EXAMINING AVIAN COMMUNITIES IN WETLANDS AT MULTIPLE SPATIAL EXTENTS

by

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ABSTRACT

Destruction and impairment of wetlands has been extensive throughout the conterminous United States, resulting in the loss of both crucial ecosystem functions and productive habitat for a wide variety of organisms. Over the last few decades, efforts to protect, restore, and create wetlands have led to increases in wetland area and improvements to wetland quality in many locations. However, wetlands are difficult to create or restore, and whether these initiatives will lead to wetland function that approaches historical levels remains unclear. My research focuses on how the diverse bird communities that rely on wetlands might be affected by changes to their primary habitat and the surrounding landscape. I utilized data from the North American Breeding Bird Survey (BBS) and the National Land Cover Database (NLCD) to develop a set of spatially-explicit abundance models for each of 31 species of wetland-breeding birds. Independent variables in these models included combinations of three different aquatic habitats as well as other land cover types that could potentially influence species abundance. I compared the models in an information-theoretic framework to determine which cover types most influenced species abundance. All species were positively associated with one or more types of aquatic cover, and when considered in the broad spatial context of entire landscapes, other cover types likely affect abundances of many species as well. Next, I conducted a review of previously published studies on avian use of anthropogenic wetlands, including a meta-analysis that compared wetland bird community metrics between anthropogenic wetlands and reference sites. My results

suggested that while created and restored wetlands do support many avian species, these communities are typically dissimilar from those at natural wetlands. Finally, I used data from the BBS and the NLCD to describe the characteristics of wetland bird communities and the composition of the landscape (including how these factors have changed over time) at the level of the Bird Conservation Region. These data indicate that both wetlands and the bird communities associated with these systems have experienced changes in recent years, but total regional wetland area has been fairly stable.

I. RATIONALE FOR RESEARCH

Historical and current trends in wetlands

A wetland is an ecosystem that depends on permanent or regular shallow water or saturation of the substrate (NRC 1995). Wetlands are transitional areas between terrestrial and aquatic systems that generally are delineated on the basis of the presence of water, hydric soils, and hydrophilic plants (Cowardin et al. 1979). Geology, hydrology, and vegetation vary among wetlands, which include vernal pools, prairie potholes, marshes, bogs, forested swamps, and riparian areas. The functions of wetlands include but not are limited to water filtration, pollution abatement, nutrient cycling, flood protection, shoreline stabilization, and provision of habitat for a wide variety of organisms, including dozens of bird species (Dahl 1990, NRC 1995, Findlay et al. 2002).

Throughout the conterminous United States, wetland loss has been extensive since European colonization. Historically, wetlands were considered to be of little use to humans, and alteration was thought to increase their value. As a result, both coastal and freshwater wetlands were drained, filled, and otherwise altered to facilitate agriculture, forestry, transportation, and urbanization (Dahl 2006). Between 1780 and 1980, the estimated area of wetlands in the conterminous United States was reduced by 53%, from 89 million hectares to 42 million hectares, with reductions of wetland area in 22 states exceeding 50% and in ten states exceeding 70% (Dahl 1990). With these changes to wetlands came losses of a wide variety of ecosystem functions and economic benefits to humans (Costanza et al. 1997, Tiner 2005).

In 1990, policy was established under the Clean Water Act that no net loss of wetlands would be permitted (USEPA/ACE 1990). As a result, permits for projects that will alter wetlands or convert them to another land cover type usually stipulate that such activity must be mitigated, either by creating a new wetland or by restoring wetlands that previously were impaired (Brinson and Rheinhardt 1996). The mean annual rate of wetland loss between 1986 and 1997 was 23,700 hectares, which was only 20% of the mean annual loss during the previous decade (Dahl 2006). Initially, the legal obligation of mitigation was usually satisfied with creation or restoration of an area of wetland equal to the lost or altered area, but recent requirements have been more stringent. Between 1993 and 2000, an average of 1.78 hectares of mitigation was required for every hectare of wetland lost or altered (NRC 2001). A U.S. Fish and Wildlife Service publication on wetland trends from 1998 through 2004 reported that for the first time, wetland area in the conterminous United States increased (Dahl 2006). These increases resulted from a combination of required mitigation; government initiated conservation programs, such as the Wetland Reserve Program; and efforts of non-governmental organizations, such as Ducks Unlimited (Dahl 2006).

This trend reversal suggests that no net loss regulations may be increasing the area of wetlands. However, these increases in wetland area are equivalent to a small fraction of historical losses, and an increase in wetland area does not guarantee that the natural characteristics of the lost wetlands have been effectively recreated. To achieve no net loss, anthropogenic wetlands must replace not only historical area, but also typical ecosystem function (Zedler 1996, Findlay et al. 2002). Although functional equivalency is difficult to fully assess, new wetlands often differ from natural wetlands with respect to size, number of individual wetland basins, depth and duration of inundation, primary productivity, and plant species composition (NRC 2001, Kettlewell et al. 2008).

The quality and functioning of some natural wetlands have also been affected by anthropogenic activities beyond their borders. About 61% of the wetlands in the conterminous United States are embedded within human-influenced landscapes (Theobald 2010). Urban land use, agriculture, and forestry in close proximity to wetlands may affect these systems through inputs of chemicals and nutrients, increased distances between wetland patches, and changes in primary productivity. Therefore, it may be worthwhile to examine composition of the land cover surrounding natural wetlands and changes in this land cover when addressing potential effects of loss of wetlands.

Wetlands as habitat for birds

Wetlands provide resources, such as food, water, and shelter for reproduction and protection from predators, for many groups of organisms. For example, wetlands provide habitat for birds, some of which are wetland obligates, in both the breeding and non-breeding seasons. Additionally, many species of long-distance migratory birds use wetlands as stopover sites during their migrations between breeding and wintering grounds. Alterations to wetlands and the surrounding landscape have potential to affect wetland-breeding birds at the individual, population, and community levels.

Eighty-seven bird species regularly breed in the wetlands of the conterminous United States (Sauer et al. 2011). These species are members of ten orders (Anseriformes, Charadriiformes, Ciconiiformes, Coraciiformes, Falconiformes, Gaviiformes, Gruiformes, Passeriformes, Pelecaniformes, and Podicipediformes) and 20 families. The

87 species have different geographic range sizes, abundances, nesting locations, diets, and feeding strategies (Appendix A, Appendix B). Natural wetlands often support high species richness of birds and other taxonomic groups within small areas, likely due to the many microhabitats and resources that often occur in such wetlands (Weller 1999).

The population trends of the bird species that breed in wetlands differ. Population trends of many wetland species have been positive. From 1966 - 2008, the abundances of 58% of wetland-breeding species increased across the conterminous United States (Ziolkowski et al. 2010). The abundances of some groups, such as the herons (order Pelecaniformes), have increased in portions of their range and decreased elsewhere (Fleury and Sherry 1995), perhaps because certain threats have been minimized (e.g., hunting, use of dichlorodiphenyltrichloroethane [DDT]) whereas other threats have increased (e.g., habitat loss). Other species, such as the King Rail (*Rallus elegans*) and Purple Gallinule (*Porphyrula martinica*), have declined across their ranges (Conway 2009, Ziolkowski et al. 2010). Throughout history, declines in abundance of wetland-breeding bird species have been attributed to a variety of human activities such as hunting for meat, sport, and the plume trade, poisoning from agricultural and industrial chemicals, and loss of breeding sites (Weller 1999).

A variety of wetland characteristics affect the presence and abundance of wetland breeding species (Ma et al. 2010, Ward et al. 2010). However, avian habitat selection has long been considered a multiple-step process (Svardson 1949, Hutto 1985) during which a bird first responds to broad characteristics of the landscape (such as the presence of water or herbaceous vegetation) before honing in on the site-specific features (such as water depth or the presence of particular food items) by which it selects a nest site.

Wetland bird species potentially respond to resources across a region and exploit a mosaic of wetlands. It also is likely that apparent patterns in species richness and abundance of wetland birds are, in part, a function of the spatial and temporal scale of data analysis (Böhning-Gaese et al. 1994). Trends for particular species may vary greatly among regions (Böhning-Gaese et al. 1994, Fleury and Sherry 1995). Therefore, the destruction, creation, and restoration of wetlands could affect avian community dynamics beyond a given wetland. Furthermore, data on avian communities at large spatial and temporal extents potentially could be used to identify how landscape change might affect wetland birds at the population or even species level.

Overview of dissertation

My dissertation research is presented in the next three chapters. Chapter II describes my use of data from the North American Breeding Bird Survey (BBS) and the National Land Cover Database (NLCD) to examine associations between land cover and abundance of various wetland bird species at the level of BBS routes. First, I identified wetland bird species for which BBS data met my criteria for modeling abundance as a function of explanatory variables. Then, for each species, I developed a set of competing models that examined associations between abundance and percent cover of different land cover types, of which three were aquatic. I used an information-theoretic framework to compare spatially explicit models and determine which cover types were most strongly associated with abundance.

Chapter III presents my review of the literature on use of created and restored wetlands by avian communities. I used a meta-analysis approach to evaluate whether anthropogenic wetlands support avian assemblages that are comparable to those at reference sites in terms of avian abundance, species richness, and diversity. Additionally, I reviewed differences in species composition and assessed how avian communities at anthropogenic wetlands change over time.

In Chapter IV, I used data from the BBS to calculate wetland bird community metrics and data from the NLCD to describe land cover composition at the level of the Bird Conservation Region. With these data, I estimated regional relationships between wetland bird community metrics and the amount of various types of land cover. I also described changes in regional wetland bird populations and regional land cover composition.

II. ABUNDANCES OF WETLAND BIRDS IN HETEROGENEOUS LANDSCAPES

Introduction

Many bird species that have specific nesting requirements are also capable of dispersing long distances daily and seasonally, thereby encountering a wide variety of land cover types, resources, and threats and perhaps using a variety of habitats. Wetland-breeding birds (ducks, geese, herons, some shorebirds and blackbirds) are an example – nesting is confined to wetland or shoreline but other land cover types might be used or avoided for foraging and other activities. Therefore, the local abundances of these species could depend in part on the composition of the landscape, not just the availability of wetlands.

Moreover, during the last several decades, abundances of some wetland bird species have increased whereas abundances of other species have decreased or been stable (Ziolkowski et al. 2010, Sauer et al. 2011). This suggests that wetland birds have different responses to anthropogenic changes to wetlands (e.g., drainage and conversion, mitigation and restoration) and their surrounding landscapes (Dahl 2006, Mitsch and Gosselink 2007). Understanding the environmental factors associated with the presence and abundance of various wetland bird species can inform management of wetlands for bird communities. Several recent studies have explored environmental effects (Smith and Chow-Fraser 2010, Tozer et al. 2010, Valente et al. 2011, Quesnelle et al. 2013, Pickens and King 2014) with data from surveys within a particular watershed or ecoregion over one to three years. Although these studies can inform local management, determining whether their results can be generalized to larger spatial and temporal extents is difficult. Many areas across a species' range may not have been surveyed and, in some cases, results for a particular species may vary among the locations or time periods studied (Böhning-Gaese et al. 1994).

Although there are regions of the United States with extensive wetlands (e.g. southern Louisiana), much of the remaining wetlands exist as a mosaic embedded in a matrix of non-wetlands. Using remotely sensed land cover data and incorporating information from multiple spatial extents (to a maximum buffer of 109 km), Theobald (2010) found that 61% of wetlands in the conterminous United States were embedded in human-influenced landscapes, and about 22% were in landscapes described as human-dominated. Increases in wetland bird abundance may be associated with certain types of anthropogenic land cover and decreases associated with other types of anthropogenic land cover – and these effects may vary among species. For example, developed land near breeding areas may lead to low nesting success and high mortality due to interactions between birds and humans or domestic animals (Carney and Sydeman 1999, Erickson et al. 2005, Loss et al. 2013). Agricultural lands may increase food availability for wetland birds (Lovvorn and Baldwin 1996, Elphick 2000) or reduce habitat quality through inputs of pesticides (Best and Fischer 1992).

As a complement to local field studies, data from the North American Breeding Bird Survey (BBS) can be used to examine the relationships between land cover composition and abundances of wetland bird species across extensive areas. The BBS, initiated in 1966, collects annual count data for hundreds of bird species on over 3,000 survey routes within the conterminous United States. BBS data have been used in over

450 publications (Sauer et al. 2011), primarily to estimate trends in abundance, describe habitat associations, document range shifts, identify the factors associated with species richness, and explore relationships between changes in landscape characteristics and trends in abundance (Flather and Sauer 1996, Jones et al. 2000, Veech 2006*b*, Ziolkowski et al. 2010, Rittenhouse et al. 2012). Only a few studies have used BBS data for analyses that explicitly target species that breed in wetlands. These studies each focused on a particular species (Lang 1991, Peterjohn and Sauer 1997, Blackwell and Dolbeer 2001), state (Fleury and Sherry 1995), or Bird Conservation Region (designated by the North American Bird Conservation Initiative) (Forcey et al. 2007, 2011).

I used BBS data to assess whether abundances of various wetland bird species were associated with particular land cover types at the level of BBS routes (39.4 x 0.8 km curvilinear areas). My goal was to identify the extent to which the abundances of different species were associated with the percentage of wetlands and other cover types along BBS routes. In addition, I compared the relative strength of association of different land cover types with the abundances of the different species. Unlike most previous studies of wetland bird abundance, I used data from large areas and considered associations with multiple types of land cover.

Methods

Data sources

I obtained species data from the North American Breeding Bird Survey. Within the United States, BBS monitoring is coordinated by the U.S. Geological Survey (USGS). A trained volunteer observer drives a 39.4 km route and stops every 0.8 km to record all birds seen or heard during three minutes within a 400 m radius of each of 50 points (Robbins et al. 1986). These routes typically follow rural roads and highways, and longer distances are sometimes traveled if some stretches of road are not appropriate for conducting a survey. Most routes are surveyed in May or June and are intended to detect breeding birds as opposed to migrating or overwintering birds. I used data from 3,127 BBS routes across the conterminous United States that were surveyed at least three times between 2001 and 2011. For each species, analyses included data from all routes on which the species was detected during at least three annual surveys. I selected this time period because it was centered on the year (2006) of the land cover data.

I obtained land cover data from the 2006 version of the National Land Cover Database (NLCD). The NLCD is produced by the Earth Resources Observation and Science Center (USGS and other federal agencies) from images captured by the Landsat 5 and 7 satellites (Homer et al. 2004, 2007, Fry et al. 2011). The NLCD identifies 16 classes of natural and anthropogenic land cover at 30-m resolution; each of 27 billion pixels within the conterminous United States is classified. I used ArcGIS 10.0 (ESRI, Redlands, California) to quantify the number of pixels of each land cover type within a 400 m buffer on both sides of the route traveled by the observer (Small et al. 2012); 400 m is presumed to be the maximum distance surveyed by a BBS observer at each stop (Robbins et al. 1986). I then converted the number of pixels of each land cover type to a percentage.

Although the NLCD differentiates 16 land cover classes, I combined some land cover classes that were not considered primary habitat to create a manageable number of independent variables for the regression models (see next section). I combined developed, open space; developed, low intensity; developed, medium intensity; and developed, high intensity (classes 21, 22, 23, 24) into a single *developed* class and pasture and hay (81) and cultivated crops (82) into *agriculture* [see Homer et al. (2004) for descriptions of land cover classifications and codes]. I hypothesized that some species might have similar associations with both types of wetland cover or with total aquatic cover. Therefore, I also combined woody and herbaceous into total wetland and combined woody wetland, herbaceous wetland, and open water into total aquatic cover. Overall, I included eight land cover classes in my analyses: open water, emergent woody wetland, emergent herbaceous wetland, total wetland, total aquatic cover, developed, grassland, and agriculture. I did not include the percent cover of other classifications (e.g., forest, barren land, and ice/snow) because I wanted to keep the total number of independent variables reasonably small and avoid oversaturating the abundance models. Therefore, I only included land cover variables that I expected to have a clear, ecological reason for influencing species abundance. Because many climatic conditions and environmental factors change along latitudinal and longitudinal gradients, I included the latitude and longitude of the center point of each route in the analysis.

From the 87 species identified by the BBS as breeding in wetlands (Sauer et al. 2011), I retained 36 species that were documented on at least 100 routes (Appendix B). This criterion was necessary to ensure that sample sizes were sufficiently large ($N \geq 80$) for regression models with a maximum of eight independent variables. I randomly selected 80% of the routes on which each species was recorded and used data from these routes to develop abundance models. I reserved the other 20% of routes for model evaluation. For each species, I calculated mean annual abundance on each route over the

11-year period. I then log-transformed mean abundance to obtain a normal distribution, and used the transformed value as the response variable in regression models.

Model development and comparison

In preliminary examination of the data, I found substantial spatial autocorrelation in the residuals of ordinary least squares (OLS) models of species abundance, which violates the assumption of independently and identically distributed residuals. For each species, there was some amount of positive spatial autocorrelation, meaning that residual values for routes in close proximity were more similar than expected by chance. Therefore, I used a spatial autoregressive technique to control for spatial autocorrelation in the regression analysis (Keitt et al. 2002, Bahn et al. 2006, Rangel et al. 2006, Dormann et al. 2007).

I used the software program Spatial Analysis in Macroecology (SAM, version 4.0, http://www.ecoevol.ufg.br/sam/, accessed February 24, 2013) to construct simultaneous autoregressive models (Rangel et al. 2010). I chose the SAR_{err} (spatial error) model because spatial patterns were not identical for all species and SAR_{err} models have been shown to minimize autocorrelation in model residuals and accurately estimate model parameters for data with various forms of spatial autocorrelation (Kissling and Carl 2008). The SAR_{err} model estimates the effect of spatial dependence in the residuals by including an additional term, $\lambda W\mu$, in the regression equation (Rangel et al. 2006, Dormann et al. 2007, Kissling and Carl 2008). SAR_{err} models fit the following regression equation to the data: $Y = X\beta + \lambda W\mu + e$. Here, Y, X, β, and e are the response variable, independent variables, partial regression coefficients, and error term, respectively. The additional term $\lambda W\mu$ includes the spatial autoregression coefficient (λ), a matrix of weights based on the Euclidean distances between the center points of all pairs of routes (W), and an error term (μ) that models spatial dependence (Dormann et al. 2007).

I conducted two steps of model selection (Anderson 2008) to identify the model (or set of models) of route-level abundance best supported by the data for each of the 36 species. Because I believed all candidate models should include some description of nesting habitat, I first compared models that included only explanatory variables representing aquatic cover (woody wetland, herbaceous wetland, open water, total wetland, and total aquatic cover) and selected the best model for further development. For each species, this first step included ten models representing all possible combinations of the five cover classes, except those in which variables would be redundant (e.g., because total aquatic cover includes all other aquatic predictors, it was only included in a single-variable model). Correlations between independent variables included within the same model were typically small; only correlations between aquatic cover types were larger than 0.2, and the strongest correlation was between woody wetland and herbaceous wetland with a correlation coefficient of 0.31. Therefore, I did not utilize any methods to correct for collinearity. I used Akaike's Information Criterion adjusted for small samples sizes (AIC_c) to assess relative support for each model. I used the model with the lowest AIC_c as a base model for that species. When ΔAIC_c values were ≤ 2, I retained multiple base models for the next step (Burnham and Anderson 1998).

For each species, I created a second set of models that included the base models and additional models built from the base models; these additional models included all combinations of the five other independent variables (latitude, longitude, and percentage of developed land, grassland, and agriculture). This yielded a total of 32 competing models per species (or multiples of 32 models if more than one base model was selected). For each species, I identified the best model (from the entire set) as the one with the lowest AIC_c value and used its coefficient of determination (R^2 value) to assess model fit. For SAR_{err} models, SAM 4.0 software presents one R^2 value for the variation in the response variable explained by both the independent variables and the spatial term and another R^2 that represents the variability explained by only the independent variables. The difference in the two values is attributable to the variability explained by the spatial component.

For most species, several models had AIC values that were close (within two units) to the AIC value of the best model, and I wanted to ensure that the information from those models was also considered. I used ΔAIC_c values and Akaike weights (w_i) to identify a confidence set of models that together accounted for 95% of the total weight of all competing models (i.e., there is a 0.95 probability that the best model is included in the confidence set) (Johnson and Omland 2004, Anderson 2008). To develop an averaged model for each species, I calculated weighted averages of the standardized partial regression coefficients (β values) for each independent variable included in models of the 95% confidence set. I used these averaged models of the confidence set (instead of the single best-fit model) to assess the relationship between each cover type and abundance of each species. I compared the standardized partial regression coefficients (β values) of the averaged model for each species to identify which independent variables had the strongest associations (largest β) with abundance. In particular, I was interested in determining which wetland cover types had the strongest association with abundance and how that association compared to the non-wetland cover types.

To evaluate the models, I used regression coefficients from the averaged model to estimate expected log-transformed abundances for the 20% of routes for each species that were not included in the initial model selection. I then calculated Pearson's correlation coefficients to assess the relationship between these estimated values and observed abundances (log-transformed) for each species – this is a fairly common approach to model validation (Guisan and Zimmermann 2000, Potts and Elith 2006). Additionally, I calculated the Root Mean Square Prediction Error (RMSPE) as an indicator of how similar estimated and observed abundances were for each species. RMSPE was calculated as:

$$RMSPE = \sqrt{\sum_{i=1}^{n} \frac{\left(y_{i,data} - y_{i,pred}\right)^2}{n}},$$

where y_{data} = the log-transformed species abundances that were documented along validation routes, y_{pred} = the route abundances estimated from the regression coefficients of the independent variables, and n = the number of routes in the validation set (Potts and Elith 2006, Hooten and Hobbs 2015).

Results

Aquatic cover composed approximately 6.9% of the area surveyed along all BBS routes [open water: 1.2% (SD = 9.2), woody wetland: 4.6% (SD = 4.2), herbaceous wetland: 1.2% (SD = 12.4)]. Developed land covered a mean of 9.6% (SD = 8.3) of the land cover within buffered BBS routes, whereas grassland and agriculture encompassed

10.6% (SD = 18.8) and 27.4%, (SD = 27.5), respectively. The percentage of each cover type varied considerably among the routes as illustrated by the many standard deviations that were greater than the mean. Median percent cover and interquartile ranges for routes occupied by various species are found in Table 2.1.

Annual abundances of the wetland bird species varied considerably. The median number of individuals per route ranged from 0.6 for the Belted Kingfisher (*Megaceryle alcyon*) to 25.9 for the Red-winged Blackbird (*Agelaius phoeniceus*) (Appendix B). The number of routes on which species were detected also varied; Red-winged Blackbirds were detected on the greatest number of routes (2641) and Northern Pintails (*Anas acuta*) were detected on the fewest (103) (Table 2.4).

Model selection

Only spatially explicit (SAR_{err}) models were candidates in the model selection because they were necessary to reduce spatial autocorrelation in model residuals for all species. Each of the ten possible base models was included in the second modeling step for at least one species. The only base model with three independent variables (woody wetland, herbaceous wetland, and open water) was the most prevalent model (17 of 36 species) to be included in the second phase of model building. For eight species, only one base model was selected. For other species, between two and four base models were selected for the second phase of model building.

After the second phase of model selection, relationships between independent variables and abundances of five species, Ring-billed Gull (*Larus delawarensis*), White Ibis (*Eudocimus albus*), Cattle Egret (*Bubulcus ibis*), Black-crowned Night Heron (*Nycticorax nycticorax*), and Bald Eagle (*Haliaeetus leucocephalus*) were not statistically significant (all P values were > 0.05) in any of the models; therefore, I do not present further results for these species. Among the remaining 31 species, 28 distinct models (different combinations of variables) had the lowest AIC_c (Table 2.2). That is, the best model for almost every species was different. The number of predictors in the best model for each species ranged from one to seven.

Open water was included in the best models for 23 of the 31 species (19 significantly positive βs), woody wetland in 11 (four significantly positive and one significantly negative β), herbaceous wetland in 15 (14 significantly positive βs), developed in 12 (seven significantly positive and three significantly negative), grassland in nine (three significantly positive and one significantly negative), and agriculture in 17 (13 significantly positive βs and one significantly negative).

Among species, adjusted R^2 values for the best SAR_{err} model ranged from 0.112 (Double-crested Cormorant, *Phalacrocorax auritus*) to 0.540 (Red-winged Blackbird) (Table 2.2). For most species, the best model did not have a large weight (Table 2.2). The confidence sets for each species contained from two (Mallard, Red-winged Blackbird) to 103 (Double-crested Cormorant) competing models. Including geographic coordinates of the routes often resulted in a model with lower AIC_c; latitude, longitude, or both were included in the best model for 19 species (Table 2.2), and one or both were included in the confidence set of models for each species.

Relationships between abundance and cover type

Open water – Route-level abundance was significantly (model-weighted $P < 0.05$) and positively associated with open water in the averaged models for 23 species (Table 2.3). There were no negative associations between abundance and the percentage of open water (Figs. 2.1 and 2.2). Open water had the strongest positive association with abundance in the averaged models for Common Loon (*Gavia immer*), Double-crested Cormorant, American White Pelican (*Pelecanus erythrorhynchos*), Gadwall (*Anas strepera*), Blue-winged Teal (*Anas discors*), Northern Shoveler (*Anas clypeata*), Wood Duck (*Aix sponsa*), Great Blue Heron (*Ardea herodias*), Wilson's Phalarope (*Phalaropus tricolor*) Spotted Sandpiper (*Actitis macularius*), Osprey (*Pandion haliaetus*), Belted Kingfisher, and Marsh Wren (*Cistothorus palustris*) (Figure 2.2). The mean standardized partial regression coefficient (β) for open water was 0.20 (SD: 0.14, range: 0.00 to 0.50) over all species for which open water was included in the averaged model (Figure 2.1, Table 2.3).

Herbaceous wetland – Abundance was significantly and positively associated with percent cover of herbaceous wetland in the averaged models for 19 species (Table 2.3) (mean β = 0.16, SD: 0.13, range: −0.01 to 0.44). Herbaceous wetland was the variable most strongly associated with abundances of Pied-billed Grebe (*Podilymbus podiceps*), American Bittern (*Botaurus lentiginosus*), Snowy Egret (*Egretta thula*), American Coot (*Fulica americana*), Wilson's Snipe (*Gallinago delicata*), and Willet (*Tringa semipalmata*) (Figure 2.2).

Woody wetland – Unlike the results for open water and herbaceous wetland, most associations between abundance and percentage of woody wetland were not significant, and some species had a positive and some a negative association with woody wetland (mean β = 0.01, SD: 0.09, range: −0.16 to 0.22). Four species had a significant positive association and two had a significant negative association with woody wetland (Table

2.3). Woody wetland was not the variable most strongly associated with abundance of any species.

Combined aquatic – Total aquatic cover was significantly and positively associated with abundance for six species (mean $\beta = 0.17$, SD: 0.11, range: 0.07 to 0.38) and not significantly negatively associated with abundance of any species (Table 2.3). Total aquatic cover was the variable most strongly associated (positively or negatively) with abundance of three species, Common Merganser (*Mergus merganser*), Northern Pintail, and Swamp Sparrow (*Melospiza georgiana).* Abundances of three species were significantly and positively associated with total wetland cover (mean $\beta = 0.14$, SD: 0.06, range: 0.09 to 0.16) and no species had abundances that were significantly negatively associated with total wetland (Table 2.3); total wetland cover was the variable most strongly associated with abundance of Sora (*Porzana carolina*).

Developed – The abundances of seven species (Mallard [*Anas platyrhynchos*], Canada Goose [*Branta canadensis*], Great Blue Heron, Great Egret [*Ardea alba*], Little Blue Heron [*Egretta caerulea*], Osprey, and Red-winged Blackbird) were significantly and positively associated with percentage of developed land whereas abundances of three species (Common Loon, American White Pelican, Gadwall) were significantly and negatively associated with percentage of developed land (Figure 2.2). Mean β for developed land was approximately zero (SD: 0.10, range: −0.23 to 0.26) (Figure 2.1).

Grassland – Abundances of five species (Mallard, Canada Goose, Great Blue Heron, Red-winged Blackbird, and Marsh Wren) were significantly and positively associated with percent cover of grassland whereas Belted Kingfisher abundances were significantly and negatively associated with grassland (mean β = 0.03, SD: 0.07, range: −0.13 to 0.20, Figure 2.2, Table 2.3).

Agriculture – Agriculture was included in the averaged models for 23 species (all except Osprey); the standardized partial regression coefficient was significant and positive for 13 species and significantly negative for one species (Table 2.3). For eight species, Mallard, Canada Goose, Great Egret, Little Blue Heron, Green Heron (*Butorides virescens*), Sandhill Crane (*Grus canadensis*), Red-winged Blackbird, and Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*), agriculture was the predictor variable with the largest standardized partial regression coefficient (mean β = 0.16, SD: 0.19, range: −0.11 to 0.69) (Figure 2.1).

Geographic coordinates – Latitude and longitude each were significantly positively or negatively associated with abundance in the averaged models for five and four species, respectively. The mean β for latitude was 0.01 (range: −0.33 to 0.29), and the mean β for longitude was 0.09 (range: -0.02 to 0.43).

Model evaluation

The model evaluation assessed the averaged model for each species by comparing actual log-transformed abundances documented on the set of validation routes to expected log-transformed abundances calculated from the averaged regression coefficients. Correlation coefficients for the relationships between observed and expected abundances along the validation routes were all positive and ranged from 0.017 (Belted Kingfisher) to 0.721 (Green Heron). Correlations were significant ($p < 0.05$) for 22 of the 31 species. Values for Root Mean Squared Prediction Error ranged from 0.301 (Spotted Sandpiper) to 2.186 (Little Blue Heron)(Table 2.4).

Discussion

I examined relationships between land cover composition and abundances of wetland bird species at a relatively large spatial extent (approximately 0.8 by 39.4 km) not often examined in previous studies of wetland birds. The lack of studies may be due to the BBS being an unrecognized source of abundance and distribution data for wetland species. The BBS was not intentionally designed to survey for wetland birds; nonetheless most routes provide data on wetland species. I included data (routes) from throughout the United States, giving my study a broad geographic scope of inference. The extent to which species' abundances were related to the percentages of particular land cover types along survey routes varied considerably. Although abundances of some species were negatively associated with some types of aquatic cover, the mean abundances of all species were significantly and positively associated with at least one of the aquatic cover types. Aquatic cover comprised approximately 7% of the total area of the BBS routes included in this study and typically less than 10% of individual routes. Thus, my results indicate that land-cover associations may be apparent across extensive areas even when the particular land cover type is not a major component of the landscape. Even relatively small proportions of wetlands in a large landscape may contribute to maintenance of wetland birds.

Abundances of 13 species were most strongly associated with open water (lakes, ponds, rivers, and wetlands with little emergent vegetation). This group includes several piscivorous species that typically forage in open water, such as Common Loons, Double-crested Cormorants, American White Pelicans, Osprey, and Belted Kingfishers (Poole et al. 2002, Appendix A). Wilson's Phalaropes and Spotted Sandpipers often nest near shorelines (Colwell and Jehl 1994, Reed et al. 2013), Common Loons and American White Pelicans often breed on islands within lakes (Winkler 1996, Knopf and Evans 2004, Evers et al. 2010), and Marsh Wrens nest in marshes, which often are located along the edge of lakes (Kroodsma and Verner 2014). Gadwalls, Blue-winged Teals, and Northern Shovelers are dabbling ducks frequently found in hemi-marsh (half open water, half emergent vegetation) during the breeding season (Dubowy 1996, Leschack et al. 1997, Rohwer et al. 2002). Abundances of Wood Ducks and Great Blue Herons were positively associated with both types of wetlands and with open water, and both species use a variety of aquatic habitats during the breeding season, especially if those habitats are close to nest trees (Vennesland and Butler 2011, Hepp and Bellrose 2013).

Although herbaceous wetland was positively associated with abundance in the averaged models for 19 of the species, it was the land cover variable most strongly associated with abundance for only six species. All six species tend to nest in close proximity to herbaceous wetland. Pied-billed Grebes and American Coots build floating nests amongst emergent marsh vegetation and often forage in nearby open water (Muller and Storer 1999, Brisbin and Mowbray 2002). Both species' abundances also were significantly associated with open water. American Bitterns typically nest in emergent vegetation several centimeters above the water (Lowther et al. 2009) and forage along the edge of emergent vegetation. Wilson's Snipes and Willets often nest on the ground near the edge of shallow wetlands (Mueller 1999, Lowther 2001). Snowy Egrets nest in trees or bushes, often over or near dense herbaceous vegetation (Parsons and Master 2000).

Woody wetland was not strongly associated with abundances of most species. Abundances were both positively and negatively associated with woody wetland, but the model-averaged βs generally were small and often were not statistically significant. In no case was a species' abundance most strongly associated with woody wetland, and only five species had βs that were significantly different than zero. The four species (Wood Duck, Great Blue Heron, Great Egret, and Swamp Sparrow) that had significant positive associations with woody wetland often nest and forage in wooded areas (Mowbray 1997, McCrimmon et al. 2011, Vennesland and Butler 2011, Hepp and Bellrose 2013). The non-significant relationships between woody wetland and abundances of most species could in part reflect that these species are more difficult to detect along roadsides that are heavily wooded than in more open conditions.

Associations between abundance and developed land were inconsistent among species. Abundances of seven species were significantly and positively associated with this cover type but two species were significantly and negatively associated. The majority of land cover classified as developed was not heavily modified by humans. Over all BBS routes, 76% of the area I classified as developed was developed open space (NLCD cover type 21). Developed open space has impervious surface cover < 20% and primarily consists of large lawns, urban parks, golf courses, and other recreational areas (Wickham et al. 2013). Low intensity (NLCD cover type 22), medium intensity (23), and high intensity (24) development covered 19%, 4%, and 1%, respectively, of the area of the developed class. Mallards, Canada Geese, and Great Blue Herons are regular visitors to parks and Ospreys often nest on man-made structures (Poole et al. 2002). The relative lack of species (only two) negatively associated with developed land could reflect that species not effectively surveyed by the BBS (and also excluded from my analyses) could include those with the strongest negative associations with urbanization and human activity.

Agriculture was significantly and positively associated with the abundances of 12 species and negatively associated with none. For nine of these species, the association with agriculture was stronger than the association with any type of aquatic cover (Figure 2.2). Although several of these species had previously been found to be associated with cropland or pasture (Poole 2005), my results indicate their associations with agricultural areas were even stronger than with the wetlands typically viewed as their primary habitat. Three of these species (Little Blue Heron, Red-winged Blackbird, and Yellow-headed Blackbird) have significantly declined in abundance along BBS routes within at least one of three broad regions (Western, Central, or Eastern) of the United States (Sauer et al. 2011). It is possible that changes in agricultural practices (e.g., crops grown, chemical use, and the relative proportions of cropland and pasture) have affected these species' population trends, as has been found for populations of grassland birds (Murphy 2003). These species may forage in crop fields, pasture, and along irrigation ditches, and a closer examination of the landscape-level connectivity between nesting and foraging habitat for these species may be warranted.

Latitude, longitude, or both were included in the best models for 19 species (Table 2.2). These results could indicate that one or more unmeasured variables are correlated with either latitude or longitude and are also associated with abundance (e.g., Barry and Elith 2006). Geographic coordinates often capture gradients in temperature, precipitation, or elevation. Another possibility is that more specific land cover classifications vary along latitudinal or longitudinal gradients. For example, the specific composition of the cropland or rangeland that contributed to the *agriculture* class certainly varied from north to south and from east to west. Additionally, the configuration of one or a few land cover types may vary as latitude or longitude varies. Abundance of birds that breed in wetlands may decrease as fragmentation of previously large, contiguous tracts of wetlands or other cover types (e.g., agricultural land) increases.

For some species, the standardized partial regression coefficients used to identify the relationships described above were calculated from a confidence set of models that was quite large. For example, the confidence sets for the Double-crested Cormorant and the American Bittern included 103 and 62 models, respectively. For the Double-crested Cormorant, this is likely due to the fact that its abundance was significantly associated with only one independent variable (open water) and the SAR_{err} R^2 value for its best model was only 0.112. With so little of the variability in abundance explained, several other independent variables (in different combinations) were included in models with all having relatively similar AIC_c values - despite that these variables had very weak and non-significant associations with the response variable. In the case of the American Bittern, herbaceous wetland was the only independent variable to have a strong relationship with abundance and the only one included in the best model. However, including other land cover types in the model did lead to a slight increase in SAR_{err} R^2 value from 0.225 (for the best model) up to a maximum of 0.249. Even after being penalized for four additional parameters this model was included in the confidence set with an average model weight of 0.001. Figure 2.2 demonstrates that despite these other independent variables being included in the confidence set and in the average model, their standardized partial regression coefficients are very small and thus have a minimal impact when assessing the relative importance of independent variables or when estimating abundances using the averaged model.

For some species, variation in abundance was mostly attributable to the spatial component. Four species (Common Merganser, Sora, Wilson's Phalarope, and Willet) had less than 5% of their variation in abundance attributable to independent variables ($R^2_{pred} < 0.05$). Abundances for each of these species were significantly associated with only a single type of land cover, which was an aquatic cover type in each case. For other species, almost no variability in abundance was attributable to the spatial component. For four species (Double-crested Cormorant, Northern Shoveler, Northern Pintail, and Yellow-headed Blackbird), adjusted R^2_{pred} values were actually slightly larger than the adjusted R^2_{err} values. This indicates that after adjusted R^2 values were penalized for the increase in model parameters (due to the spatial component), any additional variability explained was trivial.

It is becoming increasingly common to use spatially explicit techniques when modeling relations between environmental variables and abundance at any level (Lichstein et al. 2002, Bahn et al. 2006). In the work presented here, the use of SAR_{err} models consistently led to better model fit (lower AIC_c, higher R^2) and reduced spatial autocorrelation in model residuals compared to OLS models. If left uncontrolled, spatial autocorrelation often results in the misidentification or exaggeration of relationships among variables (Dormann et al. 2007). Preliminary OLS models produced inflated R^2 values and likely erroneous p-values (results not shown). This highlights the need for national- and regional-level analyses to take into account spatial autocorrelation when analyzing species abundance data from the BBS or any other spatially extensive monitoring program.

Management implications

In the United States, wetland creation and restoration (compensatory mitigation) are often required to offset filling or other alterations of natural wetlands. Along with conservation efforts, such mitigation has led to increases in wetland area in some regions (Dahl 2006). Whether these anthropogenic wetlands are high-quality habitat for wetland bird species remains to be fully evaluated. Nest success and recruitment often depend on the quality of habitat in the immediate area of nesting pairs. Identifying similar patterns at a route level (versus a point level) lends further indirect support to the idea that species-habitat relationships are consistent at the level of a nesting pair and at the population level (Veech 2006a, Thogmartin and Knutson 2007).

In order to effectively manage wetland bird species, the factors associated with the abundances of those species must be understood. This study demonstrates that those factors often include land cover heterogeneity at a spatial extent greater than what might be occupied by a breeding pair. The majority of wetlands in the conterminous United States are embedded in landscapes that have substantial (>20% of the landscape) human influence (Theobald 2010). However, at the extent examined in this study, human-influenced land cover does not preclude these areas from supporting wetland bird communities. Further, certain types of non-wetland habitat (e.g., agriculture) often have a positive association with abundance. Thus, maintaining heterogeneous landscapes around wetlands could increase the probability of preserving wetland bird communities.

Table 2.1. Median percent cover of six land cover types within the area surveyed along North American Breeding Bird Survey routes occupied by 31 wetland-breeding bird species. Interquartile range in parentheses.

Species	Open water	Woody wetland	Herbaceous wetland	Developed	Grassland	Agriculture
Pied-billed Grebe	1.03 (0.32, 2.82)	0.53 (0.06, 2.57)	1.73 (0.55, 5.50)	6.77 (4.85, 9.58)	5.56 (1.79, 19.88)	41.35 (2.85, 68.19)
Common Loon	3.09 (1.93, 5.66)	9.93 (4.29, 18.68)	1.50 (0.65, 3.87)	8.72 (6.53, 12.12)	1.12 (0.34, 3.19)	5.40 (0.26, 22.77)
Double-crested Cormorant	2.03 (0.73, 5.64)	1.58 (0.16, 9.58)	1.79 (0.31, 6.34)	8.89 (6.33, 16.48)	2.33 (0.47, 10.70)	26.89 (4.37, 60.94)
American White Pelican	1.28 (0.47, 3.22)	0.21 (0.03, 1.16)	1.82 (0.68, 4.91)	6.57 (5.48, 8.20)	9.88 (1.66, 30.73)	44.06 (7.61, 72.91)
Common Merganser	1.28 (0.19, 3.14)	1.29 (0.23, 4.12)	0.39 (0.08, 1.14)	7.86 (3.82, 12.06)	3.57 (0.49, 12.77)	3.54 (0.07, 16.71)
Mallard	0.41 (0.07, 1.51)	0.83 (0.08, 4.04)	0.28 (0.02, 1.26)	8.29 (6.05, 12.90)	2.06 (0.34, 13.89)	29.74 (6.33, 61.77)
Gadwall	0.49 (0.12, 1.44)	0.31 (0.02, 1.17)	0.97 (0.15, 3.17)	6.12 (3.11, 7.98)	15.01 (3.77, 42.83)	25.35 (2.61, 57.73)
Blue-winged Teal	0.52 (0.16, 1.81)	0.43 (0.07, 1.27)	1.35 (0.30, 3.94)	6.58 (5.64, 8.07)	14.08 (2.85, 46.16)	55.46 (26.47, 74.78)
Northern Shoveler	0.44 (0.13, 1.70)	0.14 (0.01, 0.76)	1.35 (0.30, 3.69)	6.04 (2.96, 7.18)	17.27 (4.86, 52.34)	42.52 (5.87, 70.13)

Table 2.1, Continued

Species	Open water	Woody wetland	Herbaceous wetland	Developed	Grassland	Agriculture
Northern Pintail	0.26 (0.10, 1.52)	0.14 (0.00, 0.59)	1.26 (0.21, 3.93)	5.97 (2.97, 6.95)	19.74 (5.40, 46.16)	42.01 (5.82, 69.71)
Wood Duck	0.75 (0.25, 2.13)	2.74 (0.34, 11.29)	0.42 (0.05, 1.48)	9.15 (7.29, 12.71)	1.61 (0.36, 4.29)	37.31 (16.77, 63.55)
Canada Goose	0.63 (0.22, 1.73)	1.25 (0.15, 5.15)	0.24 (0.02, 1.12)	9.34 (7.10, 13.61)	1.47 (0.29, 5.18)	34.76 (13.59, 61.54)
American Bittern	0.90 (0.27, 2.23)	1.42 (0.12, 8.08)	2.35 (0.71, 6.35)	7.32 (6.04, 9.08)	2.41 (0.62, 10.69)	32.69 (9.60, 65.34)
Great Blue Heron	0.51 (0.15, 1.51)	1.58 (0.19, 6.86)	0.17 (0.00, 1.02)	9.01 (7.08, 12.84)	1.79 (0.41, 6.48)	35.11 (13.83, 61.09)
Great Egret	0.67 (0.23, 2.04)	7.12 (1.15, 16.07)	0.61 (0.07, 2.42)	9.77 (7.47, 13.37)	2.31 (0.55, 6.93)	33.08 (11.84, 54.89)
Snowy Egret	1.15 (0.33, 4.50)	9.02 (1.60, 23.45)	1.76 (0.18, 8.60)	10.38 (7.35, 16.83)	1.06 (0.16, 3.63)	33.92 (9.92, 56.51)
Little Blue Heron	0.65 (0.22, 1.87)	10.73 (3.91,22.53)	0.65 (0.10, 2.44)	10.27 (7.41, 13.47)	2.32 (0.61, 6.40)	24.10 (10.28, 46.76)
Green Heron	0.53 (0.18, 1.46)	2.37 (0.36, 10.42)	0.15 (0.00, 0.94)	9.74 (7.55, 13.61)	1.63 (0.40, 4.31)	37.48 (18.79, 58.22)
Sandhill Crane	0.42 (0.06, 1.55)	4.06 (0.86, 14.73)	1.70 (0.45, 4.50)	7.78 (5.21, 10.33)	2.69 (0.90, 7.71)	21.27 (4.88, 50.25)
Sora	0.52 (0.07, 2.20)	0.58 (0.11, 1.71)	1.88 (0.35, 5.84)	6.34 (4.43, 7.72)	6.52 (2.59, 24.62)	42.65 (12.12, 70.89)
American Coot	0.58 (0.16, 1.82)	0.32 (0.03, 1.32)	1.03 (0.16, 3.91)	6.57 (3.98, 8.88)	7.59 (1.51, 24.78)	28.04 (1.75, 63.36)

Table 2.1, Continued

Species	Open water	Woody wetland	Herbaceous wetland	Developed	Grassland	Agriculture
Wilson's Phalarope	0.27 (0.08, 1.31)	0.31 (0.03, 1.05)	1.02 (0.18, 3.96)	5.87 (1.57, 7.18)	19.74 (4.95, 50.29)	28.10 (4.41, 57.86)
Wilson's Snipe	0.28 (0.02, 1.27)	1.03 (0.17, 3.58)	0.99 (0.17, 3.14)	6.11 (2.42, 8.06)	5.57 (1.15, 22.11)	10.89 (1.26, 37.39)
Willet	0.60 (0.05, 2.87)	0.51 (0.05, 2.34)	2.89 (0.40, 7.95)	6.79 (4.83, 9.05)	8.97 (1.49, 30.40)	26.23 (3.53, 54.13)
Spotted Sandpiper	0.43 (0.06, 2.03)	1.07 (0.15, 3.10)	0.57 (0.03, 1.61)	6.65 (2.76, 9.43)	3.59 (0.71, 11.00)	4.42 (0.12, 37.99)
Osprey	1.86 (0.60, 4.93)	5.14 (1.15, 14.64)	1.19 (0.30, 5.22)	10.43 (6.86, 15.91)	1.89 (0.45, 5.94)	9.52 (0.45, 28.74)
Belted Kingfisher	0.70 (0.15, 1.95)	1.44 (0.13, 6.51)	0.17 (0.00, 0.87)	8.89 (6.86, 12.51)	1.33 (0.34, 4.73)	22.99 (7.38, 45.81)
Yellow-headed Blackbird	0.36 (0.07, 1.31)	0.35 (0.05, 1.26)	1.05 (0.13, 3.37)	6.33 (3.48, 8.30)	7.49 (1.58, 27.87)	33.47 (4.60, 66.31)
Red-winged Blackbird	0.34 (0.07, 1.12)	1.00 (0.09, 5.30)	0.16 (0.00, 0.95)	8.44 (6.35, 12.06)	2.18 (0.47, 9.89)	25.62 (6.35, 53.98)
Swamp Sparrow	1.05 (0.34, 2.64)	5.26 (1.45, 12.75)	0.83 (0.34, 2.35)	8.67 (6.75, 12.15)	0.77 (0.25, 2.11)	20.01 (5.23, 45.71)
Marsh Wren	1.05 (0.28, 3.31)	1.04 (0.11, 3.69)	2.85 (1.04, 6.52)	7.88 (6.24, 12.16)	2.97 (0.81, 9.15)	47.30 (17.03, 75.24)

Table 2.2. Variables included, R^2 values, and model weight for the best-fit (lowest Akaike's Information Criterion adjusted for small sample sizes) model for each wetland bird species. Variables are listed in order of strength of relationship with the response variable, from highest to lowest absolute values of β. Independent variables that had statistically significant ($p < 0.05$) relationships with the response variable are in bold. OPW – open water, WWT – emergent woody wetland, HWT – emergent herbaceous wetland, TTW – total aquatic cover, WTL – total wetland, LON – longitude, LAT – latitude, DEV – developed, GRS – grassland, AGR – agriculture.

Species	Variables in model	R^2 SAR_{err} [a]	R^2 SAR_{pred} [b]	R^2 SAR_{space} [c]	w_i [d]
Pied-billed Grebe	**HWT + OPW** + LON – LAT	0.385	0.126	0.259	0.113
Common Loon	**OPW – DEV** + LAT	0.462	0.270	0.192	0.177
Double-crested Cormorant	**OPW +** LAT + AGR + LON + HWT – WWT	0.112	0.115	-0.003	0.043
American White Pelican	**OPW – DEV –** LAT	0.309	0.195	0.114	0.090
Common Merganser	**TTW**	0.280	0.014	0.266	0.184
Mallard	**AGR + HWT + OPW + DEV + LAT + GRS – WWT**	0.255	0.168	0.087	0.654
Gadwall	**OPW – DEV + AGR**	0.245	0.243	0.002	0.122
Blue-winged Teal	**OPW + AGR** + LON – LAT – WWT + DEV	0.487	0.087	0.400	0.226

Table 2.2, continued

Species	Variables in model	R^2 SAR_{err} [a]	R^2 SAR_{pred} [b]	R^2 SAR_{space} [c]	w_i^d
Northern Shoveler	**OPW** + AGR + LAT	0.311	0.317	-0.006	0.058
Northern Pintail	**LAT + TTW**	0.219	0.233	-0.014	0.111
Wood Duck	**OPW + HWT + WWT + LON + AGR + DEV**	0.172	0.161	0.011	0.299
Canada Goose	**AGR + GRS + OPW + DEV + HWT** + WWT	0.191	0.093	0.098	0.233
American Bittern	**HWT**	0.225	0.088	0.137	0.111
Great Blue Heron	**OPW + AGR + WWT** + LON + **HWT + GRS + DEV**	0.247	0.170	0.077	0.205
Great Egret	**AGR + LON – LAT + HWT + WWT + DEV + OPW**	0.382	0.317	0.065	0.731
Snowy Egret	**HWT + LON + AGR + WWT** + OPW – GRS	0.425	0.264	0.161	0.104
Little Blue Heron	**TTW + AGR** + LON + **DEV** + LAT	0.429	0.274	0.155	0.208
Green Heron	**AGR – LAT + OPW + HWT** + WWT	0.262	0.255	0.007	0.333
Sandhill Crane	**AGR + HWT** + GRS	0.246	0.245	0.001	0.111
Sora	**WTL**	0.360	0.019	0.341	0.200
American Coot	**HWT + OPW** – WWT	0.210	0.128	0.082	0.131

Table 2.2, continued

Species	Variables in model	R^2 SAR_{err} [a]	R^2 SAR_{pred} [b]	R^2 SAR_{space} [c]	w_i [d]
Wilson's Phalarope	**OPW**	0.160	0.036	0.124	0.146
Wilson's Snipe	**HWT + AGR** + WWT – OPW + GRS	0.314	0.066	0.248	0.155
Willet	**HWT** + OPW	0.328	0.012	0.316	0.164
Spotted Sandpiper	**OPW** – AGR	0.384	0.104	0.280	0.099
Osprey	**OPW + DEV** + WTL + AGR – LAT	0.288	0.192	0.096	0.057
Belted Kingfisher	**LON + OPW – AGR – GRS**	0.184	0.126	0.058	0.220
Yellow-headed Blackbird	**AGR + HWT + LON + GRS** + OPW – WWT	0.214	0.222	-0.008	0.113
Red-winged Blackbird	**AGR + HWT + GRS + OPW + LAT + DEV** – WWT	0.540	0.53	0.010	0.634
Swamp Sparrow	**TTW – DEV** + LON	0.214	0.208	0.006	0.085
Marsh Wren	**OPW** + GRS	0.290	0.104	0.186	0.076

[a] Adjusted R^2 value for variance explained in the SAR_{err} model by the independent variables and the spatial component
[b] Adjusted R^2 value for variance explained in the SAR_{err} model by only the independent variables.
[c] Adjusted R^2 value for variance explained in the SAR_{err} model by the spatial component.
[d] Akaike weight

Table 2.3. Model-weighted average regression coefficients calculated from the standardized partial regression coefficients from multiple Simultaneous Autoregressive (SAR_{err}) abundance models for each of 31 wetland bird species. Coefficients that are bold indicate statistically significant ($p < 0.05$) relationships between that independent variable and mean annual abundance of that species.

Species Name	OPW	WWT	HWT	DEV	GRS	AGR	TTW	WTL	LAT	LON
Pied-billed Grebe	**0.231**	**-0.122**	**0.376**	-0.017	-0.026	-0.014			-0.190	0.128
Common Loon	**0.497**	0.000	0.000	**-0.233**	0.018	0.025			0.153	0.014
Double-crested Cormorant	**0.106**	-0.120	0.054	-0.024	-0.001	0.061			0.083	0.066
American White Pelican	**0.425**	-0.020	0.000	**-0.119**	0.007	-0.003			-0.076	0.010
Common Merganser				0.046	0.014	-0.005	**0.259**		-0.036	0.123
Mallard	**0.163**	**-0.070**	**0.229**	**0.159**	**0.116**	**0.348**			**0.122**	0.057
Gadwall	**0.414**	-0.028	0.042	**-0.178**	-0.009	**0.159**			-0.007	-0.006
Blue-winged Teal	**0.241**	-0.103		0.025	0.047	**0.238**			-0.073	0.077
Northern Shoveler	**0.483**	-0.037	0.027	-0.024	-0.033	0.134			0.100	-0.008
Northern Pintail	**0.062**		**0.067**	-0.038	-0.008	0.093	**0.217**		**0.292**	-0.017
Wood Duck	**0.221**	**0.135**	**0.206**	0.065	0.004	**0.121**			-0.004	**0.160**

Table 2.3, continued

Species Name	OPW	WWT	HWT	DEV	GRS	AGR	TTW	WTL	LAT	LON
Canada Goose	**0.180**	0.026	**0.107**	**0.134**	**0.200**	**0.289**			-0.025	0.037
American Bittern	0.029	-0.012	**0.292**	-0.016	0.013	0.085			-0.032	0.006
Great Blue Heron	**0.338**	**0.154**	**0.145**	**0.077**	**0.064**	**0.318**			-0.018	0.131
Great Egret	**0.243**	**0.215**	**0.218**	**0.264**		**0.465**		**0.087**	**-0.331**	**0.426**
Snowy Egret	0.133	0.114	**0.313**	-0.011	-0.128	**0.150**			0.072	0.293
Little Blue Heron	**0.034**			**0.095**	0.015	**0.468**	**0.376**	**0.126**	0.070	0.172
Green Heron	**0.246**	0.077	**0.230**	0.006	0.011	**0.279**			**-0.252**	0.003
Sandhill Crane	-0.003	0.022	**0.320**	-0.009	0.076	**0.442**			-0.011	0.011
Sora			**0.085**	-0.028	0.002	0.025	**0.156**		0.011	0.049
American Coot	0.181	-0.159	**0.229**	-0.043	-0.009	0.006			-0.040	0.050
Wilson's Phalarope	**0.264**			-0.064	0.008	0.020			-0.012	0.062
Wilson's Snipe	0.078	0.020	**0.440**	0.007	0.121	0.020			0.146	0.328
Willet	0.048		**0.290**	-0.004	0.009	-0.006	**0.067**		0.015	0.013

Table 2.3, Continued

Species Name	OPW	WWT	HWT	DEV	GRS	AGR	TTW	WTL	LAT	LON
Spotted Sandpiper	**0.210**	0.008	-0.013	-0.021	0.013	-0.066			-0.007	0.014
Osprey	**0.301**	0.032	0.049	**0.150**	0.017	0.076	0.070		-0.062	0.056
Belted Kingfisher	**0.286**	0.000	0.018	-0.014	**-0.082**	**-0.110**			-0.005	**0.316**
Yellow-headed Blackbird	**0.113**	0.002	**0.283**	-0.041	0.081	**0.426**			0.021	**0.202**
Red-winged Blackbird	**0.095**	-0.012	**0.198**	**0.090**	**0.164**	**0.693**			**0.095**	0.019
Swamp Sparrow	**0.067**	**0.072**	**0.051**	-0.133	0.004	-0.004	0.101	**0.201**	-0.004	0.029
Marsh Wren	**0.235**		**0.099**	-0.007	**0.126**	0.029	**0.109**		-0.013	-0.019

Table 2.4. Values for model evaluation, including the number of routes used for modeling and the total number of routes on which each species was detected, Pearson's correlation coefficient for the relationship between estimated values and observed log-transformed abundances for the 20% of routes retained for model evaluation, the p-value for that correlation coefficient, and the Root Mean Squared Prediction Error based on the estimated values and the observed abundances. Species are ordered from strongest to weakest relationship between predicted and actual abundances, based on the Pearson's correlation coefficients.

Species Name	Routes	Pearson's correlation coefficient	Pearson's p-value	RMSPE
Green Heron	126/157	0.721	0.000	0.419
Swamp Sparrow	93/116	0.636	0.000	0.393
Great Blue Heron	184/230	0.621	0.000	0.608
Little Blue Heron	99/123	0.554	0.000	2.186
Northern Pintail	92/114	0.554	0.011	1.653
American Bittern	1040/1300	0.552	0.004	0.329
Wilson's Snipe	164/205	0.549	0.000	2.172
Snowy Egret	144/179	0.544	0.002	1.559
American Coot	94/117	0.538	0.000	0.646
Yellow-headed Blackbird	83/103	0.520	0.000	1.711
Gadwall	440/549	0.512	0.001	0.610
Wilson's Phalarope	902/ 1127	0.494	0.022	0.466
Great Egret	101/126	0.469	0.000	1.072
Osprey	1253/1566	0.448	0.001	0.372

Table 2.4, Continued

Species Name	Routes	Pearson's correlation coefficient	Pearson's p-value	RMSPE
Northern Shoveler	392/490	0.442	0.034	0.478
Common Merganser	118/147	0.429	0.045	0.342
Mallard	204/254	0.427	0.000	0.937
Double-crested Cormorant	660/824	0.418	0.004	0.613
Canada Goose	238/297	0.415	0.000	0.635
Marsh Wren	104/130	0.402	0.016	0.634
Common Loon	153/192	0.394	0.062	1.965
Red-winged Blackbird	88/109	0.356	0.000	0.484
Wood Duck	357/446	0.306	0.001	0.697
Sora	110/137	0.301	0.134	0.487
Blue-winged Teal	198/247	0.293	0.087	0.504
Spotted Sandpiper	209/261	0.275	0.055	0.303
Willet	499/623	0.253	0.201	0.520
Sandhill Crane	257/321	0.208	0.113	0.483
American White Pelican	2113/2641	0.203	0.341	1.407
Pied-billed Grebe	265/331	0.124	0.506	0.398
Belted Kingfisher	142/177	0.017	0.848	0.789

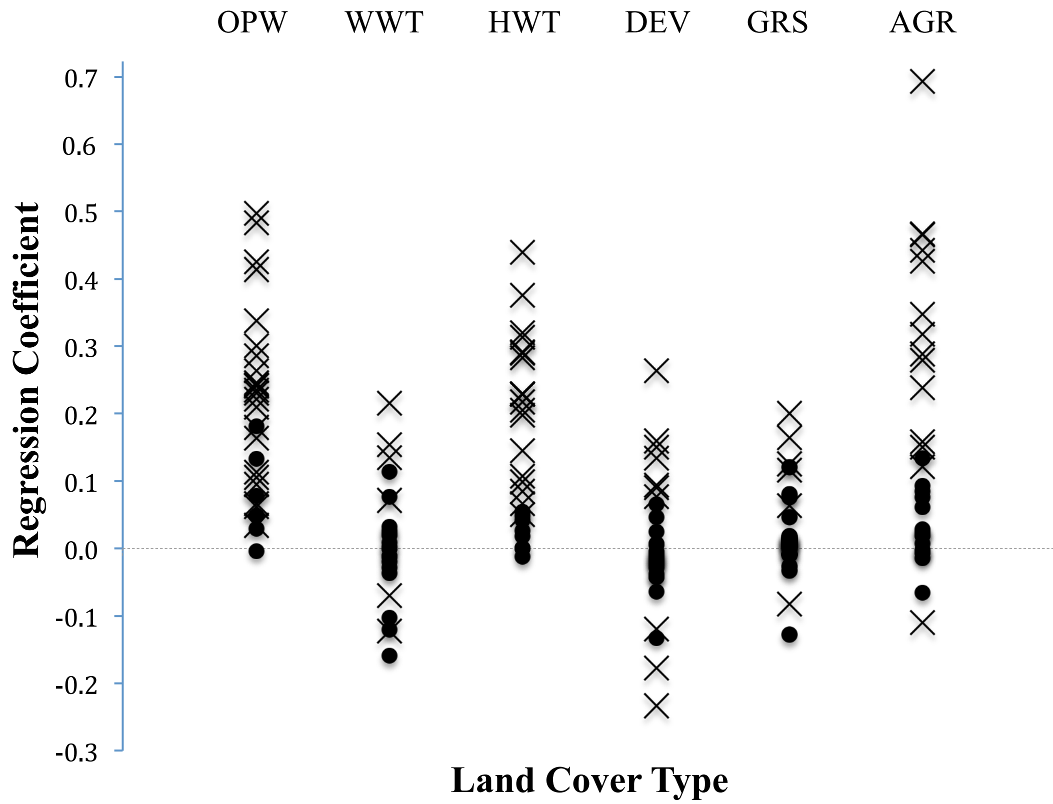

Figure 2.1. Associations between land cover and mean abundances of 31 wetland bird species on routes of the North American Breeding Bird Survey from 2001 – 2011. Regression coefficients are the model-weighted averages of the standardized partial regression coefficients from multiple Simultaneous Autoregressive (SAR_{err}) models for each species. X, statistically significant coefficients (weighted $P < 0.05$); solid dots, non-significant coefficients. WWT – woody wetland; HWT – herbaceous wetland; OPW – open water; DEV – developed; GRS – grassland; AGR – agriculture.

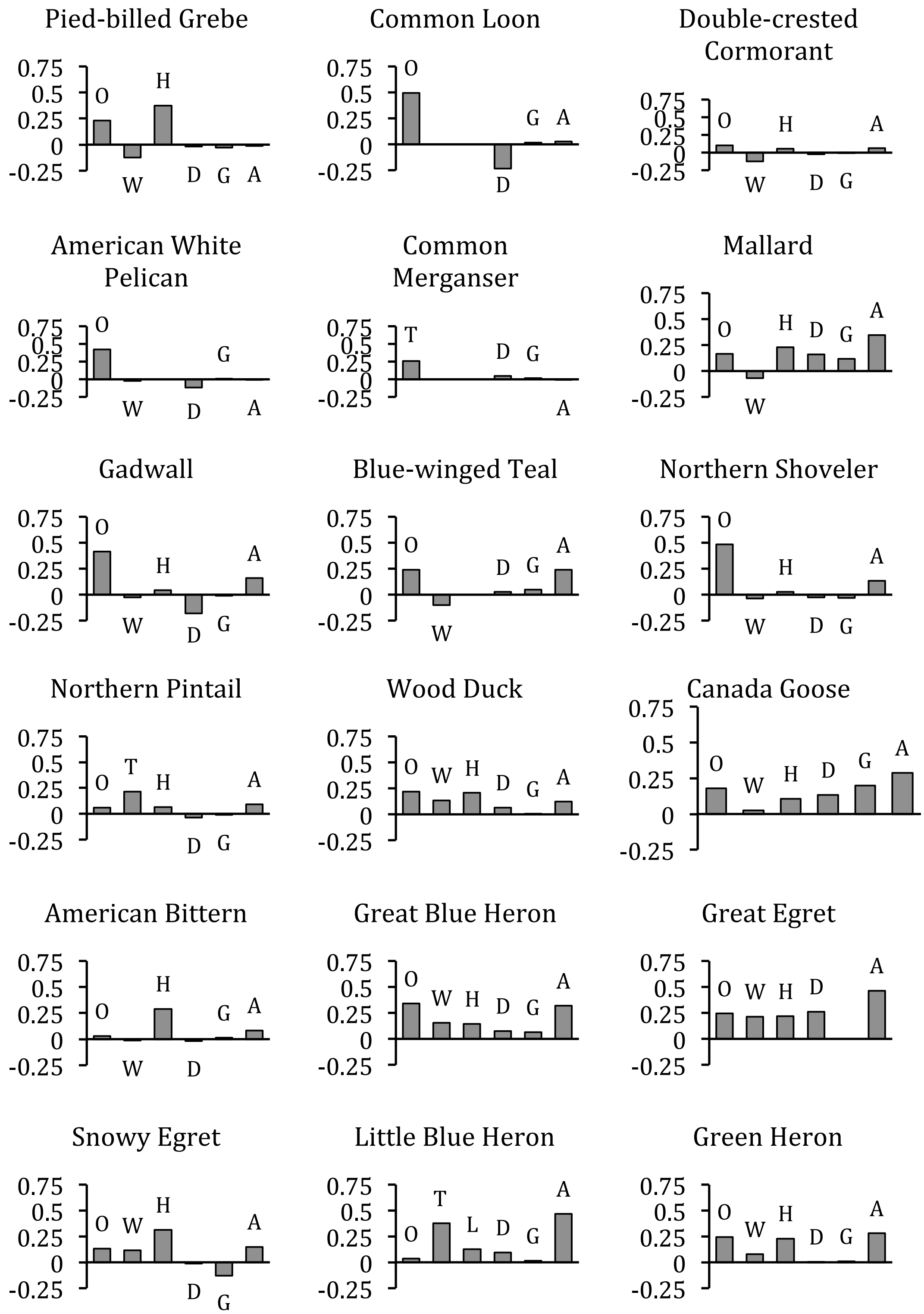

Figure 2.2. Weighted averaged standardized partial regression coefficients for 31 wetland-breeding birds. W – woody wetland, H – herbaceous wetland, O – open water, T – total aquatic cover, L – total wetland, D – developed, G – grassland, A – agriculture.

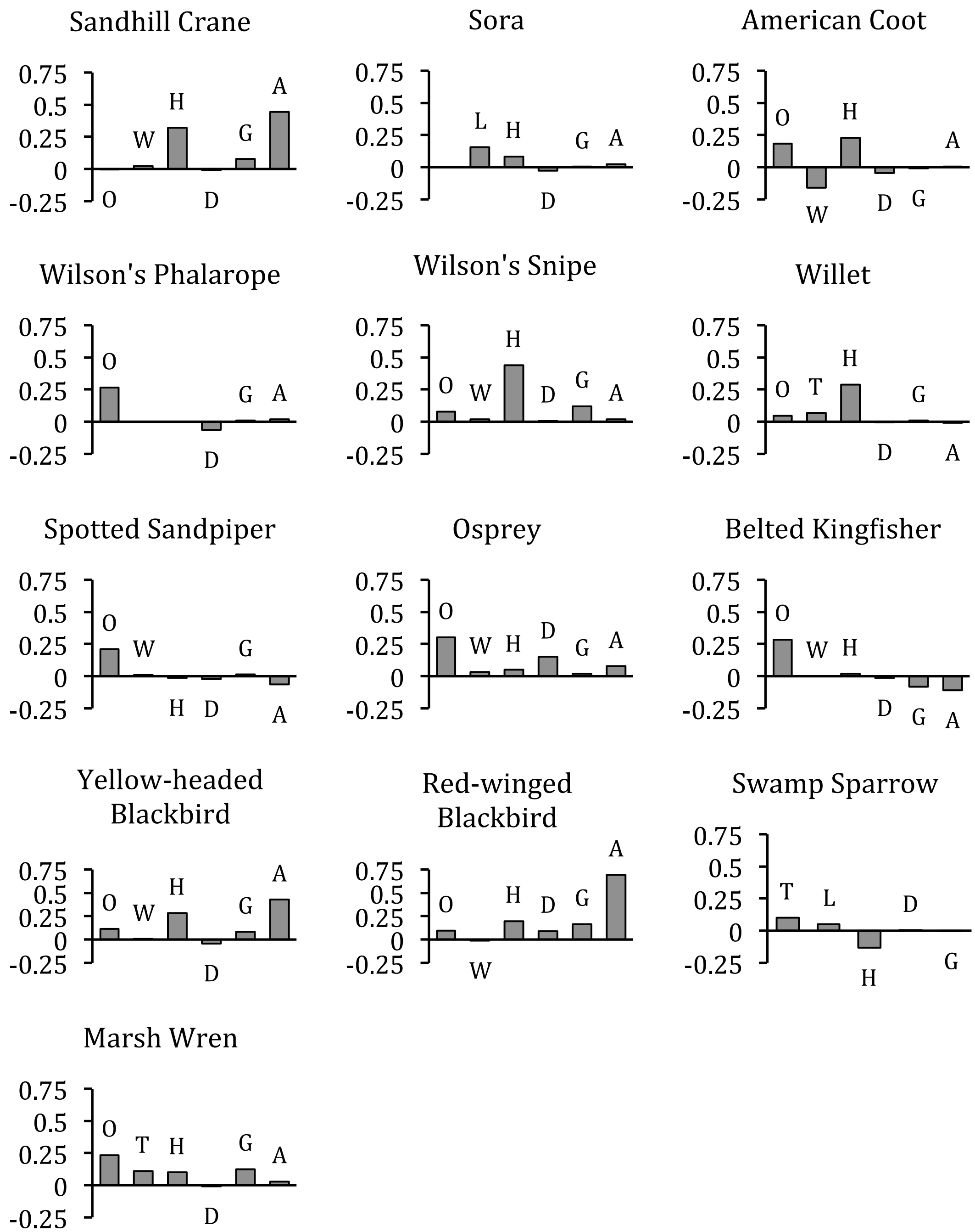

Figure 2.2, continued. Weighted averaged standardized partial regression coefficients for 31 wetland-breeding birds. W – woody wetland, H – herbaceous wetland, O – open water, T – total aquatic cover, L – total wetland, D – developed, G – grassland, A – agriculture.

III. A REVIEW OF AVIAN USE OF ANTHROPOGENIC WETLANDS

Introduction

Wetland loss, creation, and restoration

Wetland loss has been extensive throughout the world for the past few centuries. For example, from 1780 to 1980, approximately 53% of the wetland area in the conterminous United States was lost as these systems were drained, filled, or otherwise altered (Dahl 1990). Worldwide, wetland loss also was estimated to be close to 50% (Mitsch and Gosselink 2007). With alteration of wetlands comes the loss of natural water filtration, biogeochemical cycling, flood protection, shoreline stability, and high-quality habitat for a wide variety of organisms, including many species of birds (NRC 1995).

In the 1980s, the United States established policy under Section 404 of the 1972 Clean Water Act that prohibited net loss of wetlands (USEPA/ACE 1990). Permits issued by the U.S. Army Corps of Engineers or by Environmental Protection Agency-approved state programs for projects that will destroy or alter wetlands often stipulate that these changes must be compensated with mitigation, typically wetland creation or restoration (Brinson and Rheinhardt 1996). New wetland area may be created by excavating a depression, manipulating natural hydrology to inundate previously dry soils, or adding substrate to a coastline to increase the area of the intertidal zone. Restoration efforts often include restoring natural hydrology to drained systems or removing barriers to tidal flow.

In addition to legally required mitigation, other initiatives have been implemented to increase the quantity and quality of wetlands. Federal subsidies available through the Wetland Reserve Program are available for landowners who voluntarily restore wetlands on their property (King et al. 2006), and non-profit organizations such as Ducks Unlimited have conserved millions of hectares of wetlands (Tori et al. 2002). The U.S. Fish and Wildlife Service reported that between 1998 and 2004, due to these combined efforts, total wetland area increased by an average of 12,900 hectares annually within the continental United States (Dahl 2006).

The goal of mitigation is not only area but also function: that the ecological functions of new systems are equal to or exceed those of the wetlands that were lost or impaired (Zedler 1996, Findlay et al. 2002). Developing new wetlands that function as natural wetlands is difficult, and anthropogenic systems typically do not have the entire suite of functions (e.g., primary productivity, water filtration, nutrient cycling, and provision of habitat) (Mitsch and Wilson 1996, NRC 2001). In 2001, the Committee on Mitigating Wetland Losses (formed by the National Research Council), concluded that mitigation policy had not achieved the goal of no net loss of wetland function (NRC 2001).

Serious shortcomings of anthropogenic wetlands, specifically mitigation sites, have been identified. For example, mitigation sites often differ from the lost or altered sites with respect to the number and size of individual wetlands, surrounding land use, or wetland type (Kettlewell et al. 2008). If mitigation sites (or any anthropogenic wetlands) are intended to serve as replacements for lost wetlands, they should be as similar as possible to the sites that have been destroyed (Brinson and Rheinhardt 1996, NRC 2001). Additionally, anthropogenic sites often lack the heterogeneity in bathymetry, vegetation, or other fine-resolution attributes present at natural sites (NRC 2001). To assess functional equivalency, direct comparisons must be made between anthropogenic sites and high-quality reference sites that are in close proximity and have characteristics similar to the wetlands that have been lost (Brinson and Rheinhardt 1996).

Furthermore, there are few long-term data on replacement wetlands. Many studies have evaluated whether natural wetland functions have developed at mitigation sites, but data are typically focused on a specific wetland complex over a few years following its creation or restoration (Mitsch and Wilson 1996, Findlay et al. 2002). Most mitigation permits require 3-5 years of monitoring, but freshwater marshes can take 15-20 years to fully develop natural structure and function (Mitsch and Wilson 1996). Coastal or forested wetlands may take several decades reach a mature state (Snell-Rood and Cristol 2003). Created or restored wetlands may become more similar to natural sites over time, but monitoring at most sites is insufficient to evaluate this possibility.

Wetlands as avian habitat

Many species of birds are obligate or facultative users of wetlands during both the breeding and non-breeding seasons. Additionally, wetlands provide stopover habitat for many long-distance migratory bird species during their migrations between breeding and wintering grounds. As a group, avian species utilizing wetlands benefit from high primary productivity and emergent vegetation for nesting and protection from predators. The diets, feeding behaviors, and nesting requirements of bird species that use wetlands are diverse (Appendix A).

Many small wetlands support high avian species richness across several functional groups, likely due to substantial heterogeneity within natural wetlands (Weller 1999). When wetlands are destroyed or compromised, avian communities may be affected through mechanisms such as a reduced prey base, loss of nesting structure, and increased competition with other species. Since the North American Breeding Bird Survey was initiated in 1966, abundances of some wetland species have increased substantially (Sauer et al. 2003) whereas abundances of other species have been stable or decreased. Some of these trends have been documented throughout the conterminous United States while others have occurred within particular regions (Sauer et al. 2011). Whether abundance trends are positive or negative may depend in part on whether created and restored wetlands provide habitat for various species. Thus, it is relevant to determine whether anthropogenic wetlands are providing resources for birds that compensate for the resources lost when natural wetlands are destroyed.

Avian density, avian diversity, and occupancy of a wetland by a given avian species or guild depends on numerous wetland characteristics. Species richness and total avian abundance can be positively associated with total wetland area (VanRees-Siewert and Dinsmore 1996, Brown and Smith 1998, Stevens et al. 2003), amount of emergent vegetation (VanRees-Siewert and Dinsmore 1996, Stevens et al. 2003), and amount of open water (Burger et al. 1982). Species composition of birds within a wetland is associated with the presence and proportional representation of permanently inundated areas, bare substrate, and emergent vegetation, each of which is likely to support different species (Armitage et al. 2007) or guilds (Darnell and Smith 2004). Proximity to man-made structures (Armitage et al. 2007), water depth (Bellio et al. 2009), variability in water depth, water chemistry, bathymetry, prey availability, and configuration (Ma et al. 2010) are also relevant.

I conducted a meta-analysis to assess whether avian habitat in anthropogenic wetlands is functionally equivalent to that in natural wetlands. Many papers have been published on the avian communities that use anthropogenic wetlands. In this meta-analysis, I focused on studies that included direct comparisons between anthropogenic wetlands and reference sites. I also conducted a qualitative review of papers on similar topics that did not meet criteria for inclusion in a meta-analysis.

Methods

I searched Google Scholar and Web of Science with the terms '*bird* OR avian OR waterfowl AND restor* OR creat* OR anthropogenic OR "man?made" AND wetland OR marsh OR swamp'. I identified additional papers that were cited in the papers I found through these database searches. Many of the human-manipulated wetlands described in the papers I found were intended to mimic the ecological functions of natural wetlands. I classified these wetlands as "created" if they were established on previously terrestrial soil. I classified the wetlands as "restored" if natural hydrology had been restored to an area that had originally been a wetland but had been previously drained or filled. I did not include papers on existing wetlands that had been enhanced or improved. During the search, I also found papers that assessed avian use of anthropogenic aquatic features (e.g., rice fields, water treatment ponds, saltpans) that were not intended to replicate the functions of natural wetlands, but were supporting bird populations. I classified the wetlands these papers described as "other" to contrast with the "created" and "restored" wetlands that were intended to mimic natural wetlands. Hereafter, I use *anthropogenic wetlands* to refer to systems that have been created or restored and to these other human-made wetlands.

I retained papers that presented avian community metrics such as overall density or species richness; I did not retain papers on single species. I also eliminated papers that did not fit into one of two groups. The first group of papers includes comparisons of bird communities at anthropogenic wetlands to those at reference sites intended to represent natural conditions. The second group of papers includes descriptions of avian communities over at least three years following establishment of anthropogenic wetlands. While three years is likely not enough time for a wetland to develop its climax community, the avian species that are documented in a newly established anthropogenic wetland could offer insight into which species may utilize the wetland in the future.

From here forward, I reference these papers by number (see Table 3.1) as a superscript. Most of the papers were based on studies conducted within the United States, but I also included papers describing studies from seven other countries. A few papers described avian communities at a single mitigation site[19,30], but most included multiple anthropogenic wetlands. The paper with the largest sample size surveyed 80 wetlands, 41 anthropogenic and 39 reference[5].

Sites in some of the studies were created or restored to fulfill legal requirements to compensate for destruction of wetlands[3,30]. In certain cases, new wetlands were constructed to meet other goals, such as shoreline stabilization[24] or creation of habitat for waterfowl[5] or rare species[12]. Other studies evaluated wetlands that resulted from particular land uses, such as shallow ponds remaining after cessation of commercial salt harvest[32] or agricultural activities[18]. Most studies surveyed all avian species, but some focused on a given taxonomic or functional group, such as shorebirds[2] or waterfowl[29].

In the retained papers, the most common avian community metrics presented for anthropogenic and reference wetlands were density, species richness, and diversity. For the comparison of avian density, I included data that were presented as a density (i.e. number of birds per unit area). I also used data that were presented as abundances (i.e., number of individuals detected) if the associated methods indicated that the area surveyed was similar in size between the two groups of wetlands (anthropogenic and reference). For species richness, I used the maximum number of avian species that were documented. For diversity, I used the Shannon diversity index calculated as:

$$H' = -\Sigma\,(p_i)(\ln p_i),$$

where p_i is the proportion of total individuals belonging to the species i. Some papers reported only one of these community metrics; other papers included all three (Appendices C-E). For each of these three community metrics, I used a meta-analytical approach to assess whether values differed between anthropogenic and reference wetlands.

For each meta-analysis, I included studies that either reported the mean value of the metric ($\bar{Y}$), standard deviation (s), and sample size (n) for both wetland groups (reference and anthropogenic) or that included data that allowed me to calculate these values. In several cases, the authors reported information on density, species richness, or diversity for multiple sites, years, or seasons. In these cases, I calculated the mean and standard deviation of the various values and used the number of values that were included as the sample size.

For each study and community metric, I calculated the effect size using the natural log of the response ratio (Koricheva et al. 2013), which is a standardized measure that reflects the difference in mean values ($\overline{Y_1}$ and $\overline{Y_2}$) between two locations (in this case, the anthropogenic wetlands and the reference wetlands). The natural log of the response ratio (*lnR*) is calculated as:

$$lnR = ln\left(\frac{\overline{Y_1}}{\overline{Y_2}}\right),$$

with the variance estimate calculated as:

$$\mathrm{var}(lnR) = \frac{s_1^2}{n_1\bar{Y}_1^2} + \frac{s_2^2}{n_2\bar{Y}_2^2}.$$

Here, n_1 and n_2 are sample sizes and s_1^2 and s_2^2 are the respective variances for $\overline{Y_1}$ and $\overline{Y_2}$. The values for anthropogenic wetlands are given a subscript of 1 and values for reference wetlands are given a subscript of 2. Negative values of *lnR* reflect instances where the value for a given community metric (e.g., density) was higher for reference wetlands than for anthropogenic wetlands, positive values signify that the value for anthropogenic wetlands was higher (in an absolute sense, not a statistical sense), and zero indicates the values were the same. I chose *lnR* over other possible measures of effect size (e.g, Hedge's *D*) because interpreting its ecological meaning is fairly straightforward. Specifically, the final averaged values for *lnR* can be back-transformed and used to present the averaged percent difference in response variable between treatment (anthropogenic wetlands) and control (reference wetlands) groups.

I used MetaWin 2.0 (http://www.metawinsoft.com/, accessed September 12, 2014) to calculate estimates of *lnR* and var*(lnR)* for each study and community-metric combination. Also in MetaWin, I used a random effects model with anthropogenic wetland type (created, restored, or other) as a covariate to calculate weighted average effect sizes for each community metric and a 95% confidence interval for each weighted average *lnR* value. I used these confidence intervals to identify statistically significant differences between anthropogenic wetlands and reference wetlands.

Because *lnR* is a standardized value, it is possible to combine different responses (that are meaningfully related) in order to estimate an overall effect. Therefore, I also calculated an overall mean *lnR* value across all reported values for density, richness, and diversity. Many studies presented results for two or all three of the community metrics. Including more than one metric for a single study would lead to statistical issues associated with non-independence, so I first used MetaWin to calculated a composite (weighted mean) effect size and pooled variance across the multiple metrics from each study. I then used these composite values within a random effects model (with anthropogenic wetland type as a covariate) to calculate average effect sizes and 95% confidence intervals across all studies.

In addition, I qualitatively reviewed differences in species composition and breeding activity between anthropogenic and reference wetlands, as well as avian composition over time following the establishment of anthropogenic wetlands that were reported in the papers I retained. I did not apply a meta-analysis to these characteristics because the information about them often was descriptive or not consistent among studies. For several of the topics that I review qualitatively, quantitative results are presented within the original studies. As examples, community similarity was described numerically using Jaccard's similarity index and changes in avian community metrics were described numerically as an increase in avian density or a change in the number of species that were present at a study site during the years following creation or restoration. However, fundamental to the process of meta-analysis is the requirement of both an average measure of the effect of interest across multiple samples within the primary study and a value indicating the precision associated with that average value (e.g., standard deviation or confidence interval). Such values were not consistently available besides for the three communities metrics (density, richness, and diversity) described above.

Results

Comparisons between anthropogenic and reference wetlands

Twenty-seven studies directly compared avian communities at sites that had been created or restored through human efforts and reference sites. Most of the reference sites had minimal human modification, but some reference sites had been diked[32] or mowed[7]. Additionally, one study examined reference sites that had been clear-cut at approximately the same time as the mitigation sites were created. Because the wetlands in this case were forested bottomlands dominated by slow-growing trees, this design allowed for comparison between sites that had vegetation of similar ages[31].

Avian density – Twenty-one of the 27 studies compared avian density (the number of birds per unit area) between anthropogenic and reference wetlands. Eighteen of these included the data required for meta-analysis (Appendix C, Table 3.2). The average effect size (*lnR*) among these studies was 0.084 (CI: -0.588 to 0.756), indicating no significant difference in density of birds between anthropogenic and reference sites. Average density of birds was about 9% higher at anthropogenic sites than at reference sites (back-transformed *lnR* = 1.09). Separate meta-analyses for each of the three categories of anthropogenic wetlands (created, restored, and other) yielded no statistically significant differences between anthropogenic and reference wetlands (Table 3.2). Of individual studies that included tests of significance, five found higher densities of birds at reference sites[6,8,13,15,35], one documented higher densities at anthropogenic sites[4], and four reported similar densities[3,25,28,31]. In some cases the differences reported were dramatic. Tourenq et al. (2001) reported that in France, they observed 99% of all birds at reference wetlands[31] and only 1% at anthropogenic wetlands (ricefields), but 39 times more birds were detected at treatment ponds in Florida than at natural sites[4]. Two studies reported greater densities in reference wetlands during some seasons (breeding season[14], spring and fall[22]) but similar densities during other seasons. One study estimated avian density throughout the year and reported that density was significantly higher in created marshes than in reference marshes during the breeding season (March – July), but higher at reference marshes during non-breeding seasons[24].

Species richness – Twenty-three studies compared species richness between anthropogenic and reference sites. Nineteen had sufficient data for a meta-analysis (Appendix D, Table 3.2). The average effect size (*lnR*) was -0.087 (CI: -0.295 to 0.121), indicating no significant difference between anthropogenic and reference sites. Average avian species richness was 8% lower at anthropogenic sites (back-transformed *lnR* = 0.92). Separate meta-analyses for each category of anthropogenic wetlands yielded no statistically significant differences between anthropogenic and reference wetlands (Table 3.2). Fifteen studies reported results of significance tests. Of those, eight identified significantly higher avian species richness at reference wetlands than at anthropogenic sites[5,6,8,9,10,19,24,31] and another found higher species richness of breeding birds at reference sites[13]. One found higher species richness as anthropogenic sites[4] and five reported similar species richness[3,18,20,25,28]. Two studies identified seasonal differences in species richness between anthropogenic and reference sites; they both documented higher species richness at reference sites in some seasons (breeding season[14], spring, summer, and fall[22]) and similar species richness at reference and anthropogenic sites in other seasons[14,22]. Another found that four of five restored wetlands had higher species richness than their paired reference sites[2].

Diversity – Twelve studies used the Shannon index to compare wetland bird communities; 11 provided sufficient data to be included in the meta-analysis (Appendix E, Table 3.2). The average effect size (*lnR*) was -0.185 (CI: -0.282 to -0.088), indicating diversity values that were significantly lower at anthropogenic sites than reference wetlands. The back-transformed average log ratio was 0.83, meaning diversity was on average 17% lower at anthropogenic sites. However, I found no statistically significant difference between created, restored, or other anthropogenic wetlands and reference wetlands (Table 3.2). In three studies, diversity was significantly lower at anthropogenic wetlands than at reference sites[5,24,31]. Four studies documented similar avian diversity at anthropogenic and reference wetlands[3,18,20,28]. In one study, diversity was higher at anthropogenic sites for three of five pairs of wetlands[2], but no studies reported consistently higher diversity at anthropogenic sites.

Composite effect size - The average effect size (*lnR*) for the composite values was -0.216 (CI: -0.342 to -0.089) indicating that the combined community metric values were significantly lower at anthropogenic wetlands. The composite effect size values were 19% lower at anthropogenic sites (back-transformed *lnR* = 0.81) than at reference sites. Separate meta-analyses for each category of anthropogenic wetlands also found that composite effect sizes were significantly smaller at anthropogenic wetlands classified at “other” (*lnR* = -0.599, CI: -0.908 to -0.290), but no statistically significant differences were found between created or restored wetlands and their reference counterparts (Table 3.2).

Species composition - Four studies assessed the similarity between the avian communities at anthropogenic wetlands and reference sites. One study reported 64.7% Jaccard’s similarity between reference and anthropogenic sites[18]. Two other studies paired each anthropogenic site with a reference site; these matched pairs averaged 44%[14] and 36%[31] similarity in species composition. Two studies reported that community composition was less similar between reference and restored wetlands than among reference sites[8,31].

Twenty-one studies classified bird species on the basis of their taxonomic relatedness (grouped by order or family) or functional guilds (e.g., wading birds or diving piscivores) and then compared the number of detections or proportional representation (based on abundances) of different groups between anthropogenic and reference sites (Table 3.3). Two studies conducted in Texas found lower proportions of shorebirds at anthropogenic wetlands than reference sites[12,24]. In one case, gulls and terns comprised the largest proportion of the avian community at created wetlands, but shorebirds, waders, and sparrows were the most abundant groups documented at natural sites[24]. The other study described an area of created wetland in which the proportion of shorebirds was smaller than at the reference sites that the created wetland was intended to replace[12]. In a study conducted in China, the proportion of shorebirds and other waders was higher in reference wetlands than anthropogenic wetlands, whereas the proportion of ducks and other swimming species was greater in anthropogenic sites than reference sites[22]. The proportion of waterfowl was greater than that of other groups in anthropogenic wetlands in Florida, although passerines were the most common group at reference wetlands[4]. At reference wetlands in Saskatchewan, diving birds and woodland associated birds were found in higher proportions, whereas grassland species and shorebirds were documented in greater proportions at restored sites[5]. In this case, differences in avian communities between reference and anthropogenic wetlands were primarily driven by woodland and grassland birds as opposed to wetland obligates. Other studies documented distinct differences in avian communities not only between reference and anthropogenic sites, but also among multiple anthropogenic and reference wetlands[2,6,7].

Some anthropogenic wetlands had relatively lower abundances of particular groups such as passerines[31], rails[24], dabblers[32], and insectivores[18] than reference wetlands. In other cases, anthropogenic wetlands had greater abundances of edge species[18], surface feeders[32], and waterfowl[3]. Several studies reported similar abundances of groups such as waterfowl[13,31], herons[22], and passerines[3] at anthropogenic and natural wetlands.

Differences in recorded densities and abundances of individual species were also noted. Canada Geese (*Branta canadensis*)[28], grackles (*Quiscalus* spp.)[12], Killdeer (*Charadrius vociferus*)[13], Wood Ducks (*Aix sponsa*)[3], American Goldfinches (*Spinus tristis*)[3], and three species of ducks[28] were all reported to have higher densities within anthropogenic wetlands than reference wetlands in certain studies. Species with higher abundances at reference sites included Song Sparrows (*Melospiza melodia*)[3], Swamp Sparrows (*Melospiza georgiana*)[13], Marsh Wrens (*Cistothorus palustris*)[13], Red-winged Blackbirds (*Agelaius phoeniceus*)[13], Common Yellowthroats (*Geothlypis trichas*)[13], and Seaside Sparrows (*Ammodramus maritimus*)[12]. Abundances of several other species were similar between the two wetland groups[3,13,14] (Table 3.3). Six studies reported that certain species were found exclusively in either reference or anthropogenic wetlands. In each case, a greater number of species were unique to reference sites than to anthropogenic sites[6,19,21,22,24,33] (Table 3.3).

Four studies addressed whether differences in species composition were related to the strength of the species' association with wetlands (e.g., from wetland dependent to wetland associated to non-wetland). For example, DesRochers et al. (2008) ranked species from 1 (occasional use) to 5 (obligate wetland users) and found species detected at anthropogenic wetlands were on average less wetland-dependent than species at reference sites[14]. Similarly, another study reported that passerines present at created wetlands were less wetland-dependent than other passerine species found at natural wetlands[31]. However, one study reported a similar proportion of wetland obligates at both created and natural wetlands[18]. In one year (of three), the mean density of wetland dependent species was higher at natural sites than restored sites, but in other years, densities were similar[8].

Breeding activity – Three studies compared factors related to breeding activity, such as number of nests, number of breeding species, or probability of chicks fledging, between anthropogenic and reference wetlands. One study reported no differences in the number of completed clutches (nests from which some offspring fledged) across all species, but Red-winged Blackbirds (*Agelaius phoeniceus*) averaged more completed clutches at natural sites than created sites[14]. In another study, Red-winged Blackbird nests were found at two reference sites, but not at a created site, and 31 Marsh Wren (*Cistothorus palustris*) nests were documented at reference sites with only one wren nest at the nearby created site[19]. At the same location, seven years later, four breeding species were documented at reference wetlands and no breeding activity was observed at the created site[19]. Another study found significant differences in carotenoids concentrations within egg yolks[25]. Carotenoids depend on maternal diet and can be used as a proxy for egg quality. These results were interpreted to indicate that reference sites provided better breeding habitat in 2008, whereas habitat quality at restored sites was higher in 2009 when several natural wetlands were left dry by a drought[25].

Changes in species composition after wetland creation

Thirteen studies assessed bird communities over time following wetland creation or restoration (Table 3.4). Some of these indicated new wetlands might gradually host additional species of wetland birds over a few years. For example, several studies conducted over 3-5 years documented yearly increases in at least one wetland bird community metric following wetland creation or restoration[30,34,35]. For example, shorebird density increased from 9.1 birds per hectare to 47.5 birds per hectare over three years following restoration of intertidal mudflats[35]. At restored prairie wetlands, the number of species breeding per wetland increased from the first year to the fourth year following restoration, although changes in species richness were not statistically significant[34]. The number of nests per hectare increased nearly ten-fold from the first to the third year following creation of a sewage marsh in Arizona[26]. Simenstad and Thom (1996) documented a gradual increase in species richness over five years following wetland restoration, although about 70% of the species detected in the fifth year were detected in the first year[30]. Two studies from the United Kingdom found over less than five years, avian species composition at newly created estuaries became similar to assemblages occupying nearby natural wetlands[1,23]. For example, results from multivariate analysis indicate that the bird community at a newly created wetland was significantly different in terms of species present from that at adjacent reference sites for two years following creation but similar by the third year[23]. However, with only three years of data, it is possible that such change is attributable to natural annual variation.

Longer-term data suggest results vary among study sites over time. A positive correlation between species richness and wetland age (R^2 =0.64) was identified over seven years following wetland restoration in China[11], but wetland age was not significantly associated with species richness or density of individual species for three- to eight-year old wetlands in Ohio[27]. Avian abundance increased at both a created wetland and two reference sites from five years to twelve years after establishment of the new site in Virginia[19]. However, this increase was much smaller (13%) at the created site than at nearby natural sites (220%) despite the fact that the created marsh equaled or exceeded the natural sites in terms of chemical parameters and abundance and diversity of other organisms[19]. Avian communities in created woody wetlands became more similar to reference sites as succession (tree regrowth) proceeded, but the authors estimated created sites would develop their climax bird community approximately 16 years later than reference sites that were re-growing after logging. Additional research indicated that avian use of anthropogenic wetlands might not increase over extended periods. Measurements of density and species richness at older restored (9 - 16 years post-creation) wetlands were similar to those at recently restored wetlands (< 6 years), indicating little further development of the bird community beyond the first few years of restoration[25].

Other studies suggested that avian use of anthropogenic wetlands might decrease after initial establishment of the wetland. A study conducted in salt marshes found that emergent vegetation expanded over time at created sites replacing exposed substrate that shortly after creation had been heavily used by shorebirds, wading birds, gulls, and terns[12]. In this case, the oldest created site was least similar to natural sites, suggesting created wetlands may not always maintain their new characteristics over time. Similarly, wetland bird communities in created and restored wetlands in Wisconsin did not persist[17]. These sites were surveyed within four years of restoration and again ten years later. Average species richness per wetland did not change over this time, but there was a shift from wetland-dependent species to oldfield and ruderal species.

Discussion

The work I reviewed documented that avian communities (including wetland obligate species) were present at anthropogenic wetlands. Meta-analysis did not identify significant differences in avian density or species richness between anthropogenic and reference wetlands. In fact, many studies reported similar avian densities between anthropogenic and reference sites, and greater abundances of certain species and guilds at anthropogenic wetlands. However, I suspected that the mean *lnR* values for these two metrics were heavily influenced by one outlier[4] in which density and richness at anthropogenic sites were 39x higher and 4x higher, respectively, than at reference sites. As an exploration I ran both the avian density and species richness analyses with the original data set, but excluded data from that one study. Results from these meta-analyses indicated significantly lower species richness (95% CI for *lnR*: – 0.183 to – 0.025) at anthropogenic sites, but avian densities between anthropogenic and reference sites were still statistically similar (95% CI for lnR: –0.461 to 0.124). The lack of a significant difference between anthropogenic and reference wetlands for these metrics may also be due in part to low power. As additional data on avian communities at anthropogenic and reference sites become available, the power of future meta-analyses likely will increase and results will become less sensitive to individual studies. Here, I was able to increase my sample size by calculating composite measures of effect size for each study and then including all 23 studies that presented at least one comparison of community metrics in a single analysis. Values for the composite effect size were significantly lower at anthropogenic wetlands, which suggest avian communities at anthropogenic sites are, in some ways, depauperate compared to references sites. More specifically, avian diversity (as measured by the Shannon index) was significantly lower at anthropogenic wetlands than at reference sites. This metric depends on both the number of species present at a location and how evenly distributed the abundances of those species are. Lower diversity at anthropogenic wetlands likely indicates that these areas have more individuals of a few species compared to natural wetlands or fewer individuals of species that are uncommon.

Additionally, species composition of avian assemblages was often different between anthropogenic and reference sites. This suggests that anthropogenic wetlands might be suitable for different avian species or groups than those that occupy natural reference sites. For example, the proportion of shorebirds often was lower at anthropogenic wetlands than reference wetlands[12,15,21,22,24,35 (but see 2,5)]. Passerines were less frequently reported on as a group, but Snell-Rood and Cristol (2003) found that created wetlands had a smaller number of passerine individuals and that those passerines were more likely to be omnivores or generalist herbivores than passerines in natural wetlands, which were more likely to be carnivores and/or specialize on certain types of food. Further, passerines at anthropogenic wetlands were less likely to be migratory than those at reference sites. Snell Rood and Cristol (2003) interpreted these differences as an indication that passerines inhabiting reference wetlands were more likely to be of high conservation values. Other papers reported that the proportions of certain songbird species (Song Sparrow, Swamp Sparrow, Seaside Sparrow, Marsh Wren, Red-winged Blackbird, Common Yellowthroat) were lower in anthropogenic wetlands than reference wetlands[3,12,13] and that opportunistic species (e.g., grackles) dominated the perching bird community at created wetlands[12].

However, several papers reported that waterfowl abundances at anthropogenic wetlands equaled or exceeded waterfowl abundances at reference wetlands[3,4,13,22,28,35]. Many species of waterfowl often occupy hemi-marsh (a mixture of open water and emergent herbaceous vegetation) but are also regularly found in a wide variety of aquatic habitats. Because many waterfowl species (e.g., Mallards, Canada Geese) are generalists, anthropogenic wetlands may provide habitat even if the characteristics of the new wetlands differ substantially from the characteristics of natural sites. Other species (besides ducks and grackles) that were found in higher proportions at anthropogenic wetlands include the Killdeer and American Goldfinch.

The authors of some papers[2,12] pointed out that habitat associations are consistent from anthropogenic to reference wetlands. Thus, wetlands with similar hydrology and vegetation are likely to have similar avian communities. In fact, the anthropogenic wetlands in several studies differed from their reference counterparts in ways that likely contributed to differences in avian species composition. In some cases, anthropogenic sites were smaller[3,31] and had steeper shorelines[12] than references sites. In some studies, water at anthropogenic sites was deeper than at natural sites[3,6,18], but other cases, anthropogenic sites had shallower water[5,24] and more variable water depth[24]. Heterogeneity of vegetation[24] and shorelines[5] were greater at some reference wetlands than at anthropogenic wetlands, but one study reported higher diversity of cover types (vegetation, water, sand or mud) [2] at anthropogenic sites. Lower turbidity than at reference sites was also documented at created wetlands[18].

Other inconsistencies between anthropogenic and reference wetlands included significant differences in the percent cover[3] and height of vegetation[14], as well as plant species composition[3,12]. Studies that compared macroinvertebrate communities at anthropogenic and reference wetlands reported higher biomass at mitigation sites[3]; similar diversity at both; but, differences in the proportions of some insect groups[18]. Differences in the landscape surrounding the wetlands included reference sites that were further from human activity, either because roads or man-made structures were closer to or more dense near anthropogenic sites[2, 5,31].

It is likely that these differences in wetland characteristics have a stronger effect on presence of a given species or avian diversity than simply whether the wetland is natural or man-made. For example, the presence of one Marsh Wren nest at a created tidal marsh and 31 Marsh Wren nests at a reference site in Virginia was likely due to lack of nesting substrate in the created marsh; natural marshes had much larger areas of *Spartina alternaflora* than created marshes[19]. In another case, differences in species composition between restored and reference wetlands in Saskatchewan were likely due to the fact that natural reference sites were closer to wooded areas and further from roads than restored sites[5].

Knowledge of anthropogenic wetlands and the bird communities they support is incomplete. There is a clear need for long-term data to better understand trends in avian abundance and diversity at created and restored wetlands over time. As suggested by Mitsch and Wilson (1996), it likely is necessary to monitor anthropogenic wetlands for several decades to determine whether they develop characteristics similar to the wetlands they are intended to replace. It is unclear whether anthropogenic wetlands are likely to become more or less similar to natural wetlands over time. Long-term data on bird communities following wetland creation or restoration may allow modeling of long-term outcomes on the basis of a few years of empirical information[30]. If reliable predictive models could be developed, it might be possible to adapt management of wetlands and possibly to increase the likelihood that anthropogenic wetlands will develop into mature systems that provide high-quality habitat for avian communities.

Few studies addressed whether anthropogenic wetlands provided habitat for rare, sensitive, or declining species. However, there is evidence that wetland-obligate species, which are highly dependent on wetland habitat and most likely to be affected by the destruction of natural wetlands, were less prevalent in the created systems than in reference sites[8,14,31]. For example, when Snell-Rood and Cristol classified each species based on life history traits, they found created wetlands supported avian assemblages of lower conservation concern based on their trophic level and migratory patterns than natural sites[31]. Created and restored wetlands may be particularly poor at providing habitat for species most tied to wetland systems.

No studies compared reproductive output (number of eggs or number of chicks fledged) between anthropogenic and reference sites, and only four studies assessed any measure related to breeding beyond the number of potential pairs. More information on the number of eggs laid or chicks fledged per nest would be valuable. Obtaining such data costs more in terms of time and money than obtaining data on occupancy and abundance. However, these data could contribute considerable insight into whether anthropogenic wetlands are providing habitat that can sustain breeding populations.

This review was limited to wetlands that were created on historically non-aquatic land or that were restored years after being converted to a non-wetland cover type. Another potential method of increasing the amount of habitat for wetland birds is to enhance existing wetlands that have become homogenous or degraded by colonization of non-native invasive species, sedimentation, or eutrophication. Excavating vegetation, organic debris, and sediment from densely vegetated wetlands to create a mix of emergent plant life and open water has led to higher densities of several wetland bird species (Creighton et al. 1997) and more broods of ducks (Stevens et al. 2003) than in unrestored wetlands. Removal of non-native invasive plants and planting of native wetland plants was associated with higher mean Shannon diversity than in unmanaged sites within two years (Curado et al. 2013). Given that conversion of uplands to wetlands is almost certain to have negative effects on species not associated with wetlands, enhancement of degraded wetlands may be an effective way to increase and improve the quality of habitat for wetland birds without adversely affecting other species.

Table 3.1. Thirty-five studies on avian use of anthropogenic wetlands. Reference sites included - paper compared anthropogenic wetlands and reference sites; Change - paper assessed avian habitat at anthropogenic wetlands over time.

#	Authors and year of publication	Journal	Location of study	Wetland type	Reference sites included	Change
1	Atkinson et al. 2004	Ibis	Essex, UK	Created		X
2	Armitage et al. 2007	Restoration Ecology	California, USA	Restored	X	
3	Balcombe et al. 2005	Ecological Engineering	West Virginia, USA	Created	X	
4	Beck et al. 2013	Wilson Journal of Ornithology	Florida, USA	Other	X	
5	Begley et al. 2012	Raffles Bulletin of Zoology	Saskatchewan, Canada	Restored	X	
6	Bellio et al. 2009	Biological Conservation	Sri Lanka	Created	X	
7	Brawley et al. 1998	Environmental Management	Connecticut, USA	Restored	X	
8	Brown and Smith 1998	Journal of Wildlife Management	New York, USA	Restored	X	
9	Brown and Veneman 2001	Wetlands	Massachusetts, USA	Created	X	
10	Burger et al. 1982	Biological Conservation	New Jersey, USA	Created	X	
11	Cui et al. 2009	Ecological Engineering	China	Restored		X
12	Darnell and Smith 2004	Waterbirds	Texas, USA	Created	X	X
13	Delphey and Dinsmore 1993	Wetlands	Iowa, USA	Restored	X	

Table 3.1, Continued

#	Authors and year of publication	Journal	Location of study	Wetland type	Reference sites included	Change
14	DesRochers et al. 2008	Ecoscience	Virginia, USA	Created	X	
15	Dias et al. 2013	Environmental Management	Portugal	Other	X	
16	Gucel et al. 2012	Pakistan Journal of Botany	Cyprus	Created	X	
17	Hapner et al. 2011	Wetlands	Wisconsin, USA	Varied		X
18	Hartzell et al. 2007	Wetlands	Oklahoma, USA	Created	X	
19	Havens et al. 1995, 2002	Ecological Engineering	Virginia, USA	Created	X	X
20	Juni and Berry 2001	Proc. of the SD Acad. of Science	South Dakota, USA	Created	X	
21	Li et al. 2013	Bird Conservation International	China	Other	X	
22	Ma et al. 2004	Biodiversity and Conservation	China	Other	X	
23	Mander et al. 2007	Estuarine, Coastal and Shelf Sci.	Humber Estuary, UK	Created		X
24	Melvin and Webb 1998	Wetlands	Texas, USA	Created	X	
25	Newbrey et al. 2013	Wetlands	Alberta, Canada	Restored	X	X
26	Piest and Sowls 1985	Journal of Wildlife Management	Arizona, USA	Created		X
27	Porej 2004	Doctoral Dissertation	Ohio, USA	Varied		X

Table 3.1, Continued

#	Authors and year of publication	Journal	Location of study	Wetland type	Reference sites included	Change
28	Ratti et al. 2001	Journal of Wildlife Management	N. and S Dakota, USA	Restored	X	
29	Ruwaldt et al. 1979	Journal of Wildlife Management	South Dakota, USA	Created	X	
30	Simenstad and Thom 1996	Ecological Applications	Washington, USA	Restored		X
31	Snell-Rood and Cristol 2003	The Condor	Virginia, USA	Created	X	X
32	Takekawa et al. 2001	Hydrobiologia	California, USA	Other	X	
33	Tourenq et al. 2001	Biological Conservation	France	Other	X	
34	VanRees-Siewert and Dinsmore 1996	Wetlands	Iowa, USA	Restored		X
35	Wilcox 1986	Colonial Waterbirds	California, USA	Restored	X	X

Table 3.2. Results of meta-analysis of avian community metrics in anthropogenic and reference wetlands. Negative values of *lnR* signify that values of the metric were lower in anthropogenic wetlands than reference wetlands.

Metric					Number of studies that reported			
Wetland type	Number of studies	Studies in meta-analysis	Average *lnR* (with 95% confidence interval)	Back-transformed *lnR*	Significantly higher in reference wetlands	Significantly higher in anthropogenic wetlands	No significant difference	Mixed results[a] or no significance test
Density								
Total	21	18	0.084 (+/- 0.672)	1.09	5	1	4	11
Created	7	6	0.072 (+/- 1.391)	1.07	0	0	2	5
Restored	6	6	-0.072 (+/- 1.403)	0.93	3	0	2	1
Other	8	6	0.266 (+/- 1.463)	1.31	2	1	0	5
Richness								
Total	23	19	-0.087(+/- 0.208)	0.92	9	1	5	8
Created	10	7	-0.234 (+/- 0.416)	0.79	5	0	3	2
Restored	7	7	-0.008 (+/- 0.375)	0.99	3	0	2	2
Other	6	5	-0.018 (+/- 0.561)	0.98	1	1	0	4

Table 3.2, Continued

Metric					Number of studies that reported			
Wetland type	Number of studies	Studies in meta-analysis	Average *lnR* (with 95% confidence interval)	Back-transformed *lnR*	Significantly higher in reference wetlands	Significantly higher in anthropogenic wetlands	No significant difference	Mixed results[a] or no significance test
Diversity								
Total	12	11	-0.185 (+/- 0.097)*	0.83	3	0	4	5
Created	6	5	-0.191 (+/- 0.221)	0.83	2	0	3	1
Restored	4	4	-0.003 (+/- 0.210)	1.00	1	0	1	2
Other	2	2	-0.476 (+/- 1.071)	0.62	0	0	0	2
Composite								
Total		23	-0.216 (+/- 1.26)*	0.81				
Created		9	-0.137 (+/- 0.237)	0.87				
Restored		7	-0.068 (+/- 0.232)	0.93				
Other		7	-0.599 (+/-0.309)*	0.55				

[a] Mixed results - indicates studies that reported findings that varied among seasons, years, or sites within the study.

Table 3.3. Brief description of studies that compared species composition between anthropogenic and reference wetlands.

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[2]Armitage et al. 2007	Tidal wetlands and restored tidal wetlands	~	~	~	Density of individual species varied between and among anthropogenic and reference sites.
[3]Balcombe et al. 2005	Natural palustrine wetlands and constructed and partially restored mitigation sites	Song Sparrow	Wood Duck, American Goldfinch, waterbirds, waterfowl	Red-winged Blackbird, European Starling, Canada Goose, Common Yellowthroat, Tree Swallow, Cedar Waxwing, American Crow, Indigo Bunting, Red-eyed Vireo, Willow Flycatcher, Mallard, Yellow Warbler, Gray Catbird, Northern Cardinal, American Robin, Barn Swallow, Eastern Towhee, Great Blue Heron, passerines	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[4]Beck et al. 2013	Marsh and stormwater treatment wetlands	Passerines	Waterfowl, diving piscivores	~	~
[5]Begley et al. 2012	Natural prairie potholes and restored prairie potholes	Woodland birds, diving birds	Grassland birds, shorebirds	Wetland-dependent birds	There were differences in upland birds due to differences in surrounding vegetation.
[6]Bellio et al. 2009	Natural wetlands and irrigation, salt ponds, rice paddies	Northern Pintail, Pied Avocet, Greater Sand Plover, Asian Dowitcher, Terek Sandpiper, Painted Snipe, Great Knot, Sanderling (unique to natural wetlands)	Western Reef Egret (unique to artificial wetlands)	~	Species composition varied between and among anthropogenic and reference sites

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[7]Brawley et al. 1998	Natural marsh and restored marsh (previously impounded)	~	~	~	Species composition varied between and among anthropogenic and reference sites
[8]Brown and Smith 1998	Natural palustrine wetlands and restored wetlands	~	~	~	Community similarity values were lower between natural and reference sites than within groups
[12]Darnell and Smith 2004	Natural salt marsh and created salt marsh	Seaside Sparrow, shorebirds (compared to one created site), wading birds (compared to two created sites)	Grackles (*Quiscalus* spp.), perching birds (at one created site), gulls and terns (at one created site)	~	There were significant differences in relative abundance of bird groups among created sites.

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[13]Delphey and Dinsmore 1993	Natural and restored prairie potholes	Marsh Wren, Common Yellowthroat, Swamp Sparrow (both breeding use and abundance), Red-winged Blackbird (abundance), Brown-headed Cowbird (breeding use)	Killdeer (abundance) Scolopacidae (migrating)	Mallard, Blue-winged Teal, Red-winged Blackbird (breeding use)	~
[14]DesRochers et al. 2008	Natural salt marsh and created salt marsh	Red-winged Blackbird (completed clutches)	~	Clapper Rail	Jaccard Similarity Index values ranged from 24-67% (average 44%) at matched pairs of anthropogenic and reference wetlands.
[15]Dias et al. 2013	Natural estuarine flats and created saltpans	Common Ringed Plover, Snowy Plover, Black-bellied Plover, Dunlin, Curlew Sandpiper, Redshank	European Avocet, Black-winged Stilt, Black-tailed Godwit, Little Stint	~	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[18]Hartzell et al. 2007	Natural depressional wetlands and created wetlands	Insectivorous species	Edge species	Waterfowl, shorebirds, rails, residents, migrants, edge species, upland species, omnivores	Higher proportion of a few dominant species at created sites, 64.7% Jaccard's similarity
[19]Havens et al.1995, 2002	Natural tidal marsh and constructed tidal marsh	Laughing Gull, Common Tern, Yellow-crowned Night-Heron, Osprey, Downy Woodpecker, Blue Jay, House Finch, Song Sparrow, White-throated Sparrow, Eastern Towhee, Indigo Bunting, Yellow-rumped Warbler, Common Yellowthroat, Gray Catbird, Brown Thrasher, Marsh Wren, Tufted Titmouse, Carolina Chickadee, Blue-gray Gnatcatcher, American Robin (all unique to reference site), Neotropical migrants	Zero unique species	~	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[21]Li et al. 2013	Natural wetlands and aquaculture ponds, paddy fields, irrigation canals, and saltpans	Tufted Duck, Tundra Swan, Eurasian Curlew, Great Knot and eighteen other (not listed) unique species	Green Sandpiper, Common Snipe, Little Curlew, Whiskered Tern, Little Tern, Common Sandpiper, Marsh Sandpiper (unique to anthropogenic site)	~	~
[22]Ma et al. 2004	Natural tidelands and aquaculture ponds	Dunlin, Great Knot and eighteen other (not listed) unique species, shorebirds, cranes, gulls	Great Cormorant, Ruddy Shelduck, Mandarin Duck, Eurasian Coot, Little Ringed Plover, Black-winged Stilt (unique to anthropogenic site), waterfowl and other swimming birds	Herons	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[24]Melvin and Webb 1998	Natural salt marshes and created salt marshes	Least Bittern, Green Heron, Black-crowned Night-Heron, Green-winged Teal, Hooded Merganser, Red-breasted Merganser, Black Rail, American Oystercatcher, Spotted Sandpiper, Whimbrel, Marbled Godwit, Dunlin (unique species), shorebirds, rails	Pied-billed Grebe, Yellow-crowned Night-Heron, Black-necked Stilt, Lesser Yellowlegs, Ring-billed Gull, Herring Gull, Common Nighthawk, Horned Lark (unique species), gulls and terns (nesting)	~	Natural marshes hosted a more even distribution of different guilds of birds
[28]Ratti et al. 2001	Natural wetlands and paired restored wetlands of same size class and similar features	~	Canada Goose, Mallard, Redhead, Ruddy Duck	American Coot, Blue-winged Teal, Green-winged Teal, Gadwall, Killdeer, Lesser Scaup, Northern Pintail, Northern Shoveler, Pied-billed Grebe	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[31]Snell-Rood and Cristol 2003	Natural bottomland forests and created bottomland forests	Passerines, especially wetland-dependent passerines	~	Wading birds, raptors, waterfowl, aerial feeders, woodpeckers	Similarity of species between matched pairs of wetlands was on average 36% (+/- 10%).
[32]Takekawa et al. 2001	Natural baylands and artificial salt evaporation ponds	Dabblers	Surface feeders	Shallow probers	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[33]Tourenq et al. 2001	Natural marshes and rice fields	Great Crested Grebe, Black-necked Grebe, Little Grebe, Great Bittern, White Stork, Mute Swan, Greylag Goose, Northern Shoveler, Northern Pintail, Common Teal, Eurasian Wigeon, Garganey, Gadwall, Common Pochard, Tufted Duck, Red-crested Pochard, Common Coot, Black-winged Stilt, European Golden Plover, Dunlin, Marsh Sandpiper, Bar-tailed Godwit, Eurasian Curlew, Jack Snipe, Little Gull, Caspian Tern, Common Tern (unique species)	Squacco Heron, Little Bittern, Whimbrel (unique species)	~	~

Table 3.3, Continued

Authors and year	Wetland types	Species or groups with greater occupancy or abundance at reference wetlands than anthropogenic wetlands	Species or groups with greater occupancy or abundance at anthropogenic wetlands than reference wetlands	Species or guilds with similar occupancy or abundance at anthropogenic and reference wetlands	Other results
[35]Wilcox 1986	Natural intertidal mudflats and restored intertidal mudflats	Western Sandpipers, shorebirds, shallow probers	Killdeer, American Avocet, Dowitcher, dabbling ducks*	~	~

* Dabbling duck abundance was similar in year one, but by year three counts were almost 2x those at natural sites

Table 3.4, Studies of avian communities over time following wetland creation or restoration.

Authors and year	Time from creation or restoration to first survey	Time from creation or restoration to last survey	Avian response variables	Major results
[1]Atkinson et al. 2004	2 months	5 years	Abundances of various wetland species and groups over five consecutive winters following expansion of wetland	Waterbirds colonized new wetlands by second year; after five years, the waterbird community was similar to those at nearby natural wetlands.
[11]Cui et at. 2009	0 years	7 years	Monthly bird species richness over 7 years following wetland restoration	There was a significant positive association between year and species richness.
[12]Darnell and Smith 2004	2 years	4 years	Proportional representation of four wetland bird guilds at three created and three natural saltmarsh sites	The oldest created site was least similar to natural sites due to colonization of vegetation over time.
[17]Hapner et al. 2011	2 years	15 years	Overall species richness, species richness per survey, overall avian density, and the relative abundances of various species at created and restored wetlands	Avian density increased; species richness per survey did not change; there was a net loss of five wetland species and a net gain of 21 non-wetland species.

Table 3.4, Continued

Authors and year	Time from creation or restoration to first survey	Time from creation or restoration to last survey	Avian response variables	Major results
[19]Havens et al. 1995, 2002	5 years	12 years	Avian abundance, richness, and diversity at created and natural wetlands	Bird abundance at natural sites increased by 220% over seven years, abundance at the created marsh increased by only 13%; species richness and diversity values were lower at created sites than natural sites after twelve years.
[23]Mander et al. 2007	0 months	3 years	Similarity (ANOSIM test) between avian species composition at created and reference sites	Avian assemblages at created and reference sites were statistically different for first two years but statistically similar the third year.
[25]Newbrey et al. 2013	4 years	16 years	Avian abundance and species richness at natural, recently restored, and restored (>9 years) wetlands	No significant differences in abundance or richness between wetland groups.
[26]Piest and Sowls 1985	1 year	3 years	Number of duck breeding pairs and density of duck nests at a created marsh	The number of breeding pairs and the number of duck nests increased over the three years.

Table 3.4, Continued

Authors and year	Time from creation or restoration to first survey	Time from creation or restoration to last survey	Avian response variables	Major results
[27]Porej 2004	3 years	8 years	Abundances of individual avian species at created and restored wetlands	Age of wetland was not significantly associated with species abundance.
[30]Simenstad and Thom 1996	0 years	4 years	Avian species richness at a restored wetland.	Species richness increased each year. 80 of 112 total species were present the first year.
[31]Snell-Rood and Cristol 2003	7 years	11 years	Avian abundance, species richness, and species composition at created wetlands, natural wetlands that were clear-cut and allowed to regrow, and mature wetlands	Created wetlands became more similar to mature wetlands over time, but their trajectory was slower than that of regenerating natural wetlands.
[34]VanRees-Siewert and Dinsmore 1996	1 year	4 years	Total avian species richness, species richness of breeding birds, species richness of waterfowl, species richness of breeding waterfowl, and species composition at restored wetlands	Breeding species richness increased with wetland age, but age was not related to the other richness metrics. Species composition changed over time (i.e., species nesting in one- and two-year old wetlands were typically different from those nesting in three- and four-year old wetlands).

Table 3.4, Continued

Authors and year	Time from creation or restoration to first survey	Time from creation or restoration to last survey	Avian response variables	Major results
[35]Wilcox 1986	0 months	3 years	Shorebird and waterfowl densities at restored and natural wetlands	Restored sites showed a gradual increase in avian density over time. Dabbling ducks began using the site more quickly than shorebirds

IV. PATTERNS AND TRENDS IN WETLAND BIRD COMMUNITIES AND LAND COVER BY BIRD CONSERVATION REGION

Introduction

Bird Conservation Regions (BCRs) were established by the North American Bird Conservation Initiative to aid in region-level management and protection of avian communities (Sauer et al. 2003). Each BCR is intended to represent a particular set of climatic and ecological characteristics and bird communities that might be experiencing similar threats. These regions serve as manageable geographic units in which a variety of stakeholders (e.g., government agencies, conservation-focused non-profits, and property owners) can cooperate to implement strategies for protecting and managing bird communities (USNABCI 2000). Previous assessment has found BCRs to be an appropriate geographical unit for summarizing data from the North American Breeding Bird Survey (Sauer et al. 2003). Each BCR has a variety of different land cover types including open water, wetland, developed land, agriculture, grassland, and forest, but the proportion of each cover type varies among BCRs. As landscapes across the United States continue to be modified by human activity, monitoring changes in land cover in each BCR could inform planning for regional bird conservation. As an example, change in wetland cover continues to be very dynamic (local losses and gains) and such ecosystems certainly have a dependent suite of bird species.

Wetlands generally have higher avian species richness per unit area than other types of land cover (Weller 1996). Within the conterminous United States, 87 species are classified as obligate wetland nesters (Sauer et al. 2011), and many other bird species feed or roost within wetlands either during stopovers on their migrations or over the winter. The diverse avian communities that rely on wetlands are susceptible to a wide variety of threats due to changes to wetlands and other aquatic habitats, such as lakes and rivers, which are often used for foraging. These threats may be more severe in regions where changes to aquatic habitat have been extensive.

Wetlands have undergone many changes as a result of human expansion and development. From 1780 to 1980, approximately 53% of the wetland area in the conterminous United States was converted to other types of land cover (Dahl 1990). To minimize loss of ecological and economic functions of wetlands (NRC 2001), policy was established requiring that the filling or dredging of wetlands be approved and permitted (either by the United States Corps of Engineers or by Environmental Protection Agency-approved state agencies) and that those permits should require compensation in the form of wetland creation, restoration, preservation, or enhancement, typically at nearby locations (USEPA/ACE 1990).

As permits continue to be issued, legally required mitigation and voluntary efforts from both public and private entities have added hundreds of thousands of hectares of new and restored wetlands to the conterminous United States (Dahl 2006). Since the implementation of no net loss policy, total wetland area within the conterminous United States has been increasing or stable. From 1998 to 2004, wetland area within the conterminous United States increased (Dahl 2006) and the total change in wetland area from 2004 to 2009 was not statistically significant (Dahl 2011).

This cessation and reversal of overall wetland loss may be beneficial for the diverse communities that are typically supported by wetlands. However, the results of the meta-analysis presented in Chapter III indicate that new wetland area (added through creation or restoration) may not fully compensate for natural wetlands that have been lost, in terms of habitat for wetland bird communities.

Furthermore, my analyses in Chapter II demonstrate that the abundances of several species of wetland birds are associated with the percent cover of open water, agriculture, or development within the 16 km^2 area surrounding Breeding Bird Survey routes. As such, wetland bird populations could potentially be affected by changes in other types of land cover. Between 1973 and 2000, agricultural areas decreased by 89,507 km^2 and developed land increased by 77,529 km^2 within the conterminous United States (Sleeter et al. 2013) – for comparison Maine has an area of 79,932 km^2. Changes in agriculture have been linked to the decline of some wetland species (Blackwell and Dolbeer 2001). Urbanization can affect wetland birds through several mechanisms, such as human disturbance near nest sites (Carney and Sydeman 1999), increases in pollutants (Best and Fischer 1992), and changes in hydrology (Ward et al. 2010). Thus, cumulative changes in the amount of various types of land cover within a region might be associated with regional population trends of some wetland bird species. Overall, my objectives for this chapter were to:

1. Describe each Bird Conservation Region in terms of its land cover and its wetland bird community.
2. Describe regional associations between land cover and wetland bird community metrics.
3. Document regional changes in land cover from 2001 to 2011.

4. Identify wetland bird species with abundances that changed significantly from 2001 to 2011.

Methods

Land cover

For each of 30 Bird Conservation Regions (BCRs) or portions of BCRs within the conterminous United States (Figure 4.1), I used data from the National Land Cover Database 2011 Land Cover Change product ($NLCD_{ch}$) to quantify land cover composition in 2001 and 2011 and changes in land cover composition over the 10 years. The $NLCD_{ch}$ has a resolution of 30 m wherein each 30 m pixel is assigned to a land cover change category that represents its land cover in 2001 and 2011. The $NLCD_{ch}$ includes 16 land cover classes, yielding 240 possible transitions and 16 static states.

I chose not to include three land cover classes that were unlikely to have a strong influence on wetland bird communities (barren land, shrub/scrub, and perennial ice/snow). I combined some of the remaining cover types to create broader categories of classification. Specifically, I created one *developed* class by combining developed, open space; developed, low intensity; developed, medium intensity; and developed, high intensity. I created a single class of *forest* by combining deciduous forest, evergreen forest, and mixed forest. I also combined pasture and hay with cultivated crops into a single class called *agriculture*. This left me with seven cover classes: open water, woody wetland, herbaceous wetland, developed, agriculture, grassland, and forest,

I used ArcGIS 10.0 to determine the number of pixels of each type of land cover within each BCR for both 2001 and 2011. I used the pixel counts to estimate both the total area and the percentage of each cover type in each year, as well as the mean value between the two years. I then calculated the increase or decrease in each cover type between the two years. Hereafter, I refer to this value as the *percentage point change*, calculated as:

$$\text{percentage point change} = \text{percent cover in 2011} - \text{percent cover in 2001}.$$

I also calculated change in land cover as a percentage of the 2001 amount of that cover type in 2001. The *percent change* in each cover type was calculated as:

$$\text{percent change} = \left(\frac{\text{percentage point change}}{\text{percent cover in 2001}}\right) * 100.$$

I calculated the percentage of open water, woody wetland, and herbaceous wetland in each region that was converted from that cover type (to another cover type) between 2001 and 2011 and the percentage of the region that was converted to that cover types over the decade. For example, fifteen classifications represented cover classified as open water in 2001, but a cover type other than open water in 2011. I summed these to create a single *open water percentage point loss* class. From this value, I estimated the percentage of a BCR that was open water in 2001 but converted to a different cover type by 2011. Similarly, I calculated *open water percentage point gain* as the percentage of a BCR that was not open water cover in 2001, but was open water in 2011. As above, I used these gain and loss values to calculate percent gain and percent loss, based on the amount to that cover type present in 2001. Thus, for open water, woody wetland, and herbaceous wetland, I present change values representing conversions to and from that cover type as well as the overall change.

Avian data

I used North American Breeding Bird Survey (BBS) data from 2001 through 2011 to calculate wetland bird community metrics for each BCR. I used data on 87 bird species that are known to breed in the wetlands of the conterminous United States (Appendix A) from 3,190 routes that had been surveyed during this period. I calculated total wetland bird abundance, species richness (number of wetland bird species), and diversity (Shannon index) for each of these BBS routes in every year from 2001 through 2011. From the yearly route-level values, I calculated the mean annual route-level value for each of the three community metrics for each route. For each BCR, I identified the mean, minimum, and maximum values for each mean annual route-level metric across all routes in that region. The regional species pool was calculated as the number of wetland species detected during BBS surveys from 2001 through 2011 time period. Mean community representation (proportion of the regional species pool detected during each route-level survey) was calculated for each BCR as the mean annual route-level species richness divided by the regional species pool.

To identify trends in abundance for individual species within a given BCR, I divided the number of individuals of each species that were detected within the BCR each year by the number of routes surveyed in the BCR that year. I then used a randomization test (Veech 2006a,b) to identify trends for each species that was detected within a region during at least 10 of the 11 years. Specifically, for each route, the randomization test compared the slope of a least–squares regression of the observed abundance vs. year to a distribution of 10,000 slopes in which the order of years was randomized. The proportion of randomized slopes that were steeper than the observed slope functioned as a p–value (e.g., if more than 5% of the random slopes were steeper than the actual slope, then $p > 0.05$). Thus, observed slopes with values greater than or less than 95% of the random slopes indicated significantly increasing or decreasing abundance, respectively.

Regional relationships between avian metrics and land cover

At the level of the Bird Conservation Region, I examined patterns between land cover and species richness, abundance, diversity, and community representation by fitting single-factor regressions. Each regression model included one type of land cover (average of 2001 and 2011 values) as the independent variable and one community metric as the dependent variable. For species richness models, the dependent variable was the regional species pool (cumulative number of wetland species detected during BBS surveys from 2001 to 2011). As the independent variable, each regression included the total regional area of one of the following cover types: open water, woody wetland, herbaceous wetland, developed land, agriculture, grassland, or forest. Both the dependent and independent variables were log transformed and then linear regression was applied.

In the single-factor linear regressions for the other community metrics (abundance, diversity, and community representation), the dependent variable was the mean regional value of the mean annual route-level values for that metric. The independent variables for these models (one per regression) were the percent cover of open water, woody wetland, herbaceous wetland, developed land, agriculture, grassland, and forest within the region (average of 2001 and 2011 values). For all comparisons, I used a Bonferroni corrected significance level of 0.007 (0.05/7) because there were seven regressions for each dependent variable. This correction was used in order to minimize the chance of Type I error (i.e., accepting an alternative hypothesis when no significant association exists) that typically increases with multiple related comparisons.

Results

Land cover

Land cover in 2001 - The percentage of area covered by aquatic ecosystems varied considerably among Bird Conservation Regions (Table. 4.1). The percentage of total aquatic cover in 2001 ranged from a minimum of 0.3% in Sierra Madre Occidental (BCR 34) to a maximum of 43.2% in Peninsular Florida (BCR 31). In 16 BCRs, the greatest percentage of aquatic cover was woody wetland. Open water and herbaceous wetland were the most extensive aquatic cover types in 11 and three BCRs, respectively. The percentage of other types of land cover also varied among regions (Table 4.2). The minimum and maximum percentages of developed land were 0.9% in the Northern Rockies (BCR 10) and 26.3% in the New England/Mid-Atlantic Coast (BCR 30). The percentage of a given BCR covered by agriculture ranged from 0.3% in the Sierra Nevada (BCR 15) to 67.9% in the Eastern Tallgrass Prairie (BCR 22). Grassland covered a minimum of 0.3% in the Mississippi Alluvial Valley region (BCR 26) and a maximum of 61.6% in Badlands and Prairies (BCR 17). The minimum percentage of forest was 1.1% in the Sonoran and Mohave Desert (BCR 33) whereas the maximum was 73.4% in the Atlantic Northern Forest (BCR 14).

Land cover change – Between 2001 and 2011, the amount of aquatic cover at the BCR level was quite stable (Table 4.1). For all categories of aquatic cover, percentage point change was always less than one percentage point when calculated across an entire region. The mean percentage point change among BCRs was + 0.04pp (SD: 0.12) for open water, - 0.06pp (SD: 0.19) for woody wetland, and + 0.10pp (SD: 0.17) for herbaceous wetland. Breaking down this percentage point change into gains and losses of aquatic cover gives a more complete picture of the amount of conversion to and from these cover types that has occurred. Specifically, increases in open water were as high as 0.8pp in the Gulf Coast Prairie (BCR 37) and decreases were as much as 0.4pp in the Mississippi Alluvial Valley (BCR 26). For woody wetland, the greatest increase was 0.4pp (Mississippi Alluvial Valley) and the greatest decrease was 1.12pp (Peninsular Florida, BCR 31). The greatest increase in herbaceous wetland was 0.8pp (Peninsular Florida) and the greatest herbaceous wetland decrease was 0.9pp in the Gulf Coast Prairie.

The area of developed land increased in all of the BCRs (Table. 4.2). The median percentage point increase was 0.29pp, with a maximum percentage point increase of 1.44pp (from 26.31% to 27.75%) in the New England/Atlantic (BCR 30). Agriculture increased in 11 BCRs and decreased in 19 BCRs, with a median percentage point change of – 0.08pp The maximum percentage point increase of agriculture was 0.28pp (30.06% to 30.33%) in the Shortgrass Prairie region (BCR 18) while the Piedmont region (BCR 29) had the greatest percentage point decrease at – 0.94pp. (21.09% to 20.15%). Grassland cover increased in 22 BCRs and decreased in 8, with a median percentage point change of + 0.19pp, The greatest percentage point increase for grassland was 1.31pp (4.07% to 5.38%) in the West Gulf Plains/Ouachitas (BCR 25) and the maximum percentage point loss was – 0.32pp (3.65% to 3.33%) in the Gulf Coast Prairie (BCR 37). Forest decreased in all BCRs, with a median percentage point change of – 0.61pp. The

Northern Pacific Rainforest (BCR 5) had the largest percentage point loss (– 3.52pp, from 65.44% to 61.92%) of forest.

Avian data

Regional values of wetland bird community metrics also varied greatly among BCRs. Species richness ranged from 10 in the Edwards Plateau (BCR 20) to 66 in the Prairie Potholes (BCR 11), with a mean of 40.8 (SD: 12.5) species per region (Table 4.3). Mean regional values for mean annual route-level abundance of wetland birds ranged from 3.5 individuals in the Edwards Plateau (BCR 20) to 555.2 individuals in the Gulf Coast Prairie (BCR 37). The Gulf Coast Prairie also had the highest regional diversity (1.574) and community representation (30.4%). The Chihuahuan Desert had the lowest diversity (0.134) and community representation (4.6%) (Table 4.3). Maximum mean annual route-level values for all metrics were recorded on route 14166 in the Great Basin; mean annual abundance was 5456 individuals, species richness was 42.4, and diversity was 3.394.

Abundances of three species increased significantly within five or more Bird Conservation Regions: Bald Eagle (10 BCRs), Osprey (7), and Double-crested Cormorant (5) (Table 4.4). Abundances of seven species decreased significantly in abundance within five or more Bird Conservation Regions: Belted Kingfisher (8 BCRs), Red-winged Blackbird (8), Green Heron (7), Great Blue Heron (6), Mallard (5), Canada Goose (5), and Spotted Sandpiper (5). Abundances of seven species increased within multiple BCRs and declined within more than one BCR (Double-crested Cormorant, Black-crowned Night-Heron, Mallard, Canada Goose, Northern Pintail, Great Blue Heron, and Willet).

Regional relationships between avian metrics and land cover

At the level of BCRs, the relationship between mean species richness of wetland birds and area of open water and herbaceous wetland was statistically significant (open water: $R^2 = 0.27$, $p = 0.002$) and herbaceous wetland ($R^2 = 0.76$, $p < 0.001$) (Figure 4.2). Relationships between species richness and area of woody wetland and non-aquatic cover types were not statistically significant at the Bonferroni corrected significance level of 0.007.

At the level of BCRs, mean abundance of wetland birds was positively associated with percent cover of open water ($R^2 = 0.39$, $p < 0.001$), herbaceous wetland ($R^2 = 0.47$, $p < 0.001$), and agriculture ($R^2 = 0.29$, $p = 0.001$)(Figure 4.3). Percent cover of woody wetland, development, grassland, and forest were not significantly associated with mean abundance.

Mean wetland bird diversity was positively associated with percent cover of open water ($R^2 = 0.54$, $p < 0.001$), woody wetland ($R^2 = 0.29$, $p = 0.001$), and herbaceous wetland ($R^2 = 0.55$, $p < 0.001$)(Figure 4.4). Relationships between diversity and non-aquatic cover types were not significant.

Mean community representation within a BCR also was positively associated with the regional percent cover of open water ($R^2 = 0.68$, $p < 0.001$), woody wetland ($R^2 = 0.22$, $p = 0.006$), and herbaceous wetland ($R^2 = 0.72$, $p < 0.001$)(Figure 4.5). Relationships with other types of land cover were not significant.

Discussion

Composition of both land cover and wetland bird communities varied considerably among Bird Conservation Regions throughout the conterminous United States. The percent cover of aquatic ecosystems within BCRs ranged from less than 1% in four regions within the arid Southwest to more than 20% in five regions along the Great Lakes, Atlantic coast, and Gulf of Mexico. This variability in aquatic cover likely has an influence on the range of values for wetland bird community metrics across the different BCRs. The number of wetland bird species in the regional pool was positively related to the total regional area of both open water and herbaceous wetland. A logarithmic function fit these relationships, consistent with the classic hypothesis that species richness increases up to an asymptote as the area of habitat increases. For wetlands birds this relationship has been documented at the level of individual wetlands (Weller 1999), but my results suggest that this pattern also occurs at the regional level, with the asymptote in the range of 40 - 60 species per region. In each Bird Conservation Region with more that 6,000 km^2 of herbaceous wetland, ≥ 40 wetland bird species across several taxonomic orders have been recorded. Many of the wetland birds that occupy the conterminous United States nest in dense herbaceous vegetation, but others nest on shorelines or in trees and shrubs over shallow water (Appendix A). These nest sites are often located along the edges of open water that typically offer a variety of food sources and protection from predators that may approach via land. Increases in area of these two cover types may correspond to increases in the number of microhabitats and niches available for wetland birds, thus supporting a more diverse (species rich) regional community. While the presence of woody wetland offers different types of nesting structure (large trees over water) that could increase the regional species pool, some species may be difficult to detect in densely wooded areas. My previous work suggested that abundances of only four species (Wood Duck, Great Blue Heron, Great Egret, and Swamp Sparrow) had significant positive associations with woody wetland (Chapter II), and these were each also positively associated with other types of wetland cover and were detected within all BCRs within their described ranges.

Mean route-level abundance within a BCR was associated with percent cover of open water, herbaceous wetland, and agriculture. Results from Chapter II indicated that several species that regularly form large groups (Mallards, Canada Geese, Sandhill Cranes, Yellow-headed Blackbirds, and Red-winged Blackbirds) are positively associated with percent cover of agriculture. Additionally, crops often provide food for a variety of songbirds, shorebirds, and waterfowl (Rodewald 2015). Thus, it is not surprising that greater average abundances were documented within regions that had more agricultural land within their borders.

Both mean route-level wetland bird diversity and mean route-level community representation were positively related to the percent cover of all three types of aquatic cover, but not to any other type of land cover. In most BCRs, some regionally common species (e.g., Red-winged Blackbirds, Great Blue Herons, and Mallards) are detected along nearly every route. Shannon index values increase as these numerically dominant species comprise a smaller proportion of the overall community and as overall species richness increases (Krebs 1989). Similarly, as less abundant members of the regional species pool are detected at more samples sites (routes), mean route-level community representation values increase. Thus high values of diversity and community representation reflect that species with relatively low abundance are detected on many BBS routes. As percent cover increases, so may the diversity of resources and microhabitats. Further, the distance between patches may decrease, allowing for easier dispersal among the routes and increasing the probability of detecting rare species on a given route.

Within each BCR, the percentage point change in each of the three aquatic cover types was less than 1%; this may indicate that regulations are maintaining the total area of wetlands at the regional level. Wetland area has also recently been stable within the conterminous United States (Dahl 2001). This regional stability indicates that conversion of area to and from aquatic cover types is fairly equal within a region and that compensation is being implemented to a degree that balances the total destroyed wetland area at this extent. However, a previous study has shown that compensation often occurs at large wetland mitigation sites that do not replicate the configuration of lost wetland patches and that are sometimes found in different watersheds than the wetlands that were lost (Kettlewell et al 2008). This is despite the fact that mitigation guidelines state that wetlands established to fulfill mitigation requirements should be located as close as possible to the location for which the compensation is occurring (i.e., the lost sites)(USEPA/ACE 1990, NRC 2001).

The percent change in aquatic cover varied more among regions (Appendix F), but large percent changes in aquatic cover typically reflected small changes in cover within areas in which aquatic cover was limited. For example, in the Sierra Madre Occidental (BCR 34), an increase in herbaceous wetland from 0.04% in 2001 to 0.07% in 2011 resulted in a percent increase of 78% although the percentage-point increase was only 0.03pp. In a very dry region, this large percent increase in aquatic cover would likely benefit birds or other species, but it is important to note that this increase (which amounts to about 40 km^2) represents a much smaller total area than smaller percentage changes in regions with more aquatic cover.

Small percentage point changes at the BCR level can mask the overall amount of conversion to and from aquatic cover occurring throughout the study area. These changes were revealed in both the gains and losses within each region. Further, the percent cover of developed land increased within every BCR, and agricultural area decreased in almost two thirds of the regions. Based on the considerable changes to both their primary habitat and the surrounding landscape, it is not surprising that abundances of some species of wetland-dependent birds have decreased. Several of the wetland bird species that declined in abundance within certain regions are among the most widespread and abundant wetland-breeding birds in the United States (e.g., Belted Kingfishers, Red-winged Blackbirds, Great Blue Herons, Canada Geese, and Mallards). Of these, Red-winged Blackbirds, Great Blue Herons, Canada Geese, and Mallards, as well as Green Herons, all had strong, positive associations with agriculture (Chapter II), and their abundances tended to be decreasing within regions in which the percent cover of agriculture was decreasing. Belted Kingfishers nest in burrows that they excavate along embankments, typically near water, and tend to be sensitive to human activities (Kelly et al. 2009). Increases in development, which often occur near waterways, are likely to decrease the probability of occurrence of this species.

However, abundances of many other wetland species are stable or increasing. These species may be habitat generalists, insensitive to certain types of change, or may occupy wetlands in regions where fewer changes to the landscape occurred. The three species with abundances that appeared to increase in the greatest number of BCRs, Bald Eagle, Osprey, and Double-crested Cormorant, have made considerable recoveries following population declines that were caused by reproductive failure due to bioaccumulation of toxicants in their food supply (Buehler 2000, Poole et al. 2002).

Birds with abundances that significantly increased within some BCRs and decreased in others included several species of waterfowl (Mallard, Canada Goose, Northern Pintail) and herons (Great Blue Heron, Black-crowned Night-Heron). These groups use a variety of aquatic habitats, including anthropogenic wetlands (see Chapter III). It is possible that these species are the most likely to occupy new wetlands, especially when the previous cover type also was aquatic.

In fact, much of the change in aquatic land cover reflected change in type of aquatic cover rather than a change between aquatic and non-aquatic cover. Both the increase in percentage of open water and the decrease in percentage of herbaceous wetland were greatest in the Gulf Coast Prairie (BCR 37); more than 70% of the reduction in area of herbaceous wetland reflected conversion to open water. Similarly, Peninsular Florida (BCR 31) had the greatest reduction in percentage of woody wetland and the greatest increase in percentage of herbaceous wetland, and the Mississippi Alluvial Valley (BCR 26) had the greatest decrease in percentage of open water and the greatest increase in percentage of woody wetland. In some cases, these changes may reflect natural (or anthropogenic, but unintentional) processes such as vegetation succession, erosion, and sedimentation. Additionally, anthropogenic conversion between different classes of aquatic cover (such as during ecological restoration) may require less effort than conversion from terrestrial to aquatic cover. Conversion among aquatic cover types might require dredging or planting, but major hydrologic manipulation is less likely. Furthermore, because many of the species that nest in particular types of wetlands use other aquatic habitats throughout the nesting season, conversion among aquatic cover types is unlikely to affect the wetland bird community as strongly as conversion between terrestrial and aquatic cover.

Species composition and community metrics varied among Bird Conservation Regions. Differences in abundance, species richness, diversity, and community representation are likely due to substantial differences in regional land cover (specifically open water, woody wetland, herbaceous wetland, and agriculture). This chapter offers an overview of these regional patterns and documents changes in wetland bird populations and land cover over an eleven-year time span. While the percentage point change in regional aquatic cover was typically small over this time frame, each region did experience some land cover conversion both to and from aquatic cover. Further, I documented several avian species that had experienced significant regional trends in abundance over the eleven years of my study. The direct causes for these trends are not immediately evident from this research but as land cover conversion is likely to continue, regional land cover data (such as those presented here) should be important part of conservation planning.

Table 4.1. Percent composition of three aquatic cover types in each of 30 Bird Conservation Regions in 2001 and 2011

Bird Conservation Region	Open Water		Woody Wetland		Herbaceous Wetland	
	2001	2011	2001	2011	2001	2011
Northern Pacific Rainforest (5)	1.11	1.12	1.32	1.32	0.54	0.54
Great Basin (9)	1.63	1.53	0.33	0.36	0.51	0.57
Northern Rockies (10)	0.94	1.00	0.60	0.63	0.71	0.70
Prairie Potholes (11)	2.60	2.81	0.73	0.73	3.05	3.00
Boreal Harwood Transition (12)	6.36	6.36	24.81	24.57	4.90	5.14
Lower Great Lakes/St. Lawrence Plain (13)	4.05	4.04	6.69	6.66	0.87	0.92
Atlantic Northern Forests (14)	4.15	4.14	7.96	7.96	0.90	0.90
Sierra Nevada (15)	1.97	2.09	0.01	0.01	0.37	0.45
Southern Rockies/Colorado Plateau (16)	0.36	0.33	0.70	0.73	0.19	0.20
Badlands and Prairies (17)	1.30	1.44	1.24	1.22	0.56	0.48
Shortgrass Prairie (18)	0.26	0.27	0.26	0.28	0.39	0.40
Central Mixed-grass Prairie (19)	0.86	0.82	0.66	0.65	0.61	0.62

Table 4.1, Continued

Bird Conservation Region	Open Water		Woody Wetland		Herbaceous Wetland	
	2001	2011	2001	2001	2011	2001
Edwards Plateau (20)	0.68	0.67	0.19	0.18	0.00	0.00
Oaks and Prairies (21)	2.02	1.97	2.27	2.25	0.15	0.21
Eastern Tallgrass Prairie (22)	1.29	1.34	1.30	1.29	0.31	0.40
Prairie Hardwood Transition (23)	3.26	3.37	6.14	6.11	2.91	2.90
Central Hardwoods (24)	1.92	1.93	0.84	0.84	0.14	0.15
West Gulf Coastal Plain/Ouachitas (25)	2.86	2.75	10.66	10.58	0.37	0.65
Mississippi Alluvial Valley (26)	6.55	6.41	21.75	21.79	2.46	2.55
Southeastern Coastal Plain (27)	1.81	1.84	18.71	18.38	2.12	2.34
Appalachian Mountains (28)	1.25	1.25	0.86	0.85	0.12	0.13
Piedmont (29)	2.04	2.12	2.38	2.34	0.06	0.11
New-England/Mid-Atlantic Coast (30)	5.35	5.37	13.46	13.28	4.17	4.19
Peninsular Florida (31)	5.52	5.69	23.55	22.58	14.10	14.52

Table 4.1, Continued

Bird Conservation Region	Open Water		Woody Wetland		Herbaceous Wetland	
	2001	2011	2001	2001	2011	2001
Coastal California (32)	1.29	1.36	0.42	0.42	0.95	0.94
Sonoran and Mohave Deserts (33)	0.81	0.74	0.29	0.32	0.04	0.10
Sierra Madre Occidental (34)	0.11	0.13	0.14	0.14	0.04	0.07
Chihuahuan Desert (35)	0.17	0.13	0.14	0.21	0.06	0.08
Tamaulipan Brushlands (36)	0.42	0.62	2.32	2.25	0.46	0.44
Gulf Coastal Prairie (37)	10.48	10.98	7.89	7.70	19.50	19.03

Table 4.2. Percent composition of four non-aquatic cover types in each of 30 Bird Conservation Regions in 2001 and 2011.

Bird Conservation Region	Development		Agriculture		Grassland		Forest	
	2001	2011	2001	2011	2001	2011	2001	2011
Northern Pacific Rainforest (5)	6.64	6.76	6.03	5.97	3.92	4.88	65.44	61.91
Great Basin (9)	1.78	1.86	10.00	9.98	7.57	7.95	14.41	13.94
Northern Rockies (10)	0.94	0.97	3.24	3.24	15.12	15.56	39.29	37.52
Prairie Potholes (11)	4.48	4.55	64.22	64.27	22.52	22.28	1.30	1.29
Boreal Harwood Transition (12)	4.21	4.25	9.49	9.46	2.26	2.71	44.57	43.55
Lower Great Lakes/St. Lawrence Plain (13)	13.02	13.57	35.60	35.35	1.37	1.40	35.43	34.99
Atlantic Northern Forests (14)	3.41	3.46	4.45	4.44	0.59	0.80	73.44	72.79
Sierra Nevada (15)	1.30	1.31	0.31	0.32	3.10	3.18	61.38	59.83
Southern Rockies/Colorado Plateau (16)	0.99	1.03	1.93	1.93	16.16	16.14	33.17	32.58
Badlands and Prairies (17)	1.39	1.42	13.08	13.24	61.60	61.53	5.74	5.48
Shortgrass Prairie (18)	3.75	3.91	30.05	30.33	48.44	48.29	1.23	1.21
Central Mixed-grass Prairie (19)	4.22	4.31	33.24	33.39	43.98	44.26	2.12	2.03

Table 4.2, Continued

Bird Conservation Region	Development		Agriculture		Grassland		Forest	
	2001	2011	2001	2011	2001	2011	2001	2011
Edwards Plateau (20)	4.23	4.62	1.00	1.10	11.22	11.59	24.82	23.59
Oaks and Prairies (21)	8.94	9.49	26.59	26.67	29.65	29.77	19.32	18.69
Eastern Tallgrass Prairie (22)	9.76	10.18	67.90	67.51	7.67	7.61	11.50	11.37
Prairie Hardwood Transition (23)	10.65	11.15	51.00	50.57	2.50	2.52	22.59	22.38
Central Hardwoods (24)	6.89	7.21	37.04	36.85	1.97	2.28	50.46	49.80
West Gulf Coastal Plain/Ouachitas (25)	6.65	6.97	16.80	16.54	4.07	5.38	50.19	47.26
Mississippi Alluvial Valley (26)	6.57	6.77	57.25	56.98	0.29	0.27	4.29	4.14
Southeastern Coastal Plain (27)	7.03	7.42	19.91	19.04	2.88	4.14	38.20	35.32
Appalachian Mountains (28)	8.29	8.60	16.58	16.40	2.25	2.54	69.03	68.07
Piedmont (29)	14.84	16.11	21.09	20.14	4.99	5.53	52.29	49.40
New-England/Mid-Atlantic Coast (30)	26.31	27.75	14.90	14.41	0.60	0.72	32.79	31.71
Peninsular Florida (31)	16.13	17.22	22.11	21.30	2.04	2.24	9.85	9.21

Table 4.2, Continued

Bird Conservation Region	Development		Agriculture		Grassland		Forest	
	2001	2011	2001	2011	2001	2011	2001	2011
Coastal California (32)	13.02	13.53	21.32	21.09	25.95	25.73	12.97	12.85
Sonoran and Mohave Deserts (33)	3.15	3.54	3.01	2.90	1.70	1.88	1.12	1.10
Sierra Madre Occidental (34)	1.05	1.09	0.62	0.65	4.44	4.80	36.10	34.94
Chihuahuan Desert (35)	1.15	1.25	0.94	1.00	7.24	7.94	3.53	3.46
Tamaulipan Brushlands (36)	5.96	6.24	19.78	19.53	17.48	17.66	1.47	1.41
Gulf Coastal Prairie (37)	9.76	10.61	37.12	36.57	3.65	3.33	4.58	4.24

Table 4.3.Wetland bird community metric values for each of 30 Bird Conservation Regions based on data collected during Breeding Bird Surveys from 2001 to 2011.

Bird Conservation Region	Regional species richness	Mean route-level values		Community Representation
		Abundance	Diversity	
Northern Pacific Rainforest (5)	47	21.4	0.717	7.14
Great Basin (9)	61	148.3	1.043	9.77
Northern Rockies (10)	60	64.6	0.988	9.22
Prairie Potholes (11)	66	331.1	1.334	19.34
Boreal Harwood Transition (12)	50	60.9	1.067	11.18
Lower Great Lakes/St. Lawrence Plain (13)	35	121.2	0.592	13.83
Atlantic Northern Forests (14)	33	25.4	0.837	12.03
Sierra Nevada (15)	39	22.1	0.618	8.68
Southern Rockies/Colorado Plateau (16)	50	30.1	0.536	5.80
Badlands and Prairies (17)	54	72.6	0.794	9.70
Shortgrass Prairie (18)	48	58.8	0.319	5.27
Central Mixed-grass Prairie (19)	48	79.5	0.420	7.21
Edwards Plateau (20)	10	3.5	0.231	11.16
Oaks and Prairies (21)	33	77.3	0.800	13.33
Eastern Tallgrass Prairie (22)	37	152.2	0.337	9.40
Prairie Hardwood Transition (23)	52	191.4	0.715	12.96
Central Hardwoods (24)	25	56.4	0.410	12.07
West Gulf Coastal Plain/Ouachitas (25)	30	28.7	0.748	11.83
Mississippi Alluvial Valley (26)	39	288.0	0.869	18.43
Southeastern Coastal Plain (27)	45	34.3	0.917	9.88
Appalachian Mountains (28)	34	39.7	0.455	8.22
Piedmont (29)	24	22.0	0.572	10.70
New-England/Mid-Atlantic Coast (30)	44	76.2	0.919	12.43
Peninsular Florida (31)	43	210.1	1.536	26.13
Coastal California (32)	48	152.2	0.609	9.55
Sonoran and Mohave Deserts (33)	35	258.4	0.348	9.60
Sierra Madre Occidental (34)	25	8.1	0.184	5.12
Chihuahuan Desert (35)	26	9.4	0.134	4.56
Tamaulipan Brushlands (36)	33	146.7	0.581	11.71
Gulf Coastal Prairie (37)	49	550.2	1.574	30.40

Table 4.4. Species with abundances that increased or decreased significantly within more than one Bird Conservation Region (BCR) between 2001 and 2011.

Increases in regional abundance	Number of BCRs	Decreases in regional abundance	Number of BCRs
Bald Eagle	10	Red-winged Blackbird	8
Osprey	7	Belted Kingfisher	8
Double-crested Cormorant	5	Green Heron	7
Black-crowned Night-Heron	3	Great Blue Heron	6
Mallard	3	Mallard	5
Canada Goose	3	Canada Goose	5
Sora	3	Spotted Sandpiper	5
Mottled Duck	2	Wilson's Snipe	4
Snowy Egret	2	Willet	3
Least Bittern	2	Black-crowned Night-Heron	3
Great Egret	2	Double-crested Cormorant	3
Swamp Sparrow	2	Little Blue Heron	3
Northern Shoveler	2	Forster's Tern	3
Eared Grebe	2	Yellow-headed Blackbird	3
Northern Pintail	2	Northern Pintail	3
Great Blue Heron	2	Tricolored Heron	2
Willet	2	Common Moorhen	2
Wood Duck	2	Boat-tailed Grackle	2
American Bittern	2	Herring Gull	2
Ring-billed Gull	2	Pied-billed Grebe	2
		Black Tern	2
		Gadwall	2
		Ruddy Duck	2
		American Wigeon	2
		American White Pelican	2

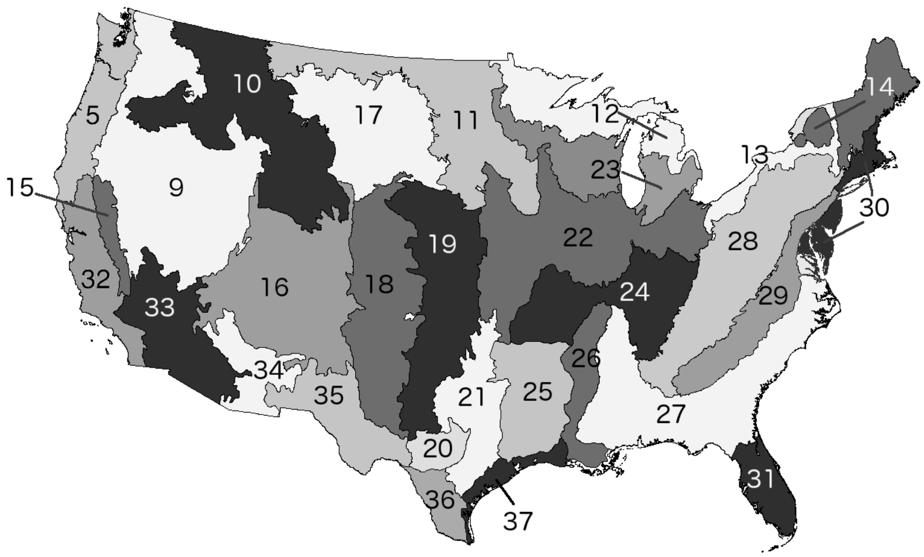

Figure 4.1. Bird Conservation Regions (BCRs) of the conterminous United States. BCR 5: Northern Pacific Rainforest, BCR 9: Great Basin, BCR 10: Northern Rockies, BCR 11: Prairie Potholes, BCR 12: Boreal Hardwood Transition, BCR 13: Lower Great Lakes/St. Lawrence Plain, BCR 14: Atlantic Northern Forests, BCR 15: Sierra Nevada, BCR 16: Southern Rockies/Colorado Plateau, BCR 17: Badlands and Prairie, BCR 18: Shortgrass Prairie, BCR 19: Central Mixed-grass Prairie, BCR 20: Edwards Plateau, BCR 21: Oaks and Prairies, BCR 22: Eastern Tallgrass Prairie, BCR 23: Prairie Hardwood Transition, BCR 24: Central Hardwoods, BCR 25: West Gulf Coastal Plains/Ouachitas, BCR 26: Mississippi Alluvial Valley, BCR 27: Southeastern Coastal Plain, BCR 28: Appalachian Mountains, BCR 29: Piedmont, BCR 30: New England/Mid-Atlantic Coast, BCR 31: Peninsular Florida, BCR 32: Coastal California, BCR 33: Sonoran and Mohave Deserts, BCR 34: Sierra Madre Occidental, BCR 35: Chihuahuan Desert, BCR 36: Tamaulipan Brushlands, BCR 37: Gulf Coastal Prairie

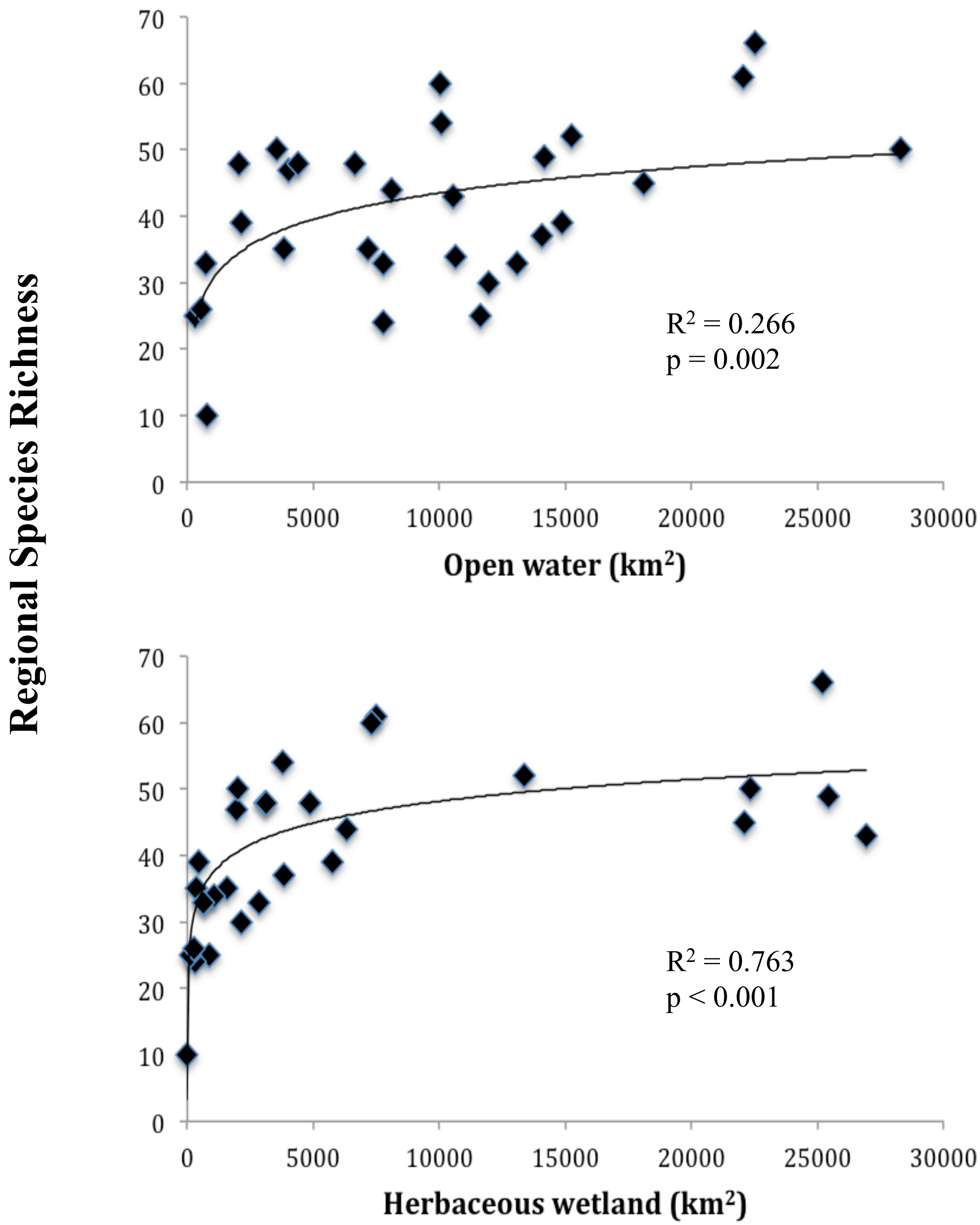

Figure 4.2. Regional associations (one point = one Bird Conservation Region) between total area of open water and herbaceous wetland and the cumulative number of species detected along Breeding Bird Survey routes between 2001 and 2011.

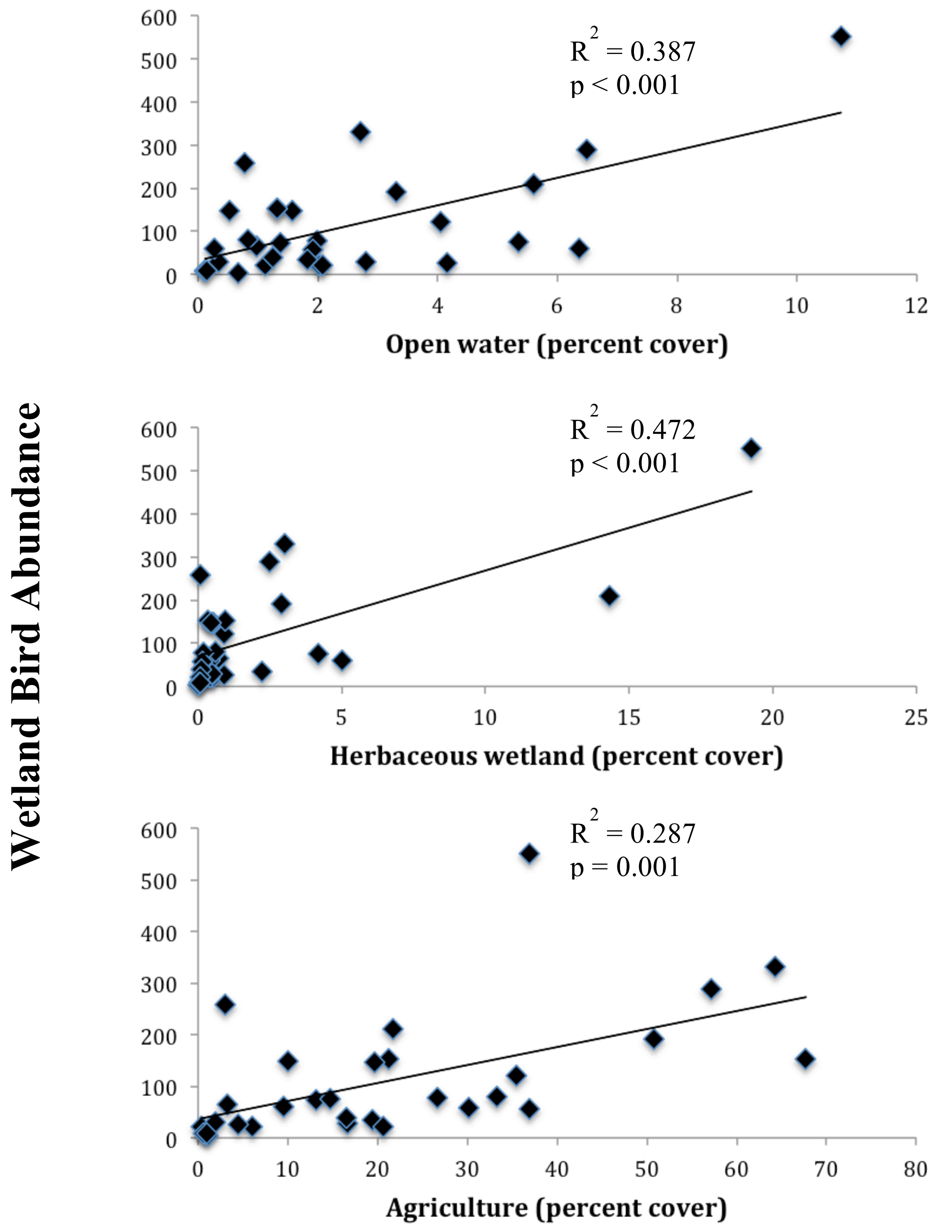

Figure 4.3. Regional associations (one point = one Bird Conservation Region) between percent cover of open water, herbaceous wetland, and agriculture and mean annual route-level abundance recorded along Breeding Bird Survey routes within the region between 2001 and 2011.

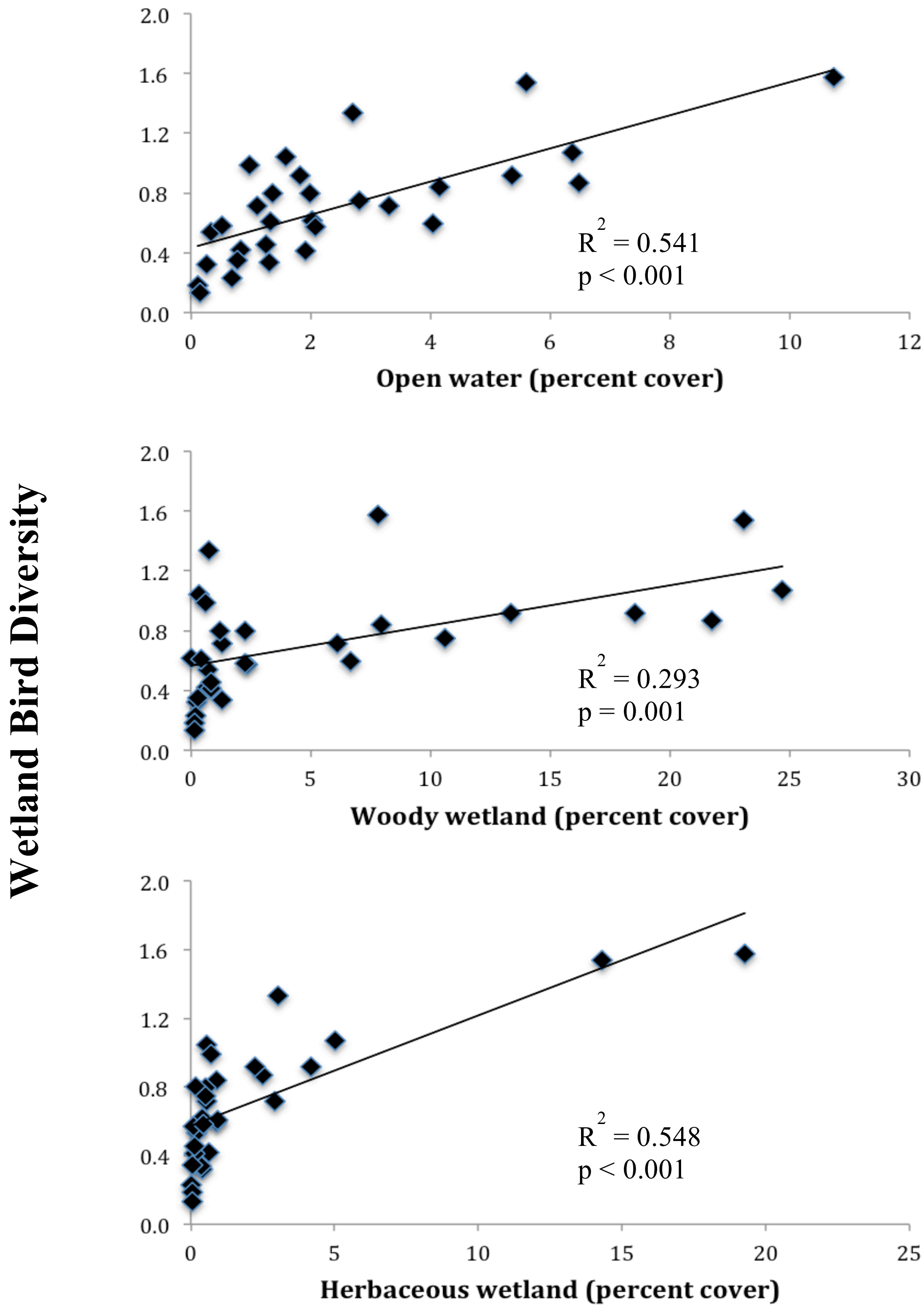

Figure 4.4. Regional associations (one point = one Bird Conservation Region) between percent cover of open water, woody wetland, and herbaceous wetland and mean values of the Shannon index derived from detections along Breeding Bird Survey routes.

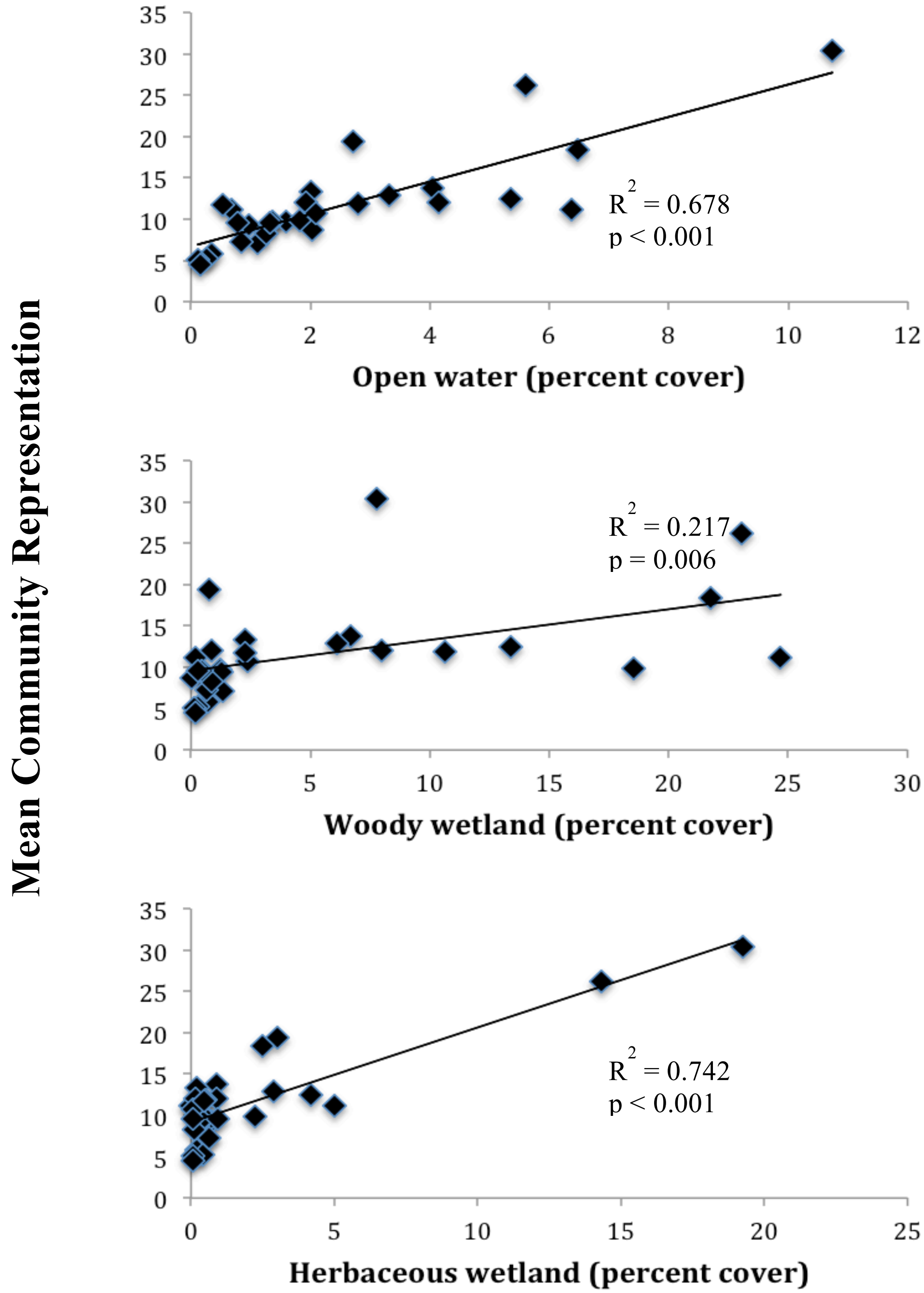

Figure 4.5. Regional associations (one point = one Bird Conservation Region) between percent cover of open water, woody wetland, and herbaceous wetland and mean community representation (percentage of species from the regional species pool) detected along Breeding Bird Survey routes.

V. AFTERWORD

When I began my exploration of regional changes in land cover composition and wetland bird communities, I was interested in conducting a study that explicitly linked population and community trends of wetland birds with land cover conversion. My original plan used each BBS route as a unit of observation and assessed whether there were associations between changes in different types of land cover and route-level trends in abundance, diversity, or species richness. Subsequently, I sought to identify similar trend relationships at regional levels. Despite attempting to quantify such temporal relationships using a variety of analytical strategies, I concluded that the data sources used for my dissertation were not well suited for such analyses. At the route level, most landscapes surrounding BBS survey sites had very small percentage point change in aquatic cover. Net change in aquatic cover at the level of the Bird Conservation Region was also minimal. This lack of change in aquatic area suggests that wetland mitigation and aquatic conservation efforts are succeeding in terms of avoiding net loss of wetland areas. However, my findings in Chapter III indicate that more information is needed on whether new wetlands areas are providing habitat for all of the avian species that depend of these systems. Moving forward, I am interested in applying the knowledge that I have gained over the course of my graduate education to design and conduct ecological studies that will help us better understand the role of anthropogenic wetlands in maintaining sustainable wetland bird communities.

APPENDIX SECTION

Appendix A. Feeding and nesting characteristics for 87 species of birds that breed in the wetlands of the conterminous United States (DeGraaf et al. 1985, Ehrlich et al. 1988, Poole 2005).

Common name	Major food items	Feeding technique	Nesting habitat	Nest placement and structure
Western Grebe	Fishes, aquatic invertebrates	Surface diving	Marsh, adjacent to open water	Floating platform
Clark's Grebe	Fishes, aquatic invertebrates	Surface diving	Marsh, adjacent to open water	Floating platform
Red-necked Grebe	Aquatic invertebrates, fishes	Surface diving	Marsh, adjacent to open water	Floating platform
Horned Grebe	Aquatic invertebrates, fishes	Surface diving	Marsh, adjacent to open water	Floating platform
Eared Grebe	Aquatic invertebrates, fishes	Surface diving	Marsh, adjacent to open water	Floating platform
Pied-billed Grebe	Aquatic invertebrates, fishes	Surface diving	Marsh, adjacent to open water	Floating platform
Common Loon	Fishes, aquatic invertebrates	Surface diving	Freshwater lakes and ponds, often with islands	Ground at water’s edge

Herring Gull	Omnivore	Ground gleaning, aerial diving, surface dipping	Shoreline, often islands	Scrape on ground
California Gull	Terrestrial invertebrates, aquatic invertebrates, small vertebrates, garbage	Aerial diving, ground gleaning	Shoreline, often islands	Scrape on ground
Ring-billed Gull	Omnivore	Ground gleaning, aerial diving, surface dipping	Shoreline, often islands	Scrape or shallow mat on ground
Franklin's Gull	Terrestrial invertebrates, earthworms, fishes	Ground gleaning, hawking, hovering	Freshwater marsh	Floating platform
Caspian Tern	Fishes, aquatic invertebrates	Aerial diving	Varies	Lined scrape on ground
Forster's Tern	Fishes, aquatic invertebrates, terrestrial invertebrates	Aerial diving	Marsh, adjacent to open water	Platform, floating, or on ground
Common Tern	Fishes, aquatic invertebrates, terrestrial invertebrates	Aerial diving	Shoreline, marshes, often islands	Lined scrape on ground

Black Tern	Terrestrial invertebrates, aquatic invertebrates, fishes	Aerial diving, surface gleaning, hawking	Marsh	Platform, floating or on ground
Anhinga	Fishes, aquatic invertebrates, small vertebrates	Surface diving	Freshwater swamps, lakes, streams	Platform in tree or shrub near water
Double-crested Cormorant	Fishes, aquatic invertebrates	Surface diving, surface dipping	Varies	Platform on tree, cliff, or ground
American White Pelican	Fishes	Surface dipping	Islands on lakes, rivers, bays	Scrape on ground
Common Merganser	Fishes, aquatic invertebrates	Surface diving	Forested areas near varied aquatic habitats	Cavity
Hooded Merganser	Fishes, aquatic invertebrates	Surface diving	Forested areas near varied aquatic habitats	Cavity
Mallard	Seeds, greens, aquatic invertebrates, terrestrial invertebrates	Dabbling	Varies	Lined scrape on ground
American Black Duck	Aquatic invertebrates, seeds, tubers	Dabbling	Marsh	Lined scrape on ground

Mottled Duck	Aquatic invertebrates, terrestrial invertebrates, greens	Dabbling	Marsh	Lined scrape on ground
Gadwall	Greens, terrestrial invertebrates, aquatic invertebrates	Dabbling, surface diving	Small wetlands with herbaceous vegetation, sometimes islands	Lined scrape on ground
American Wigeon	Greens, aquatic invertebrates	Dabbling	Shallow freshwater wetlands, sometimes islands	Lined scrape on ground
Green-winged Teal	Seeds, aquatic invertebrates	Ground gleaning, dabbling	Grassy area near marsh or pond	Lined scrape on ground
Blue-winged Teal	Seeds, greens, aquatic invertebrates	Surface dipping, dabbling	Shallow ponds and wetlands	Lined scrape on ground
Cinnamon Teal	Seeds, terrestrial invertebrates, mollusks	Surface dipping, dabbling	Freshwater ponds and marshes	Lined scrape on ground
Northern Shoveler	Greens, aquatic invertebrates	Surface dipping, straining	Shallow wetland with open water, wet meadows	Ground
Northern Pintail	Seeds, greens	Dabbling, ground gleaning	Shallow wetland with open water, sometimes islands in lakes, wet grasslands and fields	Ground

Wood Duck	Aquatic invertebrates, seeds	Dabbling	Forested wetlands	Cavity
Redhead	Greens, aquatic invertebrates	Surface diving, dabbling	Varies	Floating basket
Canvasback	Greens, aquatic invertebrates	Surface diving	Varies	Floating basket
Lesser Scaup	Aquatic invertebrates, aquatic plants	Surface diving	Marsh near open water	Ground
Ring-necked Duck	Greens, aquatic invertebrates	Surface diving	Marsh near open water	Floating or scrape on ground
Common Goldeneye	Aquatic invertebrates	Surface diving	Wooded areas, near densely vegetated water	Cavity
Barrow's Goldeneye	Aquatic invertebrates	Surface diving	Forested wetlands, wooded areas near open water	Cavity
Bufflehead	Aquatic invertebrates	Surface diving	Wooded areas near open water	Cavity
Ruddy Duck	Aquatic invertebrates, greens	Surface diving	Freshwater marshes and ponds	Floating platform or scrape on ground

Canada Goose	Greens, grains, invertebrates	Surface dipping, dabbling, ground gleaning	Varied habitats	Lined scrape on ground
Black-bellied Whistling-Duck	Seeds	Ground gleaning, dabbling	Wooded wetlands	Cavity
Fulvous Whistling-Duck	Greens, seeds	Ground gleaning, dabbling	Wetlands, impoundments, flooded grassland	Ground or tree
Mute Swan	Greens, aquatic invertebrates	Surface dipping, dabbling	Ponds, marshes, slow moving rivers	Platform on ground
Roseate Spoonbill	Fishes, aquatic invertebrates, terrestrial invertebrates	Sweeping, straining	Varies	Platform in tree, shrub, ground
White Ibis	Aquatic invertebrates, fishes, small vertebrates	Probing, ground gleaning	Varies	Platform in tree
Glossy Ibis	Aquatic invertebrates, terrestrial invertebrates, small vertebrates	Probing, ground gleaning	Marsh, swamp	Platform on ground, shrub, tree
White-faced Ibis	Aquatic invertebrates, terrestrial invertebrates, small invertebrates	Probing, ground gleaning	Shallow ponds and wetlands	Ground (islands), shrub, tree

Wood Stork	Fishes, amphibians, aquatic invertebrates	Probing	Forested wetlands	Platform in tree
American Bittern	Fishes, aquatic invertebrates, small vertebrates	Stalking, ground gleaning	Wetlands with herbaceous vegetation	Platform on ground
Least Bittern	Fishes, aquatic invertebrates, terrestrial invertebrates	Stalking, ground gleaning	Wetlands with herbaceous vegetation	Platform on ground, low shrub
Great Blue Heron	Fishes, aquatic invertebrates, small vertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree
Great Egret	Fishes, aquatic invertebrates, small vertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree or shrub
Snowy Egret	Aquatic invertebrates, fishes, terrestrial invertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree or shrub
Tricolored Heron	Fishes, amphibians, aquatic invertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree or shrub
Little Blue Heron	Fishes, amphibians, aquatic invertebrates, terrestrial invertebrates	Stalking	Varied wetland habitats with woody vegetation	Platform in tree or shrub

Cattle Egret	Terrestrial invertebrates, small vertebrates	Ground gleaning	Wet fields, marshes	Platform in tree or shrub
Green Heron	Fishes, terrestrial invertebrates, aquatics invertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree, shrub
Black-crowned Night-Heron	Fishes, aquatic invertebrates	Stalking	Wooded areas near various aquatic habitats	Platform in tree, shrub
Yellow-crowned Night-Heron	Aquatic invertebrates, fishes, terrestrial invertebrates	Stalking, ground gleaning	Wooded areas near various aquatic habitats	Platform in tree, shrub
Sandhill Crane	Omnivore	Probing, ground gleaning	Shallow wetlands	Ground or floating
King Rail	Aquatic invertebrates, terrestrial invertebrates, fishes	Probing, ground gleaning	Freshwater swamps and marshes	Platform on ground
Clapper Rail	Aquatic invertebrates, terrestrial invertebrates, fishes	Probing, ground gleaning	Salt marsh and mangrove swamp	Platform on ground
Virginia Rail	Terrestrial invertebrates, aquatic invertebrates, seeds	Probing, ground gleaning, stalking	Densely vegetated marsh	Platform on ground

Sora	Seeds, terrestrial invertebrates, aquatic invertebrates	Ground gleaning, probing	Densely vegetated marsh	Floating basket
Purple Gallinule	Omnivore	Ground gleaning	Densely vegetated marsh	Floating platform
Common Gallinule	Greens, snails, terrestrial invertebrates, seeds	Surface dipping, ground gleaning, foliage gleaning	Densely vegetated marsh	Floating platform
American Coot	Omnivore	Surface dipping, ground gleaning, foliage gleaning	Varied aquatic habitats with some dense marsh	Floating platform
Wilson's Phalarope	Aquatic invertebrates, seeds	Surface dipping, probing	Wetlands and adjacent vegetated uplands	Lined scrape on ground
American Avocet	Omnivore	Sweeping, probing	Shallow wetlands	Lined scrape on ground
Black-necked Stilt	Aquatic invertebrates, terrestrial invertebrates,	Probing, ground gleaning	Shoreline, often islands	Lined scrape on ground
Wilson's Snipe	Terrestrial invertebrates, earthworms	Probing	Wet fields, marshes	Ground (islands), shrub, tree
Marbled Godwit	Aquatic invertebrates, terrestrial invertebrates,	Probing, ground gleaning	Wet fields, marshes	Lined scrape on ground

Willet	Aquatic invertebrates	Probing, ground gleaning	Lakes, marshes, and adjacent uplands	Lined scrape on ground
Spotted Sandpiper	Terrestrial invertebrates, aquatic invertebrates	Ground gleaning	Shoreline, often with dense vegetation	Lined scrape on ground
Bald Eagle	Fishes, birds, small mammals	Aerial diving	Varies	Platform in tree
Osprey	Fishes	Aerial diving	Varies	Platform in tree
Belted Kingfisher	Fishes	Aerial diving	Varies	Burrow in bank near water
Yellow-headed Blackbird	Terrestrial invertebrates, seeds	Ground gleaning, foliage gleaning, hawking	Freshwater marsh	Cupped nest in reeds or shrub
Red-winged Blackbird	Terrestrial invertebrates, seeds	Ground gleaning, foliage gleaning, hawking	Marsh, riparian areas, cropland	Cupped nest in reeds or shrub
Tricolored Blackbird	Terrestrial invertebrates, seeds, snails	Ground gleaning, foliage gleaning	Marshes, adjacent to cropland	Cupped nest in reeds or shrub
Rusty Blackbird	Terrestrial invertebrates, seeds	Ground gleaning	Forested wetlands, riparian areas	Cupped nest in tree or shrub

Boat-tailed Grackle	Omnivore	Ground gleaning, hawking	Coastal marsh and adjacent upland	Cupped nest in tree or shrub
Nelson's Sparrow	Terrestrial invertebrates, seeds	Ground gleaning	Marsh, wet meadow	Cupped nest in grass
Seaside Sparrow	Terrestrial invertebrates, seeds	Ground gleaning, foliage gleaning	Saltmarsh	Cupped nest in grass
Swamp Sparrow	Terrestrial invertebrates, seeds	Ground gleaning	Marsh, wet meadow	Cupped nest in shrub
American Dipper	Aquatic invertebrates, fishes	Bottom gleaning	Rivers, streams	Cliff face, among vegetation
Marsh Wren	Terrestrial invertebrates, snails	Ground gleaning, foliage gleaning, hawking	Marsh with dense vegetation	Sphere in reeds or shrub

Appendix B. The number of North American Breeding Bird Survey routes on which each of 87 wetland-breeding species was detected from 2001 through 2011 and the median and maximum mean annual number of detections of the species on those routes.

Common name	Scientific name	Routes	Median number of detections	Maximum number of detections
Western Grebe	*Aechmophorus occidentalis*	58	3.25	329.09
Clark's Grebe	*Aechmophorus clarkii*	17	2.45	46.00
Red-necked Grebe	*Podiceps grisegena*	7	1.91	29.91
Horned Grebe	*Podiceps auritus*	3	0.55	0.64
Eared Grebe	*Podiceps nigricollis*	33	7.55	541.18
Pied-billed Grebe	*Podilymbus podiceps*	157	1.18	14.27
Common Loon	*Gavia immer*	116	1.39	9.75
Herring Gull	*Larus argentatus*	76	2.98	132.40
California Gull	*Larus californicus*	84	9.55	508.20
Ring-billed Gull	*Larus delawarensis*	203	8.64	447.64
Franklin's Gull	*Leucophaeus pipixcan*	35	18.18	338.45
Caspian Tern	*Hydroprogne caspia*	39	1.60	32.18
Forster's Tern	*Sterna forsteri*	58	2.14	86.45
Common Tern	*Sterna hirundo*	8	2.31	16.64
Black Tern	*Chlidonias niger*	73	4.20	66.00
Anhinga	*Anhinga anhinga*	77	1.00	25.50
Double-crested Cormorant	*Phalacrocorax auritus*	230	2.34	280.00

American White Pelican	*Pelecanus erythrorhynchos*	123	6.25	208.73
Common Merganser	*Mergus merganser*	114	0.82	28.09
Hooded Merganser	*Lophodytes cucullatus*	34	0.60	2.00
Mallard	*Anas platyrhynchos*	1300	2.52	560.91
American Black Duck	*Anas rubripes*	16	1.20	3.30
Mottled Duck	*Anas fulvigula*	57	2.00	41.00
Gadwall	*Anas strepera*	205	3.14	452.27
American Wigeon	*Anas americana*	72	1.50	33.45
Green-winged Teal	*Anas crecca*	65	1.18	7.25
Blue-winged Teal	*Anas discors*	179	2.63	100.18
Cinnamon Teal	*Anas cyanoptera*	96	1.78	94.18
Northern Shoveler	*Anas clypeata*	117	2.18	57.91
Northern Pintail	*Anas acuta*	103	2.27	28.50
Wood Duck	*Aix sponsa*	549	1.13	70.25
Redhead	*Aythya americana*	76	4.27	68.91
Canvasback	*Aythya valisineria*	25	3.40	11.36
Lesser Scaup	*Aythya affinis*	44	5.08	77.64
Ring-necked Duck	*Aythya collaris*	46	2.11	12.90
Common Goldeneye	*Bucephala clangula*	9	0.91	1.88
Barrow's Goldeneye	*Bucephala islandica*	6	0.80	1.55
Bufflehead	*Bucephala albeola*	12	1.33	16.45
Ruddy Duck	*Oxyura jamaicensis*	80	3.11	81.73
Canada Goose	*Branta canadensis*	1127	6.36	883.10

Black-bellied Whistling-Duck	*Dendrocygna autumnalis*	74	4.90	56.09
Fulvous Whistling-Duck	*Dendrocygna bicolor*	23	9.83	62.33
Mute Swan	*Cygnus olor*	26	1.00	11.91
Roseate Spoonbill	*Platalea ajaja*	30	2.95	78.75
White Ibis	*Eudocimus albus*	155	10.22	810.50
Glossy Ibis	*Plegadis falcinellus*	35	3.64	64.00
White-faced Ibis	*Plegadis chihi*	59	16.91	968.33
Wood Stork	*Mycteria americana*	62	1.78	184.78
American Bittern	*Botaurus lentiginosus*	126	1.23	21.88
Least Bittern	*Ixobrychus exilis*	19	1.18	8.50
Great Blue Heron	*Ardea herodias*	1566	1.20	52.91
Great Egret	*Ardea alba*	490	2.67	184.00
Snowy Egret	*Egretta thula*	147	3.13	135.75
Tricolored Heron	*Egretta tricolor*	70	2.48	76.50
Little Blue Heron	*Egretta caerulea*	254	1.68	163.17
Cattle Egret	*Bubulcus ibis*	404	12.32	834.43
Green Heron	*Butorides virescens*	824	0.82	27.33
Black-crowned Night-Heron	*Nycticorax nycticorax*	121	1.10	21.55
Yellow-crowned Night-Heron	*Nyctanassa violacea*	50	1.05	76.67
Sandhill Crane	*Grus canadensis*	297	3.73	66.50
King Rail	*Rallus elegans*	15	0.55	3.50

Clapper Rail	*Rallus longirostris*	26	2.64	11.20
Virginia Rail	*Rallus limicola*	26	0.56	3.91
Sora	*Porzana carolina*	130	1.00	9.71
Purple Gallinule	*Porphyrio martinicus*	8	0.89	1.82
Common Gallinule	*Gallinula chloropus*	69	1.70	76.09
American Coot	*Fulica americana*	192	3.36	342.64
Wilson's Phalarope	*Phalaropus tricolor*	109	2.45	49.25
American Avocet	*Recurvirostra americana*	84	2.00	192.38
Black-necked Stilt	*Himantopus mexicanus*	85	3.00	181.91
Wilson's Snipe	*Gallinago delicata*	446	2.69	41.27
Marbled Godwit	*Limosa fedoa*	61	3.11	24.82
Willet	*Tringa semipalmata*	137	3.43	65.45
Spotted Sandpiper	*Actitis macularius*	247	1.00	20.00
Bald Eagle	*Haliaeetus leucocephalus*	154	0.64	10.73
Osprey	*Pandion haliaetus*	261	1.18	23.09
Belted Kingfisher	*Megaceryle alcyon*	623	0.55	6.70
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	321	4.60	416.70
Red-winged Blackbird	*Agelaius phoeniceus*	2641	25.91	3395.33
Tricolored Blackbird	*Agelaius tricolor*	17	41.91	713.78
Rusty Blackbird	*Euphagus carolinus*	3	0.50	1.00
Boat-tailed Grackle	*Quiscalus major*	97	8.91	342.00
Nelson's Sparrow	*Ammodramus nelsoni*	17	1.18	3.55
Seaside Sparrow	*Ammodramus maritimus*	17	3.82	16.82

Swamp Sparrow	*Melospiza georgiana*	331	2.14	28.83
Marsh Wren	*Cistothorus palustris*	177	2.78	163.25

Appendix C. Papers that compared avian density between anthropogenic and reference wetlands. Results of significance tests are reported if included by the original authors and are presented as: “+” – anthropogenic wetlands had significantly higher avian density than reference wetlands, “–“ – anthropogenic wetlands had significantly lower density than reference wetlands, “=” densities were statistically similar for anthropogenic and reference wetlands, “Mixed” – relative avian density varied between sites, years, or seasons as reported by the authors. Only papers that included all data required to calculate *lnR* were included in the meta-analysis of overall effect size (Table 3.2). Negative values for *lnR* signify anthropogenic wetlands with lower avian density than reference wetlands.

Authors	Wetland type	Significant difference	Anthropogenic			Reference			*lnR*	var*(lnR)*
			$\bar{Y}^a$	s^b	n^c	$\bar{Y}$	s	n		
[3]Balcombe et al.	Created	=	27.09	7.20	11	28.46	9.88	4	-0.05	0.04
[4]Beck et al.	Other	+	43.00	4.16	6	1.10	0.53	7	3.67	0.03
[6]Bellio et al.	Other	–	6.57	2.62	7	10.05	1.65	2	-0.43	0.04
[7]Brawley et al.	Restored	No test	11.30	4.95	2	11.50	0.78	3	-0.02	0.10
[8]Brown and Smith	Restored	–	30.14	6.30	18	40.22	4.91	8	-0.29	0.00
[10]Burger et al.	Created	No test	3342.75	1924.02	4	674.00	90.51	2	1.60	0.09
[13]Delphey and Dinsmore	Restored	–	33.56	11.54	11	61.15	19.07	7	-0.60	0.02
[14]DesRochers et al.	Created	Mixed	5.11	2.31	11	7.45	3.39	11	-0.38	0.04

[15]Dias et al.	Other	–	~	~	~	~	~	~	~	~
[16]Gucel et al	Other	No test	989.50	712.06	2	829.50	866.21	2	0.18	0.80
[19]Havens et al. (2 papers)	Created	No test	37.00	16.97	2	100.25	39.95	2	-0.96	0.07
[21]Li et al.	Other	No test	32.95	19.22	79	75.90	10.90	27	-0.83	0.00
[22]Ma et al.	Other	Mixed	773.42	833.09	4	4912.11	8078.36	4	-1.85	0.97
[24]Melvin and Webb	Created	Mixed	76.70	~	~	42.00	~	~	-0.95	0.30
[25]Newbrey et al.	Restored	=	78.29	118.44	12	20.70	20.36	10	1.33	0.29
[28]Ratti et al.	Restored	=	84.27	187.72	39	52.75	73.82	39	0.47	0.18
[29]Ruwaldt et al.	Created	No test	3.84	1.56	2	2.13	1.10	2	0.59	0.22
[31]Snell-Rood and Cristol	Created	=	11.3	1.5	6	15.5	1.6	5	-0.32	0.01
[32]Takekawa et al.	Other	No test	9.10	5.93	4	8.33	5.61	4	0.09	0.22
[33]Tourenq et al.	Other	No test	33	~	~	4301	~	~	~	~
[35]Wilcox	Restored	–	30.23	19.49	3	97.93	30.95	3	-1.18	0.17

[a] Mean metric value

[b] Sample variance

[c] Sample size

Appendix D. Papers that compared avian species richness between anthropogenic and reference wetlands. Results of significance tests are reported if included by the original authors and are presented as: “+” – anthropogenic wetlands had significantly higher avian species richness than reference wetlands, “–“ – anthropogenic wetlands had significantly lower species richness than reference wetlands, “=” species richness was statistically similar for anthropogenic and reference wetlands, “Mixed” – relative species richness varied between sites, years, or seasons as reported by the authors. Only papers that included all data required to calculate effect sizes were included in the meta-analysis of overall effect size (Table 3.2). Negative values for *lnR* signify anthropogenic wetlands with lower species richness than reference wetlands.

Authors	Wetland type	Significant difference	Anthropogenic $\bar{Y}^a$	Anthropogenic s^b	Anthropogenic n^c	Reference $\bar{Y}$	Reference s	Reference n	*lnR*	var(*lnR*)
[2]Armitage et al.	Restored	Mixed	3.76	0.81	5	2.57	1.26	5	0.38	0.06
[3]Balcombe et al.	Created	=	11.27	1.33	11	11.24	1.24	4	0.00	0.00
[4]Beck et al.	Other	+	7.30	0.24	6	1.80	0.53	7	1.40	0.01
[5]Begley et al.	Restored	–	8.10	2.60	41	9.70	3.00	39	-0.18	0.01
[6]Bellio et al.	Other	–	19.14	9.46	7	36.50	3.50	2	-0.65	0.04
[7]Brawley et al.	Restored	No test	12.00	0.00	2	9.00	1.73	3	0.29	0.01
[8]Brown and Smith	Restored	–	12.71	1.89	18	16.80	1.62	8	-0.28	0.00

[9]Brown and Veneman	Created	–	~	~	~	~	~	~	~	~
[10]Burger et al.	Created	–	~	~	~	~	~	~	~	~
[13]Delphey and Dinsmore	Restored	–	4.70	0.90	11	8.13	0.66	7	-0.55	0.00
[14]DesRochers et al.	Created	Mixed	2.78	1.24	11	4.43	2.23	11	-0.47	0.04
[16]Gucel et al.	Created	No test	30.00	7.07	2	30.50	2.12	2	-0.02	0.03
[18]Hartzell et al.	Created	=	6.21	5.56	6	7.32	5.32	12	-0.16	0.18
[19]Havens et al. (2 papers)	Created	–	5.16	0.23	2	8.06	3.46	2	-0.45	0.09
[20]Juni and Berry	Created	=	~	~	~	~	~	~	~	~
[21]Li et al.	Other	No test	58.00	~	~	73.00	~	~	~	~
[22]Ma et al.	Other	Mixed	29.50	14.62	4	37.25	19.10	4	-0.23	0.13
[24]Melvin and Webb	Created	–	17.57	12.08	7	19.29	11.41	7	-0.09	0.12
[25]Newbrey et al.	Restored	=	8.38	2.98	12	5.10	3.34	10	0.49	0.05
[28]Ratti et al.	Restored	=	9.38	1.29	39	9.11	1.12	39	0.03	0.00
[31]Snell-Rood and Cristol	Created	–	10.5	2.4	6	16.8	3.7	5	-0.47	0.02
[32]Takekawa et al.	Other	No test	33.50	11.47	4	41.00	21.60	4	-0.20	0.10

[33]Tourenq et al.	Other	No test	18.50	7.59	4	40.50	4.43	4	-0.78	0.05

[a] Mean metric value

[b] Sample variance

[c] Sample size

Appendix E. Papers that compared avian species diversity (Shannon index) between anthropogenic and reference wetlands. Results of significance tests are reported if included by the original authors and are presented as: “+” – anthropogenic wetlands had significantly higher avian diversity than reference wetlands, “–“ – anthropogenic wetlands had significantly lower species diversity than reference wetlands, “=” avian diversity was statistically similar for anthropogenic and reference wetlands, “Mixed” – relative species diversity varied between sites, years, or seasons as reported by the authors. Only papers that included all data required to calculate effect sizes were included in the meta-analysis of overall effect size (Table 3.2). Negative values for *lnR* signify anthropogenic wetlands with lower avian diversity than reference wetlands.

Authors	Wetland type	Significant difference	Anthropogenic			Reference			*lnR*	var(*lnR*)
			$\bar{Y}^a$	s^b	n^c	$\bar{Y}$	s	n		
[2]Armitage et al.	Restored	Mixed	0.71	0.14	5	0.55	0.25	5	0.26	0.05
[3]Balcombe et al.	Created	=	3.09	1.76	11	2.76	0.94	4	0.11	0.06
[5]Begley et al.	Restored	–	1.80	0.33	41	2.00	0.31	39	-0.11	0.00
[7]Brawley et al.	Restored	No test	2.00	0.02	2	1.28	0.80	3	0.45	0.13
[18]Hartzell et al	Created	=	0.90	0.74	6	1.23	0.78	12	-0.31	0.15
[19]Havens et al. (2 papers)	Created	No test	1.98	0.21	2	2.19	0.54	2	-0.10	0.04
[20]Juni and Berry	Created	=	~	~	~	~	~	~	~	~

[21]Li et al.	Other	No test	1.29	0.22	79	2.37	0.94	27	-0.61	0.01
[24]Melvin and Webb	Created	–	0.42	0.13	7	0.58	0.12	7	-0.32	0.02
[28]Ratti et al.	Restored	=	3.47	0.46	39	3.40	0.43	39	0.02	0.00
[31]Snell-Rood and Cristol	Created	–	2.2	0.3	6	2.7	0.2	5	-0.20	0.00
[32]Takekawa et al.	Other	No test	2.13	0.28	4	3.03	0.17	4	-0.35	0.01

[a] Mean metric value

[b] Sample variance

[c] Sample size

Appendix F. Characteristics of the wetland bird community, changes in the wetland bird community, percentage of different types of land cover, and changes in land cover summarized for each of 30 Bird Conservation Regions (BCRs) of the conterminous United States. All changes are from 2001 to 2011.

BCR 5: Northern Pacific Rainforest (United States only)

Land Cover Data

Aquatic Cover (Total cover 3.0%)

2001: Open water: 1.1%; Woody wetland: 1.3%; Herbaceous wetland: 0.5%

Percentage point change in open water: + 0.01pp (gain: 0.03pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp (gain: 0.03pp; loss 0.03pp)

Percentage point change in herbaceous wetland: 0.00pp (gain: 0.04pp; loss 0.04pp)

Percent change in open water: + 0.9% (gain: 2.7%, loss; 1.8%)

Percent change in woody wetland: + 0.1% (gain 2.6%; loss 2.5%)

Percent change in herbaceous wetland: + 0.7% (gain: 7.4%; loss 6.8%)

Other land cover types

2001: Developed: 6.6%; Agriculture: 6.0%; Grassland: 3.9%; Forest: 65.4%

Percentage point change:

Developed: + 0.13pp; Agriculture: – 0.07pp; Grassland: + 0.96pp; Forest: – 3.52pp

Percent change:

Developed: + 1.9%; Agricultural: – 1.1%; Grassland: 24.4%; Forest: – 5.4%

Bird Data – 106 routes

Mean route abundance: 21.4 (range 0 to 156.9)

Species richness: Regional pool – 47, Mean route richness – 3.4 (range: 0 to 12.7)

Mean route diversity: 0.717 (range 0 to 1.933)

Mean community representation: 7.14%

Species for which abundances significantly increased: Great Egret

Species for which abundances significantly decreased: Great Blue Heron, Spotted Sandpiper

BCR 9: Great Basin

Land Cover Data

Aquatic Cover (Total cover 2.5%)

2001: Open Water: 1.6%; Woody Wetland: 0.3%; Herb. Wetland: 0.5%

Percentage point change in open water: - 0.10pp; (gain: 0.10pp; loss 0.19pp)

Percentage point change in woody wetland: + 0.03pp; (gain: 0.04pp; loss 0.02pp)

Percentage point change in herbaceous wetland: + 0.06pp (gain: 0.09pp; loss 0.03pp)

Percent change in open water: - 5.9% (gain: 5.9%; loss: 11.9%)

Percent change in woody wetland: + 8.7% (gain: 13.5%; loss: 4.8%)

Percent change in herbaceous wetland: + 11.4% (gain: 17.1%; loss: 5.8%)

Other land cover

2001: Developed: 1.8%; Agriculture: 10.0%; Grassland: 7.6%; Forest: 14.4%

Percentage point change:

Developed: + 0.07pp; Agriculture: – 0.02pp; Grassland: + 0.39pp; Forest: – 0.47pp

Percent change:

Developed: + 4.1%; Agricultural: – 0.2%; Grassland: + 5.1%; Forest: – 3.3%

BBS Wetland Bird Data – 217 routes

Mean route abundance: 148.3 (range 0 to 156.9)

Species richness: Regional pool – 61, Mean route richness – 6.0 (range: 0 to 42.4)

Mean route diversity: 1.043 (range 0 to 3.394)

Mean community representation: 9.77%

Species for which abundances significantly increased: Common Merganser, Wood Duck, American Bittern, Green Heron, Sora, Bald Eagle, Osprey

Species for which abundances significantly decreased: Double-crested Cormorant, Mallard, American Wigeon, Northern Pintail, Ruddy Duck, American Avocet, Black-necked Stilt, Belted Kingfisher, Yellow-headed Blackbird

BCR 10: Northern Rockies (United States only)

Land Cover Data

Aquatic Cover (Total cover 2.3%)

2001: Open Water: 0.9%; Woody Wetland: 0.6%; Herb. Wetland: 0.7%

Percentage point change in open water: + 0.06pp; (gain: 0.07pp; loss 0.01pp)

Percentage point change in woody wetland: + 0.03pp; (gain: 0.05pp; loss 0.01pp)

Percentage point change in herbaceous wetland: - 0.01pp (gain: 0.04pp; loss 0.05pp)

Percent change in open water: + 5.9% (gain: 6.9%; loss: 1.0%)

Percent change in woody wetland: + 5.1% (gain: 7.6%; loss: 2.5%)

Percent change in herbaceous wetland: - 1.2% (gain: 6.2%; loss: 7.4%)

Other land cover

2001: Developed: 0.9%; Agriculture: 3.2%; Grassland: 15.1%; Forest: 39.3%

Percentage point change:

Developed: + 0.03pp; Agriculture: + 0.01pp; Grassland: + 0.44pp; Forest: – 1.78pp

Percent change:

Developed: + 2.9%; Agricultural: + 0.2%; Grassland: + 2.9%; Forest: – 4.5%

BBS Wetland Bird Data – 169 routes

Mean route abundance: 64.6 (range 0 to 1481.1)

Species richness: Regional pool – 60, Mean route richness – 5.5 (range: 0 to 32.3)

Mean route diversity: 0.988 (range 0 to 2.508)

Mean community representation: 9.22%

Species for which abundances significantly increased: California Gull, Ring-billed Gull, Common Goldeneye, Snowy Egret, Willet, Bald Eagle

Species for which abundances significantly decreased: American White Pelican, Mallard, Northern Pintail, Wilson's Phalarope, Wilson's Snipe, Spotted Sandpiper, Belted Kingfisher

BCR 11: Prairie Potholes (United States only)

Land Cover Data

Aquatic Cover (Total cover 6.4%)

2001: Open Water: 2.6%; Woody Wetland: 0.7%; Herb. Wetland: 3.1%

Percentage point change in open water: + 0.21pp; (gain: 0.33pp; loss 0.12pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.02pp; loss 0.02pp)

Percentage point change in herbaceous wetland: - 0.06pp (gain: 0.17pp; loss 0.23pp)

Percent change in open water: + 8.0% (gain: 12.6%; loss: 4.6%)

Percent change in woody wetland: 0.0% (gain: 2.7%; loss: 2.7%)

Percent change in herbaceous wetland: - 1.8% (gain: 5.7%; loss: 7.5%)

Other land cover

2001: Developed: 4.5%; Agriculture: 64.2%; Grassland: 22.5%; Forest: 1.3%

Percentage point change:

Developed: + 0.07pp; Agriculture: + 0.05pp; Grassland: – 0.23pp; Forest: – 0.01pp

Percent change:

Developed: + 1.5%; Agricultural: + 0.1%; Grassland: – 1.0%; Forest: – 1.1%

BBS Wetland Bird Data – 102 routes

Mean route abundance: 331.1 (range 28.5 to 2158.9)

Species richness: Regional pool – 66, Mean route richness – 12.8 (range: 1.7 to 39.5)

Mean route diversity: 1.334 (range 0.038 to 2.548)

Mean community representation: 19.34%

Species for which abundances significantly increased: Northern Pintail, Canvasback, Sora, Bald Eagle, Marsh Wren

Species for which abundances significantly decreased: Western Grebe, Eared Grebe, Franklin's Gull, Forster's Tern, Gadwall, Black-crowned Night-Heron, Willet

BCR 12: Boreal Hardwood Transition (United States only)

Land Cover Data

Aquatic Cover (Total cover 36.1%)

2001: Open Water: 6.4%; Woody Wetland: 24.8%; Herb. Wetland: 4.9%

Percentage point change in open water: 0.00pp; (gain: 0.04pp; loss 0.04pp)

Percentage point change in woody wetland: - 0.23pp; (gain: 0.07pp; loss 0.30pp)

Percentage point change in herbaceous wetland: + 0.25pp (gain: 0.32pp; loss 0.07pp)

Percent change in open water: - 0.1% (gain: 0.6%; loss: 0.7%)

Percent change in woody wetland: - 0.9% (gain: 0.3%; loss: 1.2%)

Percent change in herbaceous wetland: + 5.0% (gain: 6.5%; loss: 1.5%)

Other land cover

2001: Developed: 4.2%; Agriculture: 9.5%; Grassland: 2.3%; Forest: 44.6%

Percentage point change:

Developed: + 0.04pp; Agriculture: – 0.03pp; Grassland: + 0.45pp; Forest: – 1.02pp

Percent change:

Developed: + 1.0%; Agricultural: – 0.4%; Grassland: + 19.8%; Forest: – 2.3%

BBS Wetland Bird Data – 117 routes

Mean route abundance: 60.9 (range 0 to 346.8)

Species richness: Regional pool – 50, Mean route richness – 5.6 (range: 0 to 16.4)

Mean route diversity: 1.067 (range 0 to 2.097)

Mean community representation: 11.18%

Species for which abundances significantly increased: Ring-billed Gull, Sandhill Crane, Bald Eagle, Osprey

Species for which abundances significantly decreased: Common Loon, Forster's Tern, Black Tern, American White Pelican, Hooded Merganser, Wood Duck, Great Blue Heron, Green Heron, Red-winged Blackbird

BCR 13: Lower Great Lakes/St. Lawrence Plain (United States only)

Land Cover Data

Aquatic Cover (Total cover 11.6%)

2001: Open Water: 4.1%; Woody Wetland: 6.7%; Herb. Wetland: 0.9%

Percentage point change in open water: - 0.01pp; (gain: 0.03pp; loss 0.04pp)

Percentage point change in woody wetland: - 0.03pp; (gain: 0.05pp; loss 0.08pp)

Percentage point change in herbaceous wetland: + 0.05pp (gain: 0.08pp; loss 0.04pp)

Percent change in open water: - 0.3% (gain: 0.7%; loss: 1.0%)

Percent change in woody wetland: - 0.5% (gain: 0.7%; loss: 1.1%)

Percent change in herbaceous wetland: + 5.4% (gain: 9.8%; loss: 4.3%)

Other land cover

2001: Developed: 13.0%; Agriculture: 35.6%; Grassland: 1.4%; Forest: 35.4%

Percentage point change:

Developed: + 0.55pp; Agriculture: – 0.25pp; Grassland: + 0.03pp; Forest: – 0.44pp

Percent change:

Developed: + 4.2%; Agricultural: – 0.7%; Grassland: + 2.1%; Forest: – 1.2%

BBS Wetland Bird Data – 72 routes

Mean route abundance: 121.2 (range 0 to 573.8)

Species richness: Regional pool – 35, Mean route richness – 4.8 (range: 0 to 12.0)

Mean route diversity: 0.592 (range 0 to 1.100)

Mean community representation: 13.83%

Species for which abundances significantly increased: Osprey, Swamp Sparrow

Species for which abundances significantly decreased: Mallard, Red-winged Blackbird

BCR 14: Atlantic Northern Forests (United States only)

Land Cover Data

Aquatic Cover (Total cover 13.0%)

2001: Open Water: 4.2%; Woody Wetland: 8.0%; Herb. Wetland: 0.9%

Percentage point change in open water: - 0.01pp; (gain: 0.01pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.03pp; loss 0.03pp)

Percentage point change in herbaceous wetland: 0.00pp (gain: 0.03pp; loss 0.03pp)

Percent change in open water: - 0.2% (gain: 0.2%; loss: 0.4%)

Percent change in woody wetland: 0.0% (gain: 0.4%; loss: 0.4%)

Percent change in herbaceous wetland: + 0.5% (gain: 3.4%; loss: 2.9%)

Other land cover

2001: Developed: 3.4%; Agriculture: 4.4%; Grassland: 0.6%; Forest: 73.4%

Percentage point change:

Developed: + 0.05pp; Agriculture: – 0.01pp; Grassland: + 0.20pp; Forest: – 0.65pp

Percent change:

Developed: + 1.3%; Agricultural: – 0.2%; Grassland: + 34.2%; Forest: – 0.9%

BBS Wetland Bird Data – 118 routes

Mean route abundance: 25.4 (range 0 to 109.5)

Species richness: Regional pool – 33, Mean route richness – 4.0 (range: 0 to 14.5)

Mean route diversity: 0.837 (range 0 to 2.028)

Mean community representation: 12.03%

Species for which abundances significantly increased: Mallard

Species for which abundances significantly decreased: Wilson’s Snipe, Spotted Sandpiper

BCR 15: Sierra Nevada

Land Cover Data

Aquatic Cover (Total cover 2.3%)

2001: Open Water: 2.0%; Woody Wetland: 0.0%; Herb. Wetland: 0.4%

Percentage point change in open water: + 0.11pp; (gain: 0.12pp; loss 0.01pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.00pp; loss 0.00pp)

Percentage point change in herbaceous wetland: + 0.08pp (gain: 0.11pp; loss 0.03pp)

Percent change in open water: + 5.8% (gain: 6.3%; loss: 0.5%)

Percent change in woody wetland: + 51.2% (gain: 56.6%; loss: 5.5%)

Percent change in herbaceous wetland: + 22.7% (gain: 31.0%; loss: 8.3%)

Other land cover

2001: Developed: 1.3%; Agriculture: 0.3%; Grassland: 3.1%; Forest: 61.4%

Percentage point change:

Developed: + 0.01pp; Agriculture: + 0.01pp; Grassland: + 0.09pp; Forest: – 1.55pp

Percent change:

Developed: + 1.1%; Agricultural: + 1.8%; Grassland: + 2.8%; Forest: – 2.5%

BBS Wetland Bird Data – 30 routes

Mean route abundance: 22.1 (range 1 to 152.0)

Species richness: Regional pool – 39, Mean route richness – 3.4 (range: 1.0 to 11.0)

Mean route diversity: 0.618 (range 0 to 1.737)

Mean community representation: 8.68%

Species for which abundances significantly increased: Wood Duck, Canada Goose

Species for which abundances significantly decreased: None

BCR 16: Southern Rockies/Colorado Plateau

Land Cover Data

Aquatic Cover (Total cover 1.2%)

2001: Open Water: 0.4%; Woody Wetland: 0.7%; Herb. Wetland: 0.2%

Percentage point change in open water: - 0.03pp; (gain: 0.02pp; loss 0.04pp)

Percentage point change in woody wetland: + 0.03pp; (gain: 0.05pp; loss 0.02pp)

Percentage point change in herbaceous wetland: + 0.02pp (gain: 0.03pp; loss 0.01pp)

Percent change in open water: - 7.8% (gain: 4.5%; loss: 12.3%)

Percent change in woody wetland: + 4.6% (gain: 6.8%; loss: 2.2%)

Percent change in herbaceous wetland: + 8.1% (gain: 14.5%; loss: 6.4%)

Other land cover

2001: Developed: 1.0%; Agriculture: 1.9%; Grassland: 16.2%; Forest: 33.2%

Percentage point change:

Developed: + 0.04pp; Agriculture: + 0.00pp; Grassland: – 0.02pp; Forest: – 0.59pp

Percent change:

Developed: + 4.3%; Agricultural: + 0.2%; Grassland: – 0.1%; Forest: – 1.8%

BBS Wetland Bird Data – 196 routes

Mean route abundance: 30.1 (range 0 to 527.4)

Species richness: Regional pool – 50, Mean route richness – 2.9 (range: 0 to 19.1)

Mean route diversity: 0.536 (range 0 to 2.469)

Mean community representation: 5.80%

Species for which abundances significantly increased: Western Grebe, Eared Grebe, Ruddy Duck, American Bittern, Great Blue Heron, Bald Eagle

Species for which abundances significantly decreased: American Wigeon, Green-winged Teal, Northern Pintail, Wilson's Snipe, Spotted Sandpiper, Belted Kingfisher

BCR 17: Badlands and Prairie

Land Cover Data

Aquatic Cover (Total cover 3.1%)

2001: Open Water: 1.3%; Woody Wetland: 1.2%; Herb. Wetland: 0.6%

Percentage point change in open water: + 0.13pp; (gain: 0.16pp; loss 0.03pp)

Percentage point change in woody wetland: - 0.02pp; (gain: 0.08pp; loss 0.10pp)

Percentage point change in herbaceous wetland: - 0.08pp (gain: 0.05pp; loss 0.12pp)

Percent change in open water: + 10.1% (gain: 12.4%; loss: 2.3%)

Percent change in woody wetland: - 1.5% (gain: 6.2%; loss: 7.7%)

Percent change in herbaceous wetland: -13.9% (gain: 8.5%; loss: 22.4%)

Other land cover

2001: Developed: 1.4%; Agriculture: 13.1%; Grassland: 61.6%; Forest: 5.7%

Percentage point change:

Developed: + 0.02pp; Agriculture: + 0.16pp; Grassland: – 0.07pp; Forest: – 0.26pp

Percent change:

Developed: + 1.7%; Agricultural: + 1.3%; Grassland: – 0.1%; Forest: – 4.5%

BBS Wetland Bird Data – 101 routes

Mean route abundance: 72.6 (range 0 to 306.6)

Species richness: Regional pool – 54, Mean route richness – 5.2 (range: 0 to 15.0)

Mean route diversity: 0.794 (range 0 to 2.134)

Mean community representation: 9.70%

Species for which abundances significantly increased: Eared Grebe, Northern Shoveler, Northern Pintail, Canada Goose, Great Blue Heron, Sora, American Coot, Willet, Osprey

Species for which abundances significantly decreased: Ruddy Duck, Spotted Sandpiper, Belted Kingfisher

BCR 18: Shortgrass Prairie

Land Cover Data

Aquatic Cover (Total cover 0.9%)

2001: Open Water: 0.3%; Woody Wetland: 0.3%; Herb. Wetland: 0.4%

Percentage point change in open water: + 0.01pp; (gain: 0.05pp; loss 0.05pp)

Percentage point change in woody wetland: + 0.03pp; (gain: 0.04pp; loss 0.01pp)

Percentage point change in herbaceous wetland: + 0.01pp (gain: 0.06pp; loss 0.05pp)

Percent change in open water: + 2.0% (gain: 21.0%; loss: 19.0%)

Percent change in woody wetland: + 10.5% (gain: 16.0%; loss: 5.5%)

Percent change in herbaceous wetland: + 3.1% (gain: 15.1%; loss: 12.0%)

Other land cover

2001: Developed: 3.8%; Agriculture: 30.1%; Grassland: 48.4%; Forest: 1.2%

Percentage point change:

Developed: + 0.16pp; Agriculture: + 0.28pp; Grassland: – 0.15pp; Forest: – 0.02pp

Percent change:

Developed: + 4.3%; Agricultural: + 0.9%; Grassland: – 0.3%; Forest: – 1.3%

BBS Wetland Bird Data – 119 routes

Mean route abundance: 58.8 (range 0 to 551.0)

Species richness: Regional pool – 48, Mean route richness – 2.5 (range: 0 to 11.6)

Mean route diversity: 0.319 (range 0 to 1.572)

Mean community representation: 5.27%

Species for which abundances significantly increased: Double-crested Cormorant, Cinnamon Teal, Northern Shoveler, Wilson's Phalarope, American Avocet

Species for which abundances significantly decreased: Canada Goose

BCR 19: Central Mixed-grass Prairie

Land Cover Data

Aquatic Cover (Total cover 2.1%)

2001: Open Water: 0.9%; Woody Wetland: 0.7%; Herb. Wetland: 0.6%

Percentage point change in open water: - 0.03pp; (gain: 0.05pp; loss 0.08pp)

Percentage point change in woody wetland: - 0.01pp; (gain: 0.01pp; loss 0.02xpp)

Percentage point change in herbaceous wetland: 0.02pp (gain: 0.10pp; loss 0.08pp)

Percent change in open water: - 4.1% (gain: 5.4%; loss: 9.4%)

Percent change in woody wetland: -1.8% (gain: 1.7%; loss: 3.5%)

Percent change in herbaceous wetland: + 2.9% (gain: 16.5%; loss: 13.6%)

Other land cover

2001: Developed: 4.2%; Agriculture: 33.2%; Grassland: 44.0%; Forest: 2.1%

Percentage point change:

Developed: + 0.09pp; Agriculture: + 0.15pp; Grassland: + 0.28pp; Forest: – 0.09pp

Percent change:

Developed: + 2.1%; Agricultural: + 0.5%; Grassland: + 0.6%; Forest: – 4.1%

BBS Wetland Bird Data – 102 routes

Mean route abundance: 79.5 (range 0.4 to 403.0)

Species richness: Regional pool – 48, Mean route richness – 3.5 (range: 0.4 to 19.2)

Mean route diversity: 0.420 (range 0 to 2.235)

Mean community representation: 7.21%

Species for which abundances significantly increased: Canada Goose, White-faced Ibis

Species for which abundances significantly decreased: Double-crested Cormorant, Gadwall, Yellow-headed Blackbird

BCR 20: Edwards Plateau

Land Cover Data

Aquatic Cover (Total cover 0.9%)

2001: Open Water: 0.7%; Woody Wetland: 0.2%; Herb. Wetland: 0.0%

Percentage point change in open water: - 0.01pp; (gain: 0.01pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.00pp; loss 0.00pp)

Percentage point change in herbaceous wetland: 0.00pp (gain: 0.00pp; loss 0.00pp)

Percent change in open water: - 2.1% (gain: 0.9%; loss: 3.1%)

Percent change in woody wetland: - 0.8% (gain: 0.5%; loss: 1.3%)

Percent change in herbaceous wetland: + 27.6% (gain: 46.0%; loss: 18.4%)

Other land cover

2001: Developed: 4.2%; Agriculture: 1.0%; Grassland: 11.2%; Forest: 24.8%

Percentage point change:

Developed: + 0.40pp; Agriculture: + 0.10pp; Grassland: + 0.37pp; Forest: – 1.23pp

Percent change:

Developed: + 9.4%; Agricultural: + 9.5%; Grassland: + 3.3%; Forest: – 5.0%

BBS Wetland Bird Data – 16 routes

Mean route abundance: 3.5 (range 0 to 15.5)

Species richness: Regional pool – 10, Mean route richness – 1.1 (range: 0 to 2.8)

Mean route diversity: 0.231 (range 0 to 0.748)

Mean community representation: 11.16%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: None

BCR 21: Oaks and Prairies

Land Cover Data

Aquatic Cover (Total cover 4.4%)

2001: Open Water: 2.0%; Woody Wetland: 2.3%; Herb. Wetland: 0.2%

Percentage point change in open water: - 0.04pp; (gain: 0.06pp; loss 0.10pp)

Percentage point change in woody wetland: - 0.01pp; (gain: 0.02pp; loss 0.04pp)

Percentage point change in herbaceous wetland: + 0.06pp (gain: 0.07pp; loss 0.01pp)

Percent change in open water: - 2.2% (gain: 2.8%; loss: 5.0%)

Percent change in woody wetland: - 0.6% (gain: 1.0%; loss: 1.7%)

Percent change in herbaceous wetland: + 38.6% (gain: 45.1%; loss: 6.5%)

Other land cover

2001: Developed: 8.9%; Agriculture: 26.6%; Grassland: 29.6%; Forest: 19.3%

Percentage point change:

Developed: + 0.55pp; Agriculture: + 0.08pp; Grassland: + 0.13pp; Forest: – 0.63pp

Percent change:

Developed: + 6.1%; Agricultural: + 0.3%; Grassland: + 0.4%; Forest: – 3.3%

BBS Wetland Bird Data – 56 routes

Mean route abundance: 77.3 (range 1.5 to 989.7)

Species richness: Regional pool – 33, Mean route richness – 4.4 (range: 1.0 to 10.3)

Mean route diversity: 0.800 (range 0 to 1.530)

Mean community representation: 13.33%

Species for which abundances significantly increased: Mallard

Species for which abundances significantly decreased: White Ibis, Common Gallinule, Belted Kingfisher

BCR 22 – Eastern Tallgrass Prairie

Land Cover Data

Aquatic Cover (Total cover 2.9%)

2001: Open Water: 1.3%; Woody Wetland: 1.3%; Herb. Wetland: 0.3%

Percentage point change in open water: + 0.06pp; (gain: 0.07pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.01pp; loss 0.02pp)

Percentage point change in herbaceous wetland: + 0.10pp (gain: 0.11pp; loss 0.01pp)

Percent change in open water: + 4.4% (gain: 5.8%; loss: 1.4%)

Percent change in woody wetland: - 0.4% (gain: 1.0%; loss: 1.4%)

Percent change in herbaceous wetland: + 31.0% (gain: 35.5%; loss: 4.5%)

Other land cover

2001: Developed: 9.8%; Agriculture: 67.9%; Grassland: 7.7%; Forest: 11.5%

Percentage point change:

Developed: + 0.42pp; Agriculture: – 0.38pp; Grassland: – 0.06pp; Forest: – 0.12pp

Percent change:

Developed: + 4.3%; Agricultural: – 0.6%; Grassland: – 0.8%; Forest: – 1.1%

BBS Wetland Bird Data – 224 routes

Mean route abundance: 152.2 (range 11.0 to 1094.8)

Species richness: Regional pool – 37, Mean route richness – 3.5 (range: 1.0 to 8.4)

Mean route diversity: 0.337 (range 0 to 1.528)

Mean community representation: 9.40%

Species for which abundances significantly increased: Double-crested Cormorant, Bald Eagle, Swamp Sparrow

Species for which abundances significantly decreased: Great Blue Heron, Green Heron, Red-winged Blackbird

BCR 23: Prairie Hardwood Transition

Land Cover Data

Aquatic Cover (Total cover 12.3%)

2001: Open Water: 3.3%; Woody Wetland: 6.1%; Herb. Wetland: 2.9%

Percentage point change in open water: + 0.11pp; (gain: 0.14pp; loss 0.04pp)

Percentage point change in woody wetland: - 0.02pp; (gain: 0.03pp; loss 0.05pp)

Percentage point change in herbaceous wetland: 0.00pp (gain: 0.09pp; loss 0.09pp)

Percent change in open water: + 3.2% (gain: 4.4%; loss: 1.1%)

Percent change in woody wetland: - 0.4% (gain: 0.4%; loss: 0.8%)

Percent change in herbaceous wetland: - 0.2% (gain: 3.0%; loss: 3.1%)

Other land cover

2001: Developed: 10.6%; Agriculture: 51.0%; Grassland: 2.5%; Forest: 22.6%

Percentage point change:

Developed: + 0.50pp; Agriculture: – 0.44pp; Grassland: + 0.01pp; Forest: – 0.21pp

Percent change:

Developed: + 4.7%; Agricultural: – 0.9%; Grassland: + 0.5%; Forest: – 0.9%

BBS Wetland Bird Data – 125 routes

Mean route abundance: 191.4 (range 6.0 to 694.9)

Species richness: Regional pool – 52, Mean route richness – 6.7 (range: 1.0 to 20.8)

Mean route diversity: 0.715 (range 0 to 1.957)

Mean community representation: 12.96%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: Pied-billed Grebe, Forster's Tern, Black Tern, Canada Goose, Mute Swan, Great Blue Heron, American Coot, Wilson's Snipe, Yellow-headed Blackbird, Red-winged Blackbird, Swamp Sparrow

BCR 24: Central Hardwoods

Land Cover Data

Aquatic Cover (Total cover 2.9%)

2001: Open Water: 1.9%; Woody Wetland: 0.8%; Herb. Wetland: 0.1%

Percentage point change in open water: + 0.01pp; (gain: 0.03pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.02pp; loss 0.01pp)

Percentage point change in herbaceous wetland: + 0.02pp (gain: 0.02pp; loss 0.00pp)

Percent change in open water: + 0.6% (gain: 1.6%; loss: 1.0%)

Percent change in woody wetland: + 0.4% (gain: 1.9%; loss: 1.5%)

Percent change in herbaceous wetland: + 12.8% (gain: 15.5%; loss: 2.7%)

Other land cover

2001: Developed: 6.9%; Agriculture: 37.0%; Grassland: 2.0%; Forest: 50.5%

Percentage point change:

Developed: + 0.32pp; Agriculture: – 0.18pp; Grassland: + 0.31pp; Forest: – 0.66pp

Percent change:

Developed: + 4.6%; Agricultural: – 0.5%; Grassland: + 15.5%; Forest: – 1.3%

BBS Wetland Bird Data – 127 routes

Mean route abundance: 56.4 (range 0.1 to 239.0)

Species richness: Regional pool – 25, Mean route richness – 3.0 (range: 0.1 to 7.5)

Mean route diversity: 0.410 (range 0 to 1.295)

Mean community representation: 12.07%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: Canada Goose, Green Heron, Belted Kingfisher

BCR 25: West Gulf Coastal Plains/Ouachitas

Land Cover Data

Aquatic Cover (Total cover 13.9%)

2001: Open Water: 2.9%; Woody Wetland: 10.7%; Herb. Wetland: 0.4%

Percentage point change in open water: - 0.12pp; (gain: 0.06pp; loss 0.18pp)

Percentage point change in woody wetland: - 0.08pp; (gain: 0.33pp; loss 0.41pp)

Percentage point change in herbaceous wetland: + 0.28pp (gain: 0.34pp; loss 0.06pp)

Percent change in open water: - 4.1% (gain: 2.2%; loss: 6.3%)

Percent change in woody wetland: - 0.7 % (gain: 3.1%; loss: 3.8%)

Percent change in herbaceous wetland: + 75.9% (gain: 93.3%; loss: 17.4%)

Other land cover

2001: Developed: 6.6%; Agriculture: 16.8%; Grassland: 4.1%; Forest: 50.2%

Percentage point change:

Developed: + 0.32pp; Agriculture: – 0.26pp; Grassland: + 1.31pp; Forest: –2.94pp

Percent change:

Developed: + 4.8%; Agricultural: – 1.5%; Grassland: + 32.2%; Forest: – 5.8%

BBS Wetland Bird Data – 74 routes

Mean route abundance: 28.7 (range 0.2 to 185.9)

Species richness: Regional pool – 30, Mean route richness – 3.6 (range: 0.2 to 10.8)

Mean route diversity: 0.748 (range 0 to 1.573)

Mean community representation: 11.83%

Species for which abundances significantly increased: Double-crested Cormorant

Species for which abundances significantly decreased: Pied-billed Grebe, Green Heron, Little Blue Heron

BCR 26: Mississippi Alluvial Valley

Land Cover Data

Aquatic Cover (Total cover 30.8%)

2001: Open Water: 6.5%; Woody Wetland: 21.7%; Herb. Wetland: 2.5%

Percentage point change in open water: - 0.14pp; (gain: 0.28pp; loss 0.41pp)

Percentage point change in woody wetland: + 0.04pp; (gain: 0.41pp; loss 0.37pp)

Percentage point change in herbaceous wetland: + 0.10pp (gain: 0.33pp; loss 0.23pp)

Percent change in open water: - 2.1% (gain: 4.3%; loss: 6.3%)

Percent change in woody wetland: + 0.2% (gain: 1.9%; loss: 1.7%)

Percent change in herbaceous wetland: + 4.0% (gain: 13.5%; loss: 9.5%)

Other land cover

2001: Developed: 6.6%; Agriculture: 57.3%; Grassland: 0.3%; Forest: 4.3%

Percentage point change:

Developed: + 0.20pp; Agriculture: – 0.27pp; Grassland: – 0.03pp; Forest: – 0.15pp

Percent change:

Developed: + 3.0%; Agricultural: – 0.5%; Grassland: – 9.1%; Forest: – 3.6%

BBS Wetland Bird Data – 50 routes

Mean route abundance: 288.0 (range 11.0 to 1127.2)

Species richness: Regional pool – 39, Mean route richness – 7.2 (range: 2.3 to 16.5)

Mean route diversity: 0.869 (range 0.030 to 2.167)

Mean community representation: 18.43%

Species for which abundances significantly increased: Mottled Duck, Common Gallinule, Bald Eagle

Species for which abundances significantly decreased: None

BCR 27: Southeastern Coastal Plain

Land Cover Data

Aquatic Cover (Total cover 22.6%)

2001: Open Water: 1.8%; Woody Wetland: 18.7%; Herb. Wetland: 2.1%

Percentage point change in open water: + 0.04pp; (gain: 0.07pp; loss 0.04pp)

Percentage point change in woody wetland: - 0.33pp; (gain: 0.35pp; loss 0.69pp)

Percentage point change in herbaceous wetland: + 0.22pp (gain: 0.45pp; loss 0.23pp)

Percent change in open water: + 2.0% (gain: 4.0%; loss: 2.1%)

Percent change in woody wetland: - 1.8% (gain: 1.9%; loss: 3.7%)

Percent change in herbaceous wetland: + 10.5% (gain: 21.5%; loss: 11.0%)

Other land cover

2001: Developed: 7.0%; Agriculture: 19.9%; Grassland: 2.9%; Forest: 38.2%

Percentage point change:

Developed: + 0.39pp; Agriculture: – 0.87pp; Grassland: + 1.25pp; Forest: – 2.88pp

Percent change:

Developed; + 5.5%; Agriculture: – 4.4%; Grassland: + 43.5%; Forest: – 7.5%

BBS Wetland Bird Data – 221 routes

Mean route abundance: 34.3 (range 1.7 to 316.8)

Species richness: Regional pool – 45, Mean route richness – 4.4 (range: 1.0 to 23.3)

Mean route diversity: 0.917 (range 0 to 2.346)

Mean community representation: 9.88%

Species for which abundances significantly increased: Anhinga, Least Bittern, Purple Gallinule, Bald Eagle, Osprey

Species for which abundances significantly decreased: Herring Gull, Ring-billed Gull, Tricolored Heron, Little Blue Heron, Cattle Egret, Red-winged Blackbird, Boat-tailed Grackle

BCR 28: Appalachian Mountains

Land Cover Data

Aquatic Cover (Total cover 2.2%)

2001: Open Water: 1.3%; Woody Wetland: 0.9%; Herb. Wetland: 0.1%

Percentage point change in open water: - 0.01pp; (gain: 0.02pp; loss 0.02pp)

Percentage point change in woody wetland: - 0.01pp; (gain: 0.01pp; loss 0.02pp)

Percentage point change in herbaceous wetland: + 0.02pp (gain: 0.02pp; loss 0.00pp)

Percent change in open water: - 0.5% (gain: 1.3%; loss: 1.8%)

Percent change in woody wetland: - 1.2% (gain: 0.8%; loss: 1.9%)

Percent change in herbaceous wetland: + 13.0% (gain: 16.0%; loss: 3.0%)

Other land cover

2001: Developed: 8.3%; Agriculture: 16.6%; Grassland: 2.2%; Forest: 69.0%

Percentage point change:

Developed: + 0.31pp; Agriculture: – 0.19pp; Grassland: + 0.29pp; Forest: – 0.96pp

Percent change:

Developed: + 3.7%; Agricultural: – 1.1%; Grassland: + 13.1%; Forest: – 1.4%

BBS Wetland Bird Data – 328 routes

Mean route abundance: 39.7 (range 0 to 252.9)

Species richness: Regional pool – 34, Mean route richness – 2.8 (range: 0 to 10.0)

Mean route diversity: 0.455 (range 0 to 1.772)

Species for which abundances significantly increased: Great Egret, Bald Eagle, Osprey

Species for which abundances significantly decreased: Belted Kingfisher

BCR 29: Piedmont

Land Cover Data

Aquatic Cover (Total cover 4.5%)

2001: Open Water: 2.0%; Woody Wetland: 2.4%; Herb. Wetland: 0.1%

Percentage point change in open water: + 0.07pp; (gain: 0.09pp; loss 0.02pp)

Percentage point change in woody wetland: - 0.04pp; (gain: 0.05pp; loss 0.09pp)

Percentage point change in herbaceous wetland: + 0.05pp (gain: 0.05pp; loss 0.00pp)

Percent change in open water: + 3.7% (gain: 4.5%; loss: 0.8%)

Percent change in woody wetland: - 1.7% (gain: 1.9%; loss: 3.6%)

Percent change in herbaceous wetland: + 81.2% (gain: 88.8%; loss: 7.6%)

Other land cover

2001: Developed: 14.8%; Agriculture: 21.1%; Grassland: 5.0%; Forest: 52.3%

Percentage point change:

Developed: + 1.26pp; Agriculture: – 0.94pp; Grassland: + 0.53pp; Forest: – 2.89pp

Percent change:

Developed: + 8.5%; Agricultural: – 4.5%; Grassland: + 10.7%; Forest: – 5.5%

BBS Wetland Bird Data – 124 routes

Mean route abundance: 22.0 (range 0 to 109.2)

Species richness: Regional pool – 24, Mean route richness – 2.6 (range: 0 to 6.5)

Mean route diversity: 0.572 (range 0 to 1.369)

Mean community representation: 10.70%

Species for which abundances significantly increased: Black-crowned Night-Heron

Species for which abundances significantly decreased: Canada Goose, Green Heron

BCR 30: New England/Mid-Atlantic Coast

Land Cover Data

Aquatic Cover (Total cover 23.0%)

2001: Open Water: 5.4%; Woody Wetland: 13.5%; Herb. Wetland: 4.2%

Percentage point change in open water: + 0.01pp; (gain: 0.05pp; loss 0.04pp)

Percentage point change in woody wetland: - 0.18pp; (gain: 0.05pp; loss 0.23pp)

Percentage point change in herbaceous wetland: + 0.02pp (gain: 0.09pp; loss 0.06pp)

Percent change in open water: + 0.2% (gain: 1.0%; loss: 0.8%)

Percent change in woody wetland: - 1.4% (gain: 0.4%; loss: 1.7%)

Percent change in herbaceous wetland: + 0.5% (gain: 2.1%; loss: 1.6%)

Other land cover

2001: Developed: 26.3%; Agriculture: 14.9%; Grassland: 0.6%; Forest: 32.8%

Percentage point change:

Developed: +1.44pp; Agriculture: – 0.50pp; Grassland: + 0.12pp; Forest: – 1.09pp

Percent change:

Developed: + 5.5%; Agricultural: – 3.3%; Grassland: + 19.4%; Forest: – 3.3%

BBS Wetland Bird Data – 104 routes

Mean route abundance: 76.2 (range 3.3 to 481.5)

Species richness: Regional pool – 44, Mean route richness – 5.5 (range: 1.3 to 20.7)

Mean route diversity: 0.919 (range 0.119 to 2.045)

Mean community representation: 12.43%

Species for which abundances significantly increased: Common Loon, Bald Eagle, Osprey

Species for which abundances significantly decreased: Herring Gull, Mallard, American Black Duck, Canada Goose, Glossy Ibis, Great Blue Heron, Black-crowned Night-Heron, Belted Kingfisher, Red-winged Blackbird, Seaside Sparrow

BCR 31: Peninsular Florida

Land Cover Data

Aquatic Cover (Total cover 43.2%)

2001: Open Water: 5.5%; Woody Wetland: 23.5%; Herb. Wetland: 14.1%

Percentage point change in open water: + 0.17pp; (gain: 0.31pp; loss 0.014pp)

Percentage point change in woody wetland: - 0.96pp; (gain: 0.16pp; loss 1.12pp)

Percentage point change in herbaceous wetland: + 0.42pp (gain: 0.75pp; loss 0.34pp)

Percent change in open water: + 3.1% (gain: 5.6%; loss: 2.5%)

Percent change in woody wetland: - 4.1% (gain: 0.7%; loss: 4.8%)

Percent change in herbaceous wetland: + 2.9% (gain: 5.3%; loss: 2.4%)

Other land cover

2001: Developed: 16.1%; Agriculture: 22.1%; Grassland: 2.0%; Forest: 9.9%

Percentage point change:

Developed: + 1.09pp; Agriculture: – 0.80pp; Grassland: + 0.20pp; Forest: – 0.64pp

Percent change:

Developed: + 6.8%; Agricultural: – 3.6%; Grassland: + 9.8%; Forest: –6.5%

BBS Wetland Bird Data – 58 routes

Mean route abundance: 210.1 (range 1.8 to 2177.5)

Species richness: Regional pool – 43, Mean route richness – 11.2 (range: 0.9 to 23.5)

Mean route diversity: 1.536 (range 0.182 to 2.436)

Mean community representation: 26.13%

Species for which abundances significantly increased: Black-bellied Whistling-Duck, Black-crowned Night-Heron

Species for which abundances significantly decreased: Anhinga, Double-crested Cormorant, Great Blue Heron, Tricolored Heron, Little Blue Heron, Green Heron, Yellow-crowned Night-Heron, Common Gallinule, Willet, Red-winged Blackbird, Boat-tailed Grackle

BCR 32: Coastal California (United States only)

Land Cover Data

Aquatic Cover (Total cover 2.7%)

2001: Open Water: 1.3%; Woody Wetland: 0.4%; Herb. Wetland: 1.0%

Percentage point change in open water: + 0.07pp; (gain: 0.10pp; loss 0.03pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.01pp; loss 0.02pp)

Percentage point change in herbaceous wetland: - 0.02pp (gain: 0.03pp; loss 0.05pp)

Percent change in open water: + 5.5% (gain: 7.9%; loss: 2.4%)

Percent change in woody wetland: - 0.9% (gain: 2.7%; loss: 3.6%)

Percent change in herbaceous wetland: - 1.7% (gain: 3.2%; loss: 4.9%)

Other land cover

2001: Developed: 13.0%; Agriculture: 21.3%; Grassland: 26.0%; Forest: 13.0%

Percentage point change:

Developed: + 0.51pp; Agriculture: – 0.22pp; Grassland: – 0.22pp; Forest: – 0.12pp

Percent change:

Developed: + 3.9%; Agricultural: – 1.0%; Grassland: – 0.9%; Forest: – 0.9%

BBS Wetland Bird Data – 75 routes

Mean route abundance: 152.2 (range 0 to 2625.0)

Species richness: Regional pool – 48, Mean route richness – 4.6 (range: 0 to 19.6)

Mean route diversity: 0.609 (range 0 to 1.935)

Mean community representation: 9.55%

Species for which abundances significantly increased: Double-crested Cormorant

Species for which abundances significantly decreased: Mallard, White-faced Ibis, Green Heron, Black-crowned Night-Heron

BCR 33: Sonoran and Mohave Deserts (United States only)

Land Cover Data

Aquatic Cover (Total cover 1.1%)

2001: Open Water: 0.8%; Woody Wetland: 0.3%; Herb. Wetland: 0.0%

Percentage point change in open water: - 0.07pp; (gain: 0.03pp; loss 0.10pp)

Percentage point change in woody wetland: + 0.03pp; (gain: 0.05pp; loss 0.02pp)

Percentage point change in herbaceous wetland: + 0.05pp (gain: 0.06pp; loss 0.00pp)

Percent change in open water: - 9.1% (gain: 3.7%; loss: 12.7%)

Percent change in woody wetland: + 10.9% (gain: 16.8%; loss: 5.9%)

Percent change in herbaceous wetland: + 118.4% (gain: 125.3%; loss: 6.9%)

Other land cover

2001: Developed: 3.1%; Agriculture: 3.0%; Grassland: 1.7%; Forest: 1.1%

Percentage point change:

Developed: + 0.40pp; Agriculture: – 0.10pp; Grassland: + 0.18pp; Forest: – 0.02pp

Percent change:

Developed: + 12.6%; Agricultural: – 3.4%; Grassland: + 10.8%; Forest: – 2.2%

BBS Wetland Bird Data – 36 routes

Mean route abundance: 258.4 (range 0 to 4043.5)

Species richness: Regional pool – 35, Mean route richness – 3.4 (range: 0 to 15.6)

Mean route diversity: 0.348 (range 0 to 1.561)

Mean community representation: 9.60%

Species for which abundances significantly increased: Caspian Tern, Double-crested Cormorant, Mallard, Least Bittern, Virginia Rail, Yellow-headed Blackbird, Red-winged Blackbird

Species for which abundances significantly decreased: Marsh Wren

BCR 34: Sierra Madre Occidental (United States only)

Land Cover Data

Aquatic Cover (Total cover 0.3%)

2001: Open Water: 0.1%; Woody Wetland: 0.1%; Herb. Wetland: 0.0%

Percentage point change in open water: + 0.02pp; (gain: 0.04pp; loss 0.02pp)

Percentage point change in woody wetland: 0.00pp; (gain: 0.01pp; loss 0.01pp)

Percentage point change in herbaceous wetland: + 0.03pp (gain: 0.03pp; loss 0.00pp)

Percent change in open water: + 22.4% (gain: 36.8%; loss: 14.4%)

Percent change in woody wetland: + 2.3% (gain: 10.7%; loss: 8.4%)

Percent change in herbaceous wetland: + 78.0% (gain: 86.2%; loss: 8.2%)

Other land cover

2001: Developed: 1.0%; Agriculture: 0.6%; Grassland: 4.4%; Forest: 36.1%

Percentage point change:

Developed: + 0.05pp; Agriculture: + 0.03pp; Grassland: + 0.36pp; Forest: – 1.15pp

Percent change:

Developed: + 4.5%; Agricultural: + 4.2%; Grassland: + 8.0%; Forest: – 3.2%

BBS Wetland Bird Data – 31 routes

Mean route abundance: 8.1 (range 0 to 78.9)

Species richness: Regional pool – 25, Mean route richness – 1.3 (range: 0 to 7.4)

Mean route diversity: 0.184 (range 0 to 1.230)

Mean community representation: 5.12%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: None

BCR 35: Chihuahuan Desert (United States only)

Land Cover Data

Aquatic Cover (Total cover 0.4%)

2001: Open Water: 0.2%; Woody Wetland: 0.1%; Herb. Wetland: 0.1%

Percentage point change in open water: - 0.04pp; (gain: 0.03pp; loss 0.07pp)

Percentage point change in woody wetland: + 0.07pp; (gain: 0.07pp; loss 0.00pp)

Percentage point change in herbaceous wetland: + 0.02pp (gain: 0.02pp; loss 0.00pp)

Percent change in open water: - 24.2% (gain: 19.2%; loss: 43.5%)

Percent change in woody wetland: + 48.8% (gain: 50.8%; loss: 2.0%)

Percent change in herbaceous wetland: + 27.9% (gain: 33.7%; loss: 5.8%)

Other land cover

2001: Developed: 1.1%; Agriculture: 0.9%; Grassland: 7.2%; Forest: 3.5%

Percentage point change:

Developed: + 0.10pp; Agriculture: + 0.06pp; Grassland: + 0.70pp; Forest: – 0.07pp

Percent change:

Developed: + 8.9%; Agricultural: + 6.6%; Grassland: + 9.6%; Forest: – 1.9%

BBS Wetland Bird Data – 41 routes

Mean route abundance: 9.4 (range 0 to 146.6)

Species richness: Regional pool – 26, Mean route richness – 1.2 (range: 0 to 7.5)

Mean route diversity: 0.134 (range 0 to 1.038)

Mean community representation: 4.56%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: Red-winged Blackbird

BCR 36: Tamaulipan Brushlands (United States only)

Land Cover Data

Aquatic Cover (Total cover 3.2%)

2001: Open Water: 0.4%; Woody Wetland: 2.3%; Herb. Wetland: 0.5%

Percentage point change in open water: + 0.21pp; (gain: 0.23pp; loss 0.02pp)

Percentage point change in woody wetland: - 0.07pp; (gain: 0.06pp; loss 0.13pp)

Percentage point change in herbaceous wetland: - 0.02pp (gain: 0.11pp; loss 0.13pp)

Percent change in open water: + 49.3% (gain: 54.2%; loss: 4.9%)

Percent change in woody wetland: - 2.9% (gain: 2.6%; loss: 5.4%)

Percent change in herbaceous wetland: - 3.4% (gain: 24.9%; loss: 28.3%)

Other land cover

2001: Developed: 6.0%; Agriculture: 19.8%; Grassland: 17.5%; Forest: 1.5%

Percentage point change:

Developed: + 0.27pp; Agriculture: – 0.25pp; Grassland: + 0.19pp; Forest: – 0.06pp

Percent change:

Developed: + 4.6%; Agricultural: – 1.2%; Grassland: + 1.1%; Forest: – 3.8%

BBS Wetland Bird Data – 22 routes

Mean route abundance: 146.7 (range 4.6 to 892.1)

Species richness: Regional pool – 33, Mean route richness – 3.9 (range: 1.2 to 10.9)

Mean route diversity: 0.581 (range 0.171 to 1.194)

Mean community representation: 11.71%

Species for which abundances significantly increased: None

Species for which abundances significantly decreased: Willet

BCR 37: Gulf Coastal Prairie (United States only)

Land Cover Data

Aquatic Cover (Total cover 37.9%)

2001: Open Water: 10.5%; Woody Wetland: 7.9%; Herb. Wetland: 19.5%

Percentage point change in open water: + 0.50pp; (gain: 0.80pp; loss 0.30pp)

Percentage point change in woody wetland: - 0.19pp; (gain: 0.17pp; loss 0.36pp)

Percentage point change in herbaceous wetland: - 0.47pp (gain: 0.43pp; loss 0.91pp)

Percent change in open water: + 4.8% (gain: 7.6%; loss: 2.9%)

Percent change in woody wetland: - 2.4% (gain: 2.1%; loss: 4.5%)

Percent change in herbaceous wetland: - 2.4% (gain: 2.2%; loss: 4.6%)

Other land cover

2001: Developed: 9.8%; Agriculture: 37.1%; Grassland: 3.7%; Forest: 4.6%

Percentage point change:

Developed: + 0.85pp; Agriculture: – 0.56pp; Grassland: – 0.32pp; Forest: – 0.34pp

Percent change:

Developed: + 8.7%; Agriculture: – 1.5%; Grassland: – 8.9%; Forest: – 7.5%

BBS Wetland Bird Data – 29 routes

Mean route abundance: 550.2 (range 18.0 to 1355.8)

Species richness: Regional pool – 49, Mean route richness – 14.9 (range: 2.7 to 26.0)

Mean route diversity: 1.574 (range 0.166 to 2.360)

Mean community representation: 30.40%

Species for which abundances significantly increased: Mottled Duck, Fulvous Whistling-Duck, Snowy Egret, Little Blue Heron, Black-crowned Night-Heron

Species for which abundances significantly decreased: None

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