HABITAT SELECTION BY BIRDS IN WILLOW-RINGED WETLANDS: MANAGEMENT IMPLICATIONS FOR HARVESTING WILLOW BIOMASS

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Melissa Dawn Mushanski

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SUPERVISORY AND EXAMINING COMMITTEE

Melissa Dawn Mushanski, candidate for the degree of Master of Science in Biology**,** has presented a thesis titled, ***Habitat Selection by Birds in Willow-Ringed Wetlands: Management Implications for Harvesting Willow Biomass,*** in an oral examination held on April 15, 2015. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

External Examiner:	Dr. Glenn Sutter, Royal Saskatchewan Museum
Supervisor:	Dr. Christopher Somers, Department of Biology
Committee Member:	Dr. Stephen K. Davis, Adjunct
Committee Member:	Dr. Britt Hall, Department of Biology
Chair of Defense:	Dr. Maria Velez Caicedo, Department of Geology

ABSTRACT

Increase in prices of fossil fuels and escalating environmental conflicts have generated renewed interest in bioenergy production. Abundant small wetlands ringed with willow species (willow rings) growing naturally in the Prairie Ecozone of North America may provide a source of natural biomass as a bioenergy feedstock. Subsequently, a bioenergy crop from these wetlands could increase their economic value and help reduce their drainage and loss. Little is known about the importance of willow vegetation to birds, and what habitat features may be important to consider when planning biomass harvest. To address this knowledge gap, I conducted point count surveys in the spring of 2012 and 2013 at 92 willow rings in south-eastern Saskatchewan. My objectives were to determine: 1) what species make up the willow- ring bird community; 2) what wetland and vegetation characteristics influence bird abundance; and 3) whether abundance of willow-ringed wetland birds varies as a function of the surrounding upland habitat (cropland vs. grassland). I found that the willow ring community is composed of at least 66 species from 3 distinct guilds: woodland, wetland, and grassland birds, and that members of each guild responded differently to willow ring structure and habitat features. For example, American robin (*Turdus migratorius*) and yellow warbler (*Setophaga petechia*), both woodland species, increased in abundance as willow area increased. A wetland bird species, the American coot (*Fulica americana),* decreased in abundance as % willow cover increased. However, all other species were unaffected by changes in the willow ring structure, suggesting that willow harvest will have little impact on these birds. Woodland bird species may decrease as their habitat is lost; however, management practices such as partial harvests or rotational harvest by year

may make willow harvest sustainable for all species. Furthermore, land managers should adjust harvest guidelines to reflect local bird management objectives. In doing so, willow harvest can likely be done with minimal impact on bird species associated with willow-ringed wetlands.

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DEDICATION

To my family and all who played a part in making this possible.

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1. GENERAL INTRODUCTION

1.1 INTRODUCTION

1.1.1 World energy demand

Humans reshape the environment through the extraction and burning of fossil fuels in an attempt to meet the energy demands of a growing population (Shafiee and Topal 2009). In 2010 alone, over 500 quadrillion British Thermal units were required to power the world; a value that is expected to increase approximately 1% per year (Shafiee and Topal 2010) with roughly 87% of this energy demand being met by oil, natural gas, and coal (Popp et al. 2014). Resource extraction causes massive surface disturbances that lead to habitat destruction and species extinction (Mclellan and Shackleton 1988). The burning of fossil fuel releases greenhouse gases into the atmosphere and contributes to increasing global temperatures and climate change risks (Harte 2007, Popp et al. 2014). Fossil fuels are also finite resources. Shafiee and Topal (2009) projected reserve depletion times for oil, natural gas, and coal to be 35, 37, and 107 years respectively. Increased demand and limited supply of fossil fuels will inevitably lead to increased prices, which have greatly contributed to world financial crises in the past (Shafiee and Topal 2010). Regardless of the negative consequences associated with the extraction and consumption of fossil fuels, the development of renewable resources worldwide has not kept pace with the increasing energy demand (Popp et al. 2014).

Of all the energy used worldwide, only 13% comes from renewable energy resources (Popp et al. 2014), and 80% of this energy is derived from plants (McKendry 2002). The burning of woody or herbaceous biomass (hereafter biomass) is a clean and renewable alternative to fossil fuels. It is not a net contributor of greenhouse gases to the atmosphere because re-growth of the harvested vegetation ensures that the carbon dioxide released is returned back to the cycle of plant growth (McKendry 2002). Willow (*Salix sp.*) has become an important energy crop because it produces high yields of biomass with minimal energy inputs and low nutrient requirements (McKendry 2002). Production of willow biomass for energy purposes began in Sweden in the 1980's (Rosenqviste et al. 2000). In the 1990's, research on willow biomass for the production of energy was conducted in Canadian institutions (Labrecque and Teodorescu 2005, Yemshanov and McKenney 2008). The original focus of willow biomass-use was on planting and maintaining plantations of willow as a short rotation crop. However, such crops often require a land use change from agricultural food production to the production of energy (Popp et al. 2014). It is projected that agricultural production will need to increase 60% over the next 40 years to meet global food demands. Meanwhile, much of our agricultural land has become degraded due to intensive and unsustainable production practices (Popp et al. 2014). Taking agricultural land out of food production to grow energy crops may lead to additional clearing of natural areas, destroying valuable carbon sinks and furthering habitat destruction (Popp et al. 2014). One alternative that is currently being researched and developed is to harvest willow biomass that occurs naturally (Schroeder et al. 2009).

1.1.2 Willow ring harvest

A reliable and sufficient source of natural willow biomass in the Great Plains of North America is available from millions of small depressional wetlands with willows growing along their perimeters (Mirck and Schroeder 2013). These willow rings are being recognized as valuable biomass sources that can be used for bioenergy in the place of willow plantations. Schroeder et al (2009) deviated from the typical practice of growing willow cultivars as short-rotation plantation crops towards sustainably harvesting natural willow biomass from wetlands. Natural willow rings are potentially more cost effective than plantations as a fuel source because no energy resources go into planting or maintaining them (Mirck and Schroeder 2013). In addition, the willow species on the prairies are naturally adapted for rapid re-growth following harvest (Kuzovkina and Quigley 2005). As a result, the only biomass production costs associated with willow bioenergy are harvest, transportation, and processing (Mirck and Schroeder 2013). However, harvest of willow biomass drastically changes the vegetation structure of the wetland.

The presence of willow rings increases the structural complexity of a wetland and allows woodland birds to inhabit prairie wetlands. Harvesting willow biomass temporarily removes the standing willow vegetation (Schroeder et al. 2009) and reduces bird diversity (Heltzel and Earnst 2006). Although willow harvest destroys habitat initially, the rings re-grow quickly and the woodland birds eventually return (Earnst et al. 2005). The fast recovery of the willow vegetation means harvest may be sustainable if done on an appropriate cycle and may benefit birds. The re-growth is young and healthy and provides better cover and more food resources than senescent or dead vegetation. Wetlands with degraded woody vegetation support 10 times fewer birds than wetlands with healthy riparian areas (Argent and Zwier 2007, Taylor 1986). This rejuvenation of willow has been documented in studies of overgrazed riparian areas that, once allowed to recover, provide better quality cover for woodland birds (Taylor 1986). The majority of these studies have been conducted on linear riparian areas with no focus on the willow-ringed wetlands of the prairies. Research on willow-ringed wetlands is required to understand how changes in willow affect the associated bird community to create ways to harvest willow sustainably. Not only is it important to develop a clean and renewable energy source, it is important that willow ring communities also maintain high ecological value and integrity.

1.1.3 Value of prairie wetlands for bird species

Prairie wetlands are diverse in shape, size, vegetation types, and hydrology, and change from one year to the next. The major differences among wetlands can be classified based on their annual hydrologic cycle. Ephemeral wetlands (class 1) are inundated briefly during the spring. Internal seepage due to porous soils characterizes their short hydrologic period. Temporary wetlands (class 2) maintain water levels for a few weeks after spring snow melt and occasionally hold water into the fall with high levels of precipitation. Seasonal wetlands (class 3) remain inundated until early summer but are typically dry by late summer or fall. Semi-permanent wetlands (class 4) maintain water levels into fall and winter. If water levels are stable year round the wetland is considered permanent (class 5). It is these varying degrees of water permanence that dictate the vegetation classes that occur within concentric zones peripheral to the central zone of greatest water permanence. Ephemeral wetlands are dominated by short grasses and forbs. Temporary wetlands support sedges due to their slightly longer inundation periods. Seasonal wetlands include medium height aquatic vegetation such as pond smart weed (*Persicaria amphibian*), water plantain (*Alisma triviale*), slough grass (*Beckmannia syzigachne*), and few submerged plant species, such as duck weed (*Lemna* *minor*). Semi-permanent wetlands are dominated by communities of tall and thick stemmed aquatic vegetation such as bulrushes and cattails (*Scirpus sp. and Typha sp.*) and a community of submergent vegetation. Permanent wetlands are unable to support emergent vegetation (Stewart and Kantrud 1971) and are instead dominated by areas of open water. In addition to these vegetation classes, woody vegetation may also colonize the edge of wetlands because it is adapted to hypoxic soil conditions characteristic of these zones (Kuzovkina et al. 2001).

The large diversity of wetlands within the prairies and the many resources and niches they provide are essential to maintain a high diversity of birds. Within the Canadian portion of the prairies, 341 bird species occur. The largest group of bird species is land birds (36%), followed by waterfowl (25%), shorebirds (21%) and waterbirds (19%) (Environment Canada 2013). Of these bird species, 118 qualify as priority species; 30 are listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), 26 listed under the federal Species at Risk Act, and 18 listed by provincial species at risk legislation (Environment Canada 2013). The largest number of priority birds is associated with wetlands (66%) and includes waterfowl, shorebirds, and waterbirds (Environment Canada 2013). This region of wetlands is commonly referred to as the “duck factory” because of high waterfowl production. Alone, these wetlands support 50-80% of North America’s total waterfowl population (Poiani and Johnson 1991). Aside from their intrinsic value, waterfowl also contribute to the economy by being an important part of the hunting industry. Cortus et al (2013) estimated that waterfowl hunting contributes approximately $12.77/ha of wetlands per year to Saskatchewan’s economy. The insectivorous species breeding in the prairies also play an important role in farmland ecology by reducing common crop pests (Tremblay et al. 2001), increasing the economic benefits of these birds.

Outside of the breeding season the wetlands of the prairie region also play an important role for migratory species. This matrix of wetlands serves as a vital stopover for roughly 130 migratory bird species (United States Subcommittee on Interior Environmental and Related Agencies et al 2007). During spring and fall migration some species travel up to 25,000 km between wintering and breeding grounds, making this the most energetically demanding period of their life cycle (Leon and Smith 1999). According to Skagen (2006), 70% of northbound shorebird populations (totaling over five million individuals) use prairie wetlands as a staging area. Millions of birds, including priority species such as whooping crane (*Grus americana*), piping plover (*Charadrius melodus*), red knot (*Calidris canutus*), and others, obtain critical resources needed to refuel fat stores to complete their migration (Leon and Smith 1999). While much literature exists surrounding the importance of prairie wetlands in maintaining high bird diversity, this region continues to face threats from wetland drainage and habitat destruction (Mirck and Schroeder 2013).

1.1.4 Historical wetland degradation

When the glacial retreat created prairie wetlands it also created the most fertile soils of North America (Rashford et al. 2011). Since settlement, 50% of historical wetland area in the United States and 71% in Canada has been drained (Rashford et al. 2011). Of the 200,000 ha of Canadian prairie wetlands that have been lost, 62% were converted for agricultural activities including crop and livestock production (Rashford et al. 2011). In addition, agricultural and urban activities altered upland grasslands, lowering the habitat suitability of the wetlands for biota (MacArthur and MacArthur 1961, Naugle et al. 2000). The prairie ecozone has become fragmented, often leaving wetlands isolated in a matrix of unsuitable upland habitat for native species. The loss of wetland connectivity hinders many species that use multiple wetlands within a season (Haig et al. 1998). This destruction and fragmentation of the prairies means loss of habitat for the millions of birds that associate with wetlands during breeding and migration. Intensive domestic livestock grazing can also impact wetlands. According to Knopf and Cannon (1981), overgrazing is the most widespread cause of riparian destruction in the United States. It removes vegetation needed for nesting cover causing a seven fold reduction in nest success (Taylor 1986). Furthermore, hoof traffic causes erosion and siltation, which can disrupt respiration within the body of water and alter the hydrologic cycle (Knopf and Cannon 1981). These disturbances leave the prairie ecozone with fewer and degraded wetlands and less native vegetation.

Climate change also threatens prairie wetlands through increased periods of drought. During historical droughts the number of wetlands has been severely reduced and many remain dry for multiple years (Millett and Johnson 2009). Fewer wetlands correlates with a decrease in wetland obligate birds because their breeding, foraging, and staging habitat has decreased (Greenwood et al. 1995). The remaining wetlands are not able to provide enough resources to maintain waterfowl populations (Greenwood et al. 1995). If drought frequency and duration on the prairies does increase as predicted, the number of inundated wetlands will decrease causing a decline in waterfowl populations (Millett et al. 2009). Loss of these wetlands puts pressure on over 300 bird species throughout North America. To ensure that the needs of these species are met during all seasons, as many wetlands as possible must be protected (Millett et al. 2009).

1.1.5 Thesis Objectives

Harvesting willow ring biomass for energy production will undoubtedly alter wetland habitats and, in at least the short term, affect many bird species. It is necessary to understand the interactions between the wetland inhabitants and their habitat to use willow rings as a renewable energy resource without causing additional habitat destruction. The purpose of my research was to examine the importance of willow rings to a variety of bird species and to assess potential impacts associated with willow harvest. I used point counts of birds and measurements of wetland and willow vegetation structure to address three objectives:

(1) Characterize bird communities associated with willow-ringed wetlands.

(2) Examine features of the willow-ringed wetlands, including surrounding upland habitat, that influence avian habitat selection.

(3) Evaluate how harvest of willow vegetation might affect associated birds and make recommendations for management.

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2: HABITAT SELECTION BY BIRDS IN WILLOW-RINGED WETLANDS: MANAGEMENT IMPLICATIONS FOR HARVESTING WILLOW BIOMASS

2.1 INTRODUCTION

Fossil fuels are finite resources whose extraction and use negatively impact the environment. The majority of the world's energy demand is met by non-renewable resources such as oil, natural gas, and coal (Popp et al. 2014, Shafiee and Topal 2009). The burning of fossil fuels releases greenhouse gases into the atmosphere, contributing to climate change worldwide (Harte 2007, Popp et al. 2014). Resource extraction activities cause surface disturbances that lead to habitat loss and fragmentation (Dyer et al. 2001, Lyon and Anderson 2003, Mclellan and Shackleton 1988, Walker et al. 2007) and the subsequent decline and extinction of species by altering or destroying their habitats (Dyer et al. 2001, Popp et al. 2014, Walker et al. 2007). Although non-renewable resources cause major environmental damage and are limited in supply, renewable resources contribute only 13% to the world's energy use (Popp et al. 2014). Finite reserves of fossil fuels are decreasing, which will have long-term economic consequences as the cost of energy increases (Shafiee and Topal 2009, Shafiee and Topal 2010). Fossil fuels are not sustainable economically or environmentally and reliable sources of alternative renewable energy need to be developed and used.

Biomass is a cost effective, clean, and renewable fuel source that has been largely under-exploited. The term biomass encompasses all organic material stemming from plants, including woody and herbaceous plants and algae (McKendry 2002). Combustion of woody or herbaceous biomass is a clean and renewable alternative to fossil fuels because any carbon dioxide released into the atmosphere is recaptured by the vegetation that continues to grow after harvest (Campbell et al. 2008, McKendry 2002, Mirck and

Schroeder 2013, Volk et al. 2006). Willow (*Salix spp.*) is an ideal biomass energy crop because it produces high yields with low energy inputs and nutrient requirements (Kusovkina and Quigley 2005, McKendry 2002, Volk et al. 2006). However, growing energy crops in plantations takes agricultural land out of food production (Campbell et al. 2008, Popp et al. 2014). As the world population increases it is projected that our agricultural production will need to increase 60% within the next 40 years to keep up with global food demands (Popp et al. 2014). This creates a pressing need to examine alternative sources of woody biomass for fuel feedstock that occur in natural environments.

The Northern Great Plains are home to millions of small depressional wetlands surrounded by willow rings, making it an attractive region for harvesting natural biomass. The willow vegetation in this area evolved with natural disturbances such as fire and ungulate grazing and browsing (Kuzovkina and Quigley 2005, Mirck and Schroeder 2013). Willow recovers quickly after disturbance and provides high yields of biomass that can be harvested every 4-5 years (Kuzovkina and Quigley 2005, Schroeder et al 2009). These attractive qualities of natural willow influenced Schroeder et al (2009) to develop techniques for harvesting natural biomass from willow-ringed wetlands rather than growing cultivars as a short-rotation woody crop (Volk et al. 2006, Yemshanov and Mckenney 2008). The use of willow biomass has many positive features as an alternative fuel source to fossil fuels. However, the impacts willow harvest might have on wetland wildlife communities are unknown. Prairie wetlands hold high ecological value and are already highly disturbed by humans, so the effect of willow harvest on wetlands and wetland inhabitants must be understood to manage willow rings sustainably.

Prairie wetlands maintain high bird diversity, supporting over 300 species during breeding and migration (Environment Canada 2013). This includes land birds, waterfowl, shorebirds, and waterbirds, 118 of which are priority species listed under federal and provincial species at risk legislation (Environment Canada 2013). These same wetlands host over 150 bird species during the breeding season, including 50-80% of North America's waterfowl (Poiani and Johnson 1991). Although this region is valuable for maintaining high bird diversity, it is highly degraded by human activities such as agriculture (Cortus et al. 2011, Rashford et al. 2011). Degradation of these wetlands leaves less suitable habitat available for many bird species that rely on these wetlands.

Wetlands are often viewed as unproductive land and are drained to enhance farming operations (Cortus et al. 2011, Rashford et al. 2011). Approximately 50-70% of North American prairie wetlands have been drained since European settlement (Rashford et al. 2011). These wetlands are also highly dynamic (Millett et al. 2009) and can dry up during times of drought and remain dry for many years, providing significantly less resources to wetland-dependent species (Greenwood et al. 1995). Climate change models predict increased droughts on the prairies, which will reduce the number of breeding and migratory bird species that can be supported in these habitats (Millett et al. 2009). Schroeder et al. (2009) recommended harvesting wetland willow vegetation to help provide economic incentive to landowners to retain wetland basins. However, harvesting wetland willow vegetation may have dire consequences for wildlife that rely on these habitats. Not only is it important to retain as many wetlands as possible on the landscape, but it is also important to maintain the quality of the wetlands. While willow management can aid in wetland conservation little is known about how birds select their habitat among willow rings or how willow harvest will impact species abundance.

I examined habitat use and selection by birds associated with wetland willow rings in south-eastern Saskatchewan, Canada. Previous research has investigated how woody structure in linear riparian areas affects the presence of bird species (Heltzel et al. 2006, Stauffer and Best 1980); however, no research has focused on woody vegetation in prairie wetlands. Willow is very common in these habitats but many studies disregard it and its influence on bird communities (Naugle et al. 2000). My objectives were to:

1. Document the bird species that make up the willow ring bird community.
2. Examine characteristics of the wetland basins, willow rings, and upland vegetation cover to determine what influences avian habitat selection.
3. Determine how the harvest of willow vegetation will potentially affect birds.

Understanding what species use willow rings will enable me to provide insight into development of best practice guidelines to help future management of willow rings for biomass. This in turn may be useful in the conservation of prairie wetlands, ensuring they provide high quality habitat for bird species that inhabit them.

2.2 METHODOLOGY

2.2.1 Study Area

My study was conducted during spring/summer of 2012 and 2013 on 92 wetlands surrounded by natural willow rings in southeastern Saskatchewan, Canada (Fig. 1). This area, known as the Indian Head Plain, is a part of the Aspen Parkland ecoregion (Acton et al. 1998).

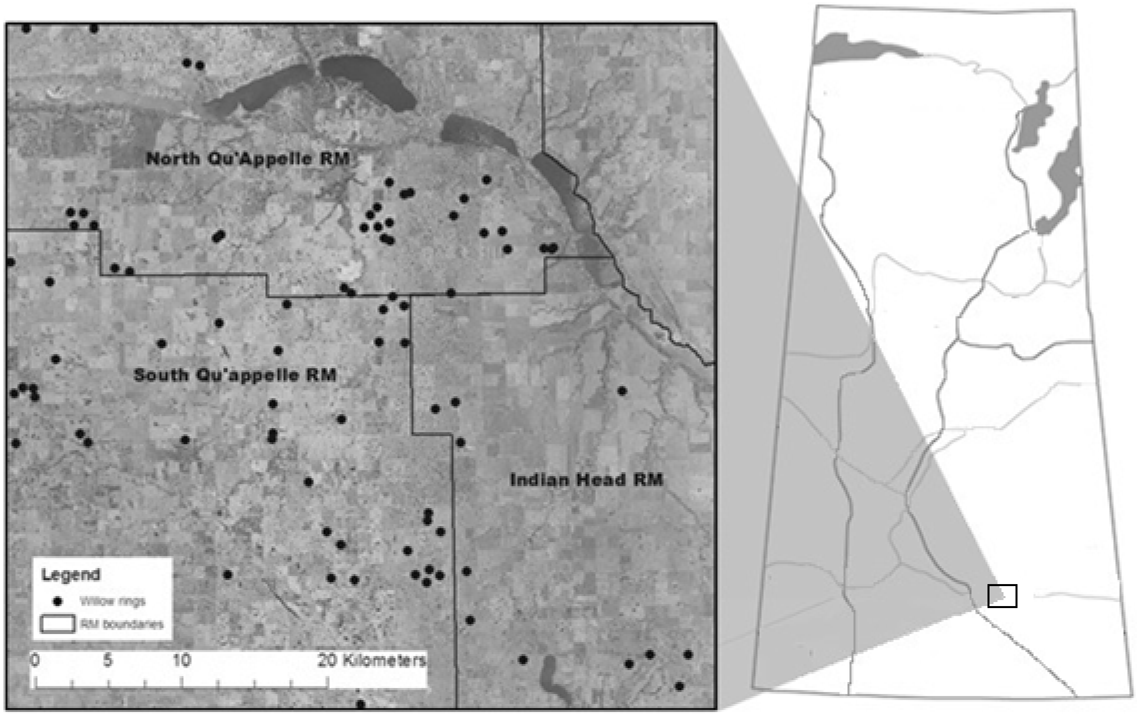

Fig. 1. Study area location in south-eastern Saskatchewan, Canada. Black circles indicate the location of wetlands with willow rings that were surveyed for bird communities and habitat characteristics in 2012 and 2013 (n=92).

The Aspen Parkland ecoregion is a transition zone between the Boreal Forest and the Moist Mixed Grasslands ecoregion, and is characterized by a matrix of aspen groves and grasslands (Acton et al. 1998). Woody vegetation species native to this area include various willow (*Salix spp*) and trembling aspen (*Populus tremuloides* Michx), which are often located in low-lying areas and coulees while higher elevations are dominated by fescue grasses (*Festuca spp*.) (Acton et al. 1998). This area contains a portion of the Prairie Pothole Region (PPR) and is characterized by a high density of depressional wetlands, often called 'sloughs', and their associated wetland vegetation. Woody vegetation, such as willow, tends to establish on the periphery of wetlands because of high soil moisture, creating 'willow rings' (Acton et al. 1998, Mirck and Schroeder 2013).

This area has a humid continental climate with a mean annual precipitation of 420 mm. Of that precipitation, an average of 262 mm falls from May to September, but the actual amount varies considerably, causing changes in the number of inundated wetlands between seasons (Environment Canada 2014). The majority of the land in this region is privately owned with the most common land use being production of grains, row crops, and livestock (Acton et al. 1998). Typical land cover in this region includes annual crops and perennial grasses and forbs for forage (Acton et al. 1998). This region has undergone extensive wetland drainage and conversion of native grass to cropland (Rashford et al. 2011).

2.2.2 Site Selection

I used a geographic information system (GIS) to examine aerial photos acquired from the Saskatchewan Geospatial Imagery Collaborative (www.flysask.ca), taken in

2008 and 2009, to locate willow-ringed wetland sites for this study. I overlaid a map containing quarter section divisions (Information Services Corporation of Saskatchewan 1999) onto aerial photos of the study area along with the AAFC Prairie crop mapping layer (Agriculture and Agri-foods Canada 2009) using ArcMap (Esri ArcGIS v.10.1 Advanced License, Redlands, Calif.). I identified wetlands that were surrounded primarily by cropland or grassland based on the AAFC Prairie crop mapping layer. Cropland cover of various crop types included flax, wheat, barley, canola and pulse crops (legumes). Grassland cover included native and planted perennial grass and forage. I selected 150 wetlands surrounded by cropland and 150 surrounded by grassland using a random number generator and omitted any wetlands without a ring of woody vegetation. I ground-truthed the remaining sites prior to the bird breeding season to ensure the wetlands included willow vegetation. If a wetland did not have willow, I included the nearest willow ring instead. I also verified the type of upland vegetation cover present around each wetland. This process yielded 116 willow-ringed wetlands in 2012. The number of sites was reduced to 92 in 2013 because of wetland drainage by land owners.

2.2.3 Bird Surveys

I conducted bird surveys during late May to early July at each wetland in 2012 and 2013. Each wetland was surveyed by a single observer using point-count survey methods (Ralph et al. 1995) at a predetermined fixed location approximately 50 m away from the willow ring (Figure 2). I randomly selected fixed locations for point counts using ArcMap to ensure surveys were not biased to areas of the wetland with more or less willow or birds. I recorded all birds seen or heard inside a 100-m radius half-circle that were within the willow-ringed wetlands (Figure 2); birds within the survey area but

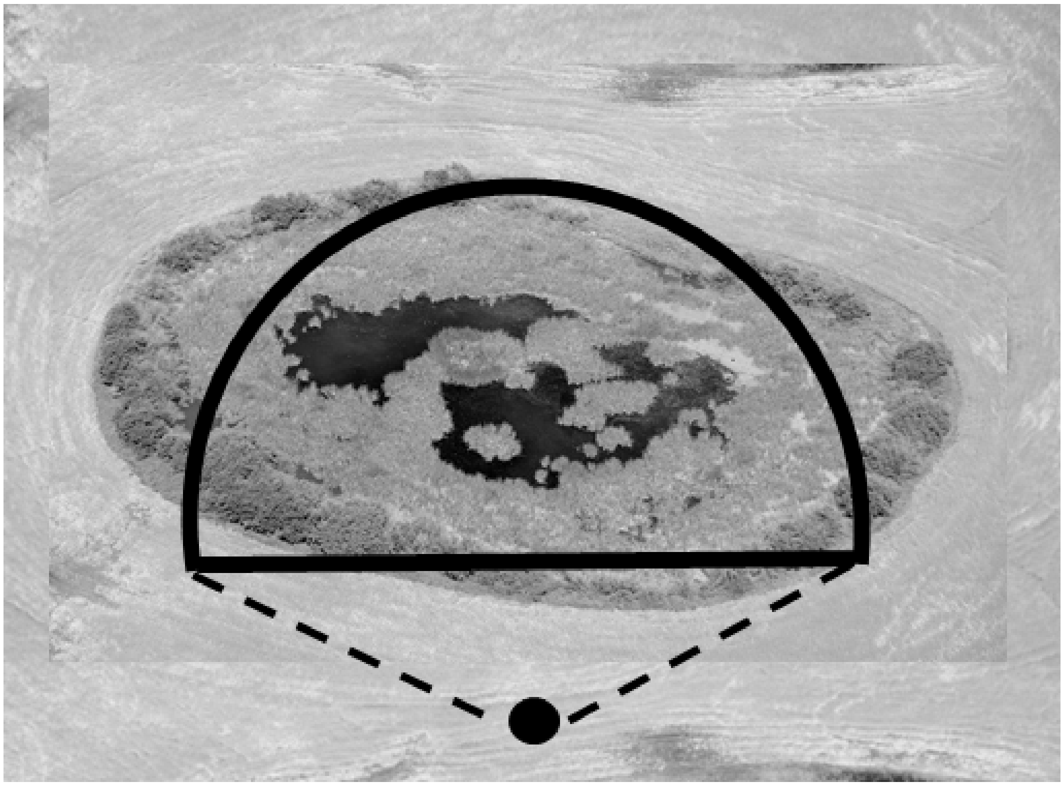

Fig. 2. Diagram of survey area used for bird point counts. The solid half circle represents the 100 m radius survey area. The black circle represents the observer, approximately 50 m away from the survey area.

detected in upland vegetation were not included in the analyses. The 100 m radius encompassed the entire wetland at 68 sites. Each point count was five minutes long, consisting of four 75-second intervals to estimate detection probability based on removal sampling (Farnsworth et al. 2002). I began surveys at sunrise and concluded approximately 4 hours after. Surveys were conducted at sunrise on mornings with wind < 20 km/hr and no precipitation (Ralph et al. 1995). A Kestrel 3000 wind meter was used to measure the wind speed and temperature at each site.

2.2.4 Vegetation and wetland surveys

I quantified vegetation structure of the willow ring community including, willow height, stem density, % deadwood, willow area, and % willow cover. Height was measured to the nearest tenth of a cm using a telescoping measuring rod. I calculated stem density by counting all live and dead stems > 30 mm in circumference within two 1-m wide transects through the willow ring, oriented north-south and east-west. I derived an estimate of the mean stem density and % deadwood of the willow ring. I measured willow area using ArcMap by digitizing the willow community around each wetland and summing the area of each willow polygon associated with the wetlands. Percent willow cover was quantified as a ratio of willow area to wetland area.

I classified wetlands according to Stewart and Kantrud (1991), and recorded water level, wetland area, wetland density, and % cover of cattails and bulrushes (*Typha sp*. and *Scirpus sp*.). Wetlands were classified by identifying which vegetation class dominated the deepest part of the wetland basin (Stewart and Kantrud 1991). Percent emergent vegetation cover of the total wetland basin was visually estimated in the field. Wetland area was calculated by digitizing the area of each wetland basin in a GIS and measuring the polygon. The amount of water in the wetland was visually estimated as: dry (no water visible), wet (water present and emergent vegetation throughout the wetland basin), or open (distinct area of open water with emergent vegetation only growing along the edges). Due to low sample size the dry category was omitted. Wetland density was calculated using ArcMap by creating a 400-m radius buffer around each wetland. The number of wetlands within the buffer was counted and used as wetland density.

2.2.5 Statistical Analysis

I calculated frequency of occurrence of each species to determine those most commonly detected. I restricted all analyses to species that occurred in ≥ 10% of sites because habitat models for less common species failed to converge. I used Huggins close capture models in Program MARK 6.1 to calculate detection probabilities for each species (Huggins 1991). I used four encounter intervals, consisting of the four 75-second intervals used during my point-count surveys. I included 5 covariates in the analysis, including wind speed, season (early or late half of the breeding season), year, wetland classification, and stem density. I included wind and season because high wind speeds can reduce the ability of an observer to hear bird calls and different bird species may be more active at different times of the breeding season (Ralph et al. 1995). Wetland classification and stem density were included because wetland vegetation, such as bulrushes, cattails, and thicker willow density may reduce an observer's ability to see and hear birds. The recapture probability (c) was set to zero because the surveys were conducted once per year. I examined all model subsets along with a global and null model; the model with the lowest AICc value was considered the top model. I used the top model to calculate a correction factor for species abundance using the individual covariate plot in Program MARK (Yi=β0(intercept)+β1(covariate)+β2(covariate)+ β3(covariate)). Correction factors were applied to the raw counts prior to analysis.

I performed a community analysis including all species present at >10% of sites to examine associations between bird assemblages and environmental variables, including water level, wetland classification, % cattails , % willow cover, and upland cover type using Canonical Correspondence Analysis (CCA). I completed this analysis using the Vegan package (Oksanen et al. 2013) in R 3.1.0 (R Development Core Team 2014).

For all bird-habitat models I used generalized linear mixed models (PROC GLIMMIX; Allison 1999) and modeled bird abundance as a function of wetland and willow variables (Table 1) using a Poisson distribution with a log link. For all models I incorporated a random effect of willow-ring site to account for using the same wetland both years. I used Akaike's Information Criterion corrected for small sample size (AICc; Akaike 1974) to rank models and considered the model with the lowest AIC score and greatest weight to fit the data the best (Arnold 2010). I first reduced the number of variables considered for each species model by analyzing each covariate individually and comparing their AICc value with a null model. Individual covariates that outperformed the null model were retained and included in a global model. I then examined all subsets of the global model to identify top and competing models. Competing models were those that were within 2 AICc units of the best model with the same or fewer parameters (Arnold 2010). Model averaging was conducted on all top models whose cumulative AIC weights were ≥ 0.90. I calculated 85% confidence intervals for all variables from the top models and considered variables uninformative if confidence intervals included zero. I calculated relative variable importance values from the entire suite of models to evaluate the relative extent to which each of the covariates influenced habitat selection (Arnold 2010). Analyses were completed using SAS 9.2 (SAS institute Inc. 2008).

Table 1. Description of variables used in generalized linear mixed models.

Variables Modeled	Description
Upland vegetation cover	Type of upland vegetation cover surrounding each site (grassland or cropland)
Wetland Variables	
Wetland Area	Area (m^2) of wetland basin
Wetland Density	Number of wetlands within 400m of study sites
Wetland Classification	Categorical variables representing 4 wetland classes; ephemeral, temporary, seasonal, semi-permanent and permanent
% Emergent Vegetation	Estimate of percent cover of cattails/bulrushes in wetland basin
Water level	Categorical variables representing the amount of water in wetland; dry, wet or open.
Willow Variables	
Willow area	Area (m^2) of willow on wetland basin
% willow	% of wetland basin covered with willow
stem density	Number of willow stems/m^2
% deadwood	% of willow ring made up of dead vegetation
Height	Average willow height (m)

2.3 RESULTS

A large amount of variability within each of the wetland and willow variables existed among the wetland basins and the willow-ring structures (Table 2). The sites surveyed ranged from permanent wetlands with full willow rings to ephemeral wetlands with few willows. Five wetland classes (Stewart and Kantrud 1971) were represented in my study with permanent wetlands (class 5) the most common and ephemeral wetlands (class 1) least common (Table 3). The water level present in each wetland at the time of the bird surveys varied with open water sites present in the highest frequency and dry sites having the lowest (Table 3). Ephemeral wetlands and wetlands considered 'dry' were omitted from analyses because of low sample sizes. I recorded 66 different bird species making use of willow-ringed wetlands over the two years of the study (Appendix A, Table A.1). On average there were 10.5 ± 4.5 (SD) individual birds and 5.2 ± 2.1 (SD) species detected per wetland. Species that were present in <10% of sites were excluded from habitat selection modeling, leaving 16 bird species for analyses (Table 4).

Table 2.

Mean values (±SD) of wetland and willow ring variables: wetland area, wetland density, % emergent vegetation, stem density, % deadwood, willow height, willow area, % willow cover recorded at all study sites (n=92).

Environmental Variable	Mean	SD	Minimum	Maximum
Wetland Area (m^2)	5377	5269	638	42590
Wetland Density (# of wetlands/400 m buffer)	5.97	4.05	1	22
% Emergent Vegetation	22	30	0	95
Stem Density (stems/m^2)	1.23	0.91	0.09	5.16
% Dead Wood	17	18	0	95
Willow Height (m)	3.12	0.92	1.40	6.98
Willow Area (m^2)	1966	1683	127	9810
% Willow Cover	43	22	4	95

Table 3.

Frequency of wetland and upland vegetation class variables: wetland classification, upland vegetation cover and water level recorded for all study sites (n=92).

Wetland Classification	**Frequency**	**Percent**
Ephemeral (Class 1)	2	2.2
Temporary (Class 2)	7	7.6
Seasonal (Class 3)	16	17.4
Semi-permanent (Class 4)	26	28.3
Permanent (Class 5)	41	46.7
Upland Cover		
Cropland	55	60.9
Grassland	37	39.1
Water Level		
Dry	3	3.3
Wet	33	35.9
Open	56	60.9

Table 4

Combined number of species detections at all willow-ringed wetlands and frequency of occurrence of commonly detected species (occurred at ≥ 10% of willow-ringed wetlands) at each site, divided into woodland, wetland and grassland habitat guilds.

Species		**4 Letter Code**	**# Detections (no.)**	**Site Occurance (%)**
Woodland[1]				
Yellow warbler	*Setophaga petechia*	YEWA	265	82.6
Song sparrow	*Melospiza melodia*	SOSP	85	56.5
Brown-headed cowbird	*Molothrus ater*	BHCO	68	46.7
American goldfinch	*Spinus tristis*	AMGO	62	34.8
Least Flycatcher	*Empidonax minimus*	LEFL	46	30.4
American robin	*Turdus migratorius*	AMRO	22	20.7
Eastern kingbird	*Tyrannus tyrannus*	EAKI	22	15.2
Wetland				
Red-winged blackbird	*Agelaius phoeniceus*	RWBL	551	94.6
American coot	*Fulica americana*	AMCO	97	59.8
Sora	*Porzana carolina*	SORA	58	44.5
Blue-winged teal	*Anas discors*	BWTE	33	20.7
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	YHBL	52	16.3
Northern shoveler	*Anas clypeata*	NSHO	25	14.1
Grassland				
Clay-colored sparrow	*Spizella pallida*	CCSP	228	64.1
Savannah	*Passerculus sandwichensis*	SAVS	65	40.2

[1] Habitat classification based on Peterjohn et al. (1995).

sparrow				
Vesper sparrow	*Pooecetes gramineus*	VESP	54	33.7

2.3.1 Willow-wetland bird community

Based on CCA results, northern shoveler, blue-winged teal, American coot, and sora abundance had positive associations with permanent wetlands and wetlands with open water. Yellow-headed blackbird and red-winged black bird abundance was most strongly associated with an increase in tall aquatic vegetation. Vesper sparrow and savannah sparrow abundance was associated with sites classified as wet and temporary wetlands, whereas clay-colored sparrow abundance was correlated with the amount of upland grass vegetation surrounding wetlands. Song sparrow, yellow warbler, American robin, and brown-headed cowbird abundances were positively associated with increases in willow cover (Figure 3).

2.3.2 Willow-wetland influences on willow-ring bird abundance

Of the 16 species included in the analyses 10 species had informative models describing variation in species abundance in willow-ringed wetlands. Six species included willow ring variables in their models, while the remaining species were affected by wetland and landscape variables (Appendix B, Table B.1.). Willow and wetland variables were poor predictors of abundance for American goldfinch, blue-winged teal, northern shoveler and vesper sparrow. Models for these species all had beta estimates with 85% confidence intervals that included zero, indicating that the willow and wetland variables measured had little influence on their abundance (Table 5). As well, all class variables for these species had overlapping beta estimates with 85% confidence intervals, indicating that the variables had little influence on abundance.

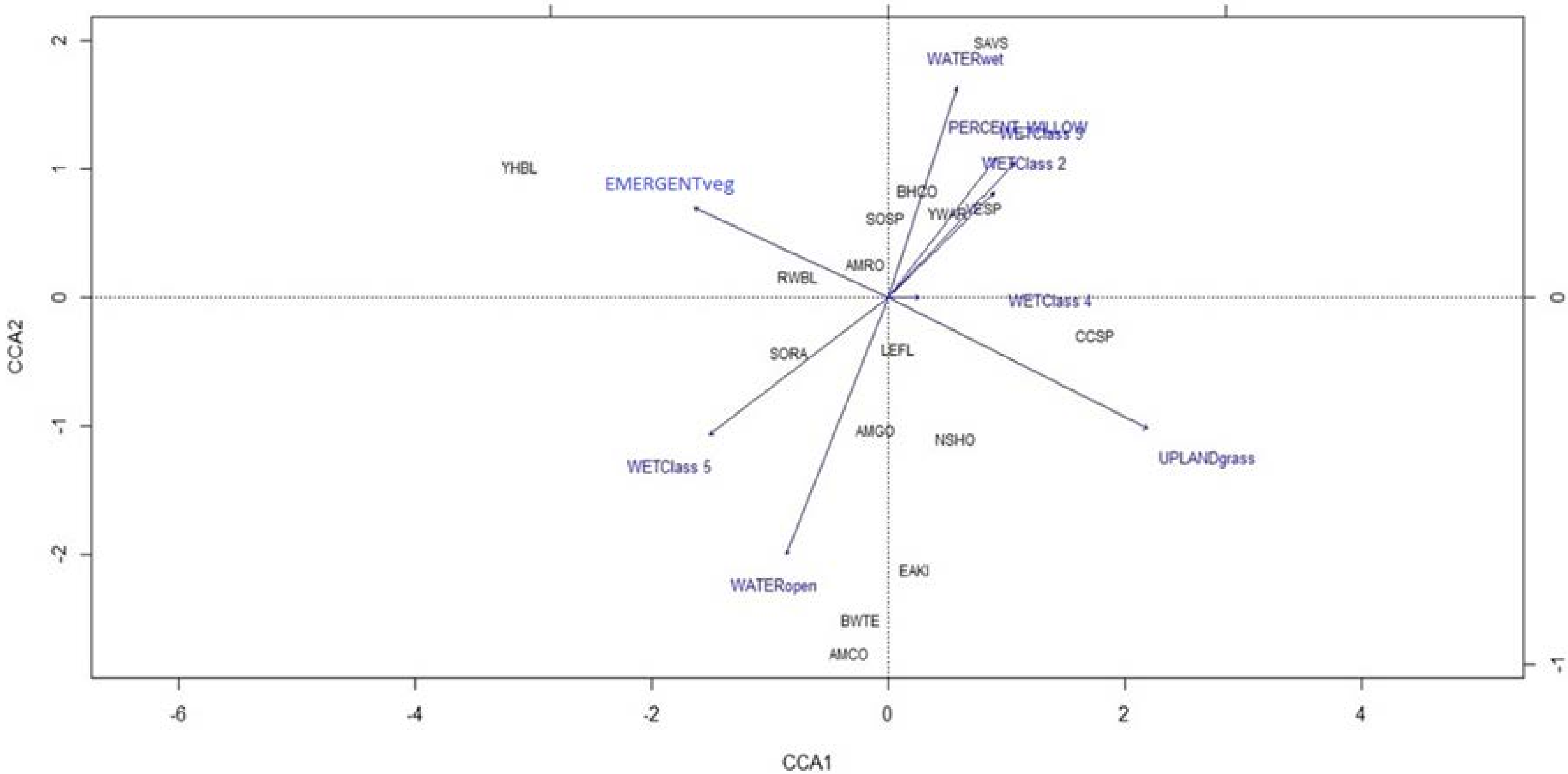

Fig. 3. Canonical correspondence analysis of the willow ring bird community constrained by habitat variables. EMERGENTveg (the % of bulrush and cattails/site), WATER (water levels of wetlands), UPLAND (upland cover), and WETclass (wetland classification) with species represented by points and environmental variables by vector arrows. Direction of the arrows represent gradients of the corresponding variables. Length of vectors depicts strength of variable's influence. Perpendicular projection of species from the vector shows average association with corresponding variable

Table 5. Model averaged beta estimates with 85% confidence intervals. Model averaging was conducted on all models with cumulative weights of 0.90.

Species	Variable	Category	Beta estimate	85% Confidence Interval
Woodland				
American goldfinch	water level	wet	-2.19	(-2.75– -1.63)
		open	-1.63	(-2.21– -1.04)
	wetland class	2	-1.26	(-2.32– -0.19)
		3	-3.64	(-5.18– -2.10)
		4	-1.83	(-2.44– -1.22)
		5	-1.47	(-1.94– -0.99)
	wetland density		-0.07	(-0.15– 0.006)
American robin	deadwood		0.03	(-.07– 0.01)
	stem density		0.10	(-0.27– 0.46)
	wetland area		0.30	(-0.28– 0.88)
	willow area		0.57	(0.12– 1.03)
	willow height		-0.53	(-0.98– -0.08)
Brown-headed cowbird	wetland density		-0.08	(-0.14– -0.02)
	willow height		0.28	(0.07– 0.49)
Eastern kingbird	willow height		0.58	(0.07– 1.09)
	wetland area		0.69	(0.03– 1.36)
	water level	wet	-3.90	(-5.17– -2.63)
		open	-3.22	(-4.44– -2.00)
	stem density		-0.58	(-1.46– -0.29)
Least flycatcher	wetland density		0.07	(-0.01– 0.15)
Song sparrow	wetland density		4.64	(0.86– 8.43)
	willow area		0.49	(0.12– 0.86)
	willow height		0.50	(0.21– 0.80)
Yellow warbler	% willow		0.00	(-0.00– 0.02)
	wetland density		0.05	(0.02– 0.07)
	wetland area		0.25	(-0.14– 0.63)
	willow area		0.41	(0.23– 0.58)
Wetland				
American coot	% willow		-0.02	(-0.03– -0.01)
	deadwood		0.01	(0.01–0.02)
	stem density		0.01	(-0.22– 0.24)
	water level	wet	-1.17	(-1.47– -0.87)
		open	-0.53	(-0.78– -0.28)
	wetland area		0.37	(0.12– 0.62)

	wetland class	2	-1.26	(-2.32– -0.19)
		3	-1.00	(-1.54– -0.46)
		4	-0.78	(-1.10– -0.44)
		5	-0.80	(-1.07– -0.52)
Blue-winged teal	stem density		-0.69	(-1.40– 0.02)
	water level	wet	-3.22	(-4.02– -2.42)
		open	-2.44	(-3.23– -1.64)
Northern shoveler	water level	wet	-5.71	(-8.09– -3.33)
		open	-5.28	(-7.60– -2.94)
Red-winged blackbird	water level	wet	1.45	(1.27– 1.63)
		open	1.41	(1.17– 1.65)
	wetland area		0.31	(0.16– 0.47)
	wetland class	2	0.74	(0.29– 1.19)
		3	1.17	(0.91– 1.43)
		4	1.45	(1.28– 1.63)
		5	1.74	(1.61– 1.87)
Sora	% willow		-0.13	(-0.02– 0.00)
	upland vegetation	crop	-1.16	(-1.55– -0.78)
		grass	-1.41	(-1.79– -1.04)
	wetland area		0.14	(-1.15– 0.43)
	wetland class	2	-1.19	(-2.02– -0.36)
		3	-2.12	(-2.95– -1.29)
		4	-1.34	(-1.74– -0.94)
		5	-0.86	(-1.10– -0.61)
Yellow-headed blackbird	upland vegetation	crop	-3.06	(-4.08– -2.03)
		grass	-5.80	(-7.78– -3.82)
	emergent veg		0.02	(0.00– -0.03)
	wetland area		1.65	(0.74– 2.56)
Grassland				
Clay-colored sparrow	emergent veg		-0.01	(-0.02– -0.00)
	upland vegetation		-0.93	(-1.26– -0.60)
		grass	1.10	(0.85– 1.36)
	water level	wet	0.46	(0.21– 0.71)
		open	-0.29	(-0.57– -0.01)
	willow height		0.10	(-2.67– -1.31)
Savannah sparrow	emergent veg		-422.69	(-1311.86– 466.47)
	water level	wet	-1.99	(-2.67– -1.31)
		open	-1.99	(-2.67– -1.31)

	wetland area		0.49	(0.12– 0.87)
	wetland class	2	-0.79	(-1.65– 0.07)
		3	-1.17	(-1.86– -0.49)
		4	-1.25	(-1.72– -0.78)
		5	-2.04	(-2.54– - 1.54)
	wetland density		-0.07	(-0.14– -0.004)
Vesper sparrow	emergent veg		-0.13	(-0.02– -0.00)
	upland vegetation	crop	-1.96	(-3.04– -0.88)
		grass	-1.63	(-2.16– - 1.10)
	water level	wet	-1.70	(-2.20– -1.19)
		open	-2.32	(-2.94– - 1.70)

American robin, yellow warbler, song sparrow, brown-headed cowbird, Eastern kingbird, and American coot abundance was explained to some extent by willow-ring variables (Table 5). American robin, yellow warbler, and song sparrow abundance was explained by willow area (Table 5), with abundance increasing as willow area increased (Figure 4). Willow area had the strongest influence on yellow warbler abundance, whereas willow height had the greatest influence on song sparrow, American robin, and brown-headed cowbird abundance (Table 6). American robin decreased as willow height increased, while the other two species increased in abundance as willow height increased (Figure 5). Eastern kingbird was also most strongly influenced by willow height (Table 6); however, the predictive power of this variable is poor for this species as the null model was < 2 AICc units away from the top model, however, it cannot be discounted as a plausible model (Appendix B, Table B.1.). American coot abundance was best explained by deadwood cover and willow cover (Appendix B, Table B.1.), with willow cover being most influential (Table 6). Percent willow cover had a negative impact on coot abundance, which increased as the presence of deadwood increased (Figure 6).

Table 6

Relative importance of variables to abundance of willow-ring bird species calculated by adding the weight of all models containing each variable.

Species	Variable	Relative Variable Importance
Woodland		
American goldfinch	wetland class	0.58
	water level	0.53
	wetland density	0.47
American robin	willow height	0.73
	willow area	0.66
	deadwood	0.55
	wetland area	0.38
	stem density	0.34
Brown-headed cowbird	willow height	0.68
	wetland density	0.69
Eastern kingbird	willow height	0.54
	wetland area	0.54
	water level	0.50
	stem density	0.38
Least flycatcher	wetland density	0.72
Song sparrow	willow height	0.60
	willow area	0.17
	wetland density	0.20
Yellow warbler	willow area	0.84
	wetland density	0.67
	wetland area	0.25
	% willow	0.22
Wetland		
American coot	deadwood	0.98
	water level	0.93
	% willow	0.90
	wetland area	0.86
	stem density	0.25
	wetland class	0.09
Blue-winged teal	stem density	0.55
	water level	0.51
Northern Shovelor	water level	0.51
Red-winged blackbird	water level	1.00
	wetland area	0.97
	wetland class	0.38

Sora	% willow	0.70
	wetland class	0.59
	wetland area	0.36
	upland vegetation	0.35
Yellow-headed blackbird	wetland area	0.92
	upland vegetation	0.92
	emergent vegetation	0.62
Grassland		
Clay-colored sparrow	upland vegetation	1.00
	water level	0.99
	emergent vegetation	0.94
	willow height	0.35
	wetland class	0.09
Savannah sparrow	water	0.83
	emergent veg	0.69
	wetland area	0.64
	wetland density	0.46
	wetland class	0.18
Vesper sparrow	upland vegetation	0.59
	emergent veg	0.56
	water level	0.56

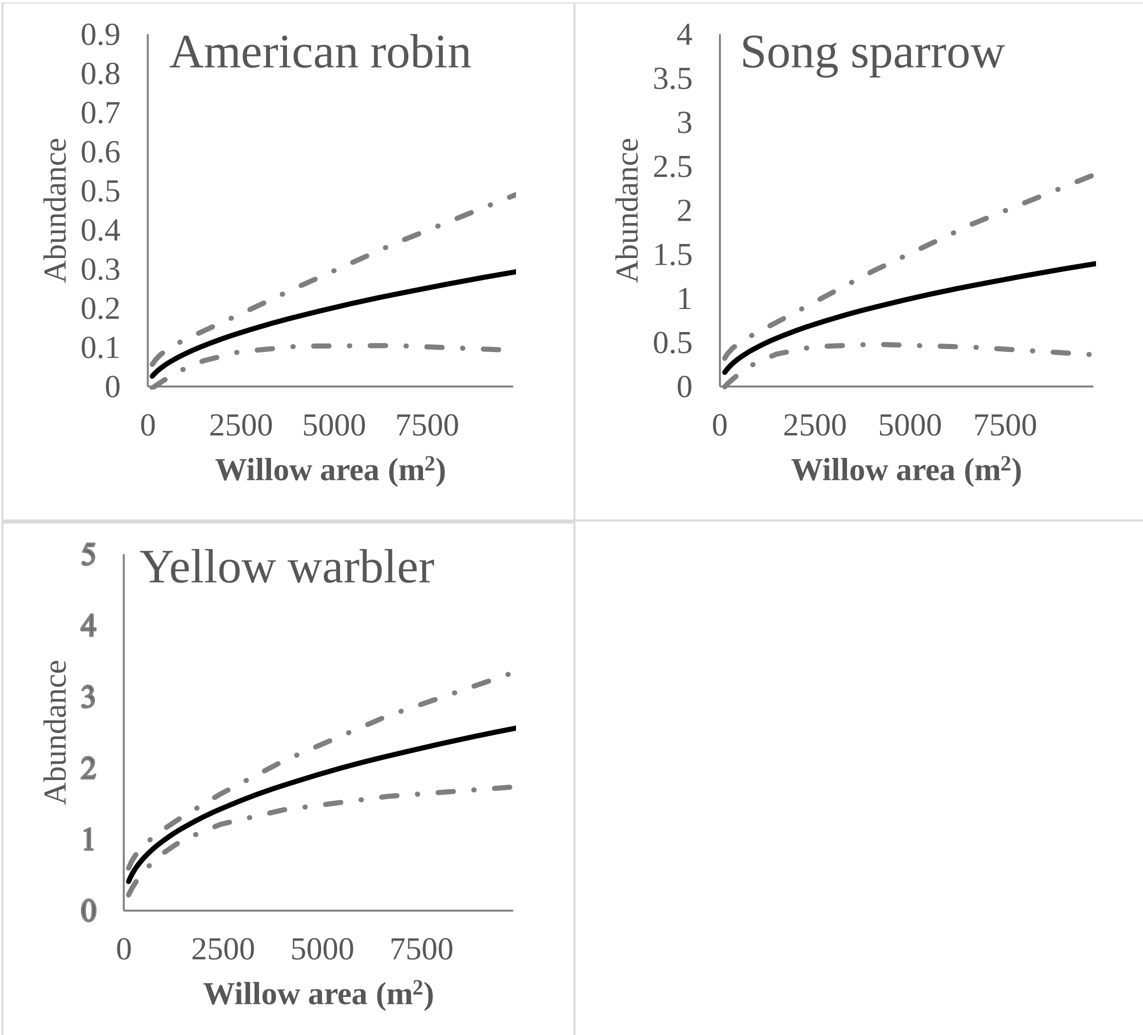

Fig. 4. Model predicted relationships between the abundance (85% confidence interval) of American robin, song sparrow and yellow warbler and willow area.

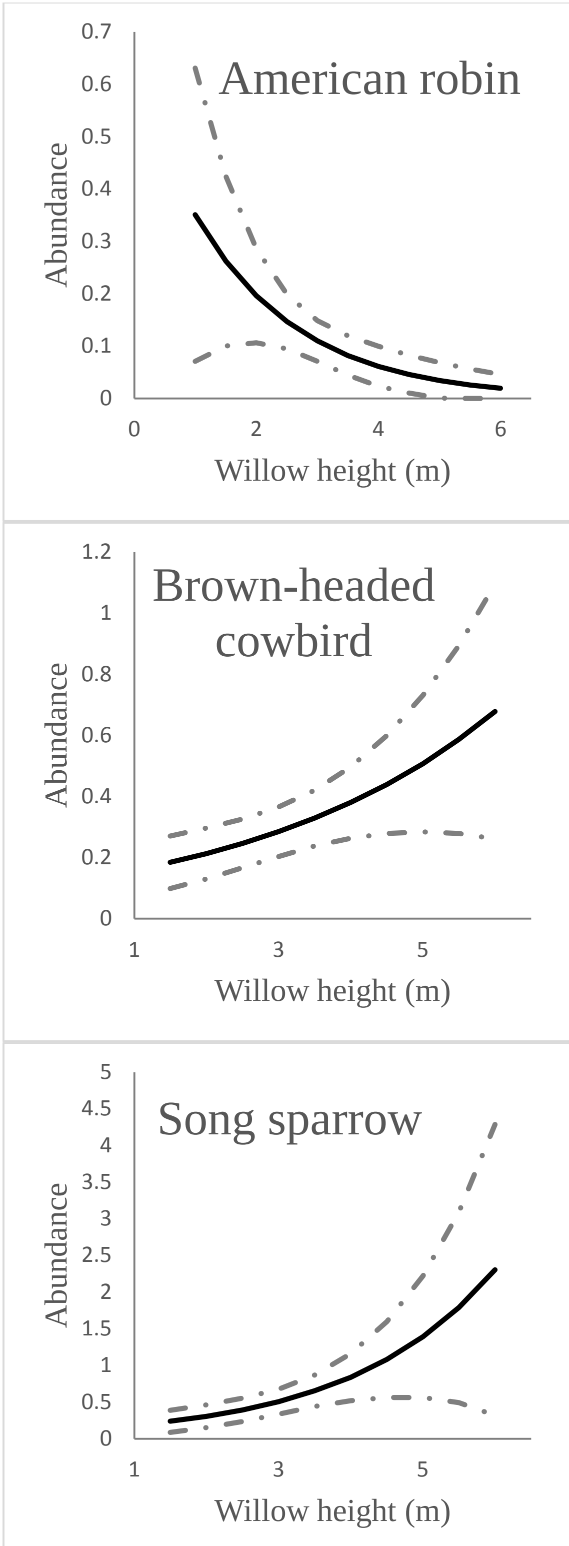

Fig. 5. Model predicted relationships between the abundance (85% confidence interval) of American robin, brown-headed cowbird and song sparrow and willow height.

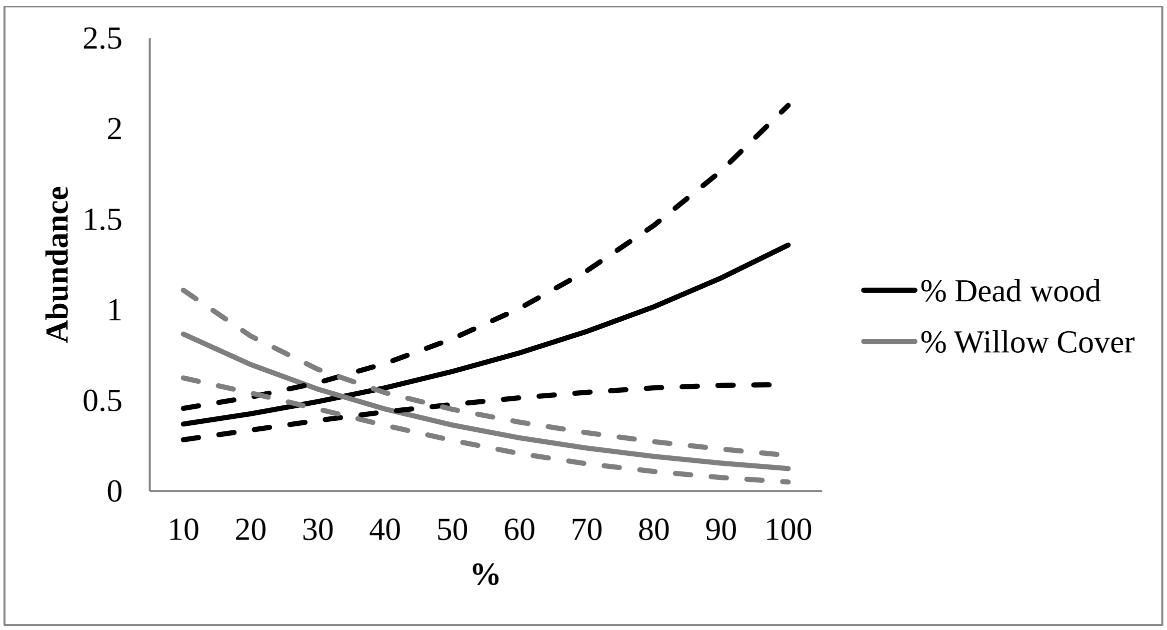

Fig. 6. Model predicted relationships between abundance (with 85% confidence interval) of American coots, % willow cover, and % deadwood.

Variation in abundance for some species was also explained by wetland characteristics such as wetland area, water level, and wetland class. Wetland area influenced the abundance of American coot, red-winged blackbird, Eastern kingbird, and savannah sparrow. Abundance of these species increased as wetland area increased (Figure 7). Water level also affected species abundance. American coot and clay-colored sparrow had water level as a variable in their top model with an RVI of 93% and 99% (Table 6), respectively, suggesting that it was a highly influential variable for both species. American coot abundance was highest in wetlands classified as having open water, while clay-colored sparrow abundance was greatest in wetlands classified as wet (Table 7). Water level was also a variable in the competing models for red-winged black bird; however, 85% confidence intervals overlapped (Table 5). Wetland classification also drove variation in red-winged blackbird abundance (Appendix B, Table B.1.). While the RVI was lower than other variables that influenced this species (Table 6), red-winged blackbird abundance was highest in permanent wetlands and lowest in temporary wetlands (Figure 9). Sora abundance was also influenced by the wetland class; however, most categories had overlapping beta estimates with the exception of seasonal and permanent wetlands (Table 5). Sora abundance was highest in permanent wetlands and lowest in seasonal wetlands (Figure 9).

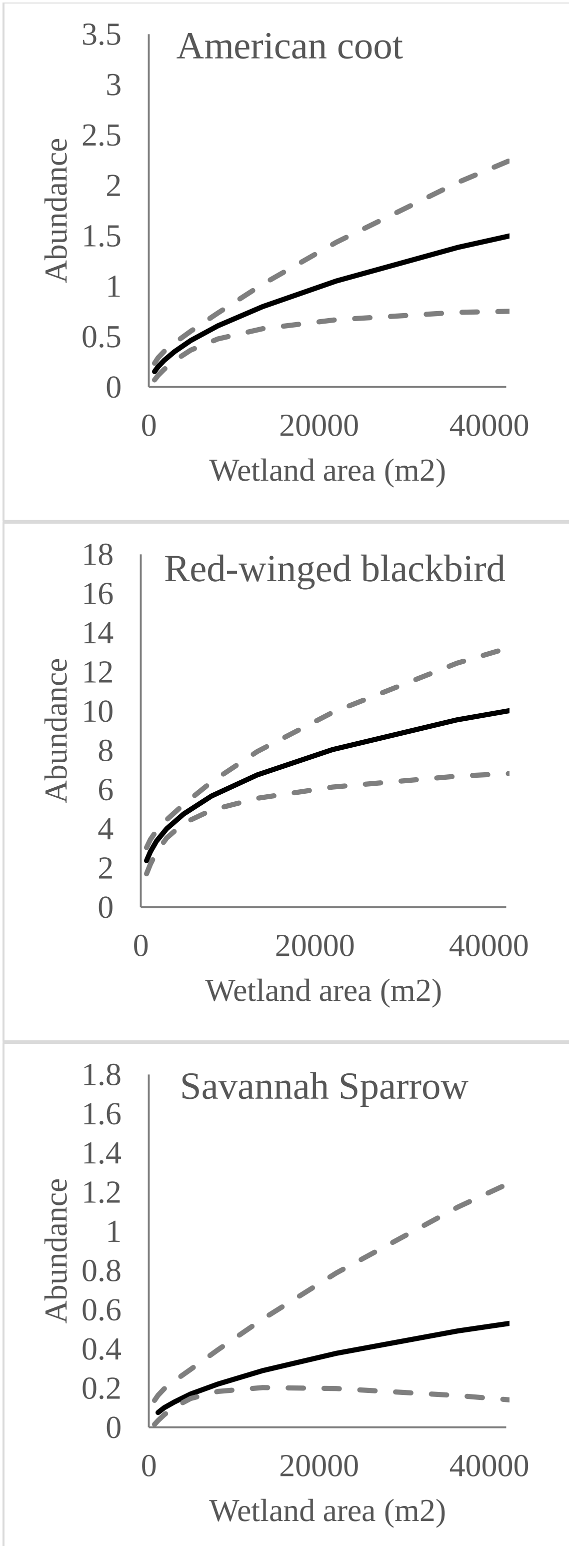

Fig. 7. Model predicted relationships between the abundance (85% confidence interval) of American coot, red-winged blackbird, and song sparrow and wetland area.

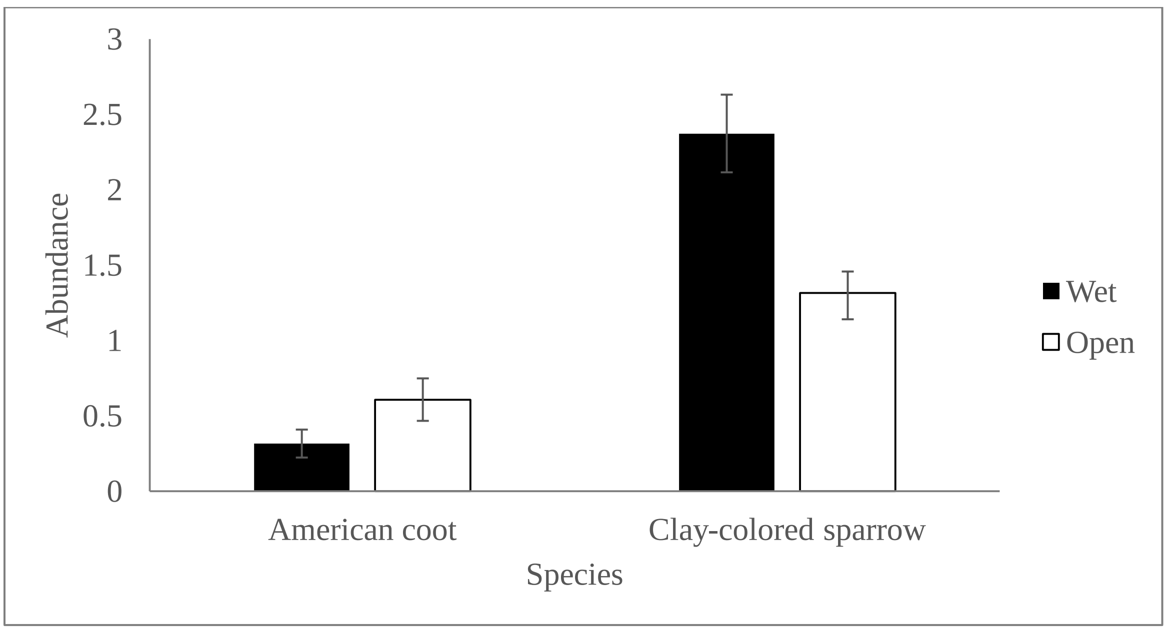

Fig. 8. Model predicted relationships between abundance (85% confidence interval) of clay-colored sparrow, American coot and water levels in each type of wetland.

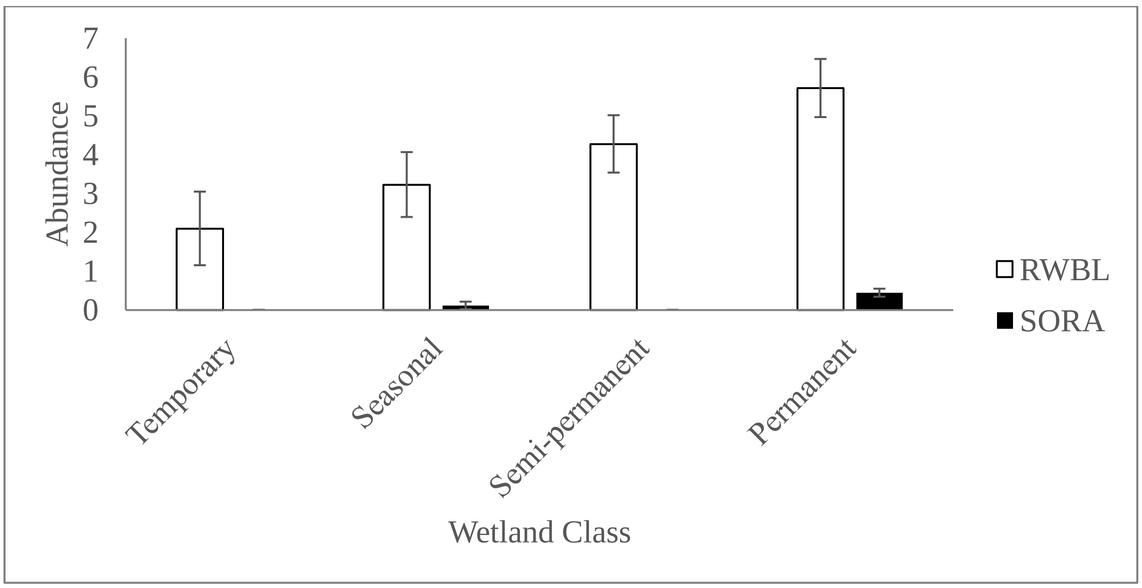

Fig. 9. Model predicted relationships between abundance (85% confidence interval) of red-winged black bird (RWBL), sora (SORA) and wetland class.

2.3.3 Landscape influences on willow-ring bird abundance

Wetland density was present in the competing models for American goldfinch, brown-headed cowbird, song sparrow, least flycatcher, savannah sparrow, and yellow warbler; however, 85% confidence intervals included zero for American goldfinch and least flycatcher (Appendix B, Table B.1, Table 5). Based on RVI wetland density played a lesser role than willow area, but abundance tended to increase with increased density of wetlands within 400-m of the focal wetland (Figure 10). Wetland density played the most important role for the brown-headed cowbird with abundance decreaing as wetland density increased (Table 6, Figure 10).

Several species included upland vegetation cover as a variable in their top model, including vesper sparrow, sora, yellow-headed blackbird, and clay-colored sparrow (Appendix B, Table B.1.). Analysis of beta estimates and their 85% confidence intervals revealed this variable to be largely uninformative except for clay-colored sparrow (Table 5). With an RVI of 100%, upland vegetation cover was the major factor driving variation in clay-colored sparrow abundance (Table 6). Wetlands surrounded by grassland cover had the highest abundance of this species, while wetlands surrounded by cropland cover had the lowest abundance (Figure 11).

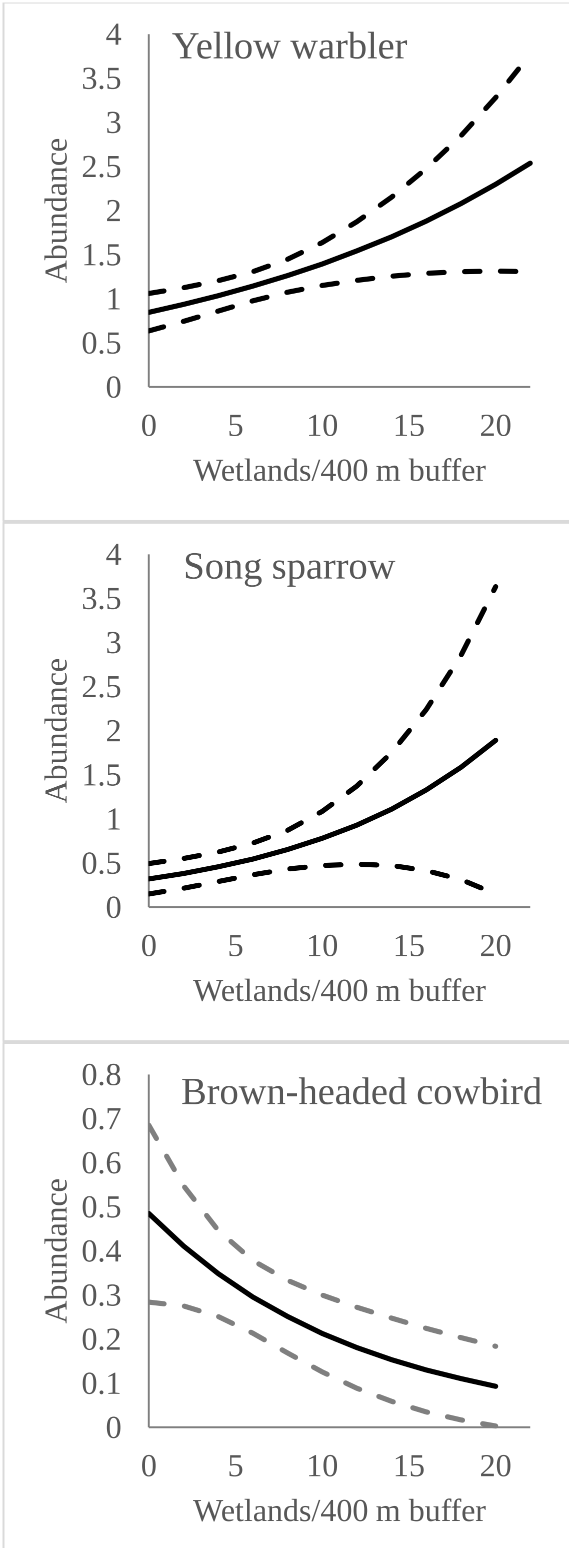

Fig. 10. Model predicted relationships between the abundance (85% confidence interval) of yellow warbler, song sparrow, brown-headed cowbird and wetland density.

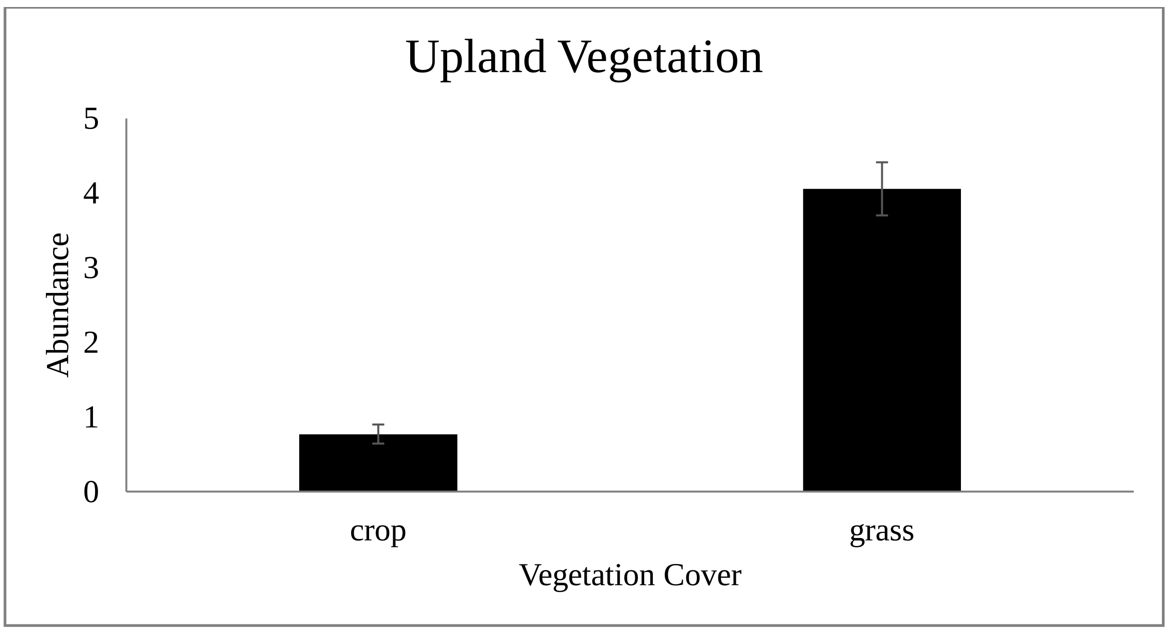

Fig. 11. Model predicted relationships between abundance (85% confidence interval) of clay-colored sparrow and upland vegetation cover type.

2.4 DISCUSSION

I documented 66 different bird species associated with willow-ringed wetlands. This level of species richness can be attributed to the different food, water, and cover resources that can be found within these wetlands as a result of the presence of woody vegetation, riparian vegetation, water and the upland vegetation surrounding the wetlands. Included among the species I recorded are four birds that are listed as species at risk in Canada; bobolink and barn swallow, which are both listed as threatened, and Baird's sparrow and horned grebe, which are both listed as special concern (COSWEIC 2009, 2010, 2011, 2012). Many of the species I recorded are common, but are still important indicators of the health of their environment (Gregory et al. 2004) and may also play an important role in agricultural ecosystems. Various bird species aid in seed dispersal and pollination, some species consume carrion, decreasing diseases and pests, and many are predators of common crop pests, aiding in agricultural production (Baker et al. 2012, Tremblay et al. 2001). Therefore agro-ecosystem management practices, such as willow-ring harvest, must be conducted with knowledge and care in order to maintain these bird populations.

The process of harvesting willow biomass from natural willow rings can disturb willow-ring habitat to a large extent. Harvesting willow initially reduces the amount of above ground willow present in wetlands; however, remaining coppiced stems re-grow from below-ground roots (Schroeder et al. 2009). Willow-ringed wetlands provide habitat for a variety of different birds. Considering the varying effects of willow characteristics on avian abundance in my study, the impacts of willow harvest is likely going to be variable and highly dependent on the bird species present. Some species will likely be negatively affected by willow biomass harvest (e.g., yellow warbler), some will be positively affected (e.g., Amercian coot), and many species will be unaffected by changes in willow cover.

Woodland species will be negatively affected the most by changes in willow ring structure. Yellow warbler, song sparrow, and American robin require woody vegetation for reproduction and survival. American robins and yellow warblers get 78 and 95% of their food, respectively, by gleaning insects from woody vegetation (Lowther et al. 1999, Vanderhoff et al. 2014). Both species nest in woody vegetation where their nests are well concealed and receive some level of protection from predators and inclement weather (Arcese et al. 2002, Lowther et al. 1999 Vanderhoff et al. 2014). However, an important point that may be overlooked is that willow vegetation can become degraded. Reduction and degradation of woody riparian vegetation through natural processes and human activities negatively impacts woodland bird species through loss of cover for nesting and protection from predators. Woodland birds are displaced once these habitat features are lost. Willow vegetation is also reduced and degraded by intense cattle grazing, such that it no longer provides sufficient nesting and foraging cover (Argent and Zwier 2007). In such cases, the levels of predation and brood parasitism may increase (Argent and Zwier 2007). Taylor et al. (1986) found that riparian areas that were ungrazed had 2.5 times more birds than heavily grazed sites because the increased amount of healthy willow provided more cover. Willow harvest would have similar effects on bird species as it also removes vegetation cover. However, unlike uncontrolled grazing, a properly managed willow harvest allows the vegetation time to recover from the disturbance. Because of this, willow harvesting can improve the quality of willow rings by removing senescing and dead vegetation, allowing new, healthy vegetation to thrive (Mirck and Schroeder 2013). Historically, natural disturbances, such as fires and large mammal grazing, would have performed this function but these disturbances are typically lacking on the prairies because of human intervention. Willow harvest would also maintain the willow at a shorter height, which may impact woodland bird species abundance. Song sparrows increased in abundance as willow height increased, therefore reducing the average height of willow cover may decrease the suitability of the habitat for this species. Brown-headed cowbird abundance also followed this trend; however, reducing this species abundance may decrease instances of brood parasitism, benefitting other species within the willow ring community (Lowther 1993). Therefore, willow harvest may have a positive effect on woodland bird species in the long term depending on how it is managed.

Properly managed willow harvest may have positive effects on some wetland bird species. The American coot, an example of a wetland species, declined in abundance with the presence of large amounts of willow cover. The abundance of American coots decreased as the proportion of willow vegetation increased. Dense vegetation cover provides perch sites and concealment for common predators of wetland bird species, such as hawks, owls, and coyotes (Brisbin et al. 2002, Melvin and Gibbs 2012). Murphy (1997) found that great horned owls of the Northern Great Plains rely heavily on wetland bird species as a food source with 35% of their diet consisting of ducks and 11% consisting of rails, predominately American coots. Complex wetland vegetation can also be a major visibility obstruction for wetland birds (Whittingham and Evans 2004). Increased visibility obstructions may impede the ability of prey species to detect predators until they are too close to be avoided (Metcalf 1984). In wetlands that decrease visibility, birds are forced to increase vigilance and spend less time foraging (Whittingham and Evans 2004). These results are consistent with Hierl et al. (2007) who found that soras selected wetlands with 10-30% shrub cover. Guillemain et al. (2001) found that dabbling ducks increase vigilance when visibility decreases, lowering their foraging efficiency. These trends in wetland species abundance in regards to the willow ring structure suggests that harvesting the willow biomass would increase the amount of suitable wetland habitat for these birds. Willow vegetation harvested on a rotational basis provides an opportunity to manage willow rings in a way that would benefit both woodland and wetland bird species. The initial harvest removes visibility obstructions, creating habitat for wetland bird species. While this initial harvest decreases woodland bird habitat, it allows the willow vegetation a chance to be rejuvenated, creating better woodland habitat in the long term. In areas with many willow rings, rotational harvest allows good habitat for both wetland and woodland birds to be present at the same time and also allow sufficient timing for willow rings to re-grow.

The surrounding upland habitat is also a factor affecting which bird species occupy willow rings. Historically, wetlands have been drained to increase area for crop production in agricultural lands (Cortus et al. 2011). To conserve wetlands effectively, harvest of willow biomass should target wetlands in cropland areas because they are more susceptible to drainage (Cortus et al. 2011). Providing landowners with economic incentive to maintain wetlands on the landscape is the most effective way to conserve these wetlands (Schroeder et al. 2009). Clay-colored sparrow, a grassland species, is most abundant in willow rings surrounded by grassland vegetation. The influence of upland vegetation cover is likely a result of the additional resources present; specifically, cover and/or food (Brontons et al. 2005). Brontons et al. (2005) describe three hypotheses that might explain why species like clay-colored sparrow are influenced by the surrounding landscape: supplementation, compensation and complementation. The complementation hypothesis suggests that species require resources from multiple habitat types to meet their needs. The compensation hypothesis predicts that species are able to use other habitat types to obtain resources when natural habitat is absent. Species abundance can also be explained by the supplementation hypothesis, which suggests that species gather resources from nearby habitats to add to the resources within their natural habitat (Brontons et al. 2005). Although willow variables did not affect clay-colored sparrow abundance, because they are shrub-nesting species willow harvest may have unforeseen impacts on their breeding territory. If management of willow rings were focused in areas of cropland where these birds are less abundant it will reduce the amount of their habitat being disturbed. In this way harvest of cropland willow rings is a sustainable option for both wetland conservation and avian conservation.

Conserving the number of wetlands within the landscape may be an important step in maintaining certain bird populations. The amount of wetlands present in the surrounding uplands also impacts the abundance of some bird species. Song sparrows and yellow warblers increased in abundance as the number of wetlands within 400 m increased. The influence of surrounding wetland density suggests that these bird species are making use of surrounding wetland habitat for additional resources (Brontons et al. 2005). Continued loss of wetlands on the prairies will cause a decline in these species populations as their habitat is lost, making it important to maintain as many wetlands within the landscape. Understanding what aspects of willow-ringed wetlands and their surrounding landscapes affect variation in bird abundance is vital to determining how and where to harvest willow biomass so that prairie wetlands are conserved, and remain ecologically functional and capable of supporting bird populations.

2.4.1 Best Practice Guidelines

Based on the response of bird species to the natural variation in willow traits, willow harvest is a practice that is feasible and sustainable for the species of the willow-ring bird community. Because specific willow traits did not have a strong effect on the majority of bird species that used the wetlands, harvest can be tailored to meet the specific management objectives of local areas. These practices should be sustainable long term with some best practice guidelines specific to the land use type:

1. Harvest should be conducted in areas of cropland cover when possible.
2. When harvest is conducted in areas with livestock, grazing activity or access to riparian vegetation should be limited while willow vegetation recovers.

3. If multiple willow rings are present, a rotational harvest method should be used allowing some woodland habitat to remain intact.
4. When other sources of woodland habitat are not present on the landscape partial harvest of willow rings should be conducted to maintain woodland habitat for local bird species.

In addition, specific guidelines for sustainable willow harvest should be followed including harvesting in late fall once breeding and migration seasons are over. Harvest should be conducted on wetlands that are dry and when ground is frozen. Sufficient time, approximately 4-5 years, should be allowed for willow to recover before a second harvest (Shroeder et al. 2009).

2.5 CONCLUSIONS

My objectives were to: (1) determine what species make up willow-ring bird communities; (2) examine the features of willow ring-wetlands and upland vegetation that drive the habitat selection of birds; and (3) evaluate how changes in willow ring structure might affect associated birds. The results of my research on willow-ring bird communities and the effects of willow harvest indicate that harvesting willow biomass will have variable effects on the bird community but can be sustainable if best practice guidelines are followed.

I recorded 66 different bird species associated with willow-ring wetlands including woodland, wetland and grassland habitat guilds. Woodland bird species will most certainly decline in abundance once willow vegetation is removed from prairie wetlands. However, as willow cover decreases, the abundance of wetland species will likely increase. The grassland species have little association with the willow vegetation and therefore their abundance will not be directly impacted by willow removal.

Declines in woodland bird species as willow vegetation decreased were anticipated and are consistent with the results of studies examining the structure of linear riparian areas (Heltzel and Earnst 2006, Stauffer and Best 1980, Willson 1974). However, I had not anticipated increased abundance of wetland species as willow cover or density decreased. Although wetland and woodland birds react to changes in willow vegetation differently, willow harvest can be conducted in a way that conserves both types of species through rotational and partial harvests. While this study was unable to directly manipulate the willow-ring structure to determine how harvest would affect bird species, future research should monitor the willow ring bird community before and after harvest to observe community changes directly. Monitoring harvested sites as willow re-grows would also determine how long it takes for displaced birds to return after the willow ring is re-established. My work only includes data on species that use willow rings during the breeding season. Because prairie wetlands are of high importance to migratory birds, future research should examine species that use willow rings during migration. My data and analyses focused on abundance; however, using other measurements such as species richness and diversity indices or looking at reproduction and survival may give a stronger indication of which habitat types provide optimal resources for willow ring bird species.

The results from this study can be used to inform industry and land owners on sustainable willow biomass harvest from wetlands. If conducted correctly, biomass harvest has potential to mitigate wetland drainage that threatens the prairie ecozone.

Adding economic importance to these wetlands through the sale and use of willow will incent landowners to retain wetlands which significantly contribute to environmental and ecological sustainability of prairie agro-ecosystems.

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APPENDIX A – SPECIES DETECTED

Appendix A. Table A.1. List of all species detected at site in 2012 and 2013 divided by habitat guild, including federal status. Species without status have not been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Common name	Scientific Name	Federal Status
Wetland		
American bittern	*Botaurus lentiginosus*	
American coot	*Fulica americana*	
American wigeon	*Anas americana*	
Black tern	*Chlidonias niger*	
Blue-winged teal	*Anas discors*	
Canada goose	*Branta canadensis*	
Canvasback	*Aythya valisineria*	
Eared grebe	*Podiceps nigricollis*	
Gadwall	*Anas strepera*	
Green- winged teal	*Anas crecca*	
Horned grebe	*Podiceps auritus*	Special concern
Killdeer	*Charadrius vociferus*	

Mallard	*Anas platyrhynchos*	
Marsh wren	*Cistothorus palustris*	
Nelson's sharp-tailed sparrow	Ammodramus nelsoni	
Northern pintail	*Anas acuta*	
Northern shoveler	*Anas clypeata*	
Pied-billed grebe	*Podilymbus podiceps*	
Redhead	*Aythya americana*	
Red-winged black bird	*Agelaius phoeniceus*	
Ruddy duck	*Oxyura jamaicensis*	
Sora	*Porzana carolina*	
Willet	*Tringa semipalmata*	
Wilson's phalarope	*Phalaropus tricolor*	
Wilson's snipe	*Gallinago delicata*	
Yellow-headed black bird	*Xanthocephalus xanthocephalus*	
Woodland		
Alder flycatcher	*Empidonax alnorum*	
American goldfinch	*Spinus tristis*	
American robin	*Turdus migratorius*	
Baltimore oriole	*Icterus galbula*	
Black-capped chickadee	*Poecile atricapillus*	
Brown-headed cowbird	*Molothrus ater*	
Cedar waxwing	*Bombycilla cedrorum*	
Common yellowthroat	*Geothlypis trichas*	
Eastern kingbird	*Tyrannus tyrannus*	
Gray catbird	*Dumetella carolinensis*	
Hairy woodpecker	*Picoides villosus*	
House wren	*Troglodytes aedon*	
Least flycatcher	*Empidonax minimus*	
Norther flicker	*Colaptes auratus*	
Sharp-tailed grouse	*Tympanuchus phasianellus*	
Song sparrow	*Melospiza melodia*	
Tree swallow	*Tachycineta bicolor*	
Warbling vireo	*Vireo gilvus*	
Yellow warbler	*Setophaga petechia*	
Grassland		
Baird's sparrow	*Ammodramus bairdii*	Special concern
Bobolink	*Dolichonyx oryzivorus*	Threatened
Clay-colored sparrow	*Spizella pallida*	
Grasshopper sparrow	*Ammodramus savannarum*	
Horned lark	*Eremophila alpestris*	
Le Conte's sparrow	*Ammodramus leconteii*	
Savannah sparrow	*Passerculus sandwichensis*	

Upland sandpiper	*Bartramia longicauda*	
Vesper sparrow	*Pooecetes gramineus*	
Western meadowlark	*Sturnella neglecta*	
Successional		
American crow	*Corvus brachyyrhynchos*	
Barn swallow	*Hirundo rustica*	Threatened
Black-billed magpie	*Pica hudsonia*	
Brewer's blackbird	*Euphagus cyanocephalus*	
Common grackle	*Quiscalus quiscula*	
Lark sparrow	*Chondestes grammacus*	
Mourning dove	*Zenaida macroura*	
Northern harrier	*Circus cyaneus*	
Northern mockingbird	*Mimus polyglottos*	
Red-tailed hawk	*Buteo jamaicensis*	
Swainson's hawk	*Buteo swainsoni*	

APPENDIX B – EFFECT OF WETLAND AND WILLOW VARIABLES ON HABITAT SELECTION OF THE WILLOW RING BIRD COMMUNITY

Appendix B. Table B.1. Top and competing models relating wetland and willow characteristics of sites to species abundance. Top model is indicated by the lowest Akaike's Information Criterion (AICc) score. Competing models include models within 2 AICc units of the top model with the same or fewer parameters. All competing models with weights contributing to wi=0.90 and the null model are included with corresponding number of parameters (K), Log likelihood score (LL), AICc score, ΔAICc score, and model weight (*Wi*).

Species	Model	K	LL	AICc	ΔAICc	Wi
Woodland						
American goldfinch	wetland class	2	236.73	247.10	0.00	0.18
	water level	2	241.88	248.02	0.92	0.11
	wetland density+	2	242.46	248.61	1.51	0.08
	null	1	244.76	248.83	1.73	0.08
American robin	willow height–willow area+deadwood–	4	126.33	134.57	0.00	0.15
	willow height–willow area+	3	129.06	135.21	0.64	0.11
	willow area+deadwood–	3	130.26	136.40	1.83	0.06
	willow height–wetland area+	3	130.74	136.88	2.31	0.05
	willow height–wetland area+deadwood–	4	128.70	136.94	2.37	0.04
	willow height–willow area+stem density+	4	128.82	137.06	2.49	0.04
	willow height–willow area+wetland area+	4	128.98	137.22	2.65	0.04
	willow height–	2	133.52	137.59	3.02	0.03
	willow height–stem dens+wetland area+	4	129.42	137.66	3.09	0.03
	willow area+stem density+deadwood–	4	129.54	137.78	3.21	0.03

	willow area+	2	133.72	137.79	3.22	0.03
	willow height–deadwood–	3	131.65	137.79	3.22	0.03
	willow height–stem density+	3	131.94	138.08	3.51	0.03
	willow height–stem density+deadwood–	4	130.23	138.47	3.90	0.02
	willow area+wetland area+deadwood–	4	130.24	138.48	3.91	0.02
	willow area+stem density+	3	132.67	138.81	4.24	0.02
	stem density+wetland area+deadwood–	4	130.60	138.84	4.27	0.02
	null	1	138.39	140.41	5.84	0.01
Brown-headed cowbird	willow height+wetland density–	3	284.92	293.17	0.00	0.47
	willow height+	2	288.61	294.76	1.59	0.21
	wetland density–	2	288.76	294.90	1.73	0.20
	null	1	291.69	295.76	2.59	0.13
Eastern kingbird	willow height+wetland area+water level	4	124.07	134.44	0.00	0.11
	willow height+wetland area	3	126.48	134.72	0.28	0.10
	willow height+water level	3	126.81	135.05	0.61	0.08
	willow height+	2	129.24	135.38	0.94	0.07
	wetland area+water level	3	127.20	135.44	1.00	0.07
	wetland area+	2	129.45	135.60	1.16	0.06
	water level	2	129.46	135.61	1.17	0.06
	stem density–	2	129.63	135.78	1.34	0.06
	null	1	131.71	135.78	1.34	0.06
	wetland area+stem density–	3	127.65	135.89	1.45	0.06
	willow height+wetland area+stem density–	4	125.79	136.15	1.71	0.05
	stem density–water level	3	127.96	136.20	1.76	0.05
	wetland area+stem density–water level	4	125.94	136.31	1.87	0.04
Least flycatcher	wetland density+	2	221.94	228.07	0.00	0.72
	null	1	225.93	229.99	1.92	0.28

Song sparrow	willow height+	2	701.14	707.29	0.00	0.60
	willow area+	2	703.60	709.75	2.46	0.18
	wetland density+	2	704.15	710.29	3.00	0.13
	null	1	707.24	711.31	4.02	0.08
Yellow warbler	willow area+wetland density+	3	531.35	539.59	0.00	0.53
	willow area+	2	535.78	541.92	2.33	0.16
	willow area+wetland area+	3	535.65	543.90	4.31	0.06
	willow area+ % willow+	3	535.78	544.02	4.43	0.06
	null	1	546.17	550.24	10.65	0.00
Wetland						
American coot	% willow–wetland area+deadwood+water level	5	302.08	314.59	0.00	0.50
	% willow–deadwood+water level	4	307.81	318.17	3.58	0.08
	wetland area+deadwood+water level	4	309.45	319.81	5.22	0.04
	wetland area+water level+deadwood+wetland class	5	309.45	319.81	5.22	0.04
	% willow–wetland area+deadwood+	4	309.62	319.98	5.39	0.03
	% willow–deadwood+stem density– water level	5	307.79	320.31	5.72	0.03
	null	1	337.03	341.10	26.51	0.00
Blue-winged teal	stem density–	2	163.56	169.70	0.00	0.28
	stem density–water level	3	161.63	169.87	0.17	0.26
	water level	2	163.80	169.94	0.24	0.25
	null	1	166.33	170.40	0.70	0.20
Northern shovelor	water level	2	132.94	139.08	0.00	0.51
	null	1	135.12	139.18	0.10	0.49
Red-winged blackbird	wetland area+water level	3	904.13	902.37	1.00	0.62
	null	1	977.67	981.74	0.00	0.00
Sora	% willow–wetland class	3	244.89	255.25	0.00	0.22

	% willow–	2	252.75	256.83	1.58	0.10
	% willow–upland vegetation	3	251.28	257.43	2.18	0.07
	wetland class	2	249.39	257.63	2.38	0.07
	% willow–wetland area+	3	251.57	257.72	2.47	0.06
	wetland area+	2	254.36	258.43	3.18	0.04
	wetland area+wetland class	3	248.08	258.45	3.20	0.04
	wetland class+upland vegetation	3	248.54	258.90	3.65	0.04
	null	1	257.48	259.51	4.26	0.03
Yellow-headed blackbird	wetland area+emergent vegetation +upland vegetation	4	150.16	160.53	0.00	0.52
	wetland area+upland vegetation	3	153.22	161.46	0.93	0.33
	emergent vegetation+ upland vegetation	3	157.16	165.40	4.87	0.05
	null	1	165.73	169.80	9.27	0.01
Grassland						
Clay-colored sparrow	water level+emergent veg– upland vegetation	4	632.62	642.98	0.00	0.59
	null	1	752.99	757.06	114.08	0.00
Savannah sparrow	wetland density–emergent vegetation–wetland area+ water level	5	245.97	258.48	0.00	0.23
	emergent veg–wetland area+ water level	4	248.43	258.79	0.31	0.20
	wetland density–emergent vegetation– water level+	4	249.26	259.62	1.14	0.13
	wetland class+emergent vegetation–wetland area+ water level	5	244.20	261.09	2.61	0.06
	wetland density– water level	3	252.96	261.20	2.72	0.06
	emergent vegetation– water level	3	253.33	261.57	3.09	0.05
	wetland density–wetland area+ water level	4	251.79	262.15	3.67	0.04
	wetland density–wetland class+wetland area+ water level	5	245.91	262.80	4.32	0.03
	water level	2	256.82	262.97	4.49	0.02
	wetland area+water level+wetland class	4	248.42	263.10	4.62	0.02
	wetland density–wetland class+emergent vegetation–	4	252.79	263.15	4.67	0.02

	wetland density–emergent vegetation–wetland area+ wetland class	5	246.30	263.19	4.71	0.02
	emergent vegetation–wetland area+ wetland class	4	248.87	263.56	5.08	0.02
	null	1	264.58	268.65	10.17	0.00
Vesper sparrow	water level+emergent vegetation– upland vegetation	4	231.84	242.20	0.00	0.18
	emergent vegetation–water level	3	234.11	242.35	0.15	0.16
	upland vegetation	2	236.49	242.64	0.44	0.14
	emergent vegetation– upland vegetation	3	234.42	242.66	0.46	0.14
	upland vegetation+water level	3	234.50	242.74	0.54	0.13
	water level	2	237.33	243.47	1.27	0.09
	emergent vegetation–	2	237.43	243.57	1.37	0.09
	null	1	240.02	244.09	1.89	0.07