AREA-SENSITIVITY, LANDSCAPE HABITAT ASSOCIATIONS AND DISTRIBUTION OF BREEDING MARSH BIRDS WITHIN THE GLACIATED REGION OF OHIO, USA.

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

By

Benjamin Michael Kahler

Graduate Program in Environment and Natural Resources

The Ohio State University

2013

Master's Examination Committee:

Dr. Robert J. Gates, Advisor

Dr. Paul G. Rodewald, Advisor

Dr. S. Mazeika P. Sullivan
Abstract

Secretive marsh birds, including bitterns, rails, coots, gallinules, grebes, and Black Terns (*Childonias niger*) are obligate wetland birds that require emergent marsh to meet annual life cycle requirements. Area of emergent wetlands has declined dramatically over the last century. Studies suggest several secretive marsh bird species have experienced strong population declines. Identification of limiting factors and development of biological models describing species-habitat associations are essential to developing habitat conservation strategies that achieve population goals. Previous studies of marsh bird habitat associations focused almost exclusively at patch or microhabitat scales. Although results from these studies have been informative, marsh bird conservationists identified a need to analyze habitats at larger spatial scales to improve regional, national, and continental conservation planning. I conducted call-broadcast surveys for nine species of secretive marsh birds in the glaciated region of Ohio, USA, during the breeding seasons in 2009 and 2010. The goals of this study were to (1) assess whether standardized monitoring protocols are adequate to capture peak detection periods of focal species, (2) assess species-specific area-sensitivity and area requirements, and (3) compare predictive performance of landscape suitability models of marsh bird presence using a suite of landscape variables at multiple spatial scales using three ecological niche modeling algorithms.

Call-broadcast methods increased the detectability of focal species by 20 – 780 % relative to passive listening. The survey window recommended by the standardized protocol (1 May – 15 June) is adequate to capture peak detection periods of focal species. Summaries of species observation rates, source (sight vs. call) and distance to detection, and temporal changes in
responses to call playbacks can be used to implement marsh bird monitoring protocols for secretive marsh birds in Ohio and the Midwestern U.S.

All focal species exhibited area-sensitivity to some degree. Wetland size, water permanence, and scale-dependent wetland area were all important predictors of marsh bird observation probability. Regional conservation planning efforts have used population estimates based on expert opinion to set habitat management objectives for these species. Density estimates presented here may be used to improve population estimates and habitat objectives for focal species in the study area.

The landscape context of a wetland’s location is important for secretive marsh bird occurrence. Occurrence of focal marsh birds was associated with local wetland characteristics, landscape descriptors of natural and anthropogenic influences, and the amount of emergent wetland at multiple spatial scales. Habitat models with mixtures of local and landscape predictors were better descriptors of marsh bird presence than models with either local or landscape predictors alone. High landscape suitability for all species tended to occur in areas with a high level of current conservation effort. Suitable habitat for marsh birds was generally concentrated in the southwestern Lake Erie region and locally concentrated in large, inland conservation areas in west central and northeast Ohio. Local and regional populations of secretive marsh birds may be more efficiently and positively affected if habitat conservation and restoration efforts are targeted to larger, semi-permanently flooded wetlands in areas with higher amounts of landscape wetland area. Further, conservation and restoration efforts positively influencing marsh bird populations can be improved by including aspects of forest cover and anthropogenic metrics in the decision process depending on the species of interest.
Dedication

To my wife (Jessica)
for sharing a passion for science and the natural world,
a hut in the Pacific, and a love deeper than the earth.
Acknowledgments

I would like to thank my advisors, Robert J. Gates and Paul G. Rodewald for giving me the opportunity to conduct this research and for their help throughout. I thank S. Mazeika P. Sullivan for serving as my committee member and for his assistance, particularly in the formulation of my research approach. This project was a collaborative effort between two graduate students and I want to thank Karen L. Willard for her determination, keen insights and contributions to the study. I appreciate all the hard work of our technicians: Bryce T. Adams, Wilma J. Bird, Lydia R. Doerr, Eric M. Dougherty, Chad S. Incorvia, Jay M. Jordon, John E. Price, and Katlyn A. Steinkirchner. Our field work would not have been possible without access to both private and public wetlands. I am grateful to all the private landowners for granting us permission to access their properties.

Support was provided by U.S. Fish and Wildlife Service at Ottawa National Wildlife Refuge Biologist Ron Huffman, state wetland managers and state private lands biologists. Funding was provided by the Federal Aid in Wildlife Restoration Program (W-134-P, Wildlife Management in Ohio) and administered jointly by the U.S. Fish and Wildlife Service and the Ohio Division of Wildlife. Additional support was provided by the School of Environment and Natural Resources and the Ohio Agricultural Research and Development Center. I thank Dennis Hull, Program Manager for the Terrestrial Wildlife Ecology Laboratory, for his generous logistical and administrative support. Thanks to John W. Simpson, manager of the Winous Point Shooting Club and Marsh Conservancy for housing and logistical support. This research benefited greatly from advice and instruction from Richard G. Pearson, American Museum of
Natural History, and Stephen J. Phillips, At&T Labs Research. Lastly, I thank Greg J. Souliere for his editorial review and Barbara J. Pardo for her strong support and encouragement through this process.
Vita

2003 ........................................... B.S. Natural Resources with Distinction in Fisheries and Wildlife Management

B.A. Anthropology, The Ohio State University

2004 to 2007 ................................. Volunteer, U.S. Peace Corps, Republic of Vanuatu

Summer 2008 .................................. Piping Plover Recovery Technician, The Nature Conservancy

2008 to 2010 ................................. Graduate Teaching Associate, School of

   Environment and Natural Resources, The Ohio State University

2010 to 2011 ................................. Biological Science Technician, U.S. Fish and Wildlife Service

2012 - present ............................... Wildlife Biologist, U.S. Fish and Wildlife Service

Fields of Study

Major Field: Environment and Natural Resources

Specialization: Fisheries and Wildlife Science
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Chapter 1: Introduction

Effective planning, evaluation and delivery of conservation actions rely on an understanding of species’ ecology. In the absence of perfect knowledge, researchers and managers use the best available information to make habitat management decisions in an adaptive management framework. The information used to make these decisions should be continually improved through feedback loops of research and monitoring that address important knowledge gaps in our understanding of species’ ecology (National Ecological Assessment Team 2006).

Population monitoring is often used to assess species population status and trends. Monitoring data can also be used to inform our understanding of species ecology including their distribution in time and space, and to assess species-habitat associations at multiple spatial scales. The prediction of a species distribution from survey data is an important component of conservation planning (Guissan and Zimmerman 2000, Scott et al. 2002, Johnson and Gillingham 2005). Recent advances in quantitative methods, geographic information systems, and remote sensing techniques have enabled researchers to incorporate landscape-level measures into ecological research (Bissonette 1997, Klopatek and Gardner 1999, Turner et al. 2001). These advancements have given researchers and managers the ability to model species-habitat associations at multiple spatial scales and predict species distributions (Scott et al. 2002).

Marsh birds, including bitterns, rails, coots, gallinules, grebes, and Black Tern (*Chlidonias niger*) are obligate wetland bird species (Weller 1999). According to the North American Breeding Bird Survey (BBS), many marsh bird species are declining at continental and
regional scales (Sauer et al. 2011). However, these estimates can be misleading and may not accurately reflect true population trends as wetland-dependent birds have been historically underrepresented on BBS routes (Herkert 1995).

Pied-billed Grebes (*Podilymbus podiceps*), American Bitterns (*Botaurus lentiginosus*), Least Bitterns (*Ixobrychus exilis*), King Rails (*Rallus elegans*), Virginia Rails (*R. limicola*), Soras (*Porzana carolina*), Common Gallinules (*Gallinula galeata*), and American Coots (*Fulica americana*) are commonly referred to as secretive marsh birds (Conway 2009). They require palustrine emergent marsh (freshwater, non-tidal wetlands with erect, rooted hydrophytes; Cowardin et al. 1979) to meet annual life cycle requirements (Weller 1999). They occur in Ohio during the breeding period, predominantly in areas previously influenced by glacial activity (Peterjohn 2001). Current estimates of their temporal and spatial distribution during the breeding period have been based largely on anecdotal and local incidence records due to their propensity for secretiveness in tall, emergent vegetation (Conway 2009).

Secretive marsh birds and Black Tern have high conservation and management importance at state and federal levels (Boylan and MacLean 1997). Populations are believed to be declining across their ranges (Conway 2009), and all are listed as Birds of Management Concern by the U.S. Fish and Wildlife Service (USFWS 2011). All are designated as species of greatest conservation need in the Ohio Department of Natural Resources’ Comprehensive Wildlife Conservation Strategy (Ohio Department of Natural Resources 2006). These designations have focused habitat conservation planning and prescribed managemnt activities directly benefitting their populations in Ohio and the Midwestern U.S (ODNR 2006, Souliere et al. 2007, UMRGLR JV 2007).

Loss and degradation of emergent marsh habitats across North America is generally viewed as the main driver of population declines in marsh birds (Conway 2009). An estimated 1.9
million ha of palustrine emergent wetland was lost between the mid-1950s and mid-1970s in the conterminous United States (Tiner 1984). In Ohio, 75% of historic wetland area was converted largely to agriculture and development (Dahl 1990). Marsh area adjacent to Lake Erie has been reduced by one-half since the mid-1950s (Eddleman et al. 1988).

Monitoring efforts that specifically target secretive marsh birds have recently been developed and implemented at regional (Crewe et al. 2006) and continental scales (Conway 2009). Population trend analyses based on data collected via call-broadcast methods indicate significant annual declines among all secretive marsh birds and Black Tern in the Great Lakes region (Table 1.1). Although call-broadcast methods have been conducted for these species in many U.S. states and several Canadian Provinces, these methods have not been applied extensively in Ohio. Data collected through call-broadcast survey methods can improve our understanding of secretive marsh bird population status, distribution, and species-habitat associations during the breeding period. This information can be used to inform conservation planning and delivery activities for these species in Ohio and the Midwestern U.S.

Previous studies of species-habitat associations of secretive marsh birds have focused almost exclusively at the patch or microhabitat scales (e.g., Weller 1961, Sugden 1979, Brackney and Bookhout 1982, Gorenzel et al. 1982, Brown and Dinsmore 1986, Johnson and Dinsmore 1986, Post and Seals 1993, Riffell et al. 2001, Lor and Malecki 2006, Darrah and Krementz 2009, Budd and Krementz 2010, Harms 2011, Willard 2011). These studies resulted in well-documented accounts of characteristics of breeding site locations including water depth, vegetation characteristics, and some included microhabitat at nest sites (e.g., Darrah and Krementz 2009, Harms 2011, Willard 2011). However, only few studies described the surrounding landscape above the microhabitat scale (e.g., Naugle et al. 1999, Riffell et al. 2001, Lor and Malecki 2006, Rehm and Baldasarre 2007, Willard 2011), and fewer included landscape
scale variables (e.g., wetland area, density of wetlands, anthropogenic measures such as density of roads) in developing predictive habitat models for secretive marsh birds (see Naugel et al. 1999 and Maxon et al. 2007). Although results from local habitat studies have been informative, researchers and managers are interested in conducting habitat analyses at larger spatial scales because conservation planning is occurring at regional (e.g., Soulliere et al. 2007, Wires et al. 2010), national (e.g., Brown et al. 2001), and continental (e.g., Kushlan et al. 2002) scales.

Understanding landscape and environmental variables associated with where marsh birds occur during the breeding period will increase the efficacy of species management programs. For example, evaluating habitat associations of marsh birds will allow predictions of how habitat management and restoration activities will impact populations. Linking their occurrence with landscape configurations will identify specific areas where more focused studies on individual species productivity may be conducted. Knowledge regarding both occurrence and productivity can result in significant refinement in resource allocations towards conservation for marsh birds (Guisan and Thuiller 2005).

The overall goal of my project was to determine the landscape and environmental (extrinsic) habitat features associated with the distribution and abundance of secretive marsh birds during the breeding period in Ohio’s glaciated region. In this chapter, I summarize the literature on marsh bird ecology, status and trends of marsh bird populations, marsh bird monitoring methods, habitat selection theory, and ecological niche modeling. In chapter 2, I describe my use of standardized call-broadcast survey methods (Conway 2009) to determine observation chronologies and distances. In chapter 3, I use information theoretic methodology (AIC) to model scale-dependent area-sensitivity among focal species. In chapter 4, I use information theoretic methodology (AIC) and a comparative modeling approach to model marsh bird species presence as a function of landscape characteristics at multiple spatial scales.
Adaptive habitat management

Our understanding of species ecology and life-history requirements drives the formulation of conceptual and inferential models for bird habitat conservation (NEAT 2006). Meaningful management objectives can be set by understanding the biological processes involved in controlling a species distribution (Young and Hutto 2002). However, new information and a more refined understanding of species ecology can increase the efficacy of habitat conservation planning and delivery efforts (USFWS 2008).

Adaptive habitat management activities for secretive marsh birds are currently being conducted in Ohio and the upper Midwest region of the U.S. The Ohio Department of Natural Resources Division of Wildlife is responsible for planning, implementing, and managing wildlife resource programs. Their strategic plans are aimed at managing, enhancing and restoring wetlands across the state, and conducting active management and monitoring programs for marsh birds (ODNR 2006). The Upper Mississippi River and Great Lakes Region Joint Venture (JV) is a conservation partnership among state and federal wildlife agencies and non-governmental organizations in the upper Midwest. The JV estimated population sizes and established conservation objectives for secretive marsh birds and Black Terns at the scale of Bird Conservation Regions (BCR, NABCI 2011, Soulliere et al. 2007). The JV designated focal marsh bird species that represent other species requiring similar habitat conditions (e.g. shallow semi-permanent marsh, hemi marsh) and created conceptual spatial models that identify areas likely to provide breeding habitat for these species (Soulliere et al. 2007). From these models, the JV established bird habitat conservation targets for emergent and other major cover types used by JV focal species across the region (UMRGLR JV 2007).

Conceptual and inferential models, hereafter “decision support tools”, are being used to guide marsh bird habitat planning and management activities in both the public and private
sectors. With a set of initial decision support tools and habitat conservation objectives, JV partners including the Ohio Department of Natural Resources are working together to target conservation delivery across the Great Lakes region. However, improving our understanding of species’ ecology and habitat associations will enable Ohio and Midwest wildlife managers to more effectively and efficiently target marsh bird habitat conservation in an adaptive framework.

**Focal species ecology**

Wetlands can be viewed as an interface or ecotone between terrestrial and open water bird habitats (Mitsch and Gosselink 2000). The focus of my research, Pied-billed Grebes, American Bitterns, Least Bitterns, King Rails, Virginia Rails, Soras, Common Gallinules, American Coots and Black Terns, are wetland-obligate species. They breed in wetlands with well-developed zones of emergent vegetation using emergent and submergent aquatic vegetation for nest building and as substrate for food (Eddleman et al. 1988, Weller 1999). They rely on wetlands to meet physiological and biological needs and have evolved physical adaptations (e.g., narrow bodies help to minimize energy expenditure while moving through dense vegetation) to exploit resource niches in these often ephemeral habitats (Weller 1999). There are several dietary and behavioral differences among secretive marsh bird species (Appendix A). Despite these differences, they share important similarities in distribution during the pre-breeding period, mating systems, and population threats.

*Pre-breeding period.* All focal species winter in the southern U.S., mainly in coastal areas, south through Mexico and Central America and portions of northern South America. Little information is known about migratory behavior in these species. Most are assumed to migrate nocturnally and at low altitudes (Conway 1995, Melvin and Gibbs 1996, Muller and Storer 1999, Bannor and Kiviat 2002, Brisbin and Mowbray 2002). Some have been observed following water courses and crossing relatively large expanses of unsuitable habitat (Brisbin and Mowbray 2002),
while others have been observed migrating hundreds of kilometers out to sea (Melvin and Gibbs 1994). They are not generally considered to be strong fliers and are thought to be short to mid-range migrants, making many stopovers in the spring before settling and establishing breeding territories.

There is a dearth of knowledge regarding the environmental and/or physiological controls that influence the initiation of spring migration in these species. Weather (e.g. freezing temperatures) and emergent plant phenology are thought to be proximate migration cues (Conway 1995, Melvin and Gibbs 1996). Marsh birds begin arriving in Ohio from mid-March to early April depending on species, the earliest being American Coots (Brisbin and Mowbray 2002).


*Population threats.* Wetland loss, habitat alteration, land use conversion, and hunting and trapping have negatively affected populations of secretive marsh birds (Table 1.2). However, loss and degradation of emergent marsh across North America is generally viewed as the main driver of population declines in these species (Conway 2009). An estimated 1.9 million hectares (ha) of palustrine emergent wetlands were lost between the mid-1950s and mid-1970s in the conterminous United States (Tiner 1984). Palustrine and riverine wetlands are the two most
threatened by alteration or drainage and filling (Eddleman et al. 1988). Over 75% of total wetland area in Ohio has been lost since the 1780s, due in large part to large-scale conversion to agriculture (Dahl 1990, Dahl and Allord 1996). An estimated 1.38 million hectares (ha) of Ohio wetlands were lost between the 1820s and 1974 (Dahl and Allord 1996). The majority (~90%) of this loss occurred between 1860 and 1900 with the draining of the Great Black Swamp in northwestern Ohio, a largely forested wetland complex the size of Connecticut (Dahl and Allord 1996). Draining of the vast Lake Erie coastal marshes occurred later, with nearly half of their historic area lost since the mid-1950s (Eddleman et al. 1988). Fortunately, the rate of wetland loss in the conterminous U.S. has slowed in recent decades concomitant with expanding efforts to restore and create wetlands (Dahl 2000).

**Conservation status and population trends**

Secretive marsh birds and Black Terns have high conservation and management importance at multiple levels. Many of them are considered species of special concern or listed as threatened or endangered in Ohio (Table 1.3). All are listed as Birds of Management Concern by the U.S. Fish and Wildlife Service (USFWS 2011). American Bitterns, Least Bitterns, King Rails and Pied-billed Grebes are considered to be of high continental concern in the North American Waterbird Conservation Plan (NAWCP) (Kushlan et al. 2002) based on assessments of population status and trends, breeding and non-breeding distribution, and threats to breeding and non-breeding habitat. Black Terns, Common Gallinules, Soras and Virginia Rails are considered to be of moderate concern and American Coots are considered to be of low concern in the NAWCP assessment (Kushlan et al. 2002). According to the Upper Mississippi Valley / Great Lakes Waterbird Conservation Plan (Wires et al. 2010), most marsh birds species are of high conservation importance in the Midwestern U.S. Secretive marsh birds and Black Terns are
designated as species of greatest conservation need in the Ohio Department of Natural Resources’ Comprehensive Wildlife Conservation Strategy (ODNR 2006).

Marsh bird populations are believed to be declining across their range (Conway 2009). Long-term (1966-2010) and short-term (2000-2010) population trends based on North American Breeding Bird Survey (BBS) data suggest slight decline or stability for these species (Table 1.4). Other attempts to analyze population trends of secretive marsh birds with BBS data have yielded similar results (Swanson and Dettmers 2002). However, population trend estimates for secretive marsh birds derived from BBS may not be accurate (Herkert 1995). Herkert (1995) found that wetland bird species were underrepresented on Midwestern BBS routes from 1966-1993, and suggested that implementation of additional marsh bird surveys or monitoring programs was needed in the region.

The National Marsh Bird Monitoring Program, the first continental effort to monitor secretive marsh birds, uses call-broadcast surveys to increase the probability of detecting these species in occupied habitats (Conway 2009). Call-broadcast surveys are generally regarded superior to passive point counts (e.g., BBS), resulting in much improved estimates of marsh bird population status and trends (Nadeau et al. 2008, Conway 2009).

**Wetland distribution and classification**

Wetland distribution can be viewed as an emergent property of hydrogeomorphology, the combined effects of climate, hydrology, and geomorphology in a landscape (Güntner et al. 2004). There is a dearth of knowledge regarding landscape characteristics and the processes related to distribution of wetlands. Hydrology is probably the most important determinant of wetland establishment and the maintenance of wetland processes affecting nutrient cycling, primary production, and species composition and richness (Mitsch and Gosselink 2000). However, current
hydrological models are not able to characterize the spatial pattern of wetlands in the landscape (Günther et al. 2004).

Small wetlands play an important role in metapopulation dynamics of wetland-obligate wildlife (Gibbs 1993, Semlitsch and Bodie 1998). Small wetlands may play a greater role in metapopulation dynamics than their cumulative area in a landscape implies as they may increase the total number of dispersers in wetland mosaics by reducing inter-wetland distance (Gibbs 1993). Loss of wetlands in the landscape can negatively impact the distribution of wetland-dependent plants and animals (Semlitsch and Bodie 1998, Gibbs 2000), resulting in a cumulative loss of wetland function at the landscape scale (Johnston 1994).

The U.S. Fish and Wildlife Service adopted a classification system (Cowardin et al. 1979) for wetlands and deepwater habitats in the United States in 1979 (Cowardin and Golet 1995). Wetlands are defined under this system as having a predominance of hydrophytes, evidence of hydric soils, or a substrate saturated or covered with water during part of the growing season, whereas deepwater habitats are permanently flooded lands where the water is too deep to support emergent vegetation (Cowardin et al. 1979). This system aids resource decision processes by providing nationally consistent wetland definition and terminology and ecologically-based mapping units used in the National Wetlands Inventory (NWI) (Cowardin and Golet 1995).

Information developed by the NWI program is used extensively by decision makers (e.g. land owners, public and private land managers, land developers, local, state and federal agencies) to meet jurisdictional requirements and to aid in conservation planning and implementation. Scientists have evaluated the use of NWI data for purposes such as delineating jurisdictional wetlands (Kudray and Gale 2000, Stolt and Baker 1995), quantifying Whooping crane (Grus americana) stopover habitat (Stalhecker 1992), and examining landscape-level habitat relationships for amphibian species (Knutson et al. 1999). Despite its widespread use in studying
wetland-dependent species-habitat associations (e.g., Knutson et al. 1999), there are several important limitations to NWI data (Tiner 1997). For example, there is a moderate amount of interpretation error inherent in NWI data. Linear wetlands, forested wetlands (especially those that are small or in areas dominated by coniferous species), and wetlands close to river margins are often difficult to correctly identify via photointerpretation (Stolt and Baker 1995, Tiner 1997, Kudray and Gale 2000). Wetlands that are either seasonally saturated or temporarily flooded and those that are either grazed or mowed are also difficult to identify via photointerpretation (Tiner 1997). Currently, NWI photo interpreters operate under a goal of classifying wetlands to a minimum 80% correct classification (Rob MacLeod, Ducks Unlimited, Inc., personal communication). Researchers who use NWI data to derive patch-level or landscape-level variables in species-habitat analyses likely propagate interpretation errors into their results.

**Habitat selection theory**

Wildlife species life requisites (e.g., food, water, areas suitable for nesting) are not randomly distributed in the landscape. Organisms have evolved morphological traits and environmental tolerances that allow them to survive and successfully breed where specific habitat conditions exist. As a result, organisms too are not randomly distributed in the landscape (Bissonnette 1997). This is especially true among migratory species such as marsh birds.

Habitat selection is the process by which specific landscape features trigger a settling response within an organism (Lack 1933). It may be a hierarchical process that an individual or species uses to settle at locations with a set of physical environmental factors that maximize their survival and reproductive potential (Hildén 1965, Jones 2001). Species presence in a patch may be a function of (1) patch size, (2) degree of isolation (i.e., distance from other patches), (3) configuration of the surrounding landscape and (4) proportion of different habitat types in a landscape mosaic (Andrén 1994). Proximate factors such as landscape configuration and terrain,
and the availability of nesting, foraging, drinking and singing sites may stimulate a settling response in an individual bird (Fretwell and Lucas 1969, Rottenberry 1985). The location of the resource with the most limited distribution (e.g. certain plant species, nest sites, nesting material, etc.) is likely to exert the most powerful constraint on where an individual settles (Orians and Wittenberger 1991). The quality and quantity of available food resources is the ultimate factor that may maintain an individual’s settling response in a chosen habitat patch and may stimulate territory establishment (Hildén 1965, Klopfer and Ganzhorn 1985). This may result in the disproportionate use of habitats as individuals seek to maximize foraging, mating and nesting opportunities while minimizing losses to predation and weather events (Burger 1985).

Birds are guided by instinctive responses to external stimuli acting on their own internal motivations (e.g., breeding dispersal) (Hildén 1965). They choose habitats based on past experience, search images or imprinting on areas where they have been reproductively successful (Lack 1933, Klopfer and Ganzhorn 1985). The cues that birds use to identify and assess potential habitat are likely to be visual and concern the structure, density, and composition of vegetation communities (Klopfer and Ganzhorn 1985). There is also evidence to suggest secretive marsh birds use aural cues to assess potential breeding habitat (Post and Seals 1993, Ward et al. 2010).

Birds may respond to features at multiple spatial scales during the habitat selection process (Hildén 1965, Fretwel and Lucas 1969, Burger 1985, Naugle et al. 1999, Sullivan et al. 2007). Theoretically, an individual first explores a general area and may settle after assessing food availability, territorial space, nesting material, and other resource needs (Hildén 1965, Burger 1985).

Different features or combinations of features may influence habitat selection responses among birds at different spatial scales (Cody 1981, Rotenberry 1985, Monfils et al. 2012). However, it is often not possible to know the appropriate scale at which to measure species
response to habitat or resource availability. I have little knowledge of scale dependence of habitat patterns or how marsh birds respond to them. Habitat configuration and vegetation structure are likely more important at a larger spatial scale and vegetation taxonomic composition is likely more important at a smaller scale (Rotenberry 1985). Researchers often test habitat selection by a species at spatial scales based on an understanding of the species’ ecology (e.g., home range, breeding territory size; see Scott et al. 2002). However, a bird’s ability to perceive its surroundings likely differs from our own (Klopfer and Ganzhorn 1985). Moreover, an individual bird’s perceptual range, mobility and its ability to perceive the configuration of the landscape and connectivity of suitable habitat may limit their ability to maximize survival and reproduction (Wiens 1994, With and Crist 1995, Alderman et al. 2005).

**Call-broadcast methods**

It is often difficult to establish the true presence or absence of a species at a particular site (Tozer et al. 2006). Most detections of secretive marsh birds are aural rather than visual because they use dense, emergent vegetation. Passive point count methods like those conducted through the BBS lead to low detection rates of marsh birds (Nadeau et al. 2008). However, call-broadcast methods are effective at increasing the probability of detecting secretive marsh birds in areas where they occur (Nadeau et al. 2008, Conway 2009).

The call-broadcast method involves broadcasting individual species calls via a cassette, compact disc, or digital music player and a set of speakers with alternating periods of broadcast and silence during a timed point count survey (Conway 2009). Secretive marsh birds are more frequently detected during call-broadcast intervals than during passive listening intervals (Gibbs and Melvin 1993, Allen et al. 2004, Nadeau et al. 2008). Call-broadcast survey methods are used in regional (Crewe et al. 2006) and continental (Conway 2009) monitoring programs for secretive marsh birds. These methods have also been used to survey for secretive marsh birds in the
Midwestern U.S. (Johnson and Dinsmore 1986, Darrah and Krementz 2009) and Ontario, Canada (Tozer et al. 2006). Although effective at increasing detections among secretive marsh birds, there are temporal and environmental factors affecting response rates during call-broadcast surveys.

Seasonal chronology, time of day, wind speed and cloud cover may affect response rates of secretive marsh birds during call-broadcast surveys (Swift et al. 1988, Gibbs and Melvin 1993, Tozer et al. 2006, Rehm and Baldasarre 2007, Conway 2009). Rehm and Balldasarre (2007) suggested timing and duration of call-broadcast surveys for secretive marsh birds should coincide with local peak detection periods. Peak detection periods coincide with peak nest-initiation periods of secretive marsh birds (Lor and Malecki 2006). Tozer et al. (2006) found response varied seasonally for Sora and Common Gallinule, but not for Virginia Rail or Least Bittern. Gibbs and Melvin (1993) showed peak response rates of individual species varied throughout the breeding season (late April to late June). Response rates for Virginia Rail and Sora have been found to decline after egg laying (Dinsmore 1986). Studies have shown that peak response rates for American Bittern and Pied-billed Grebe occur before those of Sora and Virginia Rail (Gibbs and Melvin 1993, Rehm and Baldasarre 2007). Swift et al. (1988) reported high rates of calling from mid-May to mid-June.

Time of day may affect response rates of secretive marsh birds to broadcast surveys (Conway 2009). Nadeau et al. (2008) reported that detection probabilities were higher during morning surveys than in afternoon surveys, but not significantly so for all species. However, Kryzs (2002) found no differences in detecting marsh birds between morning and afternoon surveys. The national monitoring program recommends conducting call-broadcast surveys for marsh birds from a half an hour before to two hours after sunrise and two hours before to a half an hour after sunset when vocalization frequency is highest (Conway 2009).
Wind speed and cloud cover also affect response rates of secretive marsh birds during call-broadcast surveys. Swift et al. (1988) found that calling response rates for secretive marsh birds were higher during calmer wind periods, but were not different under varying cloud conditions. Gibbs and Melvin (1993) reported that response rates of American Bitterns were lower under cloudy conditions and when wind speed was >5 km/hr. However, they reported higher response rates for Virginia Rail under cloudy conditions (Gibbs and Melvin 1993).

Environmental variables and an observer’s experience may also affect their ability to detect marsh birds during call-broadcast surveys. Simons et al. (2007) studied processes that affect auditory detection of calling birds. They found that additional background noise, the vocalizations of non-target birds (e.g., Marsh Wren), noise of call-broadcast intervals, and higher wind conditions reduce an observer’s ability to detect target species. Swift et al. (1988) reported significant differences in observers’ ability to detect marsh bird responses and stressed the need to train observers to conduct call broadcast surveys. However, Nadeau et al. (2008) reported a high degree of similarity among detections by observers and concluded that call broadcast methods do not have significant negative effects on observer ability to detect secretive marsh birds.

Given the seasonal and environmental factors influencing secretive marsh bird detectability, Gibbs and Melvin (1993) determined that presence/absence of target secretive marsh birds can be determined with 90% certainty by conducting call broadcast surveys during three visits to wetland sites. However, it may require up to eight visits to reach this level of confidence for Least Bitterns (Tozer et al. 2006).

**Ecological niche modeling**

Models seek to document and quantify relationships that occur in nature, although they may explain only part of the answer about a system. They are limited in that they are simplifications of reality and thus incomplete (Levins 1966). Most useful models are ecologically
meaningful, interpretable, able to be displayed visually, not too complicated, and completely data driven (Austin 2002).

Modeling a species’ distribution, also referred to as its ecological or environmental niche, involves modeling the distribution of suitable environments where the species can persist (Pearson 2007). Ecological niche models use associations between species occurrence records and environmental variables to identify conditions in which populations can be maintained (Austin 2002). Mechanistic and correlative approaches can be used to characterize the environmental conditions suitable for a species (Pearson 2007). Mechanistic models aim to incorporate expert knowledge of a species’ physiology and tolerance limits to environmental conditions and do not require spatially referenced records of known occurrence. Correlative models (Figure 1.1) aim to estimate the suitable environmental conditions for a species by associating spatially referenced occurrence records with suites of topographic and environmental variables assumed to affect the species’ physiology and persistence (Pearson 2007).

**Theoretical framework.** An important distinction exists between geographic space and environmental space in the context of distribution modeling (Figure 1.2). Ecological niche modeling is used to relate spatially referenced occurrence records with environmental conditions (environmental space) to project modeled distributions onto geographic space. Hutchinson (1957) defined a fundamental niche as the full range of abiotic conditions within which a species can persist. When plotted in geographic space, the fundamental niche is referred to as the potential distribution. The actual distribution of a species is the area within its fundamental niche that it truly occupies. When the actual distribution is plotted in environmental space it is known as a species’ occupied niche (Pearson 2007). However, most methods used to model ecological niches estimate a species’ realized niche which is not the same as its occupied niche. The realized niche includes a species occupied niche and other areas where it cannot persist (e.g. non-habitat or
habitat sinks). A species’ occupied niche is the actual area where it occurs and is viable. Including all spatially referenced occurrence locations for a species in geographic space in its occupied niche is of limited value in conservation planning without estimates of population demography (e.g. survival probability).

Implementing ecological niche modeling methods without accounting for population demographic parameters results in a species’ realized niche (Dias 1996, Pearson 2007). A species will occupy areas where it cannot persist locally, also known as habitat sinks (Pulliam 1988, Pulliam and Danielson 1991). However, habitats may fluctuate between being habitat sinks ($\lambda < 1$) and sources ($\lambda \geq 1$) depending on annual resource fluctuations (e.g. water and food), predation, and conspecific competition (Pulliam and Danielson 1991, Dias 1996). Therefore, applying ecological niche modeling with species presence/absence data while not accounting for source/sink dynamics results in predictions of areas likely to serve as either population sources or sinks.

**Ecological niche modeling methods.** Many techniques have been developed to model a species’ distribution for conservation planning (Guisan and Thuiller 2005). Spatially explicit ecological niche modeling methods couple survey data with classified aerial imagery and a growing body of spatially-referenced data. When linked to geographic information system (GIS), predictive models illustrate and infer the suitability of habitats. Many studies have used GIS to analyze wildlife-habitat associations at multiple spatial scales (e.g., Naugle et al. 1999, Scott et al. 2002, Elith et al. 2006).

Ecological niche modeling methods can be divided into two groups, those that use a species’ recorded (i) presence only or presence and pseudo-absence or (ii) presence and true absence (Austin 2002). Detailed descriptions of these commonly used presence only, presence/pseudo-absence, and presence/absence methods have been provided (Austin 2002, Guisan and Thuiller 2005, and Elith et al. 2006). Applying different modeling algorithms to the
same survey data may lead to very different predictions of a species’ distribution, mainly because the output of each algorithm is unique but similar to others (Austin 2002). Brotons et al. (2004) evaluated the relative performance of environmental niche factor analysis (ENFA), a presence-only model, and generalized linear models (GLM) using presence/absence data to model the habitat suitability of forest birds. They found presence/absence models were more accurate than presence-only models, concluding that absence data provides information that is useful and reliable in model calibration (Brotons et al. 2004). In this project I compare ecological niche modeling methods that use presence/absence records.

The most commonly used presence/absence techniques implemented to model species’ distribution are artificial neural networks (ANN) (Pearson et al. 2002) and regression procedures including generalized linear models (GLM), generalized additive models (GAM), classification and regression trees (CART), boosted regression trees (BRT), and multivariate adaptive regression splines (MARS) (Lehman et al. 2002, Elith et al. 2006, Leathwick et al. 2006, Elith and Leathwick 2007, Elith et al. 2008). There is no one best method for modeling a species’ distribution. However, the goal of building regression and neural network models to estimate a species’ distribution is to predict the species’ occurrence in previously unsampled sites by identifying biologically important variables (Young and Hutto 2002).

Many studies have used a comparative approach to model species distribution with variable results. Moisen and Frescino (2002) compared five modeling techniques (GLM, GAM, CART, MARS, and ANNs) to characterize forest land in the interior western U.S., and found each technique performed better than the others depending on specific conditions. Muñoz and Felícísimo (2004) compared logistic multiple regression (LMR), principle components analysis (PCA), and classification and regression trees (CART) with MARS to test their accuracy, reliability and implementation to predict the distribution of two plant species in a GIS. They
found MARS and CART achieved the best prediction success, although CART was difficult to apply cartographically due to its complexity (Muñoz and Felicísimo 2004). Thuiller et al. (2003) used GLM, GAM, and CART to model the distribution of four Mediterranean tree species across three scales (local, country, and regional). They found that the predictive accuracy of models generated under GAM procedures were robust at multiple scales because they can incorporate complex response curves to environmental variables (Thuiller et al. 2003).

This study was part of a larger effort to better understand statewide distribution of marsh birds in the glaciated region of Ohio. The overall goal of my project was to determine the landscape and environmental habitat features associated with the distribution and abundance of secretive marsh birds during the breeding period. I used three means of inquiry to address this goal. First, I describe my use of standardized call-broadcast survey methods (Conway 2009) to determine observation chronologies and distances to focal marsh birds in the study area. Secondly, I model scale-dependent area-sensitivity among focal species using information theoretic methodology (AIC). Finally, I use information theoretic methodology (AIC) and a comparative modeling approach to model marsh bird species presence as a function of landscape characteristics at multiple spatial scales. I compare models of species presence using three modeling algorithms viewed as generally having increasing model performance in species distribution modelling: Generalized Linear Models, Generalized Additive Models and Boosted Regression Trees (Elith et al. 2006).
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Table 1.1. Estimated population index trends (percent annual change) for marsh bird species derived from Marsh Monitoring Program (MMP) data collected along Great Lakes coastal marsh routes, 1995-2004 (Crewe et al. 2006, Timmermans et al. 2008).

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>-4.8</td>
<td>-7.5*</td>
<td>-21.3*</td>
</tr>
<tr>
<td>American Bittern</td>
<td>-12.4*</td>
<td>-7.6*</td>
<td>-1.7</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>-12.8*</td>
<td>-11.0*</td>
<td>-15.0*</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>-9.6*</td>
<td>-3.6*</td>
<td>-10.0*</td>
</tr>
<tr>
<td>Sora</td>
<td>-7.9</td>
<td>-5.3*</td>
<td>-15.1*</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>-12.7*</td>
<td>-3.5</td>
<td>-15.2*</td>
</tr>
<tr>
<td>American Coot</td>
<td>-11.5*b</td>
<td>-4.1*b</td>
<td>-20.5*</td>
</tr>
<tr>
<td>Black Tern</td>
<td>-2.9*</td>
<td>-15.8*</td>
<td>-19.3*</td>
</tr>
</tbody>
</table>

* Statistically significant ($P < 0.05$)

a Population trend of King Rail was not assessed in any of the studies above.

b ‘MOOT’ category—combined records for indistinguishable vocalizations of AMCO and COMO
Table 1.2. Categories and descriptions of identified threats to populations of secretive marsh birds.

<table>
<thead>
<tr>
<th>Threat category</th>
<th>Threat description</th>
<th>Source:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat conversion</td>
<td>Wetland loss</td>
<td>Eddleman et al. 1988, Conway 1995</td>
</tr>
<tr>
<td>Habitat alteration</td>
<td>Waterfowl management, esp. row crop planting for food plots</td>
<td>Eddleman et al. 1988, Conway 1995</td>
</tr>
<tr>
<td></td>
<td>Fire application may temporarily reduce habitat availability</td>
<td>Eddleman et al. 1988</td>
</tr>
<tr>
<td></td>
<td>Livestock grazing</td>
<td>Eddleman et al. 1988</td>
</tr>
<tr>
<td></td>
<td>Pesticides and contaminants (e.g., lead shot)</td>
<td>Eddleman et al. 1988</td>
</tr>
<tr>
<td>Hunting</td>
<td>Virginia Rails, Soras, Common Gallinules, and American Coots</td>
<td>Eddleman et al. 1988, Melvin and Gibbs 1994</td>
</tr>
</tbody>
</table>

Table 1.3. State population status designation of secretive marsh birds in Ohio, USA (ODNR 2006).

<table>
<thead>
<tr>
<th>Species</th>
<th>Status in Ohio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>-</td>
</tr>
<tr>
<td>American Bittern</td>
<td>Endangered</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>Threatened</td>
</tr>
<tr>
<td>King Rail</td>
<td>Endangered</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>Species of Concern</td>
</tr>
<tr>
<td>Sora</td>
<td>Species of Concern</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>Species of Concern</td>
</tr>
<tr>
<td>American Coot</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 1.4. Marsh bird population trends (% annual change and 95% confidence limits) and credibility measure from the North American Breeding Bird Survey for the periods 1966-2010 and 2000-2010 (Sauer et al. 2010).

<table>
<thead>
<tr>
<th>Species</th>
<th>Credibility Measure</th>
<th>N&lt;sup&gt;b&lt;/sup&gt;</th>
<th>1966-2010 Trend</th>
<th>95% CI</th>
<th>2000-2010 Trend</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>2</td>
<td>1,047</td>
<td>-0.5 (-3.4, 0.8)</td>
<td>-1.3 (-4.3, 2.0)</td>
<td></td>
<td></td>
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<tr>
<td>American Bittern</td>
<td>2</td>
<td>1,087</td>
<td>-1.1 (-3.1, 0.1)</td>
<td>0.5 (-2.0, 3.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Bittern</td>
<td>2</td>
<td>155</td>
<td>0.5 (-1.8, 3.0)</td>
<td>3.3 (-1.8, 10.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>King Rail</td>
<td>2</td>
<td>87</td>
<td>-4.8 (-7.4, -2.3)</td>
<td>-3.7 (-10.0, 4.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>1</td>
<td>382</td>
<td>0.7 (-3.4, 2.4)</td>
<td>3.6 (-0.2, 8.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sora</td>
<td>3</td>
<td>980</td>
<td>0.2 (-1.6, 1.5)</td>
<td>2.6 (-0.4, 5.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>2</td>
<td>260</td>
<td>-1.5 (3.1, 0.1)</td>
<td>-0.4 (-3.7, 3.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Coot</td>
<td>3</td>
<td>1,007</td>
<td>-0.8 (-3.6, 1.0)</td>
<td>0.5 (-3.6, 5.4)</td>
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<td></td>
</tr>
<tr>
<td>Black Tern</td>
<td>3</td>
<td>536</td>
<td>-0.3 (-7.4, -1.7)</td>
<td>-3.5 (-8.1, 1.2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Credibility measure: 1 - reflects data with an important deficiency; 2 - reflects data with a deficiency; 3 - reflects data with at least 14 samples in the long term, of moderate precision, and of moderate abundance on routes.

<sup>b</sup> Number of survey routes used in trend analysis.
Collate GIS database of environmental layers

Process environmental layers to generate ecologically meaningful predictor variables

Map localities of the species’ known presence and absence

Apply modeling algorithm

Model calibration

Test predictive performance via data-splitting or independent data

Create map of current distribution

If possible, test prediction against observed data in invaded region.

Predict species’ distribution in different region or climate (projection)

Figure 1.1. Example flow diagram detailing main steps required for building and validating a correlative model of species distribution. Adapted from Pearson (2007:6).
Figure 1.2. Illustration of the relationship between a hypothetical species distribution in geographical space and environmental space. Adapted from Pearson (2007).
Chapter 2: Observations of secretive marsh birds using standardized protocols in the glaciated region of Ohio, USA.

ABSTRACT

Standardized monitoring protocols were recently developed for secretive marsh birds (rails, bitterns, and grebes) to assess their population status and trends. Although they have been conducted at similar latitudes these protocols were only recently implemented in Ohio. I examined the responses of 9 “focal species” to the broadcast of calls in Ohio marshes, during the breeding seasons in 2009 and 2010. The goals of this study were to assess whether the survey period as recommended by the standardized protocols (Conway 2009) is adequate to capture peak detection periods for focal species, and whether survey data collected can be used to assess status and trends of target species. I investigated temporal and survey-level factors known to affect detection of these species. Call-broadcast methods increased the detectability of focal species by 20 – 780 % relative to passive listening. Soras were detected earlier than all other focal species. Increasing wind speed negatively affected detectability of Pied-billed Grebes and American Bitterns. Increasing background noise negatively affected detectability of Least Bitterns. Observation distances were generally shorter for rails and greater for Pied-billed Grebes, American Bitterns, and Black Terns. The survey window recommended by the standardized protocol (1 May – 15 June) is adequate to capture peak detection periods of focal species. Summaries of species observation rates, source (sight vs. call) and distance to detection, and
temporal changes in responses to call playbacks can be used to implement marsh bird monitoring protocols for secretive marsh birds in Ohio and the Midwestern U.S.

INTRODUCTION

Effective conservation planning relies on population monitoring data to estimate species’ status and trends (NEAT 2006). Marsh birds including bitterns, rails, coots, gallinules, grebes, and Black Terns (*Chlidonias niger*) are obligate wetland birds (Weller 1999). Like other wetland-dependent bird species, their relative abundance and population trends are poorly monitored by the North American Breeding Bird Survey (Herkert 1995, Gibbs and Melvin 1993). They represent a disproportionately large fraction of species listed as threatened or engendered at state and national levels (Boylan and MacLean 1997), due largely to declines in their wetland (Dahl 1990) and grassland (Samson and Knopf 1996) habitats.

Pied-billed Grebes (*Podilymbus podiceps*), American Bitterns (*Botaurus lentiginosus*), Least Bitterns (*Ixobrychus exilis*), King Rails (*Rallus elegans*), Virginia Rails (*R. limicola*), Soras (*Porzana carolina*), Common Gallinules (*Gallinula galeata*), and American Coots (*Fulica americana*) are secretive marsh birds that have declined in North American since the 1970s (Eddleman et al. 1988). Inaccessible habitats coupled with their secretive behaviors (Bystrak 1981) have resulted in sparse marsh bird population status or trend estimates across their ranges (Conway 2009). They have high conservation importance to the Ohio Department of Natural Resources (ODNR 2006). Estimates of their population status and trends are currently lacking (but see Timmermans et al. 2008) and needed in Ohio to direct conservation planning and conservation delivery activities that would directly benefit their populations.

Special efforts have been made in the last 15 years to create monitoring programs specifically designed for secretive marsh birds at regional (Crewe et al. 2006, Ward et al. 2010) and continental scales (Conway 2009). A standardized monitoring protocol was developed
specifically for this group of birds and has been implemented in many states across the U.S. including the Midwest (Conway 2009). The protocol can generate naïve estimates of site-level presence for most secretive marsh bird species (Gibbs and Melvin 1993, Tozer et al. 2006). Although standardized monitoring protocols have been conducted at similar latitudes (Lor and Malecki 2002, Rehm and Baldasarre 2007), these protocols were only recently implemented in Ohio.

Response rates of secretive marsh birds may be affected by seasonal migration and breeding chronologies (Gibbs and Melvin 1993, Rehm and Baldasarre 2007), wind speed (Swift et al. 1988, Gibbs and Melvin 1993, Simons et al. 2007), and the amount of background noise at survey locations (Simons et al. 2007). The standardized protocol attempts to correct for seasonal variation in response rates by (1) conducting three replicate surveys at predetermined intervals during the breeding period and (2) limiting sampling to a 45-day window with timing based on average maximum daily temperatures across North America (Conway 2009).

The standardized monitoring protocol for secretive marsh birds (Conway 2009) is designed to span peak detection intervals for target species across the breeding period. However, secretive marsh birds migrate and initiate breeding asynchronously (Gibbs et al. 1992a, b, Meanley 1992, Conway 1995, Melvin and Gibbs 1996, Muller and Storer 1999, Bannor and Kiviat 2002, Brisbin and Mowbray 2002, Lor and Malecki 2006). Peak detection intervals are also asynchronous among secretive marsh birds (Johnson and Dinsmore 1986, Gibbs and Melvin 1993, Lor and Malecki 2002, Lor and Malecki 2006, Rehm and Baldasarre 2007). Breeding chronologies, including timing of nest site selection, courtship, breeding, nesting, egg incubation, hatching, and post-hatch fledging, also vary among species (Gibbs et al. 1992a, b, Meanley 1992, Conway 1995, Melvin and Gibbs 1996, Muller and Storer 1999, Bannor and Kiviat 2002, Brisbin and Mowbray 2002). Pied-billed Grebes arrive as early as late February in Ohio (Muller and
Storer 1999) while Virginia Rails arrive in late April (Peterjohn 2001), and other marsh bird species occurring between these two time periods (Gibbs et al. 1992a, b, Melvin and Gibbs 1996, Bannor and Kiviat 2002, Brisbin and Mowbray 2002). Marsh birds demonstrate considerable congruency between detection periods (Lor and Malecki 2002) and nest initiation periods (Lor and Malecki 2006). However, some research suggests the recommended protocol may not include peak detection periods for all species (Rehm and Baldasarre 2007).

Knowing seasonal patterns in the use of different call types in an area provides useful information. Most secretive marsh birds have multiple unique vocalizations, and each may serve a different social function (e.g., mate attraction, mate communication, territorial defense) and that indicate pair status and breeding chronology (Appendix B). Frequency of call types changes through the breeding period and may vary among geographic regions (Conway 2009). Detection distances also vary among species (Gibbs and Melvin 1993, Allen et al. 2004), and may vary among vocalization types within species (Conway 2009). Detection probability and observer bias may differ with various call types (e.g., incorrectly identifying species with similar vocalizations) (Conway and Nadeau 2006).

The goals of this chapter were to assess (1) whether the survey period as recommended by the standardized marsh bird monitoring protocol (Conway 2009) is adequate to capture peak detection periods for target marsh bird species, and (2) whether survey data collected using the standardized protocol can be used to assess status and trends of target species. Specifically, I examined the responses of 9 “focal species” to the broadcast of calls in Ohio marshes. These species included Pied-billed Grebes, American Bitterns, Least Bitterns, King Rails, Virginia Rails, Soras, Common Gallinules, American Coots, and Black Terns. I investigated temporal and survey-level factors known to affect detection of these species by addressing the following research hypotheses:
1. Call-broadcast methods will increase the detectability of focal species relative to passive listening.

2. Observation chronologies will vary among focal species and among vocalization types within a species.

3. The probability of observing focal species will be negatively affected by increasing wind speed and background noise levels.

4. Average observation distances will vary among focal species, among vocalization types within a species, and across the breeding period.

**STUDY AREA**

I conducted call-broadcast surveys at 450 sites in the glaciated region of Ohio, USA, 209 sites in 2009 and 241 sites in 2010. About half \( n=236 \) \( (52\%) \) the sites were located on private lands and the rest were publicly-owned sites. Surveys were conducted in 45 of 88 Ohio counties, 36 in 2009 and 35 in 2010. Sites were not evenly distributed among Bird Conservation Regions (BCRs). Forty-four percent of sites were located in BCR13 (Lower Great Lakes / St. Lawrence Plain), 39% in BCR 23 (Prairie Hardwood Transition), 14% in BCR 22 (Eastern Tallgrass Prairie), and 2% in BCR 28 (Appalachian Mountains) (Figure 2.1). Nine different observers conducted surveys, 5 in 2009 and 6 in 2010.

**METHODS**

**Point sampling**

I used the National Wetlands Inventory (NWI) to select survey locations. Wetlands thought to contain habitat suitable for focal species based on a review of literature included the lacustrine littoral (L2) and palustrine (P) systems in the emergent (EM) or aquatic bed (AB) class (Cowardin et al. 1979). Forested, scrub/shrub and unconsolidated bottom wetlands cross
classified with emergent or aquatic bed also were included to sample a wider range of potential marsh bird habitat. Survey locations were randomly selected from NWI data (http://www.ducks.org/conservation/glaro/gis-nwi-update) based on 2005-2007 aerial photographs (Ducks Unlimited 2008).

I used a generalized random-tessellation stratified (GRTS) design to select survey locations within NWI polygons (Kincaid et al. 2008). A stratified random sample of 350 points with a 50% oversample (extra points) was selected each year (annual draws were independent). Sample points were stratified by water regime and wetland size. Water regime was categorized as either seasonal (temporary and seasonally flooded) or semi-permanent (semi-permanently flooded, intermittently exposed, and permanently flooded) (Cowardin et al. 1979), and wetland size was divided into small (0.05-1.0 ha), medium (1.0-10.0 ha), and large (>10.0 ha). Wetlands within each stratum were sampled in proportion to their area across the study area in 2009. Temporarily flooded wetlands were removed from the sampling routine in 2010 because 2009 data and observer experience suggested these areas did not contain suitable emergent cover for secretive marsh birds. Equal numbers of seasonally and semi-permanently flooded wetlands were sampled in 2010. The samples were drawn in R (R Development Core Team 2005) using the spsurvey package version 2.0 (Kincaid et al. 2008).

I used a combination of county auditor Geographical Information Systems (GIS; http://www.caao.org/GIS/index.html) and plat books to identify landowners for survey locations in both years. I sent letters to private land owners asking their permission to conduct surveys (Appendix C), and gained permission to conduct surveys on publicly-owned land at all governmental levels.
Survey methods

Marsh bird surveys closely followed methods outlined in the Standardized North American Marsh Bird Monitoring Protocol (Conway 2009) except that survey sites were randomly located within a wetland and not necessarily on dikes, roads, or at the vegetation-water interface. I conducted surveys from 8 May to 28 June 2009 and 8 May to 22 June 2010. Points were surveyed three times during the field season with 10-15 days between each survey. Surveys were conducted from 30 minutes before sunrise (civil twilight) to 2-3 hours after sunrise and from 2 hours before sunset to 30 minutes after sunset (civil twilight). Background noise, wind (Beaufort scale) and sky conditions (U.S. Weather Bureau code) were recorded prior to each survey. I did not conduct surveys with winds>20 km/hr or during sustained rain, per protocol guidelines (Conway 2009).

The call-broadcast sequence was obtained from the North American Marsh Bird Monitoring Program (Conway 2009) and consisted of a 5-minute passive listening period followed by 5-7 minutes of calls. Each minute of the call-broadcast period included 30 seconds of vocalizations by individual species, with 30 seconds of silence between species. Only species whose detectability is improved by call-broadcast were included in the survey (C. Conway, U.S. Geological Survey, personal communication). The order of species in the call broadcast was as follows: Least Bittern, Sora, Virginia Rail, King Rail, and Pied-billed Grebe. I added American Bittern and an additional Least Bittern call to the end of the broadcast series in 2010 (Appendix D). Field personnel were trained to identify marsh bird vocalizations using audio CDs beginning in April and participate in a week of daily in situ practice surveys and vocalization identification evaluations.

I broadcasted the call sequence at 90 dB 1 m from the source (Conway 2009) using an mp3 player (SanDisk Sansa Clip 512 MB, SanDisk Corporation, Milpitas, California, USA)
attached to a pair of amplified speakers (Phillips Model SB220A, Koninklijke Philips Electronics, Amsterdam, The Netherlands). I placed the speakers approximately 1.5 m above ground and pointed them toward the interior of the wetland. I recorded all visual and aural observations for the nine focal species. I recorded the minute of the sequence during which each vocal and/or visual observation was confirmed. Observers estimated distance (m) to each bird observed with laser range finders and aerial photographs.

**Analysis**

*Weather data.* Local distribution of marsh birds during the breeding period may vary with seasonal precipitation (Newton 1998). Temperature highs and lows may affect response rates to call-broadcast among secretive marsh birds (Nadeau et al. 2008). I tested for annual differences in all analyses and included weather data that may help to explain these differences where appropriate. Although precipitation and temperature patterns likely influence the range-wide breeding distributions of secretive marsh birds, I assumed that marsh bird distributions in the study area were similar between survey years. I compared measurements of precipitation and temperature at survey sites between survey years and against long-term averages to assess this assumption.

I evaluated precipitation and temperature between years in two ways; 1) from records at cooperative weather stations (http://gis.ncdc.noaa.gov/map/monthly) closest to each survey location and 2) interpolated climate data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate group at Oregon State University (http://www.prism.oregonstate.edu/).

I gathered monthly surface weather data from the National Climate Data Center (NCDC) for cooperative stations ($n = 128$) nearest (0.9 - 41.5 km) to survey locations (Appendix E) for April-June in both years. I summed monthly precipitation totals for April – June by year (total
breeding period precipitation). I inspected the data for trends and outliers using trend and semivariogram analysis tools in Geostatistical Analyst in ArcGIS 10.0 (ESRI, Redlands, CA, USA). Stations with outlier data points on total breeding period precipitation were removed before analyses and interpolation. Removal of stations with outlying estimates had negligible influence on final interpolation output as they were all ≤ 20 km from ≥ 2 weather stations. Histograms, normal quantile plots and boxplots were used to inspect monthly and seasonal precipitation data. Paired t-tests or Wilcoxon sign-ranked tests were performed on monthly and seasonal precipitation data to assess the null hypothesis of no difference in precipitation between survey years (Quinn and Keough 2002).

I used the Geostatistical Wizard in ArcGIS 10.0 to generate interpolated prediction and standard error surfaces for total breeding period precipitation for both years. I compared optimized inverse distance weighted and ordinary kriging interpolation models through an iterative process to find a “best fit” prediction of the data.

The U.S. Department of Agriculture Natural Resources Conservation Service's PRISM spatial climate data are interpolations of temperature and precipitation across the continental United States (PRISM Climate Group 2004). PRISM data are derived from NCDC climate data from and integrated with the National Elevation Dataset (PRISM Climate Group 2004). I obtained PRISM data layers for monthly average daily temperatures (°C, mean, minimum and maximum) for April-June 2009 and 2010 and for long-term averages (1971-2000) and extracted them to the sample frame. Values for monthly precipitation and temperature were assigned to survey points and were compared between survey years and with long-term averages using paired t-tests or non-parametric Mann-Whitney U tests.

Observations. I used the two-sample test for equality of proportions to test for differences in the frequency of occurrence between passive listening and call-broadcast periods to
test whether call-broadcast survey methods increased detectability of focal species. Responses were treated cumulatively by species, as species detection was evaluated by passive vs. broadcast periods (i.e., species detection during species-specific broadcasts was not assessed). I used Pearson’s Chi-squared test to test for independence among frequencies of observations among wind speed and background noise categories.

I calculated summary statistics (e.g., mean, standard error, median, range) of observation chronologies for marsh bird species. I used Analysis of Variance (ANOVA) to test for differences in detection date (1) among focal species, (2) among individual species vocalization types and (3) between years. Residual plots were inspected to assess distributional assumptions of parametric models. I determined for each species the percent of individuals observed from vocalizations versus visual only detections. I calculated the cumulative percentage of sites with observations and cumulative percentage of observations for each species after each survey visit to examine the differences in observation chronologies among species.

I calculated summary statistics (e.g., mean, standard error, median, range) of initial observation distances to each marsh bird species. Observations were filtered post hoc into species-specific observation radii. I inspected the distribution of observation distances and used the third quartile (75th percentile) as a guide for setting maximum bounds on observation (observation radius). This process reduced the number of observations but did not change the presence/absence status of focal species at sites. I used ANOVA to test for differences in initial observation distance among marsh birds. Species differences were further tested between survey years, across visits, among vocalization types, among wind speed categories, and among background noise categories using t-tests, ANOVA, and the post hoc Tukey’s honest significant test. I used simple linear regression of initial observation distance on ordinal date for marsh bird
species to test for temporal effects across the survey season. All statistics were conducted in R version 2.11.1 (R Development Core Team 2010).

RESULTS

Weather

April precipitation was lower in 2010 than in 2009 for cooperative stations (U = 1194, Z = -6.41, P < 0.001) (Table 2.2). May precipitation was 41.4 mm higher in 2010 (95% CI: 34.3-48.3; t100=11.64, P < 0.001) than in 2009. June Precipitation was 58.2 mm higher in 2010 (95% CI: 48.3-68.1; t100=11.74, P ≤ 0.001) than in 2009. Total breeding period precipitation was 59.7 mm higher in 2010 vs. 2009 (95% CI: 47.0-73.4; t100 = 9.27, P < 0.001). General patterns of total breeding period precipitation differed between years although there was a positive westward trend in both years; see Appendix E for prediction surfaces. Similar differences in precipitation were observed between PRISM and for cooperative weather stations (Table 2.1). Total precipitation for the year prior to the breeding season was 202.9 mm higher in 2009 vs. 2010 (95% CI: 187.52-218.22; t316 = 26.00, P < 0.001).

Monthly mean daily temperature was slightly higher in 2010 than in 2009 for March - June (Table 2.2). This pattern was largely repeated for monthly mean daily minimum and maximum temperatures (Table 2.2). Despite differences in precipitation and temperature at sites between years, the distribution of sites where focal species were observed was similar between years across the sample frame (Appendix E).

Detections

Frequency of recorded occurrence of marsh bird species and total observations varied among survey sites (Table 2.3). Common Gallinules were observed on 17.1% of sites and their frequency of occurrence on survey sites was higher in 2010 vs. 2009 (95% CI: 0.014 – 0.160; \( \chi^2 \))
The frequency of sites with observations of focal species was similar between survey years for Pied-billed Grebes (25.3%, $\chi^2 = 1.96, P = 0.161$), American Bitterns (3.3%, $\chi^2 = 0.60, P = 0.440$), Least Bitterns (9.3%, $\chi^2 = 3.81, P = 0.051$), Virginia Rails (12.9%, $\chi^2 = 0.17, P = 0.685$), Soras (11.6%, $\chi^2 = 0.00, P = 1.000$), and American Coots (8.4%, $\chi^2 = 0.15, P = 0.696$). I observed King Rails and Black Terns on only 0.4% and 1.6% of sites respectively (see Willard 2011 for detailed descriptions of sites with observations of these species).

Species that were observed with higher frequency during call-broadcast periods than from passive listening periods included Pied-billed Grebes (95% CI: 0.127 – 0.258; $\chi^2 = 33.48, P \leq 0.001$), Least Bitterns (95% CI: 0.016 – 0.500; $\chi^2 = 13.43, P \leq 0.001$), Virginia Rails (95% CI: 0.536 – 0.735; $\chi^2 = 105.06, P \leq 0.001$), Soras (95% CI: 0.563 – 0.812; $\chi^2 = 73.00, P \leq 0.001$), and Common Gallinules (95% CI: 0.033 – 0.207; $\chi^2 = 7.45, P = 0.006$) (Table 2.4). I failed to detect differences in frequencies of observations between call-broadcast and passive listening periods for American Bitterns ($\chi^2 = 1.47, P = 0.225$), King Rails ($\chi^2 = 1.37, P = 0.242$), American Coots ($\chi^2 = 3.12, P = 0.077$), and Black Terns ($\chi^2 = 0.00, P = 1$) (Table 2.4).

**Observation chronologies.** Mean observation date varied among species ($F_{8,32} = 10.08, P \leq 0.001$) with Sora observations occurring earlier than all other species (Tukey’s HSD, 95% confidence limit range: 2-34 days, $P$ range: $\leq 0.001 – 0.017$). Marsh birds as a group were most commonly observed in late May and early June (Figure 2.2). The probability of observing a marsh bird at a site increased with the number of survey visits (Table 2.3). Site-level presence and percent of total observations of marsh birds accumulated at different rates (Table 2.3). The majority of observations of Sora were recorded by the end of the first survey period, recording half of their observations by May 17th (Figure 2.3). The majority of observations for all other focal species were recorded during the second survey period. I recorded half of my observations of Pied-billed Grebes, Least Bitterns, Virginia Rails, Common Gallinules, American Coots, Black
Terns by 1 June. Common Gallinule, Least Bittern, Pied-billed Grebe and Virginia Rail observations were more evenly spaced among survey visits. Half of all American Bitterns were observed by 5 June. The majority of King Rail observations were recorded during the final survey period, half of them by 9 June. Pied-billed Grebe and Common Gallinule had very similar observation chronologies (Figure 2.3). Sora and Virginia Rail, species with similar breeding habitat requirements (Appendix A), had very different observation chronologies, with observations of Sora occurring earlier than Virginia Rails (Figure 2.2).

Mean observation date for Virginia Rails was 4.8 days earlier in 2010 than in 2009 (95% CI: 0.3 - 9.4; \( t_{127} = 2.10, P = 0.037 \)) (Table 2.5). I failed to detect differences in mean observation date between survey years for Pied-billed Grebes \( (t_{414} = 1.45, P = 0.150) \), American Bitterns \( (t_{15} = 0.50, P = 0.623) \), Least Bitterns \( (t_{59} = 0.00, P = 0.995) \), Soras \( (t_{78} = 1.45 P = 0.149) \), Common Gallinules \( (t_{256} = 0.60, P = 0.549) \), and American Coots \( (t_{64} = 1.07, P = 0.287) \) (Table 2.5).

All focal species were observed primarily from vocalizations, and vocalizations were dominated (≥ 67%) by a single call type for each species (Table 2.5). Vocal observation for American Bitterns, Least Bitterns, and Black Terns were limited to a single vocalization type. Mean observation date for Soras varied among vocalization types \( (F_{2,76} = 3.78, P = 0.027) \) with “whinny” vocalizations occurring 10.4 days earlier than “keep” vocalizations (95% CI: 1.35 – 19.5, Tukey HSD, \( P = 0.020 \)). Mean observation date was similar among vocalization types for Pied-billed Grebes \( (F_{1,392} = 3.12, P = 0.078) \), Virginia Rails \( (F_{2,123} = 0.29, P = 0.749) \), Common Gallinules \( (F_{2,245} = 1.05, P = 0.351) \), and American Coots \( (F_{3,48} = 2.09, P = 0.114) \) (Table 2.5).

Observation ambient influences. The effects of wind speed and background noise on observation of marsh birds varied among focal species. The frequency of observations of focal species varied among wind speed categories for Pied-billed Grebe \( (\chi^2_{5} = 88.38, P < 0.001) \), American Bittern \( (\chi^2_{5} = 18.81, P = 0.002) \), Sora \( (\chi^2_{5} = 11.75, P = 0.038) \), Common Gallinule \( (\chi^2_{5} = 46 \).
= 11.43, P = 0.043), and American Coot (χ² = 19.92, P < 0.001), and declined with higher wind speed category. No evidence suggested that wind speed affected the observations of Least Bitterns (χ² = 3.39, P = 0.640) or Virginia Rails (χ² = 10.82, P = 0.055). Frequency of observations of Least Bitterns declined with increasing background noise category (χ² = 9.53, P = 0.023). There was no evidence to suggest that background noise level affected observation of Pied-billed Grebes (χ² = 2.68, P = 0.443), American Bitterns (χ² = 1.18, P = 0.757), Virginia Rails (χ² = 5.58, P = 0.134), Soras (χ² = 3.63, P = 0.304), Common Gallinules (χ² = 3.08, P = 0.380), or American Coots (χ² = 5.27, P = 0.153).

**Observation distance.** Median initial observation distances varied among species (F = 83.20, P < 0.001) (Table 2.6, Figure 2.3). Pied-billed Grebes and Black Terns were observed at farther distances than all rails (Table 2.6). The post hoc observation radii, centered roughly on the 75th percentile of all observation distances for each species, were (1) 100 m for Least Bitterns, King Rails, Virginia Rails, Soras, Common Gallinules and American Coots, (2) 150 m for American Bitterns and Black Terns, and (3) 200 m for Pied-billed Grebes (Table 2.6).

Mean initial observation distance for Virginia Rail was 9.2 m closer in 2010 than in 2009 (95% CI: 0.1 – 18.4; t = 4.03, P = 0.047) (Table 2.7). I failed to detect differences in mean initial observation distances between survey years for Pied-billed Grebes (t = 1.78, P = 0.075), American Bitterns (t = -0.54, P = 0.597), Least Bitterns (t = 0.61, P = 0.548), Soras (t = 1.50, P = 0.139), Common Gallinules (t = 1.60, P = 0.110), and American Coots (t = 1.07, P = 0.287) (Table 2.7).

I failed to detect differences in mean initial observation distances across survey visits for Pied-billed Grebes (F = 0.02, P = 0.979), American Bitterns (F = 1.23, P = 0.321), Least Bitterns (F = 0.78 P = 0.464), Virginia Rails (F = 2.26 P = 0.108), Soras (F = 0.21, P = 0.815), Common Gallinules (F = 0.11, P = 0.893), and American Coots (F = 1.54, P =
0.226). Mean initial observation distances were also similar across ordinal dates for Pied-billed Grebes \((F_{1,393} = 0.07, P = 0.786)\), American Bitterns \((F_{1,15} = 0.98, P = 0.337)\), Least Bitterns \((F_{1,59} = 0.02, P = 0.878)\), Virginia Rails \((F_{1,125} = 3.18, P = 0.077)\), Sora\((s) (F_{1,393} = 0.54, P = 0.463)\), Common Gallinules \((F_{4,245} = 1.55, P = 0.187)\), and American Coots \((F_{1,64} = 0.84, P = 0.362)\).

Observation distance varied among call types for Pied-billed Grebes \((t_{375} = -4.87, P \leq 0.001)\), Common Gallinules \((F_{2,244} = 9.16, P < 0.001)\), and American Coots \((F_{3,48} = 5.91, P = 0.002)\) (Table 2.7). Pied-billed Grebes were observed 44 m farther on average with “owhoop” than “hyena” calls (95% CI: 26 - 61; \(t_{375} = -4.87, P \leq 0.001)\). Common Gallinules were observed 16 m farther on average with “wipeout” than “keep” calls (95% CI: 7 – 25, Tukey’s HSD, \(P \leq 0.001)\). American Coots were observed 33 m farther on average with “burr-up” than “beep” calls (95% CI: 5 – 61; Tukey HSD, \(P = 0.015)\) and 39 m farther with “burr-up” than “honk” calls (95% CI: 38 – 77; Tukey HSD, \(P = 0.046)\). I failed to detect differences in mean initial observation distances among call types for Virginia Rails \((F_{2,121} = 1.31, P = 0.274)\) and Sora\((s) (F_{2,76} = 2.05, P = 0.135)\) (Table 2.7).

Observation distance for Pied-billed Grebes varied among wind speed categories \((F_{5,384} = 3.24, P = 0.007)\), and was 22 m closer for wind speed category 2 vs. 1 (95% CI: 0.7 – 43.4; Tukey HSD, \(P = 0.038)\). Observation distances of Pied-billed Grebes for all other wind speed pair comparisons among were not significantly different (Tukey HSD, \(P: 0.060 – 0.997)\). I failed to detect an effect of wind speed on mean initial observation distances for American Bitterns \((F_{3,13} = 0.42, P = 0.740)\), Least Bitterns \((F_{4,56} = 0.98, P = 0.424)\), Virginia Rails \((F_{4,122} = 1.97, P = 0.104)\), Sora\((s) (F_{3,76} = 2.02, P = 0.119)\), Common Gallinules \((F_{1,248} = 0.07, P = 0.797)\), and American Coots \((F_{4,61} = 0.64, P = 0.637)\). I also failed to detect an effect of background noise on mean initial observation distance for Pied-billed Grebes \((F_{3,386} = 1.56, P = 0.199)\), American
Bitterns ($F_{2,14} = 0.35, P = 0.714$), Least Bitterns ($F_{2,58} = 1.622, P = 0.21$), Soras ($F_{3,75} = 0.10, P = 0.962$), Virginia Rails ($F_{3,123} = 1.14, P = 0.336$), Common Gallinules ($F_{3,246} = 1.08, P = 0.358$), and American Coots ($F_{3,62} = 1.82, P = 0.153$).

**DISCUSSION**

Based on results of my study, the survey window recommended by the standardized marsh bird monitoring protocol (Conway 2009) was adequate to capture peak detection intervals of all focal marsh bird species during the breeding period in the study area. This study was part of a larger effort to better understand statewide distribution of marsh birds in the glaciated region of Ohio. I sampled wetlands in proportion to where they occurred, conducting call-broadcast surveys for marsh birds at 450 spatially-balanced sites across the state in public and private lands. I documented observation chronologies and distances to focal marsh birds by observation type (visual and vocalization by call type) and the effects of wind speed and background noise on detectability. These data can inform the timing and expectations of future marsh bird monitoring efforts in the study area.

Call-broadcast methods increased detectability of several focal species. Of the species whose vocalizations were included in the call-broadcast sequence, call-broadcast resulted in higher detectability for Pied-billed Grebes, Least Bitterns, Virginia Rails and Soras, but not American Bitterns or King Rails. Willard (2011) found that Pied-billed Grebe, Sora and Virginia Rail responses peaked in their broadcast intervals during call-broadcast surveys suggesting a direct response to broadcast; however, this was not observed for Least Bittern (Willard 2011). Call-broadcast methods increased the probability of observing several species with similar magnitude (20 – 780%) as reported in other studies (Allen et al. 2004, Conway and Nadeau 2010). Call-broadcast methods may also increase the detectability of non-target marsh birds. For example, Common Gallinule detectability was improved by 20% over passive listening even
though their vocalizations were not included in the call-broadcast sequence. This may indicate that Common Gallinules responded to heterospecific calls during call-broadcast surveys.

Observation chronologies varied among focal species, with Sora peaking earlier than all other species. However, other studies found peak detection dates for American Bitterns and Pied-billed Grebes occurred earlier than for Soras and Virginia Rails (Gibbs and Melvin 1993, Rehm and Baldasarre 2007). This may indicate that peak detection dates for marsh birds vary geographically. My observations were consistent with other studies documenting marsh bird observation chronologies during the breeding period (Johnson and Dinsmore 1986, Lor and Malecki 2002, Tozer et al. 2006).

The temporal distribution of observations I recorded closely parallel nest initiation periods observed for Pied-billed Grebes, Least Bitterns, Virginia Rails, and Soras in western New York (Lor and Malecki 2006). Although nest searches were not conducted in this study, I suspect the temporal distribution of species observations mirrored nest initiation (Dinsmore 1986). Like other studies, marsh bird vocalizations dominated species observations (Marion et al. 1981, Swift et al. 1988, Gibbs and Melvin 1993). Moreover, a single vocalization type dominated auditory observations for each species. Dominant vocalizations are believed to serve mate communication and territory defense functions (Appendix B). Among species with multiple vocalizations, I recorded differences in observation chronologies among call types for Sora only. Sora alarm calls were observed later in the survey season than vocalizations believed to function as mate communication and territorial defense. Differentiation of vocalization function may be stronger in Sora than among other species. Peak observation of Sora occurred earlier than other focal species, thus I expect their nesting chronology was completed before other species.

Higher wind speed negatively affected detectability of some marsh birds. However, results from wind speed analyses may be confounded by survey location. Species whose
observations were most effected by wind speed (e.g., Pied-billed Grebe, American Bittern) more commonly occurred in large, emergent marsh complexes < 10 km from Lake Erie where wind speeds tend to be higher than in areas further from the coast, and were detected at greater distances on average than other species. Background noise negatively affected detectability of Least Bitterns. Least Bitterns are general detected within 50 m of the observer (Gibbs and Melvin 1993) and their vocalizations are much quieter than other species.

Average observation distance varied among vocalization types for Pied-billed Grebe, Common Gallinule, and American Coot and tended to be greater for vocalizations that are believed to function in mate attraction. Obviously, species vary in their ability to project certain vocalizations and/or humans in their ability to detect them. Average observation distance also varied among species and these results were consistent with other studies (Gibbs and Melvin 1993, Allen et al. 2004).

Contrary to my hypothesis, observation distances to marsh birds were similar across the survey period, whether among survey visits or across ordinal dates. Observers adjust distance estimates based on prevailing conditions including wind speed and wind direction when species are observed by vocalizations only (Simons et al. 2007). I found that mean observation distance did not vary among wind speed categories for any species except Pied-billed Grebe. This was likely a product of the high detection distances observed for Pied-billed Grebe. Although observers were trained and evaluated in distance estimation prior to conducting surveys, and were aided by the use of laser range finders and aerial photographs during surveys, there is error in estimating true observation distances to marsh birds especially when observation were solely from vocalizations.

Distances to responding birds during call-broadcast surveys can provide a basis for estimating marsh bird density (Manci and Rusch 1988). However, the application of unlimited-
radius point counts may have resulted in under-counting of individual marsh birds during call-broadcast surveys. Simons et al. (2007) found that application of post hoc observation radii resulted in fewer observations compared with surveys conducted with predetermined observation distance bins. Several factors can bias distance estimation and associated density estimates. First, observer error in distance estimation is a significant challenge with any bird group and a most obvious source when generating density estimates. Secondly, species responsiveness may be reduced at the survey location. For example, I noticed that Pied-billed Grebes were less likely to vocalize when close (< 50 m) to the survey location, which could result in negative bias. Thirdly, some species may have been attracted to broadcasts more than others. Virginia Rails and Soras moved closer to speakers before vocalizing on several occasions. Finally, density estimation based on vocal detections could result in positive bias if birds are drawn into post hoc detection radii or negative bias if birds farther away from the broadcast location are not provoked sufficiently to respond and may go undetected.

**MANAGEMENT IMPLICATIONS**

Data collected using the standardized marsh bird monitoring protocol and related call-broadcast surveys can be used to assess status and trends of several marsh bird species in the glaciated region of Ohio. Call-broadcast methods improved the probability of observing many focal species. Although observation chronologies and distances varied among focal species and call types in this study, data suggested the survey window (1 May – 15 June) is adequate to capture peak detection periods for all species. Wind speed and background noise may lower an observer’s ability to observe certain focal species. Strict adherence to the standardized protocol regarding surveying during high wind and background noise is recommended. Summaries of species observation rates, source (sight vs. call) and distance to detection, and temporal changes
in responses to call playbacks can be used to implement marsh bird monitoring protocols for secretive marsh birds in Ohio and the Midwestern U.S.
LITERATURE CITED


Ohio Department of Natural Resources Division of Wildlife. 2006. Comprehensive wildlife conservation strategy. Ohio Department of Natural Resources, Columbus, Ohio. USA.


Willard, K. 2011. Habitat associations of breeding marsh birds within the glaciated region or Ohio, USA. Master’s thesis: The Ohio State University, Columbus, Ohio, USA.
Table 2.1. Mean monthly precipitation in mm (± 95% confidence interval) at locations surveyed for marsh birds in the glaciated region of Ohio, USA, for 2009, 2010 and long-term (1971-2000) ranges. Data were assigned to survey locations from PRISM spatial climate layers (PRISM Climate Group 2004).

<table>
<thead>
<tr>
<th></th>
<th>Survey sites, 2009 (n = 209)</th>
<th>Survey sites, 2010 (n = 241)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March:</td>
<td>85.08 ± 2.79</td>
<td>71.60 ± 0.71</td>
</tr>
<tr>
<td>April:</td>
<td>99.57 ± 1.68</td>
<td>85.21 ± 0.51</td>
</tr>
<tr>
<td>May:</td>
<td>75.39 ± 1.32</td>
<td>94.37 ± 0.89</td>
</tr>
<tr>
<td>June:</td>
<td>96.93 ± 1.29</td>
<td>102.64 ± 0.56</td>
</tr>
</tbody>
</table>
Table 2.2. Daily temperatures in °C (mean ± 95% confidence interval; mean, minimum, and maximum) at locations surveyed for marsh birds in the glaciated region of Ohio, USA, for 2009, 2010 and long-term (1971-2000) ranges. Data were assigned to survey locations from PRISM spatial climate layers (PRISM Climate group 2004).

<table>
<thead>
<tr>
<th></th>
<th>Survey sites, 2009 (n = 209)</th>
<th>Survey sites, 2010 (n = 241)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009</td>
<td>1971-2000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>March:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>-2.95 ± 0.08</td>
<td>-0.96 ± 0.08</td>
</tr>
<tr>
<td>minimum</td>
<td>-2.28 ± 0.10</td>
<td>-2.45 ± 0.08</td>
</tr>
<tr>
<td>maximum</td>
<td>10.47 ± 0.13</td>
<td>8.08 ± 0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>2.35 ± 0.07</td>
<td>5.18 ± 0.12</td>
</tr>
<tr>
<td>minimum</td>
<td>3.71 ± 0.08</td>
<td>2.95 ± 0.10</td>
</tr>
<tr>
<td>maximum</td>
<td>15.56 ± 0.08</td>
<td>14.72 ± 0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>7.80 ± 0.08</td>
<td>11.27 ± 0.12</td>
</tr>
<tr>
<td>minimum</td>
<td>9.20 ± 0.08</td>
<td>9.00 ± 0.12</td>
</tr>
<tr>
<td>maximum</td>
<td>21.68 ± 0.08</td>
<td>20.95 ± 0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>13.73 ± 0.07</td>
<td>22.37 ± 0.08</td>
</tr>
<tr>
<td>minimum</td>
<td>13.80 ± 0.13</td>
<td>14.14 ± 0.13</td>
</tr>
<tr>
<td>maximum</td>
<td>25.62 ± 0.10</td>
<td>25.9 ± 0.07</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean daily temperature is not available for the period 1971-2000.
Table 2.3. Cumulative percentage of survey sites with observations and cumulative percentage of total observations of focal marsh birds in the glaciated region of Ohio, USA. Surveys included 3 visits at each site May—June 2009 (n = 209) and 2010 (n = 241). Note: Cumulative values for visit 3 = 100%.

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Sites (% of total)</th>
<th>Detections (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>Visit 1</td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td>2009</td>
<td>46</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>68</td>
<td>75</td>
</tr>
<tr>
<td>American Bittern</td>
<td>2009</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>2009</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>King Rail</td>
<td>2009</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>2009</td>
<td>25</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>Sora</td>
<td>2009</td>
<td>21</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>38</td>
<td>45</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>2009</td>
<td>26</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>51</td>
<td>65</td>
</tr>
<tr>
<td>American Coot</td>
<td>2009</td>
<td>16</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>22</td>
<td>59</td>
</tr>
<tr>
<td>Black Tern</td>
<td>2009</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>5</td>
<td>40</td>
</tr>
</tbody>
</table>
Table 2.4. Number of surveys with observations of marsh bird species in the glaciated region of Ohio, USA, May—June 2009 and 2010. The number of observations by survey segment (passive listening, call-broadcast, and outside timed survey period) is also provided.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of surveys with observations</th>
<th>Survey segment detections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Passive listening</td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td>416</td>
<td>235</td>
</tr>
<tr>
<td>American Bittern</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>61</td>
<td>31</td>
</tr>
<tr>
<td>King Rail</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>129</td>
<td>12</td>
</tr>
<tr>
<td>Sora</td>
<td>80</td>
<td>11</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>258</td>
<td>146</td>
</tr>
<tr>
<td>American Coot</td>
<td>66</td>
<td>33</td>
</tr>
<tr>
<td>Black Tern</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>
Table 2.5. Mean ordinal date (± 95% confidence interval) for initial observation type (vocalization or visualization) of individual marsh birds recorded during call-broadcast surveys in the glaciated region of Ohio, USA, May—June 2009 and 2010. Ordinal date of 120 = 30 April; 140 = 20 May; 160 = 9 June. For descriptions of call types see Appendix B.

<table>
<thead>
<tr>
<th>Species</th>
<th>Observation type</th>
<th>Call type</th>
<th>n</th>
<th>Mean ± 95% CI</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>Vocalization</td>
<td>&quot;hyena&quot;</td>
<td>40</td>
<td>152.4 ± 4.6</td>
<td>135</td>
<td>156</td>
<td>166</td>
<td>(130, 168)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;owhoop&quot;</td>
<td>480</td>
<td>149.5 ± 1.1</td>
<td>137</td>
<td>150</td>
<td>162</td>
<td>(121, 173)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>28</td>
<td>155.8 ± 4.2</td>
<td>148</td>
<td>162</td>
<td>164</td>
<td>(129, 168)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>416</td>
<td>149.8 ± 1.2</td>
<td>136</td>
<td>150</td>
<td>163</td>
<td>(121, 173)</td>
</tr>
<tr>
<td>American Bittern</td>
<td>Vocalization</td>
<td>&quot;pump-er-lunk&quot;</td>
<td>15</td>
<td>154.6 ± 6.5</td>
<td>143</td>
<td>164</td>
<td>164</td>
<td>(134, 167)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>2</td>
<td>144.0 ± 19.6</td>
<td>139</td>
<td>134</td>
<td>149</td>
<td>(134, 154)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>17</td>
<td>153.4 ± 6.2</td>
<td>140</td>
<td>156</td>
<td>164</td>
<td>(134, 167)</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>Vocalization</td>
<td>&quot;coo-coo&quot;</td>
<td>59</td>
<td>150.2 ± 3.0</td>
<td>139</td>
<td>150</td>
<td>163</td>
<td>(130, 169)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;kak-kak&quot;</td>
<td>1</td>
<td>150</td>
<td></td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>1</td>
<td>164</td>
<td></td>
<td>164</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>61</td>
<td>150.4 ± 2.9</td>
<td>139</td>
<td>150</td>
<td>163</td>
<td>(130, 169)</td>
</tr>
<tr>
<td>King Rail</td>
<td>Vocalization</td>
<td>&quot;clatter&quot;</td>
<td>4</td>
<td>154 ± 6.8</td>
<td>148</td>
<td>154</td>
<td>160</td>
<td>(148, 160)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;kek&quot;</td>
<td>1</td>
<td>164</td>
<td></td>
<td>164</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>1</td>
<td>164</td>
<td></td>
<td>164</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>6</td>
<td>157.3 ± 6.0</td>
<td>151</td>
<td>160</td>
<td>163</td>
<td>(148, 164)</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>Vocalization</td>
<td>&quot;grunt&quot;</td>
<td>122</td>
<td>150.6 ± 2.3</td>
<td>141</td>
<td>152</td>
<td>161</td>
<td>(129, 176)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;sqwk&quot;</td>
<td>5</td>
<td>149.0 ± 11.4</td>
<td>141</td>
<td>156</td>
<td>159</td>
<td>(130, 159)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td>&quot;tick-it&quot;</td>
<td>11</td>
<td>148.3 ± 8.4</td>
<td>134</td>
<td>149</td>
<td>163</td>
<td>(132, 168)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>3</td>
<td>147.3 ± 1.7</td>
<td>147</td>
<td>147</td>
<td>148</td>
<td>(146, 149)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td></td>
<td>43</td>
<td>153.8 ± 3.9</td>
<td>145</td>
<td>153</td>
<td>163</td>
<td>(131, 176)</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td></td>
<td>86</td>
<td>149.0 ± 2.6</td>
<td>139</td>
<td>147</td>
<td>161</td>
<td>(130, 169)</td>
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<td>129</td>
<td>150.7 ± 2.2</td>
<td>141</td>
<td>152</td>
<td>161</td>
<td>(130, 176)</td>
</tr>
</tbody>
</table>
Table 2.5 continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Observation type</th>
<th>Call type</th>
<th>n</th>
<th>Mean ± 95% CI</th>
<th>Q1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Median</th>
<th>Q3</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sora</td>
<td>Vocalization</td>
<td>&quot;keep&quot;</td>
<td>9</td>
<td>149.4 ± 10.0</td>
<td>137</td>
<td>147</td>
<td>164</td>
<td>(132, 174)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;per-weep&quot;</td>
<td>6</td>
<td>140.8 ± 7.7</td>
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<td>139</td>
<td>147</td>
<td>(129, 155)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;whinny&quot;</td>
<td>63</td>
<td>139.2 ± 2.5</td>
<td>131</td>
<td>135</td>
<td>146</td>
<td>(129, 167)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>1</td>
<td>132</td>
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</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>80</td>
<td>140.2 ± 2.4</td>
<td>132</td>
<td>137</td>
<td>147</td>
<td>(129, 174)</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>Vocalization</td>
<td>&quot;giddy-up&quot;</td>
<td>4</td>
<td>144.5 ± 7.2</td>
<td>143</td>
<td>147</td>
<td>148</td>
<td>(134, 151)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;keep&quot;</td>
<td>86</td>
<td>151.3 ± 2.4</td>
<td>141</td>
<td>152</td>
<td>161</td>
<td>(130, 169)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;wipeout&quot;</td>
<td>240</td>
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<td>138</td>
<td>150</td>
<td>163</td>
<td>(121, 169)</td>
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<td></td>
<td>Visualization</td>
<td></td>
<td>24</td>
<td>148.8 ± 5.2</td>
<td>138</td>
<td>144</td>
<td>164</td>
<td>(134, 165)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>258</td>
<td>150.4 ± 1.5</td>
<td>139</td>
<td>151</td>
<td>163</td>
<td>(121, 169)</td>
</tr>
<tr>
<td>American Coot</td>
<td>Vocalization</td>
<td>&quot;beep&quot;</td>
<td>6</td>
<td>148.5 ± 12.9</td>
<td>135</td>
<td>149</td>
<td>161</td>
<td>(130, 168)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;burr-up&quot;</td>
<td>38</td>
<td>150.9 ± 3.7</td>
<td>141</td>
<td>150</td>
<td>163</td>
<td>(129, 166)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;hic-up&quot;</td>
<td>5</td>
<td>153.8 ± 16.7</td>
<td>153</td>
<td>164</td>
<td>165</td>
<td>(121, 166)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;honk&quot;</td>
<td>3</td>
<td>132.7 ± 1.3</td>
<td>132</td>
<td>132</td>
<td>133</td>
<td>(132, 134)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>11</td>
<td>137.0 ± 2.1</td>
<td>135</td>
<td>135</td>
<td>139</td>
<td>(134, 146)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>66</td>
<td>146.9 ± 3.2</td>
<td>135</td>
<td>147</td>
<td>162</td>
<td>(121, 168)</td>
</tr>
<tr>
<td>Black Tern</td>
<td>Vocalization</td>
<td>&quot;keff&quot;</td>
<td>13</td>
<td>146.8 ± 6.4</td>
<td>134</td>
<td>148</td>
<td>151</td>
<td>(134, 167)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>5</td>
<td>152.0 ± 5.1</td>
<td>148</td>
<td>151</td>
<td>151</td>
<td>(148, 162)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>18</td>
<td>149.0 ± 5.8</td>
<td>139</td>
<td>151</td>
<td>163</td>
<td>(121, 169)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Q1 = 25<sup>th</sup> percentile, Q3 = 75<sup>th</sup> percentile
Table 2.6. Initial observation distance (m) of all focal marsh birds recorded at survey sites during call-broadcast surveys in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Species</th>
<th>n</th>
<th>Mean ± 95% CI</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>499</td>
<td>164.1 ± 7.5</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>(15, 600)</td>
</tr>
<tr>
<td>American Bittern</td>
<td>19</td>
<td>94.7 ± 20.0</td>
<td>65</td>
<td>100</td>
<td>128</td>
<td>(30, 180)</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>76</td>
<td>74.2 ± 11.9</td>
<td>38</td>
<td>60</td>
<td>90</td>
<td>(10, 300)</td>
</tr>
<tr>
<td>King Rail</td>
<td>6</td>
<td>37.7 ± 25.7</td>
<td>21</td>
<td>33</td>
<td>34</td>
<td>(10, 100)</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>129</td>
<td>41.7 ± 4.7</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>(2, 130)</td>
</tr>
<tr>
<td>Sora</td>
<td>96</td>
<td>82.5 ± 11.3</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>(10, 350)</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>327</td>
<td>83.5 ± 6.6</td>
<td>40</td>
<td>70</td>
<td>100</td>
<td>(5, 400)</td>
</tr>
<tr>
<td>American Coot</td>
<td>75</td>
<td>70.2 ± 11.6</td>
<td>40</td>
<td>70</td>
<td>80</td>
<td>(10, 375)</td>
</tr>
<tr>
<td>Black Tern</td>
<td>16</td>
<td>126.9 ± 26</td>
<td>78</td>
<td>135</td>
<td>155</td>
<td>(30, 200)</td>
</tr>
</tbody>
</table>

* Q1 = 25th percentile, Q3 = 75th percentile
* 200 meter post hoc observation radius
* 150 meter post hoc observation radius
* 100 meter post hoc observation radius
Table 2.7. Initial observation type (vocalization or visual) by distance (m) to marsh birds during call-broadcast surveys in the glaciated region of Ohio, USA, May—June 2009, 2010, and combined (ALL).

<table>
<thead>
<tr>
<th>Species</th>
<th>Observation type</th>
<th>Call type</th>
<th>N</th>
<th>Mean ± 95% CI</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>Vocalization</td>
<td>&quot;hyena&quot;</td>
<td>34</td>
<td>91.8 ± 15.1</td>
<td>56</td>
<td>100</td>
<td>130</td>
<td>(20, 160)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;owhoop&quot;</td>
<td>343</td>
<td>135.4 ± 5.3</td>
<td>100</td>
<td>130</td>
<td>200</td>
<td>(15, 200)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>17</td>
<td>102.6 ± 29.1</td>
<td>50</td>
<td>100</td>
<td>125</td>
<td>(15, 200)</td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>395</td>
<td>130.3 ± 5.1</td>
<td>90</td>
<td>125</td>
<td>175</td>
<td>(15, 200)</td>
</tr>
<tr>
<td>American Bittern</td>
<td>Vocalization</td>
<td>&quot;pump-er-lunk&quot;</td>
<td>15</td>
<td>87.0 ± 18.2</td>
<td>65</td>
<td>80</td>
<td>113</td>
<td>(30, 150)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>2</td>
<td>70.0 ± 58.8</td>
<td>55</td>
<td>70</td>
<td>85</td>
<td>(40, 100)</td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>17</td>
<td>85.0 ± 17.0</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>(30, 150)</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>Vocalization</td>
<td>&quot;coo-coo&quot;</td>
<td>59</td>
<td>53.4 ± 6.3</td>
<td>30</td>
<td>50</td>
<td>75</td>
<td>(10, 100)</td>
</tr>
<tr>
<td></td>
<td>&quot;kak-kak&quot;</td>
<td>1</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td>&quot;kak-kak&quot;</td>
<td>1</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>61</td>
<td>53.3 ± 6.2</td>
<td>30</td>
<td>50</td>
<td>75</td>
<td>(10, 100)</td>
</tr>
<tr>
<td>King Rail</td>
<td>Vocalization</td>
<td>&quot;clatter&quot;</td>
<td>4</td>
<td>29.0 ± 8.0</td>
<td>28</td>
<td>33</td>
<td>34</td>
<td>(17, 34)</td>
</tr>
<tr>
<td></td>
<td>&quot;kek&quot;</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td>&quot;kek&quot;</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>6</td>
<td>37.7 ± 25.7</td>
<td>21</td>
<td>33</td>
<td>34</td>
<td>(10, 100)</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>Vocalization</td>
<td>&quot;grunt&quot;</td>
<td>109</td>
<td>41.6 ± 4.6</td>
<td>25</td>
<td>40</td>
<td>60</td>
<td>(2, 100)</td>
</tr>
<tr>
<td></td>
<td>&quot;sqwk&quot;</td>
<td>5</td>
<td>23.0 ± 20.2</td>
<td>5</td>
<td>15</td>
<td>30</td>
<td>(5, 60)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;tick-it&quot;</td>
<td>10</td>
<td>40.1 ± 19.1</td>
<td>20</td>
<td>30</td>
<td>58</td>
<td>(6, 100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>2</td>
<td>20.5 ± 18.6</td>
<td>16</td>
<td>21</td>
<td>25</td>
<td>(11, 30)</td>
</tr>
<tr>
<td></td>
<td>ALL, 2009</td>
<td></td>
<td>44</td>
<td>46.4 ± 6.9</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>(2, 100)</td>
</tr>
<tr>
<td></td>
<td>ALL, 2010</td>
<td></td>
<td>83</td>
<td>37.2 ± 5.5</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td>(3, 100)</td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>127</td>
<td>40.4 ± 4.4</td>
<td>20</td>
<td>40</td>
<td>55</td>
<td>(2, 100)</td>
</tr>
<tr>
<td>Sora</td>
<td>Vocalization</td>
<td>&quot;keep&quot;</td>
<td>9</td>
<td>56.7 ± 16.3</td>
<td>40</td>
<td>60</td>
<td>75</td>
<td>(10, 80)</td>
</tr>
<tr>
<td></td>
<td>&quot;per-weep&quot;</td>
<td>6</td>
<td>81.7 ± 17.8</td>
<td>65</td>
<td>90</td>
<td>100</td>
<td>(50, 100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;whinny&quot;</td>
<td>63</td>
<td>62.0 ± 6.2</td>
<td>40</td>
<td>70</td>
<td>80</td>
<td>(13, 100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>1</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALL</td>
<td></td>
<td>80</td>
<td>63.3 ± 5.5</td>
<td>40</td>
<td>70</td>
<td>80</td>
<td>(10, 100)</td>
</tr>
</tbody>
</table>

Continued
<table>
<thead>
<tr>
<th>Species</th>
<th>Observation type</th>
<th>Call type</th>
<th>N</th>
<th>Mean ± 95% CI</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Gallinule</strong></td>
<td>Vocalization</td>
<td>&quot;giddy-up&quot;</td>
<td>4</td>
<td>45.0 ± 24.7</td>
<td>40</td>
<td>50</td>
<td>55</td>
<td>(10, 70)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;keep&quot;</td>
<td>75</td>
<td>46.0 ± 6.2</td>
<td>20</td>
<td>50</td>
<td>60</td>
<td>(5, 100)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;wipeout&quot;</td>
<td>168</td>
<td>61.9 ± 4.1</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>(10, 100)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>8</td>
<td>65.1 ± 21.6</td>
<td>55</td>
<td>60</td>
<td>95</td>
<td>(10, 100)</td>
</tr>
<tr>
<td></td>
<td><strong>ALL</strong></td>
<td></td>
<td>255</td>
<td>57.4 ± 3.5</td>
<td>30</td>
<td>60</td>
<td>80</td>
<td>(5, 100)</td>
</tr>
<tr>
<td><strong>American Coot</strong></td>
<td>Vocalization</td>
<td>&quot;beep&quot;</td>
<td>6</td>
<td>34.2 ± 8.9</td>
<td>26</td>
<td>35</td>
<td>40</td>
<td>(20, 50)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;burr-up&quot;</td>
<td>38</td>
<td>67.2 ± 7.5</td>
<td>60</td>
<td>73</td>
<td>80</td>
<td>(10, 100)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;hic-up&quot;</td>
<td>5</td>
<td>44.0 ± 30.1</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>(10, 100)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td>&quot;honk&quot;</td>
<td>5</td>
<td>28.3 ± 31.2</td>
<td>13</td>
<td>15</td>
<td>38</td>
<td>(10, 60)</td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
<td>11</td>
<td>45.5 ± 10.7</td>
<td>40</td>
<td>40</td>
<td>55</td>
<td>(10, 80)</td>
</tr>
<tr>
<td></td>
<td><strong>ALL</strong></td>
<td></td>
<td>66</td>
<td>56.7 ± 6.4</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>(10, 100)</td>
</tr>
<tr>
<td><strong>Black Tern</strong></td>
<td>Vocalization</td>
<td>&quot;keff&quot;</td>
<td>11</td>
<td>124.5 ± 25.9</td>
<td>85</td>
<td>120</td>
<td>150</td>
<td>(70, 200)</td>
</tr>
<tr>
<td></td>
<td>Vocalization</td>
<td></td>
<td>5</td>
<td>156.0 ± 64.6</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>(30, 200)</td>
</tr>
<tr>
<td></td>
<td><strong>ALL</strong></td>
<td></td>
<td>16</td>
<td>126.9 ± 26.0</td>
<td>78</td>
<td>135</td>
<td>155</td>
<td>(30, 200)</td>
</tr>
</tbody>
</table>

* Q1 = 25th percentile, Q3 = 75th percentile
Figure 2.1. Locations of marsh bird surveys in glaciated portions of Bird Conservation Regions in Ohio, USA, May—June 2009 and 2010.
Figure 2.2. Distribution of observations of focal marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010. See Appendix A for species 4-character codes. Note: Half (50%) of observations fall within the box with the solid, horizontal line representing the median value and the top of the box representing the 75th percentile. Twenty-five percent (25%) of values occur between the top of the box and the upper whisker (maximum value minus outliers (dots)) and 25% of observations fall between the lower whisker and the bottom of the box.
Figure 2.3. Observation distances (m) of focal marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010. See Appendix A for 4-character code is the American Ornithologist’s Union code for each species. Half (50%) of observations fall within the box with the solid, horizontal line representing the median value and the top of the box representing the 75th percentile. Twenty-five percent (25%) of values occur between the top of the box and the upper whisker (maximum value minus outliers (dots)) and 25% of observations fall between the lower whisker and the bottom of the box.
Chapter 3: Area-sensitivity of secretive marsh birds during the breeding period in the glaciated region of Ohio, USA.

ABSTRACT

Species that occur at lower frequencies or at lower abundance in smaller habitat patches are considered to be area-sensitive. Secretive marsh birds, including grebes, bitterns and rails are obligate wetland birds, and have experienced strong population declines. Current estimates of secretive marsh bird populations have been determined largely through expert opinion. I conducted call-broadcast surveys for nine species of secretive marsh birds in the glaciated region of Ohio, USA, during the breeding seasons in 2009 and 2010. The goals of this study were to determine frequency of occurrence and density of focal species among wetland size classes and water permanence categories and the probability of observing a focal species given scale-dependent wetland area and water permanence category. All focal species of secretive marsh birds that I studied exhibited area-sensitivity to some degree. Wetland size, water permanence, and scale-dependent wetland area were all important predictors of marsh bird observation probability. Local and regional populations of secretive marsh birds may be more efficiently and positively affected if habitat conservation and restoration efforts are targeted to larger, semi-permanently flooded wetlands in areas with higher amounts of landscape wetland area. Regional conservation planning efforts have used population estimates based on expert opinion to set habitat management objectives for these species. Density estimates presented here may be used to improve population estimates and habitat objectives for focal species in the study area.
INTRODUCTION

Effective conservation planning relies on a firm understanding of species-habitat requirements (NEAT 2006). The identification of limiting factors and development of models describing species-habitat associations are essential to developing habitat conservation objectives that achieve population goals (USFWS 2008). Resource managers use the best available information about species-habitat associations to make habitat conservation decisions when scientific understanding is incomplete (Petit et al. 1995). Understanding of the amount and type of habitat a species requires for survival is key to setting habitat conservation objectives for a species (Mueller et al. 1999).

The idea that some bird species are area-dependent or area-sensitive for their chosen habitat has been long studied (Bond 1957, Bayard and Elphick 2010). Area-sensitivity is often determined by evaluating differential use of habitats by a species across a gradient of habitat areas and types (Bayard and Elphick 2010). Area-sensitivity in birds has been expressed in various (3) ways; as the pattern of variation in frequency of occurrence (Bond 1957, Brown and Dinsmore 1986), or density (Brackney and Bookhout 1982, Benoit and Askins 2002, Miller et al. 2004) among habitat patches of varying size classes and habitat characteristics (Sugden 1979, Brackney and Bookhout 1982), and species’ occurrence as a function of habitat area and type (Robbins et al. 1989, Vickery et al. 1994, Naugle et al. 1999, Riffell et al. 2001).

Considerable attention has been given to studying the area requirements of forest-dependent (e.g., Robbins et al. 1989) and grassland-dependent (e.g., Vickery et al. 1994, Winter and Faaborg 1999) birds. Few studies have focused on determining area requirements of wetland-dependent birds (Brown and Dinsmore 1986, Craig and Beal 1992, Naugle et al. 1999, Johnson and Igl 2001, Riffell et al. 2001, Benoit and Askins 2002, Craig 2008). Even fewer studies have evaluated area requirements for secretive, wetland-dependent marsh birds including rails, bitterns,
coots, moorhens, and grebes whose populations have declined in the Great Lakes region (Timmermans et al. 2008). In addition, previous studies of area requirements of wetland-dependent birds were compromised of passive sampling approaches (Brown and Dinsmore 1986, Cashen 1998, Craig and Beal 1992, Naugle et al. 1999, Feaga 2010), which can lead to negative bias in local occurrence and density estimates (Conway 2009).

Determining area-sensitivity of wetland-dependent birds has several important conservation implications. First, the total area of emergent wetland has declined dramatically over the last century (Dahl 2000). Second, populations of wetland-dependent birds have declined over the last two decades (Crewe et al. 2006, Timmermans et al. 2008). Third, wetland-dependent bird species are a disproportionately large fraction of species listed as threatened or endangered (Boylan and Maclean 1997). Finally, several on-going conservation planning efforts for wetland-dependent birds make assumptions about area requirements that are untested (ODNR 2006, Soulliere et al. 2007, UMRGLR JV 2007).

Secretive marsh birds, including Pied-billed Grebes (*Podilymbus podiceps*), American Bitterns (*Botaurus lentiginosus*), Least Bitterns (*Ixobrychus exilis*), King Rails (*Rallus elegans*), Virginia Rails (*R. limicola*), Soras (*Porzana carolina*), Common Gallinules (*Gallinula galeata*), and American Coots (*Fulica americana*), and Black Terns (*Chlidonias niger*) are obligate wetland species requiring emergent marsh habitats throughout the annual cycle (Conway 2009). Understanding area-sensitivity of marsh birds is crucial for on-going conservation planning efforts in the Midwest region. Among these species, Virginia Rails are thought to have the lowest area-sensitivity with little to no differential habitat selection among emergent wetlands of varying sizes or types (Conway 1995, Zimmerman et al. 2002b), while American Bitterns have the highest area-sensitivity (Dechant et al. 2002). However, understanding of site-specific (e.g., wetland type and size) and landscape (e.g. % wetland area within various radii) area-sensitivity of
secretive marsh birds is not found in most species’ accounts or peer-reviewed literature, despite that most are assumed to be area-sensitive (Melvin and Gibbs 1996, Muller and Storer 1999, Bannor and Kiviat 2002, Brisbin and Mowbray 2002, Zimmerman et al. 2002a).

Area-sensitivity of marsh birds is often measured as the probability that a wetland is occupied by a certain species as a function of the wetland’s size and type (Gibbs et al. 1992a, b, Conway 1995, Melvin and Gibbs 1996, Muller and Storer 1999). However, there is a lack of information and disagreement in the literature on area-sensitivity for several secretive marsh birds. For example, Pied-billed Grebes use seasonal or permanent ponds \( \geq 0.2 \) ha in size, but Muller and Storer (1999) provided no landscape context (e.g. minimum percent wetland within a given radius required for site occupancy) for their observations. By contrast, Rehm and Baldassarre (2007) found that the area of marsh within 5 km radius of survey locations was a reliable predictor of Pied-billed Grebe relative abundance in New York marshes. Additionally, Crewe et al. (2006) labeled all secretive marsh birds except Common Gallinule and American Coot as area-sensitive marsh nesters in Great Lakes coastal marshes, conflicting with the findings of other studies (Bannor and Kiviat 2002, Brisbin and Mowbray 2002).

I assessed area-sensitivity for secretive marsh birds in the glaciated region of Ohio, USA. Improved understanding of species-habitat associations will increase effectiveness of bird habitat conservation decision-makers in selecting wetland habitat restoration and enhancement sites across this region (ODNR 2006, Soulliere et al. 2007, UMRGLR JV 2007, Cooper 2008, Wires et al. 2010). Using site-specific and landscape-specific area-sensitivity measures for these species allowed me estimate the probability of individual species observation at any emergent wetland in the glaciated region of Ohio during the breeding period.

My goal was to determine area requirements of Pied-billed Grebes, American Bitterns, Least Bitterns, King Rails, Virginia Rails, SoraS, Common Gallinules, American Coots, and
Black Terns in the glaciated region of Ohio, USA. I investigated sites surveyed for these focal species relative to water permanence, wetland size, and relative wetland area (i.e. proportion of landscape covered by emergent wetland). If focal species are area-sensitive, then I would expect them to be absent from survey sites in marshes smaller than a threshold or occur at a lower density in smaller wetlands.

My objectives were to determine frequency of occurrence and density of my focal species among wetland size classes and water permanence categories and the probability of observing a focal species given scale-dependent wetland area and water permanence category. Research hypotheses included: (1) frequency of occurrence and density of secretive marsh birds varies among wetlands of different size classes and water permanence categories, and tends to be lower in smaller wetlands with less permanent water, and (2) probability of observing focal species is positively associated with the proportional amount of wetland area assessed at three spatial scales (100 m, 1 km, and 10 km).

STUDY AREA

I conducted call broadcast surveys at 450 sites in the glaciated region of Ohio, USA, 209 in 2009 and 241 in 2010 (Figure 3.1). Over half (n=236, 52%) of the sites were located on private land. Surveys were conducted in 45 of 88 Ohio counties, 36 in 2009 and 35 in 2010. Sites were not evenly distributed among Bird Conservation Regions (BCRs). Forty-four percent of sites were located in BCR 13 (Lower Great Lakes / St. Lawrence Plain), 39% in BCR 23 (Prairie Hardwood Transition), 14% in BCR 22 (Eastern Tallgrass Prairie), and 2% in BCR 28 (Appalachian Mountains). Nine different observers conducted surveys, 5 in 2009 and 6 in 2010.
METHODS

Point sampling

I used the National Wetlands Inventory (NWI) to select survey locations. Wetlands thought to contain habitat suitable for focal species based on a review of literature included the lacustrine littoral (L2) and palustrine (P) systems in the emergent (EM) and aquatic bed (AB) classes (Cowardin et al. 1979). Forested, scrub/shrub and unconsolidated bottom wetlands that were cross-classified with emergent or aquatic bed also were included to sample a wider range of potential marsh bird habitat. Survey locations were randomly selected from NWI data (http://www.ducks.org/conservation/glaro/gis-nwi-update) based on 2005-2007 aerial photographs (Ducks Unlimited 2008).

I used a generalized random-tessellation stratified (GRTS) design to select survey locations within NWI polygons (Kincaid et al. 2008). A stratified random sample of 350 points with a 50% oversample was selected each year (annual draws were independent). Sample points were stratified by 1) water regime, categorized as either seasonal (temporary and seasonally flooded) or semi-permanent (semi-permanently flooded, intermittently exposed, and permanently flooded: Cowardin et al. 1979) and 2) wetland size: small (0.05-1.0 ha), medium (1.0-10.0 ha), and large (>10.0 ha). I assumed wetlands < 0.05 ha were too small to serve as breeding habitat for focal species and were thus excluded. Wetlands within each stratum were sampled in proportion to their area across the study area in 2009 (Figure 2.1). Temporarily flooded wetlands were removed from the sampling frame in 2010 because 2009 data and observer experience suggested these areas did not contain suitable emergent cover for secretive marsh birds. Equal numbers of seasonally and semi-permanently flooded wetlands were sampled in 2010. The samples were drawn in R (R Development Core Team, 2005) using the package spsurvey version 2.0 (Kincaid et al. 2008).
I used a combination of county auditor Geographical Information Systems (http://www.caa.org/GIS/index.html) and plat books to identify landowners for sample locations in both years. I sent letters and aerial photographs to private land owners asking their permission to conduct surveys (Appendix C), and gained permission to conduct surveys on publicly owned land managed by agencies at all governmental levels.

**Survey methods.**

Marsh bird surveys using call-broadcasts closely followed methods outlined in the Standardized North American Marsh Bird Monitoring Protocol (Conway 2009) except that survey locations were randomly located within a wetland and not necessarily located on dikes, roads, or at the vegetation-water interface. Points were attended three times during the field season with 10-15 days between each survey. I conducted surveys from 8 May to 28 June 2009 and 8 May to 22 June 2010, beginning 30 minutes before sunrise (civil twilight) to 2-3 hours after sunrise and from 2 hours before sunset to 30 minutes after sunset (civil twilight). Background noise, wind (Beaufort scale) and sky conditions (U.S. Weather Bureau code) were recorded prior to each survey. I did not conduct surveys in windy conditions (> 20km/hr) or during sustained rain, per protocol guidelines (Conway 2009).

The call-broadcast sequence was obtained from the North American Marsh Bird Monitoring Program (Conway 2009) and consisted of a 5-minute passive listening period followed by 5 minutes of call-broadcast. Each minute of the call-broadcast period included 30 seconds of vocalizations of a single species and 30 seconds of silence. The order of species in the call broadcast was as follows: Least Bittern, Sora, Virginia Rail, King Rail, and Pied-billed Grebe. I added American Bittern and a second Least Bittern call to the end of the broadcast series in 2010 (Appendix D). Survey technicians were trained to identify of marsh bird vocalizations
using audio CDs beginning in April and participated in a week of daily \textit{in situ} practice surveys and vocalization evaluations.

Surveyors broadcasted the call sequence at 90 dB measure 1 m from the source using an mp3 player (SanDisk Sansa Clip 512 MB, SanDisk Corporation, Milpitas, California, USA) attached to a pair of amplified speakers (Phillips Model SB220A, Koninklijke Philips Electronics Amsterdam, The Netherlands). I placed the speakers approximately 1.5 m above ground and pointed them toward the interior of the wetland. I recorded all visual and aural observations for 9 focal species at each survey point: Pied-billed Grebe, American Bittern, Least Bittern, King Rail, Sora, Virginia Rail, Common Gallinule, American Coot, and Black Tern. I recorded the minute of each sequence during which each vocal and/or visual observation was confirmed. Observers estimated distance (m) to each bird observed with laser range finders and aerial photographs.

\textit{Assumptions}. I made the following assumptions on survey data to compare variation in site-level presence, abundance, and area sensitivity of focal species among sampling strata and scale-dependent wetland area: 1) the population was closed during the sampling period, 2) call-broadcast methods increase the probability of observing focal species, and 3) three visits are adequate to determine site-level presence of focal species with a high level (90\%) of certainty. Logistic regression models of species-habitat relationships can be sensitive to individuals who are present but undetected and can lead to biased parameter estimates (Gu and Swihart 2004). Call-broadcast intervals may reduce an observer’s ability to detect all vocalizing individuals during surveys (Nadeau et al. 2008). This may result in negatively-biased estimates of true abundance of focal species at sites (Nadeau et al. 2008). The standardized call-broadcast protocol is adequate to determine estimates of site-level presence for most secretive marsh bird species (Melvin and Gibbs 1993, Tozer et al. 2006). However, Tozer et al. (2006) found three call-broadcast surveys are needed to determine site-level presence of secretive marsh birds with 90\% certainty in Great
Lakes coastal marshes; however, it may take 8 visits for Least Bittern. Nevertheless, Willard (2011) found that detection probability changes across survey periods for these species in the study area and that detection probability is affected by habitat characteristics for some species.

Analysis

Site-level presence of each focal species was defined as whether they were observed at a survey location during any of the three visits within a given year; 0 = absent, 1 = present. To determine site-level presence, I first calculated summary statistics of initial observation distances to each marsh bird. I filtered observations into species-specific observation radii centered on the third quartile (75th percentile). This process reduced the number of observations but did not alter the presence/absence status of focal species at sites. I calculated the proportion and 95% Agresti-Coull binomial confidence intervals (Agresti and Coull 1998) for all marsh bird species within sampling strata. I tested for differences in the proportion of sites with observations of each species (1) between survey years, (2) between water permanence strata, and (3) among wetland size strata using two-sample tests for equality of proportions with continuity correction (Quinn and Keough 2002).

I used logistic regression to estimate the natural logarithm of the odds of observing a focal species as a function of scale-dependent wetland area and water permanence category. Predictor variables representing percent emergent, aquatic bed, and total wetland area were extracted from NWI data in ArcGIS 10.0 (see Appendix F for details) at 0.1, 1, and 10 km spatial scales. Variable screening preceded creation of a priori candidate models for each species. I generated a Spearman’s rank correlation matrix for continuous predictor variables (Appendix G). Predictor variables that were highly correlated (\(|r_s| \geq 0.70\)) were not included in the same a priori candidate model.
A priori candidate models were developed for each focal species based on a review of published studies and species’ accounts and model selection proceeded with Akaike’s Information Criterion (AIC) (Burnham and Anderson, 2002) (Appendix H). Candidate models were ranked according to the difference in model AIC values ($\Delta$AIC = AIC$_{\text{model}}$ - AIC$_{\text{min}}$). Models with $\Delta$AIC ≤ 2.0 were considered equally plausible given the data (Burnham and Anderson 2002). Model averaging was implemented where multiple candidate models had $\Delta$AIC values that met this criterion (Burnham and Anderson 2002). Parameters from the best models were considered good predictors of a species’ site-level presence when 95% confidence intervals of untransformed coefficients did not include 0. I calculated Wald’s test statistic ($\chi^2$) for each predictor variable to evaluate their effect in the final model. I calculated to likelihood-ratio test statistics ($G^2$) and employed the Wald test ($\chi^2$) to evaluate the overall model goodness-of-fit, comparing the fit of full model (best candidate model) - reduced models (null model) (Quinn and Keough 2002). I also calculated the Hosmer-Lemeshow test statistic ($\hat{C}$) to evaluate goodness-of-fit of the highest ranked model (Quinn and Keough 2002). I developed response plots with 95% confidence limits showing the probability of observing a species as a function of continuous main effects for the top model(s) ($\Delta$AIC ≤ 2.0) for each species.

The maximum count of each focal species observed at a site during any of the three visits and within the post hoc detection radii (raw counts) was converted into the number of individuals detected per wetland hectare (ha). Density estimates were averaged across wetland size and water permanence strata and by year. The distribution of density estimates across survey strata was highly skewed, making parametric tests unreliable (Quinn and Keough 2002). I tested for differences in density estimates among survey strata and years using the nonparametric Mann-Whitney rank-sum and Kruskal-Wallis tests. All statistics were conducted in R version 2.11.1 (R Development Core Team 2010).
RESULTS

Site-level presence of focal species

The order of highest to lowest proportion of total sites occupied by focal species was Pied-billed Grebes (0.253, 95% CI: 0.215-0.296), Common Gallinules (0.171, 95% CI: 0.139-0.209), Virginia Rails (0.129, 95% CI: 0.101-0.163), Soras (0.116, 95% CI: 0.089-0.149), Least Bitterns (0.093, 95% CI: 0.070-0.124), American Coots (0.084, 95% CI: 0.062-0.114), American Bitterns (0.033, 95% CI: 0.020-0.055), Black Terns (0.016, 95% CI: 0.007-0.032) and King Rails (0.004, 95% CI: 0-0.017) (Table 3.1). Common Gallinules were detected on a higher proportion of sites in 2010 vs. 2009 (95% CI: 0.014-0.160; \( \chi^2 = 5.40, P = 0.020 \)). I failed to detect a difference in frequency of occurrence between years for Pied-billed Grebes (\( \chi^2 = 1.96, P = 0.161 \)), American Bitterns (\( \chi^2 = 0.60, P = 0.440 \)), Least Bitterns (\( \chi^2 = 3.81, P = 0.051 \)), Virginia Rails (\( \chi^2 = 0.16, P = 0.685 \)), Soras (\( \chi^2 = 2.73, P = 0.098 \)), and American Coots (\( \chi^2 = 0.15, P = 0.696 \)).

The frequency of occurrence of marsh birds across wetland size and water permanence strata varied among species. Pied-billed Grebes, Least Bitterns, Common Gallinules, and American Coots were not observed in small (0.05-1.0 ha) wetlands (Table 3.1). American Bitterns were observed only in large (> 10.0 ha) wetlands. Black Terns were observed only on large, semi-permanently flooded wetlands. King Rails were observed only at a large, seasonally-flooded wetland in 2009 and a small (0.05-1.0 ha), semi-permanently flooded wetland in 2010. I observed Virginia Rails in all wetland sizes and wetland permanence categories except for small, semi-permanently flooded wetlands. Soras were observed in all wetland size and water permanence categories (Table 3.1).

The proportion of sites with observations of focal species was higher in large (> 10.0 ha) vs. wetlands ≤ 10.0 ha for Pied-billed Grebes (95% CI: 0.036 – 0.422; \( \chi^2 = 103.54, P < 0.001 \)),
Least Bitterns (95% CI: 0.008 – 0.161; $\chi^2 = 35.91, P \leq 0.001$), Virginia Rails (95% CI: 0.052 – 0.181; $\chi^2 = 19.03, P \leq 0.001$), Soras (95% CI: 0.052 – 0.181; $\chi^2 = 13.47, P \leq 0.001$), Common Gallinules (95% CI: 0.016 – 0.293; $\chi^2 = 71.63, P \leq 0.001$), and American Coots (95% CI: 0.008 – 0.145; $\chi^2 = 31.30, P \leq 0.001$) (Table 3.1).

The proportion of sites with observations of focal species was higher in semi-permanently flooded wetlands than in seasonally flooded wetlands for Pied-billed Grebes (95% CI: 0.084 – 0.424; $\chi^2 = 66.98, P \leq 0.001$), Least Bitterns (95% CI: 0.022 – 0.165; $\chi^2 = 25.54, P \leq 0.001$), Soras (95% CI: 0.053 – 0.313; $\chi^2 = 60.90, P \leq 0.001$), Common Gallinules (95% CI: 0.031 – 0.313; $\chi^2 = 60.90, P \leq 0.001$), and American Coots (95% CI: 0.022 – 0.147; $\chi^2 = 21.22, P \leq 0.001$) (Table 3.1). American Bitterns were also observed on a higher proportion of semi-permanently flooded than seasonally flooded wetlands (95% CI: 0.008 – 0.058; $\chi^2 = 6.99, P = 0.008$), although this was not true with comparisons among large wetlands only ($\chi^2 = 2.65, P = 0.104$) (Table 3.1). The proportion of sites with observations of Virginia Rails did not vary between water permanence categories ($\chi^2 = 1.04, P = 0.307$) (Table 3.1).

Density

The order of highest to lowest density (#/ha) of focal species among survey sites was Common Gallinules (0.143, 95% CI: 0.120-0.166), Pied-billed Grebes (0.102, 95% CI: 0.090-0.124), Virginia Rails (0.069, 95% CI: 0.058-0.080), Soras (0.060, 95% CI: 0.050-0.070), Least Bitterns (0.044, 95% CI: 0.036-0.052), American Coots (0.044, 95% CI: 0.035-0.053), Black Terns (0.012, 95% CI: 0.006-0.018), American Bitterns (0.008, 95% CI: 0.006-0.010), and King Rails (0.003, 95% CI: 0.001-0.005) (Table 3.2).

Median density estimates were higher in 2010 vs. 2009 for Least Bitterns ($U = 2374, Z = -2.07, P = 0.044, r = 0.10$) and Common Gallinules ($U = 23023, Z = -2.40, P = 0.016, r = 0.11$) (Table 3.2). I failed to detect differences in median density between survey years for Pied-billed
Grebes (U = 23488.5, Z = -1.62, P = 0.106, r = 0.08), American Bitterns (U = 24737, Z = -1.05, P = 0.359, r = 0.05), Virginia Rails (U = 24622, Z = -0.70, P = 0.482, r = 0.03), Soras (U = 23717, Z = -1.82, P = 0.069, r = 0.09), or American Coots (U = 24761, Z = -0.64, P = 0.503, r = 0.03) (Table 3.2).

Density of focal species varied among wetland size classes. Median density estimates were higher in large (>10.0 ha) vs. wetlands ≤10.0 ha for Pied-billed Grebes (U = 15500, Z = -9.06, P ≤ 0.001, r = 0.43), American Bitterns (U = 23482, Z = -3.5, P ≤ 0.001, r = 0.16), Least Bitterns (U = 21249.5, Z = -5.39, P ≤ 0.001, r = 0.27), Soras (U = 22232, Z = -3.42, P ≤ 0.001, r = 0.16), Common Gallinules (U = 18203, Z = -7.54, P ≤ 0.001, r = 0.35), and American Coots (U = 21643, Z = -5.04, P ≤ 0.001, r = 0.24) (Table 3.2).

Density of focal species varied among water permanence categories. Median density estimates were higher semi-permanently flooded wetlands than seasonally-flooded wetlands for Pied-billed Grebes (U = 16505, Z = -8.37, P ≤ 0.001, r = 0.39), American Bitterns (U = 24065, Z = -2.91, P ≤ 0.001, r = 0.14), Least Bitterns (U = 21653.5, Z = -5.26, P ≤ 0.001, r = 0.25), Soras (U = 21363, Z = -4.89, P ≤ 0.001, r = 0.23), Common Gallinules (U = 18092.5, Z = -7.89, P ≤ 0.001, r = 0.38), and American Coots (U = 22117, Z = -4.80, P ≤ 0.001, r = 0.38), (Table 3.2). I failed to detect differences in median density of Virginia Rails between water permanence strata (U = 24322, Z = -1.23, P = 0.218, r = 0.06) (Table 3.2).

**Area-sensitivity models**

*Pied-billed Grebe.* The best supported model (ΔAIC ≤ 2) for probability of observing Pied-billed Grebes included percent emergent wetland within 0.1 and 10 km radii and water permanence category (Table 3.3). The probability of observing Pied-billed Grebe was positively associated with each of these variables (Table 3.4). Probability of observing Pied-billed Grebe
increased by 39.4% (95% CI: 28.8-52.0) with a 1% increase in percent emergent wetland within a 10 km radius (Figure 3.2b). Probability of observing Pied-billed Grebes increased by 2.95% (95% CI: 1.69-4.32) with a 1% increase in percent emergent wetland within a 0.1 km radius (Figure 3.2a). Observers were 3.31 times (95% CI: 1.72-6.68) more likely to observe Pied-billed Grebe on semi-permanently flooded wetlands. Overall model evaluation, goodness-of fit, and pseudo-$R^2$ statistics indicate that the model was better supported than the null and is an adequate model for the data (Table 3.4).

*American Bittern.* The best supported models (ΔAIC ≤ 2) for probability of observing American Bitterns included percent emergent wetland area within a 1 km radius and water permanence (Table 3.3). Probability of observing American Bitterns was positively associated with percent emergent wetland within a 1 km radius and semi-permanently flooded wetlands; however, 95% CIs of regression coefficients for both predictor variables included values < 1 indicating they were not good predictors of the probability of observing American Bittern (Table 3.5). Nevertheless, 95% CIs for the probability of observing American Bittern for percent emergent wetland within a 1 km radius were ≥ 1 for each model independently.

*Least Bittern.* The best supported models (ΔAIC ≤ 2) for probability of observing Least Bitterns included percent emergent wetland within 0.1 and 10 km radii, water permanence, and percent aquatic bed wetland within a 1 km radius (Table 3.3). The probability of observing Least Bitterns was positively associated with each of these variables (Table 3.6), increasing by 3.58% (95% CI: 1.40-5.82) for every 1% increase in percent emergent wetland within a 0.1 km radius (Figure 3.3a). Probability of observing Least Bitterns also increased by 9.48% (95% CI: 0.01-19.7) for every 1% increase in percent emergent wetland within a 10 km radius (Figure 3.3b).
Observers were 3.93 times (95% CI: 1.64-9.40) more likely to observe Least Bittern on semi-permanently flooded wetlands (Table 3.6).

*Virginia Rail.* The best models (ΔAIC ≤ 2) of probability of observing Virginia Rails included percent emergent wetland within 0.1 and 10 km radii and water permanence category (Table 3.3). The probability of observing Virginia Rails was positively associated with each of these variables (Table 3.7), increasing by 2.10% (95% CI: 0.97-3.24) for every 1% increase in percent emergent wetland within a 0.1 km radius (Figure 3.4). The 95% CIs of regression coefficients for percent emergent marsh within a 10 km radius and water permanence included values < 1, indicating that these two parameters were not good predictors of the probability of detecting Virginia Rail (Table 3.7).

*Sora.* The best model (ΔAIC ≤ 2) estimating the logarithm of the odds of observing Soras included percent emergent wetland within a 1 km radius and water permanence category (Table 3.3). The probability of observing Soras was positively associated with each of these variables (Table 3.8), increasing by 2.10% (95% CI: 0.94-3.31) for every 1% increase in percent emergent wetland within a 1km radius (Figure 3.5). Observers were 2.65 times (95% CI: 1.28-5.77) more likely to observe Soras on semi-permanently flooded wetlands (Table 3.8). Overall, model evaluation, goodness-of-fit, and pseudo-$R^2$ statistics indicated the model was better supported than the null and was an adequate model for the data (Table 3.8).

*Common Gallinule.* The best supported model (ΔAIC ≤ 2) for probability of observing Common Gallinules included percent emergent wetland within 0.1 and 10 km radii and water permanence (Table 3.3). The probability of detecting Common Gallinules was positively associated with all three parameters (Table 3.9), increasing by 3.86% (95% CI: 2.23-5.84) for every 1% increase in percent emergent wetland within a 0.1 km radius (Figure 3.6a). The
probability of detecting Common Gallinules also increased by 18.7% (95% CI: 9.81-12.9) for every 1% increase in percent emergent wetland within a 10 km radius (Figure 3.6b). Observers were 6.04 times (95% CI: 2.70-15.4) more likely to detect Common Gallinules on semi-permanently flooded wetlands (Table 3.9). Overall model evaluation, goodness-of-fit, and pseudo-R² statistics indicated the model was better supported than the null and was an adequate model for the data (Table 3.9).

American Coot. The best supported model (AIC < 2) for probability of detecting American Coots included percent emergent wetland within 0.1 and 10 km radii, and water permanence (Table 3.3). The probability of detecting American Coots was positively associated with all three parameters (Table 3.10), increasing by 3.74% (95% CI: 6.5-16.3) for every 1% increase in emergent wetland within a 10.1 km radius (Figure 3.7a). Probability of detecting American Coots also increased by 10.9% (95% CI: 1.2-21.5) for every 1% increase in percent emergent wetland within a 10 km radius (Figure 3.7b). Observers were 3.15 times (95% CI: 1.21-9.80) more likely to detect American Coots from within semi-permanently flooded wetlands (Table 3.10). Overall model evaluation, goodness-of-fit, and pseudo-R² statistics indicated the model was better supported than the null and an adequate model for the data (Table 3.10).

**DISCUSSION**

All focal species of secretive marsh birds that I studied exhibited area-sensitivity to some degree in the glaciated region of Ohio, occurring at lower frequencies and at lower abundance in smaller habitat patches (Robbins et al. 1989). Wetland size, water permanence, and scale-dependent wetland area were all important predictors of marsh bird observation probability.

Marsh birds were more frequently or exclusively observed and at higher densities in wetlands > 10.0 ha. Large wetlands (> 10.0 ha) contained more diverse vegetation communities,
greater diversity of micro-topography and water depth, more foraging habitats, and more sites for
territory establishment. (Weller 1999). Site-level occurrence of marsh birds in large wetlands in
the study area were much lower for Sora and Virginia Rail and similar for Pied-billed Grebe and
Least Bitterns compared to large emergent wetlands in Iowa (Harms 2011). Soras and Virginia
Rails were the only species observed, although at lower frequency and density, in small wetlands
(0.05 -1.0 ha). These results are inconsistent with previous studies of marsh bird occurrence in
similar habitats. Brown and Dinsmore (1986) observed Pied-billed Grebes, Least Bitterns, and
American Coots at low frequencies in wetlands < 1 ha in Iowa. There may be inadequate
resources present in small wetlands to influence territory establishment by other secretive marsh
birds in the glaciated region of Ohio.

Marsh bird density tended to be higher in larger wetland size classes. Lor and Malecki
(2006) estimated the density of nests for secretive marsh birds in emergent wetlands in New
York. Their estimates of nest density (nests/ha) for Pied-billed Grebes (0.28), Least Bitterns
(0.14), and Virginia Rails (0.07) were similar to estimates of density in my study area (Lor and
Malecki 2006). However, their estimate of Sora nest density (0.01) was much lower than our
estimate of Sora density (Lor and Malecki 2006). Harms (2011) reported lower density estimates
for Pied-billed Grebes (0.043), higher density estimates for Sora (0.16), and similar density
estimates for Least Bitterns (0.003) and Virginia Rails (0.048) in emergent wetlands in the
Eastern Tallgrass Prairie Bird Conservation Region (BCR 22) in Iowa.

All focal species except Virginia Rails were detected more frequently in semi-
permanently flooded than in seasonally flooded wetlands. Semi-permanently flooded wetlands
generally have more stable water levels and vegetation communities than seasonally-flooded
wetlands (Weller 1999). Common Gallinules were detected on a larger proportion of total sites in
2010, which may be the result of sampling semi-permanently flooded wetlands with greater intensity in 2010 than in 2009.

Beyond point-level characteristics of wetland size and water permanence, we have a better knowledge about which spatial scales that are more likely to predict observation probability of focal marsh birds and the direction and magnitude of gradients. Not only do local wetland conditions (e.g., size) matter, but a wetland’s landscape context is also important for marsh bird use. Species whose observation probability was positively associated with percent emergent wetland within 0.1 and 10 km spatial scales were American Coot, Common Gallinule, Least Bittern and Pied-billed Grebe. Observation probability of American Bitterns and Soras were positively associated with percent emergent wetland within 1 km spatial scale. Observation probability of Virginia Rails was positively associated with percent emergent wetland within 100 m, although this model had low explanatory power. The chance of observing focal species approaches 50% when all model parameters are maximized for each focal species except Virginia Rail due to low model explanatory power. Pied-billed Grebes had the strongest area-sensitivity model, with the smallest confidence intervals and highest predicted probability of site-level presence given variable estimates. However, confidence estimates for observation probability were wide for all species except Pied-billed Grebes, and result in uncertain model predictions.

My results support previous studies documenting area-sensitivity among Pied-billed Grebes (Brown and Dinsmore 1986, Muller and Storer 1999, Naugle et al. 1999), American Bitterns (Gibbs et al. 1992a, Dechant et al. 1999, Riffel et al. 2001), and Least Bitterns (Gibbs et al. 1992b). However, studies of the remaining focal species do not agree on the degree to which they are area-sensitive. My results also indicated area-sensitivity of American Coots and Common Gallinules. Studies have found both of these species to be area-sensitive (Brown and Dinsmore 1986, Bannor and Kiviat 2002, Brisbin and Mowbray 2002). However, Crewe et al.
(2006) considered both species non-area-sensitive marsh-obligate nesters in Great Lakes coastal wetlands. There is similar disagreement in the literature on the degree of area-sensitivity of Sora (Brown and Dinsmore 1986, Melvin and Gibbs 1996). My results indicated Soras are area-sensitive and is consistent with several studies (Riffel et al. 2001, Zimmerman et al. 2002a, Crewe et al. 2006). This contradictst Brown and Dinsmore (1986) designation of Soras and Virginia Rails as “area-independent” species in Iowa.

Virginia Rail seemed to have the lowest degree of area-sensitivity among focal species, although my top candidate model had relatively low explanatory power and wide confidence intervals. Virginia Rail were detected in all sampling strata and appeared to be the most widespread of focal species. Other studies found similar results for Virginia Rail (Brown and Dinsmore 1986; Benoit and Askins 2002, Zimmerman et al. 2002b). However, Riffell et al. (2001) found a positive relationship between Virginia Rail presence and area of Great Lakes coastal wet meadows. Additionally, Crewe et al. (2006) considered Virginia Rails to be area-sensitive. Although Virginia Rails were more likely to be located in large wetlands, I failed to show strong area sensitivity among scale-dependent wetland area and water permanence type.

MANAGEMENT IMPLICATIONS

I observed secretive marsh birds at higher frequencies and densities in large (> 10.0 ha), semi-permanently flooded wetlands. Most focal species were not observed in small (< 1.0 ha) wetlands. Also, marsh bird observation probability was higher in areas with larger amounts of wetlands at multiple spatial scales. Local and regional populations of secretive marsh birds may be more efficiently and positively affected if habitat conservation and restoration efforts are targeted to larger, semi-permanently flooded wetlands in areas with higher amounts of landscape wetland area.
This study was part of a larger effort to better understand statewide distribution of marsh birds in the glaciated region of Ohio. I sampled wetlands in proportion to where they occurred, conducting call-broadcast surveys for marsh birds at spatially-balanced sites across the state in public and private lands. Future analyses of data collected with the standardized monitoring protocol may result in empirical estimates of secretive marsh bird populations at the continental scale when implemented across the species’ entire range (Conway 2009). However, current estimates of secretive marsh bird populations have been determined largely through expert opinion (Wires et al. 2010). Regional conservation planning efforts have used population estimates based on expert opinion to set habitat management objectives for these species (UMRGLR JV 2007, Wires et al. 2010). Empirically-based population estimates for these species may lead to improved conservation planning at the regional scale. An understanding of local abundance and how it varies by wetland size or type is key in determining more credible estimates of secretive populations. The abundance estimates presented here for several secretive marsh bird species can improve population estimates based on expert opinion by generating estimates of population size of focal species during the breeding period across the glaciated region of Ohio. Additionally, researchers and managers may now estimate the probability that several secretive marsh birds species will be observed in the glaciated region of Ohio during the breeding period based on local and landscape scale wetland characteristics.

Finally, King Rails and Black Terns are of high conservation concern at national (Kushlan et al. 2002) and regional (Soulliere et al. 2007, Wires et al. 2010) scales, and are state endangered in Ohio. Both species were rarely detected in this study, and I was unable to model their area-sensitivity. However, my observations should be added to other sparse data sets in the Midwest (USFWS Region 3) as they could contribute to habitat assessments at a larger spatial extent.
LITERATURE CITED


Ohio Department of Natural Resources Division of Wildlife. 2006. Comprehensive wildlife conservation strategy. Ohio Department of Natural Resources, Columbus, OH.


Willard, K. 2011. Habitat associations of breeding marsh birds within the glaciated region or Ohio, USA. Master’s thesis: The Ohio State University, Columbus, OH, USA.


Table 3.1. Frequency of occurrence of sites (95% confidence limits) with at least one observation of nine marsh bird species within wetland size and water permanence categories in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Species</th>
<th>Flooding regime</th>
<th>Wetland Size (ha)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.05 - 1.0</td>
<td>1.0 - 10.0</td>
<td>&gt; 10.0</td>
<td>All wetlands</td>
<td></td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 (0, 0.163)</td>
<td>0.027 (0.006, 0.080)</td>
<td>0.176 (0.110, 0.268)</td>
<td>0.084 (0.054, 0.128)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 (0, 0.372)</td>
<td>0.107 (0.047, 0.218)</td>
<td>0.556 (0.479, 0.631)</td>
<td>0.424 (0.361, 0.490)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0 (0, 0.127)</td>
<td>0.054 (0.027, 0.101)</td>
<td>0.418 (0.359, 0.48)</td>
<td>0.253 (0.215, 0.296)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Bittern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 (0, 0.163)</td>
<td>0 (0, 0.040)</td>
<td>0.022 (0.001, 0.081)</td>
<td>0.009 (0, 0.0340)</td>
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<td></td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 (0, 0.372)</td>
<td>0 (0, 0.077)</td>
<td>0.081 (0.047, 0.135)</td>
<td>0.058 (0.033, 0.098)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0 (0, 0.127)</td>
<td>0 (0, 0.027)</td>
<td>0.060 (0.036, 0.097)</td>
<td>0.033 (0.020, 0.055)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Bittern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 (0, 0.163)</td>
<td>0.009 (0, 0.054)</td>
<td>0.044 (0.014, 0.111)</td>
<td>0.022 (0.008, 0.052)</td>
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</tr>
<tr>
<td>semi-permanently</td>
<td>0 (0, 0.372)</td>
<td>0.018 (0, 0.103)</td>
<td>0.225 (0.167, 0.296)</td>
<td>0.165 (0.122, 0.220)</td>
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<tr>
<td>Total</td>
<td>0 (0, 0.127)</td>
<td>0.012 (0, 0.045)</td>
<td>0.159 (0.119, 0.210)</td>
<td>0.093 (0.070, 0.124)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>King Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 (0, 0.163)</td>
<td>0 (0, 0.04)</td>
<td>0.011 (0, 0.066)</td>
<td>0.004 (0, 0.027)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0.125 (0.001, 0.492)</td>
<td>0 (0, 0.077)</td>
<td>0 (0, 0.028)</td>
<td>0.004 (0, 0.027)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.031 (0, 0.171)</td>
<td>0 (0, 0.027)</td>
<td>0.004 (0, 0.025)</td>
<td>0.004 (0, 0.017)</td>
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</tbody>
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Continued
Table 3.1 continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Flooding regime</th>
<th>Wetland Size (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05 - 1.0</td>
<td>1.0 - 10.0</td>
</tr>
</tbody>
</table>

Virginia Rail

<table>
<thead>
<tr>
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<th>seasonally</th>
<th>semi-permanently</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 - 1.0</td>
<td>0.083 (0.012, 0.270)</td>
<td>0 (0, 0.372)</td>
<td>0.063 (0.007, 0.212)</td>
</tr>
<tr>
<td>1.0 - 10.0</td>
<td>0.054 (0.023, 0.115)</td>
<td>0.089 (0.035, 0.197)</td>
<td>0.066 (0.036, 0.115)</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>0.187 (0.119, 0.280)</td>
<td>0.175 (0.123, 0.242)</td>
<td>0.179 (0.137, 0.232)</td>
</tr>
<tr>
<td>All wetlands</td>
<td>0.111 (0.076, 0.159)</td>
<td>0.147 (0.106, 0.200)</td>
<td>0.129 (0.101, 0.163)</td>
</tr>
</tbody>
</table>

Sora

<table>
<thead>
<tr>
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<th>seasonally</th>
<th>semi-permanently</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 - 1.0</td>
<td>0.042 (0, 0.219)</td>
<td>0.063 (0.063, 0.599)</td>
<td>0.094 (0.025, 0.250)</td>
</tr>
<tr>
<td>1.0 - 10.0</td>
<td>0.054 (0.023, 0.115)</td>
<td>0.089 (0.035, 0.197)</td>
<td>0.066 (0.036, 0.115)</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>0.055 (0.021, 0.125)</td>
<td>0.250 (0.189, 0.323)</td>
<td>0.179 (0.137, 0.232)</td>
</tr>
<tr>
<td>All wetlands</td>
<td>0.053 (0.030, 0.091)</td>
<td>0.179 (0.134, 0.234)</td>
<td>0.116 (0.089, 0.149)</td>
</tr>
</tbody>
</table>

Common Gallinule

<table>
<thead>
<tr>
<th></th>
<th>seasonally</th>
<th>semi-permanently</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 - 1.0</td>
<td>0 (0, 0.163)</td>
<td>0.009 (0, 0.054)</td>
<td>0.024 (0.007, 0.062)</td>
</tr>
<tr>
<td>1.0 - 10.0</td>
<td>0.009 (0, 0.054)</td>
<td>0.054 (0.013, 0.152)</td>
<td>0.291 (0.238, 0.350)</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>0.066 (0.028, 0.139)</td>
<td>0.419 (0.345, 0.496)</td>
<td>0.171 (0.139, 0.209)</td>
</tr>
<tr>
<td>All wetlands</td>
<td>0.031 (0.014, 0.064)</td>
<td>0.313 (0.255, 0.376)</td>
<td>0.196 (0.157, 0.234)</td>
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</table>

American Coot

<table>
<thead>
<tr>
<th></th>
<th>seasonally</th>
<th>semi-permanently</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 - 1.0</td>
<td>0 (0, 0.163)</td>
<td>0 (0, 0.040)</td>
<td>0.012 (0, 0.045)</td>
</tr>
<tr>
<td>1.0 - 10.0</td>
<td>0 (0, 0.040)</td>
<td>0.036 (0.003, 0.128)</td>
<td>0.143 (0.105, 0.192)</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>0.055 (0.021, 0.125)</td>
<td>0.194 (0.140, 0.262)</td>
<td>0.084 (0.062, 0.114)</td>
</tr>
<tr>
<td>All wetlands</td>
<td>0.022 (0.008, 0.052)</td>
<td>0.147 (0.106, 0.200)</td>
<td>0.084 (0.062, 0.114)</td>
</tr>
</tbody>
</table>

Black Tern

<table>
<thead>
<tr>
<th></th>
<th>seasonally</th>
<th>semi-permanently</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 - 1.0</td>
<td>0 (0, 0.163)</td>
<td>0 (0, 0.040)</td>
<td>0.012 (0, 0.027)</td>
</tr>
<tr>
<td>1.0 - 10.0</td>
<td>0 (0, 0.040)</td>
<td>0.036 (0.003, 0.128)</td>
<td>0.028 (0.012, 0.058)</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>0 (0, 0.049)</td>
<td>0.044 (0.020, 0.089)</td>
<td>0.016 (0.007, 0.032)</td>
</tr>
<tr>
<td>All wetlands</td>
<td>0 (0, 0.020)</td>
<td>0.031 (0.014, 0.064)</td>
<td>0.016 (0.007, 0.032)</td>
</tr>
</tbody>
</table>
Table 3.2. Density (no./ha) ± 95% confidence interval of marsh birds within wetland size and water permanence categories in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Species</th>
<th>Flooding regime</th>
<th>Wetland Size (ha)</th>
<th>All wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05 - 1.0</td>
<td>1.0 - 10.0</td>
<td>&gt;10.0</td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0.006 ± 0.007</td>
<td>0.058 ± 0.033</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0.034 ± 0.036</td>
<td>0.238 ± 0.048</td>
</tr>
<tr>
<td>Total</td>
<td>0 ± 0</td>
<td>0.015 ± 0.013</td>
<td>0.172 ± 0.035</td>
</tr>
<tr>
<td>American Bittern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.005 ± 0.006</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.020 ± 0.011</td>
</tr>
<tr>
<td>Total</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.014 ± 0.007</td>
</tr>
<tr>
<td>Least Bittern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0.003 ± 0.006</td>
<td>0.014 ± 0.013</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0.111 ± 0.022</td>
<td>0.109 ± 0.036</td>
</tr>
<tr>
<td>Total, 2009</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.063 ± 0.037</td>
</tr>
<tr>
<td>Total, 2010</td>
<td>0 ± 0</td>
<td>0.111 ± 0.017</td>
<td>0.083 ± 0.032</td>
</tr>
<tr>
<td>Total</td>
<td>0 ± 0</td>
<td>0.006 ± 0.008</td>
<td>0.075 ± 0.024</td>
</tr>
<tr>
<td>King Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.007 ± 0.014</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0.080 ± 0.156</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Total</td>
<td>0.020 ± 0.039</td>
<td>0 ± 0</td>
<td>0.003 ± 0.005</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0.040 ± 0.057</td>
<td>0.029 ± 0.023</td>
<td>0.087 ± 0.043</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0.034 ± 0.030</td>
<td>0.105 ± 0.041</td>
</tr>
<tr>
<td>Total</td>
<td>0.003 ± 0.043</td>
<td>0.030 ± 0.019</td>
<td>0.099 ± 0.030</td>
</tr>
<tr>
<td>Sora</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0.027 ± 0.052</td>
<td>0.020 ± 0.017</td>
<td>0.028 ± 0.027</td>
</tr>
<tr>
<td>semi-permanently</td>
<td>0.080 ± 0.102</td>
<td>0.040 ± 0.039</td>
<td>0.117 ± 0.041</td>
</tr>
<tr>
<td>Total</td>
<td>0.040 ± 0.046</td>
<td>0.027 ± 0.017</td>
<td>0.085 ± 0.028</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0.003 ± 0.006</td>
<td>0.031 ± 0.026</td>
</tr>
<tr>
<td>semi-permanently</td>
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<td>0.045 ± 0.056</td>
<td>0.366 ± 0.101</td>
</tr>
<tr>
<td>Total, 2009</td>
<td>0 ± 0</td>
<td>0.004 ± 0.008</td>
<td>0.189 ± 0.081</td>
</tr>
<tr>
<td>Total, 2010</td>
<td>0 ± 0</td>
<td>0.030 ± 0.038</td>
<td>0.285 ± 0.101</td>
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<tr>
<td>Total</td>
<td>0 ± 0</td>
<td>0.017 ± 0.019</td>
<td>0.245 ± 0.068</td>
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Continued
<table>
<thead>
<tr>
<th>Species</th>
<th>Flooding regime</th>
<th>Wetland Size (ha)</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.05 - 1.0</td>
<td>1.0 - 10.0</td>
<td>&gt;10.0</td>
<td>All wetlands</td>
</tr>
<tr>
<td>American Coot</td>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.021 ± 0.019</td>
<td>0.008 ± 0.006</td>
</tr>
<tr>
<td></td>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0.017 ± 0.025</td>
<td>0.105 ± 0.039</td>
<td>0.080 ± 0.023</td>
</tr>
<tr>
<td></td>
<td>Total</td>
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<td>0.006 ± 0.008</td>
<td>0.075 ± 0.026</td>
<td>0.044 ± 0.009</td>
</tr>
<tr>
<td>Black Tern</td>
<td>seasonally</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
</tr>
<tr>
<td></td>
<td>semi-permanently</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.034 ± 0.027</td>
<td>0.024 ± 0.016</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0.022 ± 0.017</td>
<td>0.012 ± 0.006</td>
</tr>
</tbody>
</table>
Table 3.3. Top ranked ($\Delta$AIC $\leq$ 7) candidate models and null model estimating the effect of variables on the probability of observing marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010. Boldface type indicates the best model(s) ($\Delta$AIC $\leq$ 2.0).

<table>
<thead>
<tr>
<th>Species</th>
<th>Model</th>
<th>-2 Log-likelihood</th>
<th>K&lt;sup&gt;b&lt;/sup&gt;</th>
<th>AIC</th>
<th>$\Delta$AIC</th>
<th>$w_{y}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>$\pi$(EM100M + EM10KM + Semi-perm)</td>
<td>289.84</td>
<td>4</td>
<td>297.84</td>
<td>0</td>
<td>0.996</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>509.37</td>
<td>1</td>
<td>511.37</td>
<td>213.53</td>
<td>0</td>
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<tr>
<td>American Bittern</td>
<td>$\pi$(EM1KM)</td>
<td>111.22</td>
<td>2</td>
<td>115.22</td>
<td>0</td>
<td>0.589</td>
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<tr>
<td></td>
<td>$\pi$(EM1KM + Semi-perm)</td>
<td>-220.47</td>
<td>3</td>
<td>116.24</td>
<td>1.02</td>
<td>0.354</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + Semi-perm)</td>
<td>-230.87</td>
<td>3</td>
<td>121.44</td>
<td>6.22</td>
<td>0.026</td>
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<tr>
<td></td>
<td>$\pi(.)$</td>
<td>-263.06</td>
<td>1</td>
<td>133.53</td>
<td>18.31</td>
<td>0</td>
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<tr>
<td>Least Bittern</td>
<td>$\pi$(EM100M + EM10KM + Semi-perm)</td>
<td>220.07</td>
<td>4</td>
<td>228.07</td>
<td>0</td>
<td>0.412</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + AB1KM + EM10KM + Semi-perm)</td>
<td>218.99</td>
<td>5</td>
<td>228.99</td>
<td>0.91</td>
<td>0.261</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + Semi-perm)</td>
<td>223.96</td>
<td>3</td>
<td>229.96</td>
<td>1.89</td>
<td>0.160</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM1KM + Semi-perm)</td>
<td>224.53</td>
<td>3</td>
<td>230.53</td>
<td>2.45</td>
<td>0.121</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + EM10KM)</td>
<td>228.66</td>
<td>3</td>
<td>234.66</td>
<td>6.59</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + AB1KM + EM10KM)</td>
<td>226.67</td>
<td>4</td>
<td>234.67</td>
<td>6.6</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM1KM)</td>
<td>230.77</td>
<td>2</td>
<td>234.77</td>
<td>6.69</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>279.16</td>
<td>1</td>
<td>281.16</td>
<td>53.09</td>
<td>0</td>
</tr>
</tbody>
</table>

Continued
<table>
<thead>
<tr>
<th>Species</th>
<th>Modela</th>
<th>-2 Log-likelihood</th>
<th>Kb</th>
<th>AIC</th>
<th>ΔAIC</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia Rail</td>
<td>$\pi$(EM100M)</td>
<td>329.00</td>
<td>2</td>
<td>333.00</td>
<td>0</td>
<td>0.519</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + EM10KM)</td>
<td>328.90</td>
<td>3</td>
<td>334.90</td>
<td>1.90</td>
<td>0.201</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + Semi-perm)</td>
<td>328.91</td>
<td>3</td>
<td>334.91</td>
<td>1.91</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + EM10KM + Semi-perm)</td>
<td>328.85</td>
<td>4</td>
<td>336.85</td>
<td>3.85</td>
<td>0.076</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>345.84</td>
<td>1</td>
<td>347.84</td>
<td>14.84</td>
<td>0</td>
</tr>
<tr>
<td>Sora</td>
<td>$\pi$(EM1K + Semi-perm)</td>
<td>311.10</td>
<td>3</td>
<td>317.10</td>
<td>0</td>
<td>0.899</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM1K)</td>
<td>318.15</td>
<td>2</td>
<td>322.15</td>
<td>5.05</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>349.64</td>
<td>1</td>
<td>351.64</td>
<td>34.54</td>
<td>0</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>$\pi$(EM100M + EM10KM + Semi-perm)</td>
<td>268.09</td>
<td>4</td>
<td>276.09</td>
<td>0</td>
<td>0.996</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM1K + Semi-perm)</td>
<td>281.17</td>
<td>3</td>
<td>287.17</td>
<td>11.08</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>411.88</td>
<td>1</td>
<td>413.88</td>
<td>137.79</td>
<td>0</td>
</tr>
<tr>
<td>American Coot</td>
<td>$\pi$(EM100M + EM10KM + Semi-perm)</td>
<td>205.34</td>
<td>4</td>
<td>213.34</td>
<td>0</td>
<td>0.710</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + Semi-perm)</td>
<td>210.20</td>
<td>3</td>
<td>216.20</td>
<td>2.86</td>
<td>0.170</td>
</tr>
<tr>
<td></td>
<td>$\pi$(EM100M + EM10KM)</td>
<td>211.05</td>
<td>3</td>
<td>217.05</td>
<td>3.71</td>
<td>0.111</td>
</tr>
<tr>
<td></td>
<td>$\pi(.)$</td>
<td>260.54</td>
<td>1</td>
<td>262.54</td>
<td>49.2</td>
<td>0</td>
</tr>
</tbody>
</table>

*a Natural logarithm odds ($\pi = \logit = \log(p/(1-p))$) of detection as a function of area and water permanence categories.
*b K, number of parameters in model; AIC, Akaike's Information Criterion; ΔAIC, difference in AIC relative to top ranked model; wi, relative Akaike weight.
Table 3.4. Summary of logistic regression analysis for variables predicting the observation of Pied-billed Grebes in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate (β)</th>
<th>SE β</th>
<th>Wald's $\chi^2$</th>
<th>df</th>
<th>p</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-6.0633</td>
<td>0.6287</td>
<td>-9.65</td>
<td>1</td>
<td>≤ 0.001</td>
<td>NA</td>
</tr>
<tr>
<td>EM100M</td>
<td>0.0290</td>
<td>0.0065</td>
<td>4.48</td>
<td>1</td>
<td>≤ 0.001</td>
<td>1.0294</td>
</tr>
<tr>
<td>EM10KM</td>
<td>0.3325</td>
<td>0.0420</td>
<td>7.91</td>
<td>1</td>
<td>≤ 0.001</td>
<td>1.3944</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>1.1979</td>
<td>0.3403</td>
<td>3.52</td>
<td>1</td>
<td>≤ 0.001</td>
<td>3.3133</td>
</tr>
</tbody>
</table>

Test

Overall model evaluation

<table>
<thead>
<tr>
<th>Test</th>
<th>$\chi^2$</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likelihood ratio test</td>
<td>219.53</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Wald’s test statistic</td>
<td>103.90</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
</tbody>
</table>

Goodness-of-fit-test

<table>
<thead>
<tr>
<th>Test</th>
<th>$\chi^2$</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hosmer &amp; Lemeshow</td>
<td>14.27</td>
<td>8</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Note: Max rescaled $R^2 = 0.570$. NA = not applicable.

Table 3.5. Model-averaged log odds-ratio and 95% confidence limits (CL) for variables included in top ranked models (ΔAIC ≤ 2) describing the probability of observing American Bitterns in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate β</th>
<th>SE β</th>
<th>95 % CL</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-5.3751</td>
<td>0.7368</td>
<td>-6.8229</td>
<td>-3.9272</td>
</tr>
<tr>
<td>EM1KM</td>
<td>0.0414</td>
<td>0.0321</td>
<td>-0.0217</td>
<td>0.1045</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>0.7945</td>
<td>1.1617</td>
<td>-1.4883</td>
<td>3.0774</td>
</tr>
</tbody>
</table>
Table 3.6. Model-averaged log odds-ratio and 95% confidence limits (CL) for variables included in top ranked models (ΔAIC ≤ 2) describing the probability of observing Least Bitterns in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate β</th>
<th>SE β</th>
<th>Lower CL</th>
<th>Upper CL</th>
<th>$e^\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-6.4850</td>
<td>0.8018</td>
<td>-8.0605</td>
<td>-4.9095</td>
<td>NA</td>
</tr>
<tr>
<td>EM100M</td>
<td>0.0352</td>
<td>0.0109</td>
<td>0.0139</td>
<td>0.0566</td>
<td>1.0358</td>
</tr>
<tr>
<td>EM10KM</td>
<td>0.0905</td>
<td>0.0456</td>
<td>0.0010</td>
<td>0.1801</td>
<td>1.0948</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>1.3681</td>
<td>0.4437</td>
<td>0.4962</td>
<td>2.2399</td>
<td>3.9278</td>
</tr>
<tr>
<td>AB1KM</td>
<td>0.0439</td>
<td>0.0410</td>
<td>-0.0367</td>
<td>0.1244</td>
<td>1.0448</td>
</tr>
</tbody>
</table>

Table 3.7 Model-averaged log odds-ratio and 95% confidence limits (CL) for variables included in top ranked models (ΔAIC ≤ 2) describing the probability of observing Virginia Rails in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate β</th>
<th>SE β</th>
<th>Lower C.I.</th>
<th>Upper C.I.</th>
<th>$e^\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-3.3532</td>
<td>0.3753</td>
<td>-4.0907</td>
<td>-2.6156</td>
<td>NA</td>
</tr>
<tr>
<td>EM100M</td>
<td>0.0208</td>
<td>0.0056</td>
<td>0.0097</td>
<td>0.0319</td>
<td>1.0210</td>
</tr>
<tr>
<td>EM10KM</td>
<td>-0.0125</td>
<td>0.0391</td>
<td>-0.0893</td>
<td>0.0642</td>
<td>0.9875</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>-0.0922</td>
<td>0.3078</td>
<td>-0.6970</td>
<td>0.5126</td>
<td>0.9119</td>
</tr>
</tbody>
</table>
Table 3.8. Summary of logistic regression analysis for variables predicting the observation of Soras in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate (β)</th>
<th>SE β</th>
<th>Wald's $\chi^2$</th>
<th>df</th>
<th>$p$</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-3.2624</td>
<td>0.3258</td>
<td>-10.01</td>
<td>1</td>
<td>≤ 0.001</td>
<td>NA</td>
</tr>
<tr>
<td>EM1KM</td>
<td>0.0208</td>
<td>0.0059</td>
<td>3.53</td>
<td>1</td>
<td>≤ 0.001</td>
<td>1.021</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>0.9755</td>
<td>0.3802</td>
<td>2.57</td>
<td>1</td>
<td>0.010</td>
<td>2.653</td>
</tr>
</tbody>
</table>

Test

<table>
<thead>
<tr>
<th>Test</th>
<th>$\chi^2$</th>
<th>df</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall model evaluation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>38.54</td>
<td>2</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Wald’s test</td>
<td>33.10</td>
<td>2</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Goodness-of-fit-test</td>
<td>8.01</td>
<td>8</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Note: Max rescaled $R^2 = 0.152$. NA = not applicable.

Table 3.9. Summary of logistic regression analysis for variables predicting the observation of Common Gallinules in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate (β)</th>
<th>SE β</th>
<th>Wald's $\chi^2$</th>
<th>df</th>
<th>$p$</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-6.9403</td>
<td>0.8325</td>
<td>-0.83</td>
<td>1</td>
<td>≤ 0.001</td>
<td>NA</td>
</tr>
<tr>
<td>EM100M</td>
<td>0.0379</td>
<td>0.0088</td>
<td>4.32</td>
<td>1</td>
<td>≤ 0.001</td>
<td>1.039</td>
</tr>
<tr>
<td>EM10KM</td>
<td>0.1713</td>
<td>0.0402</td>
<td>4.26</td>
<td>1</td>
<td>≤ 0.001</td>
<td>1.187</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>1.7983</td>
<td>0.4376</td>
<td>4.11</td>
<td>1</td>
<td>≤ 0.001</td>
<td>6.040</td>
</tr>
</tbody>
</table>

Test

<table>
<thead>
<tr>
<th>Test</th>
<th>$\chi^2$</th>
<th>df</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall model evaluation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>143.79</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Wald’s test</td>
<td>70.10</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Goodness-of-fit-test</td>
<td>11.46</td>
<td>8</td>
<td>0.177</td>
</tr>
</tbody>
</table>

Note: Max rescaled $R^2 = 0.456$. NA = not applicable.
Table 3.10. Summary of logistic regression analysis for variables predicting the observation of American Coots in the glaciated region of Ohio, USA, May—June 2009 and 2010.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate (β)</th>
<th>SE β</th>
<th>Wald's $\chi^2$</th>
<th>df</th>
<th>p</th>
<th>$\hat{e}^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-6.7903</td>
<td>1.0454</td>
<td>-6.50</td>
<td>1</td>
<td>≤ 0.001</td>
<td>NA</td>
</tr>
<tr>
<td>EM100M</td>
<td>0.0367</td>
<td>0.0118</td>
<td>3.12</td>
<td>1</td>
<td>0.002</td>
<td>1.0374</td>
</tr>
<tr>
<td>EM10KM</td>
<td>0.1043</td>
<td>0.0472</td>
<td>2.21</td>
<td>1</td>
<td>0.027</td>
<td>1.1099</td>
</tr>
<tr>
<td>Semi-perm</td>
<td>1.1464</td>
<td>0.5221</td>
<td>2.20</td>
<td>1</td>
<td>0.028</td>
<td>3.1468</td>
</tr>
</tbody>
</table>

Test

<table>
<thead>
<tr>
<th></th>
<th>$\chi^2$</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall model evaluation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>55.20</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Wald test</td>
<td>31.10</td>
<td>3</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Goodness-of-fit-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hosmer &amp; Lemeshow</td>
<td>7.42</td>
<td>8</td>
<td>0.492</td>
</tr>
</tbody>
</table>

Note: Max rescaled $R^2 = 0.263$. NA = not applicable.
Figure 3.1. Locations of marsh bird surveys conducted in the glaciated portions of Bird Conservation regions (BCRs) in Ohio, USA, May—June 2009 and 2010.
Figure 3.2. Relationship between percent emergent marsh within a) 0.1 km radius and b) 10 km radius and Pied-billed Grebe observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% pointwise confidence limits.
Figure 3.3. Relationship between percent emergent marsh within a) 0.1 km and b) 10 km and Least Bittern observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% confidence limits.
Figure 3.4. Relationship between percent emergent marsh within a 0.1 km radius and Virginia Rail observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% pointwise confidence limits.
Figure 3.5. Relationship between percent emergent marsh within a 1 km radius and Sora observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% pointwise confidence limits.
Figure 3.6. Relationship between percent emergent marsh within a) 0.1 km radius and b) 10 km radius and Common Gallinule observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% pointwise confidence limits.
Figure 3.7. Relationship between percent emergent marsh within a) 0.1 km radius and b) 10 km radius and American Coot observation probability in the glaciated region of Ohio, May—June 2009 and 2010. Dashed lines represent 95% pointwise confidence limits.
Chapter 4: Landscape habitat associations and distribution of secretive marsh birds in the glaciated region of Ohio, USA.

ABSTRACT

Secretive marsh birds, including grebes, bitterns and rails are obligate wetland birds, and have experienced strong population declines. Previous studies of species-habitat associations of secretive marsh birds have focused almost exclusively at patch or microhabitat scales. Few studies have described the surrounding landscape beyond the microhabitat scale or included landscape variables (e.g., wetland area, density of wetlands, anthropogenic measures such as urbanization or as density of roads). Analyses at larger spatial scales are needed to improve regional, national, and continental conservation planning for these species. I conducted call-broadcast surveys for nine species of secretive marsh birds in the glaciated region of Ohio, USA, during the breeding seasons in 2009 and 2010. I assessed species-habitat associations by ranking and evaluating competing habitat models for each species under three modeling algorithms and created decision-support maps of landscape suitability that are useful to managers for each species across the glaciated region of Ohio for each modeling algorithm. The landscape context of a wetland’s location is important for secretive marsh bird occurrence. Occurrence of focal marsh birds was associated with local wetland characteristics, landscape descriptors of natural and anthropogenic influences, and the amount of emergent wetland at multiple spatial scales. Habitat models with mixtures of local and landscape predictors were better descriptors of marsh bird presence than models with either local or landscape predictors alone. High landscape
suitability for all species tended to occur in areas with a high level of current conservation effort. Suitable habitat for marsh birds was generally concentrated in the southwestern Lake Erie region and locally concentrated in large, inland conservation areas in west central and northeast Ohio. Methods generally resulted in the same predictor variables for each species, with major effects (positive or negative associations) largely maintained. Local and regional populations of secretive marsh birds may be more efficiently and positively affected if habitat conservation and restoration efforts are targeted to larger, semi-permanently flooded wetlands in areas with higher amounts of landscape wetland area. Further, conservation and restoration efforts positively influencing marsh bird populations can be improved by including aspects of forest cover and anthropogenic metrics in the decision process depending on the species of interest.

INTRODUCTION

Ecological models describing species-habitat associations are essential to developing effective habitat conservation strategies that achieve species population goals (USFWS 2008). However, a scientific understanding is often lacking and forces resource managers to make conservation decisions using the best available information regarding species-habitat associations (Petit et al. 1995). Advancing our knowledge about habitat suitability and species distributions can improve conservation planning by efficiently targeting conservation and monitoring activities (Manel et al. 2001, Austin 2002, Wilson et al. 2005).

Species distribution is an emergent property of habitat selection among local (within patch) and landscape-scale characteristics (Hanski and Gilpin 1997, Lawton 1999, Shurin and Allen 2001). Understanding of the features within each spatial scale that influence habitat selection of migratory species is critical for successful population management, especially in areas with high levels of habitat fragmentation and anthropogenic disturbance (Fretwell and Lucas 1969, Cody 1981, Rotenberry 1985, Andrén 1994, Naugle et al. 1999, Sullivan et al. 2007).
Researchers often test habitat selection by a species at spatial scales based on the species’ ecology (e.g., home range, breeding territory size; see Scott et al. 2002). However, our ability to choose spatial scales and predictors of species’ occurrence is often limited by a general lack of knowledge of these processes and fundamental differences between our perceptual abilities and those of the focal species (Klopfer and Ganzhorn 1985, Wiens 1994, With and Crist 1995).

Pied-billed Grebes (*Podilymbus podiceps*), American Bitterns (*Botaurus lentiginosus*), Least Bitterns (*Ixobrychus exilis*), VirginiaRails (*Rallus limicola*), Soras (*Porzana carolina*), Common Gallinules (*Gallinula galeata*), and American Coots (*Fulica americana*) are known as secretive marsh birds. They are obligate wetland species that require emergent marsh to meet annual life cycle requirements (Conway 2009). Total area of emergent wetland has declined dramatically over the last century (Dahl 2000). Likewise, populations of several secretive marsh bird species have experienced strong population declines (Crewe et al. 2006, Timmermans et al. 2008). Understanding landscape attributes associated with occurrence of breeding marsh birds can increase the efficacy of species management programs, plus inform assessment of habitat management and restoration activities and subsequent population change.

Little is known about the landscape features associated with marsh bird occurrence. Previous studies of species-habitat associations of secretive marsh birds have focused almost exclusively at patch or microhabitat scales (e.g., Brackney and Bookhout 1982, Brown and Dinsmore 1986, Johnson and Dinsmore 1986, Budd and Krementz 2010, Harms 2011). However, few studies have described the surrounding landscape beyond the microhabitat scale (e.g., Naugle et al. 1999, Riffell et al. 2001, Lor and Malecki 2006, Rehm and Baldasarre 2007, Willard 2011). Even fewer studies have included landscape variables (e.g., wetland area, density of wetlands, anthropogenic measures such urbanization or as density of roads) in developing predictive habitat models for secretive marsh birds (but see Naugle et al. 1999 and Maxon et al. 2007). Although
results from local marsh bird habitat studies have been informative, habitat analyses at larger spatial scales are needed to improve regional (e.g., Soulliere et al. 2007, Wires et al. 2010), national (e.g., Brown et al. 2001), and continental (e.g., Kushlan et al. 2002) conservation planning.

The goal of species distribution modeling is to predict species occurrence in unsampled areas by identifying biologically important variables (Young and Hutto, 2002). There is no single best method for modeling species distribution (Lehman et al. 2002, Pearson et al. 2002, Elith et al. 2006, Leathwick et al. 2006, Elith and Leathwick 2007, Elith et al. 2008). Applying different modeling algorithms to the same survey data may lead to very different predictions of a species’ distribution, mainly because the output of each algorithm is unique but similar to others (Austin 2002). Elith et al. (2006) reported general patterns in the performance of species distribution models developed under many algorithms. They found that novel methods (e.g., Boosted Regression Trees) outperformed algorithms that have been traditionally used to model species distribution, including Generalized Linear and Generalized Additive models (Elith et al. 2006).

Because the choice of analytical approach can strongly influence statistical results and ecological conclusions, many studies have compared the performance of several models (e.g., linear, additive models, regression trees) of individual species’ distribution (Moisen and Frescino 2002, Scott et al. 2002, Thuiller et al. 2003, Muñoz and Felicisimo 2004).

Many studies have used a comparative approach to model species distribution with variable results. Thuiller et al. (2003) used GLM, GAM, and CART to model the distribution of four Mediterranean tree species across three spatial scales (local, country, and regional). Predictive accuracy of models generated under GAM procedures were robust at multiple scales because they can incorporate complex response curves to environmental variables (Thuiller et al. 2003). Moisen and Frescino (2002) compared five modeling techniques to characterize forest
land in the interior western U.S., and found each technique performed better than the others depending on specific conditions. Muñoz and Felicísimo (2004) compared logistic multiple regression (LMR), principle components analysis (PCA), and classification and regression trees (CART) with MARS to test their accuracy, reliability and implementation to predict the distribution of two plant species in a GIS. They found MARS and CART achieved the best prediction success (Muñoz and Felicísimo 2004).

I used a comparative approach to model relationships between the presence of secretive marsh birds and an array of landscape variables potentially serving as predictors of their occurrence. My goal was to provide a tool for improving conservation decisions by determining the location of areas most suitable for Pied-billed Grebes, American Bitterns, Least Bitterns, Virginia Rails, Soras, Common Gallinules, and American Coots in the glaciated region of Ohio, USA. Three objectives were established to achieve this goal. First, I assessed species-habitat associations by building and ranking competing habitat models for each species under three modeling algorithms. Second, I compared and evaluated the performance of models of species occurrence generated from each modeling algorithm. Thirdly, I created decision-support maps of landscape suitability that are useful to managers for each species across the glaciated region of Ohio for each modeling algorithm.

STUDY AREA

I conducted call broadcast surveys at 450 sites in the glaciated region of Ohio, USA, 209 in 2009 and 241 in 2010 (Figure 4.1). Over half (n=236, 52%) of the sites were located on private land. Surveys were conducted in 45 of 88 Ohio counties, 36 in 2009 and 35 in 2010. Sites were not evenly distributed among Bird Conservation Regions (BCRs). Forty-four percent of sites were located in BCR 13 (Lower Great Lakes / St. Lawrence Plain), 39% in BCR 23 (Prairie
Hardwood Transition), 14% in BCR 22 (Eastern Tallgrass Prairie), and 2% in BCR 28 (Appalachian Mountains). Nine different observers conducted surveys, 5 in 2009 and 6 in 2010.

METHODS

Point sampling

I used the National Wetlands Inventory (NWI) to select survey sites. NWI categories thought to contain habitat suitable for focal species based on a review of literature included the lacustrine littoral (L2) and palustrine (P) systems in the emergent (EM) or aquatic bed (AB) class (Cowardin et al. 1979). Forested, scrub/shrub and unconsolidated bottom wetlands cross classified with emergent or aquatic bed also were included to sample a wider range of potential marsh bird habitat. Survey locations were randomly selected from NWI data (http://www.ducks.org/conservation/glaro/gis-nwi-update) as interpreted from 2005-2007 aerial photographs (Ducks Unlimited 2008).

I used a generalized random-tessellation stratified (GRTS) design to select survey locations within NWI polygons (Kincaid et al. 2008). A stratified random sample of 350 points with a 50% oversample was selected each year. Sample points were stratified by 1) water regime, categorized as either seasonal (temporary and seasonally flooded) or semi-permanent (semi-permanently flooded, intermittently exposed, and permanently flooded) (Cowardin et al. 1979) and 2) wetland size: small (0.05-1.0 ha), medium (1.0-10.0 ha), and large (>10.0 ha). Wetlands within each stratum were sampled in proportion to their area across the study area in 2009 (Figure 4.1). Temporarily flooded wetlands were removed from the sampling frame in 2010 because 2009 data suggested these areas did not contain suitable emergent habitat for secretive marsh birds. Equal numbers of seasonally and semi-permanently flooded wetlands were sampled in 2010. The samples were drawn in R (R Development Core Team, 2005) using the package spsurvey version 2.0 (Kincaid et al. 2008).
I used a combination of county auditor Geographical Information Systems (http://www.cao.org/GIS/index.html) and plat books to identify landowners for sample locations in both years. I sent letters and aerial photographs to private land owners asking their permission to conduct surveys (Appendix C), and gained permission to conduct surveys on publicly owned land managed by agencies at all governmental levels.

Survey methods.

Marsh bird surveys followed methods outlined in the Standardized North American Marsh Bird Monitoring Protocol (Conway 2009) except that survey locations were randomly located within a wetland, not purposefully placed on dikes, roads, or at the vegetation-water interface. Points were surveyed three times during the field season with 10-15 days between each survey. I conducted surveys from 8 May to 28 June 2009 and 8 May to 22 June 2010. Surveys were conducted from 30 minutes before sunrise (civil twilight) to 2-3 hours after sunrise and from 2 hours before sunset to 30 minutes after sunset (civil twilight). Background noise, wind (Beaufort scale) and sky conditions (U.S. Weather Bureau code) were recorded prior to each survey. I did not conduct surveys when wind speeds were >20 km/hr or during sustained rain, per protocol guidelines (Conway 2009).

The call-broadcast sequence was obtained from the North American Marsh Bird Monitoring Program (Conway 2009) and consisted of a 5-minute passive listening period followed by 5 minutes of call-broadcast. Each minute of the call-broadcast period included 30 seconds of vocalizations by a single species followed by 30 seconds of silence. The order of species in the call broadcast was as follows: Least Bittern, Sora, Virginia Rail, King Rail, and Pied-billed Grebe. I added American Bittern and an additional Least Bittern call to the end of the broadcast series in 2010 (Appendix D). Technicians conducting surveys were trained to identify marsh bird vocalizations using audio CDs beginning in April and participated in a week of daily
in situ practice surveys and vocalization identification evaluations. Nine different observers conducted surveys, 5 in 2009 and 6 in 2010.

I broadcasted the call sequence at 90 dB 1 m from the source (Conway 2009) using an mp3 player (SanDisk Sansa Clip 512 MB, SanDisk Corporation, Milpitas, California, USA) attached to a pair of amplified speakers (Phillips Model SB220A, Koninklijke Philips Electronics, Amsterdam, The Netherlands). I placed speakers approximately 1.5 m above ground and pointed them toward the interior of the wetland. I recorded all visual and aural detections for 7 focal species at each survey point including Pied-billed Grebe, American Bittern, Least Bittern, Sora, Virginia Rail, Common Gallinule, and American Coot. I recorded the minute of each sequence during which a vocal and/or visual detections were confirmed. Observers estimated distance (m) to each bird detected with laser range finders and aerial photos. I assumed detection probability was enhanced by using call-broadcast surveys (Gibbs and Melvin 1993, Conway and Gibbs 2005) and that although detection probability was not constant across survey visits (Willard 2011), I assumed that species presence is determined with 90% confidence after three visits (Tozer et al. 2006).

**Predictor variable estimation**

I hypothesized local and landscape variables (Table 4.1) that would predict marsh bird presence during the breeding season based on current understanding of life-history requirements, species-habitat associations, and expert opinion. These variables were surrogates for local and landscape processes that influence habitat selection of marsh bird species either directly or indirectly. I gathered spatial data from several sources (Table 4.1) and generated 90 m resolution raster coverages for each variable across the study area using ModelBuilder workflows in ArcGIS 10.0 (ESRI, Redlands, California, USA). See Appendix F for detailed description of the process used for each of these variables.
Analysis

I predicted the probability of focal species presence using three modeling algorithms: generalized linear models (GLM; Nelder and Wedderburn 1972), generalized additive models (GAM; Hastie and Tibshirani, 1986, 1990, Yee and Mitchell 1991), and boosted regression trees (BRT; Elith et al. 2008). All models assumed a binomial error distribution with logit link function. There were sufficient data to conduct only BRT procedures for American Bittern, although I was unable to form both model-building and validation data sets (Stockwell and Peterson 2002).

I screened potential variables for inclusion in a priori candidate GLMs and GAMs using a two-stage approach. First, univariate logistic models were fit for each variable (Table 4.1) and variables with global $P$-values $\leq 0.25$ were retained for inclusion in GLM and GAM a priori candidate models. Secondly, a pairwise Spearman’s rank correlation matrix was generated for all continuous variables (Appendix G). I selected one variable where pairs were significantly correlated ($r \geq 0.70$), keeping the variable with most likely biological influence or at the smaller scale where no clear distinction existed (e.g. TWET1KM vs. TWET10KM).

I partitioned the data into separate training (70%, n = 315) and test (30%, n = 135) sets using a spatially-balanced sampling procedure (GRTS; Kincaid et al. 2008). This ensured spatial distribution of a species presence and absence across the study area in each of the sets.

I created a suite of a priori candidate habitat models for each species (except American Bittern) for GLM and GAM selection procedures. Scale-dependent wetland area, the spatial scale at which species’ observation probability was maximized, was considered an essential component of all a priori candidate models (see Chapter 3). I hypothesized alternative habitat models for each species (Appendix K) that included scale-dependent wetland area and combinations of 1) non-anthropogenic predictors, 2) anthropogenic predictors, 3) topographic predictors, and 4)
categorical descriptors of local wetland characteristics for both local and landscape scales (Table 4.1). Null models were also included in all candidate model sets. Only main effects were considered due to sample size considerations, which was especially important in GAM selection. I used the same set of candidate models for GLM and GAM selection for each species.

I used a two-stage model ranking and improvement approach to select the best model(s) among the suite of models. First, model selection on a priori GLMs and GAMs proceeded on Akaike’s Information Criterion corrected for small samples (AICc; Burnham and Anderson 2002). Best model(s) were identified as those for which there was substantial empirical support (ΔAICc ≤ 2; Burnham and Anderson 2002). Model selection was conducted for GLM and GAM models using binomial logistic regression with logit link function. I added cubic spline smoothing terms to all continuous variables in all GAMs with a maximum of 4 degrees of freedom and set gamma equal to 1.4, a penalty term that multiplies the model df and the AIC criteria. This reduces overfitting of smoothing functions and produces increasingly smooth models without much degradation in prediction error performance (Wood 2006). Secondly, I removed non-significant smoothing functions (P > 0.10) and non-significant non-wetland variables (incl. WETSTRAT) among best models (ΔAICc ≤ 2), and re-ranked the models using AICc. Model averaging based on Akaike model weights (wi) (Burnham and Anderson 2002) was implemented where ≥ 2 models had ΔAICc ≤ 2 for each species.

Boosted regression trees (BRT), an adaptation of stochastic gradient boosting, is a relatively new technique used to model species distributions (Elith et al. 2006). The method borrows from two rather distinct fields whose methods vary substantially, machine learning (ML) and statistics. Statistical approaches to model fitting assume an appropriate model and parameters are estimated from the data. Machine learning approaches, however, use an algorithm to learn the relationships between the response and its predictors. Instead of focusing on questions related to
model architecture (e.g., should the user include interaction terms, or are effects additive?), ML algorithms try to learn the response by observing and learning from the relationships among the response and inputs by finding dominant patterns. BRT incorporates techniques from these two approaches by combining the use of classification and regression tree models with “boosting”. Instead of producing a single “best” classification or regression tree model, BRT uses boosting, a forward, stagewise procedure for improving model accuracy, combining many hundreds or thousands of simple tree models to adaptively optimize predictive performance (Elith et al. 2008).

I created optimized BRT models for each species using the following process and constraints (after Elith et al. 2008). I fit an initial BRT model with learning rate (contribution of each tree to the final model) set between 0.001 and 0.01, a bag fraction (proportion of data subsampled for each tree) between 0.50 and 0.75, and a tree complexity (number of interactions among predictor variables) ≤ 3 that achieved lowest mean predicted deviance and ≥ 1,000 trees. I simplified each model by identifying and removing the least informative predictors where the average change in predicted deviance exceeded its original standard error (Elith et al. 2008), maintaining the constraints listed above. I determined the relative importance of each predictor variable (% contribution to fitted model) and created partial dependence plots (visualizations of fitted functions) for the most informative variables (up to 12) in fitted models for each species. I determined for each model whether there were significant two-way interactions among predictor variables (Elith et al. 2008).

I used five global measures of map accuracy (evaluation indices) to assess the predictive performance of final models: sensitivity, specificity, overall prediction success (OPS), Kappa (Cohen 1960), and the area under a Receiver Operating Characteristic curve (AUC). All evaluation indices were calculated using an independent test set created by randomly withholding 30% of the survey points in the study area. The first four of these indices were dependent on a
predetermined threshold (Table 4.2). Threshold-dependent evaluation indices were derived from a confusion matrix (Figure 4.2). A confusion matrix is a 2 x 2 classification table that describes the agreement between the observed presence and absence of a species and the predicted presence and absence of a species at a given threshold value. I set the model evaluation threshold equal to prevalence of each species (proportion of species occurrences among all sites; \((a+c)/N\)) in the test data (Manel et al. 2001, Cramer 2003, Liu et al. 2005).

Sensitivity (true positive fraction) and specificity (true negative fraction) measured the proportion of sites where the observations and the predictions were in agreement. Sensitivity reflects a model’s ability to detect presence given that a species actually occurs at a location (Fielding and Bell 1997). Specificity is the inverse of sensitivity and reflects a model’s ability to predict an absence where a species does not exist. Overall prediction success (OPS), also known as correct classification rate, is a measure of the accuracy of predicting true presences and absences among all evaluation sites. Kappa measures the proportion of correctly predicted sites after the probability of chance agreement has been removed (Moisen and Frescino 2002). Kappa values of 0.0-0.4 indicate poor model performance, values of 0.4-0.75 good, and >0.75 excellent (after Landis and Koch 1977). All threshold-dependent evaluation indices are sensitive to species prevalence, although this is true to a lesser extent for Kappa (Mantel et al. 2001).

A Receiver Operating Characteristic (ROC) plot is obtained by plotting sensitivity (true positive proportion) on the y-axis against the false positive proportion (1-specificity) for all threshold values between 0 and 1 on the x-axis (Hanley and McNeil 1982; see Figure 4.11). The area under the ROC function (or curve) (AUC) provides a single measure of the overall model accuracy by incorporating model performance indices across all threshold values (Pearce and Ferrier 2000). Values of AUC range from 0.5 to 1.0. The ROC plot for a poor model will lie near the diagonal where the true positive rate equals the false positive rate for all thresholds, and has a
predictive ability equivalent to random assignment (AUC = 0.50). A good model will achieve a high true positive rate (sensitivity) while the false positive rate (1-specificity) is still relatively small, resulting in a ROC curve that rises steeply at the origin, then levels off at a value near the maximum of 1. Models with AUC values of 0.5-0.7 are considered to have low discriminatory ability, while values of 0.7-0.9 indicate moderate, and >0.90 indicate excellent discriminatory ability (Swets 1998).

All analyses were done in R version 2.15.1 (R Development Core Team 2012). Generalized additive models were fit using the gam package (Hastie and Tibshirani 1996, Venables and Ripley 2002). Boosted Regression Trees was implemented through the gbm package (Ridgeway 2013). Spatial prediction surfaces were generated in R using package raster (Hijmans and van Etten 2012) and ArcGIS 10.0 (ESRI, Redlands, CA). Ninety (90) m resolution surfaces were mean-aggregated to 900 m and smoothed with a low pass filter for presentation in figures. Prediction surfaces for each modeling algorithm by species were averaged to create a mosaic model representing mean correspondence (congruency) among models.

RESULTS

Initial ranking of GLMs and GAMs indicated substantial differences in model complexity among species (Appendix K). Initial rankings and improvement of GAM selection generally resulted in fewer competing models (ΔAICc ≤ 4) and higher ranked models (lower AICc) than GLM selection for each species. Models with mixtures of scale-dependent wetland area, anthropogenic predictors and non-anthropogenic predictors tended to be ranked higher for all focal species except Soras and Common Gallinules for which simpler models were better predictors of occurrence. Model sets and significance (P ≤ 0.05) of predictor variables in final models varied among species for both GLM (Table 4.3) and GAM (Table 4.4) procedures. Among initial models, scale dependent wetland area and percent forest cover at landscape scales
were predictors of occurrence for Virginia Rails and American Coots. There was no support for null models for any species under GLM or GAM procedures.

Model sets and relative influence (% of trees with variable participation) of predictor variables varied among species for BRT procedures (Table 4.5). Wetland and forest area at all scales generally accounted for the largest proportion of variable contributions to final BRT models. Anthropogenic and non-anthropogenic distance metrics (e.g. distance to agriculture, D2AG) were minor contributors (variable contribution to final model generally < 5%) to final BRT models for each species; however, road density within 1 km was an exception for Least Bitterns, Soras, and American Coots (Table 4.5).

**Individual species models**

*Pied-billed Grebe.* Final GLM (Table 4.3) and GAM (Table 4.4) of Pied-billed Grebe occurrence were similar. Pied-billed Grebes were more likely to be detected in non-scrub/shrub and non-forested wetlands > 10.0 ha, in areas with high percent emergent wetlands within a 10 km radius, and in either BCRs 22 or 23 than in BCRs 13 and 28 (Tables 4.6 and 4.7). Topographic wetness index was positively and non-linearly related to PBGR occurrence in the final GAM. Percent forest cover within 1 km appeared in both models, but was not a significant ($P > 0.05$) predictor of PBGR occurrence.

Partial dependence plots from the final BRT model indicated that Pied-billed grebes were more likely to occur in large (>10.0 ha) emergent wetlands, > 400 m from upland cover, and in areas with high percent emergent wetland within 10 km and low levels of forest cover within 1 km and 10 km radii (Figure 4.3).

*American Bittern.* I was able to construct a BRT model for American Bittern occurrence (Table 4.5); however, the data were not separated into training and test data sets due to low
prevalence among sampled sites. Partial dependence plots indicated that American Bittern were more likely to occur in areas with >30% emergent wetland cover within 1 km radius, low percent forest cover and low percent aquatic bed wetlands within 10 km, and far from agricultural land cover types (Figure 4.4). Longitude had the largest contribution among fitted trees, indicating that longitudinal range was centered within the southwestern Lake Erie marsh region. The model had moderate ability to predict the presence of AMBI based on internal cross-validated AUC ($\bar{x} = 0.85$; SE = 0.034). However, the model and its associated map should be viewed as having little predictive performance without evaluation with independent test data.

**Least Bittern.** Final GLM (Table 4.3) and GAM (Table 4.4) of Least Bittern occurrence had similar suites of predictor variables. However, few of the parameters were significant ($P$: 0.059 - 0.871) predictors of their presence in the final GLM (Tables 4.6). Least Bitterns were 14.7 times more likely to in BCR 23 (95% CI: 2.3 – 92.8, $\chi^2_1 = 2.86$, $P = 0.004$) than in the rest of the study area and may have been 2.27 times more likely to occur in large (>10.0 ha) emergent wetlands (95% CI: 0.9 – 100.7, $\chi^2_1 = 1.872$, $P = 0.059$, marginally significant) than in wetlands < 10.0 ha.

The addition of smoothed terms in the GAM (Table 4.7) indicated Least Bitterns were 12.5 times more likely to occur in BCR 23 (95% CI: 2.2 – 71.0, $\chi^2_1 = 2.86$, $P = 0.004$), may have been 8.7 times more likely to occur in large emergent wetlands (95% CI: 0.9 – 83.4, $\chi^2_1 = 1.872$, $P = 0.061$, marginally significant), farther from upland cover, and in areas with greater road density within 1 km. Scale-dependent wetland area and distance to upland cover were not significant predictors of Least Bittern occurrence in linear models ($P$: 0.084-0.871; Table 4.6 and 4.7).

Partial dependence plots from the final BRT model indicated that Least Bitterns were more likely to occur in areas with very low percent forest cover within 10 km radius, > 400 m
from upland cover, higher road density within 1 km radius, and high topographic wetness (Figure 4.5). Least Bittern response to higher road density within a 1 km radius may be an artifact of detecting them primarily within publicly-owned management areas where local road density may be higher than the surrounding landscape.

**Virginia Rail.** The final GLM of Virginia Rail occurrence (Table 4.6) was model-averaged from two competing models (ΔAICc < 2.0) (Table 4.3), and had the same predictor variables as the final GAM (Table 4.4). For both models, Virginia Rails were more likely to occur in large (>10.0 ha), non-scrub/shrub and non-forest-associated wetlands. With addition of smoothing terms in the GAM, Virginia Rail occurrence was non-linearly related to percent forest within a 1 km radius (response plot not shown but similar to partial dependence plot in Figure 4.6). Percent emergent wetland within a100 m radius was marginally significant (P: 0.051-0.060) in both models.

Partial dependence plots from the final BRT model indicated VIRA were more likely to occur in areas with higher percent emergent wetland within 100 m, 1 km, and 10 km radii, < 500 m from agricultural cover, and < 0.2% aquatic bed and open water wetland within a 10 km radius (Figure 4.6). A slight longitudinal gradient (X_METERS) suggested that VIRA were more likely to occur in the eastern half of the study area.

**Sora.** The final GLM of Sora occurrence (Table 4.6) was model-averaged from five relatively simple competing models (ΔAICc < 2.0) (Table 4.3) and had similar predictor variables as the final GAM (Table 4.4). Soras were more likely to occur in large (>10.0 ha), semi-permanently-flooded wetlands farther from roads (marginally significant, P = 0.061) (Table 4.6). Addition of smoothing terms indicated that Sora were more likely to occur in areas with higher
percent emergent wetland within a 1 km radius, lower road density within 1 km radius, and farther from roads (similar to partial dependence plots from BRT model, Figure 4.7) (Table 4.7).

Partial dependence plots from the final BRT model indicated that Soras were more likely to occur in semi-permanently-flooded wetlands, in areas with high percent emergent wetland within a 1 km radius, lower road density within 1 km, and higher percent wetland area within 10 km radius (Figure 4.7).

**Common Gallinule.** The final GLM of Common Gallinule occurrence (Table 4.6) was model-averaged from two competing models (ΔAICc < 2.0) (Table 4.3). Common Gallinules were more likely to occur in large (>10.0ha), semi-permanently-flooded emergent wetlands and in areas with higher percent emergent marsh within 100 m and 10 km radii. Percent forest within 10km radius and identifiers for scrub-shrub / forest-associated wetland and BCR 23 were included in the final model, although these variables were not significant (P: 0.052–0.385) predictors of Common Gallinule presence (Table 4.6).

The final GAM of Common Gallinule occurrence had similar predictor variables as the GLM (Table 4.4). Common Gallinule were more likely to occur in large (>10.0 ha), semi-permanently-flooded wetlands, in areas with higher percent emergent marsh within 10 km, higher percent forest cover, and in BCR 23 (Table 4.7).

Partial dependence plots from the final BRT model indicated that Common Gallinules were more likely to occur in areas with higher percent emergent wetland within 1 km radius, < 10% forest cover within a 10 km radius, > 500 m from upland (non-wetland) cover, higher topographic wetness, and < 2% slope (Figure 4.8).

**American Coot.** Final GLM (Table 4.3) and GAM (Table 4.4) models of American Coot occurrence had the same predictor variables. Coefficients of predictor variables indicated that
American Coot were more likely to occur in semi-permanently-flooded emergent wetlands, in areas with higher percent emergent wetland within 100 m and 10 km radii, lower percent aquatic bed and open water wetlands within a 1 km radius, and lower percent forest cover within a 100 m radius. However, percent emergent marsh within a 100 m radius was the only significant predictor of AMCO occurrence between the two models; for all remaining variables ($P: 0.071-0.608$) (Table 4.6, 4.7).

Partial dependence plots from the final BRT model indicated that American Coots were more likely to occur in areas with high percent emergent marsh within a 100 m radius, > 60% total wetland area within a 1 km radius, > 30% total wetland area within a 10 km radius, far from upland cover and in areas with low road density (Figure 4.9). Minor longitudinal and latitudinal response indicated that American Coot were more likely to occur in the northwestern portion of the study area, centered within the SW Lake Erie marshes (Figure 4.9).

**Model comparisons**

Model performance varied among species for all evaluation metrics (Table 4.8). Designation of a best model for each species varied with evaluation metrics, whether it was based on the maximization of threshold-dependent evaluation metrics or the area under the Receiver Operating Characteristic curve (AUC). The model algorithm with the highest threshold-dependent evaluation metrics was GLM for Pied-billed Grebe and American Coot (final GAM was identical model), GAM for Least Bittern and Sora, and BRT for Virginia Rail and Common Gallinule. Receiver Operating Characteristic curves (Figure 4.11; see methods for description) showed an overall predictive advantage for BRT over GLM and GAM procedures. Considering only AUC, BRT models would be chosen over GLM and GAM for all species except Pied-billed Grebe for which GLM had the highest AUC. All models for Pied-billed Grebe and Least Bittern had high predictive performance based on AUC (Swets 1998), while Common Gallinule and
American Coot models had moderate and Virginia Rail and Sora had low predictive performances (Table 4.8).

Model performance based on threshold-dependent evaluation metrics varied among model algorithms (Table 4.8). GLMs had generally lower overall prediction success than either GAMs or BRT models. GLMs more correctly predicted presence (sensitivity), but less accurately predicted absences (specificity) than other models. Conversely, BRT models more accurately predicted absences and less accurately predicted species presence. The probability of correctly predicting presence after removing the probability of chance agreement (Kappa) was generally higher for GAMs and lower for GLMs with BRTs falling between the two.

The ability of model algorithms to discriminate between a species’ predicted presence and absence was affected by species’ prevalence and model quality (i.e. % deviance explained, parameter significance). Species’ prevalence affected threshold-dependent model evaluation metrics (Table 4.8). Pied-billed Grebe and Common Gallinule, the two most prevalent species, had higher values for all threshold-independent evaluation metrics than either American Coot or Least Bittern, the two least prevalent species (Table 4.8). I would expect that distribution of sites where species were observed (present) would tend to have higher predicted probabilities than sites where it was not observed (absent). The distributions of predicted presence and absence of each species (Figure 4.9) revealed a noticeable separation among sites with species detections for Pied-billed Grebe and Common Gallinule, the two most prevalent species. However, this was not apparent for all other species. Virginia Rail and Sora had the lowest values for all evaluation metrics due to poorer model quality. I suspect model quality for these two species was diminished due to absence of within-patch habitat characteristics not studied here (e.g., vegetation composition, water depth).
The effect of species’ prevalence on model evaluation metrics can also be seen across all threshold values (Figure 4.10). The threshold at which sensitivity equals specificity (positive observations are as likely to be wrong as negative observations) increased with species’ prevalence regardless of accuracy value (Manel et al. 2001); models with higher threshold values were considered better than those with lower values. BRT models tended to have equal or higher accuracy values when this criteria was met, and at a lower threshold value. The shape and height of Kappa in threshold plots (Figure 4.10) also serves as an evaluation of model performance; curves with higher values and wider peaks (wider range of thresholds) are considered better than models with lower values and narrow peaks (see Manel et al. 2001). Based on this criterion, model performance was excellent for Pied-billed Grebe and can be good depending on threshold of interest for Least Bittern and Common Gallinule, and nearly so for American Coot (Landis and Koch 1977). Kappa values indicated that all models performed poorly for Sora and Virginia Rail regardless of threshold.

Spatial predictions

Decision-support maps of species occurrence as a function of landscape features (landscape suitability) were produced from final models for each species (Figures 4.12-4.18). Overall, landscape suitability patterns were consistent with where I detected each species (see Appendix I).

Suitable habitat for Pied-billed Grebe was highly concentrated in the southwestern Lake Erie marsh region (BCR 23) with local concentration near large, inland wetland management areas in northeast (BCR 13) and west central (BCR 22) Ohio. Prediction surfaces for Pied-billed Grebe were similar among all models; however, there were subtle differences in landscape suitability among large marsh areas in northeast Ohio (BCR13) for GLM and GAM (Figure 4.13).
Landscape suitability patterns for Pied-billed Grebe were consistent with recorded presence and absence across the sample frame (Appendix I).

Suitable habitat for American Bittern was limited to the southwestern Lake Erie marsh region (BCR 23) and the largest inland wetland management areas (Figure 4.14). However, landscape suitability patterns for American Bittern differed from where I detected them during surveys (Appendix I). I never detected American Bittern in northeast Ohio (BCR 13) even though suitable habitat was predicted to be there.

Suitable habitat for Least Bittern was concentrated almost exclusively in the southwestern Lake Erie region (BCR 23) (Figure 4.15). The amount and distribution of suitable habitat for Least Bittern varied widely among best models identified through threshold dependent and threshold-independent evaluation metrics. Survey results (Appendix I) were more consistent with distribution of suitable habitat for Least Bittern predicted from final GAM. Spatial prediction of suitable habitat from the final BRT model overemphasized landscape suitability in northeast Ohio (BCR 13), where I rarely detected Least Bittern.

Suitable habitat for both Virginia Rail (Figure 4.16) and Sora (Figure 4.17) was more widespread for all models with concentrations in the southwestern Lake Erie region (BCR 23), large inland wetland management areas in west central Ohio (BCR 22), and scattered throughout northeast Ohio (BCR 13). Distribution of suitable habitat under best models was largely consistent with recorded presence/absence (Appendix I). However, there were many locations in northeast Ohio (BCR 13) where higher landscape suitability was not consistent with Virginia Rail and Sora detections. Although model predictions suggested both species had wide tolerances across resource gradients and landscape conditions, the predictions may have been overly optimistic considering issues with explanatory power and lower model performance metrics.
Suitable habitat for Common Gallinule (Figure 4.18) and American Coot (Figure 4.19) were concentrated in the southwestern Lake Erie region (BCR 23) and large, inland wetland management areas in west central (BCR 22) and northeast (BCR 13) Ohio. BRT models for the two species added locations with moderate suitability across the study area, while areas predicted to be highly suitable were consistent with the other models. The amount and distribution of suitable habitat for American Coot varied widely among best models identified through threshold dependent and threshold-independent evaluation metrics (Figure 4.19). Survey results (Appendix I) were more consistent with distribution of suitable habitat for American Coot predicted from final GLM. Spatial prediction of suitable habitat from the final BRT model overemphasizes landscape suitability in northeast Ohio (BCR 13), where I rarely detected American Coot.

**DISCUSSION**

The landscape context of a wetland’s location is important for marsh bird occurrence in the glaciated region of Ohio. Occurrence of focal marsh birds were associated with local wetland characteristics (i.e. wetland size), landscape descriptors of natural (e.g., percent forest within a 1 km radius) and anthropogenic (e.g., road density within a 1 km radius) influences, and the amount of emergent wetland at multiple spatial scales. Habitat models with mixtures of local and landscape predictors were better descriptors of marsh bird presence than models with either local or landscape predictors alone. Marsh bird presence was positively associated with percent emergent wetland within the landscape (Rehm and Baldasarre 2007, Bolenbaugh et al. 2011). These results were consistent with the few published studies of marsh bird habitat models that incorporated landscape predictors of marsh bird presence (Naugle et al. 1999, Lor and Malecki 2006, Rehm and Baldasarre 2007, Bollenbaugh et al. 2011). Other studies have shown that incorporating landscape variables improved predictions of bird species distributions (Scott et al. 2002, Seoane et al. 2004, Richard and Armstrong 2010).
Anthropogenic landscape variables were predictors of Least Bittern and Sora presence for all model algorithms and were minor contributors to BRT models for all other species. Presence of marsh birds was generally negatively associated with road density and distance to roads, phenomenon not previously documented for these species. This may indicate habitat selection by marsh birds is influenced by degree of anthropogenic disturbance or habitat fragmentation. Anthropogenic metrics included in this study may function as surrogates for unmeasured landscape processes (e.g., habitat fragmentation and availability) or non-habitat characteristic (increased predation or noise disturbance) in the study area.

The amount of forest within 1 km and 10 km radii were influential predictors of marsh bird presence in this study. Other studies have found a negative association between marsh bird presence and percent forest cover (Budd and Krementz 2010, Bolenbaugh et al. 2011). In addition, Pied-billed Grebe were detected farther from uplands, similar to Lor and Malecki (2006) who found nest locations of Pied-billed Grebe were positively associated with increasing distance from upland cover. Conversely, Naugle et al. (1999) found that habitat use by Pied-billed Grebes in the Prairie Pothole Region was explained solely by within patch variability (e.g., wetland size), although they did not include predictors of habitat disturbance (e.g., road density). Marsh bird presence in areas with higher amounts of forest cover does not mean that marsh birds like forest cover. Wetlands may naturally occur in areas with higher amount of forest cover (e.g., BCR 13). However, it also does not indicate that forest cover inhibits use by marsh birds, although many species are negatively related to forest encroachment variables (e.g., Pied-billed Grebes, Virginia Rails, Common Gallinules, and American Coots).

High landscape suitability for all species tended to occur in areas with a high level of current conservation effort (e.g. private land conservancies, state wildlife areas, federal wildlife refuges). Suitable habitat for marsh birds was generally concentrated in the southwestern Lake
Erie region (BCR 23) and locally concentrated in large, inland conservation areas in west central (BCR 22) and northeast (BCR 13) Ohio. Nevertheless, there may be substantial suitable habitat for Virginia Rails and Soras on private land, especially in BCR 13. Overall, GLMs resulted in more conservative and BRTs more liberal estimations of potential suitable habitat across the study area.

Methods generally resulted in the same predictor variables for each species, with major effects (positive or negative associations) largely maintained. Although model evaluation metrics among the three model algorithms were similar for each species, BRT models tended to perform better than GLM and GAM (Elith et al. 2006). However, there was no overall best model algorithm for predicting occurrence among focal species after comparing spatial predictions with patterns of recorded species observations across the study area. Maximizing model evaluation metrics and consistency between predicted presence and recorded presence (specificity) resulted in an equal number of final models among the three model algorithms. Occurrence of Pied-billed Grebes and American Coots were best modeled with GLMs, while GAMs were best for Least Bitterns and Soras, and BRTs were best for Virginia Rails and Common Gallinules.

Species prevalence and life history affected the predictive ability of marsh bird habitat models (Manel et al. 2001). Overall model performance tended to improve with increasing species prevalence. Habitat models for marsh birds may be improved by including predictors of within-patch variability (e.g. water depth, dominant plant species; see Willard 2011). Virginia Rails and Soras seem to have a relatively wide tolerance of landscape conditions at scales above the patch level. This may indicate their distributions are influenced more by conditions within individual patches than by landscape conditions (Willard 2011). However, lower model performance metrics for Virginia Rails and Soras may also be a function of non-detection error (Gu and Swihart 2004). Non-detection of species present in habitat patches can negatively bias
estimates of occurrence and density (Gu and Swihart 2004). Sora and Virginia Rail detectability
was not constant across survey visits (Willard 2011), with Sora observations occurring much
earlier in the survey period. Both species are commonly observed within 50-100 m and have
vocalizations that are at times hard to hear. If I underestimated site-level occurrence of Soras and
Virginia Rails, then the misclassification of presence would reflect in model evaluation metrics
calculated using the confusion matrix.

The distribution models presented here reflect a species’ realized niche (Austin 2007) and
are just as likely to predict presence of marsh birds in areas with positive survival and
reproduction potential (source habitats) as they do areas with negative potential (sink habitats)
(Pulliam 1988). I did not assess the reproductive success or survival of marsh birds at survey
sites. Therefore, I cannot determine whether there were differences in local or landscape
predictors between habitat sinks and sources. Studies of local and landscape effects on marsh
bird productivity and survival should be conducted for several years as habitat patches can
function as sinks and sources between years (Pulliam and Danielson 1991). Researchers can use
these results in developing research to assess survival and reproductive response of individual
marsh birds to local and landscape predictors.

Finally, a true test of the predictive performance of these models can come from an
independent data set. Site-level presence and absence records of marsh birds resulting from
standardized monitoring protocols (e.g. Conway 2009) in the study area can be used to validate
the performance of each species habitat model for all model algorithms.

MANGESMENT IMPLICATIONS

Maps of habitat suitability for marsh birds in the glaciated region of Ohio highlight the
importance of the southwestern Lake Erie region and large, interior habitat focus areas such as
Grand River, Mosquito Creek, and Shenango Wilderness Areas, and Big Island, Funk Bottoms
and Killbuck Wildlife Areas. Local and regional populations of secretive marsh birds may be more efficiently and positively affected if habitat conservation and restoration efforts are targeted to larger, semi-permanently flooded wetlands in areas with higher amounts of landscape wetland area. Further, conservation and restoration efforts directly and positively influencing marsh bird populations can be improved by including aspects of forest cover and anthropogenic metrics in the decision process depending on the species of interest. Results from this study may be used to estimate the effect of habitat alteration (e.g. wetland restoration, construction of roads and other developments, expansion of woody cover) on the presence of secretive marsh birds at any location within the study area. Long-term conservation planning for marsh bird habitat can incorporate projections of landscape change and its potential effect on marsh bird distribution. Conservation planners and habitat managers using these results to target conservation actions for secretive marsh birds must remain aware of two concerns: 1) presence does not always translate to quality habitat (van Horne 1983, Pulliam 1988) (high survival/recruitment) and 2) the models need to be tested with an independent data set. Identifying habitat associations where marsh birds are more likely to occur, survive, and successfully breed will further inform conservation planning efforts and may help to efficiently target limited human and financial resources to restore or enhance habitat for marsh birds in locations that achieve desired population goals.
LITERATURE CITED


Hastie, T. 2011. gam: Generalized additive models. R package version 1.06.2. URL: http://CRAN.R-project.org/package=gam


Willard, K. 2011. Habitat associations of breeding marsh birds within the glaciated region or Ohio, USA. Master’s thesis: The Ohio State University, Columbus, OH, USA.


Table 4.1. Predictor variables used in analyses of marsh bird occurrence in wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. See Appendix F for detailed descriptions on how each variable was generated.

<table>
<thead>
<tr>
<th>Type</th>
<th>Abbreviation</th>
<th>Description</th>
<th>Scale</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-anthropogenic</td>
<td>AB100M</td>
<td>Aquatic Bed wetland within 0.1 km radius</td>
<td>x</td>
<td>%</td>
<td>National Wetlands Inventory</td>
</tr>
<tr>
<td></td>
<td>AB1KM</td>
<td>Aquatic Bed wetland within 1 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>AB10KM</td>
<td>Aquatic Bed wetland within 10 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>EM100M</td>
<td>Emergent wetland within 0.1 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>EM1KM</td>
<td>Emergent wetland within 1 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
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<tr>
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<td>EM10KM</td>
<td>Emergent wetland within 10 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>TWET100M</td>
<td>Wetland within 0.1 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>TWET1KM</td>
<td>Wetland within 1 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>TWET10KM</td>
<td>Wetland within 10 km radius</td>
<td>x</td>
<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>FOREST100M</td>
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<td>x</td>
<td>%</td>
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<tr>
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<td>FOREST1KM</td>
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<td>x</td>
<td>%</td>
<td>&quot;</td>
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<tr>
<td></td>
<td>FOREST10KM</td>
<td>Forest cover within 10 km radius</td>
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<td>%</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>D2UL</td>
<td>Distance to upland (non-wetland) cover</td>
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<td>m</td>
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<td></td>
<td>D2RIV</td>
<td>Distance to stream/river</td>
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<td>m</td>
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<td>km/km$^2$</td>
<td>TigerLine Roads</td>
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<td>km/km$^2$</td>
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<td>Road density within 10 km radius</td>
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<td>km/km$^2$</td>
<td>&quot;</td>
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<td>x</td>
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<tr>
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<td>D2DVT</td>
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<td>D2AG</td>
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<td>Topographic</td>
<td>PERSLOPE</td>
<td>Slope</td>
<td>x</td>
<td>%</td>
<td>Digital Elevation Model</td>
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<td>TWI</td>
<td>Topographic wetness index</td>
<td>x</td>
<td>Index</td>
<td>&quot;</td>
</tr>
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<td>BCR</td>
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<td>x</td>
<td></td>
<td>North American Bird Conservancy</td>
</tr>
<tr>
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<td>SIZE</td>
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<td>x</td>
<td></td>
<td>National Wetlands Inventory</td>
</tr>
<tr>
<td></td>
<td>WETSTRAT</td>
<td>Water permanence</td>
<td>x</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>SSFAW</td>
<td>Scrub/shrub or forest associated wetland</td>
<td>x</td>
<td></td>
<td>&quot;</td>
</tr>
</tbody>
</table>
Table 4.2. Threshold-dependent indices for assessing the predictive performance of models of marsh bird occurrence in the glaciated region of Ohio, May—June 2009 and 2010, calculated using a confusion matrix (after Fielding and Bell 1997, see Figure 4.2).

<table>
<thead>
<tr>
<th>Performance measure</th>
<th>Definition</th>
<th>Formula$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall prediction success</td>
<td>Proportion of all cases correctly predicted</td>
<td>$(a + d) / N$</td>
</tr>
<tr>
<td>Proportion of true positives correctly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Proportion of true negatives correctly</td>
<td>$a / (a + c)$</td>
</tr>
<tr>
<td>Specificity</td>
<td>Proportion of true positives correctly</td>
<td>$d / (b + d)$</td>
</tr>
<tr>
<td>Kappa</td>
<td>Proportion of specific agreement</td>
<td>$[(a + d) - (((a + c)(a + b) + (b + d)(c + d))/N)] / [N - (((a + c)(a + b) + (b + d)(c + d))/N)]$</td>
</tr>
</tbody>
</table>

$^a$Formula character definitions: a is true positives (presences), b is false positives (presences), c is false negatives (absences), d is true negatives (absences), N is the total number of sites ($a + b + c + d$).
Table 4.3. Model selection results (change in Akaike’s Information Criterion adjusted for small sample size, \( \Delta AIC_c \leq 4 \)) from Generalized Linear Models (GLM) of marsh bird occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. Boldface type indicates the best model(s) (\( \Delta AIC_c \leq 2.0 \)). Covariate abbreviations are given in Table 4.1.

| Species         | Parameters                                      | \(-2\)Log Likelihood | k | \(AIC_c\) | \(\Delta AIC_c\) | Relative model likelihood \(L(g|x)\) | Akaike weight \((w_i)\) | Evidence ratio \((w_i)\) |
|-----------------|-------------------------------------------------|----------------------|---|------------|------------------|----------------------------------|----------------|------------------|
| Pied-billed Grebe  | **EM100M + EM10KM + WETSTRAT + SIZE + FOREST1KM + SSFAW + BCR22 + BCR23** | 158.68               | 9 | 177.28     | 0.00             | 1.00                            | 0.74             | 1.00             |
|                 | EM100M + EM10KM + WETSTRAT + SIZE + SSFAW +FOREST1KM + RDENS1KM + D2UL + BCR22 + BCR23 | 158.36               | 1 | 181.24     | 3.96             | 0.14                            | 0.10             | 7.24             |
|                 | < NULL >                                       | 357.00               | 1 | 359.00     | 181.72           | 0.00                            | 0.00             | 2.8 x 10^39     |
| Least Bittern   | **EM100M + EM10KM + AB1KM + SIZE + RDENS1KM + D2UL + BCR23** | 130.94               | 8 | 147.41     | 0.00             | 1.00                            | 0.83             | 1.00             |
|                 | < NULL >                                       | 193.6                | 1 | 195.60     | 50.76            | 0.00                            | 0.00             | 1.05 x 10^11    |
| Virginia Rail   | **EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM** | 211.1                | 7 | 225.46     | 0.00             | 1.00                            | 0.36             | 1.00             |
|                 | EM100M + SSFAW + FOREST1KM                     | 218.31               | 4 | 226.44     | 0.98             | 0.61                            | 0.22             | 1.63             |
|                 | EM100M + EM10KM + SSFAW + FOREST1KM            | 218.00               | 5 | 228.20     | 2.74             | 0.25                            | 0.09             | 3.94             |
|                 | FOREST1KM                                      |                      |   |            |                  |                                 |                  |                  |

Continued
## Table 4.3 continued

| Species             | Parameters                                                                 | -2*Log Likelihood | k | AIC<sub>c</sub> | ΔAIC<sub>c</sub> | Relative model likelihood <i>L</i> (<i>g</i>|<i>x</i>) | Akaike weight (<i>w</i>) | Evidence ratio (<i>w</i>) |
|---------------------|----------------------------------------------------------------------------|-------------------|---|----------------|----------------|------------------|------------------|------------------|
| **Virginia Rail**   | EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + BCR22 + BCR23                | 212.22            | 8 | 228.69         | 3.23           | 0.20             | 0.07             | 5.02             |
|                     | EM100M + EM10KM + WETSTRAT + SIZE + SSFAW                                | 214.5             | 7 | 228.86         | 3.40           | 0.18             | 0.07             | 5.48             |
|                     | < NULL >                                                                  | 243.62            | 1 | 245.63         | 20.17          | 0.00             | 0.00             | < NULL >         |
| **Sora**            | 1 EM1KM + SIZE + WETSTRAT + D2RD                                         | 206.02            | 5 | 216.22         | 0.00           | 1.00             | 0.20             | 1.00             |
|                     | 2 LARGE + WETSTRAT + D2RD                                                | 209.06            | 4 | 217.20         | 0.97           | 0.61             | 0.12             | 1.63             |
|                     | 3 EM1KM + WETSTRAT + D2RD                                                | 209.08            | 4 | 217.20         | 0.98           | 0.61             | 0.12             | 1.63             |
|                     | EM1KM + WETSTRAT + RDENS1KM + D2RD                                       | 207.08            | 5 | 217.27         | 1.05           | 0.59             | 0.12             | 1.69             |
|                     | 5 SIZE + WETSTRAT                                                        | 211.78            | 3 | 217.86         | 1.63           | 0.44             | 0.09             | 2.26             |
|                     | 6 EM1KM + WETSTRAT + SIZE                                                | 210.87            | 4 | 218.97         | 2.74           | 0.25             | 0.05             | 3.94             |
|                     | 7 EM1KM + WETSTRAT                                                        | 213.34            | 3 | 219.41         | 3.19           | 0.20             | 0.04             | 4.93             |
|                     | < NULL >                                                                  | 243.62            | 1 | 245.63         | 29.40          | 0.00             | 0.00             | 2.43 x 10<sup>6</sup> |
| **Common Gallinule**| 1 EM100M + EM10KM + WETSTRAT + SIZE + FOREST10KM + BCR23                 | 184.52            | 7 | 198.88         | 0.00           | 1.00             | 0.30             | 1.00             |
|                     | EM100M + EM10KM + WETSTRAT +                                                  | 188.44            | 6 | 200.71         | 1.83           | 0.40             | 0.12             | 2.50             |
|                     | 2 SIZE + SSFAW                                                            | 190.98            | 5 | 201.16         | 2.29           | 0.32             | 0.10             | 3.14             |
|                     | 4 + FOREST10KM + SSFAW                                                    | 187.37            | 7 | 201.37         | 2.49           | 0.29             | 0.09             | 3.47             |

Continued
Table 4.3 continued

| Species        | Parameters                        | -2*Log Likelihood | k | ΔAIC<sub>c</sub> | ΔAIC<sub>c</sub> | Relative model likelihood ℒ<sub>(g|x)</sub> | Akaike weight<sup>(wij)</sup> | Evidence ratio<sup>(wij)</sup> |
|----------------|-----------------------------------|-------------------|---|-----------------|-----------------|---------------------------------|-------------------------------|-----------------------------|
| Common Gallinule | 5 EM100M + EM10KM + WETSTRAT + TWI | 191.78            | 5 | 201.98          | 3.10            | 0.21                             | 0.06                          | 4.71                        |
|                | 6 EM100M + EM10KM + WETSTRAT + AB1KM + SIZE + SSFAW | 188.18            | 7 | 202.54          | 3.67            | 0.16                             | 0.05                          | 6.25                        |
|                | 29 < NULL >                        | 288.64            | 1 | 290.64          | 91.77           | 0.00                             | 0.00                          | 8.45 x 10<sup>19</sup>      |
| American Coot  | 1 EM100M + EM10KM + WETSTRAT + AB1KM + FOREST100M | 134.56            | 6 | 259.71          | 0.00            | 1.00                             | 1.00                          | 1.00                        |
|                | 28 < NULL >                        | 184.28            | 1 | 585.89          | 326.18          | 0.00                             | 0.00                          | 6.73 x 10<sup>70</sup>      |
Table 4.4. Model selection results (change in Akaike’s Information Criterion adjusted for small sample size, ΔAICc ≤ 4) from Generalized Additive Models (GAM) of marsh bird occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. Boldface type indicates the best model(s) (ΔAICc ≤ 2.0). The evidence ratio (w_i) indicates the multiplicative probability by which the best model is more likely than competing models, given the set of candidate models and the data. Covariate abbreviations are given in Table 4.1.

| Species          | Parameters                                                                 | -2*Log Likelihood | k   | AICc | ΔAICc | $L (g_j|x)$ | Akaike weight ($w_i$) | Evidence ratio ($w_i$) |
|------------------|---------------------------------------------------------------------------|-------------------|-----|------|-------|-------------|-----------------------|-----------------------|
| Pied-billed grebe| $EM100M + s(EM10KM) + SIZE + SSFAW$                                      | 143.26            | 15  | 167.03| 0.00  | 1.00       | 0.89                  | 1.00                  |
|                  | $s(FOREST1KM) + s(TW1) + BCR22 + BCR23$                                   |                   |     |       |       |            |                       |                       |
|                  | $< NULL >$                                                                | 357.00            | 1   | 359.00| 191.98| 0.00       | 0.00                  | 4.86 × 10^{-41}       |
| Least Bittern    | $EM100M + AB1KM + SIZE + s(RDENS1KM)$                                      | 128.92            | 11  | 144.85| 0.00  | 1.00       | 0.60                  | 1.00                  |
|                  | $+ s(D2UL) + BCR23$                                                       |                   |     |       |       |            |                       |                       |
|                  | $< NULL >$                                                                | 128.82            | 12  | 146.93| 2.08  | 0.35       | 0.21                  | 2.84 × 10^{-11}       |
| Virginia Rail    | $s(EM100M) + s(EM10KM) + SIZE + SSFAW$                                    | 197.02            | 12  | 214.56| 0.00  | 1.00       | 0.69                  | 1.00                  |
|                  | $+ s(FOREST1KM)$                                                         |                   |     |       |       |            |                       |                       |
|                  | $s(EM100M) + s(EM10KM) + WETSTRAT + SIZE + SSFAW + s(FOREST1KM)$          | 196.86            | 13  | 216.59| 2.03  | 0.36       | 0.25                  | 2.76                  |
|                  | $< NULL >$                                                                | 243.62            | 1   | 245.63| 31.06 | 0.00       | 0.00                  | 5.57 × 10^{-6}        |

Continued
Table 4.4. continued

| Species          | Parameters                                                                 | -2*Log Likelihood | k | AICc | ΔAICc | Relative model likelihood $L(g|x)$ | Akaike weight $(w_i)$ | Evidence ratio $(w_i)$ |
|------------------|----------------------------------------------------------------------------|-------------------|---|------|-------|-----------------------------------|----------------------|-----------------------|
| Sora             | $s(EM1KM) + WETSTRAT + s(RDENS1KM)$                                       | 199.40            | 11| 212.02| 0.00  | 1.00                              | 0.72                 | 1.00                  |
|                  | $< \text{NULL} >$                                                          | 243.62            | 1 | 245.63| 33.61 | 0.00                              | 0.00                 | 1.99 x 10^7           |
| Common Gallinule | $s(EM10KM) + WETSTRAT + SIZE + s(FOREST10KM) + BCR23$                      | 180.45            | 10| 196.45| 0.00  | 1.00                              | 0.58                 | 1.00                  |
|                  | $< \text{NULL} >$                                                          | 288.63            | 1 | 290.64| 94.20 | 0.00                              | 0.00                 | 2.85 x 10^{20}        |
| American Coot    | $s(EM100M) + s(EM10KM) + s(AB1KM) + WETSTRAT + FOREST100M$                 | 134.56            | 12| 147.60| 0.00  | 1.00                              | 0.72                 | 1.00                  |
|                  | $< \text{NULL} >$                                                          | 184.28            | 1 | 186.29| 38.70 | 0.00                              | 0.0000               | 2.53 x 10^8           |
Table 4.5. Settings and results of Boosted Regression Tree models for the presence of marsh birds in wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. Parameter descriptions are provided in Table 4.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Relative contribution (% of trees with variable participation)</th>
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<tbody>
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<td>Tree complexity</td>
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<tr>
<td>Mean residual deviance</td>
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<tr>
<td>AUC</td>
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<tr>
<td>D2UL</td>
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<td>Y_METERS</td>
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Table 4.6. Parameter estimates (untransformed logit link function) from final Generalized Linear Models (single or model-averaged) predicting marsh occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. Parameter descriptions are provided in Table 4.1.

<table>
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<th>Species</th>
<th>Parameter</th>
<th>Estimate ($\beta$)</th>
<th>SE $\beta$</th>
<th>Wald statistic</th>
<th>df</th>
<th>P</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
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<tr>
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<td>SIZE</td>
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<td>0.6700</td>
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<td>≤ 0.001</td>
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<tr>
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| Least Bittern | (Intercept) | -9.5610            | 2.0436     | -4.68          | 1  | ≤ 0.001 | NA                     |
|               | EM100M    | 0.0259             | 0.0152     | 1.71           | 1  | 0.088 | 1.026                  |
|               | EM10KM    | 0.0113             | 0.0697     | 0.16           | 1  | 0.871 | 1.011                  |
|               | AB1KM     | 0.0569             | 0.0473     | 1.20           | 1  | 0.229 | 1.059                  |
|               | SIZE      | 2.2652             | 1.1974     | 1.89           | 1  | 0.059 | 9.633                  |
|               | RDENS1KM  | 0.0003             | 0.0001     | 2.36           | 1  | 0.019 | 1.000                  |
|               | D2UL      | 0.0012             | 0.0007     | 1.75           | 1  | 0.081 | 1.001                  |
|               | BCR23     | 2.6872             | 0.9402     | 2.86           | 1  | 0.004 | 14.691                 |

| Virginia Rail | (Intercept) | -4.5571            | 0.1874     | -24.31         | 1  | ≤ 0.001 | NA                     |
|               | EM100M    | 0.0205             | 0.0109     | 1.88           | 1  | 0.060 | 1.021                  |
|               | EM10KM    | 0.0242             | 0.0528     | 0.46           | 1  | 0.647 | 1.024                  |
|               | SIZE      | 1.3434             | 0.5587     | 2.40           | 1  | 0.016 | 3.832                  |
|               | SSFAW     | -1.0438            | 0.5305     | -1.97          | 1  | 0.049 | 0.352                  |
|               | FOREST1KM | 0.0125             | 0.0143     | 0.87           | 1  | 0.383 | 1.013                  |

| Sora         | (Intercept) | -3.4112            | 0.6636     | -5.14          | 1  | ≤ 0.001 | NA                     |
|              | EM1KM      | 0.0195             | 0.0126     | 1.54           | 1  | 0.123 | 1.020                  |
|              | SIZE       | 1.0653             | 0.5264     | 2.02           | 1  | 0.043 | 2.902                  |
|              | WETSTRAT   | 1.5887             | 0.5118     | 3.10           | 1  | 0.002 | 4.897                  |
|              | D2RD       | -0.0012            | 0.0007     | -1.87          | 1  | 0.061 | 0.999                  |
|              | RDENS1KM   | -0.0002            | 0.0011     | -0.17          | 1  | 0.867 | 1.000                  |

Continued
### Table 4.6. continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Parameter</th>
<th>Estimate (β)</th>
<th>SE β</th>
<th>Wald statistic</th>
<th>df</th>
<th>p</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Gallinule</td>
<td>(Intercept)</td>
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Table 4.7. Parameter estimates (untransformed logit link function) from final Generalized Additive Models predicting mar bird occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. Parameter descriptions are provided in Table 4.1.

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<tr>
<th>Species</th>
<th>Parameter</th>
<th>Estimate ($\beta$)</th>
<th>SE $\beta$</th>
<th>Wald statistic</th>
<th>df</th>
<th>$P$</th>
<th>$\beta$ (odds ratio)</th>
<th>Smoothing terms</th>
<th>Effective df</th>
<th>Wald statistic</th>
<th>$P$</th>
</tr>
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<th>df</th>
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<th>P</th>
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<td>0.244</td>
<td>2.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AB1KM</td>
<td>-1.0693</td>
<td>0.8177</td>
<td>-1.31</td>
<td>1</td>
<td>0.191</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FOREST100M</td>
<td>-0.0347</td>
<td>0.0192</td>
<td>-1.81</td>
<td>1</td>
<td>0.071</td>
<td>0.97</td>
<td>EM100M</td>
<td>1</td>
<td>4.82</td>
<td>0.028</td>
</tr>
</tbody>
</table>
Table 4.8 Evaluation indices of model performance from final models of marsh bird occurrence in wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. Threshold-dependent indices (OPS, sensitivity, specificity, Kappa) were based on species prevalence in test data.

<table>
<thead>
<tr>
<th>Species</th>
<th>Prevalence</th>
<th>Model(^a)</th>
<th>OPS(^b)</th>
<th>Sensitivity(^c)</th>
<th>Specificity(^d)</th>
<th>Kappa(^e)</th>
<th>AUC(^f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe</td>
<td>0.252</td>
<td>GLM</td>
<td>0.87</td>
<td>0.91</td>
<td>0.85</td>
<td>0.68</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.85</td>
<td>0.88</td>
<td>0.84</td>
<td>0.65</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.87</td>
<td>0.82</td>
<td>0.89</td>
<td>0.68</td>
<td>0.92</td>
</tr>
<tr>
<td>Virginia Rail</td>
<td>0.126</td>
<td>GLM</td>
<td>0.59</td>
<td>0.65</td>
<td>0.58</td>
<td>0.11</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.66</td>
<td>0.59</td>
<td>0.67</td>
<td>0.14</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.70</td>
<td>0.59</td>
<td>0.72</td>
<td>0.19</td>
<td>0.68</td>
</tr>
<tr>
<td>Sora</td>
<td>0.133</td>
<td>GLM</td>
<td>0.62</td>
<td>0.56</td>
<td>0.63</td>
<td>0.10</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.69</td>
<td>0.56</td>
<td>0.71</td>
<td>0.16</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.67</td>
<td>0.50</td>
<td>0.69</td>
<td>0.12</td>
<td>0.73</td>
</tr>
<tr>
<td>Least Bittern</td>
<td>0.096</td>
<td>GLM</td>
<td>0.82</td>
<td>0.85</td>
<td>0.82</td>
<td>0.39</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.84</td>
<td>0.85</td>
<td>0.84</td>
<td>0.42</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.82</td>
<td>0.62</td>
<td>0.84</td>
<td>0.31</td>
<td>0.86</td>
</tr>
<tr>
<td>Common Gallinule</td>
<td>0.170</td>
<td>GLM</td>
<td>0.79</td>
<td>0.87</td>
<td>0.78</td>
<td>0.47</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.81</td>
<td>0.91</td>
<td>0.79</td>
<td>0.51</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.86</td>
<td>0.96</td>
<td>0.84</td>
<td>0.62</td>
<td>0.94</td>
</tr>
<tr>
<td>American Coot</td>
<td>0.081</td>
<td>GLM</td>
<td>0.75</td>
<td>0.82</td>
<td>0.74</td>
<td>0.25</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAM</td>
<td>0.75</td>
<td>0.82</td>
<td>0.74</td>
<td>0.25</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>0.70</td>
<td>0.64</td>
<td>0.71</td>
<td>0.15</td>
<td>0.79</td>
</tr>
</tbody>
</table>

\(^a\) Generalized Linear Model (GLM), Generalized Additive Model (GAM), Boosted Regression Tree (BRT).  
\(^b\) Proportion of all cases correctly predicted (OPS = Overall prediction success).  
\(^c\) Proportion of true positives correctly predicted.  
\(^d\) Proportion of true negatives correctly predicted.  
\(^e\) Proportion of specific agreement; Model performance based on values 0.0-0.4 = poor, 0.4-0.75 = good, >0.75 = excellent (after Landis and Koch 1977).  
\(^f\) Area under the Receiver Operating Characteristic Curve; Model discriminatory ability based on values 0.5-0.7 = low, 0.7-0.9 = moderate, >0.9 = excellent (after Swets 1998).
Figure 4.1 Locations of survey points in emergent wetlands for marsh bird surveys conducted in the glaciated subregions of Ohio, USA, May—June 2009 and 2010.
Figure 4.2. Derivation of the confusion matrix used as a basis for performance measures in presence-absence models of marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010. The table cross tabulates observed (recorded) presence/absence patterns against those predicted: a is true positives (presences), b is false positives (presences), c is false negatives (absences), d is true negatives (or absences), N is the total number of sites (a + b + c + d).
Figure 4.3. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for Pied-billed Grebe occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where y > 0 and a greater chance of species absence than presence when y < 0 holding all other variables at their mean values.
Figure 4.4. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for American Bittern occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where $y > 0$ and a greater chance of species absence than presence when $y < 0$ holding all other variables at their mean values.
Figure 4.5. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for Least Bittern occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where $y > 0$ and a greater chance of species absence than presence when $y < 0$ holding all other variables at their mean values.
Figure 4.6. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for Virginia Rail occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where $y > 0$ and a greater chance of species absence than presence when $y < 0$ holding all other variables at their mean values.
Figure 4.7. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for Sora occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where $y > 0$ and a greater chance of species absence than presence when $y < 0$ holding all other variables at their mean values.
Figure 4.8. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for Common Gallinule occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where y > 0 and a greater chance of species absence than presence when y < 0 holding all other variables at their mean values.
Figure 4.9. Partial dependence plots for the most influential variables (contribution > 5%) in the Boosted Regression Tree model for American Coot occurrence in the glaciated region of Ohio, USA, May—June 2009 and 2010. For explanation of variables and their units see Table 4.1. Variables are ordered by increasing contribution (% of trees with variable participation) in parentheses and is highest in top left and lowest in bottom right. Y-axes are on the logit scale and are centered to have zero mean over the data distribution. For each plot, there is a greater chance of species presence than absence where $y > 0$ and a greater chance of species absence than presence when $y < 0$ holding all other variables at their mean values.
Figure 4.10. Distribution of predicted probabilities from three models (Generalized Linear, GLM; Generalized Additive, GAM; Boosted Regression Tree, BRT) of marsh bird occurrence among sites (n=135) with observed presence and absence in emergent wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. For models with good discriminatory ability, distribution of sites with recorded presence will occur disproportionately at higher predicted probabilities and sites with recorded absence will occur disproportionately at lower predicted probabilities. Note: the cross-hatched bar is truncated.
Figure 4.10 continued.

![Graphs showing predicted probability distributions for Virginia Rail and Sora across different models (GLM, GAM, BRT).](image-url)

Continued
Figure 4.10 continued.

**Common Gallinule**

GLM

GAM

BRT

**American Coot**

GLM

GAM

BRT
Figure 4.11. Threshold-dependent evaluation indices (sensitivity, specificity, and Kappa) as a function of threshold from three models (Generalized Linear, GLM; Generalized Additive, GAM; Boosted Regression Tree, BRT) of marsh bird occurrence in emergent wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. Model quality among model algorithms and species is better where Kappa reaches a maximum value and stays at a higher value for a greater range and where lines representing sensitivity and specificity cross at a higher value.
Figure 4.11 continued.
Figure 4.12. Receiver Operative Characteristic (ROC) plots from models predicting the occurrence of marsh birds in wetlands in the glaciated region of Ohio, USA, May—June 2009 and 2010. ROC curves and associated Area Under the Curve (AUC) values are reported for three algorithms (Generalized Linear Models – GLM (red), Generalized Additive Models – GAM (green), Boosted Regression Tree – BRT (blue)). Model discriminatory ability based on AUC value $0.5-0.7 =$ low, $0.7-0.9 =$ moderate, $> 0.9 =$ excellent.
Figure 4.13. Predicted landscape suitability for Pied-billed Grebes in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model displays landscape suitability based on averaged model predictions. Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.
Figure 4.14. Predicted landscape suitability for American Bitterns in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with a Boosted Regression Tree (BRT) model.
Figure 4.15. Predicted landscape suitability for Least Bitterns in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model shows landscape suitability based on averaged model predictions. 

Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.

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Figure 4.16. Predicted landscape suitability for Virginia Rails in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model shows landscape suitability based on averaged model predictions. *Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.*
Figure 4.17. Predicted landscape suitability for Soras in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model shows landscape suitability based on averaged model predictions. Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.
Figure 4.18. Predicted landscape suitability for Common Gallinules in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model shows landscape suitability based on averaged model predictions. Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.
Figure 4.19. Predicted landscape suitability for American Coots in the glaciated region of Ohio, USA, May—June 2009 and 2010 obtained with Generalized Linear (GLM), Generalized Additive (GAM) and Boosted Regression Tree (BRT) models. The mosaic model shows landscape suitability based on averaged model predictions. Note: Best model based on threshold-dependent (a) and threshold-independent (b) evaluation metrics.
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APPENDIX A:

Comparisons of dietary and behavioral characteristics of focal marsh birds.
<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level</td>
<td>&gt;25 cm for escape from nest location</td>
<td>average = 35.5 cm; all &gt;12.7 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bulrush (<em>Scirpus</em> spp.), cattail (<em>Typha latifolia</em>); and whitetop (<em>Scholochloa festucacea</em>)</td>
</tr>
<tr>
<td>Dominant plant species</td>
<td></td>
<td>such as dense stands of emergent vegetation or aquatic veg close to surface and nearby open water</td>
</tr>
<tr>
<td>Breeding habitat characteristics</td>
<td></td>
<td>similar to that of American Coot; seasonal or permanent ponds &gt;0.2 ha; 0.6-7.0 ha</td>
</tr>
<tr>
<td>Body type</td>
<td></td>
<td>highly aggressive territorially towards conspecifics and other species; mean = 2.2 ha/pair</td>
</tr>
<tr>
<td>Spacing / territory</td>
<td></td>
<td>crayfish, aquatic insects, fishes (esp. carp and minnows), amphibians, etc.; mostly aquatic insects; also ingests large quantities of its own feathers - for pellet extraction</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td>more social outside of breeding season, although some defend territories year round</td>
</tr>
<tr>
<td>Degree of sociality</td>
<td></td>
<td>not known</td>
</tr>
<tr>
<td>Site fidelity</td>
<td></td>
<td>Rehm &amp; Baldassarre</td>
</tr>
</tbody>
</table>

194
<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level</td>
<td></td>
<td>likes deep water (25-60 cm)</td>
</tr>
<tr>
<td>Dominant plant species</td>
<td></td>
<td>strong assoc. with cattail in northern regions; avoids dry areas even with suitable veg.; <em>Typha, Carex, Scirpus, Phragmites, Sagittaria, Salix, Cephalanthus, and Rhizophora</em></td>
</tr>
<tr>
<td>Breeding habitat</td>
<td></td>
<td>with dense, tall growths of aquatic or semiaquatic veg (<em>Typha, Carex, Scirpus, Sagittarius, or Myriscus</em>) interspersed with clumps of woody veg and open water as small as 0.4ha in Maine, but wetlands &gt;5ha in size in Iowa; may be area sensitive edge density (interspersion) is an important factor affecting this species.</td>
</tr>
<tr>
<td>Body type</td>
<td></td>
<td>little information; will be scattered even in suitable habitat; territorial in breeding season; variable by region; 0.4 males/ha (WI), 1-15 nests/ha various reports</td>
</tr>
<tr>
<td>Spacing / territory</td>
<td></td>
<td>small fish (minnows, sunfish, perch) snakes, frogs, insects, small mammals (rodents), crayfish, etc.; may delay breeding in response to emergence of aquatic insects as a major source of food at nesting site</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td>generally solitary pairs during breeding season; solitary out of breeding season</td>
</tr>
<tr>
<td>Degree of sociality</td>
<td></td>
<td>no information</td>
</tr>
<tr>
<td>Site fidelity</td>
<td></td>
<td>Rehm &amp; Baldassarre (2007)</td>
</tr>
<tr>
<td>Citation</td>
<td></td>
<td>Gibbs et al (1992a)</td>
</tr>
<tr>
<td>Category</td>
<td>Subcategory</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Breeding habitat</td>
<td>Water level</td>
<td>&lt; 10 cm usually</td>
</tr>
<tr>
<td></td>
<td>Dominant plant species vegetation</td>
<td><em>Typha, Sparganium, Scirpus, and Polygonum</em>; dense emergent</td>
</tr>
<tr>
<td></td>
<td>Breeding habitat characteristics</td>
<td>freshwater wetlands with tall, emergent vegetation; 0.1-1000 ha in size, prefer impoundments and beaver-created wetlands to glacial wetlands, PAB, SS, and PEM wetlands; edge density (interspersion) is an important factor affecting this species.</td>
</tr>
<tr>
<td>Body type</td>
<td>Spacing / territory</td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>Diet</td>
<td>insects, amphibians, small fish, crayfish, small mammals</td>
</tr>
<tr>
<td>Degree of sociality</td>
<td>Degree of sociality</td>
<td>largely asocial, forage solitarily</td>
</tr>
<tr>
<td>Site fidelity</td>
<td>Site fidelity</td>
<td>no information on natal philopatry</td>
</tr>
<tr>
<td>Citation</td>
<td>Citation</td>
<td>Gibbs et al (1992b)</td>
</tr>
<tr>
<td>Category</td>
<td>Subcategory</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Breeding habitat</td>
<td>Water level</td>
<td>saturated - 46 cm; may also use upland adjacent fields for nesting</td>
</tr>
<tr>
<td></td>
<td>Dominant plant species</td>
<td>Grasses (Poaceae), sedges (Cyperaceae), and rushes (Juncaceae); Cattail also important (Typha)</td>
</tr>
<tr>
<td></td>
<td>Body type</td>
<td>tidal freshwater and brackish marshes, noontide freshwater marshes, successional stages of marsh-shrub swamp, and domestic rice fields in AK, LA, and TX, mush of the same habitat as muskrat</td>
</tr>
<tr>
<td></td>
<td>Spacing / territory</td>
<td>defend territory against other species</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td>crustaceans are most important food source (crayfish &amp; crabs); aquatic insects, amphibians, insects, aquatic plant seeds</td>
</tr>
<tr>
<td>Degree of sociality</td>
<td></td>
<td>some evidence of return to previous breeding areas, but no indication on frequency</td>
</tr>
<tr>
<td>Site fidelity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citation</td>
<td></td>
<td>Meanley (1992)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reid et al (1994)</td>
</tr>
<tr>
<td>Category</td>
<td>Subcategory</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Breeding habitat</td>
<td>Water level</td>
<td>prefers &lt;10 cm of water; positively correlated with annual water level fluctuations (Lake Erie, etc.)</td>
</tr>
<tr>
<td>characteristics</td>
<td>Dominant plant species</td>
<td>drier areas than Sora, emergent vegetation dominated by Typha, bulrush; avoid emergent veg with high stem densities or standing residual vegetation - impairs movement; dominant plant species not considered a good indication of habitat suitability</td>
</tr>
<tr>
<td></td>
<td>Body type</td>
<td>most common in moist-soil wetlands, and freshwater marshes in early stage of succession; shallow water, emergent cover, and high invertebrate abundance; will use small wetlands, but 'prefer' &gt;1 ha; ** seral stage of marsh succession is probably the most influential factor affecting p/a and abundance</td>
</tr>
<tr>
<td></td>
<td>Spacing / territory</td>
<td>small aquatic invertebrates (beetles, snails, spiders, true bugs, dipera larvae); &gt;85% of diet; will also eat seeds and aquatic plants; 17.4-46 m between adjacent Virginia rails; 0.2 - 4.7 pairs/ha</td>
</tr>
<tr>
<td></td>
<td>Diet</td>
<td>solitary during breeding season; aggregation post-breeding prior to fall migration</td>
</tr>
<tr>
<td></td>
<td>Degree of sociality</td>
<td>known to breed at the same site if previously successful</td>
</tr>
<tr>
<td></td>
<td>Site fidelity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conway (1995)</td>
</tr>
</tbody>
</table>

198
<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level</td>
<td>Highest breeding densities are in relatively, shallow, shoreward portions of wetlands where water level instability produces diverse mosaics of fine and robust emergent vegetation; increased substrate for seeds and invertebrates; use a wider range of depths than Virginia rails.</td>
<td></td>
</tr>
<tr>
<td>Dominant plant species</td>
<td>Typha, Carex, Cyperus, Sparganium, and Scirpus</td>
<td></td>
</tr>
<tr>
<td>Breeding habitat characteristics</td>
<td>Primarily freshwater wetlands with shallow and intermediate water depths, dominated by robust or fine-leaved vegetation; may use wetland edges and upland fields, including row crops, adjacent to wetlands during brood-rearing or post-breeding dispersal area-independent, will use wetlands &lt;0.5 ha.</td>
<td>Edge density (interspersion) is an important factor affecting this species.</td>
</tr>
<tr>
<td>Body type</td>
<td>Very close nesters; average 9-25 m between other Soras, and closer still for Virginia Rails</td>
<td></td>
</tr>
<tr>
<td>Spacing / territory</td>
<td>Seeds of wetland plants and aquatic invertebrates; inverts at a higher proportion (but still second to veg) in spring due to lack of seed availability; wild rice, smartweeds, sedges, bulrushes and grass seeds consumed; will also eat duckweed and pondweeds</td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>Unknown out of breeding season; vigorously defend territory against Virginia rail</td>
<td></td>
</tr>
<tr>
<td>Degree of sociality</td>
<td>Little known</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Subcategory</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Water level</td>
<td>15-120 cm; pools</td>
<td>semi-permanently flooded areas &quot;preferred&quot;, will nest in other areas as well; average water depth under nest = 40.5 +/- 3.5 cm (range = 0-60cm)</td>
</tr>
<tr>
<td></td>
<td>with submerged</td>
<td>densities were highest on semi-permanently flooded wetlands with narrow-leaved, persistent emergent vegetation, an abundance of submergent aquatic plants, and a 1:1 ratio of cover to open water</td>
</tr>
<tr>
<td></td>
<td>or floating veg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>interspersed with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>emergent or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>shoreline veg;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>said to like</td>
<td></td>
</tr>
<tr>
<td></td>
<td>similar wetland</td>
<td></td>
</tr>
<tr>
<td></td>
<td>type that muskrat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>occupy</td>
<td></td>
</tr>
<tr>
<td>Breeding</td>
<td>characteristics</td>
<td></td>
</tr>
<tr>
<td>Dominant plant</td>
<td>species densities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>highest on semi-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>permanently</td>
<td></td>
</tr>
<tr>
<td></td>
<td>flooded wetlands</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with 1:1 ratio</td>
<td></td>
</tr>
<tr>
<td>Body type</td>
<td>ponds, canals,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ditches, rice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fields</td>
<td></td>
</tr>
<tr>
<td>Spacing /</td>
<td>nest located in</td>
<td></td>
</tr>
<tr>
<td>territory</td>
<td>emergent veg close</td>
<td></td>
</tr>
<tr>
<td></td>
<td>to open water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pair density = 0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 4.6 pairs/ha;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>average over SW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lake Erie = 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pairs/ha</td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>seeds of grasses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and sedges, small</td>
<td></td>
</tr>
<tr>
<td></td>
<td>snails; veg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dominates; forages</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>materials and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>macroinvertebrates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>on the water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>surface, among</td>
<td></td>
</tr>
<tr>
<td></td>
<td>submerged plants,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and in shoreline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and upland veg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>plant/animal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>composition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>percentage = 93/7</td>
<td></td>
</tr>
<tr>
<td>Degree of</td>
<td>Territorially</td>
<td></td>
</tr>
<tr>
<td>sociality</td>
<td>breeding season,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gregarious post-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>breeding/winter</td>
<td></td>
</tr>
<tr>
<td>Site fidelity</td>
<td>banding records</td>
<td></td>
</tr>
<tr>
<td></td>
<td>suggest strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>site fidelity for</td>
<td></td>
</tr>
<tr>
<td></td>
<td>all seasons in all</td>
<td></td>
</tr>
<tr>
<td></td>
<td>locations</td>
<td></td>
</tr>
<tr>
<td>Citation</td>
<td>Bannor &amp; Kiviat (2002), Brackney &amp; Bookhout (1982), Greij (1994)</td>
<td></td>
</tr>
<tr>
<td><strong>Category</strong></td>
<td><strong>Subcategory</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Water level</td>
<td>semi-permanently flooded wetlands (seasonal in high water years)</td>
<td>more permanently flooded potholes with water throughout the nesting period; occupancy rate increases with wetland size; droughts may restrict coots to permanently flooded pools; seasonal wetlands used when water levels are high.</td>
</tr>
<tr>
<td>Breeding habitat characteristics</td>
<td>high amounts of emergent plants with interspersion; cattail &amp; bulrush, reeds (Phragmites), sedges, willows, and grasses; plant height determinant of nest initiation</td>
<td>white-top (<em>Scolochla fesucacea</em>), <em>Typha</em>, and <em>Carex</em> &amp; <em>Scirpus</em>; most nests over water; early-nesters use dead veg; later nesters used new veg.; interspersion of water and emergent cover influenced # of nesting coots.</td>
</tr>
<tr>
<td>Dominant plant species</td>
<td>variable - rivers, ponds, marshes, sewage ponds, canals, open-water</td>
<td>0.3 - 0.56 ha/territory; nest #’s increase with wetland size; breeding densities 10.2 - 33.1 successful nests/ha.</td>
</tr>
<tr>
<td>Body type</td>
<td>construct nests on floating platforms always in dense emergent vegetation close to water edge (vegetative margins)</td>
<td>Aquatic vascular plants (pondweeds and sedges) and algae = dominant component; terrestrial veg. (<em>Graminae</em> - grasses); grains, aquatic inverts, and vertebrates. mostly aquatic veg, but consumption of aquatic insects and mollusks increases during the summer breeding season.</td>
</tr>
<tr>
<td>Spacing / territory</td>
<td></td>
<td>gregarious, but defend individual territories. weakly philopatric to previous breeding sites.</td>
</tr>
<tr>
<td>Degree of sociality</td>
<td></td>
<td>Citation</td>
</tr>
</tbody>
</table>
APPENDIX B:

List of common calls of focal marsh birds surveyed in the glaciated region of Ohio, USA, May—June 2009 and 2010 (adapted from Conway 2009).
<table>
<thead>
<tr>
<th>Species¹</th>
<th>Standardized call name</th>
<th>Possible function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pied-billed Grebe (PBGR)</td>
<td>hyena</td>
<td>greeting call</td>
</tr>
<tr>
<td></td>
<td>owhoop</td>
<td>courtship, communication between pair, territorial</td>
</tr>
<tr>
<td>American Bittern (AMBI)</td>
<td>pump-er-lunk</td>
<td>mate attraction, territorial signal</td>
</tr>
<tr>
<td>Least Bittern (LEBI)</td>
<td>coo</td>
<td>mate attraction</td>
</tr>
<tr>
<td></td>
<td>kak</td>
<td>mate communication, alarm call</td>
</tr>
<tr>
<td>King Rail (KIRA)</td>
<td>clatter</td>
<td>mate communication</td>
</tr>
<tr>
<td></td>
<td>kek</td>
<td>mate attraction</td>
</tr>
<tr>
<td>Virginia Rail (VIRA)</td>
<td>grunt</td>
<td>mate communication</td>
</tr>
<tr>
<td></td>
<td>kicker</td>
<td>solicitation</td>
</tr>
<tr>
<td></td>
<td>squawk</td>
<td>alarm call, territorial dispute</td>
</tr>
<tr>
<td></td>
<td>tick-it</td>
<td>mate attraction</td>
</tr>
<tr>
<td>Sora (SORA)</td>
<td>keep</td>
<td>alarm call</td>
</tr>
<tr>
<td></td>
<td>per-weep</td>
<td>mate attraction</td>
</tr>
<tr>
<td></td>
<td>whinny</td>
<td>territorial defense, mate communication</td>
</tr>
<tr>
<td>Common Gallinule (COMO)</td>
<td>giddy-up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>keep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>wipe-out</td>
<td></td>
</tr>
<tr>
<td>American Coot (AMCO)</td>
<td>burr-up</td>
<td>perturbation</td>
</tr>
<tr>
<td></td>
<td>hic-cup</td>
<td></td>
</tr>
<tr>
<td></td>
<td>honk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>keep</td>
<td></td>
</tr>
</tbody>
</table>

¹ species 4-digit American Ornithologist's Union code in parentheses
APPENDIX C:

Letter sent to private land owners for access to locations to conduct marsh bird surveys in the glaciated region of Ohio, USA, May—June 2009 and 2010.
Appendix C: Letter sent to private land owners.

![Letter content]

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If you agree to grant permission please indicate an acceptable place for one of us to park a vehicle near the road to walk to the point. Please do not hesitate to contact us if you have any questions. We look forward to hearing back from you in the near future.

Thank you for your time and attention.

Warm regards,

Benjamin Kahler & Karen Willard
Graduate Research Assistants
The Ohio State University – School of Environment & Natural Resources
210 Kottman Hall
2021 Coffey Rd
Columbus, OH 43210
Email: kahler.14@osu.edu; willard.39@osu.edu

Notice of Confidentiality: We will not collect or share personal or sensitive information with other parties without your expressed written consent. We will not report personal or sensitive information for purposes of data management, data analysis or presentation under any circumstance.
APPENDIX D:

Data sheet used to record detections of focal marsh birds during call-broadcast surveys in the glaciated region of Ohio, USA, May—June 2009 and 2010.
<table>
<thead>
<tr>
<th>Date:</th>
<th>2010</th>
<th>Point ID:</th>
<th>Access Difficulty:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer:</td>
<td></td>
<td>Azimuth:</td>
<td></td>
</tr>
</tbody>
</table>

**Put an "S" if the bird was seen, "H" if the bird was heard, and "SH" if the bird was seen and heard**

<table>
<thead>
<tr>
<th>Start Time (Military)</th>
<th>Sky</th>
<th>Wind (Beaufort)</th>
<th>Background Noise</th>
<th>Species</th>
<th>Pass 0-1</th>
<th>Pass 1-2</th>
<th>Pass 2-3</th>
<th>Pass 3-4</th>
<th>Pass 4-5</th>
<th>LEBI</th>
<th>SORA</th>
<th>KRA</th>
<th>PBRG</th>
<th>AMBI</th>
<th>LEBI</th>
<th>Outside Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responded During</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Call Type(s)</td>
<td>Distance (m)</td>
<td>Direction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comments**

**Background Noise:**
0) no noise  1) faint noise  2) moderate noise, probably can’t hear some birds >100m  3) loud noise, probably can’t hear some birds >50m  4) intense noise, probably can’t hear some birds >25m

**Beaufort Scale:**
0) smoke rises vertically  1) wind direction shown by smoke drift  2) wind felt on face, leaves rustle  3) leaves, small twigs in constant motion  4) small dust and loose paper, small branches are moved  5) small tree branches sway, crested wavelets on inland waters

**Sky:**
0) clear or a few clouds  1) partly cloudy or variable sky  2) cloudy or overcast  4) fog or smoke  5) drizzle  6) snow  8) showers

**Call Types:**

**Access Difficulty:**
1) not difficult at all  2) somewhat difficult  3) moderately difficult  4) very difficult to access  5) extremely difficult to access
APPENDIX E:

Cooperative weather station locations and interpolated total seasonal precipitation in the glaciated region of Ohio, 2009 and 2010.
Figure E-1. Cooperative weather station locations used to determine total precipitation near locations surveyed for marsh birds in the glaciated region of Ohio, USA, 2009 and 2010.
Figure E-2. Interpolated total precipitation (hundredths of inches) in the glaciated region of Ohio, USA, 2009 and 2010.
Figure 3. Standard error of interpolated total precipitation (hundredths of inches) in the glaciated region of Ohio, USA, 2009 and 2010.
APPENDIX F:

Description of remotely sensed landscape variables used in landscape habitat models of focal marsh bird presence in the glaciated region of Ohio, USA, May—June 2009 and 2010.
Variable: AB100M

Alias: Percent (%) aquatic bed wetland within 0.1 km radius.

Description: Percent (%) of a 100 meter circular buffer from the center of a 90 meter cell classified as % Aquatic Bed wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1. Start with all NWI wetlands shapefile (“all_nwi” internal process file)
2. Select by Attributes all open water and aquatic bed polygons
   a. "ATTRIBUTE" LIKE '%AB%'
3. Convert Feature to Raster; Output cell size = 10 meters, Value = 100.
4. Integer raster to convert raster to integer format.
5. Reclassify raster (100 100; NoData 0). Creates a binary raster where aquatic bed wetland = 100 and everything else = 0.
6. Mean aggregate to 30 m raster (cell factor = 3)
7. Integer raster after adding 0.5. This results in a rounded integer raster.
8. Focal Statistics; Circle, Radius = 100 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
9. Integer raster after adding 0.5. This results in a rounded integer raster.
10. Mean aggregate to 90 m raster (cell factor = 3).

Variable: AB1KM

Alias: Percent (%) aquatic bed / open water wetland within 1,000 meters.

Description: Percent (%) of a 1 km circular buffer from the center of a 90 meter cell classified as % Aquatic Bed wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1-7. the same as for AB100M
8. Focal Statistics; Circle, Radius = 1,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
9. Integer raster after adding 0.5. This results in a rounded integer raster.
10. Mean aggregate to 90 m raster (cell factor = 3).
Variable: AB10IKM

Alias: Percent (%) aquatic bed / open water wetland within 1,000 meters.

Description: Percent (%) of a 10 km circular buffer from the center of a 30 meter cell classified as % Aquatic Bed wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1-7. the same as for AB100M
8. Focal Statistics; Circle, Radius = 10,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
9. Integer raster after adding 0.5. This results in a rounded integer raster.
10. Mean aggregate to 90 m raster (cell factor = 3).

Variable: BCR

Alias: Bird Conservation Region.

Description: North American Bird Conservation Initiative Bird Conservation Region number

Data source(s): North American Bird Conservation Initiative

Process:

1. Clip BCR shapefile to study area (10 km rectangular buffer of Ohio)
2. Feature to Raster; 90 m resolution to same extent and snapped to AB100M

Variable: D2AG

Alias: Distance (meters) to agricultural land cover.

Description: Average Euclidean distance (meters) from the edge of a 30 m cell to agricultural land cover aggregated to 90 m resolution.
Data source(s): National Land Cover Database 2006

Process:

1. Extract NLCD2006 by Mask, 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Reclassify, \(\{81,82\} = 1; \) all others = 0. Creates a binary raster where agricultural land cover = 1 and all other land cover types = 0.
3. Reclassify, \(0=\text{NoData}; 1=1\). Removes all non-agricultural land covers.
4. Euclidean Distance, Output cell size = 30, Output direction raster = NULL
5. Mean aggregate to 90 m resolution (cell factor = 3)
6. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: D2DVT
Alias: Distance (meters) to developed cover.
Description: Average Euclidean distance (meters) from the edge of a 30 m cell to developed land cover aggregated to 90 m resolution.

Data source(s): National Land Cover Database 2006

Process:

1. Extract NLCD2006 by Mask, 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Reclassify, \(21-24 = 1; \) all others = 0. Creates a binary raster where all developed land covers = 1 and all remaining land covers = 0.
3. Reclassify, \(0=\text{NoData}; 1=1\). This removes all non-developed land covers.
4. Euclidean Distance, Output cell size = 30, Output direction raster = NULL
5. Integer raster after adding 0.5. This results in a rounded integer raster.
6. Mean aggregate to 90 m resolution (cell factor = 3)
7. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: D2RD
Alias: Distance (meters) to nearest road.
Description: Euclidean distance (meters) from the edge of a 90 m cell to the nearest Census 2000 TIGER/Line® road vector.

Data source(s): Census 2000 TIGER/Line® Shapefiles

Process:

1. Start with all Census 2000 TIGER/Line® roads within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Euclidean Distance, Maximum distance = 20,000, Output cell size = 90, Output direction raster = NULL
3. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: D2RIV

Alias: Distance (meters) to nearest river.

Description: Euclidean distance (meters) from the edge of a 90 m cell to the nearest National Hydrography Dataset stream/river vector.

Data source(s): National Hydrography Dataset high resolution state extracts.

Process:

1. Start with all NHD Stream/River (FType=460) within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Euclidean Distance, Maximum distance = 20,000, Output cell size = 90, Output direction raster = NULL
3. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: D2UL

Alias: Distance (meters) to upland (non-wetland) cover.

Description: Average Euclidean distance (meters) from the edge of a 30 m cell to upland (non-wetland) land cover aggregated to 90 m resolution.

Data source(s): National Land Cover Database 2006
Process:

1. Extract NLCD2006 by Mask, 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Reclassify, \{(11, 90, 95) = NoData; \{21-24\}=10; 31=20; \{41-43\}=30; 52=40; 81=50; 82=60\}, Reclassifies wetland and open water cover types to NoData and groups similar cover types into new, unique land cover types.
3. Euclidean Distance, Output cell size = 30, Output direction raster = NULL
4. Mean aggregate to 90 m resolution (cell factor = 3)
5. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: EM100M
Alias: Percent (%) emergent wetland within 100 meters.
Description: Percent (%) of a 100 meter circular buffer from the center of a 30 meter cell classified as Emergent wetland from the National Wetlands Inventory Program.
Data source(s): National Wetlands Inventory

Process:

1. Start with all NWI wetlands within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Select by Attributes all emergent polygons
   a. ATTRIBUTE LIKE ‘%EM%’
3. Convert Feature to Raster; Output cell size = 10 meters, Value = 100.
4. Reclassify raster (100 100; NoData 0). Creates a binary raster were emergent wetland = 100 and everything else = 0.
5. Mean aggregate to 90 m (Cell factor = 9)
6. Integer raster to convert raster to integer format.
7. Focal Statistics; Circle, Radius = 100 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster to convert raster to integer format.
Variable: EM1KM

Alias: Percent (%) emergent wetland within a 1 km radius.

Description: Percent (%) of a 1,000 meter circular buffer from the center of a 90 meter cell classified as Emergent wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1-6. the same as for em100m
7. Focal Statistics; Circle, Radius = 1,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster to convert raster to integer format.

Variable: EM10KM

Alias: Percent (%) emergent wetland within a 10 km radius.

Description: Percent (%) of a 10,000 meter circular buffer from the center of a 90 meter cell classified as Emergent wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1-6. the same as for em100m
7. Focal Statistics; Circle, Radius = 10,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster to convert raster to integer format.
Variable: FOREST100M

Alias: Percent (%) forested land cover in a 0.1 km radius.

Description: Percent (%) of a 100 m circular buffer from the center of a 90 meter cell classified as forested land cover in the National Land Cover Database.

Data source(s): National Land Cover Database 2006

Process:

1. Extract NLCD2006 by Mask, 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Reclassify, \(\{41, 42, 43, 52, 90\} = 100;\) all other land covers = 0. Creates a binary raster where forested land covers = 100 and all others = 0.
3. Mean aggregate to 90 m resolution (cell factor = 3)
4. Integer raster after adding 0.5. This results in a rounded integer raster.
5. Euclidean Distance, Output cell size = 90, Output direction raster = NULL
6. Integer raster after adding 0.5. This results in a rounded integer raster.
7. Focal Statistics; Circle, Radius = 1000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: FOREST1KM

Alias: Percent (%) forested land cover in a 1 km radius.

Description: Percent (%) of a 1,000 m circular buffer from the center of a 90 meter cell classified as forested land cover in the National Land Cover Database.

Data source(s): National Land Cover Database 2006

Process:

1-6. Same as for FOREST100M
7. Focal Statistics; Circle, Radius = 1,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster after adding 0.5. This results in a rounded integer raster.
Variable: FOREST10KM

Alias: Percent (%) forested land cover in a 01 km radius.

Description: Percent (%) of a 10,000 m circular buffer from the center of a 90 meter cell classified as forested land cover in the National Land Cover Database.

Data source(s): National Land Cover Database 2006

Process:

1-6. Same as for FOREST100M
7. Focal Statistics; Circle, Radius = 10,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
8. Integer raster after adding 0.5. This results in a rounded integer raster.

Variable: PERSLOPE

Alias: Slope (%).

Description: Percent slope derived from a 90 m Digital Elevation Model.

Data source(s): Digital Elevation Model; Ohio Department of Natural Resources

Process:

1. Fill DEM
2. Slope; Output_measurement = PERCENT_RISE

Variable: RDENS100M

Alias: Density of roads within a 1 km radius.

Description: Density of roads with in a 1,000 m buffer from the center of a 90 m cell.
Data source(s):  Census 2000 TIGER/Line® Shapefiles

Process:

1. Start with all Census 2000 TIGER/Line® roads within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Line Density; Population Field = NONE, Cell size = 90, Search radius = 1,000, Area units = SQUARE_KILOMETERS

Variable:  RDENS1KM
Alias:  Density of roads within a 0.1 km radius.
Description:  Density of roads within a 100 m buffer from the center of a 90 m cell.
Data source(s):  Census 2000 TIGER/Line® Shapefiles

Process:

1. Start with all Census 2000 TIGER/Line® roads within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Line Density; Population Field = NONE, Cell size = 90, Search radius = 100, Area units = SQUARE_KILOMETERS

Variable:  RDENS10KM
Alias:  Density of roads within a 10 km radius.
Description:  Density of roads within a 10,000 m buffer from the center of a 90 m cell.
Data source(s):  Census 2000 TIGER/Line® Shapefiles

Process:
1. Start with all Census 2000 TIGER/Line® roads within a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)

2. Line Density; Population Field = NONE, Cell size = 90, Search radius = 10,000, Area units = SQUARE_KILOMETERS

Variable: SIZE
Alias: Binary classification of wetland size (“large” (>10 ha) = 1, 0)
Description: Classification of wetland size based on sampling strata using the National Wetlands Inventory Program.
Data source(s): National Wetlands Inventory

Process:

1. Start with all NWI wetlands a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Select by size (>10 ha) and code shapefile based on NWI polygon area: 1 = > 10 ha, 0 = < 10 ha.
3. Convert Feature to Raster; Output cell size = 10 meters. Creates a binary raster where large wetlands = 1, smaller wetlands = 0, and non-wetland areas = NoData.
4. Majority aggregate to 90 m (cell factor = 9). Ignore NoData in calculations = TRUE.

Variable: SSFAW
Alias: Binary classification of scrub-shrub and forest associated wetlands
Description: Binary classification of scrub-shrub and forest associated wetlands based National Wetlands Inventory Program.
Data source(s): National Wetlands Inventory

Process:
1. Start with all NWI wetlands a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Select by Attribute [“Attribute” LIKE ‘%SS%’ OR “Attribute” LIKE ‘%FO%’]. Code shapefile so that SSFAW = 1 and all others = 0.
3. Convert Feature to Raster; Output cell size = 10 meters. Creates a binary raster were SSFAW wetlands = 1, non-SSFAW wetlands = 0, and non-wetland areas = NoData.
4. Majority aggregate to 90 m (cell factor = 9). Ignore NoData in calculations = TRUE.

Variable: TWET100M
Alias: Percent (%) wetland within a 0.1 km radius.
Description: Percent (%) of a 100 meter circular buffer from the center of a 90 meter cell classified as wetland (%) from the National Wetlands Inventory Program.
Data source(s): National Wetlands Inventory

Process:
1. Start with all NWI wetlands a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Convert Feature to Raster; Output cell size = 10 meters, Value = 100.
3. Reclassify raster (1=100; NoData 0). Creates a binary raster were wetland =100 and everything else = 0.
4. Mean aggregate to 90 m (cell factor = 9)
5. Integer raster after adding 0.5. This results in a rounded integer raster.
6. Focal Statistics; Circle, Radius = 100 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
7. Integer raster after adding 0.5. This results in a rounded integer raster.
Variable: TWET1KM

Alias: Percent (%) wetland within a 1 km radius

Description: Percent (%) of a 1,000 meter circular buffer from the center of a 90 meter cell classified as wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:
1-5. Same as for TWET100M
6. Focal Statistics; Circle, Radius = 1,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
7. Integer raster after adding 0.5. This results in a rounded integer raster.

---

Variable: TWET01KM

Alias: Percent (%) wetland within a 10 km radius

Description: Percent (%) of a 10,000 meter circular buffer from the center of a 90 meter cell classified as wetland from the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:
1-5. Same as for TWET100M
6. Focal Statistics; Circle, Radius = 10,000 map units (meters), Statistics type=Mean, Ignore NoData in calculations = TRUE.
7. Integer raster after adding 0.5. This results in a rounded integer raster.
Variable: TWI

Alias: Topographic wetness index.

Description: Topographic wetness index derived from a 90 m Digital Elevation Model.

Data source(s): Digital Elevation Model; Ohio Department of Natural Resources

Process:

1. Fill DEM
2. Flow Direction; Output drop raster = NULL
   a. Reclassify ({1, 4, 16, 64} = 5, {2, 8, 32, 128} = 7). Creates a distance raster.
   b. Flow Accumulation
      i. Add 1 to flow accumulation raster to get a count of how many pixel including the current are contributing the flow
      ii. Multiply by 25; results in contributing area using the number of pixels.
3. Block Statistics; Neighborhood Settings (height = 3 cells, width = 3 cells), Statistics type = MINIMUM, Ignore NoData in calculations = TRUE
   a. Subtract from Step 1. Results in edrop raster.
   b. Conditional Statement: Con(Output_edrop >= 0.005, Output_edrop, 0.005).
      This results in a change raster.
4. Divide 3.b by 2.a. Results in slope raster.
6. Add 0.559145480394366 to each cell
7. Calculate natural logarithm.
8. Block Statistics; Neighborhood Settings (height = 3 cells, width = 3 cells); Statistics type = MEAN, Ignore NoData in calculations = TRUE
9. Mean aggregate to 90 m resolution (call factor = 3).
Variable: WETSTRAT

Alias: Binary classification of wetland water permanence (semi-permanently flooded = 1, seasonally flooded = 0)

Description: Classification of wetland water permanence based on sampling strata using the National Wetlands Inventory Program.

Data source(s): National Wetlands Inventory

Process:

1. Start with all NWI wetlands a 10 km rectangular buffer of Ohio; (“AOI.shp”, internal process file)
2. Select by Water Regime (see Cowardin et al. 1979 for explanations). Seasonally flooded wetlands [B, C]; Semi-permanently flooded wetlands [  
3. Convert Feature to Raster; Output cell size = 10 meters. Creates a binary raster were semi-permanently flooded wetlands = 1, seasonally flooded wetlands = 0, and non-wetland areas = NoData.
4. Majority aggregate to 90 m (cell factor = 9). Ignore NoData in calculations = TRUE.
APPENDIX G:

Spearman’s rank ($r_s$) correlation matrix of continuous variables considered in landscape distribution models for secretive marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010.
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APPENDIX H.

Area-sensitivity candidate model sets for focal marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010.
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<sup>1</sup>Natural logarithm of the odds of detection as a function of area and water permanence categories.

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\(^1\)Natural logarithm of the odds of detection as a function of area and water permanence categories.

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\(^1\)Natural logarithm of the odds of detection as a function of area and water permanence categories.
APPENDIX I:

Presence/absence maps of focal marsh bird species in the glaciated region of Ohio, USA, May—June, 2009-2010.
Pied-billed Grebe Detections (2009 - 2010)

Legend

- Site level presence of PBGR:
  - Detected
  - Not Detected
- Focus Area boundary
- Counties included in sampling frame (2009 - 2010)
- Counties added to sampling frame (2010)
- Counties not included in sampling frame
American Bittern Detections (2009 - 2010)

Legend
- Site level presence of AMBI
  - Detected
  - Not Detected
- Focus Area boundary
- Counties included in sampling frame (2009 - 2010)
- Counties added to sampling frame (2010)
- Counties not included in sampling frame
King Rail Detections (2009 - 2010)

Legend
- Detected
- Not Detected
- Focus Area boundary
- Counties included in sampling frame (2009 - 2010)
- Counties added to sampling frame (2010)
- Counties not included in sampling frame
Common Gallinule Detections (2009 – 2010)

Legend
- Site level presence of COMO:
  - Detected
  - Not Detected
- Focus Area boundary
- Counties included in sampling frame (2009 - 2010)
- Counties added to sampling frame (2010)
- Counties not included in sampling frame
APPENDIX J.

Mean and standard error estimates of continuous variables for locations surveyed for marsh birds in the glaciated region of Ohio, USA, May—June 2009 and 2010. * indicates that a univariate logistic model of marsh bird presence given the predictor variable had a $P$ value $\leq 0.25$. 
### Pied-billed Grebe

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APPENDIX K:

Landscape habitat suitability candidate model sets for focal marsh bird presence in the glaciated region of Ohio, USA, May—June 2009 and 2010.
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| Species          | Model                                                                 | -2*Log-Likelihood | k  | AICc          | ΔAICc | Relative model likelihood (\(\mathcal{L}(g_i | x)\)) | Akaike weight (\(w_i\)) | Evidence ratio (\(w_i\)) | Emission
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| Species          | Model                                                                 | Parameters                                                                 | -2*Log-Likelihood | k  | AICc | ΔAICc | Relative model likelihood ℒ(ompson i|x ) | Akaike weight (w_i) | Evidence ratio (w_e) |
|------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------|----|------|-------|------------------------------------------|---------------------|---------------------|
| Virginia Rail    | EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM                |                                                                           | 221.09            | 7  | 225.46 | 0.00  | 1.00                                    | 0.52                | 1.00                |
|                  | 2 EM100M + EM10KM + WETSTRAT + SIZE + BCR22 + BCR23 + SSFAW         |                                                                           | 212.22            | 8  | 228.69 | 3.23  | 0.20                                    | 0.10                | 5.02                |
|                  | 3 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST10KM            |                                                                           | 214.50            | 7  | 228.86 | 3.40  | 0.18                                    | 0.10                | 5.48                |
|                  | 4 EM100M + EM10KM + WETSTRAT + SSFAW + FOREST1KM                    |                                                                           | 217.80            | 6  | 230.07 | 4.62  | 0.10                                    | 0.05                | 10.05               |
|                  | 5 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI |                                                                           | 210.06            | 10 | 230.78 | 5.32  | 0.07                                    | 0.04                | 14.33               |
|                  | 6 EM100M + TWET10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI |                                                                           | 210.51            | 10 | 231.23 | 5.77  | 0.06                                    | 0.03                | 17.90               |
|                  | 7 EM100M + WETSTRAT + SSFAW + BCR22 + BCR23 + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI |                                                                           | 210.51            | 10 | 231.23 | 5.77  | 0.06                                    | 0.03                | 17.92               |
|                  | 8 EM100M + EM10KM + WETSTRAT + FOREST1KM                             |                                                                           | 221.25            | 5  | 231.45 | 5.99  | 0.05                                    | 0.03                | 19.95               |
|                  | 9 EM100M + EM10KM + WETSTRAT + BCR22 + BCR23 + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI |                                                                           | 207.23            | 12 | 232.26 | 6.81  | 0.03                                    | 0.02                | 30.04               |
|                  | 10 EM100M + EM10KM + WETSTRAT + SSFAW + FOREST10KM                  |                                                                           | 220.20            | 6  | 232.47 | 7.01  | 0.03                                    | 0.02                | 33.36               |
|                  | 11 EM100M + EM10KM + TWET10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI |                                                                           | 209.71            | 11 | 232.58 | 7.12  | 0.03                                    | 0.01                | 35.15               |
|                  | 12 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI |                                                                           | 210.06            | 11 | 232.93 | 7.47  | 0.02                                    | 0.01                | 41.93               |
|                  | 13 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI |                                                                           | 210.06            | 11 | 232.93 | 7.47  | 0.02                                    | 0.01                | 41.93               |
|                  | 14 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI |                                                                           | 210.06            | 11 | 232.93 | 7.47  | 0.02                                    | 0.01                | 41.93               |
|                  | 15 EM100M + EM10KM + WETSTRAT + FOREST10KM                           |                                                                           | 222.78            | 5  | 232.97 | 7.52  | 0.02                                    | 0.01                | 42.85               |
|                  | 16 EM100M + EM10KM + WETSTRAT + FOREST100M                           |                                                                           | 226.09            | 5  | 236.28 | 10.82 | 0.00                                    | 0.00                | 223.80              |
|                  | 17 EM100M + EM10KM + WETSTRAT + SIZE                                |                                                                           | 226.24            | 5  | 236.43 | 10.97 | 0.00                                    | 0.00                | 241.43              |
|                  | 18 EM100M + EM10KM + WETSTRAT                                      |                                                                           | 236.04            | 4  | 238.17 | 12.71 | 0.00                                    | 0.00                | 576.21              |
|                  | 19 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW                         |                                                                           | 225.95            | 6  | 238.23 | 12.77 | 0.00                                    | 0.00                | 592.05              |
|                  | 20 EM100M + EM10KM + WETSTRAT + RDENS1KM                            |                                                                           | 229.47            | 5  | 239.67 | 14.21 | 0.00                                    | 0.00                | 1217.83             |
|                  | 21 EM100M + EM10KM + WETSTRAT + TWI                                 |                                                                           | 229.86            | 5  | 240.05 | 14.59 | 0.00                                    | 0.00                | 1474.87             |
|                  | 22 EM100M + EM10KM + WETSTRAT + D2RIV                               |                                                                           | 229.93            | 5  | 240.13 | 14.67 | 0.00                                    | 0.00                | 1550.75             |
|                  | 23 EM100M + EM10KM + WETSTRAT + SSFAW                               |                                                                           | 229.96            | 5  | 240.15 | 14.70 | 0.00                                    | 0.00                | 1552.78             |
|                  | 24 EM100M + EM10KM + WETSTRAT + D2RD                                |                                                                           | 229.98            | 5  | 240.17 | 14.71 | 0.00                                    | 0.00                | 1567.19             |
|                  | 25 EM100M + EM10KM + WETSTRAT + RDENS1KM + D2RD                     |                                                                           | 229.06            | 6  | 241.33 | 15.87 | 0.00                                    | 0.00                | 2797.93             |
|                  | 26 EM100M + EM10KM + WETSTRAT + D2RIV + TWI                        |                                                                           | 229.72            | 6  | 241.99 | 16.53 | 0.00                                    | 0.00                | 3892.54             |
|                  | 27 < NULL >                                                         |                                                                           | 243.61            | 1  | 245.63 | 20.17 | 0.00                                    | 0.00                | 23951.31            |

Continued...
| Species | Model                        | Parameters                  | -2*Log-Likelihood | k | AICc | ΔAICc | Relative model likelihood \( \mathcal{L}(g_i|x) \) | Akaike weight \( (w_i) \) | Evidence ratio \( (w_i) \) |
|---------|-----------------------------|-----------------------------|-------------------|---|------|-------|-----------------------------------------------|--------------------------|---------------------------|
| Sora    | 1 EM1KM + WETSTRAT + D2RD  |                             | 209.07            | 4 | 217.20 | 0.00 | 1.00                                           | 0.20                      | 1.00                      |
|         | 2 EM1KM + WETSTRAT + RDENS1KM + D2RD |                     | 207.08            | 5 | 217.27 | 0.07 | 0.96                                           | 0.19                      | 1.04                      |
|         | 3 EM1KM + WETSTRAT + SIZE   |                             | 210.84            | 4 | 218.97 | 1.77 | 0.41                                           | 0.08                      | 2.42                      |
|         | 4 EM1KM + WETSTRAT          |                             | 213.34            | 3 | 219.41 | 2.21 | 0.33                                           | 0.07                      | 3.02                      |
|         | 5 EM1KM + WETSTRAT + FOREST1KM |                           | 212.13            | 4 | 220.26 | 3.06 | 0.22                                           | 0.04                      | 4.63                      |
|         | 6 EM1KM + WETSTRAT + SIZE + SSFAW + FOREST1KM |                   | 208.13            | 6 | 220.40 | 3.20 | 0.20                                           | 0.04                      | 4.95                      |
|         | 7 EM1KM + WETSTRAT + TWI    |                             | 212.30            | 4 | 220.43 | 3.23 | 0.20                                           | 0.04                      | 5.02                      |
|         | 8 EM1KM + WETSTRAT + SIZE + SSFAW |                | 210.30            | 5 | 220.50 | 3.29 | 0.19                                           | 0.04                      | 5.19                      |
|         | 9 EM1KM + WETSTRAT + FOREST10KM |                            | 212.41            | 4 | 220.54 | 3.34 | 0.19                                           | 0.04                      | 5.31                      |
|         | 10 EM1KM + WETSTRAT + SIZE + SSFAW + FOREST10KM |              | 208.47            | 6 | 220.74 | 3.54 | 0.17                                           | 0.03                      | 5.88                      |
|         | 11 EM1KM + WETSTRAT + SSFAW |                             | 212.86            | 4 | 220.99 | 3.79 | 0.15                                           | 0.03                      | 6.65                      |
|         | 12 EM1KM + WETSTRAT + SSFAW + FOREST1KM |                       | 210.80            | 5 | 221.00 | 3.80 | 0.15                                           | 0.03                      | 6.67                      |
|         | 13 EM1KM + WETSTRAT + FOREST100M |                        | 213.07            | 4 | 221.19 | 3.99 | 0.14                                           | 0.03                      | 7.37                      |
|         | 14 EM1KM + WETSTRAT + RDENS1KM |                         | 213.25            | 4 | 221.38 | 4.18 | 0.12                                           | 0.02                      | 8.08                      |
|         | 15 EM1KM + WETSTRAT + SSFAW + FOREST16KM |                    | 211.24            | 5 | 221.43 | 4.23 | 0.12                                           | 0.02                      | 8.31                      |
|         | 16 EM1KM + WETSTRAT + D2RIV  |                             | 213.33            | 4 | 221.46 | 4.26 | 0.12                                           | 0.02                      | 8.40                      |
|         | 17 EM1KM + WETSTRAT + SIZE + BCR22 + BCR23 + SSFAW |           | 207.43            | 7 | 221.80 | 4.60 | 0.10                                           | 0.02                      | 9.95                      |
|         | 18 EM1KM + WETSTRAT + D2RIV + TWI |                       | 212.29            | 5 | 222.49 | 5.29 | 0.07                                           | 0.01                      | 14.06                     |
|         | 19 EM1KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI | | 202.18 | 10 | 222.90 | 5.70 | 0.06                                           | 0.01                      | 17.29                     |
|         | 20 EM1KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI | | 202.18 | 10 | 222.90 | 5.70 | 0.06                                           | 0.01                      | 17.29                     |
|         | 21 EM100M + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI | | 204.70 | 10 | 225.42 | 8.22 | 0.02                                           | 0.00                      | 60.91                     |
|         | 22 EM1KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI | | 207.62 | 9  | 226.21 | 9.01 | 0.01                                           | 0.00                      | 90.45                     |
|         | 23 EM100M + EM10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RD + D2RIV + TWI | | 203.85 | 11 | 226.72 | 9.52 | 0.01                                           | 0.00                      | 116.91                    |
|         | 24 EM100M + TWET10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI | | 208.82 | 10 | 229.55 | 12.35 | 0.00                                           | 0.00                      | 480.12                    |
|         | 25 EM1KM + WETSTRAT + SIZE + BCR22 + BCR23 + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI | | 206.96 | 11 | 229.83 | 12.63 | 0.00                                           | 0.00                      | 553.39                    |
|         | 26 EM100M + EM10KM + TWET10KM + WETSTRAT + SIZE + SSFAW + FOREST1KM + RDENS1KM + D2RIV + TWI | | 207.63 | 11 | 230.50 | 13.30 | 0.00                                           | 0.00                      | 772.91                    |
|         | 27 < NULL >                 |                             | 243.61            | 1  | 245.63 | 28.43 | 0.00                                           | 0.00                      | 1.49 x 10^6               |

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| Species          | Model Parameters                                                                 | -2*Log-Likelihood | k | AIC<sub>c</sub> | ΔAIC<sub>c</sub> | Relative model likelihood \( \mathcal{L}(g_i|x) \) | Akaike weight \( w_i \) | Evidence ratio \( (w_i) \) |
|------------------|-----------------------------------------------------------------------------------|-------------------|---|----------------|----------------|----------------------------------------|-------------------|--------------------------|
| American Coot    | 1 EM100M + EM10KM + WETSTRAT + AB1KM + FOREST100M                                | 134.56            | 6 | 259.71         | 0.00           | 1.00                                    | 1.00              | 1.00                     |
|                  | 2 EM100M + EM10KM + WETSTRAT + AB1KM + SSFAW                                    | 137.82            | 6 | 279.98         | 20.27          | 0.00                                    | 0.00              | 2.52 x 10⁴               |
|                  | 3 EM100M + EM10KM + WETSTRAT + AB1KM + FOREST10KM + RDENS1KM + D2RD + D2UL + TWI + SSFAW | 128.47            | 11| 287.99         | 28.27          | 0.00                                    | 0.00              | 1.38 x 10⁶               |
|                  | 4 EM100M + EM10KM + WETSTRAT + AB1KM + FOREST10KM + RDENS1IKM + D2RD + D2UL + TWI + SSFAW + BCR22 + BCR23 | 127.23            | 13| 308.52         | 48.81          | 0.00                                    | 0.00              | 3.97 x 10¹⁰              |
|                  | 5 EM100M + EM10KM + WETSTRAT + FOREST10KM                                       | 144.41            | 6 | 309.65         | 49.93          | 0.00                                    | 0.00              | 6.97 x 10¹⁰              |
|                  | 6 EM100M + EM10KM + WETSTRAT + RDENS1KM + D2RD                                   | 142.47            | 6 | 310.57         | 50.86          | 0.00                                    | 0.00              | 1.11 x 10¹¹              |
|                  | 7 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1KM + D2RD + D2UL + SSFAW       | 136.80            | 9 | 314.99         | 55.28          | 0.00                                    | 0.00              | 1.01 x 10¹²              |
|                  | 8 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1KM + D2RD + D2UL + SSFAW       | 136.65            | 10| 328.79         | 69.08          | 0.00                                    | 0.00              | 1.00 x 10¹⁵              |
|                  | 9 EM100M + EM10KM + WETSTRAT + FOREST10KM                                        | 148.05            | 4 | 320.44         | 60.72          | 0.00                                    | 0.00              | 1.53 x 10¹³              |
|                  | 10 EM100M + EM10KM + WETSTRAT + SSFAW                                             | 146.08            | 5 | 321.10         | 61.39          | 0.00                                    | 0.00              | 2.14 x 10¹³              |
|                  | 11 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1KM + D2RD + D2UL + SSFAW       | 136.80            | 9 | 314.99         | 55.28          | 0.00                                    | 0.00              | 1.01 x 10¹²              |
|                  |                                                                                   | 23                |   |                |                |                          |                   |                          |
|                  | 12 EM100M + EM10KM + WETSTRAT + FOREST10KM + SSFAW                               | 145.15            | 6 | 329.17         | 69.46          | 0.00                                    | 0.00              | 1.21 x 10¹³              |
|                  | 13 EM100M + EM10KM + WETSTRAT + TWI                                                | 147.38            | 5 | 330.19         | 70.48          | 0.00                                    | 0.00              | 2.02 x 10¹³              |
|                  | 14 EM100M + EM10KM + WETSTRAT + D2UL                                               | 147.51            | 5 | 331.11         | 71.40          | 0.00                                    | 0.00              | 3.19 x 10¹⁵              |
|                  | 15 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + D2RD + D2UL + SSFAW       | 135.18            | 11| 333.61         | 73.90          | 0.00                                    | 0.00              | 1.11 x 10¹⁶              |
|                  | 16 EM100M + EM10KM + WETSTRAT + RDENS1IKM                                          | 148.01            | 5 | 334.70         | 74.99          | 0.00                                    | 0.00              | 1.92 x 10¹⁶              |
|                  | 17 EM100M + EM10KM + WETSTRAT + D2UL + TWI                                         | 146.82            | 6 | 341.12         | 81.41          | 0.00                                    | 0.00              | 4.76 x 10¹⁷              |
|                  | 18 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + SSFAW                     | 145.10            | 7 | 343.77         | 84.06          | 0.00                                    | 0.00              | 1.79 x 10¹⁸              |
|                  | 19 EM100M + EM10KM + WETSTRAT + FOREST10KM + SSFAW + BCR22 + BCR23                | 143.04            | 8 | 344.10         | 84.38          | 0.00                                    | 0.00              | 2.11 x 10¹⁸              |
|                  | 20 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + D2RD + D2UL + TWI + SSFAW + BCR22 + BCR23 | 135.13            | 12| 348.89         | 89.17          | 0.00                                    | 0.00              | 2.31 x 10¹⁹              |
|                  | 21 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + D2UL + SSFAW              | 143.99            | 8 | 351.11         | 91.40          | 0.00                                    | 0.00              | 7.02 x 10¹⁹              |
|                  | 22 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + SSFAW + BCR22 + BCR23     | 142.87            | 9 | 358.51         | 98.80          | 0.00                                    | 0.00              | 2.85 x 10²¹              |
|                  | 23 EM100M + EM10KM + WETSTRAT + FOREST10KM + RDENS1IKM + D2UL + SSFAW + BCR22 + BCR23 | 141.76            | 10| 366.28         | 106.57         | 0.00                                    | 0.00              | 1.39 x 10²³              |
|                  | 24 < NULL >                                                                       | 184.28            | 1 | 585.89         | 326.18         | 0.00                                    | 0.00              | 6.73 x 10⁶⁰              |

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<td>k</td>
<td>AICc</td>
<td>ΔAICc</td>
<td>w</td>
<td>Evidence ratio (wi)</td>
</tr>
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<tr>
<td>American Coot</td>
<td>1 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST100M) + s(AB1KM) + WETSTRAT + s(FOREST10KM) + s(RDENS1KM) + s(D2RD) + s(D2UL) + s(TWI) + SSFAW</td>
<td>134.56</td>
<td>12</td>
<td>147.60</td>
<td>0.00</td>
<td>1.00</td>
<td>2.58</td>
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<td>3 s(EM100M) + s(EM10KM) + WETSTRAT + s(AB1KM) + SSFAW</td>
<td>137.82</td>
<td>12</td>
<td>150.85</td>
<td>3.26</td>
<td>0.20</td>
<td>0.51</td>
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<td>2 s(EM100M) + s(EM10KM) + WETSTRAT + s(AB1KM) + s(FOREST10KM) + s(RDENS1KM) + s(D2RD) + s(D2UL) + s(TWI) + SSFAW</td>
<td>124.93</td>
<td>27</td>
<td>153.70</td>
<td>6.10</td>
<td>0.05</td>
<td>0.12</td>
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<td>5 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM)</td>
<td>144.41</td>
<td>11</td>
<td>155.28</td>
<td>7.69</td>
<td>0.02</td>
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<td>8 s(EM100M) + s(EM10KM) + WETSTRAT + s(RDENS1KM)</td>
<td>143.04</td>
<td>11</td>
<td>155.77</td>
<td>8.17</td>
<td>0.02</td>
<td>0.04</td>
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<td>6 s(EM100M) + s(EM10KM) + WETSTRAT + s(RDENS1KM) + s(D2RD)</td>
<td>142.47</td>
<td>14</td>
<td>155.87</td>
<td>8.28</td>
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<td>0.04</td>
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<td>9 s(EM100M) + s(EM10KM) + WETSTRAT + s(TWI)</td>
<td>143.78</td>
<td>11</td>
<td>156.18</td>
<td>8.58</td>
<td>0.01</td>
<td>0.04</td>
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<td>13 s(EM100M) + s(EM10KM) + WETSTRAT</td>
<td>148.05</td>
<td>8</td>
<td>156.52</td>
<td>8.93</td>
<td>0.01</td>
<td>0.03</td>
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<td>15 s(EM100M) + s(EM10KM) + WETSTRAT + SSFAW</td>
<td>146.12</td>
<td>9</td>
<td>156.71</td>
<td>9.11</td>
<td>0.01</td>
<td>0.03</td>
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<td>11 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM)</td>
<td>145.88</td>
<td>11</td>
<td>156.89</td>
<td>9.30</td>
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<td>29</td>
<td>157.09</td>
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<td>18 s(EM100M) + s(EM10KM) + WETSTRAT + s(D2UL)</td>
<td>145.91</td>
<td>11</td>
<td>157.67</td>
<td>10.08</td>
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<td>16 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM) + s(RDENS1KM) + SSFAW</td>
<td>140.18</td>
<td>15</td>
<td>157.89</td>
<td>10.29</td>
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<td>136.80</td>
<td>21</td>
<td>157.95</td>
<td>10.36</td>
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<td>17 s(EM100M) + s(EM10KM) + WETSTRAT + s(D2UL) + s(TWI)</td>
<td>143.00</td>
<td>14</td>
<td>157.97</td>
<td>10.37</td>
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<td>19 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM) + SSFAW</td>
<td>144.97</td>
<td>12</td>
<td>158.13</td>
<td>10.53</td>
<td>0.01</td>
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<td>10 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM) + s(RDENS1KM) + s(D2RD) + s(D2UL) + s(TWI) + SSFAW</td>
<td>134.13</td>
<td>24</td>
<td>159.52</td>
<td>11.92</td>
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<td>140.11</td>
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<td>160.42</td>
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<td>25 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM) + SSFAW + BCR22 + BCR23</td>
<td>143.04</td>
<td>14</td>
<td>160.44</td>
<td>12.84</td>
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<td>135.18</td>
<td>23</td>
<td>160.97</td>
<td>13.38</td>
<td>0.00</td>
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<td>21 s(EM100M) + s(EM10KM) + WETSTRAT + s(FOREST10KM) + s(RDENS1KM) + s(D2RD) + s(D2UL) + s(TWI) + SSFAW + BCR22 + BCR23</td>
<td>132.60</td>
<td>26</td>
<td>162.72</td>
<td>15.13</td>
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<td>138.81</td>
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<td>15.68</td>
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<td>28 &lt; NULL &gt;</td>
<td>184.28</td>
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<td>186.29</td>
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