

Using occupancy modelling and community analysis to determine the habitat requirements of  
Eastern North American songbirds in an intensively managed forest.

by  
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## Abstract

Forest management often causes changes to forest ecosystems, which can alter habitat use by avian species. Even with modern forestry practices which attempt to simulate natural disturbances and reduce environmental impact, many avian species are still experiencing population declines in the Eastern Maritime provinces because of habitat alterations. Black Brook district in North Western New Brunswick is an intensively managed forest where over 90 recorded bird species reside.

My project focused on modelling which forest variables in the Black Brook district forest affect the occupancy of four resident bird species, brown creepers (*Certhia americana*), Canada warblers (*Cardellina canadensis*), olive-sided flycatchers (*Contopus cooperi*), and ovenbirds (*Seiurus aurocapilla*). I also measured the influence of these forest variables on turnover in the broader avian community. All four focal species had unique habitat requirements, and turnover analysis suggested that the community also changed dramatically among different habitats. These patterns suggest that to maximize habitat for all avian species managed forests should work to create heterogenous landscapes.

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## Chapter One – Introduction

Canada has approximately 451 regularly occurring native bird species, 66 of which are listed as endangered, threatened, or of special concern (North American Bird Conservation Initiative Canada, 2012). In the Maritimes forest bird populations have declined by approximately 10% since the 1970's, with aerial insectivores experiencing the greatest decline, a 70% population decline since the 1970's (North American Bird Conservation Initiative Canada, 2012). Overall the main consensus on why forest bird populations are in decline in Canada is because of changes in forest ecosystems (Natural Resources Canada, 2010). There are many things impacting forest ecosystems, but long-term changes are mainly caused by human activities like climate change, human development and expansion, and forest management practices (Natural Resources Canada, 2010). These declines should be a source of great concern, not only because we risk losing many of the bird species that call Canada home, but also because birds can be great indicators of forest health and sustainable forest management (Venier & Pearce, 2004).

Forest management for industry use, such as tree harvesting, can be problematic to bird communities because it changes local forest stand structures (Jobs, Nol, & Voigt, 2004). Common changes effecting bird communities and populations are: reducing snags (Fuller, Harrison, & Lachowski, 2004; Wisdom & Bate, 2008), altering tree species compositions (Danneyrolles, Arseneault, & Bergeron, 2016), changing forest structures like canopy cover, ground vegetation, and tree density (Franklin et al. 2002), and causing a prevalence of young forest stands over old growth stands (Boucher et al., 2009). These changes can result in shifts in the types of habitat available to forest birds, and as a result can shift the bird communities residing in the forest (Rodewald, & Abrams, 2002). Certain species may benefit from the changes brought on by industrial forest management, particularly habitat generalists, and species more specialised to open habitat (Canterbury et al., 2000; King, Degraaf, & Griffin, 2001; King & Schlossberg 2014), but other species more specialised to specific forest types may often experience declines and loss of habitat with increased forest management (Poulin et al., 2008; Poulin & Villard, 2011; Geleynse et al., 2016; Wilson et al., 2018; Robertson & Hutto, 2007; Robertson, 2012; King, Griffin, & Degraaf, 1996; Burke & Nol, 1998; Villard & Hache, 2012).

Therefore, industrial forest management agencies must attempt to emulate natural disturbances on the landscape (Booth, Boulter, Neave, Rotherham, & Welsh, 1993; Bergeron, Harvey, Leduc, & Gauthier, 1999), and reduce the depletion of important forest habitats for avian species.

My thesis project aimed to model habitat characteristics of four Eastern Canadian songbirds that may be affected by management activities related to harvesting: brown creepers (*Certhia americana*), Canada warblers (*Cardellina canadensis*), olive-sided flycatchers (*Contopus cooperi*), and ovenbirds (*Seiurus aurocapilla*). My study forest is a privately owned intensively managed forest in northwestern New Brunswick, meaning most forest variable changes in the landscape are a result of industrial forestry practices. My thesis also aimed to examine how overall avian communities change across the managed landscape using redundancy analysis (RDA). This was done to understand how communities respond to management and which forest variables are more likely to cause shifts in overall community dynamics.

Brown creepers are old growth forest specialists, whose habitat is commonly associated with large coniferous trees and snags (Poulin et al., 2013). This need for old growth forests may make brown creepers sensitive to forest management which can reduce the availability of old growth forest in a landscape (Poulin et al., 2008; Poulin & Villard, 2011; Geleynse et al., 2016). Canada warblers are more commonly associated with wetland forests with abundant undergrowth (Reitsma et al., 2009). This may make Canada warblers sensitive to forest management that can disturb understory growth and alter forest wetlands (Barbier, Gosselin, & Balandier, 2007; COSEWIC, 2008; Hunt, Bayne, Haché, 2017). Olive-sided flycatchers are aerial insectivores that are commonly known to rely on open gaps within the forest landscape, which are often naturally created by forest fires, for foraging (Altman & Sallabanks, 2012). When forest management reduces natural forest fires and forest gaps are then made by harvesting activities, the occupancy of olive-sided flycatchers may be affected (Robertson & Hutto, 2007; Robertson, 2012). Finally, ovenbirds, an abundant ground nesting warbler in northwestern New Brunswick, are commonly associated with more open forest floors, which are needed for foraging and breeding activities (Porneluzi, Van Horn, & Donovan, 2011). Because of these habitat needs ovenbirds may be affected by forest management activities which can alter ground vegetation and canopy cover (King, Griffin, & Degraaf, 1996; Burke & Nol, 1998). All these species appear to have

experienced habitat loss and alteration with forest management, but their habitat losses are due to different factors regarding habitat use and specialisation. Therefore, each species will likely require different management plans to conserve forest variables related to their occupancy.

Determining these different needs can be difficult since habitat selection often involves multiple variables (Kristan, Johnson, & Rotenberry, 2007). This becomes increasingly problematic when bird species are difficult to monitor because of issues around imperfect detection, such as behaviours like shyness, or simply species having low population sizes (Alpizar-Jara et al., 2004; Gu & Swihart, 2004). Figuring out the habitat needs of a species is always the first step in making management decisions. Without this knowledge management decisions are made quickly with little information, often resulting in poor outcomes (Cook, Hockings, & Carter, 2010).

Occupancy modelling is a tool that is often used to determine which environmental variables may be influencing the occupancy of avian species. Unlike other methods occupancy modelling can account for the imperfect detection of a species (MacKenzie et al., 2002, MacKenzie et al., 2003). The benefit of using occupancy modelling to monitor avian populations is that multiple sites can be monitored multiple times. This monitoring method results in a detection/ non-detection history for the species. This history is used to predict the probability a species is likely to be present at sites based on both the variables that affect occupancy, and the variables that affect species detection (MacKenzie et al., 2002, MacKenzie et al., 2003). Occupancy modelling works well in conjunction with the use of automated recording units for sampling species presence. This is why occupancy modelling is being used more and more in avian biology, since the use of automated recorders is much less labor intensive compared to in person sampling (Hobson et al., 2002; Venier et al., 2012). Automated recording devices are also less invasive to bird and forest communities, and equally, and occasionally more, accurate in interpretation than infield techniques (Hobson et al., 2002; Rempel et al., 2005; Venier et al., 2012).

The overall purpose of the modelling and community analysis was to create possible management recommendations to promote overall avian diversity among forest patches in the study area. In this thesis I also discuss the feasibility of an all-encompassing management plan, and strategies that benefit multiple species together. This is all done in the hopes of improving

current management practices aimed at conserving habitat for avian species in a forest that is constantly changing due to human influence. Finding the balance between avian habitat conservation and forestry practices is possible as long as adequate information is available to help with management decisions.

# **Chapter Two - Using occupancy modelling and community analysis to determine the habitat requirements of Eastern North American songbirds in an intensively managed forest**

## **1 | Introduction**

### **1. 1 | Background**

Over the past two centuries the logging industry has been an important influence on the landscape of Eastern Canada. Logging and forest management cause significant changes in forest structure, especially in tree species compositions (Danneyrolles, Arseneault, & Bergeron, 2016), and the prevalence of early succession forest in the landscape over old growth forests (Boucher et al., 2009). There is evidence indicating that disturbances caused by management and tree harvesting alter habitat for avian species and can impact their populations when not managed responsibly (Niemi et al., 1998; Drapeau et al., 2016). Changes in forest structure due to forest management affect bird species differently because each species has a unique niche in the forest ecosystem (Zlonis et al., 2017). As such, a particular management practice that helps create habitat for a certain species, may reduce habitat for another species. Forestry is and will continue to be a key global industry, necessitating the identification of forestry practices that allow us to maintain economic productivity while conserving biodiversity.

The province of New Brunswick in Eastern Canada has a landmass containing 85% forest, about half of which is privately owned (Department of Natural Resources, 2011). This large amount of hemiboreal forest provides important habitat for songbirds during the breeding season. Overall, 7,650 square kilometres of New Brunswick forests were harvested in 2016 (Department of Natural Resources, 2011). With a rise in the amount of forest being harvested, and about 8% of forested land being harvested in recent years forest managers in New Brunswick need to balance silvicultural targets with species conservation. Since forest disturbances and management affect bird species differently, forest managers need to determine which environmental variables are most important for the habitation of avian species, both at the community level and on an individual-species basis.

My study aimed to model the occupancy of four bird species in the actively managed Black Brook district forest in North Western New Brunswick, and to determine how avian community composition changes across the managed landscape. The four species modeled were brown creepers (*Certhia americana*), Canada warblers (*Cardellina canadensis*), olive-sided flycatchers (*Contopus cooperi*), and ovenbirds (*Seiurus aurocapilla*). Brown creepers were chosen because they are resident old growth specialists with sensitivity to forest management activities. Canada warblers and olive-sided flycatchers were chosen because of their classification of threatened and special concern respectively, by The Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2008; COSEWIC, 2018). Ovenbirds were chosen because of their ground nesting tendencies, which were of interest in a managed forest setting where ground brush and debris are highly variable throughout the landscape with different management strategies.

My study aimed to answer the following questions: a) What are the main drivers of occupancy for each of the focal species of management importance, b) How do avian communities in general change across the managed landscape, and c) Can we use the information on both the occupancy of individual species of concern and the broader avian community to create a management strategy that simultaneously promotes the occupancy of all four focal species while optimizing diversity of the avian community in Black Brook?

The overarching goal of this study is to inform forest management to conserve and possibly create habitat for species of management concern, while also promoting diversity in the avian community in general. My results will hopefully be used to inform future forest management and avian conservation in the Black Brook district and possibly elsewhere in the managed forests of Atlantic Canada.

## **1.2 | Habitat predictions for brown creepers**

Brown creepers are old growth forest specialist that nest in the crevices and under the peeling bark of older trees, and forage on the bark of large diameter trees (Poulin et al., 2013). Previous literature has indicated that because of their reliance on old growth forest, brown creepers are sensitive to disturbances caused by forest management (Imbeau, Savard, & Gagnon, 2000;

Poulin et al., 2008; Poulin & Villard, 2011; Geleynse et al., 2016). Harvesting activities and active management may cause a decline in the abundance of old growth trees in stands, thus limiting the number of nesting sites and foraging habitat for brown creepers. If the limitations of both nesting and foraging habitat are determining the population abundance of brown creepers in the Black Brook district then I predict brown creepers to have decreased occupancy in stands with decreased average tree height, which is an indicator of forest age, and decreased forest cover within the nearby surrounding area.

Alternatively, Geleynse et al. (2016) found that in undisturbed forests, brown creepers will forage on tree species in proportion to their availability on the landscape, but in stands with tree harvesting, brown creepers would selectively forage on trees associated with low wetland habitat, including balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*). This is of particular interest because most of the landscape in their study area was dominated by sugar maple (*Acer saccharum*), which was only foraged on in undisturbed stands. My study forest is 40% planted spruce stands, and 28% tolerant hardwood stands mainly composed of sugar maple, white birch (*Betula papyrifera*), and yellow birch. If habitat selection by brown creepers is determined by the availability of foraging habitat, I predict a combination of spruce, maple and/or birch cover to be key variables influencing the occupancy of brown creepers. If this is true, I predict the occupancy of brown creepers to increase in stands with increased spruce, and birch cover, and occupancy to decrease in stands with increased maple cover because of the availability of foraging trees in a disturbed landscape.

### **1.3 | Habitat predictions for Canada warblers**

Canada warblers are currently classified as threatened by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) with an estimated population decline of 4.5% annually (up to 5.4% annually in recent years) since 1968 (COSEWIC, 2008, Environment Canada, 2016).

Although over 75% of the breeding population is located in Canada, the main cause for the decline of Canada warblers has been attributed to the loss of habitat in the wintering grounds in the Northern Andes (Environment Canada, 2016, Wilson et al., 2018). However, disturbance to nesting habitat in Canada has the potential to contribute to local declines (Wilson et al., 2018).

Previous studies have shown that Canada warblers in Eastern North America prefer to nest in red maple (*Acer rubrum*) swamps and mixed wood swamps, with high shrub density and lower canopy height. Canada warblers likely prefer these swamps because they contain more sphagnum for nest building, and more suitable perching trees for males to sing and attract mates (Reitsma, Hallworth, & Benham, 2008; Hallworth et al., 2008; Reitsma et al., 2009; Morissette et al., 2013). There are very few red maple swamps within the Black Brook district because most maple tree cultivation is for upland sugar maple. If the habitat preferences of Canada warblers in the Black Brook district are similar to the studies mentioned above, then I predict that increased vertical complexity (increased vegetation layers within the forest) and decreasing average tree height will increase the occupancy of Canada warblers. This is because I predict these forest variables to increase the number of suitable perches for males to attract mates. I also predict an increase in water cover in the landscape will increase the occupancy of Canada warblers because increased water cover will likely increase the availability of habitat suitable for nesting.

#### **1.4 | Habitat predictions for olive-sided flycatchers**

Olive-sided flycatchers are a hemiboreal species that are currently classified as special concern by COSEWIC (Environment Canada, 2015; COSEWIC, 2018). Their annual population decline is estimated to be 3.4% with an over 79% population reduction since 1968 (Environment Canada, 2015). Olive-sided flycatchers are aerial sallying specialists, whose perches are usually located at canopy height adjacent to post forest fire clearings (Altman & Sallabanks, 2012). Research has suggested that forest management strategies that reduce natural and prescribed forest fires have led to olive-sided flycatchers selecting foraging and nesting territories adjacent to selectively logged areas (Robertson & Hutto, 2007; Robertson, 2012). This research also suggests that olive-sided flycatchers prefer habitat adjacent to selective harvesting over natural post-fire habitat, which may contribute to an ecological trap as nest predation can be higher adjacent to harvested land compared to post-fire clearings (Robertson & Hutto, 2007; Robertson, 2012). There has not been a large fire (prescribed or natural) within the Black Brook district since a 700ha fire in 1978, and there have been no fires larger than one hectare after 1989. If selective harvesting is a preferred habitat alternative to post-fire clearings, I predict olive-sided

flycatchers to have increased occupancy in stands with decreased forest cover within the surrounding landscape.

In addition, Roberston and Hutto (2007) and Roberston (2012), also determined that olive-sided flycatchers are selective in the trees they choose for perching and nesting. In selectively harvested forests olive-sided flycatchers chose to perch in live trees while foraging, and dead trees in post-fire clearings (Robertson, 2012). The species of the perching tree was also important, with fir and larch trees being favoured for perching (Robertson, 2012). Similar results are seen in nest site selection. Olive-sided flycatchers residing in post-fire clearings selected dead subalpine fir, while flycatchers residing in selectively harvested stands nested in live trees with no preference for tree species because of the lack of available dead trees (Robertson & Hutto, 2007). If dead trees and tree species selection are important for both perching and nest site selection, then I predict that olive-sided flycatchers will have increased occupancy in stands with increased numbers of standing dead trees. Also because of the absence of available post-fire clearings in the Black Brook district, I predict an increase in the occupancy of olive-sided flycatchers in stands with increased fir and larch tree species cover.

### **1.5 | Habitat predictions for ovenbirds**

Ovenbirds are a wide-ranging warbler commonly found across the boreal and eastern hardwood forests of Canada. They are well known for their ground nesting and gleaning behaviour in deciduous forests (Porneluzi, Van Horn, & Donovan, 2011). Previous research has suggested that the occupancy of ovenbirds is negatively affected by forest fragmentation (King, Griffin, & Degraaf, 1996; Burke & Nol, 1998; Villard & Hache, 2012). There are two theories in the literature explaining why fragmentation lowers the occupancy of ovenbirds. The first is that forest fragmentation lowers the abundance of food (ground invertebrates) within forest stands (Burke & Nol, 1998; Hache, Villard, & Bayne, 2013). The second is that fragmentation increases the number of predators within forest stands, leading to increased nesting mortality (Hache, Bayne, & Villard, 2014). If decreases in food abundance and/or increases in predators caused by increased forest fragmentation affects the habitation of ovenbirds, then I predict a decrease in the occupancy of ovenbirds in stands with decreased forest cover in the landscape.

Deciduous forest cover has also been shown to possibly be an important habitat feature for ovenbirds (Porneluzi, Van Horn, & Donovan, 2011). Old growth deciduous forests provide leaf litter and ideal ground vegetation growth for foraging and nesting which coniferous forest and spruce plantations do not provide (Burke & Nol, 1998; Villard & Hache, 2012). The Black Brook district is mostly composed of spruce stands, possibly limiting habitat for ovenbirds. If deciduous forest is important for ovenbirds, then I predict that the occupancy of ovenbirds will increase in stands with increased deciduous tree cover.

In addition, literature from previous studies has also suggested that the occupancy of ovenbirds is lower near forest edges, specifically edges with high levels of industrial noise from roads and other human activities (Habib, Bayne, & Boutin, 2007). This is because industrial noise interrupts singing males, and mate attraction behaviours (Habib, Bayne, & Boutin, 2007). If noise disturbances affect ovenbirds similarly in the Black Brook district then I predict that the occupancy or detection of ovenbirds will increase with increased distance to the nearest highly trafficked road, since large vehicle noise is the main source of noise disturbance across the Black Brook district.

## **1.6 | Community analysis predictions**

Forest management practices for tree harvesting often attempt to mimic natural disturbances, but this process can also create changes in the forest landscape that alter community composition (Norton, Hannon, & Schmiegelow, 2000; Jobes, Nol, & Voigt, 2004). Often forest management and tree harvesting shifts forest landscapes into containing more young regenerating forest stands, and open areas (Boucher et al., 2009). This shift in the ages and availability of forest in the landscape often pushes out late stage/old growth specialists and instead increases the amount of young forest and open area specialists, and habitat generalists (Canterbury et al., 2000; King, Degraaf, & Griffin, 2001; Alpizar-Jara et al., 2004, King & Schlossberg 2014). Forest management practices also shift the tree species composition of stands based on harvesting needs (Schumann, White, and Witham, 2003). This causes avian species who are specialized in a specific forest types, often categorized as coniferous, mixed, or deciduous, to be pushed out of the forest and community depending on which types of trees dominant the landscape (Villard, Trzcinski, & Merriam, 1999; Drapeau et al., 2000).

Black Brook district is managed for the production and harvest of spruce and fir trees, but also adequate amount of tolerant hardwood stands, mainly containing sugar and yellow maple, are cultivated. This makes the landscape likely to have shifted towards increasing young regenerating forest stands, and open areas, as well multiple stands types containing different tree species compositions. Because of this, I predict that avian species composition in forest stands will be mainly influenced by forest cover and stands age distribution, and the forest types in regard to the tree species compositions of stands.

## **2| Methods**

### **2.1 | Study area**

My study area was located in the Black Brook district in northwestern New Brunswick, Canada (47°23'N; 67°40'W) (Figure 1). Black Brook district forest is 200,000 ha of hemiboreal forest. Planted red, white, and Norway spruce (*Picea rubens*, *Picea glauca*, *Picea abies*) stands comprise 40% or more of the land, while tolerant hardwood stands, and shelter-wood stands comprise 28% of the land. The remaining forest area is composed of naturally-grown spruce, fir, and intolerant hardwood mixes.

To ensure adequate representation of all forest types, ages, and current management status, sites were differentiated into seventeen sub-categories (Table A1). To minimize spillover from bird songs in adjacent stands sites were selected with specific size and shape specifications. Sites were chosen such that the point of sampling within the stand had to be a minimum of 100 meters from a road or adjacent stands. Sampling sites also had to be a minimum of 200 meters from other sampling sites. These distances were chosen because the effective detection radius of the recording units used for sampling bird songs is between 75 and 100m (Rempel, Francis, Robinson, & Campbell, 2013). Sites that were currently being harvested could not be sampled for safety reasons. Over two seasons a total of 458 sites were sampled (Figure 1), including 321 sites in 2016 and 137 sites in 2017 (Table A1). Fewer sites were sampled in 2017 because 100 stationary point counts were conducted during the same time for another study.

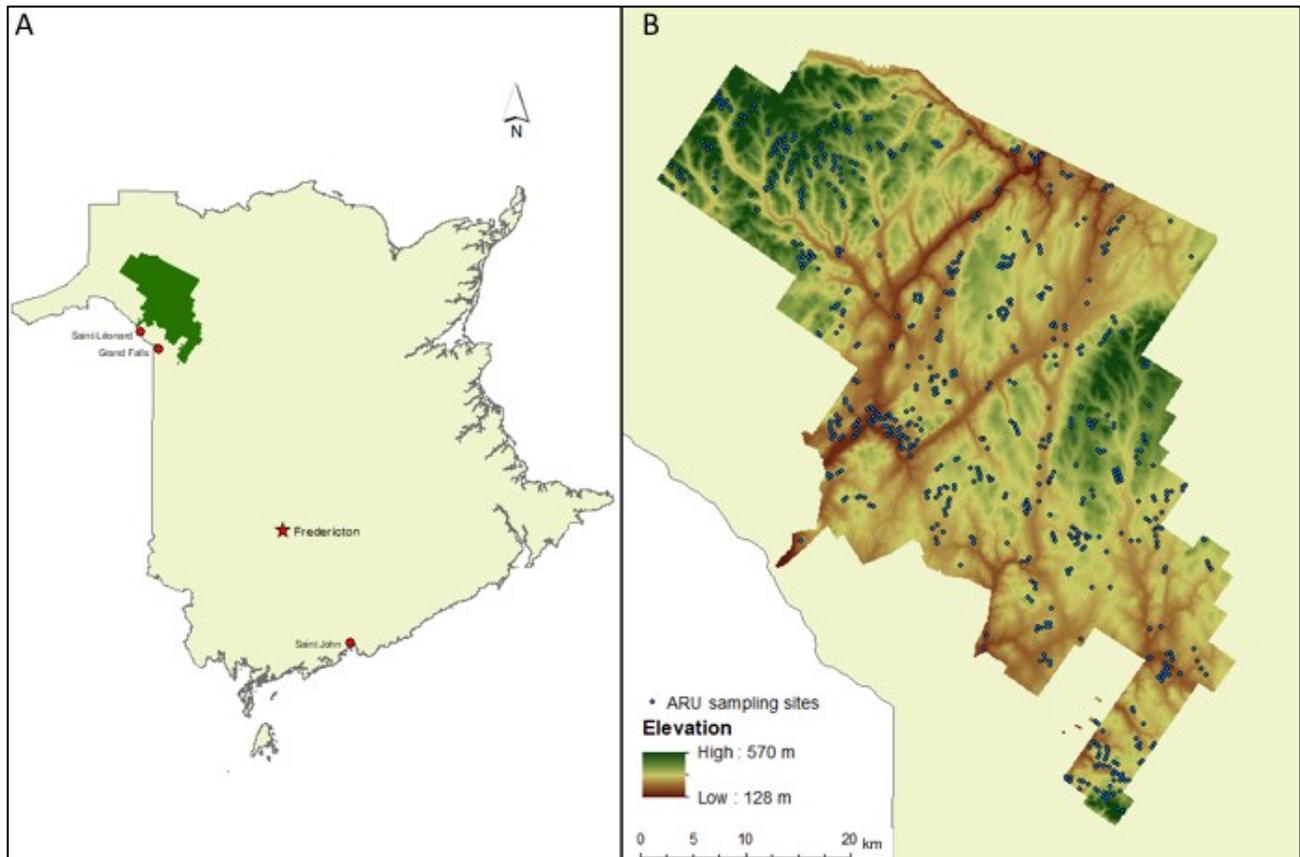


Figure 1: A) Location of the Black Brook district forest in New Brunswick, and B) sampling site distribution of automatic recording units (ARUs) in the forest.

## 2.2 | Acoustic sampling

I used Wildlife Acoustic SM4, SM3 and SM2 recorders (Wildlife Acoustics, Inc., Maynard, Massachusetts, USA) to record bird songs at forest sampling sites from May 25<sup>th</sup> to July 12<sup>th</sup>, 2016, and May 24<sup>th</sup> to July 4<sup>th</sup>, 2017. The ARUs (automatic recording units) were programmed to record for five minutes, both 30 minutes before and 30 minutes after sunrise the day of recording. ARUs were left in the field to record for a minimum of seven days. They were placed at breast height against a sturdy tree, and as high as possible on stumps or poles where no trees were present.

Presence/absence data were derived from the first four days of useable recordings for each site. Each day two five-minute samples were taken from the recordings, both 30 minutes before and 30 minutes after sunrise, resulting in eight sampling occasions. Sampling was conducted before

and after sunrise to ensure both infrequent, early, and late morning singers were caught in surveys. The first four days of clear recordings, not interrupted by rain, wind, or other noise disruptions were chosen for enumerating bird assemblages. Stations with ARUs that failed or had unfavourable weather that resulted in fewer than eight sampling periods were considered missing observations. Out of 458 sites, thirteen had fewer than eight sampling periods (one with five sampling periods, five with six sampling periods, and seven with seven sampling periods).

Recordings were listened to manually by an interpreter with help from visualized sound waves with the program Raven (Bioacoustics Research Program, 2014) to identify every species picked up on the recording. Interpretations were then checked for accuracy by another interpreter before being finalized. Ninety species of birds were identified in the two seasons.

### **2.3 | Forest variables**

Black Brook district forest was surveyed with aerial LiDAR (Light Detection and Ranging) in 2011 (Northern half of the forest) and 2013 (Southern half of the forest). From these surveys forest stand variables were extracted from raw point cloud data by Leading Edge Geomatics Ltd. Leading Edge created an EFI (Enhanced Forestry Inventory) which was imported into ArcGIS 10.3.1 (Environmental Systems Research Institute, Inc., Redlands, California, USA) for visualization and model analysis. The EFI variables calculated by Leading Edge were average tree height, basal area, crown closure, tree density (measured as merchantable trees per hectare), deadwood volume of the stand, and the vertical complexity index of the stand (Table A2). Forest inventory data from J.D. Irving Ltd calculated from ground surveys, planting data, and LiDAR gave the percent cover of each tree species in both the primary and secondary canopy layers (Table A2). ArcGIS was also used to determine the distance sampling points were from the nearest road (roads currently being used to support harvesting and forest management activities, because many roads in the map layer were unused, too isolated or overgrown to cause traffic disturbance), the percent deciduous and coniferous tree cover of the stand, the percent water cover within the 100m landscape, and the percent of predefined buffer distances (100, 200, 300, 400, 500 and 600 meters) from sampling points that were forested (average tree height of the stands was greater than 2.5 meters) (Table A2). The scales used for forest cover in the landscape were chosen so that the largest buffer distance was twice as large as the known average territory

size of focal species with the largest territory, olive-sided flycatcher (Altman & Sallabanks, 2012).

Management status of the stands was also explored as a means of examining how specific forest management activities would affect occupancy. The categories for management status were created by the forest management company J.D. Irving Ltd for their inventory purposes and are described in Table A3. However, permutation-based ANOVAs suggested that the forest variables mentioned above were strongly related to management status (Table A4). To keep results as general and applicable as possible, management status was not used in final model analysis.

## **2.4 | Occupancy Models**

Single season occupancy models were created to examine how forest variables affected the occupancy of the four focal species, and how other factors may affect their detection probabilities when modeling occupancy (MacKenzie et al., 2002). Before developing occupancy models a correlation matrix was constructed to examine multicollinearity among the forest stand variables (Figure A1). Variables with a Pearson correlation coefficient  $\geq 0.6$  were not included in models together. The correlated variable that increased model fit the most was used. These relationships between variables were expected because many factors, like tree species composition, affect both the physical structures and biological makeup of forest (Barbier, Gosselin, & Balandier, 2007). For example, Pretzsch (2014) found that crown projection significantly increases in mixed wood forests compared to pure deciduous or coniferous forests because of increasing crown overlap when both types are present in the same stand.

If a species was detected during a sampling period it was noted with a 1, and if not detected during a sampling period it was noted with a 0. Multiple sampling periods were conducted at each sampling site; therefore, models accounted for detection allowing for a true estimate of the probability of occupancy across sites and in relation to covariates of interest. For example, sites had 8 sampling periods each. If a species was detected only once out of the 8 sampling periods across multiple sites it would indicate the species has very low detection. This would mean that species would more likely be present but not detected during sampling. By having many

sampling events we hoped to reduce the bias of missing un-abundant species or low abundant species during sampling. Because ARU recordings cannot accurately differentiate among multiple individuals singing, abundance could not be determined. Instead my goal was to determine which variables could predict the occupancy of my focal species, and interpret which variables were directly or indirectly affecting occupancy.

Occupancy models were created using the package “unmarked” (Fiske & Chandler, 2011) in R version 3.4.4 (R Core Team, 2018) and used to calculate the predicted occupancy probability and detection probability. The first step in the model building process was testing detection variables (time of day, year, Julian day, and distance to the nearest road) for all four focal species (MacKenzie et al., 2002; Francis, Ortega, Cruz, 2011). The AIC values for the models testing detection variables for all four species were higher than the AIC values for the average detection model (~1~1), therefore detection variables were not used for any of the four species in their final model building process. Models were then created for each variable to determine their individual relationship with occupancy as compared to the average occupancy model (~1~1). Variables whose independent models had AIC values lower than the AIC value of the average occupancy model (~1~1) were then ranked from lowest to highest AIC value. Variables were then sequentially added (from lowest AIC to highest from the models testing individual variable relations) to the initial model with the lowest AIC to determine which variables led to the best model. Variables were retained in models if their addition lowered the AIC relative to the same model without that variable. Variables that had significant relationships with already-selected variables were added in place of the related variable already in the model (i.e., the initially-added variable(s) were removed from the models and the variable to be tested was added in their place). The new model was only kept if its AIC was lower than the model with the original related variable model. Variables were added and subtracted until all possible additions and exclusions of untested variables were attempted on the candidate model. When final top candidate model was determined the Nagelkerke’s  $R^2$  was calculated for the model. Figure 2 shows a flowchart of the model building process described above.

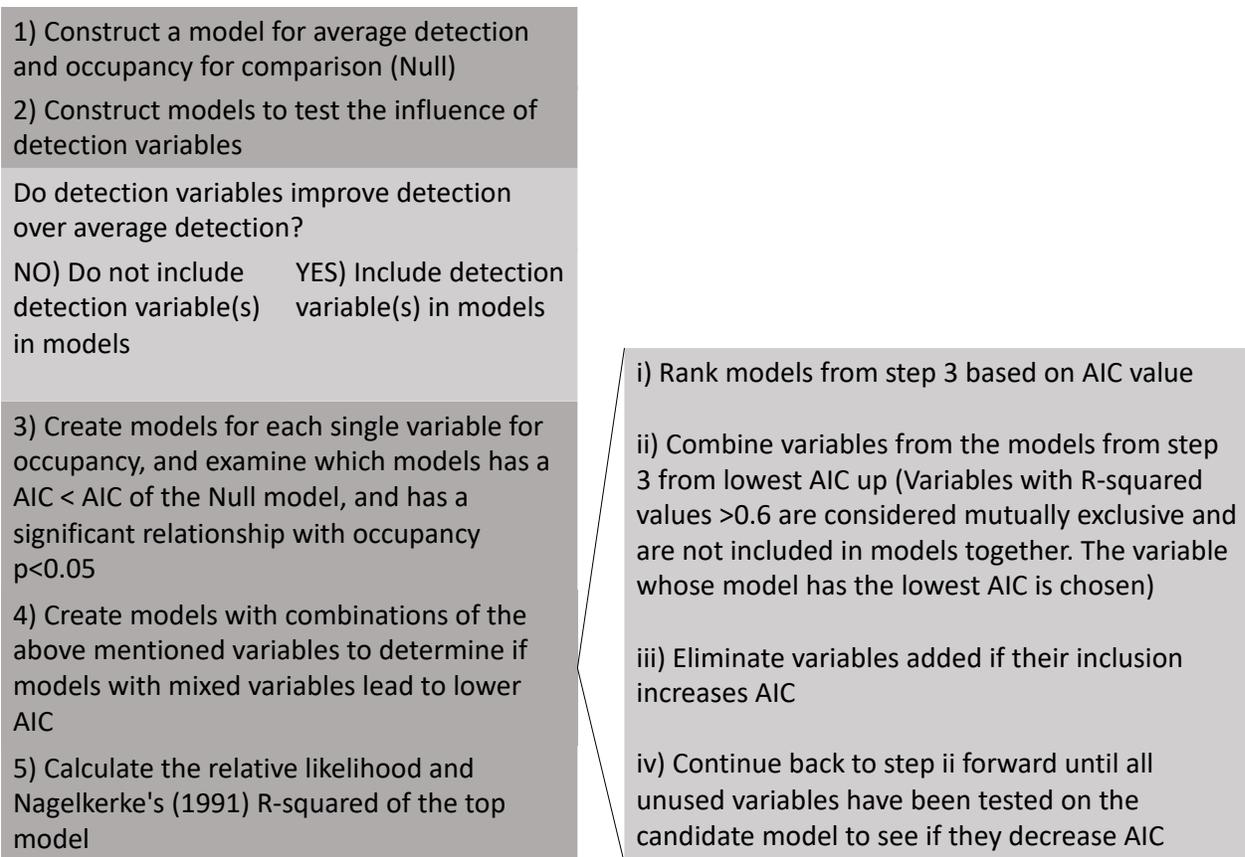


Figure 2: Occupancy model building process.

## 2.5 | Community Analysis

To examine how forest variables influenced compositional turnover, I used redundancy analysis (RDA). The RDA was created using the package “vegan” (Oksanen et al., 2018) in R version 3.4.4 (R Core Team, 2018). Species data was transformed using the Hellinger transformation (Legendre and Gallagher, 2001; Legendre and Legendre, 2012). The same set of variables used to create the occupancy models for my four focal species were used in the RDA. Variable selection for the model used the same modeling building process for the occupancy models, except higher  $R^2$  values were used for variable elimination instead of the lowest AIC values.

## 3 | Results

### 3.1 | Brown creepers

Brown creepers were detected in 134 out of 458 sites surveyed (Table A5). The top model for brown creepers had a predicted mean detection probability of 0.277 (Table A6). The probability of occupancy for brown creepers increased with the vertical complexity of the stands (Figure 3a), the percent cedar tree cover of the stand (Figure 3c), the percent standing dead tree cover of the stand (Figure 3d) and the percent water cover within the 100m landscape (Figure 3e). The probability of occupancy decreased with the percent forest cover within the 500 m landscape (Figure 3b), and percent maple tree cover of the stand (Figure 3f). (Table 1). Vertical complexity was the variable with the highest  $R^2$  value for the predicted occupancy of brown creepers (Table 1).

Table 1: The model for the predicted occupancy of brown creepers.

<b>Model</b>						<b>R<sup>2</sup></b>
~1 ~ vertical complexity + percent forest cover within 500m + % cedar + % dead trees + percent water cover + % maple						0.2
<b>Variable</b>	<b>Estimate</b>	<b>SE</b>	<b>z</b>	<b>P(&gt; z )</b>	<b>R<sup>2</sup></b>	
vertical complexity	6.37	1.019	6.25	4.03E-10	0.12	
percent forest cover within 500m	-3.93	1.411	-2.79	0.00534	0.0024	
% cedar	1.55	0.585	2.65	0.00815	0.047	
% dead trees	4.51	2.237	2.02	0.0436	0.0096	
percent water cover	1.09	0.66	1.64	0.100	0.049	
% maple	-1.03	0.663	-1.55	0.120	0.000084	

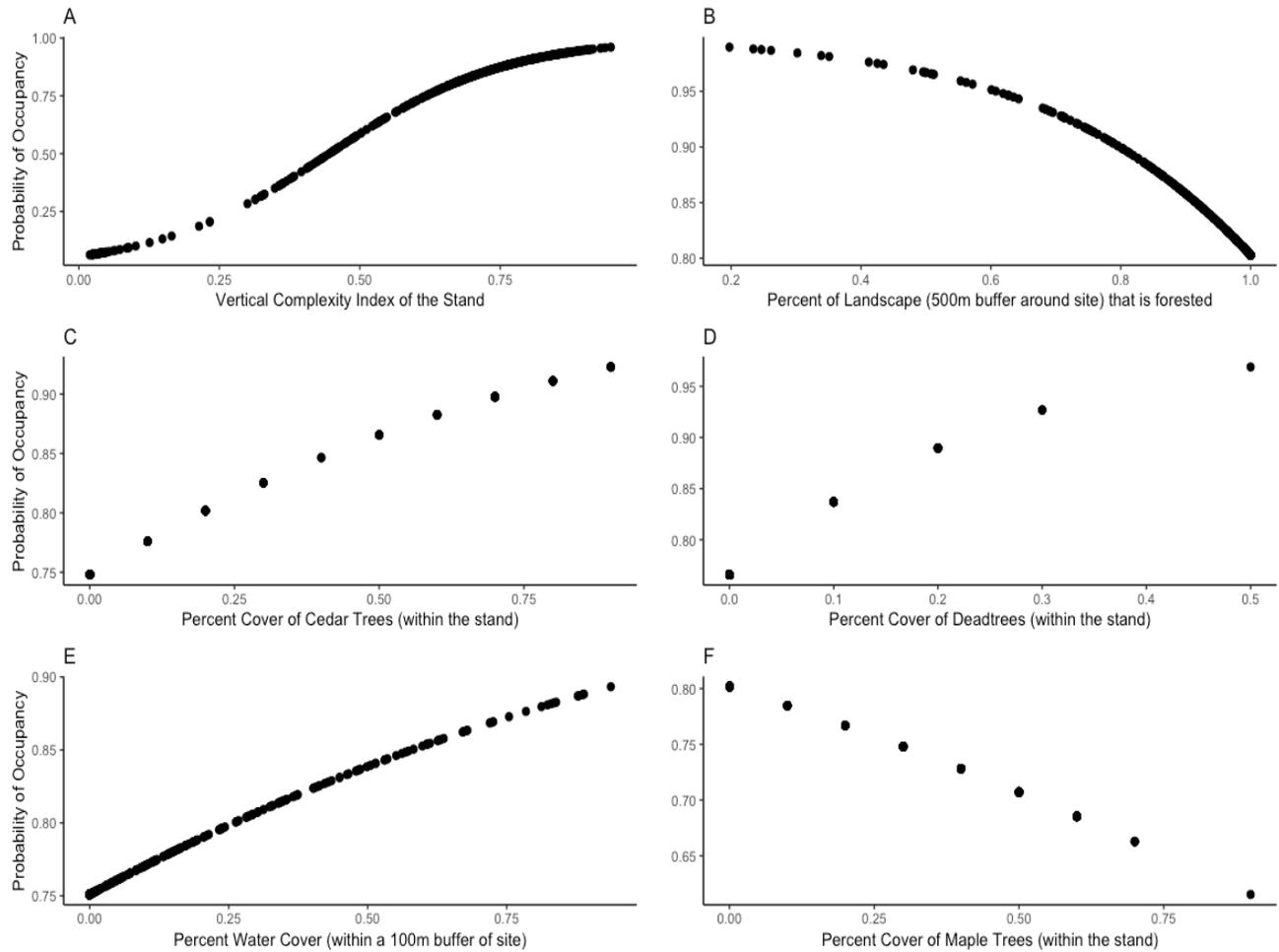


Figure 3: Probability of occupancy of brown creepers in Black Brook (Y axis) in relation to A: vertical complexity of the stand, B: percent forest cover within the 500 m landscape, C: percent cedar tree cover of the stand, D: percent standing dead tree cover of the stand, E: percent water cover within the 100m landscape, F: percent maple tree cover of the stand (X Axis).

### 3.2 | Canada warblers

Canada warblers were detected in 83 out of 458 sites surveyed (Table A5). The top model for Canada warblers had a mean predicted detection probability of 0.368 (Table A7). The probability of occupancy for Canada warblers increased with the percent fir tree cover of the stand (Figure 4B), the deadwood volume of the stand (Figure 4D), the percent cedar tree cover of the stand (Figure 4E), the forest cover within the 200m landscape (Figure 4G), and the water cover within the 100m landscape (Figure 4H). The probability of occupancy decreased with the percent fir tree cover of the stand (Figure 4A), the percent maple tree cover of the stand (Figure 4C), and the

crown closure of the stand (Figure 4F). (Table 2). Percent fir cover was the variable with the highest  $R^2$  value for the predicted occupancy of Canada warblers (Table 2).

Table 2: The model for the predicted occupancy of Canada warblers.

<b>Model</b>						<b>R<sup>2</sup></b>
~1 ~ trees per hectare + % fir + % maple + dead wood volume+ % cedar + crown closure + percent forest cover within 200m + percent water cover						0.24
<b>Variable</b>	<b>Estimate</b>	<b>SE</b>	<b>z</b>	<b>P(&gt; z )</b>	<b>R<sup>2</sup></b>	
trees per hectare	-0.00213	0.000421	-5.05	4.48E-07	0.0024	
% fir	3.24	0.898	3.61	3.09E-04	0.093	
% maple	-4.09	1.13	-3.6	3.16E-04	0.0523	
dead wood volume	0.0537	0.0171	3.13	0.00173	0.0250	
% cedar	1.74	0.587	2.97	0.00294	0.0884	
crown closure	-2.00	0.942	-2.13	0.0334	0.0194	
percent forest cover within 200m	3.19	1.51	2.1	0.0353	0.0154	
percent water cover	1.35	0.673	2.01	0.0446	0.0817	

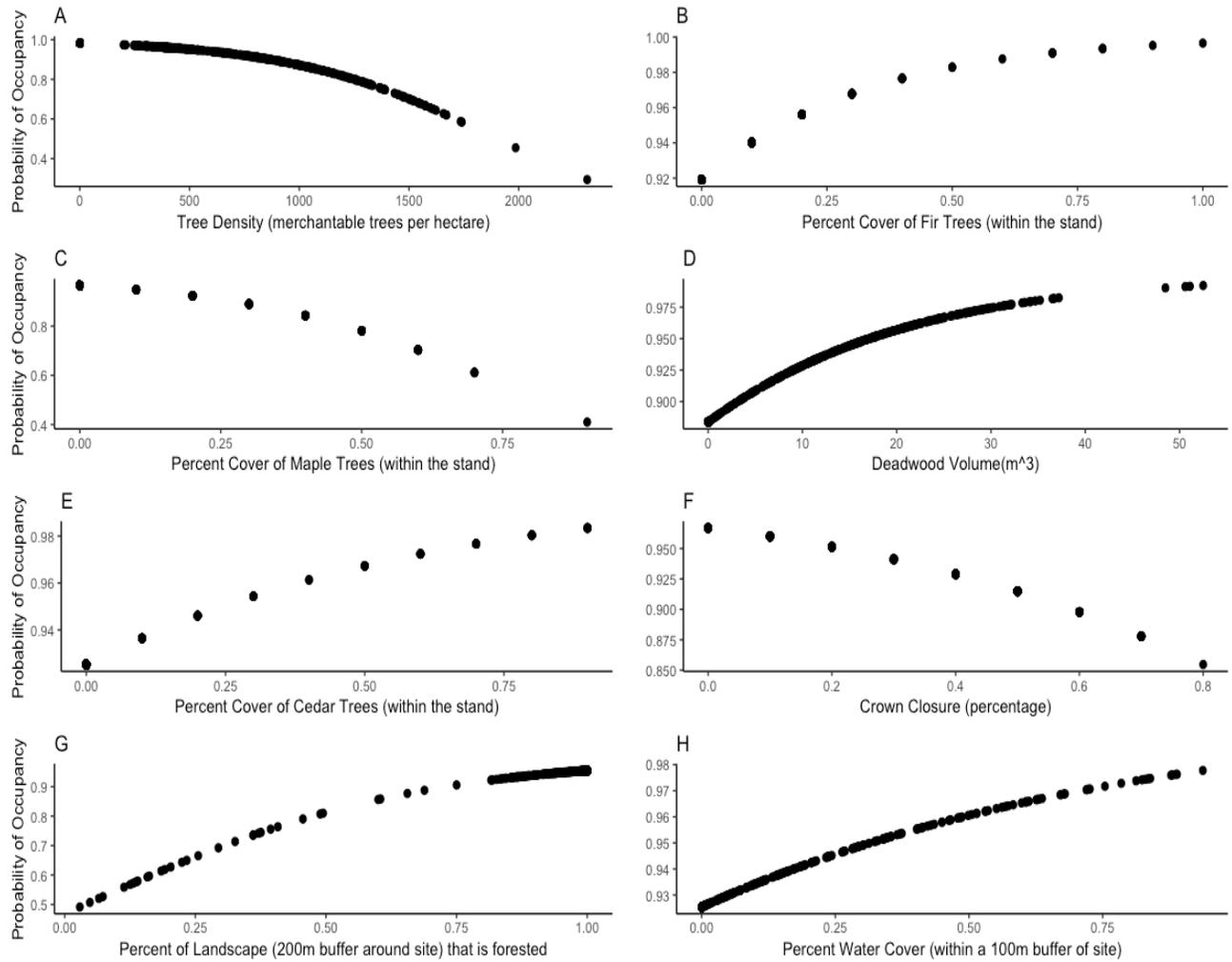


Figure 4: Probability of occupancy of Canada warblers in Black Brook (Y axis) in relation to A: tree density of the stand, B: percent fir tree cover of the stand, C: percent maple tree cover of the stand, D: deadwood volume of the stand, E: percent cedar tree cover of the stand, F: crown closure of the stand, G: percent forest cover within the 200 m landscape , H: percent water cover within the 100m landscape (X Axis).

### 3.3 | Olive-sided flycatchers

Olive-sided flycatchers were detected in 89 out of 458 sites surveyed (Table A5). The top model for olive-sided flycatchers had a predicted mean detection probability of 0.274 (Table A8). The probability of occupancy for olive-sided flycatchers decreased with the maple tree cover of the stand (Figure 5A), the tree density of the stand (Figure 5B), and the crown closure of the stand

(Figure 5C). (Table 3). Percent maple cover was the variable with the highest  $R^2$  value for the predicted occupancy of olive-sided flycatchers (Table 3).

Table 3: The model for the predicted occupancy of olive-sided flycatchers.

Model						$R^2$
~1 ~ % maple + trees per hectare + crown closure						0.067
Variables	Estimate	SE	z	P(> z )	$R^2$	
% maple	-3.954	0.777	-5.09	3.59E-07	0.0531	
trees per hectare	-0.000832	0.000238	-3.5	4.66E-04	-0.00037	
crown closure	-1.0613	0.493	-2.14	3.21E-02	0.00215	

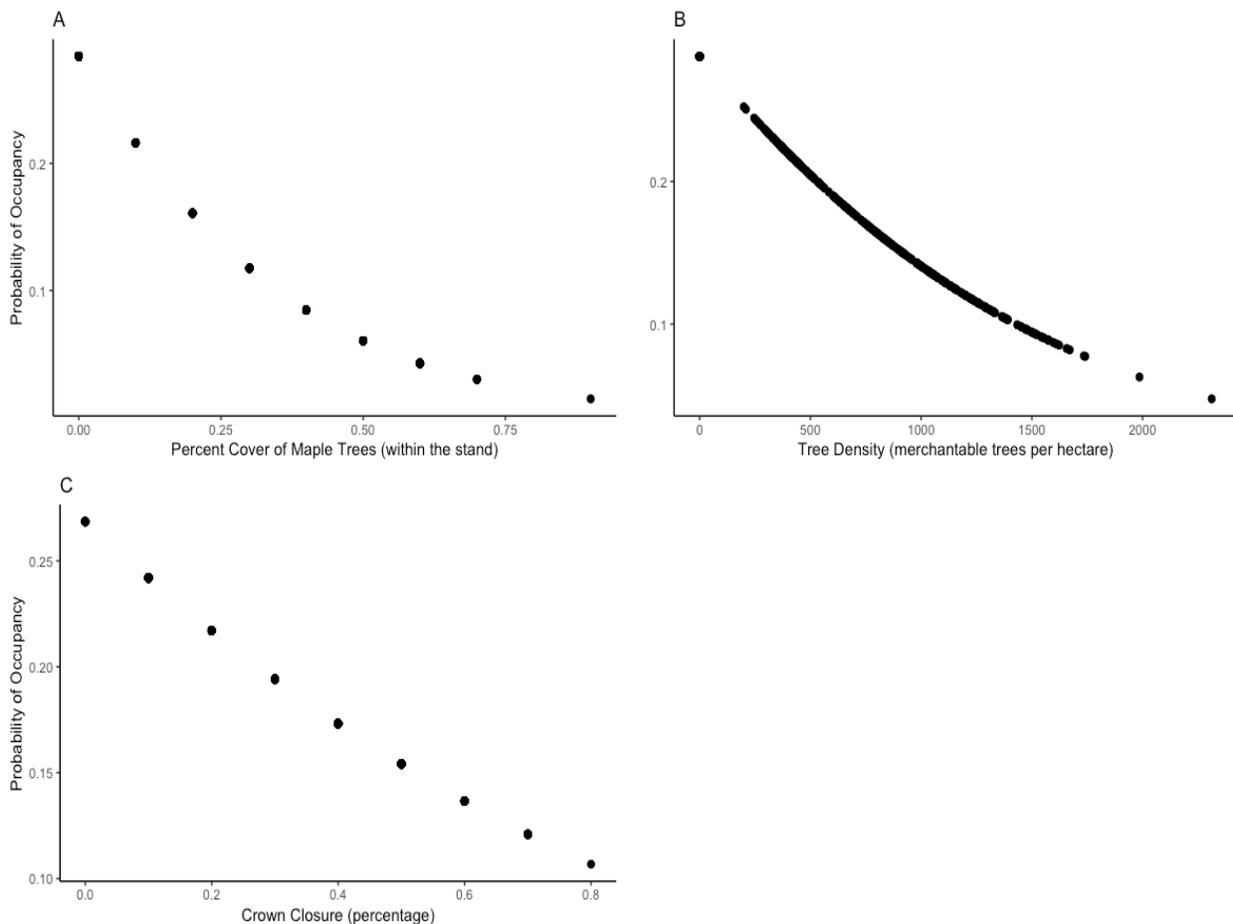


Figure 5: Probability of occupancy of olive-sided flycatchers in Black Brook (Y axis) in relation to A: percent maple tree cover of the stand, B: tree density of the stand, C: crown closure of the stand (X axis).

### 3.4 | Ovenbirds

Ovenbirds were detected in 283 out of 458 sites surveyed (Table A5). The top model for ovenbirds had a predicted mean detection probability of 0.624 (Table A9). The probability of occupancy for ovenbirds increased with the percent deciduous tree cover of the stand (Figure 6A), the deadwood volume of the stand (Figure 6B). The probability of occupancy decreased with the percent forest cover within the 500m landscape (Figure 6C), the percent cedar tree cover of the stand (Figure 6D), the percent beech tree cover of the stand (Figure 6E), and the percent water cover within the 100m landscape (Figure 6F). (Table 4). Percent deciduous tree cover was the variable with the highest  $R^2$  value for the predicted occupancy of ovenbirds (Table 4).

Table 4: The model for the predicted occupancy of ovenbirds.

<b>Model</b>						<b>R<sup>2</sup></b>
~1 ~ percent deciduous forest cover + dead wood volume + percent forest cover within 500m						0.35
+ % cedar + % beech + percent water cover						
<b>Variables</b>	<b>Estimate</b>	<b>SE</b>	<b>z</b>	<b>P(&gt; z )</b>	<b>R<sup>2</sup></b>	
percent deciduous forest cover	3.98	0.598	6.66	2.74E-11	0.320	
dead wood volume	0.0438	0.0149	2.94	0.00329	0.080	
percent forest cover within 500m	-0.596	0.214	-2.78	0.00542	0.044	
% cedar	-1.57	0.594	-2.64	0.00838	0.081	
% beech	-3.07	1.59	-1.93	0.0542	0.075	
percent water cover	-0.897	0.606	-1.48	0.139	0.063	

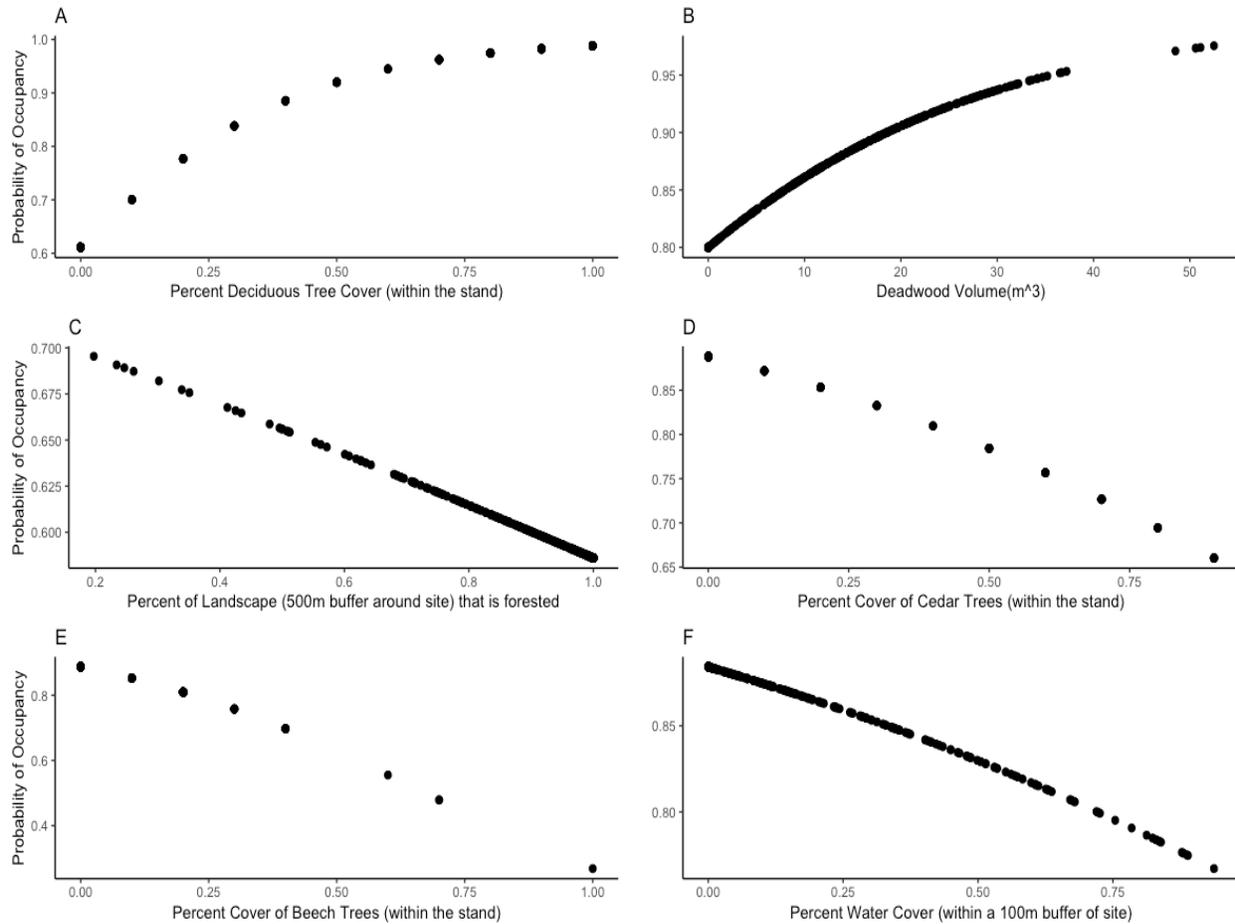


Figure 6: Probability of occupancy of ovenbirds in Black Brook (Y axis) in relation to A: percent deciduous forest cover of the stand, B: dead wood volume of the stand, C: percent forest cover within the 500 m landscape, D: percent cedar tree cover of the stand, E: percent beech tree cover of the stand, F: percent water cover within the 100m landscape (X Axis).

### 3.5 | Community Analysis

In 2016 and 2017 respectively, 88 and 77 bird species were detected on automated recording units. Over the two seasons 90 bird species were recorded (Table A5). The top RDA model had a  $R^2$  value of 0.1587. The variables included in the model were percent deciduous forest cover of the stand, percent forest cover within the 300 m landscape, percent beech tree cover of the stand, dead wood volume of the stand, percent cedar tree cover of the stand, the percent water cover within the 100m landscape, the tree density of the stand (TPH), the percent fir tree cover of the stand, the percent dead tree cover of the stand, the percent aspen tree cover of the stand, the percent pine/larch tree cover of the stand, and the percent cherry/alders cover of the stand (Figure

7). The percent deciduous forest cover of the stand ( $r^2=0.0766$ ) and the percent forest cover within the 300 m landscape ( $r^2 = 0.0261$ ) were the two most important predictors for avian community composition in the RDA (Table A10).

The RDA axis 1 (Figure 7) is most closely related to percent deciduous tree cover and beech tree cover. Cedar, fir, pine/larch cover all have negative scores on axis 1 and aspen and beech cover have positive scores. This suggests that RDA axis 1 is a measure of forest type from coniferous forest to deciduous forest. RDA axis 2 is most closely related to the percent forest cover within the 300m landscape (Figure 7). This suggests that axis 2 is possibly a measure of forest cover/the number of trees in the landscape.

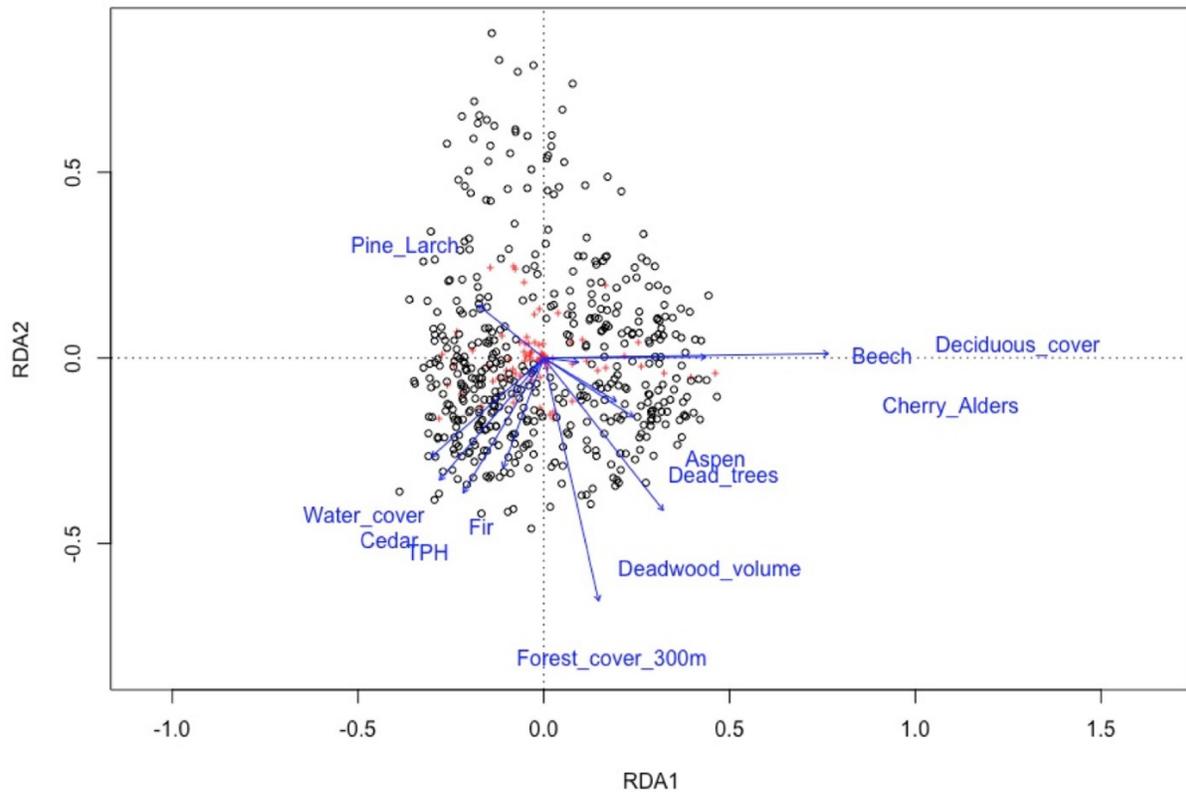


Figure 7: Axes 1 and 2 of redundancy analysis (RDA) of avian species in Black Brook district forest.

## 4 | Discussion

### 4.1 | Variables that drive the occupancy of brown creepers

The model for the occupancy of brown creepers in the Black Brook district suggests that ideal habitat is in forest stands with high vertical complexity. This means that according to the model brown creepers are more likely to be found in forest with multiple vegetation layers. This is a predictable result, because brown creepers are commonly associated with old growth forest (Poulin et al., 2013) and the vertical complexity of a stand generally increases with forest age (Kane et al., 2010). The model also suggests that habitat for brown creepers includes increased water cover in the landscape, increased cedar and dead tree cover, as well as decreased maple tree cover. This is consistent with the literature as brown creepers are known to inhabit mixed and coniferous wetlands (Poulin et al., 2013). This is because these conditions provide trees, particularly dead trees (snags), with loose or deeply furrowed bark, which are essential for foraging and nesting (Blewett & Marzluff, 2005; Poulin et al., 2013; Geleynse et al., 2016).

My model on the habitat preference of brown creepers in the Black Brook district contradicts previous literature on the need for abundant forest cover in the landscape. The model results suggest that the occupancy of brown creepers in the Black Brook district will increase with a decrease in forest cover within the 500m landscape, while other studies have suggested that brown creepers are sensitive to lower forest cover in the landscape, particularly older growth forests (Imbeau, Savard, & Gagnon, 2000; Poulin et al., 2008; Poulin & Villard, 2011; Geleynse et al., 2016). In the literature it is suggested that harvesting activities and the loss of forest in the landscape will decrease the number of dead and large-trunked trees, and therefore decrease available habitat for brown creepers to nest and forage (Hobson & Schieck, 1999). This relationship between harvesting and dead tree retention is important to keep in mind when considering forest management in the Black Brook district. Management activities in the Black Brook district may not be reducing (directly or indirectly) essential habitat for brown creepers, which is old growth mixed or coniferous wetlands with plentiful snags. This is because according to my model habitat for brown creepers is located in wet areas and as such, may be protected by the Clean Water Act (O.C. 2001- 488), which mandates the protection of riparian

buffers by prohibiting clear cuts around watersheds and, and limiting selective harvesting in and around waterbodies.

Another possible explanation as to why the amount of forest in the landscape has a negative relationship with the occupancy of brown creepers may also have to do with their inclination to reside in forest stands near water bodies. Forest cover may be lower at a landscape scale around these stands because areas around wetlands and waterbodies are generally more open when forest cover is calculated, since most bodies of water in the landscape are generally un-forested.

With these habitat requirements future management for brown creepers would likely require the conservation of old growth mixed or coniferous wetlands with increased numbers of cedars and dead trees. To ensure preservation of old growth forests, high vertical complexity, and the abundance of old and dead trees I recommend that intensive selective harvesting is avoided in mature and overmatured mixed and coniferous stands, particularly in wetter areas. This is because selective harvesting may reduce the number of dead trees (Fuller, Harrison, & Lachowski, 2004; Wisdom & Bate, 2008), and vertical complexity (Crow, Buckley, Nauertz, & Zasada, 2002). To increase available habitat for brown creepers I recommended that more areas adjacent to water bodies and in wetter areas be set aside for old growth coniferous forest, particularly cedar trees, and harvesting is reduced in these areas to ensure adequate vertical complexity and standing dead trees. Further research should consider focusing on gathering more information on how brown creepers in the Black Brook district respond to the lower amounts of old growth forest, and the possible reduction of standing dead trees in harvested areas.

#### **4.2 | Variables that drive the occupancy of Canada warblers**

The model for the occupancy of Canada warblers in the Black Brook district suggest that ideal habitat is most likely to be found in forest stands with low tree density and low crown closure. The modeled preference for forests with low tree density and crown closure is most likely caused by the need for well-developed understory vegetation (Reitsma, et al., 2009), which is typically enhanced by lower tree density and crown closure (Runkle, 1981; Canham, 1988; Kneeshaw & Bergeron, 1998). This result is expected because Canada warblers are commonly associated with more open forests with well-developed understory vegetation in the Eastern part of their range

(Reitsma, et al., 2009). My model results also suggest that Canada warblers in the Black Brook district have higher occupancy with increased water cover in the landscape, likely because they frequently nest in wetland areas, often on sphagnum moss hummocks, or decaying tree stumps (Reitsma, et al., 2009).

In addition, my model results suggest an increase in the occupancy of Canada warblers with increased fir and cedar tree cover, as well as increased deadwood. This forest type preference is common across the breeding range, although forest type preference can vary considerably in some areas (Reitsma, et al., 2009). This would suggest that individual tree species are not influencing occupancy, but rather that the individual tree species are indicators of the stand characteristics Canada warblers are seeking, such as open canopy, and wetlands with abundant vegetation (Runkle, 1981; Canham, 1988; Kneeshaw & Bergeron, 1998; Reitsma, et al., 2009).

My model results also suggest that occupancy of Canada warblers is positively related to increased forest cover in the 200m landscape. This possible response to lower forest cover in the landscape has been reported before in the context of urbanization and agricultural encroachment (Ambuel & Temple, 1983; Robbins, Dwson, & Dowell, 1989), but other literature has suggested that Canada warblers are resilient against lower forest cover in the landscape and forest loss related to forestry (Schmiegelow et al., 1997; Ball et al., 2016). However, the resiliency of Canada warblers to harvesting activities depends on the type of harvesting. Canada warblers can thrive in partially harvested stands as long as the forests retains understory vegetation and some overstory tree cover (Hagan et al., 1997; Hallworth et al., 2008b). This is likely because areas where forests have been intensively harvested cannot provide the important vegetation structure needed for sustaining resources needed by Canada warblers (Hagan et al., 1997; Hallworth et al., 2008b). In the Black Brook district, the local depletion of forest cover may be reducing occupancy because adjacent stands needed for foraging do not have the vegetation growth and structure needed to support the food supply for foraging Canada warblers. This issue may be exacerbated by the fact that Canada warblers are known to have clustered dispersion while breeding (Reitsma et al., 2009; Hunt, Bayne, & Haché, 2017). This clustering combined with reduction in foraging territory in the larger landscape could be pushing Canada warblers out of

suitable forest stands, since there is not enough forest in the surrounding landscape to support multiple breeding pairs (Flockhart et al., 2016; Hunt, Bayne, & Haché, 2017).

With these habitat requirements future management for Canada warblers would likely require conserving more open fir and cedar dominant mixed or coniferous wetlands, with plentiful deadwood. Future efforts should be made to ensure selective harvesting in stands suitable for Canada warblers is done in a way that opens up the canopy and leaves ground vegetation and natural deadwood intact. Conserving habitat for Canada warblers would also likely require conserving larger forest stands around wetland areas. Larger coniferous forest in and around wetland areas may provide more space to host multiple Canada warblers during the breeding season. This also means ensuring that stands within the nearby landscape are also retained and not completely harvested since it appears that nesting Canada warblers may need adjacent stands to support their habitation. Future work on the habitat needs of Canada warblers in the Black Brook district should considering focusing on the extent to which forest in the larger landscape need to be preserved from complete or intensive harvesting to support multiple Canada warblers.

#### **4.3 | Variables that drive the occupancy of olive-sided flycatchers**

The model for the occupancy of olive-sided flycatchers in the Black Brook district suggest that ideal habitat is in stands with low maple tree cover, tree density, and crown closure. Olive-sided flycatchers are known to prefer more open habitat, specifically coniferous forest adjacent to forest edges or openings (Altman & Sallabanks, 2012), therefore these results are consistent with the literature. Maple stands are associated with more closed forest habitat because they will have fewer openings over the landscape. This is because maple forests have large overstory crowns that often overlap adjacent trees (Barbier, Gosselin, & Balandier, 2007; Pretzsch, 2014). These results are more indicative of the habit type olive-sided flycatchers select rather than being a direct cause for occupancy, especially in regard to the negative association of the occupancy of olive-sided flycatchers and maple tree cover. The habitat of olive-sided flycatchers has been generally associated with coniferous forests (Altman & Sallabanks, 2012); therefore, the relationship between maple tree cover and the occupancy of olive-sided flycatchers is most likely because maple tree cover is negatively related to the actual habitat variables they are selecting. When we look at how maple trees are related forest openness and consider the other two

variables, we can see that olive-sided flycatchers are most likely selecting more open habitat. Stands with low maple tree cover, tree density, and crown closure are more likely to have open spaces for foraging activities.

With these habitat requirements future management for olive-sided flycatchers would likely require conserving low density, low crown closure, mixed and coniferous forest, with minimal maple tree cover. However, this suggestion should be taken with more caution than other three management suggestions in this thesis since the model created for the occupancy of olive-sided flycatchers is not as strong as those for the other three species (Table A6, A7, A8 and A9). A more fitting management plan would be to consider conserving more open forest habitats in general, possibly in coniferous dominated areas. Future studies into the habitat selection of olive-sided flycatchers in the Black Brook district should consider other forest variables such as the amount of clear cutting and selective cutting in the landscape (Robertson & Hutto, 2007; Rolek, Harrison, Loftin, & Wood, 2018).

#### **4.4 | Variables that drive the occupancy of ovenbirds**

The model for the occupancy of ovenbirds in the Black Brook district suggest that they are more likely to inhabit forests with high deciduous tree cover, high dead wood volume, and low cedar and beech tree cover. Deciduous forest habitat is commonly associated with ovenbirds, because open forest with deep leaf litter are likely a requirement for foraging (Porneluzi, Van Horn, & Donovan, 2011). Ovenbirds are also presumed to occupy mixed woods, although my model would suggest low occupancy in mixed wood forest with increased cedar tree cover.

The modeled preference for habitat with increased deadwood, low beech tree cover, and increased deciduous tree cover may be related. According to the model ovenbirds appear to avoid stands with increased beech tree cover, which contradicts an assumed preference for mixed beech/maple/birch forest (Porneluzi, Van Horn, & Donovan, 2011). The two of most common deciduous trees in the Black Brook district forest are maple and birch, which have a slight positive relationship with deadwood volume (maple:  $R^2 = 0.28$   $p < 0.001$ , birch:  $R^2 = 0.15$   $p < 0.001$ ), whereas beech tree cover does not ( $R^2 = 0.05$   $p = 0.269$ ). This suggests that deadwood is possibly a natural characteristic in some maple and birch stands in the Black Brook district, but

not in stands with high beech tree cover. Deadwood is reported to be an important forest characteristic for ovenbirds as it provides cover for nesting (Burke & Nol, 1998). This means that both deciduous tree cover and deadwood are possible important habitat characteristics for ovenbirds.

My models also indicated that ovenbirds preferred sites with lower water cover in the landscape. This is expected as ovenbirds need access to the ground within their territory to forage for food (Porneluzi, Van Horn, & Donovan, 2011) which would likely be reduced if the ground was covered in water.

Finally, my model results also indicate that the occupancy of ovenbirds is positively related to reduced forest cover within the 500m landscape. This result contraindicates the literature which reports that ovenbirds may be sensitive to lower forest cover in the landscape (King, Griffin, & Degraaf, 1996; Burke & Nol, 1998; Villard & Hache, 2012). A possible explanation for this contradiction is the influence of predators in the Black Brook district. Morton (2005) found that ovenbirds may prefer to nest adjacent to forest edges, when the most common predators, eastern chipmunks (*Tamias striatus*), are more abundant in forest interiors. If common nest predators such as eastern chipmunks and red squirrels (*Tamiasciurus hudsonicus*) (Reitsma, Holmes, & Sherry, 1990) are more abundant in forest interiors in the Black Brook district then this may be driving ovenbirds to select habitat adjacent to un-forested land.

With these habitat requirements future management for ovenbirds should consider focusing on conserving deciduous forests with plentiful deadwood in dryer areas. I also recommend that forest management consider limiting or avoiding the removal of deadwood from deciduous and mixed wood forest stands. I also recommend further research on the underlying patterns of occupancy as it relates to forest cover on the landscape. Future studies on the habitat selection of ovenbirds in the Black Brook district should also consider examining the possible relationships among nest survival, territory placement, and predator density.

#### **4.5 | Local and landscape level variable influence on avian occupancy modelling**

The models for my four focal species suggest that occupancy was related to both local and landscape level variables. This implies that management changes at both the local stand and

landscape level may affect species distributions. While I only tested two landscape level variables (Forest cover and water cover), and 18 local stand level variables, landscape variables were never the main driver of occupancy for either of my four species, and in the models where landscape variables were present, they contributed very little to the predicted occupancy of the focal species.

The importance of landscape variables is often dependent on the life history and behaviour of the species in question. Flather and Sauer (1996) found that neotropical migrants may have stronger responses to landscape variables than permanent residents. Mitchell, Lancia, and Gerwin (2001) concluded that models fit exclusively with landscape variables showed higher fit with habitat specialist compared to habitat generalist species. Among my four species Canada warblers, olive-sided flycatchers, and ovenbirds are neotropical migrants, and ovenbirds are the only species of the four that could be considered a habitat generalist.

Because brown creepers, Canada warblers, and ovenbirds had at least one or more landscape level variable influencing their predicted occupancy in the models, combined with evidence from the literature, I suggest that management efforts also focus on preserving forest variables for these birds at the landscape scale as well as at the local stand. However future work should look into the influences of more landscape level variables on top of the two examined in my models. Possible landscape variables worth examining in future research are landscape connectivity and fragmentation, and heterogeneity. Future species monitoring in the Black Brook district should consider the possible importance of landscape level variables along with local stand variables on bird occupancy, regardless of residency or habitat generalism, because conservation strategies are often most successful when considering multiple scales (Villard, Trzcinski, & Merriam, 1999; Lee et al., 2002).

#### **4.6 | Managing avian habitat in Black Brook district forest**

When comparing management recommendations for my four focal species, it is obvious that no one management strategy will maximize habitat for all four. For example, according to their models' brown creepers and Canada warblers both appear to prefer to reside in a coniferous and mixed forest wetland with abundant dead wood. However, brown creepers appear to require

dense and complex canopy layers and understory, while Canada warblers appear to require a more open or patchy forest. Conserving solely coniferous and mixed wetlands in the hopes of creating habitat for both could result in conserving forest mainly for one species.

The issue of conflicting multi-species management recommendations also occurs when we look at forest cover. In the Black Brook district, the species models indicate that decreasing forest cover in the landscape would likely create more suitable habitat for brown creepers and ovenbirds, but this would result in a theoretical reduction in suitable habitat for Canada warblers. Optimizing land to properly distribute management activities that reduce forest cover (like clear cutting) and those that preserve undisturbed habitat to accommodate multiple species requires extensive planning and difficult decision making.

Given these difficult issues, one possible option for creating species management plans in the Black Brook district is to prioritize species on their need for conservation, while also considering other obstacles to conservation like cost, feasibility, and the probability of success, and then determine to what extent each species conservation plan will take place (Regan et al., 2008). Black Brook district forest has the capacity to implement a multi-species management plan. This is because the forest is sufficiently managed and large enough to contain habitat for multiple species with unique habitat requirements if forest stand types are distributed with care. Overall this type of forest management to conserve avian species habitat suggests the need for increasing heterogeneity of forest types within the entire landscape.

If we look at how the composition of avian communities is related to various forest variables, we can also see the need to support greater heterogeneity within the forest landscape. Compositional variation in avian communities from the surveys suggests that most communities in the Black Brook district are influenced by variables closely related to the tree species composition (ie. deciduous, mixed wood, and coniferous tree cover), and the amount of forest cover in the landscape. However, instead of communities being clumped by forest type and tree cover, avian communities fall along gradients of forest types and cover amounts (Figure 7). This means that to maintain overall species diversity within the Black Brook district future management would likely have to focus on creating a highly heterogeneous landscape of various stand ages, forest

densities and cover, and coniferous to deciduous gradients. This pattern of species diversity increasing with increasing landscape heterogeneity is noted in the literature and is often used to emphasise the importance of ensuring multiple seral stages and tree species diversity when forest managers plan out forest regeneration and harvesting activities (Holmes & Sherry, 2001; Morelli et al., 2013).

In the end conservation efforts and management plans all depend on underlying goals. If the goal is to preserve habitat for a specific species, occupancy modelling can be used to help identify possible drivers of species habitat selection. These model results can then be used to create a list of possible variables needed in an environment for that species, and future management can be focused on increasing the availability of these variables in the landscape. However, most conservation efforts focus on increasing habitat for multiple species, or whole communities (Nicholson and Possingham, 2006; Mace, Possingham, & Leader-Williams, 2007). Single species conservation efforts are more typical if conservation goals want to focus on preserving habitat for species at risk or targeted species which may require more specific habitat protection (Root, Akçakaya, and Ginzburg, 2003; Mace, Possingham, & Leader-Williams, 2007).

If the goal is to provide multiple focal species with habitat or increase overall species diversity, then management activities need to be focused on increasing forest stand heterogeneity in the landscape. For forest management this means carefully planning out a patch-by-patch pattern on the landscape which represents forest stands from all seral stages and tree species compositions, while also being conscious about over fragmentation of the land (Tews et al., 2003; Smith, Fahrig, & Francis, 2011).

## Chapter 3 – Conclusion

My study examined the habitat characteristics four forest bird species (brown creepers, Canada warblers, olive-sided flycatchers, and ovenbirds), may be seeking out in the managed landscape of the Black Brook district of North Western New Brunswick, as well as the forest variables that influence the avian communities in the forest. Study sites within the forest were sampled using automated recording units to record avian species detections. The detections from the four focal species were then modeled using occupancy modelling to determine which forest variables influenced their occupancy. The species compositions of study sites were modeled using redundancy analysis to determine which forest variables influenced the avian communities. Table A11 is a summary of the predictions and results made about my focal species occupancy modelling.

The occupancy of brown creepers according to their model is mainly driven by the vertical complexity of forest stands. This factor and the other factors in its model indicate the brown creepers are most likely seeking dense old growth forest in wetter areas. The occupancy of Canada warblers according to their model is not strongly driven by any variables, but occupancy appears to be driven by the presence of fir and cedar trees, and the amount of water in the landscape. These factors and others in the model indicate that Canada warblers are most likely seeking out more open older growth coniferous/mixed wetlands with dense ground vegetation. The occupancy of olive-sided flycatchers according to their model is not strongly driven by any variables. However, the model does indicate that olive-sided flycatchers are most likely seeking out more open forests. The occupancy of ovenbirds is mainly driven by the deciduous forest cover in the landscape. This factor and others in the model indicate that ovenbirds are most likely seeking out dry, open understory deciduous forests. The redundancy analysis revealed that avian community composition in the Black Brook district is most likely being driven by the tree species composition of forest stands, and the amount of forest cover in the landscape.

The occupancy models and redundancy analysis suggest the most likely forest variables to influence species occupancy and avian communities. However, this does not mean that the variables indicated in the models are being selected for directly by a species or larger

communities. The variables indicated in models may be related to other characteristics that species are selecting when choosing habitat. Indeed, many variables I initially explored were highly correlated, suggesting some caution in interpretation. This is because in ecosystems like my study forest, most characteristics are highly related (Barbier, Gosselin, & Balandier, 2007; Pretzsch, 2014). This is easily seen by looking at the correlation matrix made for the forest variables in the Black Brook district forest (Figure A1). The relationship between variables selected in the models and other forest characteristics need to be considered when attempting to preserve or create habitat for birds. This means understanding how possible variables of interest may be describing the larger forest types over just the variables indicated in the models.

Results from this thesis emphasise the importance of increasing and maintaining landscape heterogeneity to maximize available habitat for avian communities and promoting species diversity. This method of maintaining landscape heterogeneity is common for multispecies management because of its noted effectiveness (Holmes & Sherry, 2001; Morelli et al., 2013). This management strategy may be useful in the Black Brook district to ensure the diverse avian communities there have adequate amounts of various habitat types. Black Brook district forest spans over 200,000 ha making it sufficiently large to implement this strategy to provide habitat for multiple bird species and communities. This also means that the Black Brook district forest also has the potential to be an example for how implementing management strategies that involve increasing forest type heterogeneity can provide habitat for multiple avian species for other managed forests in New Brunswick and Atlantic Canada.

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# Appendix A – Additional tables and figures

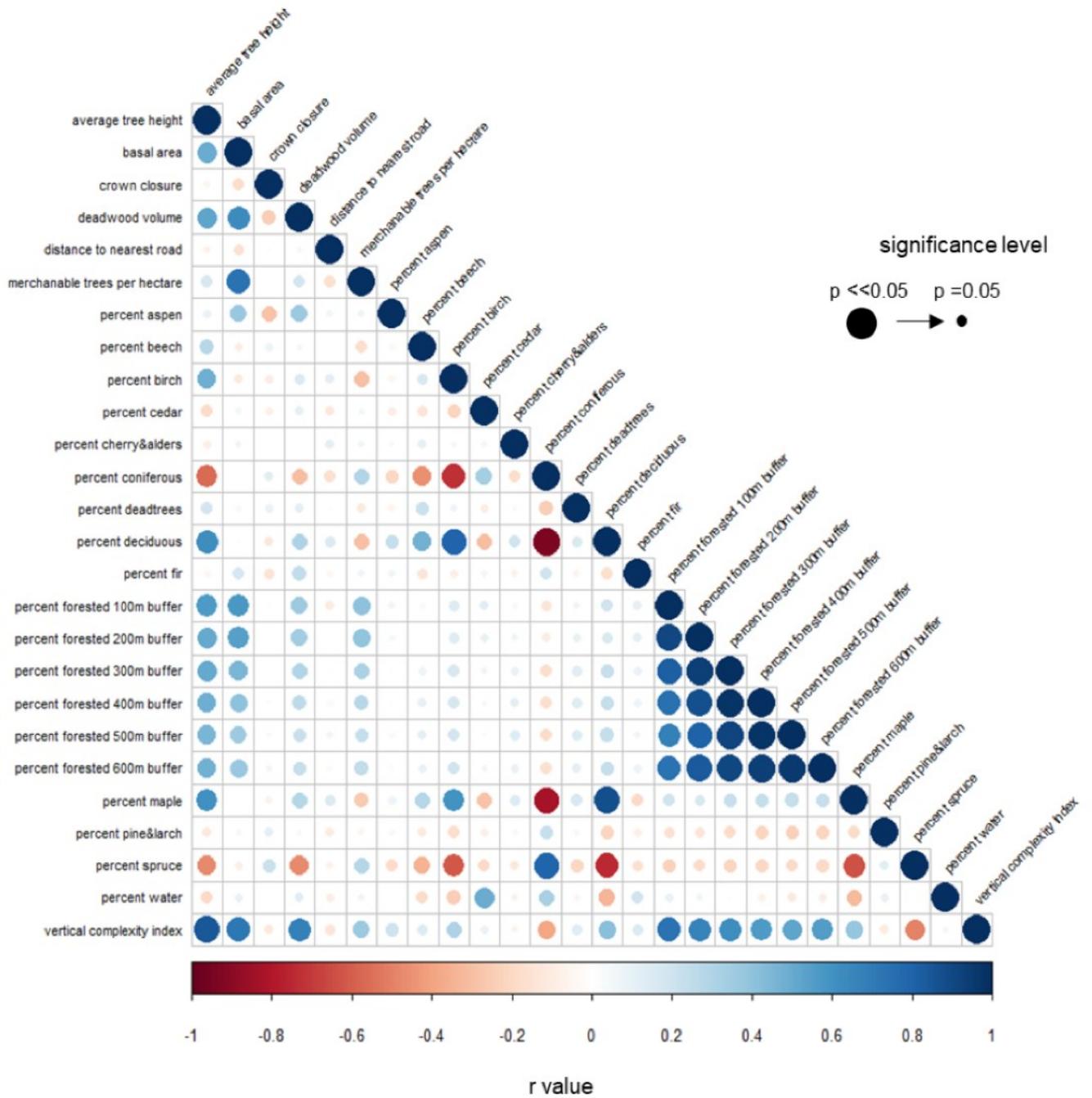


Figure A1: Correlation matrix for forest variables.

Table A1: Distribution of sampling sites from 2016 and 2017 to ensure adequate sampling in all forest types.

Forest type	2016	2017	total
Cedar mature managed	17	10	27
Cedar over mature	17	8	25
Early plantation (<10 years)	35	11	46
Intolerant immature	10	2	12
Intolerant mature	8	7	15
Mixed wood over immature	14	5	19
Mixed wood over mature	13	13	26
Old plantation (30-40 years)	45	8	53
Spruce/fir (5-15 years)	6	2	8
Spruce/fir immature (30-50 years)	8	4	12
Spruce/fir over mature	10	3	13
Shelter wood/mature riparian zone	16	5	21
Tolerant hardwood over mature	21	7	28
Tolerant hardwood over mature managed	29	18	47
Tolerant hardwood regeneration	8	3	11
Tolerant hardwood shelter wood	30	16	46
Young plantation (15-20 years)	34	15	49
<b>Total</b>	<b>321</b>	<b>137</b>	<b>458</b>

Table A2: Descriptions of the forest variables.

Forest Variable	Unit	Scale	Description
Average Tree Height	meters	Stand	Average tree height of all trees within an area

Basal Area	m <sup>2</sup> / ha	Stand	Average area occupied with tree stems and/or trunks
Crown Closure	percentage	Stand	Canopy closure: the proportion of an area covered by the crowns of live trees.
Deadwood Volume	m <sup>3</sup>	Stand	Amount of fallen deadwood in an area
Distance to Nearest Road	meters	Stand	Distance a sampling point is to the nearest highly trafficked road (roads currently being used for harvesting activities)
Percent Aspen	percentage	Stand	Percent of the forest that is made up of Aspen trees
Percent Beech	percentage	Stand	Percent of the forest that is made up of Beech trees
Percent Birch	percentage	Stand	Percent of the forest that is made up of Birch trees
Percent Cedar	percentage	Stand	Percent of the forest that is made up of Cedar trees
Percent Cherry / Alders	percentage	Stand	Percent of the forest that is made up of Choke Cherry and/or Alders
Percent Coniferous	percentage	Stand	Percent of the forest that is made up of coniferous trees
Percent Dead trees	percentage	Stand	Percent of the forest that is made up of harvestable standing dead trees
Percent Deciduous	percentage	Stand	Percent of the forest that is made up of deciduous trees
Percent Fir	percentage	Stand	Percent of the forest that is made up of Fir trees
Percent Forest cover (100m)	percentage	Landscape	Percent of the land within a 100m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover

Percent Forest cover (200m)	percentage	Landscape	Percent of the land within a 200m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover
Percent Forest cover (300m)	percentage	Landscape	Percent of the land within a 300m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover
Percent Forest cover (400m)	percentage	Landscape	Percent of the land within a 400m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover
Percent Forest cover (500m)	percentage	Landscape	Percent of the land within a 500m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover
Percent Forest cover (600m)	percentage	Landscape	Percent of the land within a 600m buffer distance that has an average tree height > 2.5 m, or any area without any tree cover
Percent Maple	percentage	Stand	Percent of the forest that is made up of Maple trees
Percent Pine/Larch	percentage	Stand	Percent of the forest that is made up of Pine and/or Larch trees
Percent Spruce	percentage	Stand	Percent of the forest that is made up of Spruce trees
Percent Water Cover	percentage	Landscape	Percent of the forest area that is considered a lake, pond, river, stream, or swamp
Tree Density	merchantable stems / ha	Stand	Number of trees within an area that are harvestable
Vertical Complexity Index	ratio	Stand	A measure of how often the forest structure changes as you move vertically up through the forest

Table A3: J. D. Irving Ltd. descriptions of forest stands management status categories.

Categories	J.D. Irving Ltd Classification	Irving Description	n
Merchantable Stand	F1	Merchantable stand (1996)	164
Merchantable and Unmerchantable Stand	F2	Merch. and unmerchantable stand (1996 interp.)	73
Unmerchantable Stand	F3	Unmerchantable stand (1996 interp.)	64
Plantation	Pl	Unmerchantable understory planted	41
		*all Plantation/Pl stands fell under the stand type 'Early Plantation (<10 Years)' (Table A4)	
Cut/Harvested	CC, PC, SC, UC, VR	CC: Clear cut PC: Partial harvest SC: Selection cut UC: Understory cut VR: Variable retention	112 (5, 15, 86, 1, 5)

Table A4: Permutation-based ANOVA testing for relationships between management status and forest variables.

Forest variable	DF	SUM SQ	MEAN SQ	ITER	Pr(Prob)
Average tree height	5	5156.1	1031.23	5000	<2.20E-16
Basal area	5	19918	3983.6	5000	<2.20E-16
Crown closure	5	0.5663	0.113265	5000	<2.20E-16
Dead wood volume	5	12067	2413.32	5000	<2.20E-16

Distance to nearest road	5	1.18E+08	23585521	5000	<2.20E-16
Percent 100m buffer forested	5	13.393	2.67866	5000	<2.20E-16
Percent 200m buffer forested	5	5.8868	1.17737	5000	<2.20E-16
Percent 300m buffer forested	5	4.7058	0.94116	5000	<2.20E-16
Percent 400m buffer forested	5	3.2041	0.64083	5000	<2.20E-16
Percent 500m buffer forested	5	2.0798	0.41597	5000	<2.20E-16
Percent 600m buffer forested	5	1.6552	0.33103	5000	<2.20E-16
Percent aspen	5	0.1854	0.037071	5000	0.0026
Percent beech	5	0.2534	0.050688	5000	0.0032
Percent birch	5	6.1723	1.23446	5000	<2.20E-16
Percent cedar	5	3.5327	0.70654	5000	<2.20E-16
Percent cherry & alders	5	0.05928	0.011856	5000	<2.20E-16
Percent coniferous	5	34.846	6.9692	5000	<2.20E-16
Percent dead trees	5	0.07011	0.014023	5000	<2.20E-16
Percent deciduous	5	27.87	5.5741	5000	<2.20E-16
Percent fir	5	1.1414	0.22828	5000	<2.20E-16
Percent maple	5	6.2861	1.2572	5000	<2.20E-16
Percent pine & larch	5	0.24364	0.048728	5000	<2.20E-16
Percent spruce	5	34.884	6.9768	5000	<2.20E-16
Percent Water Cover	5	1.6574	0.33148	5000	<2.20E-16
Tree Density	5	25263728	5052746	5000	<2.20E-16
Vertical complexity index	5	11.669	2.3338	5000	<2.20E-16

Table A5: Avian species site detection counts for the Black Brook district (2016 and 2017).

Species	Number of sites species was detected in out of 458 sites
Alder Flycatcher	153
American Bittern	27
American Crow	126
American Goldfinch	137
American Redstart	167
American Robin	423
American Woodcock	62
Bald Eagle	1
Barred Owl	27
Black-and-white Warbler	169
Bay-breasted Warbler	25
Black-capped Chickadee	179
Belted Kingfisher	3
Blue-headed Vireo	123
Bicknell's Thrush	24
Blackburnian Warbler	115
Blue Jay	203
Blackpoll Warbler	24
Bobolink	2
Boreal Chickadee	76
Brown Creeper	134
Black-throated-blue Warbler	205
Black-throated-green Warbler	329
Canada Goose	11
Canada Warbler	83
Cedar Waxwing	25

Chipping Sparrow	28
Cape-May Warbler	48
Common Grackle	2
Common Raven	69
Common Yellowthroat	135
Chestnut-sided Warbler	152
Downy Woodpecker	9
Eastern Whip-poor-will	1
Eastern Wood-pewee	58
European Starling	1
Evening Grosbeak	3
Field Sparrow	1
Fox Sparrow	112
Great-blue Heron	5
Gold-crown Kinglet	224
Great Horned Owl	11
Gray Catbird	1
Hairy Woodpecker	18
Hermit Thrush	395
Least Flycatcher	194
Lincoln Sparrow	56
Mallard	3
Magnolia Warbler	255
Mourning Dove	8
Mourning Warbler	131
Yellow-rumped Warbler (Myrtle)	291
Nashville Warbler	176
Northern Flicker	45
Northern Parula	272
Northern Waterthrush	95

Olive-sided Flycatcher	89
Ovenbird	283
Palm Warbler	16
Philadelphia Vireo	11
Pine Siskin	72
Pine Warbler	7
Pileated Woodpecker	73
Purple Finch	68
Rose-breasted Grosbeak	48
Red-breasted Nuthatch	195
Ruby-crown Kinglet	206
Red-eyed Vireo	354
Ruffed Grouse	145
Ruby-throated Hummingbird	2
Rusty Blackbird	4
Savannah Sparrow	20
Slate-coloured Junco	169
Scarlet Tanager	4
Song Sparrow	37
Swamp Sparrow	25
Swainson's Thrush	365
Tennessee Warbler	31
Tufted Titmouse	1
Veery	87
White-breasted Nuthatch	5
Wilson's Snipe	139
Wild Turkey	1
Wilson's Warbler	16
Winter Wren	344
Wood Thrush	3
White-throated Sparrow	402

Yellow-bellied Flycatcher	42
Yellow-bellied Sapsucker	314
Yellow Warbler	2
Unknown Blackbird	24
Unknown Finch	3
Unknown Flycatcher	3
Unknown Bird	81
Unknown Owl	1
Unknown Raptor	4
Unknown Shorebird	5
Unknown Thrush	55
Unknown Vireo	26
Unknown Warbler	11
Unknown Woodpecker	164
Unknown Kinglet	73

Table A6: Top predictor models for the occupancy of brown creepers.

	AIC	$\Delta$ AIC	model weight	relative likelihood	R <sup>2</sup>
~1 ~ vertical complexity + percent forest cover within 500m + % cedar + % dead trees + percent water cover + % maple	1761.194	0	0.355	1	0.2
~1 ~ vertical complexity + percent forest cover within 500m + % cedar + % dead trees + percent water cover	1761.586	0.39	0.292	0.822	0.19
~1 ~ vertical complexity + percent forest cover within 500m + % cedar + % dead trees + % maple	1761.869	0.67	0.253	0.713	0.19
~1 ~ vertical complexity + percent forest cover within 500m + % cedar + % dead trees	1764.104	2.91	0.0829	0.233	0.18

~1 ~ vertical complexity + % cedar + % dead trees + percent water cover + % maple	1767.361	6.17	0.0163	0.0458	0.18
---	----------	------	--------	--------	------

Table A7: Top predictor models for the occupancy of Canada warblers.

	AIC	$\Delta$ AIC	model weight	relative likelihood	R <sup>2</sup>
~1 ~ trees per hectare + % fir + % maple + dead wood volume+ % cedar + crown closure + percent forest cover within 200m + percent water cover	1210.269	0	0.472	1	0.24
~1 ~ trees per hectare + % fir + % maple + dead wood volume+ % cedar + crown closure + percent forest cover within 200m + percent water cover + % cherry/alders	1211.842	1.573	0.215	0.455	0.24
~1 ~ trees per hectare + % fir + % maple + dead wood volume+ % cedar + crown closure + percent forest cover within 200m	1212.143	1.874	0.185	0.392	0.24
~1 ~ trees per hectare + % fir + dead wood volume+ % cedar + crown closure + percent forest cover within 200m + percent water cover	1213.853	3.584	0.0787	0.167	0.24
~1 ~ trees per hectare + % fir + % maple + dead wood volume+ % cedar + crown closure + percent water cover	1214.821	4.552	0.0485	0.103	0.23

Table A8: Top predictor models for the occupancy of olive-sided flycatchers.

	AIC	$\Delta$ AIC	model weight	relative likelihood	R <sup>2</sup>
~1 ~ % maple + trees per hectare + crown closure	1282.654	0	0.355	1	0.067
~1 ~ % maple + trees per hectare + crown closure + percent water cover	1282.782	0.128	0.333	0.938	0.071

~1 ~ % maple + trees per hectare + crown closure + percent water cover + percent forest cover within 500m	1284.874	2.245	0.115	0.325	0.070
~1 ~ % maple + trees per hectare + crown closure + percent forest cover within 500m	1285.067	2.418	0.106	0.298	0.066
~1 ~ % maple + basal area + crown closure + percent water cover + percent forest cover within 500m	1285.367	2.723	0.091	0.256	0.069

Table A9: Top predictor models for the occupancy of ovenbirds.

	AIC	$\Delta$ AIC	model weight	relative likelihood	R <sup>2</sup>
~1 ~ percent deciduous forest cover + dead wood volume + percent forest cover within 500m + % cedar + % beech + percent water cover	3403.928	0	0.252	1	0.35
~1 ~ percent deciduous forest cover + dead wood volume + percent forest cover within 500m + % cedar + % beech	3404.151	0.223	0.225	0.894	0.35
~1 ~ percent deciduous forest cover + dead wood volume + percent forest cover within 500m + % cedar + % beech + percent water cover + % pine/larch	3404.476	0.548	0.191	0.760	0.35
~1 ~ percent deciduous forest cover + dead wood volume + % cedar + % beech + percent water cover + percent forest cover within 100m	3404.807	0.879	0.162	0.644	0.35
~1 ~ percent deciduous forest cover + dead wood volume + percent forest cover within 500m + % cedar + % beech + percent water cover + trees per hectare	3404.709	0.781	0.170	0.677	0.35

Table A10: Variables in the redundancy analysis on the Black Brook district avian species communities.

<b>Variable</b>	<b>F</b>	<b>P</b>	<b>R<sup>2</sup></b>
percent deciduous forest cover	14.024	0.005	0.0766
percent forest cover within 300m	8.654	0.005	0.0261
% beech	3.014	0.005	0.0254
dead wood volume	3.193	0.005	0.0246
% cedar	4.402	0.005	0.0217
percent water cover	2.553	0.005	0.0206
trees per hectare	4.056	0.005	0.0189
% fir	2.553	0.005	0.00909
% dead trees	2.599	0.005	0.00837
% aspen	1.820	0.005	0.00722
% pine/larch	1.575	0.020	0.00605
% cherry/alders	1.754	0.005	0.00174

Table A11: Summary of predictions made for the occupancy of the four focal species (brown creeper, Canada warbler, olive-sided flycatcher, and ovenbird), and the actual variables indicated in the occupancy modelling results

<b>Predicted variables influencing occupancy</b>	<b>Predicted response of occupancy</b>
<b><i>Brown creeper</i></b>	
Average tree height	Positive
Tree cover in landscape	Positive
Spruce and/or birch tree cover	Positive
Maple tree cover	Negative
<b><i>Canada warbler</i></b>	
Vertical complexity	Positive
Average tree height	Negative
Percent water cover	Positive
<b><i>Olive-sided flycatcher</i></b>	

Tree cover in landscape	Negative
Dead tree cover	Positive
Fir and larch tree cover	Positive
<b><i>Ovenbird</i></b>	
Tree cover in landscape	Positive
Deciduous tree cover	Positive
Distance to Road	Positive, or Positive to detection
<b>Variables influencing occupancy in models</b>	<b>Response of occupancy</b>
<b><i>Brown creeper</i></b>	
Vertical complexity	Positive
Percent tree cover within 500m landscape	Negative
Cedar tree cover	Positive
Dead tree cover	Positive
Percent water cover	Positive
Maple tree cover	Negative
<b><i>Canada warbler</i></b>	
Tree per hectare	Negative
Fir tree cover	Positive
Maple tree cover	Negative
Deadwood volume	Positive
Cedar tree cover	Positive
Crown closure	Negative
Percent tree cover within 200m landscape	Positive
Percent water cover	Positive
<b><i>Olive-sided flycatcher</i></b>	
Maple tree cover	Negative
Trees per hectare	Negative
Crown closure	Negative
<b><i>Ovenbird</i></b>	

Deciduous tree cover	Positive
Deadwood volume	Positive
Percent tree cover within 500m landscape	Negative
Cedar tree cover	Negative
Beech tree cover	Negative
Percent water cover	Negative

---



```

"numeric", "numeric", "numeric",
"numeric", "numeric", "numeric", "numeric", "numeric",
"text", "numeric", "numeric",
"numeric", "numeric", "numeric", "numeric", "numeric", "numeric", "numeric", "numeric"))
View(brcr)

#separate out all forest variables
my_data <-
brcr[,c(10,11,12,13,14,45,46,47,48,49,50,51,52,53,54,55,56,58,59,60,61,62,63,64,65,66,67)]
head(my_data,6)

res2 <- rcorr(as.matrix(my_data))
# get correlation coeff
res2$r
#get p values
res2$P

#draw correlogram
library(corrplot)

res3<- cor(my_data,method="pearson")
round(res3,2)
res3$r
res3$P

sig3 <- cor.mtest(res3, conf.level = 0.95)
sig3
sig3$p

```



```

"numeric", "numeric", "numeric", "numeric", "numeric",
"text", "numeric", "numeric",
"numeric", "numeric", "numeric", "numeric", "numeric", "numeric", "numeric" ))
View(brcr1)

brcr <- as.data.frame(brcr1)
View(brcr)
#anovas
my_data3 <-
brcr[,c(10,11,12,13,14,45,46,47,48,49,50,51,52,53,54,55,56,58,59,60,61,62,63,64,65,66,
15,16,57)]
#pull out data needed
View(my_data3)
library(lmPerm)

Status_pf_100 <- aovp(pf_100 ~ STATUS, data = my_data3)
Status_pf_400 <- aovp(pf_400 ~ STATUS, data = my_data3)
Status_pf_500 <- aovp(pf_500 ~ STATUS, data = my_data3)
Status_deadtrees <- aovp(deadtrees ~ STATUS, data = my_data3)
Status_beech <- aovp(beech ~ STATUS, data = my_data3)
Status_fir <- aovp(fir ~ STATUS, data = my_data3)
Status_spruce <- aovp(spruce ~ STATUS, data = my_data3)
Status_cedar <- aovp(cedar ~ STATUS, data = my_data3)
Status_aspen <- aovp(aspen ~ STATUS, data = my_data3)
Status_maple <- aovp(maple ~ STATUS, data = my_data3)
Status_pine_larch <- aovp(pine_larch ~ STATUS, data = my_data3)
Status_birch <- aovp(birch ~ STATUS, data = my_data3)
Status_cherry_alders <- aovp(cherry_alders ~ STATUS, data = my_data3)
Status_percent_conif <- aovp(percent_conif ~ STATUS, data = my_data3)
Status_percent_decid <- aovp(percent_decid ~ STATUS, data = my_data3)
Status_TPHmerch <- aovp(TPHmerch ~ STATUS, data = my_data3)

```

```
Status_HtAve <- aovp(HtAve ~ STATUS, data = my_data3)
Status_VCI <- aovp(VCI ~ STATUS, data = my_data3)
Status_NEAR_DIST_ROAD <- aovp(NEAR_DIST_ROAD ~ STATUS, data = my_data3)
Status_crownclosure <- aovp(crownclosure ~ STATUS, data = my_data3)
Status_BA <- aovp(BA ~ STATUS, data = my_data3)
Status_deadvol <- aovp(deadvol ~ STATUS, data = my_data3)
```

```
summary(Status_pf_100)
summary(Status_pf_400)
summary(Status_pf_500)
summary(Status_deadtrees)
summary(Status_beech)
summary(Status_fir)
summary(Status_spruce)
summary(Status_cedar)
summary(Status_aspen)
summary(Status_maple)
summary(Status_pine_larch)
summary(Status_birch)
summary(Status_cherry_alders)
summary(Status_percent_conif)
summary(Status_percent_decid)
summary(Status_TPHmerch)
summary(Status_HtAve)
summary(Status_VCI)
summary(Status_NEAR_DIST_ROAD)
summary(Status_crownclosure)
summary(Status_BA)
summary(Status_deadvol)
```



```
View(brcr1)
brcr <- as.data.frame(brcr1) #to ensure R recognizes it as a data frame
View(brcr)
```

```
y <- brcr[,1:8] #species #detections
site.Covs <- brcr[,9:83] #variables
View(y)
View(site.Covs)
```

```
##### testing detection variables
```

```
#below needs to be done since Jday and TOD are multiple columns
```

```
Jday <- brcr[,51:58] #day
TOD <- brcr[,59:66] #time of day
```

```
#to make unmarked reads NA's as missing values
```

```
TOD[TOD == '-'] <- NA
```

```
Jday[Jday == '-'] <- NA
```

```
View(TOD)
```

```
View(Jday)
```

```
sum(is.na(Jday) & !is.na(y))
```

```
sum(is.na(TOD) & !is.na(y))
```

```
which(is.na(Jday) & !is.na(y))
```

```
which(is.na(TOD) & !is.na(y))
```

```
y[is.na(Jday)] <- NA
```

```
y[is.na(TOD)] <- NA
```

```
##### testing detection variables
```

```
brcrD.occ<- unmarkedFrameOccu(y=y,  
siteCovs=site.Covs,obsCovs=list(Jday=Jday,TOD=TOD,YEAR=YEAR))
```

```
M1 <- occu(~1 ~1,brcrD.occ)
```

```
summary(M1)
```

```
#AIC1846
```

```
MR <- occu(~NEAR_DIST_ROAD-1 ~1, brcrD.occ)
```

```
summary(MR)
```

```
#AIC1935.458
```

```
M2 <- occu(~TOD-1 ~1, brcrD.occ)
```

```
summary(M2)
```

```
#AIC 1847.74
```

```
M3 <- occu(~Jday-1 ~1, brcrD.occ)
```

```
summary(M3)
```

```
#AIC 1995.614
```

```
M4 <- occu(~YEAR1 ~1, brcrD.occ)
```

```
summary(M4)
```

```
#AIC 1849.297
```

```
#####testing occupancy variables
```

```
brcr.occ<- unmarkedFrameOccu(y=y, siteCovs=site.Covs)
```

```
M1 <- occu(~1 ~1,brcr.occ)
```

```
summary(M1)
```

```
#1846
M2 <-occu(~1~STATUS,brcr.occ)
summary(M2)
#1779.4
M2b <-occu(~1~STATUS_new,brcr.occ)
summary(M2b)
#1782.435
M3 <- occu(~1~pf_100,brcr.occ)
summary(M3)
#1828.828
M4 <- occu(~1~pf_200,brcr.occ)
summary(M4)
#1832.909
M5 <- occu(~1~pf_300,brcr.occ)
summary(M5)
#1841.648
M6 <- occu(~1~pf_400,brcr.occ)
summary(M6)
#1846.044
M7 <- occu(~1~pf_500,brcr.occ)
summary(M7)
#1848.116
M8a <- occu(~1~deadtrees,brcr.occ)
summary(M8a)
#1844.647
M8b <- occu(~1~beech,brcr.occ)
summary(M8b)
#1848.916
M8c <- occu(~1~fir,brcr.occ)
summary(M8c)
#1842.757
```

```
M8d <- occu(~1~spruce,brcr.occ)
summary(M8d)
#1830.124
M8e <- occu(~1~cedar,brcr.occ)
summary(M8e)
#1827.261
M8f <- occu(~1~aspen,brcr.occ)
summary(M8f)
#1847.469
M8g <- occu(~1~maple,brcr.occ)
summary(M8g)
#1848.954
M8h <- occu(~1~pine_larch,brcr.occ)
summary(M8h)
#1848.926
M8i <- occu(~1~birch,brcr.occ)
summary(M8i)
#1848.991
M8j <- occu(~1~cherry_alders,brcr.occ)
summary(M8j)
#1847.927
M9 <- occu(~1~percent_decid,brcr.occ)
summary(M9)
#1848.989
M10 <- occu(~1~percent_conif,brcr.occ)
summary(M10)
#1848.591
MC <- occu(~1~crownclosure,brcr.occ)
summary(MC)
#1844.193
N6 <- occu(~1 ~BA, brcr.occ)
```

```

summary(N6)
#AIC 1819.859
N7 <- occu(~1 ~deadvol, brcr.occ)
summary(N7)
#AIC 1811.121
N8 <- occu(~1 ~TPHmerch, brcr.occ)
summary(N8)
#AIC 1843.631
N9 <- occu(~1 ~HtAve, brcr.occ)
summary(N9)
#1831.308
N10 <- occu(~1 ~VCI, brcr.occ)
summary(N10)
#1793.456
N11 <- occu(~1 ~NEAR_DIST_ROAD, brcr.occ)
summary(N11)
#AIC 1850.367
N12 <- occu(~1 ~percent_water, brcr.occ)
summary(N12)
#AIC 1826.584

##### model building

M67 <- occu(~1 ~percent_water+BA,brcr.occ)
summary(M67)
#1803.458
M68 <- occu(~1 ~percent_water+NEAR_DIST_ROAD,brcr.occ)
summary(M68)
#1877.803
M69 <- occu(~1 ~percent_water+BA+YEAR,brcr.occ)
summary(M69)

```

#1811.269

```
M70 <- occu(~1 ~percent_water+BA+birch,brcr.occ)
```

```
summary(M70)
```

#1800.628

```
M71 <- occu(~1 ~percent_water+BA+maple,brcr.occ)
```

```
summary(M71)
```

#1803.426

```
M72 <- occu(~1 ~percent_water+BA+birch+pine_larch,brcr.occ)
```

```
summary(M72)
```

#1802.541

```
M73 <- occu(~1 ~percent_water+BA+birch+beech,brcr.occ)
```

```
summary(M73)
```

#1801.62

```
M74 <- occu(~1 ~percent_water+BA+percent_conif,brcr.occ)
```

```
summary(M74)
```

#1798.799

```
M75 <- occu(~1 ~percent_water+BA+percent_conif+pf_500,brcr.occ)
```

```
summary(M75)
```

#1800.422

```
M76 <- occu(~1 ~percent_water+BA+percent_conif+cherry_alders,brcr.occ)
```

```
summary(M76)
```

#1798.611

```
M77 <- occu(~1 ~percent_water+BA+percent_conif+cherry_alders+aspen,brcr.occ)
```

```
summary(M77)
```

#1798.421

```
M77b <- occu(~1 ~percent_water+BA+percent_conif+aspen,brcr.occ)
```

```
summary(M77b)
```

#1799.044

```
M78 <- occu(~1 ~percent_water+BA+percent_conif+cherry_alders+aspen+pf_400,brcr.occ)
```

```
summary(M78)
```

#1800.242

```

M79 <- occu(~1 ~percent_water+BA+percent_conif+cherry_alders+aspen+deadtrees,brcr.occ)
summary(M79)
#1796.872
M79b <- occu(~1 ~percent_water+BA+percent_conif+aspen+deadtrees,brcr.occ)
summary(M79b)
#1796.93
M79c <- occu(~1 ~percent_water+BA+percent_conif+cherry_alders+deadtrees,brcr.occ)
summary(M79c)
#1796.496
M79d <- occu(~1 ~percent_water+BA+percent_conif+deadtrees,brcr.occ)
summary(M79d)
#1796.151
M80 <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+crownclosure,brcr.occ)
summary(M80)
#1796.07
M80 <- occu(~1 ~percent_water+percent_conif+deadtrees+crownclosure+TPHmerch,brcr.occ)
summary(M80)
#1810.667
M81 <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+crownclosure+fir,brcr.occ)
summary(M81)
#1796.468
M81b <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+fir,brcr.occ)
summary(M81b)
#1796.016
M82 <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+fir+pf_300,brcr.occ)
summary(M82)
#1796.003
M83 <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+fir+pf_200,brcr.occ)
summary(M83)
#1796.617
M84 <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+fir+pf_300+HtAve,brcr.occ)

```

```

summary(M84)
#1791.838
M84b <- occu(~1 ~percent_water+BA+percent_conif+deadtrees+fir+HtAve,brcr.occ)
summary(M84b)
#1790.266
M84bb <- occu(~1 ~percent_water+BA+deadtrees+fir+HtAve,brcr.occ)
summary(M84bb)
#1788.28
M84bbb <- occu(~1 ~percent_water+BA+deadtrees+HtAve,brcr.occ)
summary(M84bbb)
#1788.857
M84bbc <- occu(~1 ~percent_water+BA+HtAve,brcr.occ)
summary(M84bbc)
#1790.501
M85 <- occu(~1 ~percent_water+BA+deadtrees+HtAve+spruce,brcr.occ)
summary(M85)
#1783.533
M85b <- occu(~1 ~percent_water+BA+HtAve+spruce,brcr.occ)
summary(M85b)
#1784.069
M86 <- occu(~1 ~percent_water+BA+deadtrees+HtAve+spruce+pf_100,brcr.occ)
summary(M86)
#1784.458
M86b <- occu(~1 ~percent_water+BA+deadtrees+spruce+pf_100,brcr.occ)
summary(M86b)
#1784.904
M86bb <- occu(~1 ~percent_water+BA+spruce+pf_100,brcr.occ)
summary(M86bb)
#1786.087
M86c <- occu(~1 ~percent_water+BA+spruce,brcr.occ)
summary(M86c)

```

#1786.259

```
M87 <- occu(~1 ~percent_water+BA+deadtrees+HtAve+spruce+cedar,brcr.occ)
```

```
summary(M87)
```

#1777.133

```
M87b <- occu(~1 ~percent_water+BA+deadtrees+HtAve+cedar,brcr.occ)
```

```
summary(M87b)
```

#1777.446

```
M88 <- occu(~1 ~percent_water+deadtrees+HtAve+spruce+cedar+deadvol,brcr.occ)
```

```
summary(M88)
```

#1781.503

```
M88b <- occu(~1 ~percent_water+deadtrees+HtAve+cedar+deadvol,brcr.occ)
```

```
summary(M88b)
```

#1779.524

```
M88c <- occu(~1 ~percent_water+HtAve+cedar+deadvol,brcr.occ)
```

```
summary(M88c)
```

#1779.996

```
M89 <- occu(~1 ~percent_water+deadtrees+spruce+cedar+VCI,brcr.occ)
```

```
summary(M89)
```

#1769.927

```
M89b <- occu(~1 ~percent_water+deadtrees+cedar+VCI,brcr.occ)
```

```
summary(M89b)
```

#1767.939

```
M89c <- occu(~1 ~percent_water+cedar+VCI,brcr.occ)
```

```
summary(M89c)
```

#1768.605

```
M90 <- occu(~1 ~percent_water+deadtrees+cedar+BA,brcr.occ)
```

```
summary(M90)
```

#1790.943

```
M91 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple,brcr.occ)
```

```
summary(M91)
```

#1767.362

```
M91b <- occu(~1 ~percent_water+deadtrees+cedar+VCI,brcr.occ)
summary(M91b)
#1767.939

M91c <- occu(~1 ~percent_water+cedar+VCI,brcr.occ)
summary(M91c)
#1768.605

M92 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple+pine_larch,brcr.occ)
summary(M92)
#1769.225

M96 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple,brcr.occ)
summary(M96)
#1767.362!

M97 <- occu(~1 ~percent_water+deadtrees+cedar+VCI,brcr.occ)
summary(M97)
#1767.939

M98 <- occu(~1 ~deadtrees+cedar+VCI+maple,brcr.occ)
summary(M98)
#1770.079

M93 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple+pf_500,brcr.occ)
summary(M93)
#1761.194

M93b <- occu(~1 ~deadtrees+cedar+VCI+maple+pf_500,brcr.occ)
summary(M93b)
#1761.896

M93c <- occu(~1 ~percent_water+deadtrees+cedar+VCI+pf_500,brcr.occ)
summary(M93c)
#1761.586

M94<- occu(~1 ~percent_water+deadtrees+cedar+maple+pf_400,brcr.occ)
summary(M94)
#1816.477
```

```
#####Top models
```

```
M95 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple+pf_500,brcr.occ)
```

```
summary(M95)
```

```
#1761.194
```

```
#top model
```

```
M95b <- occu(~1 ~percent_water+deadtrees+cedar+VCI+pf_500,brcr.occ)
```

```
summary(M95b)
```

```
#1761.586
```

```
M95c <- occu(~1 ~deadtrees+cedar+VCI+maple+pf_500,brcr.occ)
```

```
summary(M95c)
```

```
#1761.869
```

```
M95d <- occu(~1 ~deadtrees+cedar+VCI+pf_500,brcr.occ)
```

```
summary(M95d)
```

```
#1764.104
```

```
M96 <- occu(~1 ~percent_water+deadtrees+cedar+VCI+maple,brcr.occ)
```

```
summary(M96)
```

```
#1767.362
```

```
f1<-fitList(Null=M1, .a=M95, .b=M95b, .c=M95c, .d=M95d, .e=M96)
```

```
f1
```

```
ms <- modSel(f1,nullmod="Null")
```

```
ms
```

### **Code of graphing predicted occupancy (olive-sided flycatcher).**

```
rm(list=ls())
```

```
setwd("~/Documents/master data_10_30_18/final occ models audio")
```

```
library(readxl)
```

```
osfl_predicted_occ_data2 <- read_excel("~/Documents/master data_10_30_18/final occ models  
audio/osfl predicted occ data.xlsx",
```

```
  col_types = c("numeric", "numeric", "numeric",  
               "numeric", "numeric", "numeric",  
               "numeric", "numeric", "numeric", "numeric" ))
```

```
plot1<-ggplot(osfl, aes(x=maple, y=maple_probocc)) +  
  geom_point(size=2)+  
  labs(x="Percent Cover of Maple Trees (within the stand)", y="Probability of Occupancy",  
       title="A")+  
  theme_bw() + theme(panel.border = element_blank(), panel.grid.major = element_blank(),  
                    panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"))  
plot1
```

```
plot3<-ggplot(osfl, aes(x=crownclosure, y=crcl_probocc)) +  
  geom_point(size=2)+  
  labs(x="Crown Closure (percentage)", y="Probability of Occupancy",  
       title="C")+  
  theme_bw() + theme(panel.border = element_blank(), panel.grid.major = element_blank(),  
                    panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"))  
plot3
```

```
plot4<-ggplot(osfl, aes(x=TPHmerch, y=tph_probocc)) +  
  geom_point(size=2)+  
  labs(x="Tree Density (merchantable trees per hectare)", y="",  
       title="B")+  
  theme_bw() + theme(panel.border = element_blank(), panel.grid.major = element_blank(),  
                    panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"))  
plot4
```

```
par(mfrow=c(2,3))
```

```
require(gridExtra)
grid.arrange(plot1, plot4, plot3, ncol=2)
```

### **Code for creating RDA for community analysis.**

```
rm(list=ls())
setwd("~/Documents/rcodes/DB_RDA")
```

```
library(vegan)
```

```
redundancy<-read.csv("species_composition_and_site_data.csv",header=TRUE)
View(redundancy)
dim(redundancy)
# 458 162
```

```
species<-as.data.frame(redundancy[,1:91])
species
envt<-as.data.frame(redundancy[,106:134])
envt
```

```
species<-decostand(species, "hellinger")
```

```
M1<- rda(species~pf_100,envt)
RsquareAdj(M1)
#0.025803
M2<- rda(species~pf_200,envt)
RsquareAdj(M2)
#0.0254394
M3<- rda(species~pf_300,envt)
RsquareAdj(M3)
#0.0261277
```

```
M4<- rda(species~pf_400,envt)
RsquareAdj(M4)
#0.02446874
M5<- rda(species~pf_500,envt)
RsquareAdj(M5)
#0.021988
M6<- rda(species~pf_600,envt)
RsquareAdj(M6)
#0.0203512
M7<- rda(species~Deadtrees,envt)
RsquareAdj(M7)
#0.008371926
M8<- rda(species~Beech,envt)
RsquareAdj(M8)
#0.02548184
M9<- rda(species~Fir,envt)
RsquareAdj(M9)
#0.009093678
M10<- rda(species~Spruce,envt)
RsquareAdj(M10)
#0.05203979
M11<- rda(species~Cedar,envt)
RsquareAdj(M11)
#0.02175629
M12<- rda(species~Aspen,envt)
RsquareAdj(M12)
#0.00722954
M13<- rda(species~Maple,envt)
RsquareAdj(M13)
#0.06141493
M14<- rda(species~Pine_Larch,envt)
```

RsquareAdj(M14)

#0.006050983

M15<- rda(species~Birch,envt)

RsquareAdj(M15)

#0.04394228

M16<- rda(species~Cherry\_Alders,envt)

RsquareAdj(M16)

#0.00174201

M17<- rda(species~P\_Coniferous,envt)

RsquareAdj(M17)

#0.07396272

M18<- rda(species~P\_Deciduous,envt)

RsquareAdj(M18)

#0.07662799

M19<- rda(species~TPH,envt)

RsquareAdj(M19)

#0.01894035

M20<- rda(species~AvgHt,envt)

RsquareAdj(M20)

#0.04476404

M21<- rda(species~VCI,envt)

RsquareAdj(M21)

#0.03719212

M22<- rda(species~Distance\_to\_Road,envt)

RsquareAdj(M22)

#0.00378309

M23<- rda(species~CrCl,envt)

RsquareAdj(M23)

```
#0.002971803
```

```
M24<- rda(species~BA,envt)
```

```
RsquareAdj(M24)
```

```
#0.02019588
```

```
M25<- rda(species~Deadwood_vol,envt)
```

```
RsquareAdj(M25)
```

```
#0.02462477
```

```
M26<- rda(species~pf_water,envt)
```

```
RsquareAdj(M26)
```

```
#0.020649
```

```
#####
```

```
# model building code not included as it is very long (same as occupancy model code building)
```

```
M39<- rda(species~P_Deciduous+pf_300+Beech
```

```
  +Cedar+pf_water+Deadwood_vol+TPH+Deadtrees
```

```
  +Aspen+Pine_Larch+ Fir+Cherry_Alders,envt)
```

```
RsquareAdj(M39)
```

```
#0.1594491
```

```
plot(M39)
```