ESTIMATING OCCUPANCY AND ABUNDANCE OF SHOREBIRDS THROUGH AERIAL SURVEYS IN THE ILLINOIS RIVER VALLEY

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Natural Resources and Environmental Sciences
in the Graduate College of the
University of Illinois at Urbana–Champaign, 2020

Urbana, Illinois

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ABSTRACT

Shorebirds are one of multiple guilds of wetland birds that have been experiencing population declines over the last 50 years. These species migrate long distances between northern breeding grounds and southern wintering grounds, and many need to stop and refuel along the way. The Illinois River Valley (IRV) serves as a crucial stopover area for migratory shorebirds in the midwestern United States despite the high prevalence of row crop agriculture and extensive wetland loss and degradation in the region. Aerial surveys are commonly used to quantify waterfowl abundance and estimate population size, but few attempts have been made to evaluate aerial surveys for other guilds of wetland birds. We investigated whether aerial surveys can be used to accurately estimate of shorebird use of stopover sites in the IRV. During July–September 2017–2019, and April–May 2018–2019, we conducted concurrent ground and aerial surveys at 5–7 sites per week. Additionally, a single observer counted and assigned all shorebird detections to either "large" (Killdeer (*Charadrius vociferus*) and larger) or "small" (Pectoral sandpiper (*Calidris melanotos*) and smaller) size classes, and recorded wetland habitat characteristics at a total of 96 sites in the IRV weekly. Dynamic occupancy analyses showed the prevalence of wet mud drove site occupancy, and higher occupancy rates were observed in the fall than the spring. Abundance analyses also found mud availability was also the driving factor in site abundance. Overall abundance and wet mud availability varied by season, with 15 times more shorebirds and more than twice the amount of wet mud available in the fall. Managers should focus on progressively exposing wet mud for migrating shorebirds especially during July–August, and also in May if the Illinois River level is low enough for managers to manipulate water levels.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Mike Ward, for his guidance and support throughout my time in Illinois. Thank you for taking a chance by bringing me on as a new graduate student straight from undergrad, and for all the time you have spent helping me accomplish each component of this project to the best of my ability. I would also like to thank my committee members Dr. Heath Hagy for getting this project started and trusting me to take it over, and Dr. Kirk Stodola for always taking the time to help me work through analyses and debugging what I am sure was incoherent R code over the years.

Thank you to everyone at the Forbes Biological Station in Havana, IL, both past and present, for helping me both in and out of the field. Without the support of the full time employees, graduate students, technicians, and volunteers, I would not have been able to collect the data needed to make this project successful. I had an awesome time working with everyone, and look forward to our paths continuing to cross down the road. A special thank you to our pilot Mike Cruce and aerial observer Aaron Yetter for making time during extremely busy times of the year to fly shorebird surveys.

I want to thank all of my friends in Champaign-Urbana, especially those affiliated with the Ward Lab, for all of the support, fun conversations, and lots of food! A special thank you to Avery for sticking with me and proving unconditional support over the years, and the many trips to visit me in the corn desert!

Finally, I want to thank my family for always helping me succeed, pushing me to be the best I can be, and always encouraging me to continue pursuing my passions. Thank you all!

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CHAPTER 1: GENERAL INTRODUCTION

Understanding the habitat and energetic needs of migratory wildlife is essential to inform effective conservation and management actions for these species. Habitat associations and energetic demands of these species can vary at different stages of a species' annual cycle, so it is important to try to understand how these change throughout the year. Changes in habitat composition at locations used during any part of the annual cycle can negatively impact species survival and fecundity. Avian species, some of which have been documented to undertake annual migrations over 80,000km roundtrip (Egevang et al. 2010), are especially susceptible to land use changes since they are making an extremely energetically taxing roundtrip each year.

Shorebirds are a guild of wetland-dependent migratory birds that migrate long distances between wintering and breeding grounds each year. These species are widely distributed across the globe, and vary in size and shape. Some shorebird species are capable of making extremely long non–stop flights between continents, such as the Bar–tailed Godwit (*Limosa lapponica*), which can make an 11,000km flight without stopping (Hedenstrom 2010). Other shorebird species migrate long distances, but incorporate a few stops to refuel along the way.

There are more than 50 species of shorebirds in North America that are widely distributed across the continent at different times of the year (Andres et al. 2012). Many species overwinter in South America, and only occur in North America during migration and breeding season (Morrison 1984). Some species of shorebirds overwinter as far south as the southern tip of South America, and breed as far north as the arctic (Morrison 1984). During migration, it is important stopover locations contain the food enabling shorebirds to refuel during their long journey. The United States is an important area for shorebirds to stopover and refuel before continuing their migration. Shorebird migration through the United States is widely distributed, encompassing both the Atlantic and Pacific coastlines, and a multitude of river floodplains, isolated lakes, agricultural areas, and anywhere else that can provide forage across the interior United States.

While migrating, shorebirds need to consume enough food at stopover sites to replenish fat stores in order to complete the journey between breeding and wintering grounds (Jenni and Jenni–Eiermann 1998). Shorebirds forage predominantly on invertebrates, but have also been documented eating small fish. On the Atlantic coast, many shorebirds rely on horseshoe crab eggs (*Limulus polyphemus*) for forage in the mid–Atlantic region during migration (Botton et al. 1994), and the decline of shorebird species such as Red Knots (*Calidris canutus*) has been linked to the decline in horseshoe crab availability (Niles et al. 2008). Shorebirds migrating through a river floodplain have been documented to forage on aquatic invertebrates from the orders Diptera, Coleoptera, Isopoda, Hemiptera, Hirudinea, Nematoda, and Cyprinodontiformes (Smith et al. 2012). Agricultural lands can also provide earthworms for shorebirds in the spring (Stodola et al. 2014).

River floodplains are spread out across the conterminous United States, and the variable habitats within these floodplains can serve as important stopover areas for migrating shorebirds (Sparks et al. 1995, Bellrose et al. 1983, Lemke et al. 2018). In the Midwest, the Illinois River Valley (IRV) has undergone drastic changes in the last century. Since river valleys provide nutrient–rich soils for agriculture, the Illinois River has become increasingly channelized through the construction of levees to prevent the river water from entering agricultural land during high-water periods. In some cases, floodplain wetlands of the Illinois River that were converted into agricultural lands were flooded so frequently that the economic losses were not worth continuing to farm the land, and the areas were eventually converted back into wetlands. Today, the river floodplain has many floodplain lakes that undergo seasonal flooding and low-water periods that promote the growth of moist–soil vegetation. These sites have varying hydrologic connections to the river, with some sites having full connections that allows water to move in and out freely throughout the year, some with partial connections that have levees and water control structures to reduce flood frequency, and some with limited/no connection to the river through tall agricultural levees (Lemke et al. 2018).

The IRV is an important stopover area for millions of waterbirds each year, including waterfowl, shorebirds, marsh birds, herons, egrets and pelicans (Havara 1999). There are more than 100 floodplain lakes, wetlands, and managed impoundments in the IRV ranging in size from 10 to 3,600 ha, and in management capability from small, private waterfowl hunting clubs to large national wildlife refuges. These sites having varying habitat compositions that include a combination of open water, mudflats, floodplain forests, and both annual and persistent emergent vegetation. For shorebirds in particular, their migration through the IRV is primarily in May during the northward trip, and in August during the southbound trip. Ideally these floodplain wetlands in the IRV will be at a low water period during migration, allowing the exposure of mudflats to provide foraging habitat for shorebirds.

Considerable research is available to help understand the full annual cycle and population success of waterfowl (Bellrose 1980, Baldassarre 2014, Rosenberg et al. 2019), but the same information is not available for shorebirds (Brown et al. 2001). The same understanding is needed for shorebirds since many shorebird species across North America have been experiencing long term population declines (Thomas et al. 2006, Rosenberg et al. 2019). It is important to understand the needs of shorebirds migrating through the IRV, and whether or not those needs are being met in order to determine management actions in the future (Smith et al. 2012). This project aims to determine how the varying habitat compositions in the IRV impact the abundance and occupancy of shorebirds during both spring and fall migration, and to investigate the role of river level and its impact on habitat composition changes throughout shorebird migration.

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CHAPTER 2: THE IMPORTANCE OF THE ILLINOIS RIVER VALLEY TO MIGRATING SHOREBIRDS

ABSTRACT

Stopover sites are critical for migrating species to stop and refuel when traveling between wintering grounds and breeding grounds. We evaluated shorebird occupancy and abundance at 96 stopover sites in the Illinois River Valley during fall and spring migration. We used ground and aerial surveys to estimate shorebird numbers over a five-week period each fall and spring, conducting surveys once a week. Surveys were conducted in fall 2017–2019 (n = 16) and spring 2018–2019 (n = 10) migrations. Shorebird site occupancy was greater in the fall than the spring, and initial occupancy was greatest in fall of 2017 (62% sites occupied, 95% CI = 37–81%), and least in spring of 2019 (7% sites occupied, 95% CI = 3–15%). The addition of wet mud significantly increased initial occupancy, with initial occupancy increasing an estimated 10.9 (2.3–51.6) times for each additional ha of mud at a site. Average abundance per survey (weekly survey of 96 sites) during the fall was 20,030 shorebirds (range 4,485–41,330), and spring surveys averaged 1,365 (range 90–3,320). Mudflat area was more than double in the fall compared to spring, and habitat composition was related to the water level of the Illinois River. Future management should prioritize the exposure of mudflats in July–August, and on increasing the amount of water manipulation control available at a site during spring high water periods.

INTRODUCTION

North American shorebird populations as a whole are experiencing long-term declines, estimated at a total loss of 37% since 1970 (Rosenberg et al. 2019). Nearly half of all the United States' (U.S.) shorebird species are experiencing population declines, although there are limited data available for many species (Brown et al. 2001). Approximately 60% of the shorebird species that migrate through the interior of North America and nearly 20% of species displaying a coastal migration are declining, with only three shorebird species in North America known to be increasing in population (Thomas et al. 2006). Potential drivers of population declines are the 50% loss of wetlands across North America (Mitsch and Gosselink 2015), changing conditions in the arctic breeding grounds (Overduijn et al. 2019), and low rates of overwinter survival (Weiser et al. 2018). Approximately 90% of the wetlands in the midwestern United States have been converted to other land use (Mitsch and Gosselink 2015). These wetlands are the habitat required for continental migrating shorebirds to refuel when traveling between wintering and breeding grounds.

Many shorebird species undergo long–distance migrations from wintering grounds in Central and South America to breeding grounds in the arctic, relying on the availability of stopover habitat in the U.S. along the way (Skagen and Knopf 1994a, Stodola et al. 2014). Dynamic river systems and their associated floodplains are important stopover areas for migrating shorebirds, including the Mississippi River, Missouri River, Wabash River, Ohio River, and Illinois River (Russel et al. 2016, LMVJV 2019). Migrating shorebirds use specific wetlands that optimize foraging ability, typically selecting for sites with mudflats and shallow water (Skagen and Knopf 1994a). Within sites, shorebirds forage in areas from bare ground to 75% vegetated cover, but mostly in sparse vegetation (<25%; Davis and Smith 1998; Dinsmore et al. 1999). Stopover site selection is expected to favor sites with large quantities of readily available food resources necessary for migration (Bauer et al. 2008, Jenni and Jenni-Eiermann 1998). While many shorebird species utilize the interior regions of North America during spring and fall migration, there is little research on the season-specific habitat composition in dynamic river floodplains and how these conditions change over time, or if habitat in either season is limiting. It has been documented that shorebird foraging habitat availability is greater in spring than fall in the Mississippi River floodplain in southeastern Missouri (Twedt 2013). Understanding migration patterns and stopover requirements for shorebird species, along with the management required to provide resources for these birds during migration, is essential to inform conservation efforts in different regions across the U.S.

Many migrating shorebirds use interior U.S. to move between wintering grounds and breeding grounds annually (Colwell 2010). For example, approximately half-a-million shorebirds migrate through the lower Mississippi Alluvial Valley each year (LMVJV 2019), while 7.3 million shorebirds stopover in the prairie pothole region in the spring and 3.9 million in the fall (Skagen et al. 2008). More shorebirds are thought to use the prairie pothole region in the spring due to elliptical migration patterns where they likely migrate further to the east in the fall (Myers et al. 1987). The Upper Mississippi River Great Lakes Region Joint Venture (JV) has documented 35 species that occur regularly during migration in the Midwest, which highlights the need to study the populations and habitat preferences of these birds throughout the year (Russell et al. 2016). The JV Shorebird Habitat Conservation Strategy in 2007 sought to have conservation planners determine migratory population estimates, breeding population estimates, and habitat needs to establish habitat conservation goals for shorebirds, but these goals have not always been reached (Potter et al. 2007). Illinois, in particular, has experienced long-term loss of wetlands and natural prairies through conversion of these areas to row crop agriculture (Dahl et al. 1990, Samson and Knopf 1994), but it is still an important stopover region for migrating shorebirds (Bailey 2003).

The Illinois River Valley (IRV), a historically important area for waterfowl, provides habitat for millions of other migrating waterbirds annually, including shorebirds, herons, egrets, rails, and pelicans (Havara 1999). Important sites in the IRV such as Chautauqua National Wildlife Refuge, a Western Hemisphere Shorebird Reserve Network site, have been estimated to attract 100,000–250,000 migrating shorebirds in the fall (Bailey 2003). The many shallow lakes and impoundments in the Illinois River floodplain can experience drastic habitat changes throughout the year based on changes in water level (Bellrose et al. 1979, Lemke et al. 2018), and the timing of these changes impacts the availability of habitat for shorebirds during fall and spring migrations (Blake-Bradshaw 2018).

Monitoring shorebirds can be difficult since large concentrations of certain species use only a few specific locations each year (Senner 2012). Species such as Red Knots (*Calidris canutus*) at beaches and marshes on the mid–Atlantic coastline in large numbers during migration (Cohen et al. 2010). Counts of 75,000 staging Sanderlings (*Calidris alba*) have been documented along the Gulf of Mexico in spring before migrating north to the prairie pothole region (Howell et al. 2019), and White-rumped Sandpipers (*Calidris fuscicollis*) migrating from South America to the arctic use one important staging area in Kansas annually (Harrington et al. 1991). Hudsonian Godwits (*Limosa haemastica*) and whimbrels (*Numenius hudsonicus*) are capable of making extremely long non-stop flights during migration, making them particularly vulnerable and requiring high quality food resources to refuel at the few stopover sites used between breeding and wintering grounds (Senner 2012, Smith et al. 2010). From a conservation perspective it is important to know where these large concentrations are located and the factors that lead to these large concentrations.

We used a combination of ground and aerial surveys in the IRV to estimate shorebird occupancy, abundance, and detection probability at 96 floodplain wetlands of the Illinois River (Figure 1) throughout fall 2017–2019 and spring 2018–2019. We aerially estimated shorebird numbers at all sites and at a subset of ground locations, and documented habitat characteristics in terms of the proportion of deep water, shallow water, wet mud, dry mud, short vegetation, and tall vegetation (Skagen and Knopf 1994a). We used a dynamic occupancy modelling framework (MacKenzie et al. 2003) to investigate overall occupancy, weekly changes in occupancy, and detection probability of aerial versus ground surveys during the spring and fall. We also used raw aerial shorebird estimates in descriptive analyses to investigate seasonal differences in abundance and to identify priority shorebird conservation areas throughout the project. The overall goals of the study were to determine how habitat composition influences shorebird occupancy, abundance and detection probability, to investigate seasonal changes (fall vs. spring) in these estimates, and to and provide information on the relative importance of river level and its impact on habitat composition across the IRV to inform conservation.

MATERIALS AND METHODS

Study Area

Surveys were conducted within the 100 year floodplain of the Illinois River from DePue, IL, to Meredosia, IL (Figure 1). This floodplain has experienced a high level of anthropogenic modification through navigational locks and dams, along with the construction of drainage and levee districts (Havera 1999). The majority of the remaining floodplain wetlands of the Illinois River are partially connected to the river through levees and water control structures, leading to seasonal flooding and regeneration during normal water-level years. A small portion of the backwaters are either fully connected to the river with no levees or entirely disconnected through tall agricultural levees, but the majority of sites are partially connected to the river through the use of smaller levees and water control structures (Bellrose et al. 1983, Lemke et al. 2018). Flood stage occurs in Havana, IL, when the Illinois River exceeds a 14-foot (4.27m) river stage and begins to flood many of the floodplain wetlands and portions of the historical floodplain. The 96 survey sites were comprised of a combination of public and private land, including National Wildlife Refuges, RAMSAR wetlands owned by non–profit organizations, state fish and wildlife management areas, and private land managed for waterfowl.

Shorebird Aerial Surveys

Aerial surveys were conducted once per week for five weeks in fall (August–early September) 2017–2019, and spring (late April–May) 2018–2019. All surveys were flown in a single–engine, fixed–wing, low–wing aircraft (Piper Arrow; Piper Aircraft, Inc., Vero Beach, FL, USA) at approximately 240 km/h and 60m above ground level (Havara 1999). Surveys were conducted as "cruise" surveys as opposed to line-transects or grid-surveys, allowing for entire wetlands or discrete portions thereof to be surveyed on both sides of the river throughout the study area, which comprised the majority of areas with available habitat within the entire IRV. This method also allowed for both a complete flight around the perimeter of a site and for return passes through the interior portions of the site to be conducted. The pilot and the aerial observer spent as much time as necessary at each site (typically 2–3 passes; ~3–5 minutes) to ensure a complete estimate of the number of shorebirds and the habitat characteristics had been completed. Any shorebirds > 24cm were considered "large" and everything else was considered "small," which meant "large" shorebirds were anything the size of a Killdeer (*Charadrius vociferus*) and larger, and "small" shorebirds were anything the size of a Pectoral Sandpiper (*Calidris melanotos*) and smaller (Appendix A). Habitat characteristics were visually estimated and classified as proportion of deep water, shallow water, wet mud, dry mud, short vegetation, and tall vegetation, similar to the methods describes in Skagen and Knopf 1994 (Table 1). The total area (ha) of each habitat covariate was determined for each site by multiplying the proportion of each habitat characteristic by the overall size of the site, which was determined by using Google Earth satellite imagery (Google Inc., Mountain View, CA, USA).

Shorebird Ground Surveys

Simultaneous ground surveys were conducted on discrete portions of large aerial survey sites to estimate shorebird detection probability and species diversity. Natural landmarks and other boundaries (e.g., shorelines, levees, vegetation, roads) were used to define discrete count areas so the ground and aerial observer surveyed the same discrete areas. If no boundaries were present, brightly painted duck decoys were used to define the boundary of ground survey location (Gilbert 2018). Simultaneous count locations were defined *a priori* and a map of the area was provided to both the ground and aerial observer. Sites were selected opportunistically based on mudflat availability to limit error in detection probability by the ground observer underestimating birds due to vegetation (see supplemental material for separate detection probability analyses). Ground crews identified and counted all shorebirds to species whenever possible in the delineated count areas using optics (e.g., spotting scope, binoculars) and from an elevated location where visibility was unobstructed. Each ground count was conducted for five minutes and concluded with the arrival of the airplane, and we make the assumption that no birds entered or exited the count area between the ground and aerial counts.

Dynamic Occupancy Statistical Analyses

We converted ground and aerial survey count data into presence/absence data for each site across all surveys and seasons. We analyzed these data using dynamic occupancy models (MacKenzie et al. 2003) in the "unmarked" package (Fiske and Chandler 2011) of Program R (Program R, R Foundation for Statistical Computing, Vienna, Austria). We estimated four parameters: initial occupancy ($\Psi 1$), colonization (γ), extinction (ε), and detection probability (ρ; MacKenzie et al. 2003). Initial occupancy is the probability of one or more individuals being present at a site during the first survey occasion, colonization is the probability that one or more individuals colonize or immigrate to a site that was unoccupied the previous survey period, extinction is the probability all individuals emigrate from a previously occupied site, and detection probability is the probability of detecting one or more individuals at a truly occupied site (MacKenzie et al. 2003).

We took an iterative approach towards understanding shorebird occupancy dynamics throughout the IRV. We first fit four detection models using the proportion of tall vegetation, which we believed would obscure visual detections, survey type (aerial or ground), the combination of tall vegetation and surveys type, and a null model with constant detection (Table 2). We used an information-theoretic approach (Burnham and Anderson 2002) to compare among detection models. Specifically, we used Akaike's Information Criterion (AIC) and weights of evidence to rank candidate models (Burnham and Anderson 2002). All four detection models included the effect of unique survey season (fall 2017–2019, spring 2018–2019) on initial occupancy since we expect inherent differences between survey seasons, and colonization and extinction were held constant. We assume that we did not over count individuals (i.e. false positives) during ground and aerial surveys (MacKenzie et al. 2003).

We then used the best fitting detection model (Table 2) when investigating occupancy dynamics. Each dynamic occupancy model included the effect of individual season (Fall 2017–2019, Spring 2018–2019) on initial occupancy, and overall season (spring vs fall) on colonization/extinction, since we expect inherent differences in occupancy between seasons, and could have differences in site use behaviors in different times of year. A Pearson's correlation test was performed before combining any covariates in the same model (Table 3). We fit six main effect models for each of six habitat covariates (hectares of deep water, shallow water, wet mud, dry mud, short vegetation, and tall vegetation), where the number of hectares in the initial survey week influenced initial occupancy, and the weekly change in hectares of each habitat covariate influenced colonization and extinction (Table 4). We also fit six models with the same habitat covariates impacting initial occupancy, but with colonization and extinction held constant. Finally, we fit one additional model that included the effect of river stage (Havana, IL gage; retrieved from the U.S. Army Corps of Engineers www.rivergages.com online database) on initial occupancy with colonization and extinction held constant (Table 4). We made inferences using the best fitting model and 95% confidence intervals on the specific effects of habitat covariates. Finally, we provide estimates of initial occupancy derived using the *predict* function in the package UNMARKED (Kéry and Chandler 2012).

Abundance Analyses

We investigated the changes in raw abundance of shorebirds detected at aerial survey sites using generalized linear models. We explored the use of N-mixture models (Royle 2004) to account for imperfect detection, but could not attain realistic estimates of abundance or effect sizes due to problems of overdispersion (Barker et al. 2018, Knape et al. 2018). Therefore, we focused on aerial estimates of shorebird numbers from entire sites and did not include the ground to aerial comparison data that was incorporated into the occupancy modeling. We used a generalized linear model with a negative binomial distribution and a log link to investigate the effects of habitat covariates on estimated shorebird abundance. We used the negative binomial due to the high prevalence of zero counts in our data (n = 1,265; 51%). We fit eight models investigating total shorebird abundance using the same covariates as the occupancy modeling process, including the main effects of deep water, shallow water, wet mud, dry mud, short vegetation, tall vegetation, river stage (at Havana, IL gage), and a null model (Table 5). All models included the effect of season (fall or spring), and were ranked using model-averaged estimates. Correlation analyses were conducted to investigate if shorebird abundance was related to specific habitat covariates or the size of a site.

RESULTS

Descriptive Occupancy Data

Over the course of 26 survey periods, we visited 2,488 sites from an airplane, of which 1,223 (49.2%) had individuals detected on them. There were 358 (29.3%) sites where only large shorebirds were present, there were 129 (10.5%) sites where only small shorebirds were present, and a combination of large and small birds at 736 (60.2%) of occupied sites. Simultaneous ground surveys were conducted 124 times (fall=82, spring=42). Ground counts averaged 77 total birds per survey, with an average of 38 large and 38 small birds per survey, and a total of 22 species in the fall (Average = 3.8 species/survey) and 17 in the spring (Average = 3.1 species/survey; Figures 2 & 3).

Initial Occupancy

The model that included the effect of unique survey season and area of wet mud on initial occupancy, and the effect of the weekly change in area of wet mud and season (fall/spring) on colonization and extinction was the best fitting model, receiving 100% of the weight of evidence (Table 4). Initial occupancy was greater in the fall compared to the spring (Figure 4; Appendix B), with initial occupancy greatest in fall of 2017 (62% sites occupied, 95% CI = 37–81%), and least in spring of 2019 (7% sites occupied, 95% CI = 3–15%; Figure 4). Additionally, the addition of wet mud significantly increased initial occupancy, with initial occupancy increasing an estimated 10.9 (2.3–51.6) times for each additional ha of mud at a site (Figure 5). While initial occupancy was predicted to be relatively low a site with no wet mud, as hectares of wet mud increase from 0 hectares to 3 hectares, initial occupancy increases to >99%, regardless of season (Figure 5). Average initial occupancy with no wet mud was 50% (SE ± 7.5) in the fall and 17% (SE ± 10.0%) in the spring, and can be increased to 93% (SE ± 2.1%) in the fall and 68% (SE ± 16.0%) in the spring with an increase of wet mud from 0 to 1 hectare (Figure 5).

Out of 2,488 total sites sampled in our 26 aerial surveys, 953 sites (38.3%) had > 3 ha of wet mud available, with 174 (18%) instances occurring in the first week of a survey season (Table 6). Of the 953 instances where > 3 ha of wet mud was available, shorebirds were detected at 761 (80%). Approximately 62% of the sites had < 3 ha of wet mud, only 30% had shorebirds detected. In fall, 49.4% of sites had at least 3 hectares of wet mud, while only 8.1% in spring. Regardless of season, 75% of the sites with 3 or more hectares of wet mud had shorebirds detected.

Colonization/Extinction

Colonization and extinction rates were relatively low regardless of season (Appendix B), although rates were greater in the spring in comparison to the fall. Colonization rates were greater in the spring being approximately 2.77 (95% CI = 0.97–7.91) times greater compared to the fall, while extinction rates in the spring were 1.47 (95% CI = 0.93–2.31) times greater than extinction rates in the fall. While colonization and extinction were relatively low overall, changes in the number of hectares of mud at a site had significant effects on colonization rate. A 1 ha change in mud increased the probability an unoccupied site became occupied by 3.12 (95% CI = 1.76–5.54) times, which meant an unoccupied site would have >99% probability of being occupied if 3 ha of mud was added.

Detection Probability

Detection probability results show that survey type is the most important variable impacting detection probability, and that an observer was approximately 19 (95% CI = 3–143) times more likely to detect a bird, given that there is one or more present at a site, from the ground than from the air. At 5 out of 124 (4%) simultaneous ground to aerial count comparisons, shorebirds were detected from the ground while none were detected from the air. Separate analyses for estimating detection probability for ground and aerial counts are outlined in Appendix D.

Descriptive Abundance Data

Average number of shorebirds estimated per weekly survey in the IRV was 20,031 (range: 4,660–41,330 birds) in the fall (n = 16 surveys), and 1,366 (range: 90–3,320 birds) in the spring (n = 10 surveys; Figures 6 & 7). Differences among years in the spring were particularly large, with an average of 204 (SE ± 62.3) shorebirds seen in 2019, compared to 2,572 (SE ± 83.3) in 2018. The fall average number of large shorebirds was 11,582 (1,425–25,615) and 8,448 small shorebirds (1,550–27,790). The average number of large shorebirds in the spring was 472 (40–1,370) and 894 (30–2,565) for small shorebirds. Regardless of season, an average of 270 shorebirds were counted at sites with > 3 ha of wet mud, and 22 at sites with < 3 ha. There were > 1,000 shorebirds counted a total of 53 different times at 26 unique sites throughout the IRV. There were > 500 shorebirds counted 131 times at 45 different sites in the IRV. The three most abundant sites in the IRV in regards to total abundance estimates accounted for an average of 21% of the birds surveyed each week, and 35% of the total shorebirds counted in all surveys. These sites include the South Pool (0–37% weekly; 15% total birds), North Pool (0–36% weekly, 9% total birds) , and South Globe unit (0–31% weekly; 11% total birds) of Chautauqua National Wildlife Refuge, owned and managed by the U.S. Fish and Wildlife Service.

Abundance Results

The top model explaining abundance of all shorebirds detected included the effect of season and the number of hectares of wet mud at a site, which received 100% of the weight of evidence (Table 5). There is no evidence for over-dispersion (residual deviance/degrees of freedom < 1). There are 2.44 (2.20–2.68) fewer shorebirds on the log scale in spring compared to fall ($p<0.001$), and for every unit increase of wet mud there is an expected 0.037 (0.033–0.041) more shorebirds on the log scale ($p<0.001$; Appendix C). Consequently, in the fall there would be an estimated 74 (SE ± 6) shorebirds at a site with no mud and 82 (SE ± 7) at a site with 3 ha of mud. In the spring there would be an estimated 6 (SE ± 0.6) shorebirds at a site with no mud and 7 (SE ± 0.67) at a site with 3 ha of mud.

As site size increases, the amount of wet mud increases, but only 29% of the variation is explained ($R^2=0.29$, $p<0.01$). In contrast, site size explained almost all of the variation in the amount of deep water ($R^2=0.97$, $p<0.01$) since most of the sites are lakes. The size of the site explained a low amount of variation in the total number of birds estimated ($R^2=0.01$, $p<0.01$; Figure 8). Total shorebird abundance was positively correlated to hectares of wet mud available at a site, however the regression only explains 4% of the variation and thus is not biologically informative ($R^2=0.04$, $p<0.01$; Figure 9).

Role of River Level

Wet mud availability is related to the stage of the Illinois River. For sites that follow the Havana, IL, river gage throughout the five aerial survey seasons, 64% of the sites had wet mud available when the river stage was < 10ft, 56% of sites when the river stage was > 10ft and < 14ft, and 6% when the river stage was > 14ft. Historically, average river stage at the Havana, IL, gage for the month of August, which many important shorebird stopover sites follow, has remained below the 14-foot flood stage since 1878 except for 3 years with summer floods (Figure 10). However, 44 out of the 127 (34.65%) years with available data, the average river stage in May, which encompasses most of spring shorebird migration, has been greater than the 14–foot flood stage. The average river stage in May 2019 during our spring shorebird surveys was 24.05 feet, which the highest average for the month of May on record (Figure 10) and likely contributes to the higher colonization and extinction rates than in August.

DISCUSSION

Our results demonstrate that the IRV is an important stopover area for migrating shorebirds, especially in the fall with an average of > 100,000 shorebirds estimated each season from 22 documented species. Our results show a high importance of wet mud for both occupancy and abundance of shorebirds when stopping over in the IRV in fall and spring. This result is well established since many other studies have shown the importance of mudflats at various stages of the shorebird annual cycle (Skagen and Knopf 1994a, Davis and Smith 1998, Long and Ralph 2001). In the IRV, the variation in both occupancy and abundance may be attributed to the dynamic nature of the Illinois River and its influence on wet mud availability. Once sites are occupied in the fall, the colonization and extinction rates are low, but these same rates are much higher in the spring. A potential driver of this difference in rates could be related to river level, such that once the river level allows water to be drawn down and mud to be exposed, sites are colonized and remain colonized. On the contrary, flooding that occurs primarily in spring can eliminate all wet mud and influence colonization and extinction. Flooding has historically more frequent in the spring which can cause extreme changes in habitat availability in short periods of time, whereas the average river level in the fall has been consistently more stable (Figure 10). Shorebird occupancy, shorebird abundance, and wet mud availability results from this study are related in an interesting manner, such that an increase of wet mud from 0 to 3 hectares increased initial occupancy to nearly 100% across the IRV (Figure 5), but shorebird abundance and area of wet mud did not show more of a linear relationship (Figure 9). This is valuable information since it shows that high shorebird abundance estimates were observed with low amounts of wet mud available at sites. Sites remaining occupied from week to week in the fall could also be driven by conspecific attraction between certain species (Folmer et al. 2010), or varying invertebrate abundance at sites throughout the IRV (Hamer et al. 2006, Smith et al. 2012, Klimas et al. 2020).

While wet mud is needed by shorebirds, providing this habitat condition may be challenging, particularly in a dynamic river floodplain. Our estimates showed an average total of 8,025 ha of wet mud available throughout the three fall seasons, compared to an average total of 2,787 ha in the two spring seasons. These values represent 5% and 2% of the total number of hectares surveyed overall, respectively. The IRV supports approximately 15 times more shorebirds on average in fall than spring (Figures 6 & 7). This difference could be due to more than twice as much wet mud available in the fall compared to the spring. However, we cannot discount other factors that can be influencing this, including the influx of juvenile shorebirds in the fall (Gratto-Trevor and Dickson 1994), the slower migration returning to wintering grounds after the breeding season compared to a more urgent timeline of rushing to breeding grounds in the spring (Nilsson et al. 2013) season-specific migration patterns of species such as stilt sandpipers that use the central flyway in the spring but have more widespread migration in the fall (Skagen et al. 2008, Jorgensen 2004), and the potential use of agricultural lands outside of our study area in the spring (Stodola et al. 2014).

The dynamics of the Illinois River and its impact on the availability of wet mud is complex. The designated 14-foot Illinois River flood stage at the Havana, IL, gage serves as a threshold where any river level higher than that will lead to river water beginning to overtop levees at multiple sites in the area. It might be expected that flooding would lead to more available habitat as the river leaves it banks, however the opposite is true. For the sites that are flooded when the Illinois River reaches 14-feet or higher, this is detrimental to shorebirds since the areas being overflowed with river water theoretically could have provided mudflats if the river had been kept out, but instead the excess floodwater drowns the entire site and accumulates in predominantly forested areas and a small portion of agricultural land. This type of flooding occurred during the spring 2019 field season, where the average river level for the month of May was 24 feet. This record-setting river level for the month of May led to drastically lower occupancy rates (Figure 4) and abundance estimates (Figure 7) since there were very few places in the IRV that were not inundated with water too deep for shorebirds.

There are only a few sites with levees tall enough to hold out the river when the level climbs more than 3 feet above the 14-foot flood stage. The sites that are capable of holding out a high river level out all are either disconnected from the river or situated behind tall levees, including the RAMSAR wetland at the Emiquon Preserve and the Sue and Wes Dixon Waterfowl refuge at Hennepin and Hopper Lakes, along with places such as Banner Marsh and Spring Lake State Fish and Wildlife Areas. On average, the river stage in the spring is much higher than in fall (Figure 10), which could be related to the large influx of water from agricultural tiling in a channelized river system that increases flashes or pulses of water that flood sites. Lower river level in the fall allows managers to have more control over decisions on what to do with water levels within a site. These potential management actions include holding water in the site, rapidly drawing down water levels to plant crops or a desired moist soil plant to provide food for the upcoming waterfowl migration, or a slower draw down that leads to progressive mudflat exposure starting from the perimeter and working inward that provides habitat for shorebirds, while promoting the natural emergence of moist soil vegetation that provides food for waterfowl. The possibility of these drawdowns occurring is much higher in the fall given the lower average river level compared to spring (Figure 10). It is not as simple as seeing a linear relationship the river level and wet mud availability (Figure 11), thus it requires site–specific management actions in order to maintain shorebird habitat.

We treated shorebirds as one group during the occupancy modeling process and not split between large/small or by species. It is important to note that even though there are no species-specific results in the occupancy analysis, we recorded 22 different species of shorebirds during the 124 ground counts in this study. Given the diversity of species seen in ground counts, the IRV is an important area continentally for migrating shorebirds. We noticed a switch in the aerial estimates from large birds being more common in the fall to small birds being more common in the spring, which is being driven by differences in Killdeer (*Charadrius vociferus*) and Greater/Lesser Yellowlegs (*Tringa sp.*), since 18 times more individuals of these species were observed during ground counts in the fall compared to the spring. These differences mirror the results of Skagen et al. 2008 where more shorebirds were observed in the spring than the fall in the mid-continental U.S., so it is possible these species are shifting their migratory pathways and migrating more westerly in the spring but coming back more easterly through the IRV in the fall.

Shorebird conservation and management requires accurately assessing population estimates over large geographic ranges, which efficient aerial surveys can contribute to. There are differences in detection probability between ground and aerial surveys, with ground surveys tending to be more accurate than aerial surveys. However, researchers have the ability to survey large areas in a short amount of time when conducted aerially, and provide estimates that must be taken as approximations of what is present on the landscape since they are not exact counts (see Appendix D).

For the IRV to continue to contribute to North American shorebird conservation, it is essential to expose mudflats whenever possible during spring and fall migrations. Our results show there is a core area around Havana, IL, that contributes a large portion of the abundance estimates, but there are other small sites scattered throughout the IRV that are important in terms of shorebird abundance as well (Figure 8). These results suggests that management does not need to focus on the largest areas, but should focus on having multiple small areas with 3 or more ha of wet mud available. The current flooding frequency in the spring minimizes the ability to expose mudflats during northward shorebird migration, but low river levels in the fall present an opportunity for managers to progressively draw water levels down and expose mud during southward migration. Long term conservation and management goals for shorebird conservation in the IRV should include the construction of sites and infrastructure that keep the river from flooding the entire site when the increase in river level is only a few feet above flood stage, and that give managers the ability to pump water out of sites to expose mudflats. This way there will be more sites that are capable of exposing mud during the flood-prone spring migration, and we could potentially see an increase in overall occupancy of shorebirds in the IRV in spring. There will always be unavoidable spring flooding that eliminates most of the shorebird habitat in years of a 5-year flood or more, but improved water resistance would be beneficial to provide mudflats in years without major floods. Future research should focus on social and historical factors driving shorebird site use, and the specific levee heights needed to keep moderately elevated river levels from flooding sites so managers can maintain control of internal water levels to have the ability to provide mudflats during both the spring and fall shorebird migration periods.

TABLES AND FIGURES

Table 1. Habitat covariate descriptions estimated at 96 sites in the Illinois River Valley during aerial shorebird surveys in fall 2017–2019 and spring 2018–2019.

Habitat Covariate	Description
Deep Water	Area covered in water too deep for shorebirds to forage (>15cm)
Shallow Water	Area covered in water shallow enough for certain shorebird species to forage (<15cm)
Wet Mud	Mudflats with a damp, shiny surface that shorebirds are able to probe through
Dry Mud	Dried mudflats characterized by visible cracks in the surface
Short Vegetation	Vegetation <20cm (i.e. early growth of moist soil grasses/sedges)
Tall Vegetation	Vegetation >20cm (i.e. mature moist soil, corn, soybeans, cattails)

Table 2. Comparison of candidate models evaluating detection probability for shorebirds in the Illinois River Valley during fall 2017–2019 and spring 2018–2019. Initial occupancy (ψ) was modeled as a function of season in all models. Colonization (γ) and extinction (ε) were modeled as constant (.), and detection (ρ) was modeled as either constant, as a function of survey type (type), or as a function of area (ha) of tall vegetation present (tall_veg). Akaike's Information Criterion (AIC) was used to rank models and relative weights (AICwt). The difference in AIC scores (ΔAIC), number of parameters (K), and model weights (AICwt) are also included.

Model	K	AIC	ΔAIC	AICwt
ψ(season)γ(.)ε(.)ρ(type)	9	2591.74	0.00	0.73
ψ(season)γ(.)ε(.)ρ(type+tall_veg)	10	2593.71	1.98	0.27
ψ(season)γ(.)ε(.)ρ(.)	8	2619.3	27.56	0.00
ψ(season)γ(.)ε(.)ρ(tall_veg)	9	2621.17	29.43	0.00

Table 3. Pearson's correlation test results on habitat covariates from shorebird aerial surveys in the Illinois River Valley in fall 2017–2019 and spring 2018–2019. Habitat covariates were estimated in terms of % cover of the entire site, and then converted into hectares after determining the total size of the size. Wet mud and shallow water were highly correlated (0.67) and therefore not used in the same model.

Habitat Covariate	Deep Water	Shallow Water	Wet Mud	Dry Mud	Short Vegetation	Tall Vegetation
Deep Water	1.00	0.32	0.36	0.21	0.15	0.08
Shallow Water	0.32	1.00	0.67	0.20	0.35	0.09
Wet Mud	0.36	0.67	1.00	0.17	0.30	0.16
Dry Mud	0.21	0.20	0.17	1.00	0.26	0.06
Short Vegetation	0.15	0.35	0.30	0.26	1.00	0.24
Tall Vegetation	0.08	0.09	0.16	0.06	0.24	1.00

Table 4. Comparison of candidate models evaluating occupancy of shorebirds in the Illinois River Valley during fall 2017–2019 and spring 2018–2019. Initial occupancy (ψ) was modeled as a function of unique survey season (fall17, spring18, etc.), and a combination of the initial area (ha) of deep water (deep_1), shallow water (shallow_1), wet mud (wet_1), short vegetation (short_1), and tall vegetation (tall_1). All colonization (γ) and extinction (ε) parameters included a covariate for season (fall or spring; "season_fs"), and were modeled as constant, or as a combination of the change in area of each habitat variable between weeks. Detection (ρ) incorporated the top model from the previous model set and was modeled as a function of survey type (type). Akaike's Information Criterion (AIC) was used to rank models and relative weights (AICwt). The difference in AIC scores (ΔAIC), number of parameters (K), and model weights (AICwt) are also included. The AIC score for the top model was 2406.44.

Model	K	ΔAIC	AICwt
ψ(season+ wet_1)γ(Δwet+season_fs)ε(Δwet+season_fs)ρ(type)	14	0.00	1.00
ψ(season+wet_1)γ(season_fs)ε(season_fs)ρ(type)	12	36.15	0.00
ψ(season+shallow_1)γ(Δshallow+season_fs)ε(Δshallow_season_fs)ρ(type)	14	41.29	0.00
ψ(season+shallow_1)γ(season_fs)ε(season_fs)ρ(type)	12	77.27	0.00
ψ(season+dry_1)γ(Δdry+season_fs)ε(Δdry+season_fs)ρ(type)	14	107.91	0.00
ψ(season+short_1)γ(Δshort+season_fs)ε(Δshort+season_fs)ρ(type)	14	127.19	0.00
ψ(season+short_1)γ(season_fs)ε(season_fs)ρ(type)	12	136.84	0.00
ψ(season+dry_1)γ(season_fs)ε(season_fs)ρ(type)	12	149.97	0.00
ψ(season)γ(season_fs)ε(season_fs)ρ(type)	11	179.44	0.00
ψ(season+river_stage)γ(season_fs)ε(season_fs)ρ(type)	11	181.21	0.00
ψ(season+tall_1)γ(season_fs)ε(season_fs)ρ(type)	12	208.89	0.00
ψ(season+deep_1)γ(Δdeep+season_fs)ε(Δdeep+season_fs)ρ(type)	14	262.59	0.00
ψ(season+tall_1)γ(Δtall+season_fs)ε(Δtall+season_fs)ρ(type)	14	381.05	0.00
ψ(season+deep_1)γ(season_fs)ε(season_fs)ρ(type)	12	551.76	0.00

Table 5. AIC ranking and model averaged results of generalized linear models investigating the effect of various habitat and site covariates on estimated shorebird abundance (Total_Birds) from aerial surveys in the Illinois River Valley in fall 2017–2019 and spring 2018–2019. A negative binomial distribution and log link was used in all models, and the effect of season (fall or spring) was included as a covariate in each model.

Model	df	AIC	ΔAIC	AICwt
Total_Birds ~ Season + Wet Mud	5	16,366.98	0	1.00
Total_Birds ~ Season + Shallow Water	5	16,408.77	41.79	0.00
Total_Birds ~ Season + River Stage	5	16,431.53	64.55	0.00
Total_Birds ~ Season + Short Vegetation	5	16,448.43	81.45	0.00
Total_Birds ~ Season + River Stage	5	16,465.00	98.02	0.00
Total_Birds ~ Season + Dry Mud	5	16,468.67	101.69	0.00
Total_Birds ~ Season + Tall Vegetation	5	16,519.52	152.54	0.00
Total_Birds ~ Season + Deep Water	5	16,527.22	160.24	0.00
Total_Birds ~ Season + Site Size	5	16,534.47	167.49	0.00
Total_Birds ~ Season	4	16,546.10	179.12	0.00

Table 6. The total number of sites with 3 or more hectares of wet mud during the first survey period from shorebird aerial surveys in the Illinois River Valley during fall 2017–2019 and spring 2018–2019.

Season	Sites with 3+ ha wet mud in 1st survey
Fall 2017	42/57
Spring 2018	25/96
Fall 2018	49/96
Spring 2019	2/96
Fall 2019	56/96

Figure 1. Study area in the Illinois River Valley included 96 floodplain wetlands of the Illinois River from DePue, IL, to Meredosia, IL.

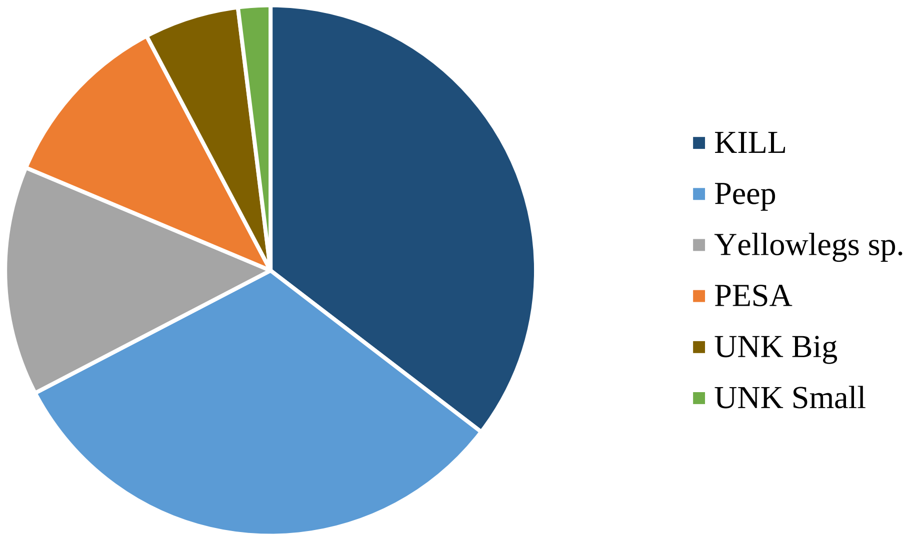

Figure 2. Subset of the 22 species observed during ground counts during shorebird aerial surveys in the Illinois River Valley in fall 2017–2019. Values calculated by averaging the weekly number of individuals of each species, then averaging the weekly averages (*n* = 8,110 individuals).

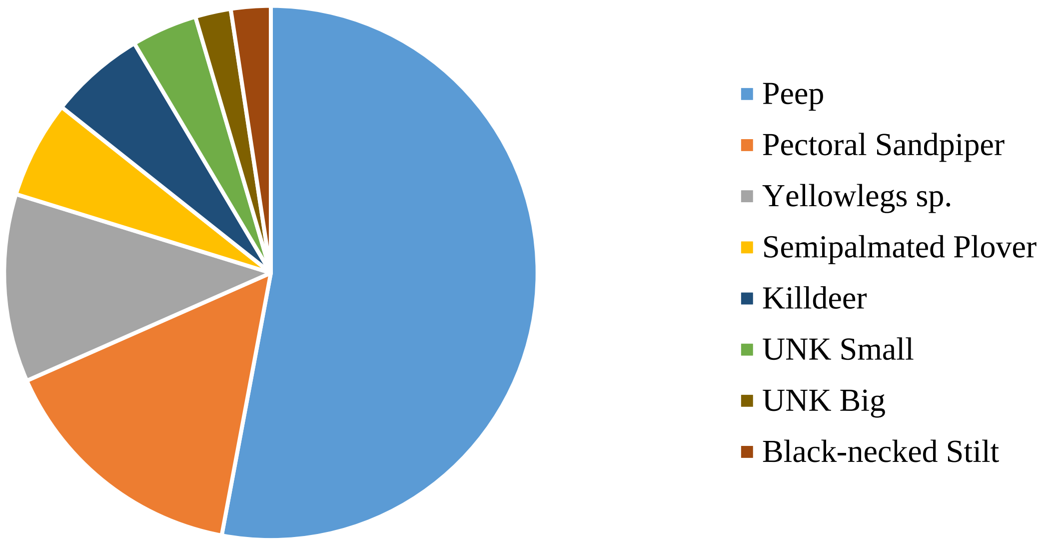

Figure 3. Subset of the 17 species observed during ground counts during shorebird aerial surveys in the Illinois River Valley in spring 2018–2019. Values were calculated by averaging the weekly number of individuals of each species, then averaging the weekly averages (*n* = 1,246 individuals).

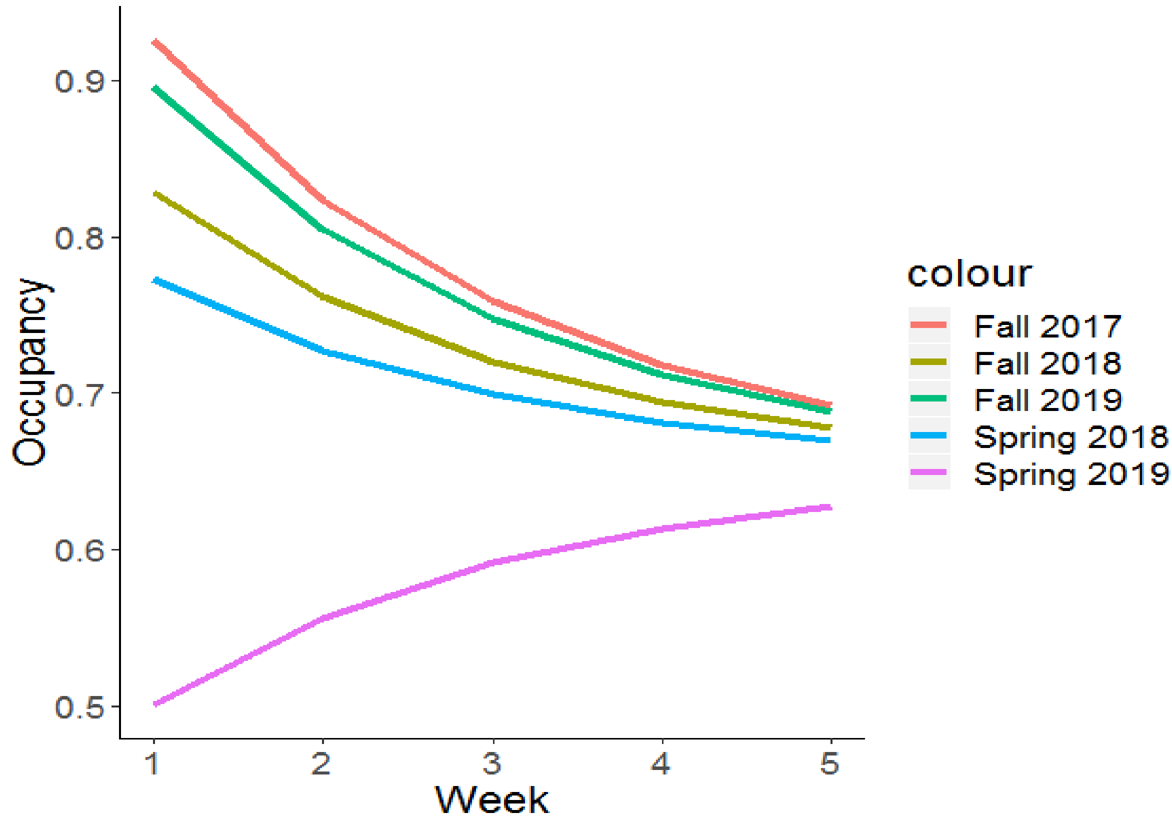

Figure 4. Weekly estimated occupancy rates for the top occupancy model, with values of 1 hectare of wet mud on initial occupancy, and a 1 hectare of wet mud between occasions. Data are from aerial shorebird surveys in the Illinois River Valley in fall 2017–2019 and spring 2018–2019.

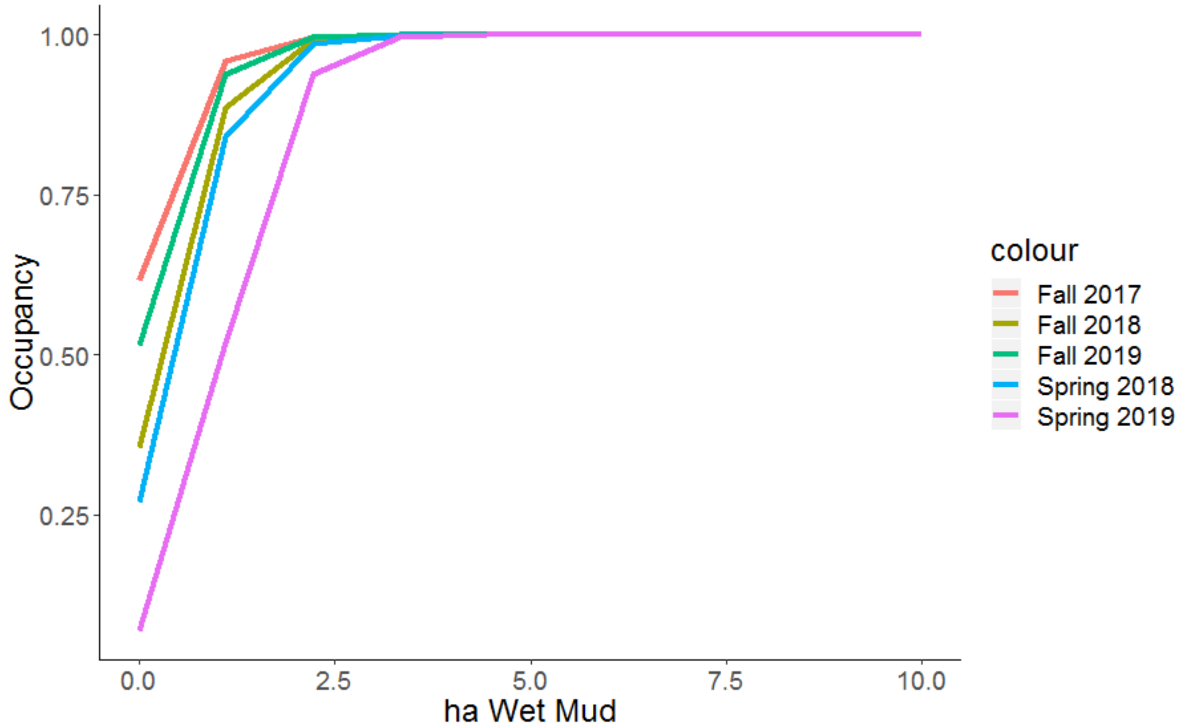

Figure 5. Predicted initial occupancy for shorebirds based on the top model in AIC showing approximately 3 hectares of wet mud is needed for initial occupancy to be maximized in spring and fall. Aerial surveys were conducted for five weeks in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley.

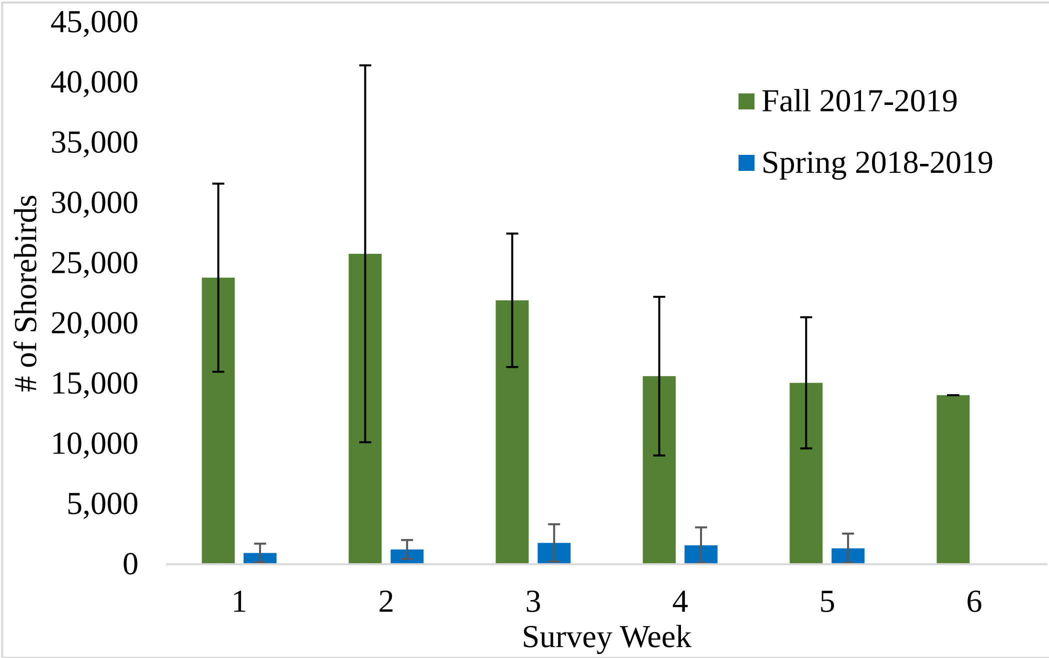

Figure 6. Average number of shorebirds estimated per week during aerial surveys in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley. Fall surveys (*n* = 16) began in the first week of August, and spring surveys (*n* = 10) began the last week of April in 2018 and the first week of May in 2019.

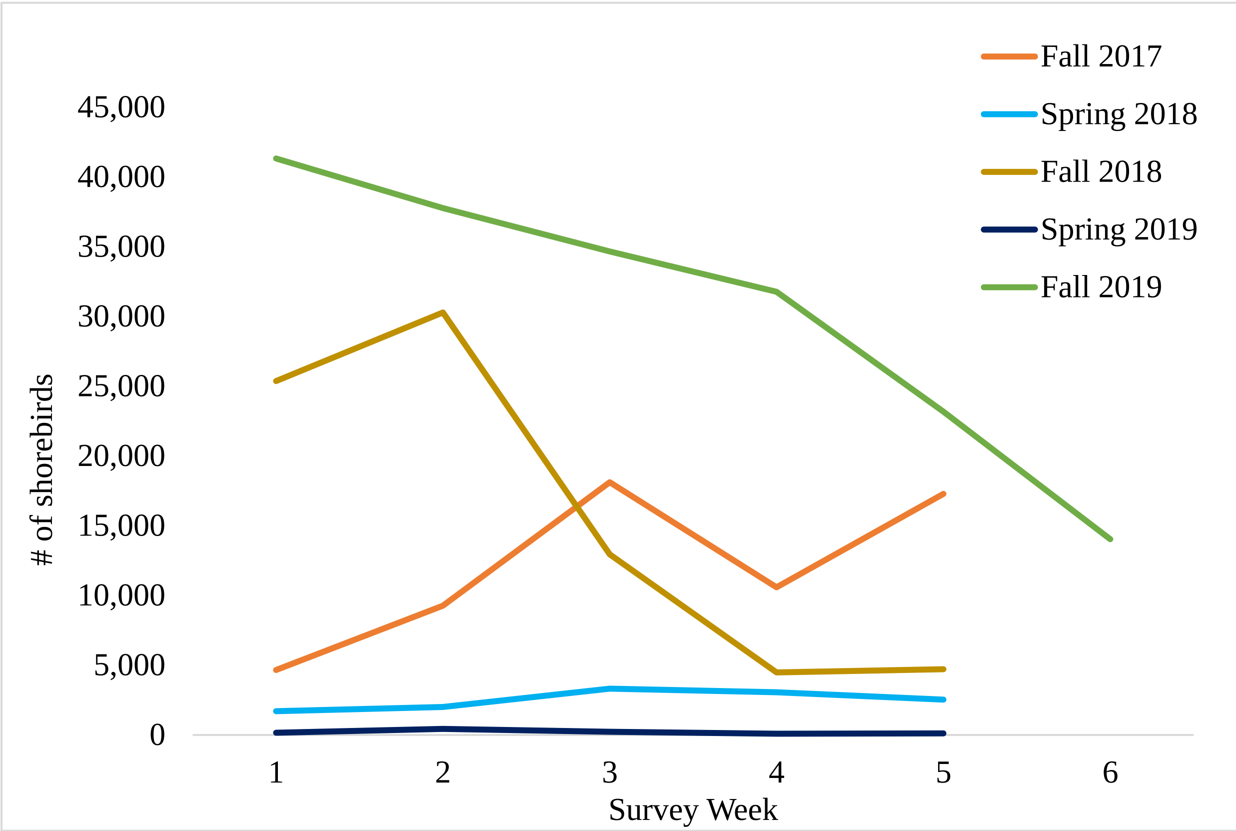

Figure 7. Estimated total number of shorebirds each week during aerial surveys of the Illinois River Valley in fall 2017–2019 and spring 2018–2019. Fall surveys (*n* = 16) began in the first week of August, and spring surveys (*n* = 10) began the last week of April in 2018 and the first week of May in 2019.

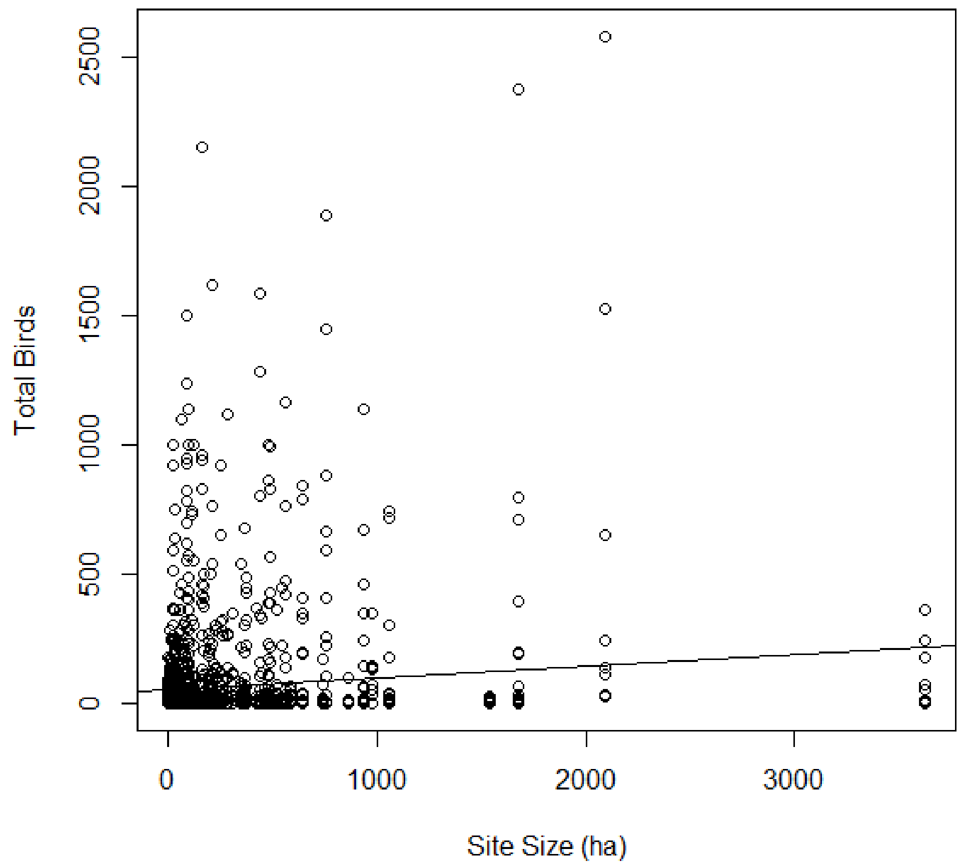

Figure 8. Site size (ha) vs total shorebird abundance. No clear relationship supports that larger sites have a greater shorebird abundance, and small sites are able to support large numbers of birds ($R^2 = 0.2$, $p<0.001$). Aerial surveys were conducted in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley.

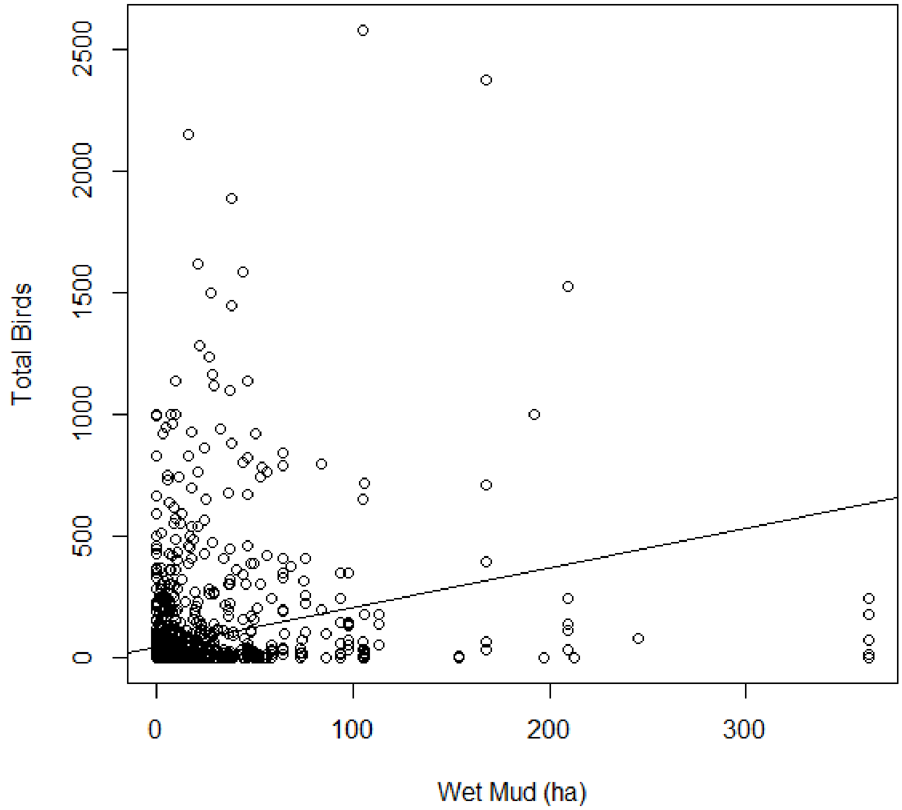

Figure 9. Area of wet mud (ha) vs total shorebird abundance. No clear relationship supports that larger areas of wet mud lead to a linear increase in shorebird abundance, and small amounts of wet mud are able to support large numbers of birds ($R^2 = 0.04$; $p<0.001$). Aerial surveys were conducted in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley.

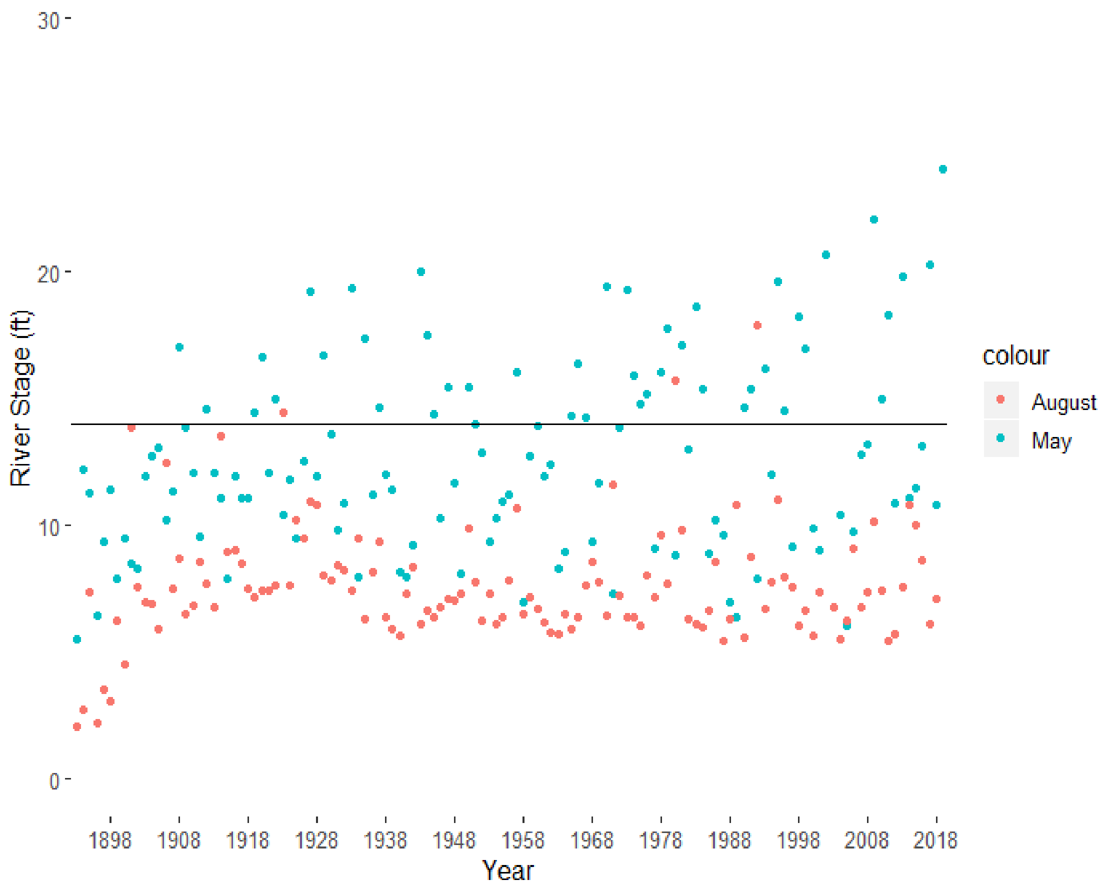

Figure 10. Average river stage during August and May at the Havana, IL, gage from 1878–2019. Horizontal line represents flood stage (14ft). Historic data were retrieved from the U.S. Army Corps of Engineers www.rivergages.com online database.

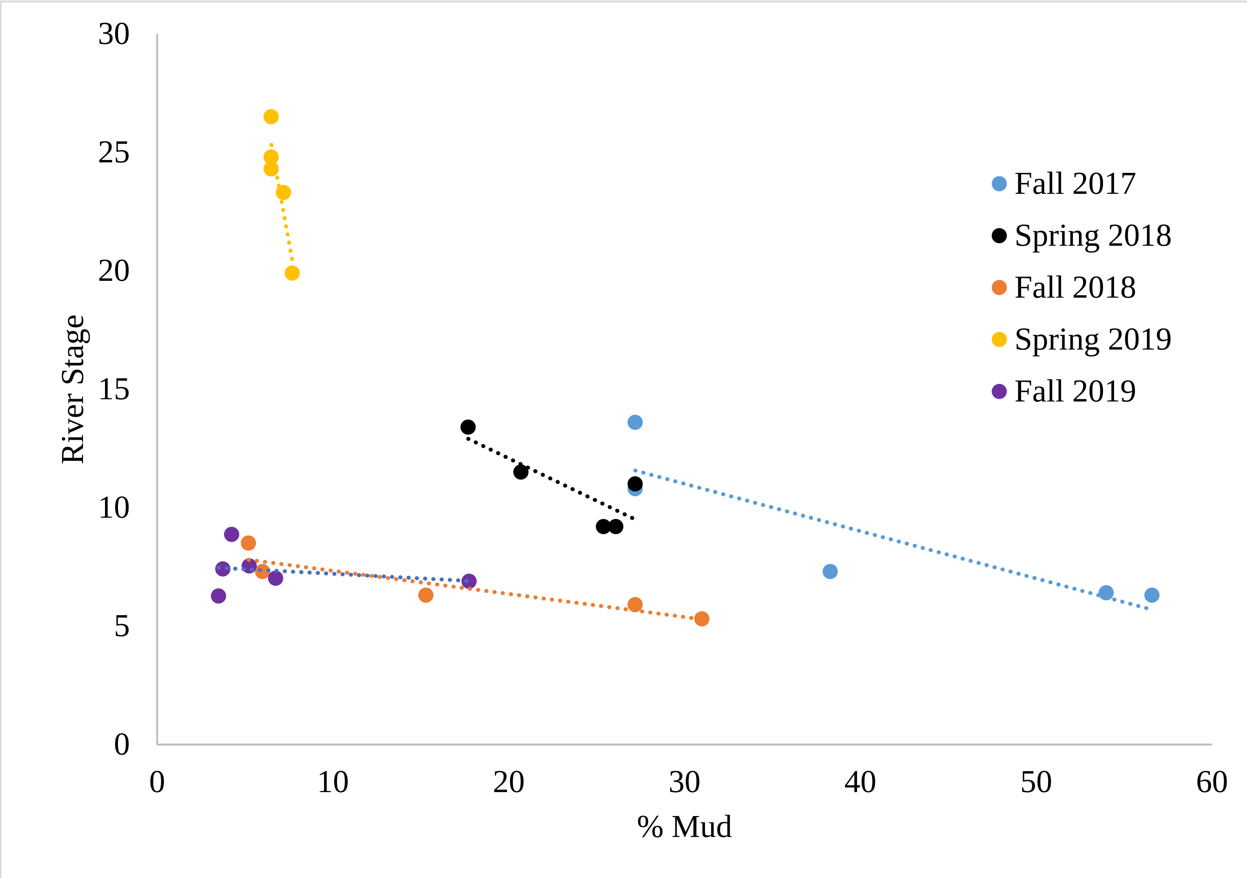

Figure 11. Average percent of wet mud at sites following the Havana, IL, river gage (*n* = 20) each week during varying river levels. Lower river levels lead to higher percentages of wet mud. Aerial surveys were conducted in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley.

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CHAPTER 3: GENERAL CONCLUSION

The IRV continues to serve as an important stopover region for millions of migrating waterbirds annually. Throughout the five field seasons of this project, we have seen a wide variety of seasonal landscape changes and the associated response of shorebird abundance and distribution. The three field seasons in the fall had moderate river levels and provided mudflats for tens of thousands of shorebirds, while the two spring seasons were much more variable. Spring 2018 had a moderate river level that remained below flood stage, and provide a small amount of mudflats for a few thousand shorebirds, while spring 2019 had the highest average river level for the month of May on record. The shorebird response to the spring 2019 flooding was remarkable, with fewer than 100 birds being seen during an entire aerial survey of the IRV.

In chapter 2, our results showed how seasonal and weekly occupancy rates changed in the IRV, along with the drastic impact that wet mud has on occupancy. If a site is able to appropriately be managed to expose even just 1 ha of mudflats, the shorebird response can be high. If that 1 ha can be turned into three or more hectares, our results show there will likely be shorebirds present. Our data show that thousands of shorebirds can be present at a site that only has a couple of hectares of wet mud available. This goes to show the massive benefits to shorebirds with only a few hectares of mud. However, there are times when the circumstances prevent even minor site-specific management actions being taken, such as extreme flooding.

Site-specific management is an important aspect of shorebird conservation in the IRV moving forward. When the river level gets high enough that it overtops levees and remains at an elevated stage about the levee height, there is nothing that can be done and that site will remain flooded until the river level recedes. However, when the river level is below levee height, it is possible to promote mudflat exposure through drawdowns and pumping (although limited). All of our sites in the IRV are unique, with different connections to the river, varying levee heights, different pumping capabilities, and different management plans depending on ownership (public/private) and target species.

Providing mudflat habitat in the IRV is the most important priority to maximize occupancy and abundance during migration and to help this region continue to be an important stopover area for shorebirds. Spring habitat availability has been and will continue to be subject to extreme flooding. Managing sites in the fall specifically for shorebirds seems unlikely and impractical in a region with such a high demand for growing food for waterfowl migration, but an adaptive management plan could be implemented in more locations, where progressive drawdowns through the end of July/beginning of August. This would allow mudflats to continuously be exposed starting from the perimeter of sites, while moist soil vegetation grows after prolonged exposure, and produces a seed head for waterfowl before the first frost occurs typically in October. Managing water levels to promote mudflat exposure in the fall, and ideally seeing a river level that does not reach flood stage in the spring can both be extremely important for shorebirds stopping over in the IRV.

APPENDIX A: SHOREBIRD SPECIES SIZE CLASSIFICATION

Small Shorebirds	**Large Shorebirds**
Baird's Sandpiper	American Avocet
Buff-breasted Sandpiper	American Golden-Plover
Dunlin	American Woodcock
Least Sandpiper	Black-bellied Plover
Pectoral Sandpiper	Black-necked Stilt
Piping Plover	Dowitcher sp.
Red-necked Phalarope	Godwit sp.
Ruddy Turnstone	Greater Yellowlegs
Sanderling	Killdeer
Semipalmated Plover	Lesser Yellowlegs
Semipalmated Sandpiper	Red Knot
Solitary Sandpiper	Upland Sandpiper
Spotted Sandpiper	Willet
Stilt Sandpiper	Wilson’s Snipe
Unknown Peep	
Western Sandpiper	
White-rumped Sandpiper	
Wilson's Phalarope	

Species considered “small” and “large” shorebirds during aerial surveys in the Illinois River Valley in fall 2017-2019 and spring 2018-2019.

APPENDIX B: DYNAMIC OCCUPANCY PARAMETER ESTIMATES

	Dynamic Occupancy (p estimated)			
Parameter	ML Estimate	SE	z	p(>|z|)
Initial occupancy (Ψ_1)				
Fall 2017	0.478	0.512	0.934	0.350
Fall 2018	–1.075	0.626	–1.717	0.086
Fall 2019	–0.415	0.684	–0.607	0.544
Spring 2018	–1.469	0.613	–2.397	0.017
Spring 2019	–3.058	0.668	–4.578	< 0.01
Wet_Mud_1	2.392	0.776	3.081	< 0.01
Colonization (γ)				
Season_Fall	–3.44	0.490	–7.02	< 0.01
Δwet_mud	1.14	0.286	3.97	< 0.01
Season_Spring	1.02	0.524	1.94	0.052
Extinction (ε)				
Season_Fall	–2.308	0.132	–17.44	< 0.01
Δwet_mud	–0.001	0.006	–0.13	0.896
Season_Spring	0.384	0.226	1.70	0.09
Detection (ρ)				
Type Aerial	1.61	0.092	17.46	< 0.01
Type Ground	2.95	1.008	2.93	< 0.01

Parameter estimates (maximum-likelihood estimates) and standard errors of the top model determined by AIC ranking in the dynamic occupancy framework for shorebirds in the Illinois River Valley during aerial surveys in fall 2017–2019 and spring 2018–2019.

APPENDIX C: ABUNDANCE PARAMETER ESTIMATES

Coefficients	Estimate	SE	z	p(>|z|)
Season Fall	4.30	0.08	53.06	< 0.001
Season Spring	–2.44	0.12	–20.18	< 0.001
Wet Mud	0.037	0.002	19.50	< 0.001

Parameter estimates and standard errors of the top model negative binomial generalized linear model on shorebird abundance in the Illinois River Valley during aerial surveys in fall 2017–2019 and spring 2018–2019.

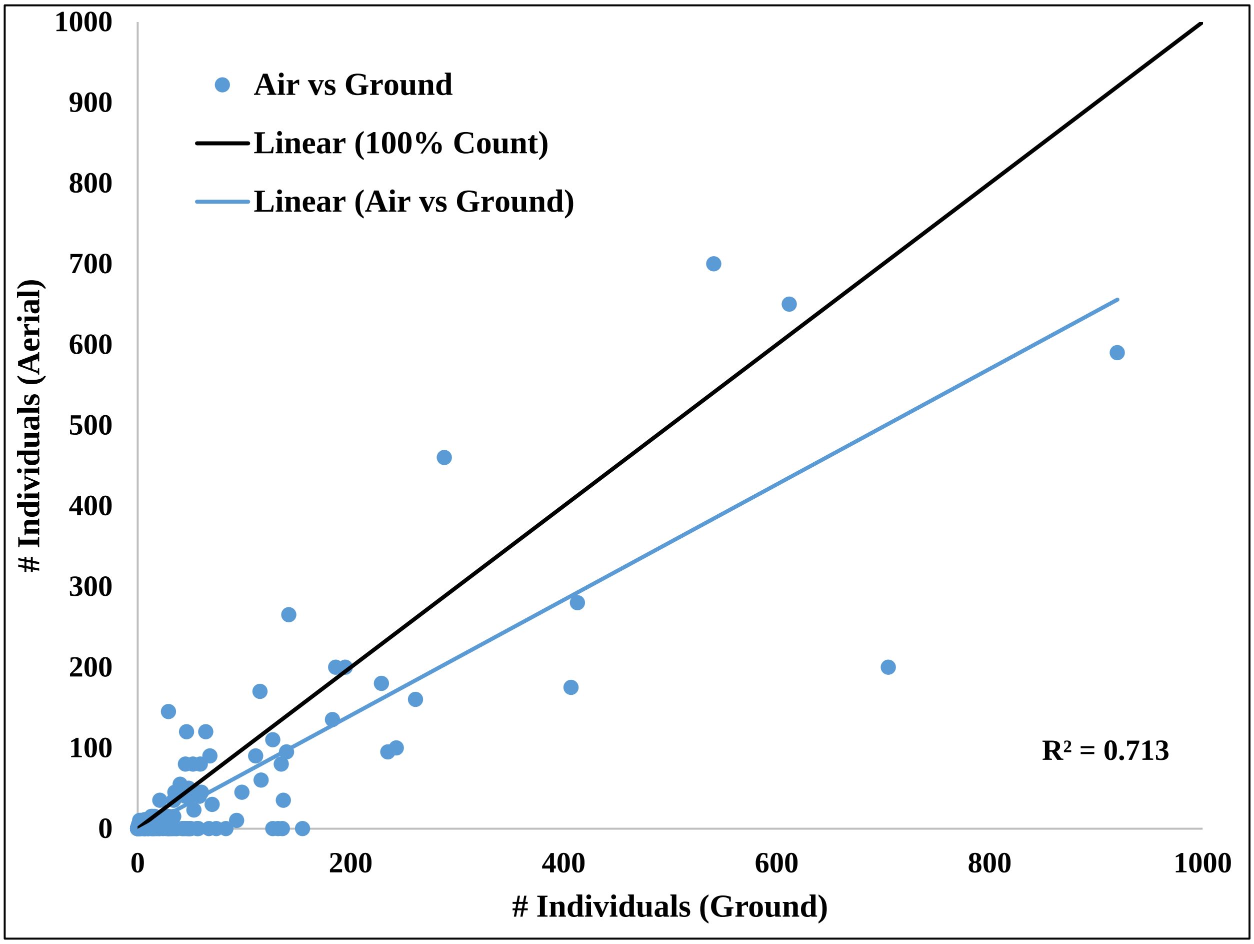
APPENDIX D: DETECTION PROBABILITY AND COUNT BIAS

Imperfect detection of the total number of individuals in a system is an important component when estimating wildlife populations. Specifically, visibility bias and its two components of detection rate and count bias (Pollock and Kendall 1987) are essential to make refined population estimates. Detection rate is the probability of detecting an individual or group of individuals when there is one or more present, and count bias is incorrectly estimating the number of individuals present within the survey area (Pollock and Kendall 1987). Both detection rate and count bias can vary by observer, weather (e.g., cloud cover, wind), vegetation coverage and characteristics, or cryptic animals (Pollock and Kendall 1987). We used a combination of double observer ground counts and ground to aerial count comparisons to estimate detection probability and count bias of aerial shorebird survey estimates. Double observer ground counts followed the same methods as the ground to aerial count comparisons described in the methods, except it involved two people conducting a five-minute ground count of the same predetermined location. We assumed there were no false positives during ground or aerial surveys, and that no shorebirds entered or exited the survey area between ground and aerial surveys. Personnel used in double-observer counts ranged from full-time waterbird biologists with extensive surveying experience to volunteers with minimal to no previous ground survey experience. Both counters used a 15x spotting scope and 10x42 binoculars while standing on opposite sides of the vehicle, and identified shorebirds to species when possible, or simply “large” or “small” (Appendix A) if unknown. No conversation about species composition or total number of birds observed was allowed before, during, or after the counts. This was done to prevent any adjustment biases developing if a trend of one observer consistently having higher counts that the other, since multiple counts with the same observers were conducted in a day.

Double observer ground counts averaged 85% similar (SE ± 2%, *n* = 102). Percent similar was calculated by taking the lower of the two counts divided by the higher count. There were also seven occasions where neither of the two observers detected a bird at site. These double observer results were consistently reliable, which allowed us to confidently use the ground counts conducted simultaneously during aerial surveys to compare to aerial estimates without incorporating a correction factor.

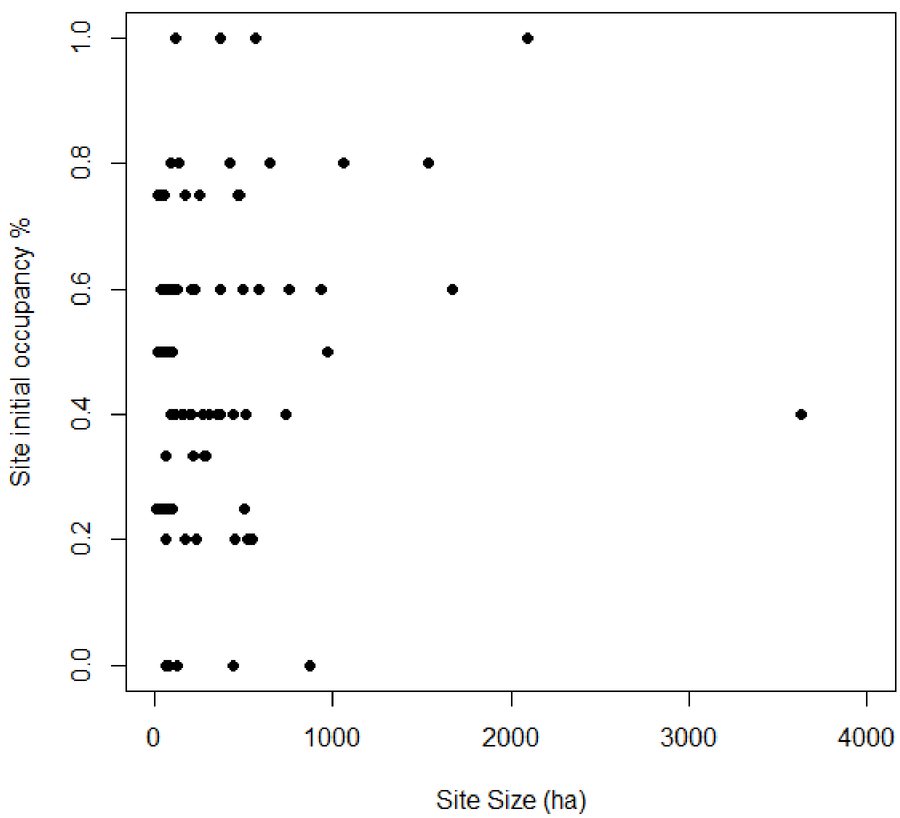
The aerial observer detected shorebirds given there were one or more present during a ground count at a site 111 out of 116 (96%), and did not detect any shorebirds when there were none present (no false positives) 8 out of 8 (100%) times. On average, these comparisons of aerial surveys to ground counts using the raw data were accurate when greater than 10 birds were counted on the ground (aerial = 91%, SE ± 7%, *n* = 92; Figure 12). There was no effect of habitat composition, temperature, cloud cover, or wind speed on visibility bias, with the null model ranking first in a negative binomial generalized linear model framework. Since the double observer ground count similarity was 85%, meaning the number of birds estimated on the ground may be slightly low, the aerial estimate of 91% may be slightly higher than the true value, but not substantially different to make a biological difference. One person conducted all of the aerial estimating during every season, so any visibility bias in the raw data is the same observer bias throughout the entire project.

Using a double-observer technique helps estimate detection probability from the ground, but it also introduces an extra parameter with the associated count bias error. Observer experience can impact double-observer count similarity and lead to larger count differences in some cases, but this variability is important to incorporate since personnel availability is a factor in most projects. The high accuracy of both the double observer ground counts and the aerial to ground comparison counts using uncorrected raw data allowed us to feel comfortable using these same data in both the dynamic occupancy modeling and abundance analyses. We acknowledge these raw counts have associated error with it, but it is a good representation of what is actually present in the IRV since there is not systematic error throughout the study design that would change the biological outcome.

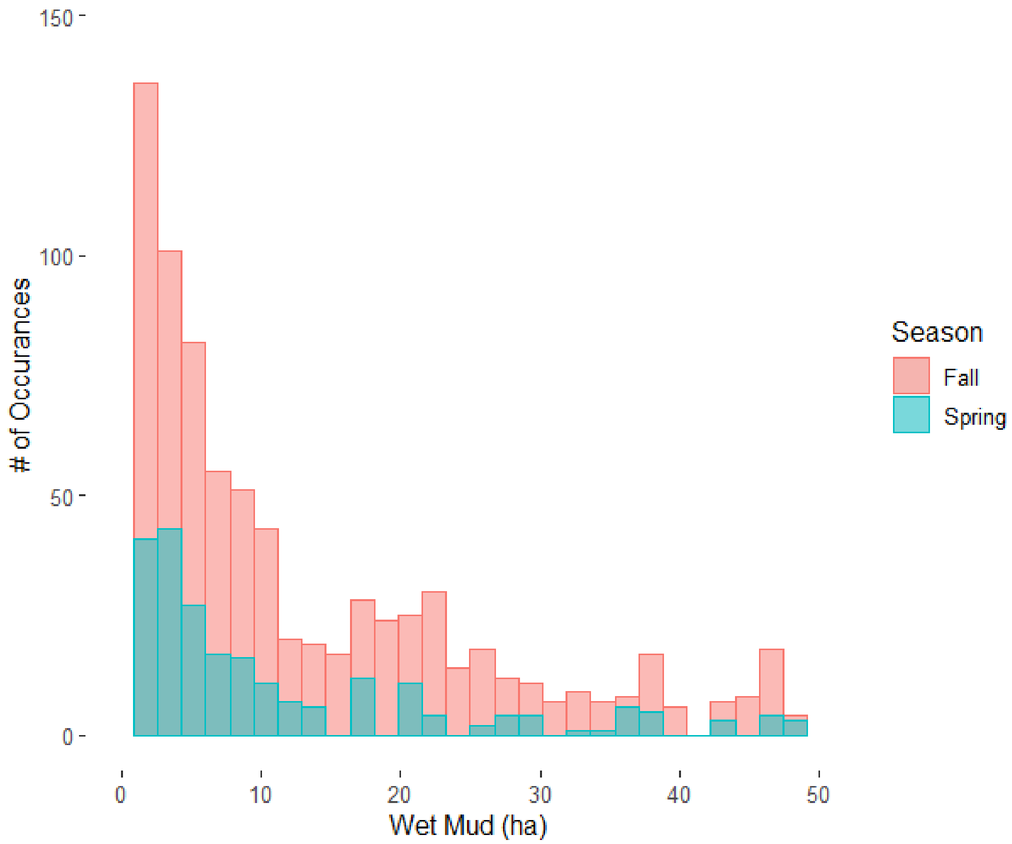


Count bias estimates of raw data during simultaneous aerial and ground counts. Aerial estimates average 91% of ground estimates (9% lower than ground, R^2 = 0.713) during shorebird aerial surveys in the Illinois River Valley in fall 2017–2019 and spring 2018–2019.

APPENDIX E: SUPPLEMENTAL MATERIAL



Site size vs initial occupancy (as a proportion of number of times occupied in the 1st survey week / five initial surveys). No clear relationship supports that larger sites have a higher change of being occupied in initial survey ($R^2 < 0.001$, $p = 0.2$). Surveys were conducted in fall 2017–2019 and spring 2018–2019 in the Illinois River Valley.



Number of occurrences of wet mud hectares during initial shorebird aerial surveys in the Illinois River Valley. Frequency varies between spring and fall, with sites in the fall having wet mud available more frequently than the spring. A total of 1425 sites were surveyed in fall 2017–2019 and 950 sites were surveyed in spring 2018–2019 (x axis limited to 50ha, but a few sites had > 50 ha available).

Season	n	% Water	Large	Small	Total
Fall 2017	25	8.4	6.4	0.8	7.2
Spring 2018	21	9.5	1.75	4.25	3.25
Fall 2018	25	7.4	7.2	0	7.2
Spring 2019	45	16.6	2.4	1.1	3.6
Fall 2019	27	11.4	7	0.2	7.2

Average number of large and small shorebirds estimated during random grid surveys in agricultural areas outside of the study area during shorebird aerial surveys in the Illinois River Valley in fall 2017-2019 and spring 2018-2019. Each random survey was a 1-square mile quadrat that was randomly selected from previously determined low density stratum quadrats outside of the 96 survey sites in the Illinois River Valley from Gilbert 2018. Shallow water and deep water were combined as "% Water."

Turnover Between Counts	% of counts (n = 197)
> 6 (-)	15
1 to 5 (-)	16
0	21
1 to 5 (+)	26
>6 (+)	22

Turnover rates of shorebirds during 5-minute ground counts in the Illinois River Valley. Ground counts of a designated site were conducted for 5-minutes, followed by a 5-minute break, and then the same site was counted again. Site turnover between counts either had a loss of birds (-), gain of birds (+) or no change (0). The number of times the turnover rate fell into each category is denoted as the % of the total number of counts (n =197). Average turnover was 4.9, with a maximum loss between counts of -92, and a maximum gain of +413 between counts. Turnover counts were conducted throughout fall 2017-2019 and spring 2018-2019 in the Illinois River Valley.