap averaged predictions. We also calculated area under the receiver operator characteristic curve (AUC) as to a measure of how well models differentiated detections (> 0 count) from nondetections. The R scripts for the offsets and models are available at <https://github.com/borealbirds>

### Spatial predictions of density estimates

Population density estimates for both species were generated across the study area, from which we generated population size estimates. This was achieved by establishing two grids across the study area. We applied a 250 m x 250 m grid across the study area (~400 cells per grid square; hereafter “prediction cells”) with a point (hereafter “prediction point”) generated at the centroid of each cell (n = 2,100,000). A total of 28,880 (ca. 1%) prediction cells had their centroid within the four national parks: Cape Breton (n = 15,447), Kouchibouguac (n = 3410), Fundy (n = 3367), and Kejimikujik (n = 6358).

We also developed a random sampling scheme to compare prediction cells inside and outside of parks. We established a 5 km x 5 km grid across the study area and tallied the number of 5 km x 5 km grid cells per park per ecoregion, where sums ranged from 7 (Fundy, ecoregion 123) to 38 (Cape Breton Highlands, ecoregion 129; Table 3). Then, we randomly sampled an equal number of 5 km x 5 km grid cells per ecoregion outside of park borders (Fig. 1; Table 3). In each nonpark grid cell, we randomly sampled the same number of prediction points as the equivalent grid square inside the corresponding park. For example, Fundy National Park contained seven grid squares in ecoregion 123, which were paired with seven randomly selected grid cells in ecoregion 123 outside of the national park. Within each pair, the same number of prediction points was used. For example, in one park grid square, only 350 prediction points fell within the park boundary. Thus, in the paired nonpark square, only 350 of a possible 400 prediction points were randomly chosen for sampling. If the paired grid square did not contain enough prediction points inside ecoregion 123 to meet this number, it was discarded, and another grid square chosen.

Prediction points were not sampled in the same spatial configuration within paired grid cells, which was impossible because of the different shapes of relevant borders. Because the prediction points are contiguous, a high level of spatial autocorrelation was to be expected within grid cells. However, we attempted to control for this by randomly selecting grid cells, which were generally not contiguous (Fig. 1).

Covariate information was extracted for each prediction point and the top model was used to generate mean and standard deviation of population density (males/ha) for each prediction point. These were summed to calculate population sizes for each park and ecoregion. We compared mean population density per grid cell between national parks and corresponding ecoregion areas outside the parks using t-tests.

**Table 3.** Grid squares (5 km x 5 km) within Maritime national parks for comparison with grid cells randomly sampled elsewhere in the corresponding ecoregion.

National Park	Area (ha)	Ecoregion	Grid squares in park	Total ecoregion area (%)	Percent of ecoregion in park
Cape Breton	96,663	128	36	1,551,054	1.8%
		129	45	234,077	29.4%
Fundy	21,051	121	12	1,317,982	0.9%
		123	9	481,733	2.0%
Kejimikujik Mainland	39,698	124	25	1,636,318	2.4%
Kouchibouguac	24,199	122	22	3,019,141	0.8%

## RESULTS

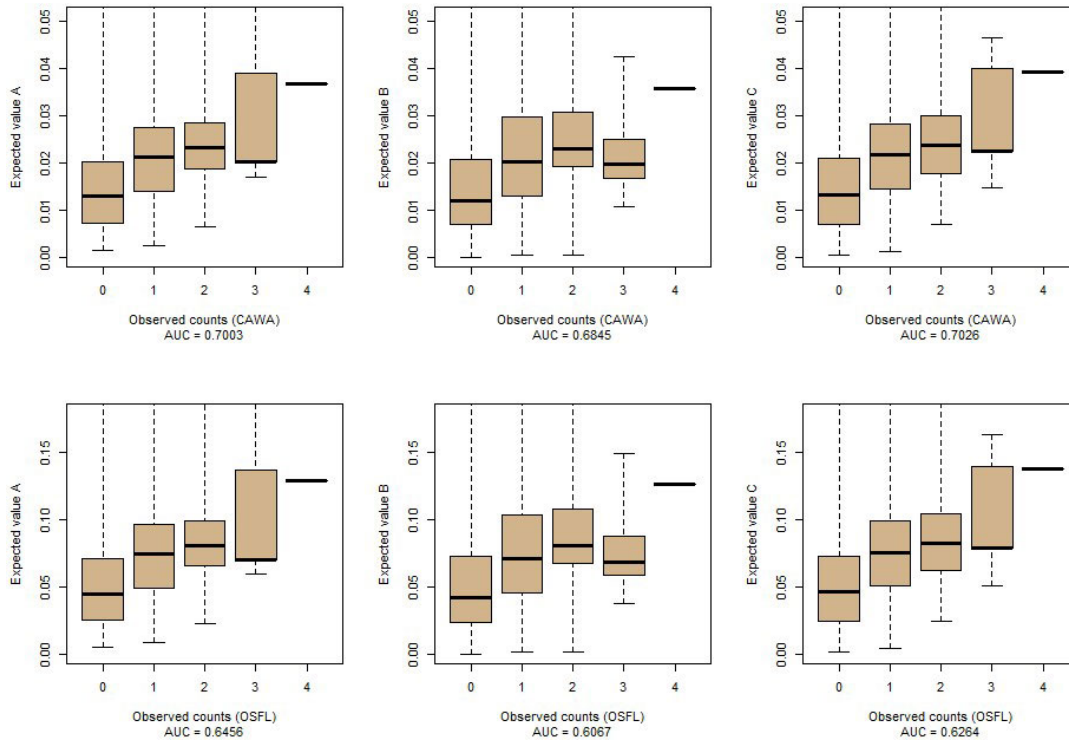
### Top models and variable selection

All model subsets performed well, with predicted mean population density showing a close positive correlation to observed count (Fig. 2) and AUC values between 0.6-0.7. For Olive-sided Flycatcher, the WETxFOR subset was the most selected in 91% of the 240 bootstrapped runs, followed by WETLANDS and WETNESS at 7% and 2% of cases, respectively. For the Canada Warbler, the WETNESS subset was selected at 100% of the bootstrapped runs.

For the Olive-sided Flycatcher, covariates with the highest selection frequency at each stage (Appendix 3) for the top model were CASFR1xDTW\_PROP territory (91% of all runs), HT\_STD territory (49%), COMPLEXITY territory (71%), FOOTPRINT territory (91%), and CONNECT territory (50%). Population density was highest in stands dominated by *Picea* spp. (but not *Picea glauca*, *Picea mariana*, and *Abies* spp.), and lowest in stands dominated by *Pinus* spp. and deciduous trees. For all tree cover types, except *Alnus* spp., Olive-sided Flycatcher population density increased with a greater proportion of area buffer covered by forest with a corresponding DTW ≤ 1 m. Population density increased with DTW\_PROP at both the local and territory scales. Population density also increased with lower mean canopy closure and standard deviation, and lower mean height. FOOTPRINT and ROAD had negative effects, whereas population density increased with greater COMPLEXITY and CONNECTIVITY. With regard to PROTECTION, sites in protected areas showed slightly higher population density than areas outside the parks.

For the Canada Warbler top model, DTW\_STD territory (100%), CASFR1 territory (78%), CANCL\_STD point (60%), COMPLEXITY territory (96%), FOOTPRINT territory (94%), CONNECTIVITY (99.2%), and PROTECTION (46%) were the most frequently selected covariates (Appendix 3). Highest densities of Canada Warblers (Appendix 4) were predicted for stands with high proportions of *Abies* spp., *Alnus* spp., *Picea* spp., *Picea mariana*, and lowest population densities were reported for stands dominated by *Acer* spp., *Larix* spp., *Picea glauca*, and *Pinus* spp. Higher DTW\_PROP point supported higher population densities of Canada Warbler, with a larger effect size at the territory scale (250 m radius). Lower DTW\_STD values were

**Fig. 2.** Goodness of fit measurements for species distribution models for the Olive-sided Flycatcher (OSFL) and Canada Warbler (CAWA) in New Brunswick and Nova Scotia across three subsets (A = WETLANDS, B = WETNESS, C = WETxFOR). Observed counts (X-axis) are compared to predicted mean population density (Y-axis), and Area Under the Curve (AUC) values reported for each model.



associated with higher population densities. Highest population density estimates were also associated with median values of CANCL\_STD, HT\_STD, and HT\_AV at both scales. Higher COMPLEXITY and CONNECTEDNESS were predicted to support higher population density. Population density was predicted to be negatively impacted by FOOTPRINT and was lower closer to ROADS. When considering PROTECTION, population densities were slightly lower in protected areas. Scatterplots and boxplots detailing the effects of each final model covariate on estimated mean population density for both species can be found in Appendix 4.

### Population density and size estimates

For both species, very little area in the parks was predicted to support high population densities (Appendix 5). In Fundy National Park (Fig. 3), which is composed mainly of a plateau, areas predicted to have high population density were largely restricted to ravines, particularly for the Olive-sided Flycatcher. The western side of Kejimikujik National Park was predicted to support higher population density than the eastern, whereas the interior of Cape Breton National Park showed higher population densities. Kouchibouguac Natural Park, largely represented by a maritime-influenced environment of beaches and saltmarshes, showed very low predicted population density throughout.

Olive-sided Flycatcher estimated mean population density in parks ranged from 0.011 males/ha (Kouchibouguac) to 0.014 males/ha (Cape Breton Highlands), whereas Canada Warbler

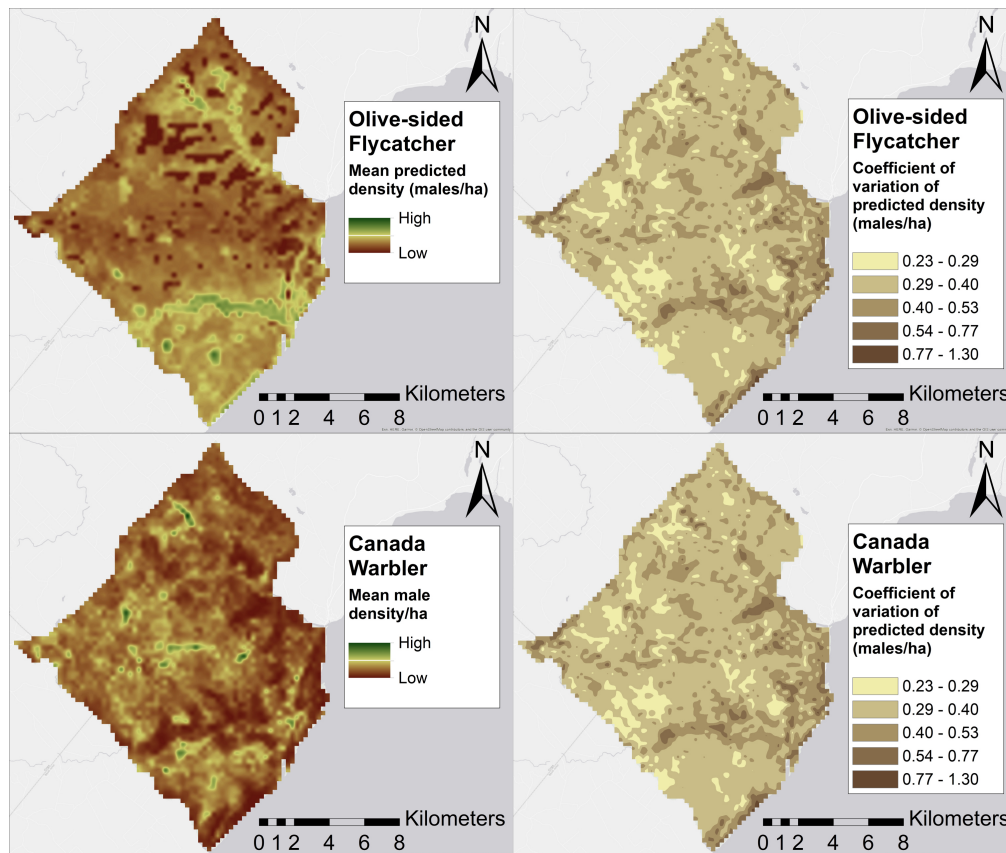
predicted population density ranged from 0.016 males/ha (Kouchibouguac) to 0.045 males/ha (Cape Breton Highlands). Total estimated population size for the four national parks was 358 male Olive-sided Flycatchers and 1092 male Canada Warblers (Table 4).

**Table 4.** Predicted population density and population size of territorial males of Olive-sided Flycatcher and Canada Warbler in four Maritime national parks.

Park	Park area (ha)	Mean population density (territorial males/ha)		Predicted number of territorial males	
		OSFL	CAWA	OSFL	CAWA
Kouchibouguac	24,199	0.011	0.016	29	43
Fundy	21,051	0.013	0.031	43	105
Cape Breton Highlands	96,663	0.014	0.045	217	695
Kejimikujik (Mainland)	39,698	0.011	0.038	67	242
<b>Total</b>	<b>401,506</b>	<b>0.011</b>	<b>0.031</b>	<b>358</b>	<b>1092</b>

Predicted population densities of Olive-sided Flycatcher inside parks were only significantly larger than outside the parks for ecoregions 123 (mean difference, mean  $\Delta$  = 0.007 males/ha, n =

**Fig. 3.** Predicted mean density of territorial males/ha (left panels) and coefficient of variation (right panels) based on the top model for the Olive-sided Flycatcher and Canada Warbler in Fundy National Park, New Brunswick, Canada.



7,  $p < 0.001$ ) and 129 (mean  $\Delta = 0.002$  males/ha,  $n = 38$ ,  $p < 0.001$ ; Fig. 4; Appendix 4). For Canada Warbler, predicted population densities were significantly higher in parks for ecoregion 123 (mean  $\Delta = 0.003$  males/ha,  $n = 7$ ,  $p < 0.001$ ), but significantly lower in parks for ecoregions 122 (mean  $\Delta = 0.024$  males/ha,  $n = 19$ ,  $p < 0.001$ ) and 129 (mean  $\Delta = 0.016$ ,  $n = 28$ ,  $p < 0.001$ ; Fig. 4, Appendix 4).

## DISCUSSION

We used the largest available avian point count dataset for New Brunswick and Nova Scotia to generate SDMs to estimate population density and population size of two landbird species at risk in national parks. We evaluated model prediction accuracy using different approaches to delineate wet forest and quantify the effects of anthropogenic disturbance on population density. Finally, we compared population density estimates in national parks versus those from other areas in the same ecoregions.

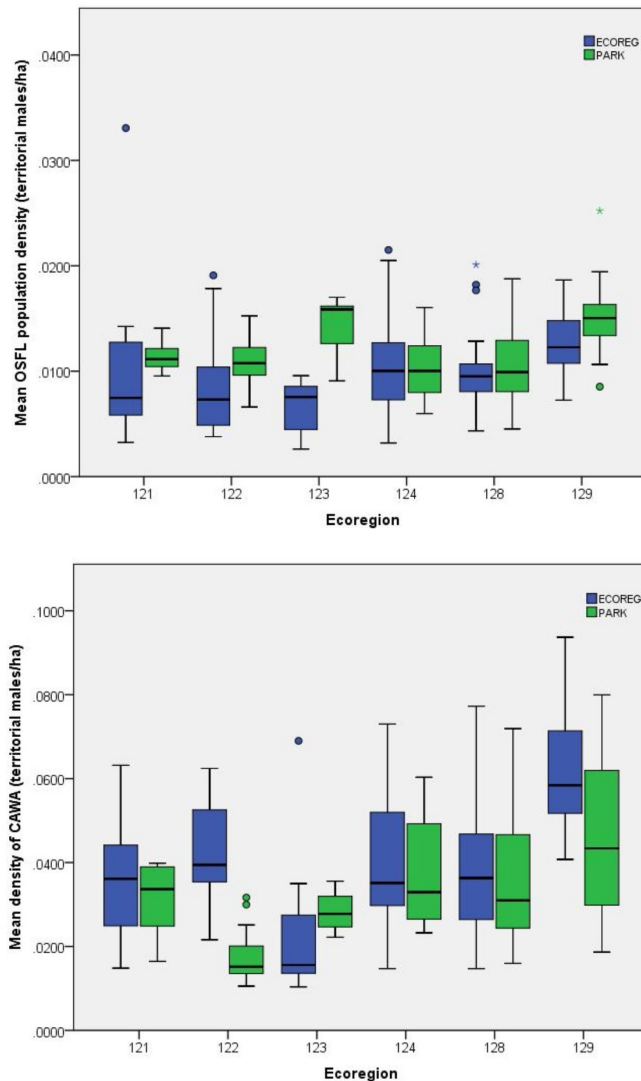
All the covariates selected in the top model for both species and corresponding relationships are consistent with known habitat associations on their breeding ranges (Reitsma et al. 2010, Altman and Sallabanks 2012). Higher Olive-sided Flycatcher population densities were predicted in wet forest stands, especially at the territory scale. Population densities were also higher where trees are patchily distributed based on coefficient for canopy cover and

height, as well as in more complex landscapes. These results could also reflect this species' preference for edges because they are known to nest in emergent trees alongside wetlands, as well as barrens, burns, and cuts (Altman and Sallabanks 2012).

Higher Canada Warbler population densities in mixedwood stands are consistent with results from other studies conducted on the eastern portion of the range (Hallworth et al. 2008a, b). In southwest Nova Scotia, Canada Warblers are known to nest in stands dominated by *Acer rubrum*, with a lesser component of *Picea mariana* (Westwood 2016), which contrasts with the negative association with large proportions of *Acer* spp. reported in our study. This may reflect within-region differences in the tree composition of forested wetlands. Another explanation may be the nature of the small territories that Canada Warblers occupy. Individual effects of tree cover covariates were stronger at the local scale, corresponding to habitat within the Canada Warbler's immediate territory (approx. 1 ha; Reitsma et al. 2018). Complexity was positively associated with Canada Warbler density. This is consistent with reported species' needs for a high diversity of trees, shrubs, and forest floor microsites for nesting, foraging, and territorial displays (Reitsma et al. 2010). The importance of complexity at larger spatial scales (indicative of a diversity of microsites) should not be confused with habitat fragmentation, which may have negative effects on Canada Warbler (Hunt et al. 2017).



**Fig. 4.** Mean population density (males/ha) of Olive-sided Flycatcher (OSFL) and Canada Warbler (CAWA) in national parks and surrounding randomly selected areas outside of national parks of the same size in New Brunswick and Nova Scotia.



For both species, model subsets using depth to water table (DTW) mapping yielded higher selection frequency than those using wetlands mapping or forest cover alone. Consistent with our results, Kreakie et al. (2012) found that prediction accuracy of waterfowl population density derived from DTW-based SDMs was greater than those based on wetland mapping derived from satellite imagery. Bale (2017) found that results from presence-only SDMs using DTW for these species and another landbird species at risk, the Rusty Blackbird (*Euphagus carolinus*), had higher prediction accuracy than those using topographic wetness index. These results and those from this study suggest the potential usefulness of DTW over other measures available to model densities of species associated with forested wetlands,

particularly if an interaction effect is included for forest cover. This is likely important for species that are nesting in stands in which saturated soils may be concealed from aerial imagery by tree cover.

### The role of national parks in regional protection of species at risk

Population densities of both Canada Warbler and Olive-sided Flycatcher showed negative associations with human footprint and roads, and positive associations with connectedness and complexity. This suggests these species at risk are sensitive to anthropogenic disturbance and habitat fragmentation. For a review of the known effects of timber harvesting on Canada Warbler habitat, see Harding et al. (2017), Hunt et al. (2017), and Westwood et al. (2017). Although parks supported significantly higher population densities of Olive-sided Flycatchers in two of six ecoregions, they only supported significantly higher population densities of Canada Warbler in one ecoregion and significantly lower in two another ecoregions, suggesting that national parks alone do not confer a substantial benefit to populations of these species under current land-use regimes.

Haché et al. (2014), using the BAM dataset and the same analytical approach, estimated the total number of territorial Olive-sided Flycatcher and Canada Warbler males in New Brunswick and Nova Scotia at approximately 80,000 and 463,000, respectively. When comparing our predicted population sizes in national parks to the BAM regional estimates, national parks would include less than 0.01% of the populations for both species, which is lower than expected given that these national parks cover 1.4% of the study area and comprise mostly forest habitat. This may reflect the limited ability of national models to capture important regional processes at the proper spatial scale (< 6.25 ha). Alternatively, national parks in this region may be capturing much less than a representative proportion of the regional population.

### Limitations and next steps

Our models did not include measures of climate, which are commonly used at larger spatial extents (e.g., Lawler et al. 2013, Stralberg et al. 2015b). Although vegetation is likely a more important driver of local variation than climate at spatial extent of our study area (Forsman and Mönkkönen 2003), climate should be considered when forecasting future habitat suitability because birds in particular have experienced recent distribution shifts due to climate change (e.g., Nogués-Bravo et al. 2012). These changes are expected to continue (Cumming et al. 2014, Stralberg et al. 2015a). Our models also averaged over 17 years of avian point count data during which time land cover likely changed. However, there is inadequate temporal replication for land-cover data in this region to test for temporal effects.

Once updated geospatial data and processing power becomes available, future work should extend our SDMs to fully cover New Brunswick and Nova Scotia. Because many of the geospatial layers we used were greater than five years old, and the rapid declines of these species as well as the strongly anticipated effects of climate change (Stralberg et al. 2015a), more recent data will be important to improve prediction accuracy. We also expected that these parks would contain a greater proportion of the populations based on regional models, because national models











**Appendix 1.** Point count locations and abundances for Olive-sided Flycatcher and Canada Warbler in New Brunswick and Nova Scotia.

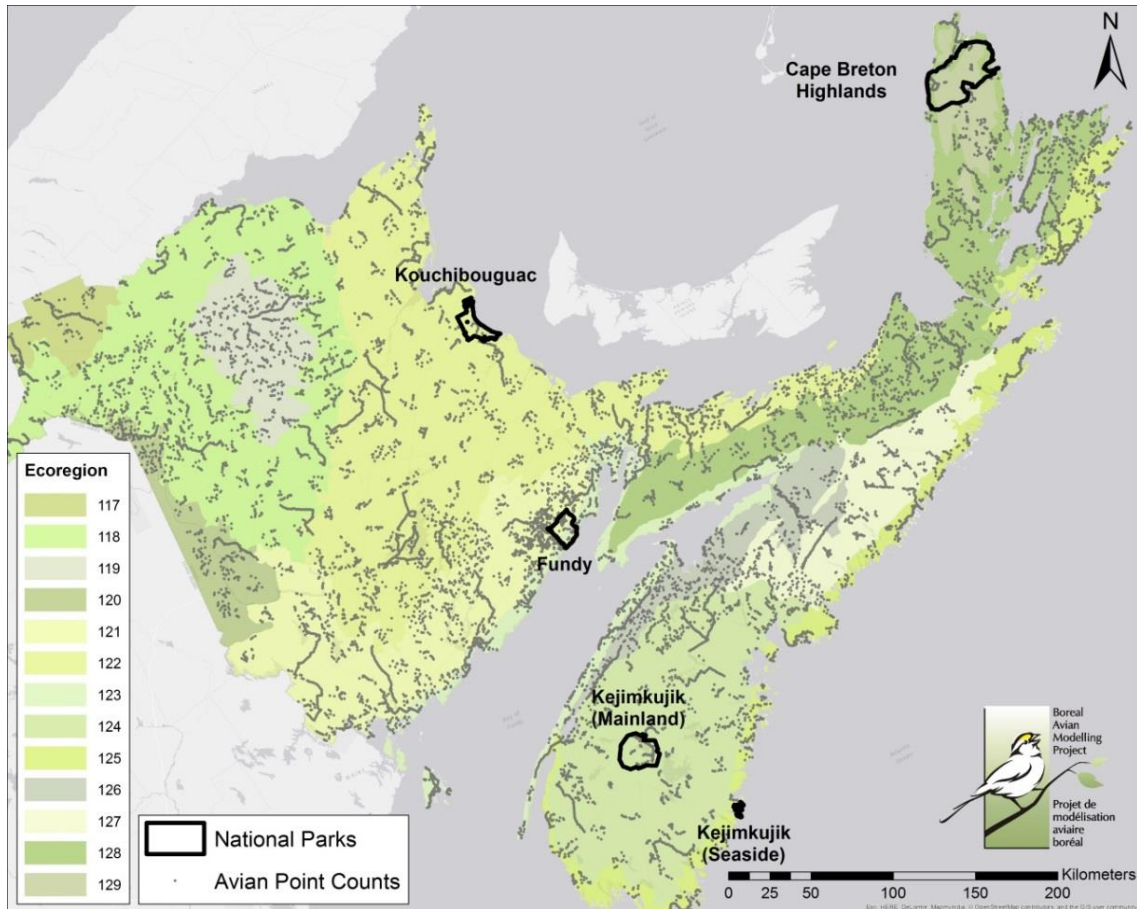


Fig. A.1, Map of the study area in New Brunswick and Nova Scotia, Canada, including the location of all point counts in the Boreal Avian Modelling Project database (Barker et al. 2015), the four studied national parks (excluding the Kejimikujik Seaside adjunct) and 13 ecoregions.

Table A.1, Number of Olive-sided Flycatcher (OSFL) and Canada Warbler (CAWA) observed from 1996-2013 at point counts in Nova Scotia and New Brunswick in the Boreal Avian Modeling project database.

Species	Birds at point count locations				
	0	1	2	3	$\geq 4$
OSFL	46179	776	25	0	0
CAWA	46322	609	41	7	1

**Appendix 2.** Spatial data layers used for covariate extraction and information for harmonizing wetlands data layers.

Table A2.1, Spatial data layers used for covariate extraction.

Layer	Description	Data Year	Resolution (m)	Rights	Citations
Avian Point Count Dataset	BAM and BBS project data	2014	vector	Boreal Avian Modelling Project	Cumming et al. 2010, Barker et al. 2015
Common Attribute Schema for Forest Resource Inventory (CASFRI)	National extent of provincial forest resource inventories, standardized to a common schema	2008-2014	vector		Cosco 2011, Cumming et al. 2015
National Ecological Framework for Canada	Canada's ecological framework, including ecozones, ecoprovinces, ecoregions, and ecodistricts.	2013	vector	CGDI National Frameworks Data; Agriculture and Agri-Food Canada	Marshall et al. 1999
Human Footprint	Extent and relative intensity of human influence on terrestrial ecosystems via human settlement, access, landscape transformation, and infrastructure	2001-2006	90	Wildlife Conservation Society Canada; Conservation Biology Institute: Data Basin	Sanderson et al. 2002; Woolmer et al. 2008
Landscape Complexity	The variety of microclimates on the landscape as function of topography, elevation range, and moisture gradients	2001-2006	90	The Nature Conservancy - Eastern Conservation Region; Conservation Biology Institute: Data Basin	Anderson et al. 2012; Anderson & Clark 2012
Local Connectedness	Strength of structural connections between natural ecosystems on a local landscape, measured as outward permeability of ecological flows from one cell to its neighbours	2005	90	The Nature Conservancy - Eastern Conservation Region; Conservation Biology Institute: Data Basin	Anderson et al. 2012; Anderson & Clark 2012
National Parks	Boundaries of National Parks	2012	vector	Geomatics Canada; Natural Resources Canada	



Layer	Description	Data Year	Resolution (m)	Rights	Citations
Protected Areas – NB	Boundaries of Protected Natural Areas and Provincial Parks In New Brunswick.	2011-2014	vector	Department of Natural Resources/GeoNB	
Protected Areas – NS	Boundaries for National Parks, Provincial Parks, Provincial Wildlife Areas, and other protected areas in NS	2013	vector	Nova Scotia Parks and Protected Areas New Brunswick Government of Canada; Natural Resources Canada; Earth Sciences Sector; Canada Centre for Mapping and Earth Observation	
Roads	Normalized Canadian road network	2014			
Streams and Waterways - NB	New Brunswick Hydrographic Network, delineating surface drainage features for New Brunswick	2012-2014	vector	New Brunswick Department of Natural Resources/GeoNB	
Streams and Waterways – NS	Provincial hydrographic features at 1:10 000 scale	unk	vector	Nova Scotia Department of Natural Resources	
Wet Areas Mapping – NB	Map of depth to water table derived from digital elevation models, indicating likelihood of water saturation	2004-2005	10m	Forest Watershed Research Center, University of New Brunswick	Murphy et al. 2009
Wet Areas Mapping – NS	Map of depth to water table derived from digital elevation models, indicating likelihood of water saturation	unk	10m	Nova Scotia Department of Natural Resources	Murphy et al. 2009
Wetlands – NB	Wetlands identified from 1:10 000 aerial photography, including wetland type, vegetation, and photograph year	2003-2012	vector	NB Department of Environment and Local Government	Department of Natural Resources Fish and Wildlife Branch 2006
Wetlands – NS	Wetlands identified from 1:10 000 aerial photography, including wetland type, vegetation, and photograph year, adapted to the Canadian Wetland Classification system	2000-2002	30m (sharpened 15m)	Nova Scotia Department of Natural Resources	

Table A2.2, Wetland vegetation type equivalencies for New Brunswick and Nova Scotia using the Canadian Wetlands Classification Guide (National Wetlands Working Group 1997).

NB Veg Type	NS Veg Type Equivalent	Reclassification
Forested Hardwood Vegetation	Treed	Treed
Forested Softwood Vegetation	Treed	Treed
Alders	Low shrub/tall shrub	Shrub
Shrub Vegetation, except alders	Low shrub/tall shrub	Shrub
Emergent Vegetation	Graminoid	Graminoid
Open Water	Aquatic Vegetation	Aquatic
Open Water Un-vegetated	Water	Water/Exposed
Coastal/Shoreline Feature Vegetated	Salt Marsh	(excluded)
Coastal/Shoreline Feature	none	(excluded)
None	Exposed	Water/Exposed

**Appendix 3.** Selection frequencies of covariates across three model subsets for estimating population density of the Olive-sided Flycatcher and Canada Warbler. Covariate full names and descriptions are available in Tables 1 and 2.

Table A3.1, Selection frequencies of covariates at each model stage across three subsets of 240 bootstrapped log-linear Poisson model runs for Olive-sided Flycatcher. Covariates are labelled by buffer size, local (L) and territory (T).

Stage	Subset	Covariate	F	%
1-2. Wetness & Forest Cover	WETxFOR	CASFRIxWET_PROP	218	90.8
	WETLANDS	WET_LENGTH (T), CASFRI (T)	16	6.7
	WETNESS	WET_LENGTH (T), CASFRI (T)	4	1.7
	WETNESS	DTW_STD (T), CASFRI (T)	2	0.8
3. Forest Structure	WETxFOR	HT_STD (T)	116	48.3
	WETxFOR	CANCL_AV (L)	56	23.3
	WETxFOR	CANCL_STD (L)	39	16.2
	WETLANDS	CANCL_AV (L)	11	4.6
	WETxFOR	HT_AV local	7	2.9
	WETNESS	CANCL_AV (L)	4	1.7
	WETLANDS	HT_STD (T)	2	0.8
	WETLANDS	CANCL_STD (L)	2	0.8
	WETNESS	HT_STD (T)	1	0.4
	WETNESS	CANCL_AV (T)	1	0.4
	WETLANDS	HT_AV local	1	0.4
4. Landscape Complexity	WETxFOR	COMPLEXITY (T)	171	71.2
	WETxFOR	Null	47	19.6
	WETLANDS	COMPLEXITY (T)	12	5.0
	WETNESS	COMPLEXITY (T)	4	1.7
	WETLANDS	Null	4	1.7
	WETNESS	Null	2	0.8
5. Disturbance	WETxFOR	FOOTPRINT (T)	218	90.8
	WETLANDS	FOOTPRINT (T)	16	6.7
	WETNESS	FOOTPRINT (T)	6	2.5
6. Road Distance	WETxFOR	Null	211	87.9
	WETLANDS	Null	11	4.6
	WETxFOR	ROAD (L)	7	2.9
	WETNESS	Null	5	2.1
	WETLANDS	ROAD (L)	5	2.1
	WETNESS	ROAD (L)	1	0.4
7. Landscape Connectivity	WETxFOR	CONNECT (T)	119	49.6
	WETxFOR	NULL	99	41.2
	WETLANDS	CONNECT (T)	14	5.8
	WETNESS	CONNECT (T)	6	2.5
	WETLANDS	Null	2	0.8

Stage	Subset	Covariate	F	%
8. Protection Status	WETxFOR	Null	149	62.1
	WETxFOR	PROTECT (L)	69	28.8
	WETLANDS	Null	9	3.8
	WETNESS	Null	8	3.3
	WETLANDS	PROTECT (L)	7	2.9
	WETNESS	PROTECT (L)	3	1.2
	WETNESS	Null	3	1.2

Table A3.2, Selection frequencies of covariates at each model stage across three subsets of 240 bootstrapped log-linear Poisson model runs for Canada Warbler. Covariates are labelled by buffer size, local (L) and territory (T). Column title abbreviations: F = Frequency, % = Percent selected.

Stage	Subset	Covariate	F	%
1-2. Wetness & Forest Cover	WETNESS	DTW_STD (T), CASFRI (T)	185	77.1
	WETNESS	DTW_STD (T), CASFRI (L)	52	21.7
	WETxFOR	CASFRIxDTW_PROP (T)	2	0.8
	WETNESS	DTW_STD (T), Null	1	0.4
3. Forest Structure	WETNESS	CANCL_STD (L)	144	60
	WETNESS	HT_STD (T)	68	28.3
	WETNESS	CANCL_AV (T)	12	5
	WETNESS	CANCL_AV (L)	8	3.3
	WETNESS	HT_AV (L)	6	2.5
	WETxFOR	CANCL_STD (L)	2	0.8
4. Landscape Complexity	WETNESS	COMPLEXITY (T)	230	95.8
	WETNESS	Null	8	3.3
	WETxFOR	Null	1	0.4
	WETxFOR	COMPLEXITY (T)	1	0.4
5. Disturbance	WETNESS	FOOTPRINT (T)	226	94.2
	WETNESS	CASFRI_DIST (T)	12	5
	WETxFOR	FOOTPRINT (T)	2	0.8
6. Road Distance	WETNESS	Null	203	84.6
	WETNESS	ROAD (L)	35	14.6
	WETxFOR	Null	2	0.8
7. Landscape Connectivity	WETNESS	CONNECT (T)	238	99.2
	WETxFOR	CONNECT (T)	2	0.8
8. Protection Status	WETNESS	Null	128	53.3
	WETNESS	PROTECT (L)	110	45.8
	WETxFOR	Null	1	0.4
	WETxFOR	PROTECT (L)	1	0.4

Table A3.3, Top ranked covariates explaining variation in density estimates for the Olive-sided Flycatcher and Canada Warbler for each model subset. Models represent the most-selected variable from each stage of the model-building process. Scale of variable is indicated as local (L) or territory (T).

Species	Subset	Top ranked model
OSFL	WETLAND S	Count ~ WET_LENGTH (T) + CASFRI (T) + HT_STD (T) + COMPLEX (T) + FOOTPRINT (T) + CONNECT (T)
	WETNESS	Count ~ DTW_STD (T) + CASFRI (T) + HT_STD (T) + COMPLEX (T) + FOOTPRINT (T) + CONNECT (T)
	WETxFOR	Count ~ CASFRIxDTW_PROP (T) + HT_STD (T)+ COMPLEX (T) + FOOTPRINT (T) + CONNECT (T)
CAWA	WETLAND S	Count ~ WET_LENGTH (T) + CASFRI (T) + CANCL_STD (L) + COMPLEX (T) + FOOTPRINT (T) + CONNECT (T) + PROTECT (L)
	WETNESS	Count ~ DTW_STD (T) + CASFRI (T) + CANCL_STD (L) + COMPLEX (T) + FOOTPRINT (T) + CONNECT (T) + PROTECT (L)
	WETxFOR	Count ~ CASFRIxDTWPROP (T) + CANCL_STD (L) + COMPLEX (T) + FOOTPRINT (T) + CONNECT ter + PROTECT (L)

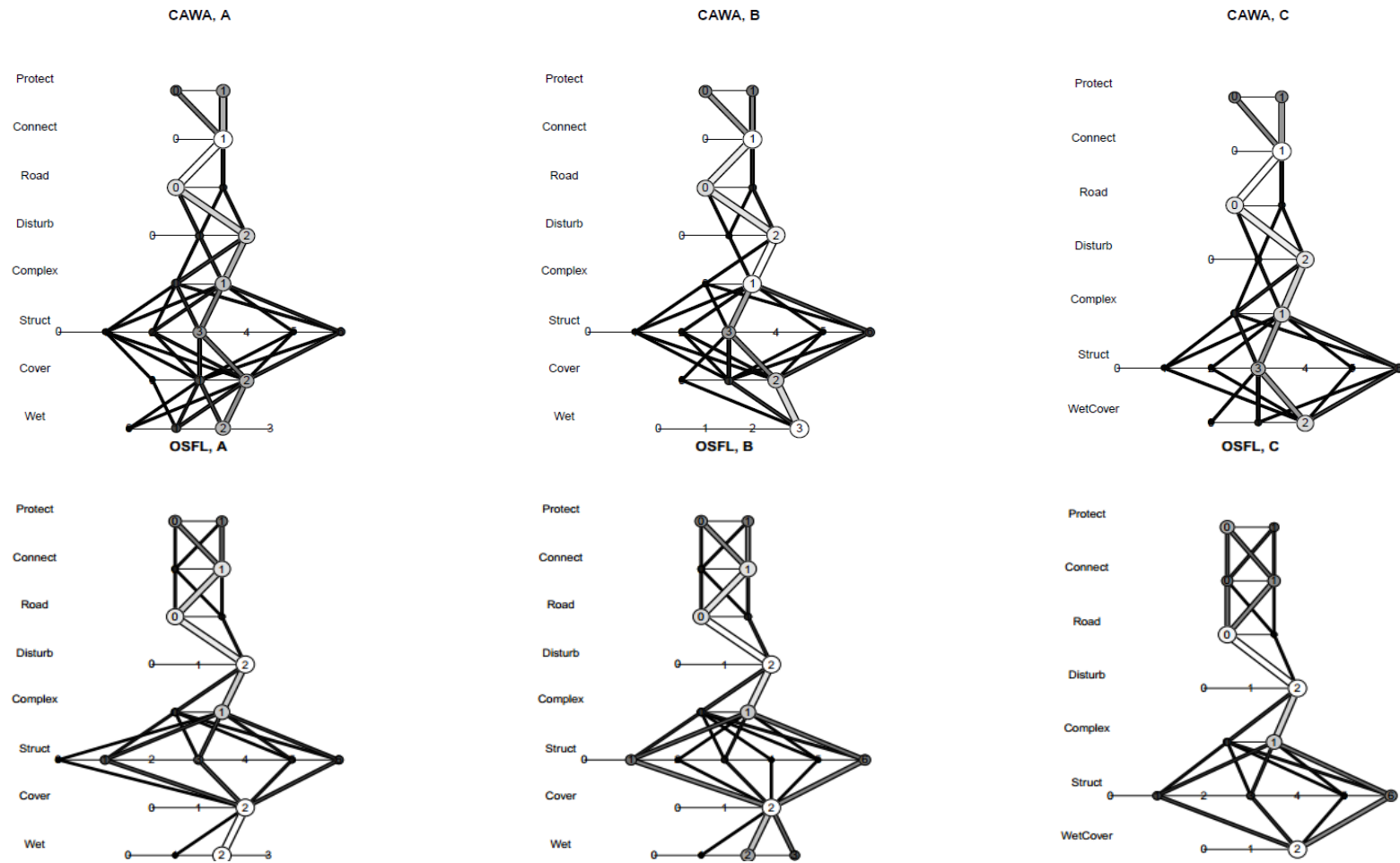


Fig A3.1, Selection paths of variables best explaining variation in density estimation of Olive-sided Flycatcher and Canada Warbler in New Brunswick and Nova Scotia based on the branching hierarchy model building process. Results for three model subsets (A – WETLANDS, B – WETNESS, C – WETxFOR) represent selection frequencies from 240 bootstrap iterations. Horizontal lines show each model stage, and numbers indicate individual covariates. Shade and thickness of line are proportional to selection frequency, with thicker lines of lighter shades indicating higher selection frequencies.

**Appendix 4.** Results for effects of individual covariates on density estimates for the Olive-sided Flycatcher and Canada Warbler in New Brunswick and Nova Scotia.

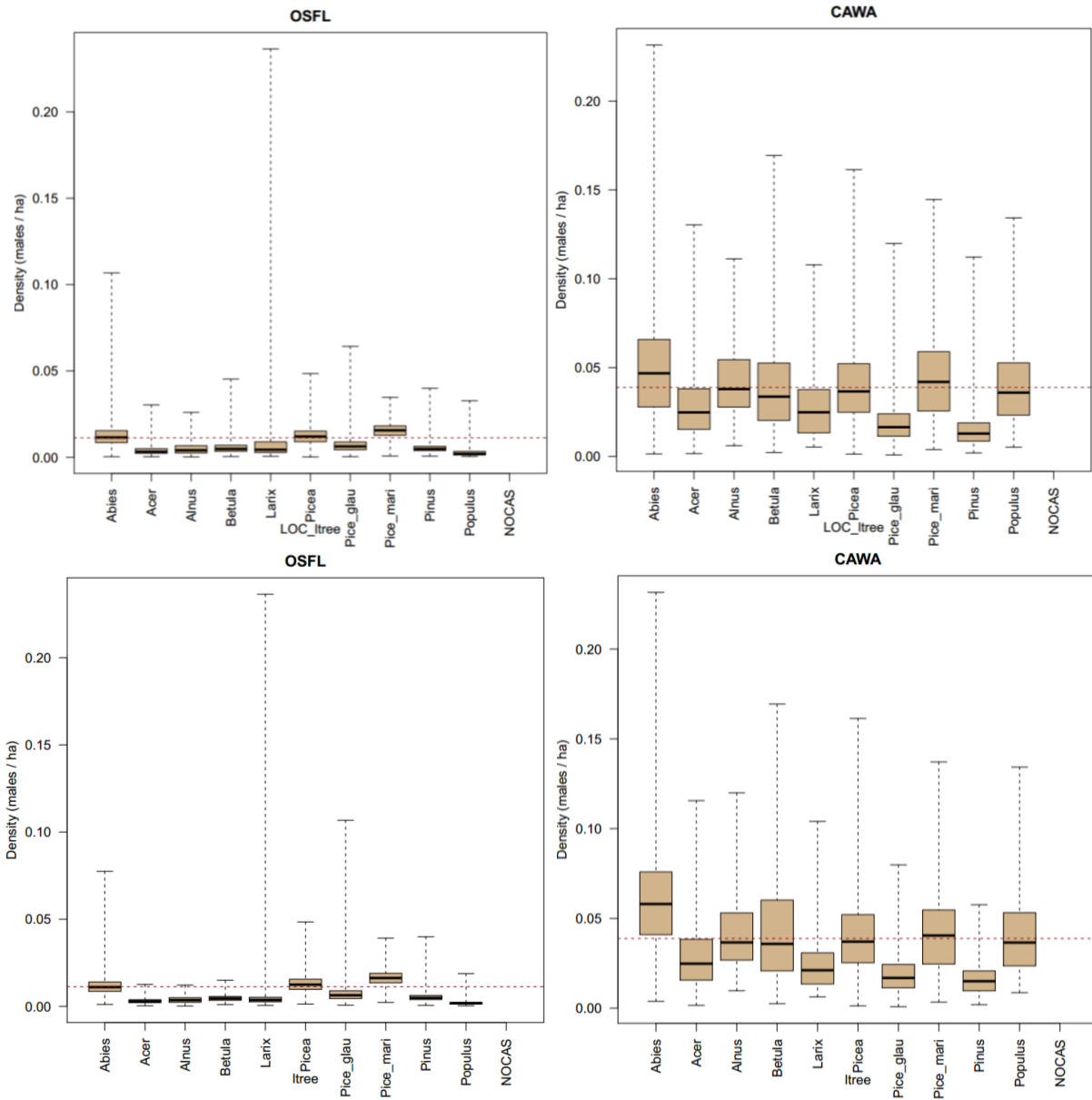


Fig. A4.1, Relationship of predicted density to forest cover at two scales for Olive-sided Flycatcher (OSFL; WETxFOR model subset), and Canada Warbler (CAWA; WETNESS model subset). Upper panels show the local scale (50m buffer for CAWA, 100m for OSFL) and lower panels show territory scale (250 m buffer).



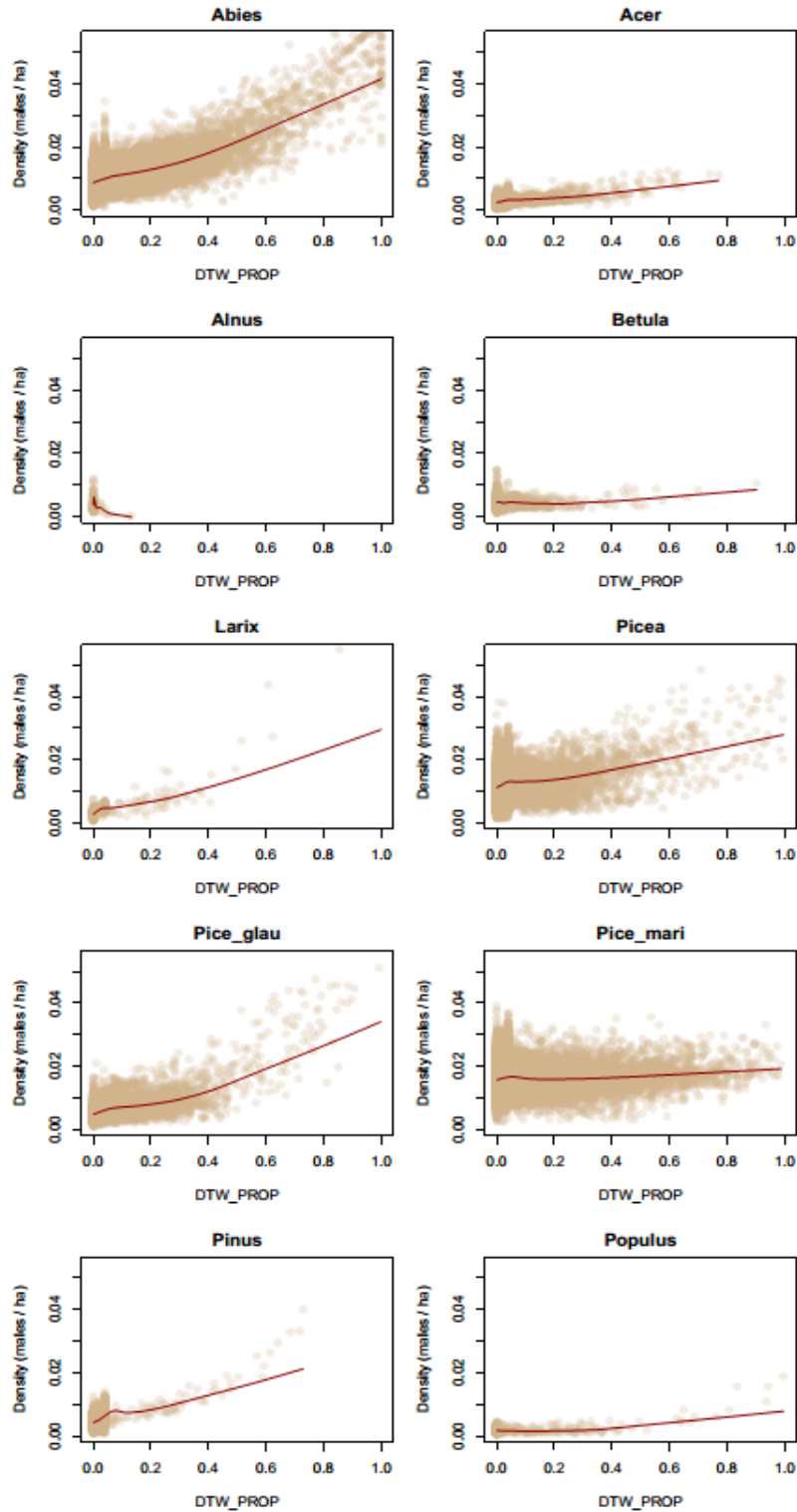


Fig. A4.2, Relationship of predicted density to forest cover and proportion of buffer classified as wet (depth to water table  $\leq 1$  m) at the territory scale (250 m) for the Olive-sided Flycatcher. Values on the X axis are standardized.

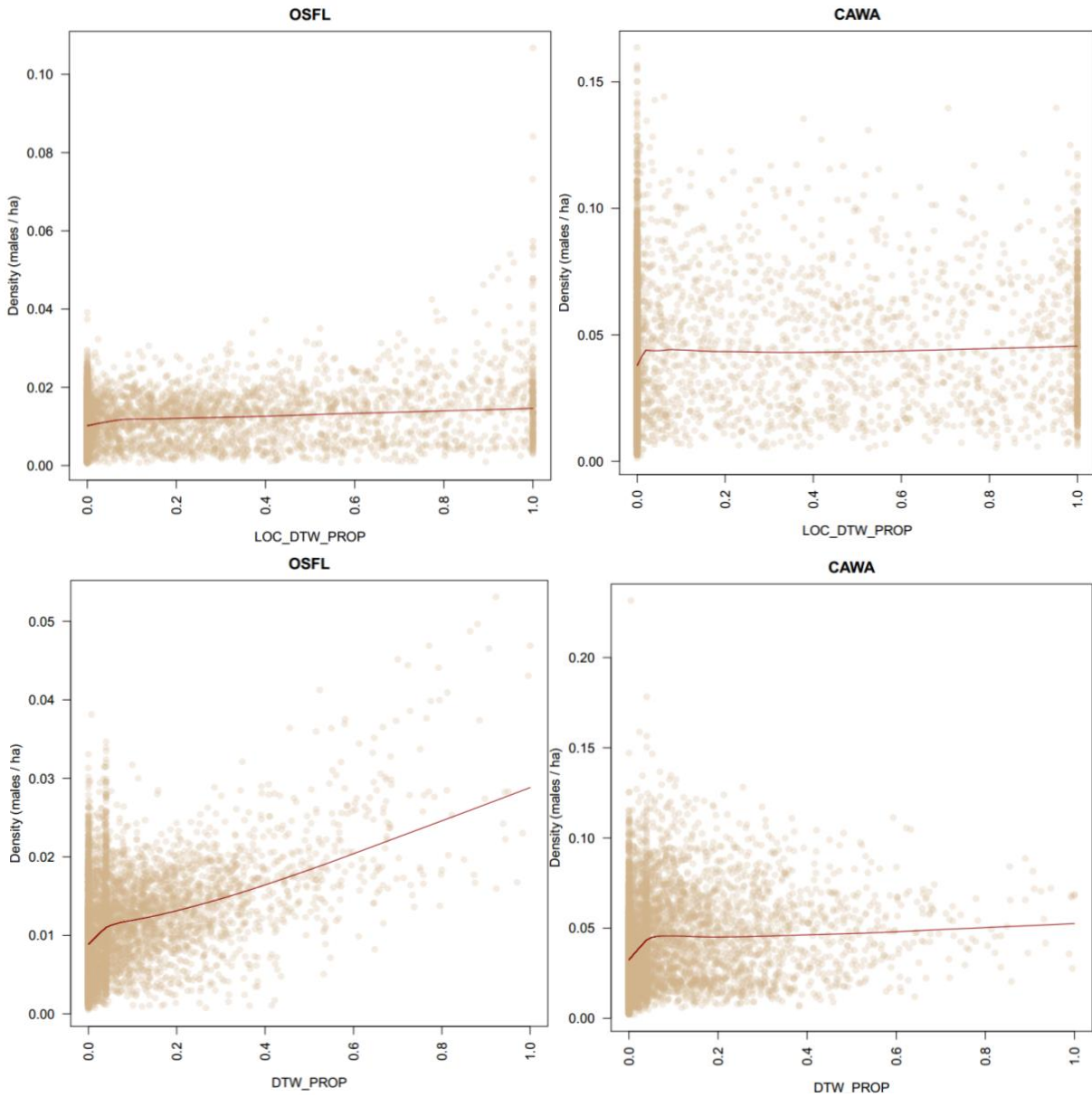


Fig. A4.3, Relationship of density of males per hectare to proportion of depth to water table classified as  $\leq 1$  in buffers for for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset). Upper panels show the local scale (50m buffer for CAWA, 100m for OSFL) and lower panels show territory scale (250 m buffer). Values on the X axis are standardized.

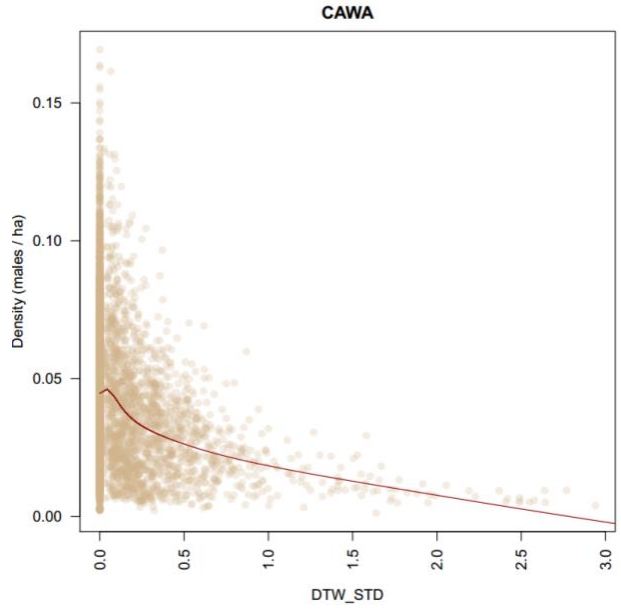


Fig. A4.5, Relationship of predicted density of males per hectare to standard deviation of depth to water table at the territory scale (250 m) for Canada Warbler (WETNESS model subset). Values on the X axis are standardized.

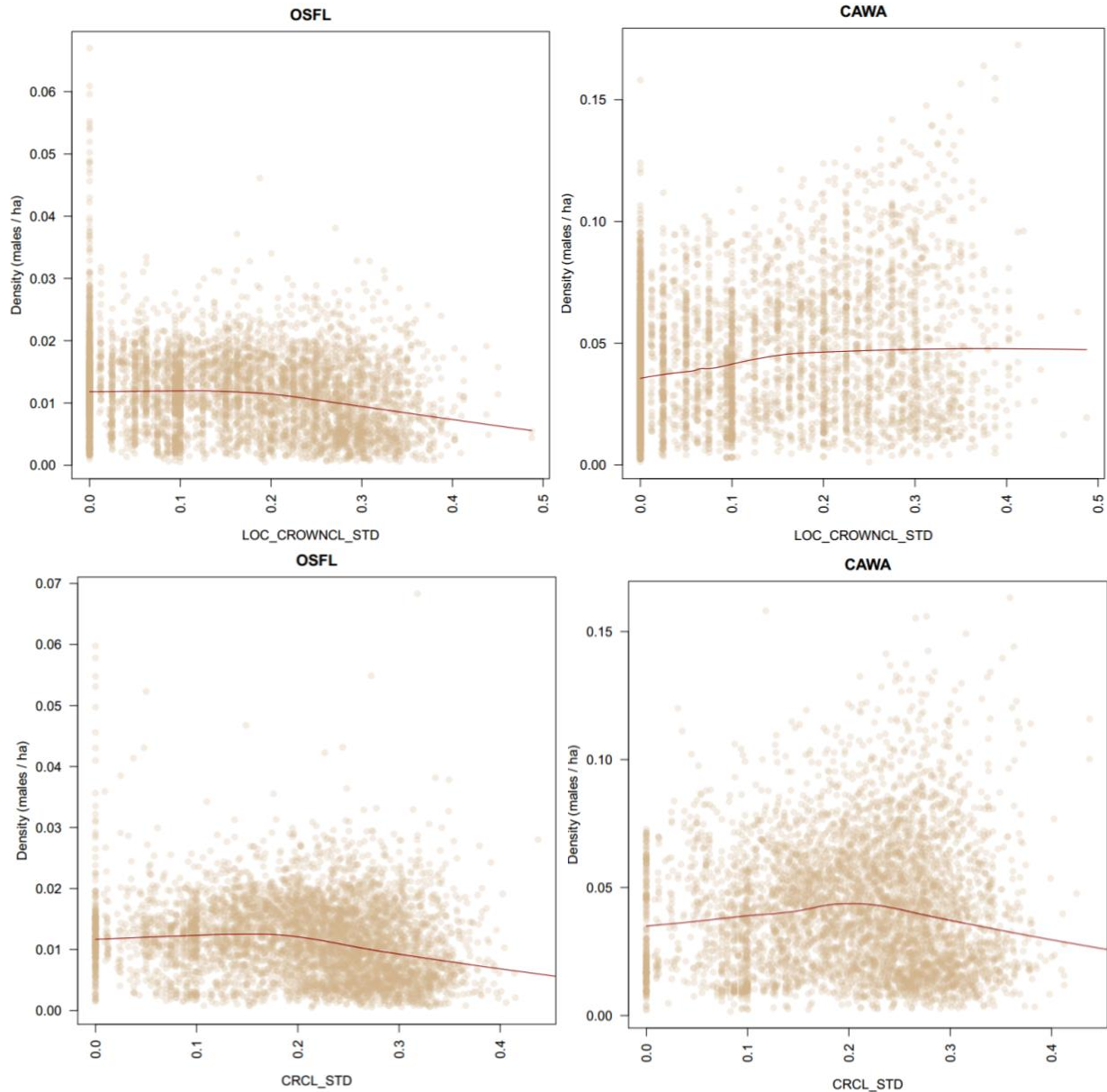


Fig. A4.6, Relationship of predicted density of males per hectare to mean and standard deviation of canopy closure at two scales for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and Canada Warbler (CAWA; WETNESS model subset). Upper panels show mean canopy height at the local scale (50m buffer for CAWA, 100m for OSFL) and lower panels show standard deviation of canopy height at the territory scale (250m buffer). Values on the X axis are standardized.

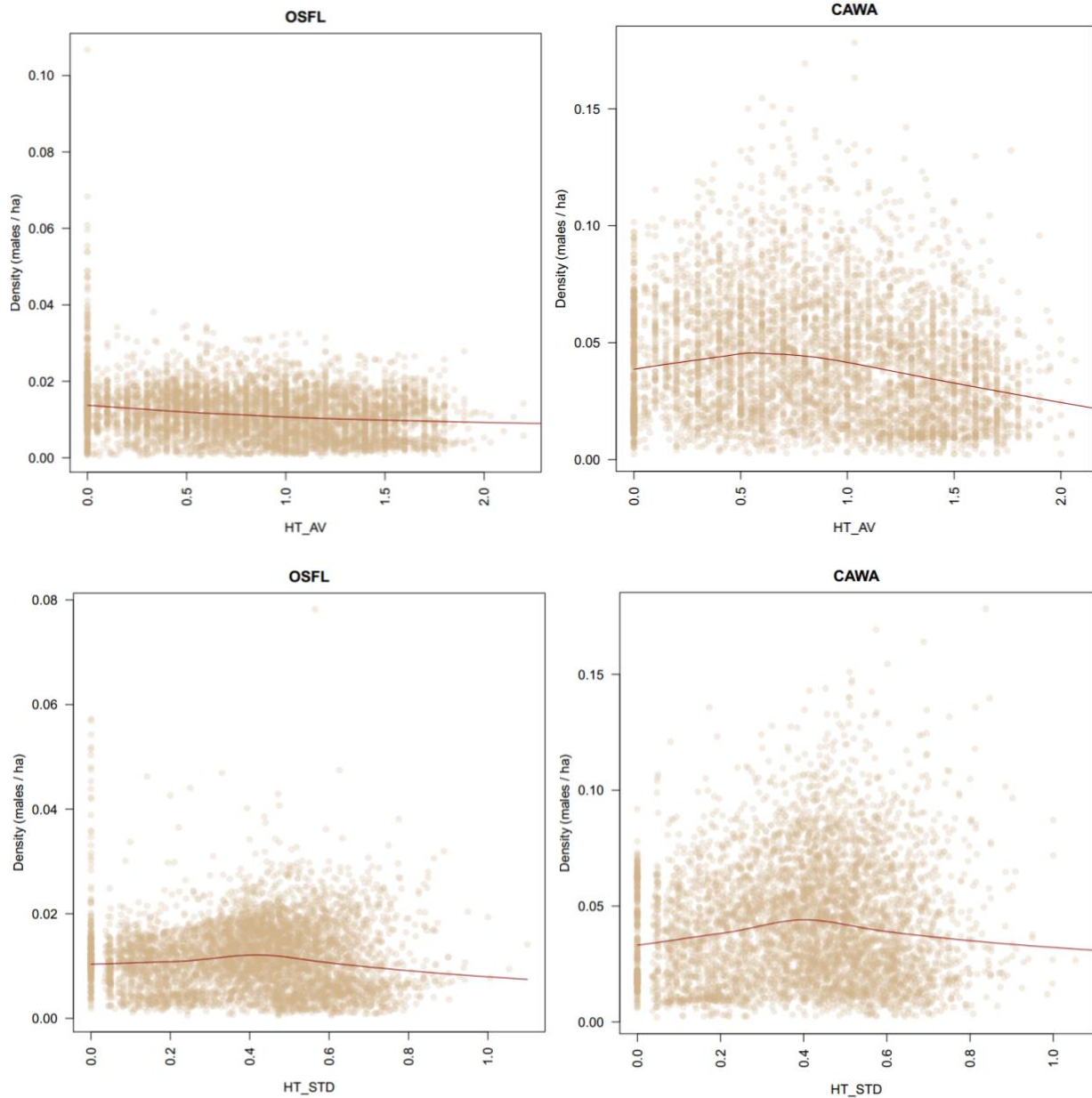


Fig. A4.7, Relationship of predicted density of males per hectare to mean and standard deviation of canopy height at two scales for Olive-sided Flycatcher (OSFL; WETxFOR model subset) and Canada Warbler (CAWA; WETNESS model subset). Upper panels show mean canopy height at the local scale (50m buffer for CAWA, 100m for OSFL) and lower panels show standard deviation of canopy height at the territory scale (250m buffer). Values on the X axis are standardized.

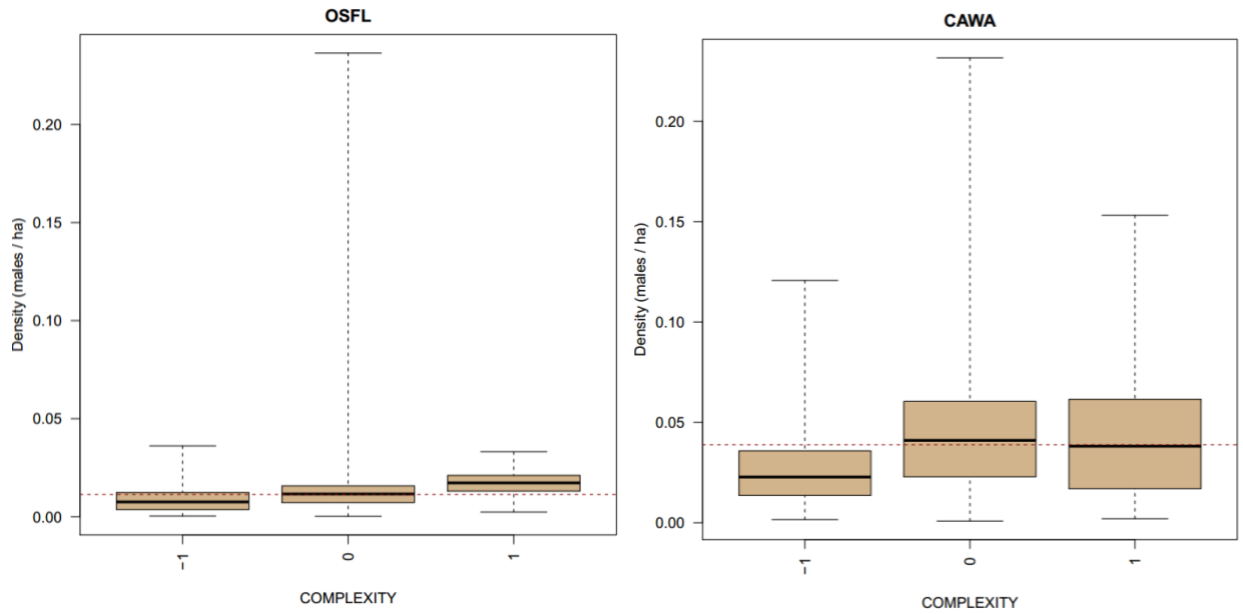


Fig. A4.8, Relationship of density of males per hectare to landscape complexity (-1 = below mean, 0 = mean, 1 = above mean) at the territory scale (250 m buffer) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset).

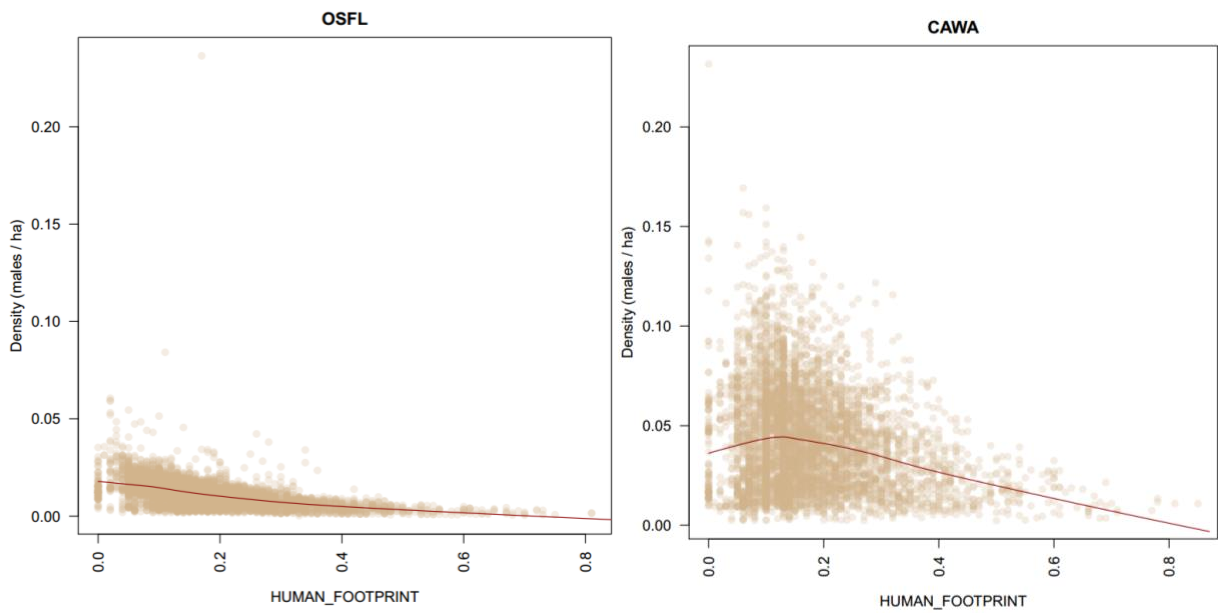


Fig. A4.9, Relationship of density of males per hectare to human footprint index at the territory scale (250 m) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset). Values on the X axis are standardized.

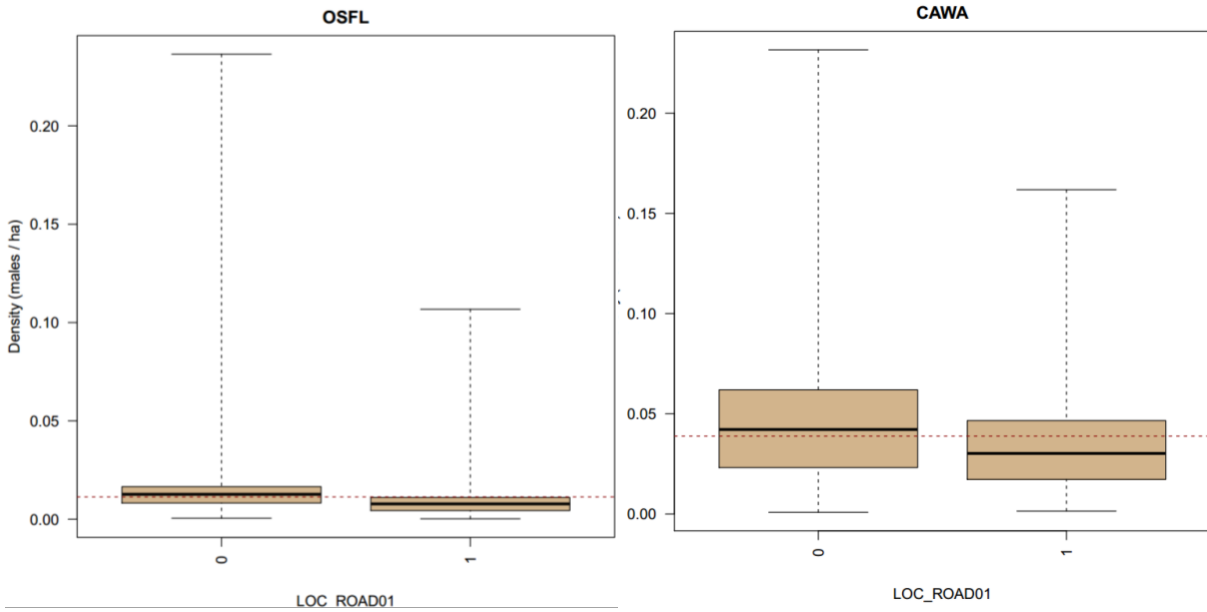


Fig. A4.10, Relationship of density of males per hectare to road condition (0 = point count off road, 1 = point count adjacent to road) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset).

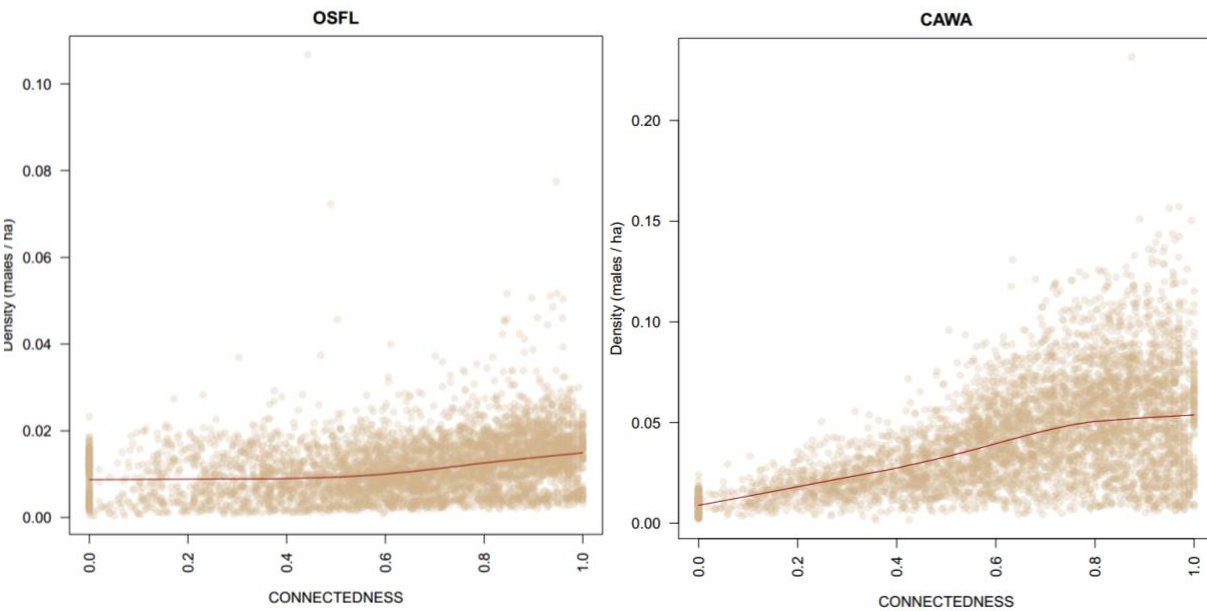


Fig. A4.11, Relationship of density of males per hectare to local connectedness index at the territory scale (250 m) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset). Values on the X axis are standardized.

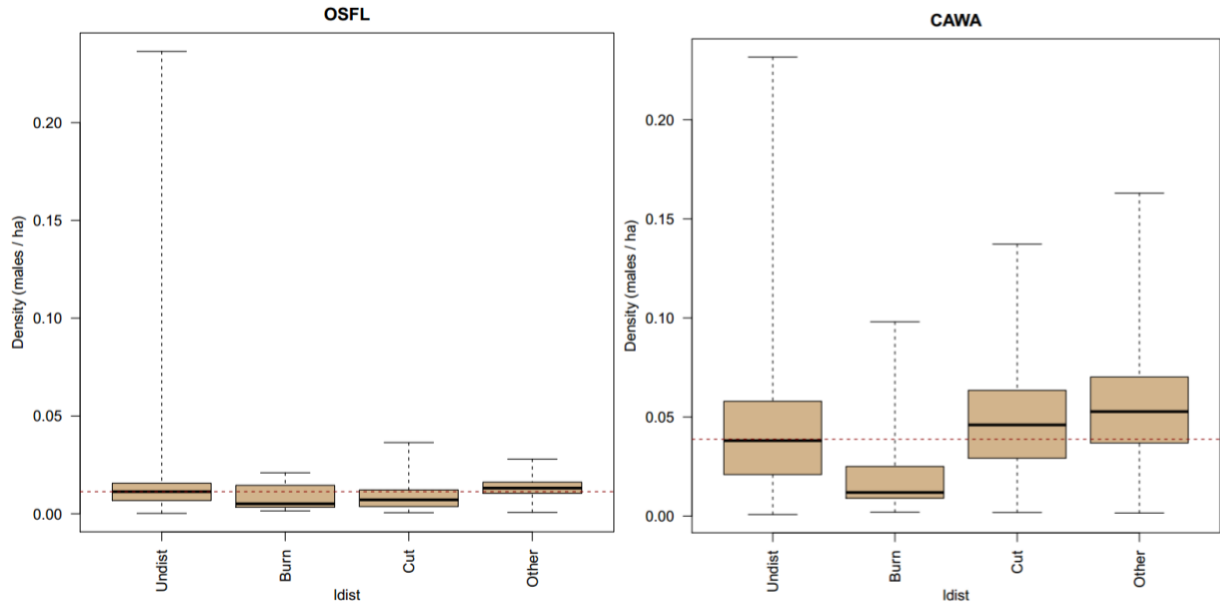


Fig. A4.12, Relationship of density of males per hectare to disturbed area within the territory buffer (250 m) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset).

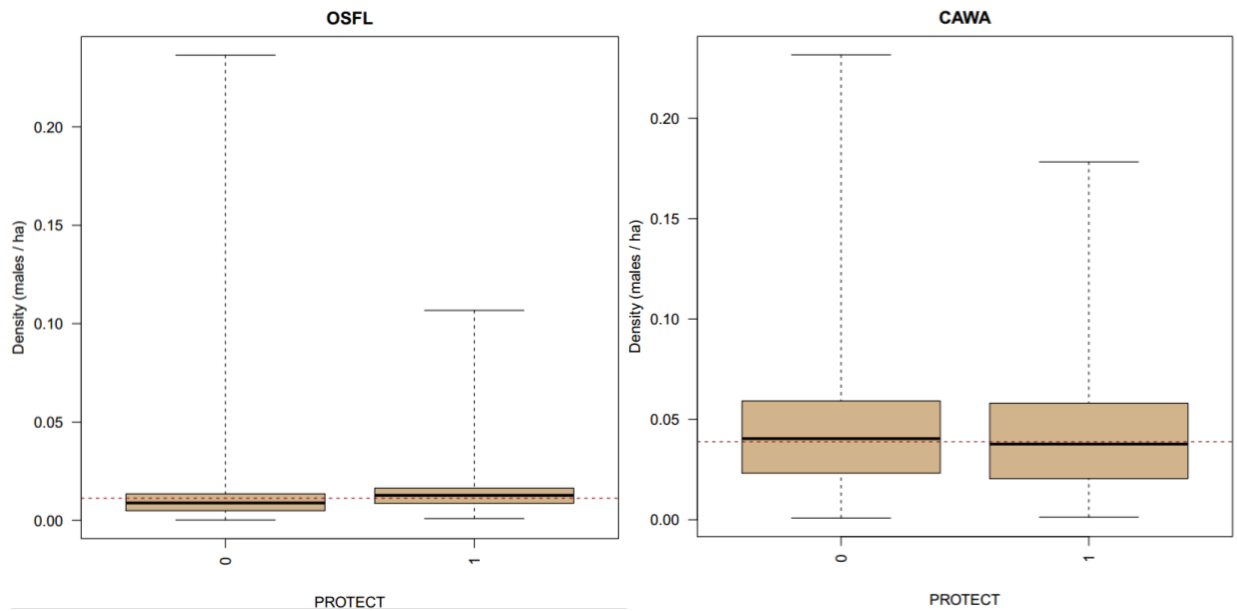


Fig. A4.13, Relationship of density of males per hectare to site protection status at the point count location (0 = unprotected, 1 = protected) for the Olive-sided Flycatcher (OSFL; WETxFOR model subset) and CAWA (CAWA; WETNESS model subset).



**Appendix 5.** Maps of density estimates for Olive-sided Flycatcher and Canada Warbler in four national parks in New Brunswick and Nova Scotia.

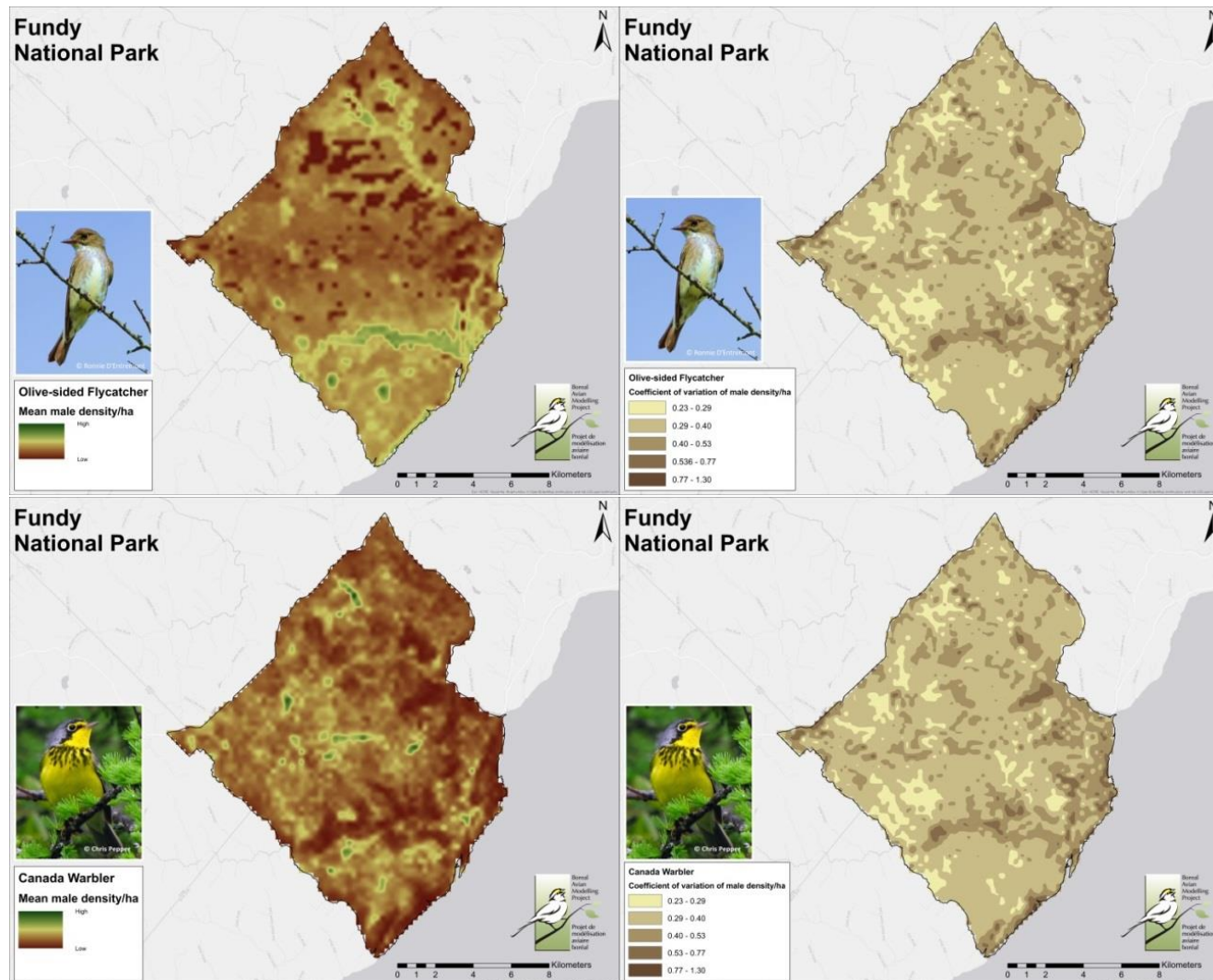


Fig. A5.1, Predicted mean density of territorial males/ha (left panels) and coefficient of variation (right panels) for Olive-sided Flycatcher and Canada Warbler in Fundy National Park, New Brunswick, Canada.

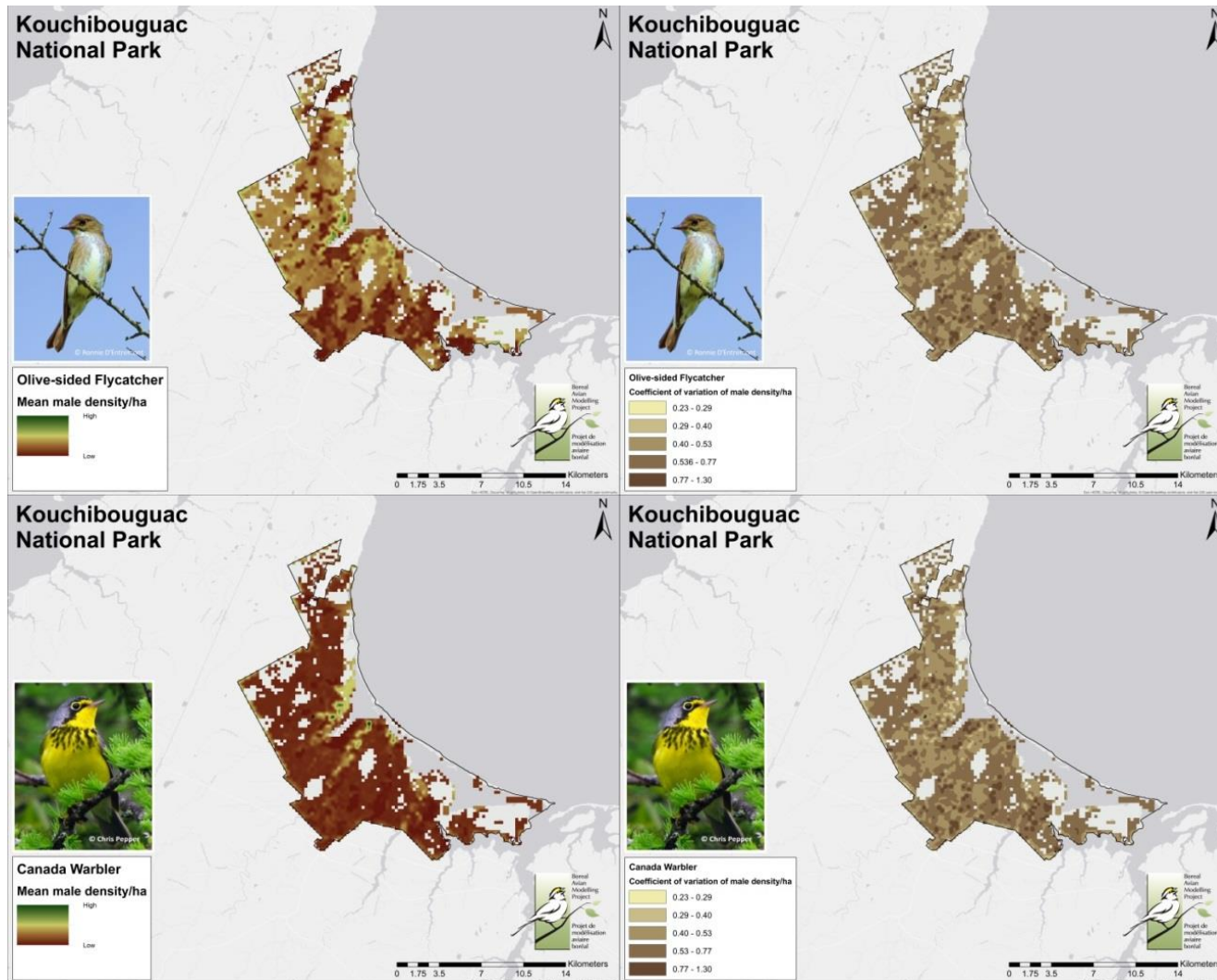


Fig. A5.2, Predicted mean density (left panels) and coefficient of variation (right panels) for Olive-sided Flycatcher and Canada Warbler in Kouchibouguac National Park.

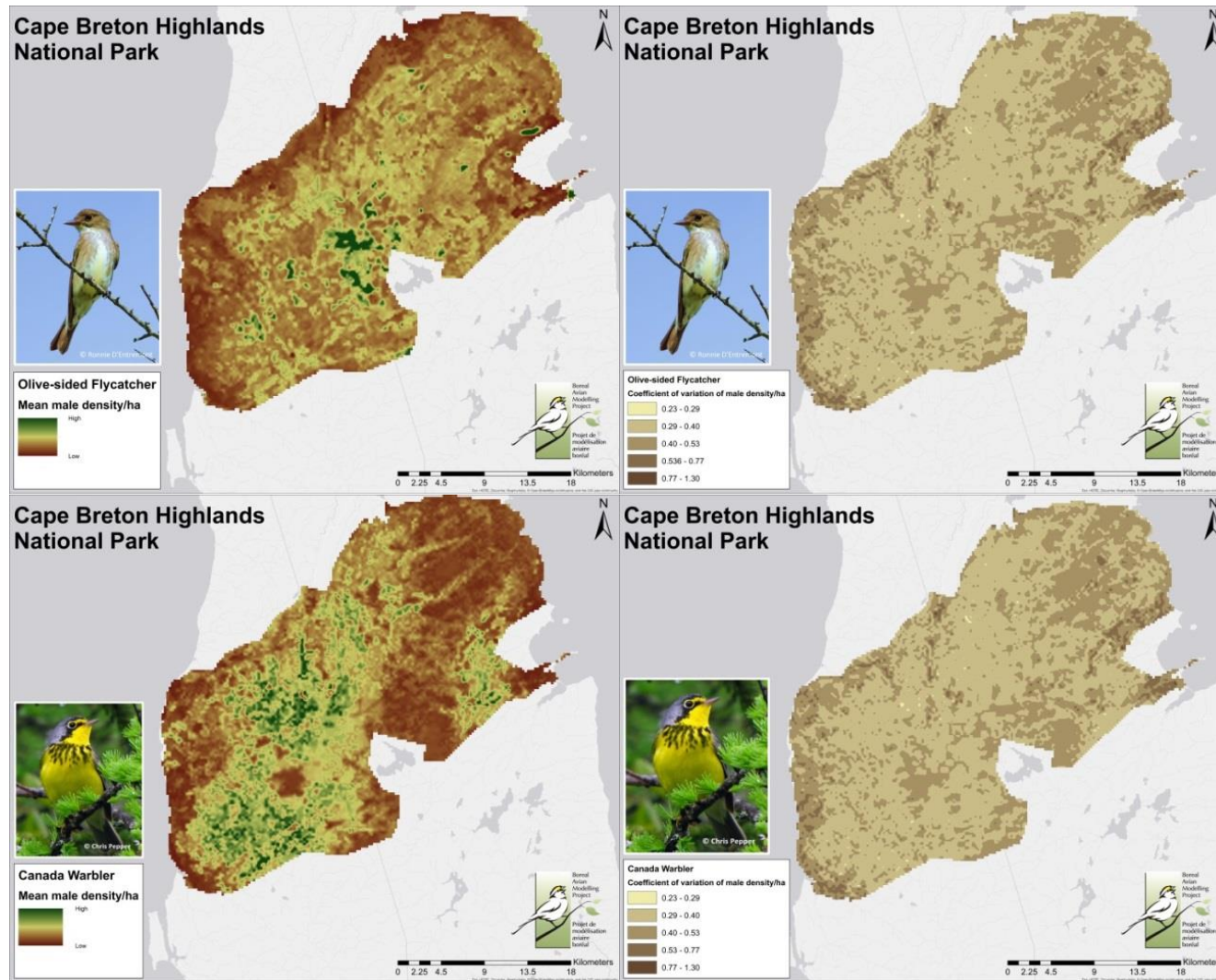


Fig. A5.3, Predicted mean density (left panels) and coefficient of variation (right panels) for Olive-sided Flycatcher and Canada Warbler in Cape Breton Highlands National Park.

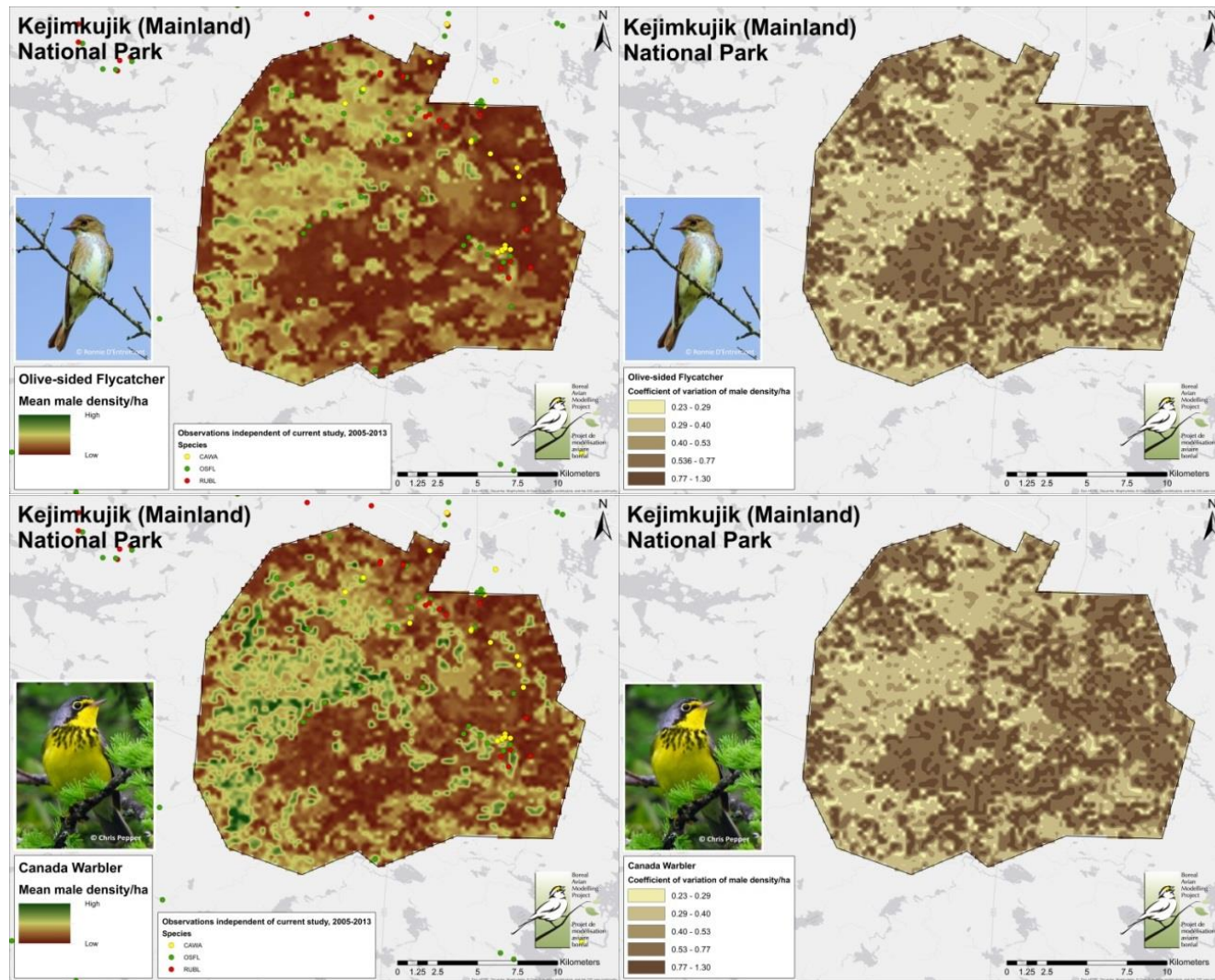


Fig. A5.4, Predicted mean density (left panels) and coefficient of variation (right panels) for Olive-sided Flycatcher and Canada Warbler in Kejimikujik Mainland National Park. Left panels show recent known locations of the study species as well as the Rusty Blackbird, another species at risk using wet forest landscapes, for comparison (authors' dataset).