

Movements and Habitat Relationships of Virginia Rails and Soras within Impounded  
Coastal Wetlands of Northwest Ohio

Thesis

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By

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## Abstract

Most coastal wetlands of the western Lake Erie basin were drained and lost to agriculture or human development since the 1850s. Many of the remaining wetlands are impounded and managed to produce food and cover for waterfowl. While managed wetlands are an important source of rail habitat in Ohio, little is known about movements of rails in these wetlands, particularly how water level manipulation affects movements and habitat use of migrating and breeding rails. I studied Virginia rails (*Rallus limicola*) and soras (*Porzana carolina*), two rail species that migrate through and breed in northern Ohio and are listed as species of concern in the state. The goals of my study were to 1) determine seasonal, local, and regional movements of Virginia rails and soras and 2) examine microhabitat selection during the spring and summer about which there is only sparse information.

I captured and fitted Virginia rails and soras with VHF frequency-coded radio transmitters and tracked their daily movements during March – September 2016 – 2019 in northwest Ohio. Virginia rails were also fitted with VHF pulse-coded radio transmitters and tracked using the Motus Wildlife Tracking System in 2018 – 2019. I measured microhabitat characteristics during 2018 – 2019 where radio-marked rails were located and nearby random locations to better understand selection of vegetation structure and composition as water levels change through late spring and summer. Microhabitat

measurements included water depth, distance to open water, distance to cover type edge, visual obstruction, percent cover vegetation, and interspersions.

A total of 293 Virginia rails and 121 soras were fitted with VHF frequency-coded radio transmitters and 83 Virginia rails were fitted with VHF pulse-coded radio transmitters during 2016 – 2019. Three main movement patterns were evident from the rail tracking data. All rails were captured at Winous Point Marsh (WPM) and then either 1) departed northwest Ohio, 2) relocated to surrounding wetland complexes, or 3) stayed at WPM. Most radio-marked rails departed WPM including 74% ( $n = 282$ ) during the pre-nesting stage and 81% ( $n = 196$ ) during the nesting stage. Seventeen of those departed rails were found at surrounding wetland complexes within 35 km of WPM, but a majority appeared to move well beyond the marshes of the western Lake Erie basin. I estimated 68 home ranges for radio-marked rails that stayed at WPM using Minimum Convex Polygon and Kernel Density Estimation methods.

Microhabitat assessments were completed in 14 unique wetland units within northwest Ohio. Rails were located in emergent vegetation 80% of the time while no radio-marked rail locations were recorded in scrub-shrub or forested areas. The comparison of recorded microhabitat measurements indicated there was minimal difference between radio-marked Virginia rail and sora locations and random locations within and across species encouraging future studies to examine microhabitat selection at a larger scale. Results from this study provide a better understanding of rail movements in wetlands with water level manipulation and aid in more informed wetland management for rail species in northern Ohio.

## Dedication

This thesis is dedicated to the women in wildlife.

To the ones who forged the way, to the ones currently paving the way, and to the ones yet to come. Our voice, knowledge, and skills are vital to the continued successes in wildlife conservation.

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## Fields of Study

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## Chapter 1. Movement Patterns of Virginia Rails and Soras within Impounded Coastal Wetlands of Northwest Ohio

### INTRODUCTION

Rails belong to a group of wetland dependent birds referred to as secretive marsh birds. The secretive nature of these marsh birds is attributed to their infrequent vocalizations and preference for densely vegetated wetland habitats. Virginia rail (*Rallus limicola*) and sora (*Porzana carolina*) are two of the most widespread migratory rail species in North America (Glahn 1974) and are commonly monitored by wildlife agencies to estimate population trends. However, little is known about Virginia rails and soras despite the extensive range and status as game species in most states.

Virginia rail and sora are known to migrate through and breed in northern Ohio (Conway 2020, Melvin and Gibbs 2020). Bent (1926), Campbell (1968), and Andrews (1973) provided early qualitative descriptions of Virginia rail, sora, and king rail (*Rallus elegans*) arrival and departure dates in northern Ohio. Limited Virginia rail, sora, and king rail nesting activity was recorded by Andrews (1973) at Winous Point Marsh in northwest Ohio during 1971 – 1972. Trapping and banding of rails during March – May in 2004 – 2015 at Winous Point Marsh (Fournier et al. 2015, B. T. Shirkey, Winous Point Marsh Conservancy, personal communication) more recently affirmed that rails are abundant during spring in the area; however, breeding activity and migratory movements within and beyond the western Lake Erie basin have not been thoroughly studied.

The most consistent information on rail populations in Ohio is currently provided by the Ohio Division of Wildlife (ODW) breeding marsh bird surveys (Kearns 2018). Monitoring of Virginia rail and sora populations is commonly done with call-broadcast surveys designed to elicit vocal responses from birds concealed within wetland vegetation (Glahn 1974, Johnson and Dinsmore 1986*a*, Mancini and Rusch 1988, Gibbs and Melvin 1993, Conway and Gibbs 2005). State agencies throughout the Midwest conduct secretive marsh bird surveys following the Standardized North American Marsh Bird Monitoring Protocol during May – June (Conway 2011). The number of rail detections appears to decline as the breeding season progresses (Glahn 1974, Giese et al. 1980, Hansen 2019) making it difficult to monitor rails during and after the breeding season. To mitigate the effects of declining vocalizations, surveys are timed to occur during the peak breeding season when focal marsh bird species are most vocal to allow for accurate population estimates of breeding adults (Conway 2011). Staff and partners of ODW conduct secretive marsh bird surveys following the standardized protocol during 7 May – 19 June in Ohio (Kearns 2018).

The breeding marsh bird surveys are designed to estimate occupancy and abundance of breeding rail populations (Conway 2011). A critical assumption to estimate occupancy and abundance is that the surveyed population is closed to immigration, emigration, births, and deaths during the survey period (Royle 2004, Dénes et al. 2015). Specific information on breeding season movements is lacking for rails; therefore, knowledge of intra- and inter-wetland movements is needed to address the population closure assumption.

Radio telemetry studies (Andrews 1973, Johnson and Dinsmore 1985, Pickens and King 2013, Kolts and McRae 2017) have been used to investigate ecology and movements of rail species over extended time periods in different parts of the United States. Several recent studies used radio telemetry to study seasonal movements, home range size, and habitat use of king rails (Pickens and King 2013, Kolts and McRae 2017). Since Virginia rails and soras are present in Ohio during spring through fall migration periods, detailed information on their movements during these seasons could be gained through use of radio telemetry to document rail migratory movements, verify rail breeding activity, and reexamine the timing of ODW survey windows in northwest Ohio.

The goal of this study was to determine seasonal, local, and regional movements of Virginia rail and sora that inhabit impounded coastal wetlands in northwest Ohio. My objectives were to 1) establish a chronology of life history events, 2) track and analyze movement patterns during pre-nesting, nesting, and post-breeding stages, and 3) estimate seasonal home ranges. Understanding rail life cycles and associated movements during various times of the annual cycle will inform monitoring and habitat management for marsh birds in northwest Ohio. Knowing the timing of the pre-nesting and nesting stages will ensure that ODW survey efforts are conducted during time periods that produce the most accurate estimates of occupancy and abundance for both species. The timing and movements of rails using the impounded coastal wetlands can also be used to guide future habitat use studies in the area and ultimately lead to more informed habitat management decisions.

## STUDY AREA

I conducted research during 2016 – 2019 at coastal wetland sites within the western Lake Erie basin in northwest Ohio, USA. My primary research site was Winous Point Marsh (WPM) in Ottawa and Sandusky Counties, Ohio, USA (41.461° N, 82.998° W; Figure 1.1). Winous Point Marsh was 2,023 ha including 1,214 ha of managed coastal wetlands. The coastal wetlands were managed as separate impoundments with a system of earthen dikes and equipped with staff gauges and water control structures that manipulate water levels to provide habitat for waterfowl, marsh birds and other wetland wildlife. Muddy Creek Bay separated WPM into north and south marsh complexes. Most of my research occurred in the northern marshes that comprised 12 impounded wetland units. The southern marshes comprised 9 impounded wetland units and 1 undiked wetland. Dominant emergent vegetation included cattail (*Typha* spp.), swamp rose mallow (*Hibiscus moscheutos*), reed canary grass (*Phalaris arundinacea*), broadleaf arrowhead (*Sagittaria latifolia*), pickerelweed (*Pontederia cordata*), American lotus (*Nelumbo lutea*), and moist-soil plants (*Echinochloa* spp., *Polygonum* spp.)

All wetland units were managed with varying intensity each year to manage water levels, vegetation growth, and to control spread of invasive plant species. Annual water level management strategies for each unit were either active or passive. Hard drawdowns where water was pumped out of the unit in a short time span to expose mudflats occurred in actively managed units to create moist-soil conditions, while passively managed units were managed with minimal water manipulation resulting in hemi-marsh conditions (B. T. Shirkey, personal communication). The resulting vegetation community provided

food, cover, and hunting opportunities for fall migrating waterfowl. Yearly grades (A – D) were assigned to each unit by marsh managers to track vegetation response to annual management activities with attention to the following criteria: 1) management staff's expectations for waterfowl hunting opportunity and success, 2) presence and prevalence of invasive vegetation species, and 3) vegetation structure and overall condition of infrastructure (B. T. Shirkey, personal communication).

Secondary research sites where radio-marked Virginia rails and soras were detected after capture and marking at WPM included surrounding wetland complexes owned and managed by private landowners, private non-governmental organizations, and state and federal agencies (Figure 1.1). Some sites were predominantly vegetated wetland impoundments similar to WPM while others were mostly flooded agricultural fields. Secondary sites also were managed to produce suitable habitat for migrating and breeding waterfowl. Land use of surrounding areas excluding the secondary research sites was primarily traditional row crop fields and flooded agricultural fields managed for waterfowl hunting.

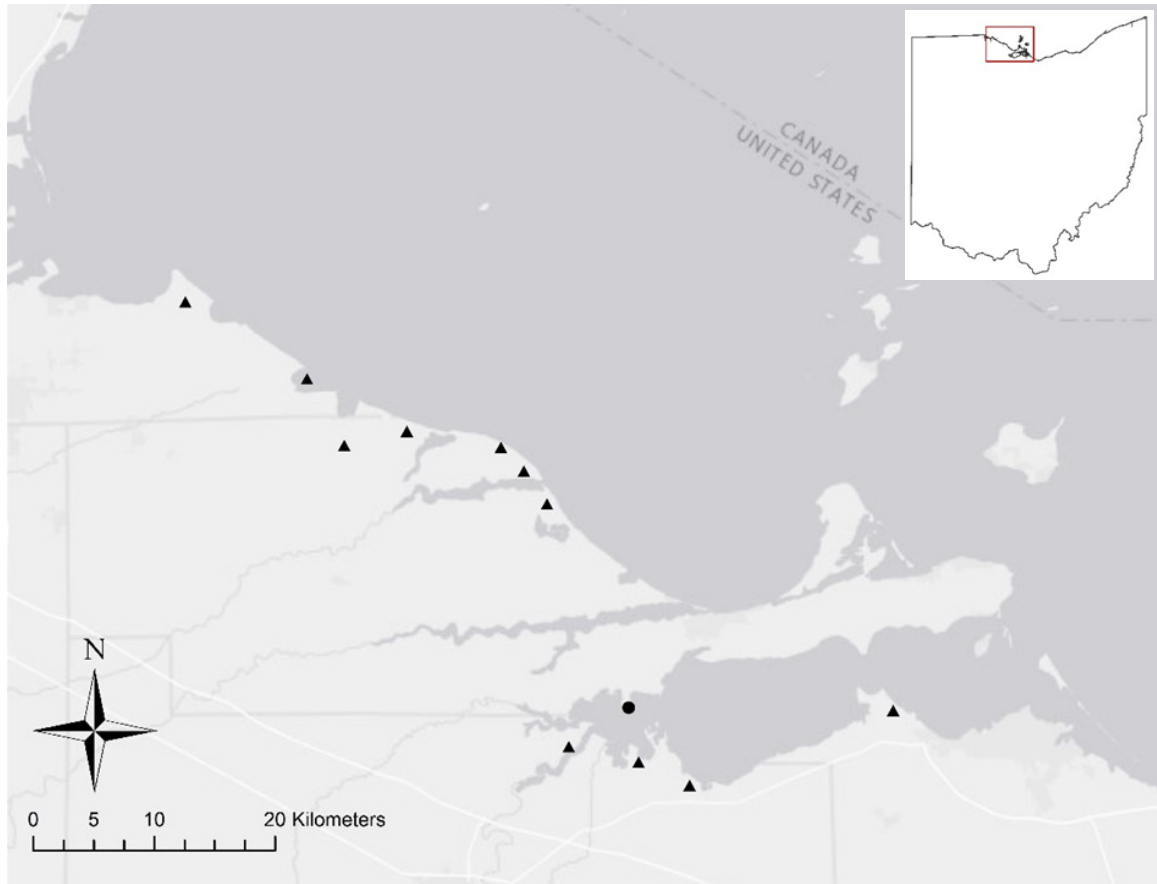


Figure 1.1. Location of coastal wetland sites where radio-marked Virginia rails and soras were detected in the western Lake Erie basin in northwest Ohio, USA during 2016 – 2019. The primary research site (north marshes of Winous Point Marsh) is shown by the circle. The triangles represent locations where rails were detected at sites owned and managed by private landowners, non-governmental organizations, and state and federal agencies.

## METHODS

### Capture and Tracking

I captured Virginia rails and soras during late March – early August during 2016 – 2019 at WPM. Trapping effort in 2018 ended in early July. I used walk-in funnel traps equipped with an audio lure of Virginia rail and sora vocalizations that were continuously played from dusk to dawn 5 – 7 nights a week to capture rails (Kearns et al. 1998,

Fournier et al. 2015). I banded all captured rails with one U.S. Geological Survey numbered size 2 aluminum band, and I recorded body mass ( $\pm 0.1$  g), wing chord (mm), culmen ( $\pm 0.1$  mm), tarsus ( $\pm 0.1$  mm), middle toe (mm), tail (mm), and body lengths (mm) along with presence and extent of cloacal protuberance (scale of 0 – 3), brood patch (scale of 0 – 5), and body fat (scale of 0 – 7; DeSante et al. 2015). I pulled the eighth primary feather from one wing and several breast feathers for sex determination. I fitted captured Virginia rails ( $>60$  g) with a frequency-coded VHF radio transmitter (hereafter frequency-coded; model A1050, Advanced Telemetry Systems, Inc., Isanti, MN, USA) or a digitally pulse-coded VHF radio transmitter (hereafter pulse-coded; model NTQB2-6-1 and ANTCW-M6-1, Lotek Wireless Inc., Newmarket, Ontario, Canada) using a leg-loop harness (Rappole and Tipton 1991). I fitted all captured soras ( $>60$  g) with a frequency-coded VHF radio transmitter. All capture, handling, and marking methods were approved by The Ohio State University Institutional Animal Care and Use Committee (2015A00000028-R1).

Tracking of rails with frequency- and pulse-coded transmitters began one day after capture and continued daily until signals were lost or the rail was found dead. Daily tracking ceased at the end of the field season each year (i.e. 30 September 2016, 28 September 2017, 28 August 2018, and 30 August 2019). Intermittent tracking efforts continued until all radio-marked rails departed the area or until estimated transmitter battery life was reached. Tracking efforts consisted of triangulations, homing to strongest signal, and presence/absence in wetland units. I recorded at least three azimuths  $\leq 20$  minutes apart using a handheld receiver and Yagi antenna from permanent stations

georeferenced on the ground using a handheld GPS. I used LOAS software (Ecological Software Solutions LLC, California, USA) to triangulate bearings for each frequency-coded rail. I conducted weekly walk-ins to determine locations by homing (White and Garrott 1990) and to determine live/dead status. Triangulations were not done on the same day when homing locations were obtained. I determined presence/absence of rails marked with frequency- and pulse-coded transmitters in wetland units when triangulations or homing locations were not obtained so departure dates could be determined for radio-marked rails. I conducted daily ground searches for radio-marked rails found missing from WPM and weekly searches at surrounding wetland complexes with the use of a vehicle-mounted telemetry system. I conducted aerial searches over surrounding wetland complexes from fixed and rotary wing ODW aircraft during May – October each year to search for missing rails. Triangulations, homing locations, presence/absence, and ground and aerial telemetry searches tracked movements and estimated home ranges and departure dates of frequency-coded rails. Homing locations, presence/absence, and ground and aerial telemetry searches estimated movements, home ranges, and departure dates of pulse-coded rails.

### **Motus Tracking**

After observing high rates of departure among rails marked with frequency-coded VHF radio transmitters during the pre-nesting and nesting seasons in 2016 and 2017, I deployed pulse-coded VHF radio transmitters on Virginia rails during 2018 – 2019. I used the Motus Wildlife Tracking System (Taylor et al. 2017) to detect movements of Virginia rails beyond WPM and the western basin of Lake Erie. The Motus collaborative

network uses automated radio telemetry towers to detect passage of tagged individuals. I maintained an array of existing telemetry towers in the area surrounding WPM (Dossman et al. 2016, Wright et al. 2018). The array consisted of 10 towers in northwest Ohio and 1 tower in southeast Michigan near the Ohio state line (hereafter local array), along with 2 additional towers farther north in southeast Michigan. I also used data collected from towers beyond the western Lake Erie basin through the Motus network (<https://motus.org/data/receiversMap?lang=en>). With the use of package ‘motus’ (Crewe et al. 2020) in program R (R Version 4.0.2, <https://www.R-project.org>, accessed 22 Jun 2020), I imported, filtered, and verified all detections associated with the pulse-coded Virginia rails. Rails detected by hand-tracking at WPM were not simultaneously detected by the automated telemetry tower located at WPM, so I considered all rail movements within a wetland independent of detections by the automated telemetry tower array. Thus, all detections from the array occurred when rails were in flight. Detections were categorized based on timing of tower detections, presence of detections through hand-tracking, and tower locations.

*Motus tower detection types:*

1. Departure – A bird was detected at one or more towers after sunset moving in an appropriate migratory direction and was not detected in the same area for the remainder of that particular stage.
2. Local – After being detected from the ground at WPM, a bird was detected at one or more towers within the local array overnight and then detected from

the ground at WPM or within the local array on the following day or during the remainder of the stage.

3. Sporadic – A bird that was no longer detected from the ground at WPM but was detected by one or more tower at inconsistent times.
4. Reappearance – A bird that “departed” during the pre-nesting or nesting stage and was detected again somewhere within the continental array during the post-breeding stage.

Movement descriptions were based on a combination of tower detections, hand-tracking, and aerial search efforts.

*Movement descriptions:*

1. *Confirmed departure* – A bird with “departure” detections that had subsequent tower detections outside the local array in an appropriate migratory direction.
2. *Probable departure* – A bird with “departure” detections that did not have subsequent tower detections outside the local array.
3. *Confirmed dispersal* – After having “local” detections, a bird that was detected from the ground at a new site within the study area where it remained until the post-breeding stage
4. *Probable dispersal* – After having “local” or “sporadic” detections, a bird that was detected from the ground at a new site within the study area for a period of time but did not stay at this site until the post-breeding stage.
5. *Nocturnal foray* – A bird that was detected from the ground at WPM the day before and after having “local” detections overnight.

6. *Return* – A bird with prior “departure” detections and then “reappearance” detections during the post-breeding stage. It was presumed this movement was a southward migratory movement based on seasonal timing.

## **Chronology**

I developed a chronology of life history events during March – December when rails were present in northwest Ohio during 2016 – 2019. My chronology was only developed for rails that stayed and attempted to breed in the study area. I relied primarily on information from movements and behavioral observations of frequency-coded and pulse-coded rails, informed also by capture data, field notes, and published literature. Variation among sex and age classes was not considered. Capture and departure histories, observed breeding behavior such as egg-laying, incubation and fledging dates, occurrences of hatch year captures, and final rail detections during each year were used to delineate the timing and duration of nesting and post-breeding stages. I divided each month into early (1<sup>st</sup> – 10<sup>th</sup>), mid (11<sup>th</sup> – 20<sup>th</sup>), and late (21<sup>st</sup> – 30<sup>th</sup>/31<sup>st</sup>) time periods to create generalized date ranges for each stage. Three stages were identified; 1) pre-nesting, 2) nesting, and 3) post-breeding.

I considered the nesting stage to include nest-building, egg-laying, incubation, hatching, fledging, and fledgling parental care. I was able to backdate or predict future dates for first egg laid, hatching, fledging, and end of parental care for all nesting activity observed even if the nesting attempt was unsuccessful. Nest-building was assumed to start with laying the first egg for both species (Kaufmann 1989). One egg was laid per day for nesting Virginia rails and soras (Pospichal and Marshall 1954, Kaufmann 1989)

with a mean clutch size of 8.5 and 10.5 eggs, respectively (Kaufmann 1989). Onset and duration of incubation varied between species, so I approximated 19 days for both species (Pospichal and Marshall 1954, Conway 2020). I considered that hatching occurred on the day after incubation ceased and chicks left the nest 3 days after hatching due to varying spans of time for hatching and nest departure, more so in soras than Virginia rails (Kaufmann 1989). Chicks are capable of flight and typically independent from their parents after 4 weeks (Kaufmann 1987) which marked the end of the nesting stage. Limited data provided the mass of chicks at varying ages (Pospichal and Marshall 1954), so I estimated ages of captured hatch year birds to determine if they were not yet capable of flight and therefore hatched at WPM or if they were possibly flighted birds that may have come from outlying areas. Post-breeding began when hatch year birds were capable of flight and likely independent from their parents.

The time period when the majority of activities that characterized each stage was designated as peak activity. Overall date ranges for each stage were noted before and after peak activity and based on the earliest and latest recorded activity that characterized each stage. The dates before and after the limits of peak activity for each stage were considered off-peak activity.

## **Statistical Analysis**

### *Home range estimation*

I used package ‘adehabitatHR’ (Calenge 2006) in program R to estimate home ranges using triangulations and homing locations. I removed triangulations with an error ellipse area >1 ha. The Minimum Convex Polygon method was used for individuals with

10 – 19 triangulations and the Kernel Density Estimation method was used for individuals with  $\geq 20$  triangulations.

*Cox proportional hazards regression model*

I applied extended Cox proportional hazards (CPH) survival analysis methods to investigate factors associated with departure dates of frequency-coded and pulse-coded Virginia rails and soras during the 2016 – 2019 field seasons. While CPH models are typically used to estimate the risk of mortality, I used CPH to model “risk” of departure (Dossman et al. 2016). The use of extended CPH models allowed me to include time-independent and time-dependent variables as predictors of departure probability (Kleinbaum and Klein 2012, Dossman et al. 2016, Wright et al. 2018). I considered a departure event as the hours from sunset to sunrise before a frequency-coded or pulse-coded rail was found missing at WPM.

Time-independent variables were all variables explaining rail traits, time, and wetland management. Rail traits included species, sex, and body condition. A private lab, iQBiotech, Miami, FL, determined gender using DNA analyses of the eighth primary feather from one wing and several breast feathers pulled from individual captured rails. Body condition was summarized with principle components analysis (PCA) of the body measurements of captured rails. I performed separate PCAs for Virginia rails and soras using the length of wing chord, culmen, tarsus, middle toe, tail, and body and then regressed the PC1 scores on observed body mass for each individual. Using that regression, I predicted body mass for each individual and calculated the residuals between observed and predicted body mass. Negative residuals indicated an individual

with lower than expected body condition and positive residuals indicated an individual with higher than expected body condition. Time variables included capture date and year.

Wetland management variables included management plan, grade, water level, and water level change. Management plan was a dichotomous variable that expressed whether an impoundment's yearly water level management plan was aligned with active (i.e. hard drawdowns occurred) or passive (i.e. minimal water manipulation occurred) management. I converted the letter grades assigned by managers to each unit to percentage grades for the CPH analysis (Appendix A). Water level data were recorded only in 2018 – 2019. Staff gauges located in the wetland units provided water levels that were taken the same day when homing locations of radio-marked rails were obtained, after rain events, and whenever time allowed. Missing daily water level measurements were imputed after fitting generalized additive models in program R with the package 'mgcv' (Wood 2017) to the observed water level measurements for each impoundment in both years. Water level change was the difference between two consecutive water level measurements at a unit. I standardized and mean-centered all water level measurements and water level changes prior to analyses.

All weather condition variables were time-dependent. I obtained weather data that was recorded 1-3 times per hour from nearby weather stations at Carl R. Keller Field Airport, Port Clinton, OH or Toledo Metcalf Field, Toledo, OH (National Oceanic and Atmospheric Administration 2020a, b). Weather variables included sky condition (five categories, clear to overcast), visibility (mi), temperature (°C), relative humidity (%), wind speed (mph), wind direction, atmospheric pressure (in Hg), and precipitation (in).

Weather conditions were represented as the mean value during the same hours during which departure events occurred except for precipitation which was the sum within the same time period. Mean wind direction was calculated following the methods of Grange (2014). Mean wind directions were transformed using Beers aspect transformation (Beers et al. 1966) so that the north aspect was given a value of 2.00 and the south aspect a value of 0.00.

Proportional hazards models assume that the hazard for any individual was proportional to the hazard for all individuals and, therefore, constant over time (Kleinbaum and Klein 2012). This assumption was tested for all weather conditions. Changes in sky condition, temperature, and wind direction were calculated and used to avoid violating the assumption due to the differences from one day to the next for each variable not varying as widely over time compared to the original values that were highly dependent on time. Positive changes in sky condition showed clearing skies, while negative changes in sky condition represented increasingly overcast conditions. Values for changes in sky condition close to 0.00 represented smaller changes while values close to 4.00/-4.00 represented larger changes. Positive changes in wind direction were shifts toward northerly winds, and negative changes showed shifts toward southerly winds.

I used package ‘survival’ (Therneau 2020) in program R to fit CPH models of potential effects of rail traits (i.e. species, sex, body condition), time (i.e. capture date and year), wetland management, and weather conditions on the probability of departure during pre-nesting, nesting, and post-breeding stages. All radio-marked rails present during each stage were included regardless of whether an individual departed during the

stage. Two datasets were used to apply CPH methods. One dataset included all rails tracked during 2016 – 2019 without water level data (variables water level and water level change; hereafter 4-year dataset) while the other dataset included rails tracked during 2018 – 2019 data when water level data was recorded (hereafter 2-year dataset). I used the information-theoretic approach (Burnham and Anderson 2002) to rank models for each stage and dataset individually. Separate candidate model subsets were created for rail traits, time, and wetland management variables. Weather variables were divided into 4 weather candidate model subsets to represent separate effect of wind, precipitation, temperature, and sky conditions. A combined weather condition model was created from the weather variables from the best wind, precipitation, temperature, and sky candidate models. I sequentially removed non-significant variables ( $P > 0.05$ ) from the combined weather condition models and ranked resulting models in addition to the top subset weather candidate models and additive and multiplicative weather condition models by using Akaike Information Criterion corrected for sample size ( $AIC_c$ ). Variables from the best candidate model from each model subset were added to the global model. If multiple competitive candidate models existed, I chose the model with more explanatory variables as the best candidate model. All variables from the best weather condition model were added to the global model. I sequentially removed non-significant variables ( $P > 0.05$ ) from the global models and ranked resulting models by  $AIC_c$ . Candidate models that did not converge or had infinite coefficients were removed from analysis. I removed one variable of inter-correlated pairs ( $r > 0.7$ ) from analyses based on which competing model had the lower  $AIC_c$  with one of the intercorrelated pair removed. The proportional

hazards assumption was reassessed for all variables in the final models including time-independent variables.

## RESULTS

A total of 497 rails were fitted with frequency- ( $n = 414$ ) and pulse- ( $n = 83$ ) coded VHF radio transmitters. A range of 1 – 98 radio-locations ( $\bar{x} = 9.36$ ) were recorded for 267 radio-marked rails that remained at WPM >1 day after capture with a total of 2,500 radio-locations obtained from rails marked with frequency- ( $n = 243$ ) and pulse- ( $n = 24$ ) coded transmitters.

Evidence of rail nesting was limited. Nine Virginia rail nests were found during 2016 – 2018, but no Virginia rail nests were found during 2019 and no sora nests were found during the entire study (Appendix A). Virginia rail nests found on 20 June 2016 and 19 June 2018 were the only successful nests, and the remaining nests likely failed due to predation (Appendix A). Three Virginia rails whose nests were discovered left WPM 3 – 6 days after nest failure. Hatch year birds that were likely capable of flight based on recorded mass ( $>52$  g;  $n = 24$ ) were typically captured during July – August, but 3 local birds (i.e. downy young) were captured on 29 May and 11 and 28 June 2018.

### Capture and Radio-tracking

Virginia rails were captured throughout the field season while soras were rarely captured in June and few were captured in July and August (Figure 1.2). A hiatus in capture rates usually occurred during June (Figure 1.2). A total of 642 Virginia rails and 216 soras were captured at WPM during 2016 – 2019 (Figure 1.2). A subset of Virginia rails ( $n = 293$ ) and soras ( $n = 121$ ) were fitted with frequency-coded VHF radio

transmitters. Additional Virginia rails ( $n = 83$ ) were fitted with pulse-coded VHF radio transmitters. Rails were captured and tracked in 12 of 21 impounded wetland units across WPM with 81% of radio-marked rails ( $n = 440$ ) using only the unit where they were captured (Appendix A).

More males ( $n = 284$ ) than females ( $n = 190$ ) were fitted with radio transmitters and 23 individuals either did not have feather samples taken for gender determination ( $n = 8$ ) or gender determination was inconclusive ( $n = 15$ ; Appendix A). Radio-marked rails included 480 after-hatch-year birds and 17 hatch year birds. Fifty-seven mortalities of frequency-coded and pulse-coded rails including 52 Virginia rails and 5 soras were detected during 2016 – 2019. Causes of mortality were suspected avian depredation ( $n = 9$ ), confirmed avian depredation (red-tailed hawk (*Buteo jamaicensis*) = 1, great horned owl (*Bubo virginianus*) = 2), suspected mammalian depredation ( $n = 9$ ), confirmed mammalian depredation (American mink (*Neovison vison*) = 1, raccoon (*Procyon lotor*) = 4), trap mortality ( $n = 2$ ), and unknown cause ( $n = 29$ ). Mortalities were excluded from all analyses.

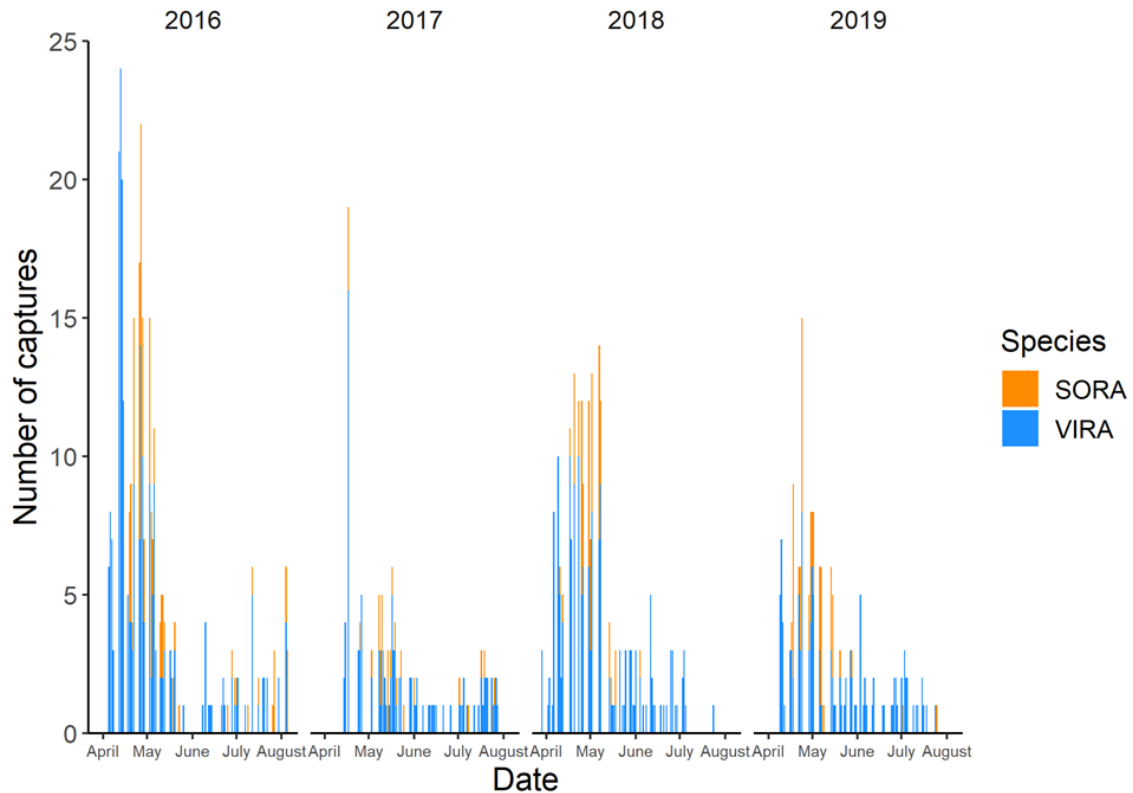


Figure 1.2. Number of captured Virginia rails (VIRA) and soras (SORA) per day at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019. Captures referred to all rail capture events including initial captures, recaptures, and trap mortalities.

### Breeding Chronology

Virginia rails exhibited three different use strategies at WPM and the surrounding wetland complexes: 1) migratory stopover before continuing farther north to breed, 2) dispersals to secondary sites within the region after capture at WPM, and 3) remaining at WPM after capture and presumably attempting to nest. Soras appeared to only migrate through the study area based on the lack of confirmed nesting activity. My chronology, therefore, mainly applies to the limited number of nesting Virginia rails with supporting

evidence from migratory rail movements. The chronology graph does not represent the nesting activities of rails that did not stay at the study area and attempt to nest.

Peak activities (i.e. time periods when the majority of activities that characterized each stage occurred) were observed during early April – late May (pre-nesting), mid-May – mid-July (nesting), and mid-July – mid-November (post-breeding; Figure 1.3). The first record of the arrival of rails in spring was late March with the earliest capture date on 29 March 2018. Rail captures and spring departure rates declined in late May or early June each year, delineating the off-peak (i.e. dates before and after the limits of peak activity) pre-nesting stage which lasted through early June (Figures 1.2 and 1.4). The earliest nesting activity was backdated to late April from a nest found in early May that was in the egg-laying stage. The latest nesting activity would have been mid-September if a nest found at the end of July had successfully hatched and fledged. Start of the post-breeding period, as indicated by rising departures and the presence of hatch year rails that were capable of flight, was in late June. The latest sign of a rail in the area was of a Virginia rail at WPM on 13 December 2019, so the post-breeding stage continued through mid-December. Departure rates increased in late June (Figure 1.4) and hatch year birds from the earliest nesting attempts would have been independent from their parents and flying by then. I split the overlapping peak periods between stages into equal parts to create 3 distinct stages for analysis purposes. The pre-nesting stage included all dates prior to and including 21 May, the nesting stage was 22 May – 15 July, and the post-breeding stage started 16 July.

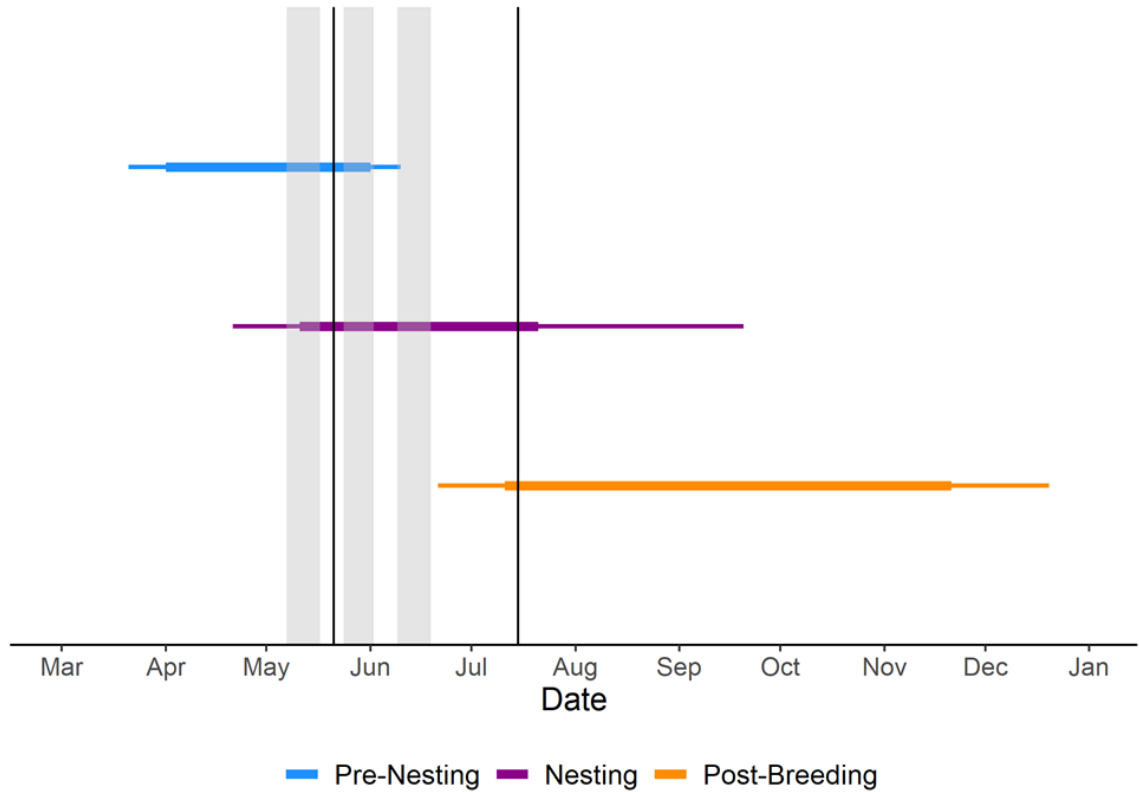


Figure 1.3. Estimated chronology of Virginia rail and sora pre-nesting, nesting, and post-breeding stages in northwest Ohio, USA during 2016 – 2019. Thick colored lines denote peak activity while thin colored lines are off-peak and stage extremes. Black vertical lines show cut-offs for each stage for analytical purposes, and shaded gray areas represent Ohio Division of Wildlife secretive marsh bird survey windows.

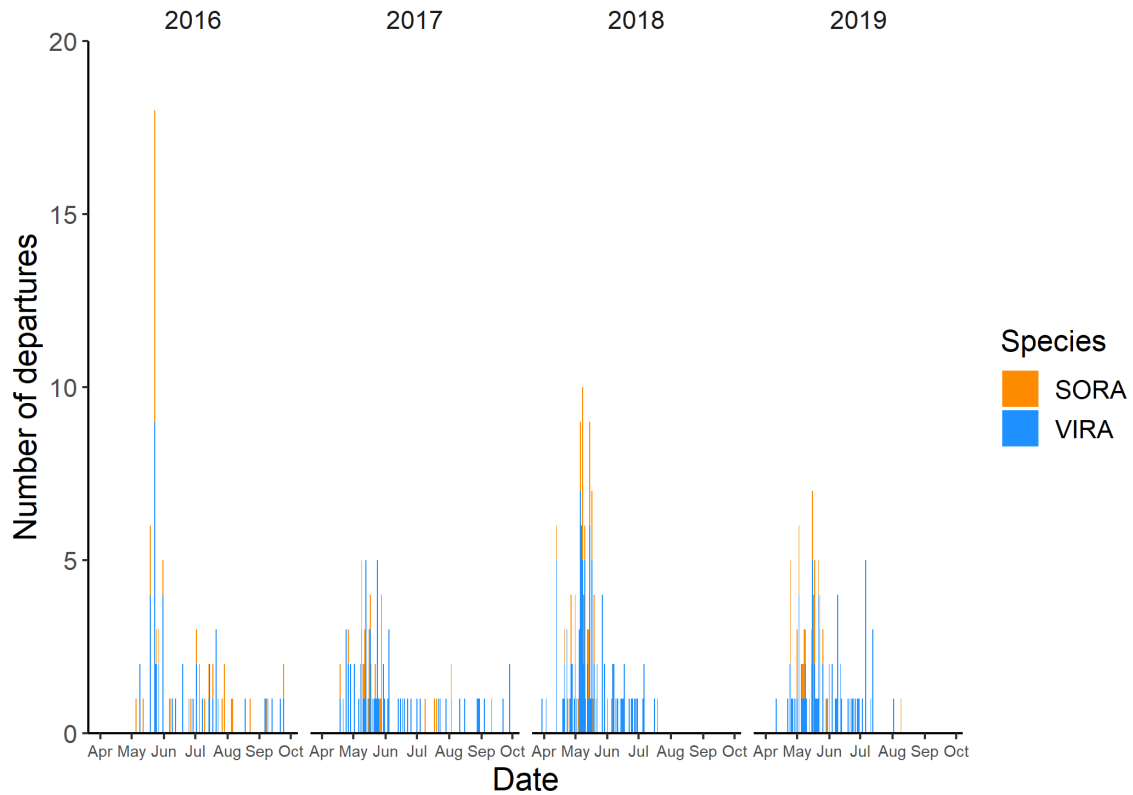


Figure 1.4. Numbers of Virginia rail (VIRA) and sora (SORA) departures per day at Winous Point Marsh (WPM), Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019. Departure dates are when a frequency-coded or pulse-coded rail’s signal was lost and marked as missing at WPM.

### Duration of Stay and Timing of Departures

Virginia rails were present at WPM throughout the entire nesting stage while few soras marked with frequency-coded transmitters remained past early June (Figure 1.4). The latest a sora was detected at WPM during the nesting stage was 7 June after which captures of soras did not occur again until late June ( $n = 3$ ), July ( $n = 14$ ), or August ( $n = 5$ ) with those frequency-coded soras only staying at WPM for short durations. The median length of stay after capture was 10 days for adult radio-marked rails with 51% ( $n$

= 423) departing by the 10<sup>th</sup> day after capture (Figure 1.5). Large numbers of radio-marked rails apparently departed WPM before the post-breeding stage with 74% ( $n = 282$ ) found missing during the pre-nesting stage and 81% ( $n = 196$ ) during the nesting stage. Seventeen of the departed rails were found at wetland complexes within 35 km of their capture locations at WPM during the pre-nesting and nesting stages (Figure 1.1), and 5 of those birds remained at off-site locations throughout the nesting and post-breeding stages. Twenty of the departed rails were only detected again during the post-breeding stage at surrounding wetland complexes ( $n = 15$ ) or at WPM ( $n = 5$ ).

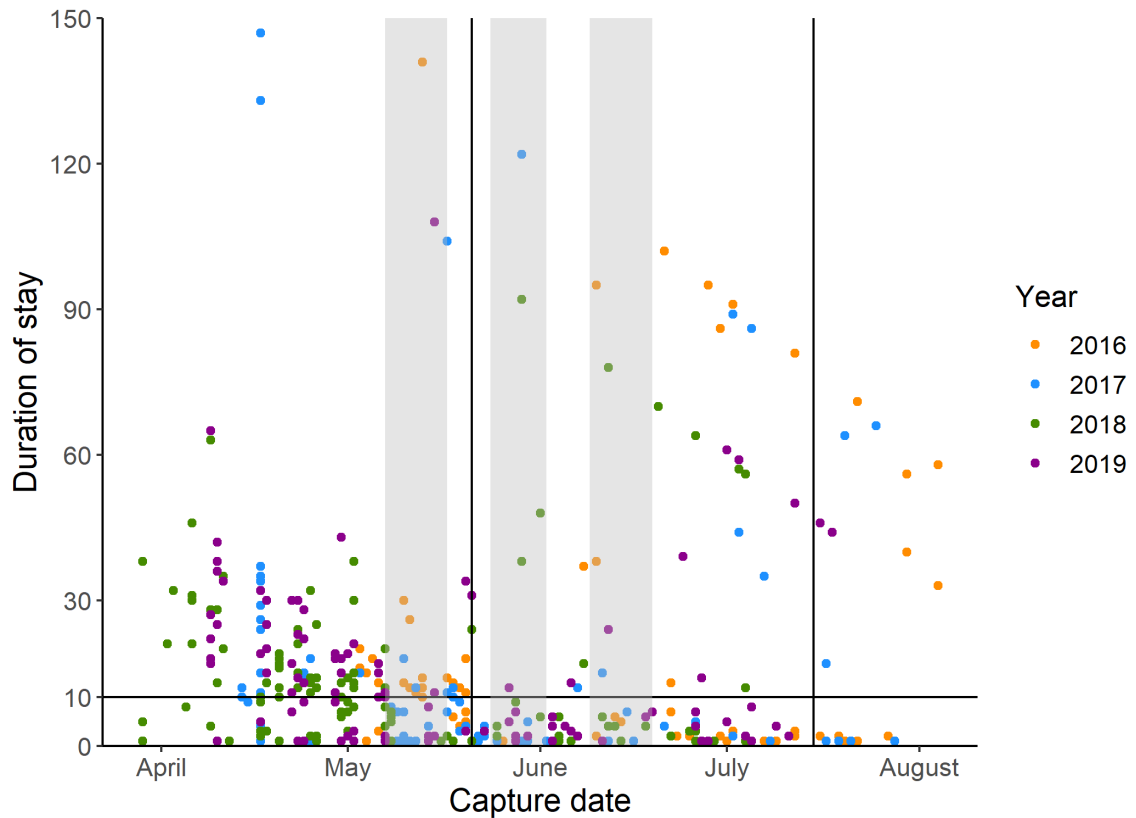


Figure 1.5. Duration of stay in days of adult frequency-coded and pulse-coded Virginia rails and soras at Winous Point Marsh (WPM), Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019. The black horizontal line denotes the median (10 days) duration of stay at WPM across all years. Black vertical lines show cut-offs for each chronological stage for analytical purposes, and shaded gray areas represent Ohio Division of Wildlife secretive marsh bird survey windows.

## Home Range Estimation

The short duration of stay for most radio-marked rails produced a diminished sample of estimated home ranges ( $n = 71$ ). I estimated 41 home ranges using the Minimum Convex Polygon method with 10 – 19 radio-locations ( $\bar{x} = 13.70$ ) per radio-marked rail and 30 home ranges using the Kernel Density Estimation method with 20 – 98 radio-locations ( $\bar{x} = 38.33$ ) per radio-marked rail. Home range sizes were estimated

(95% utilization distributions) for 1 Virginia rail marked with a pulse-coded transmitter, 65 Virginia rails with frequency-coded transmitters, and 5 soras. Home ranges of Virginia rails and soras were relatively small and mostly localized within a single wetland management unit (Figure 1.6). All home ranges were estimated for rails at WPM except for three Virginia rail home ranges estimated at Ottawa National Wildlife Refuge (Ottawa NWR) during 2017 – 2018. Virginia rails had larger home ranges than soras (Table 1.1). Home ranges of both species suggested a preference for emergent vegetation and avoidance of open water. Overlapping home ranges within and between species during the same year was also observed (Figure 1.6).

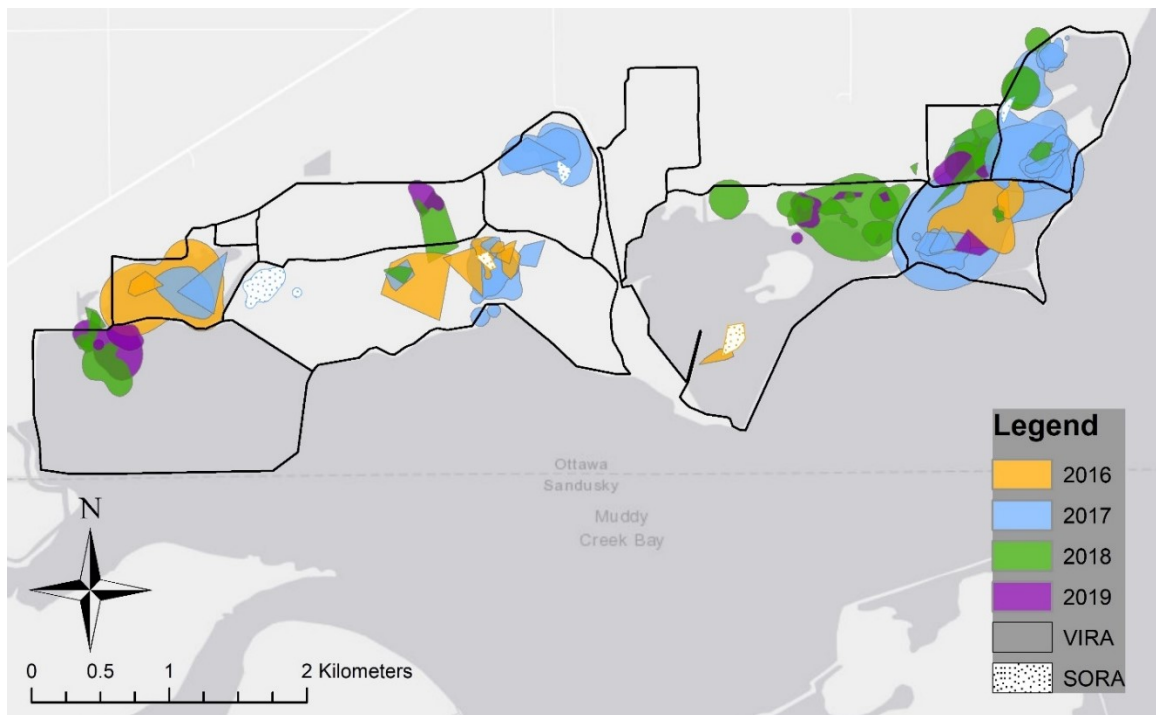


Figure 1.6. Estimated home ranges of frequency- and pulse-coded Virginia rails (VIRA) and soras (SORA) at Winous Point Marsh, Ottawa County, Ohio, USA during 2016 – 2019.

Table 1.1. Mean home range sizes of frequency- and pulse-coded Virginia rails (VIRA) and soras (SORA) at Winous Point Marsh and Ottawa National Wildlife Refuge, Ottawa County, Ohio, USA during 2016 – 2019.

Year	Mean $\pm$ standard error (range, <i>n</i> ) home range size (ha)	
	VIRA	SORA
2016	5.49 $\pm$ 2.37 (0.36 – 25.36, <i>n</i> = 11)	0.98 $\pm$ 0.44 (0.54 – 1.42, <i>n</i> = 2)
2017	6.87 $\pm$ 2.61 (0.84 – 59.20, <i>n</i> = 22)	1.50 $\pm$ 0.98 (0.45 – 3.46, <i>n</i> = 3)
2018	3.02 $\pm$ 1.01 (0.09 – 24.08, <i>n</i> = 25)	
2019	2.66 $\pm$ 0.84 (0.24 – 7.85, <i>n</i> = 8)	
Total	4.67 $\pm$ 1.04 (0.09 – 59.20, <i>n</i> = 66)	1.29 $\pm$ 0.57 (0.45 – 3.46, <i>n</i> = 5)

### Motus Tracking

Sixty one of 83 Virginia rails fitted with pulse-coded VHF radio transmitters were detected at Motus towers from lower Ontario to northern Florida (Figure 1.7). There were 33 confirmed departures and 19 probable departures. Seven of the confirmed departures were southward movements during the post-breeding stage. Southward detections occurred mainly in South Carolina, Georgia, and Florida (Figure 1.7). Northward departures during late April through early July appeared to be migrations beyond the Lake Erie region (Figure 1.8).

Nine rails had movements that I characterized as nocturnal forays that consisted of detections from one or more local towers at night that preceded or followed detections from the ground with handheld Yagi antennas. All nocturnal forays (*n* = 9) were followed within <5 days by departures or dispersal to outlying sites within the western Lake Erie marsh region.

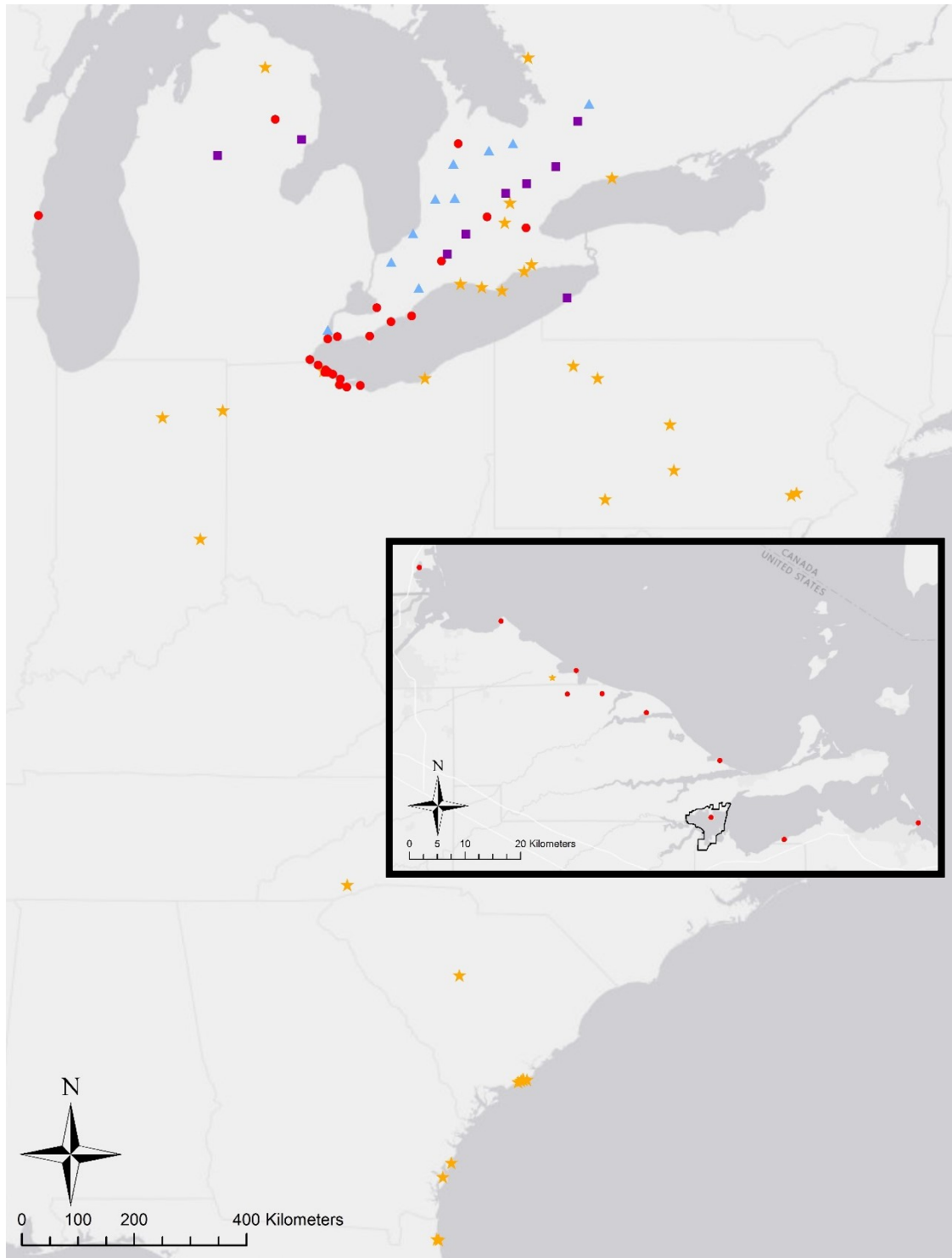


Figure 1.7. Locations where Virginia rails that were fitted with pulse-coded VHF radio transmitters at Winous Point Marsh (WPM), Ottawa and Sandusky Counties, Ohio, USA were detected at Motus Wildlife Tracking System automated telemetry towers during

April – December in 2018 and 2019. Towers that detected rails during the pre-nesting stage are shown as blue triangles, the nesting stage as purple squares, the post-breeding stage as orange stars, and in more than one stage as red circles. WPM is outlined in black in the inset map. The local array is the 11 towers within the inset map.

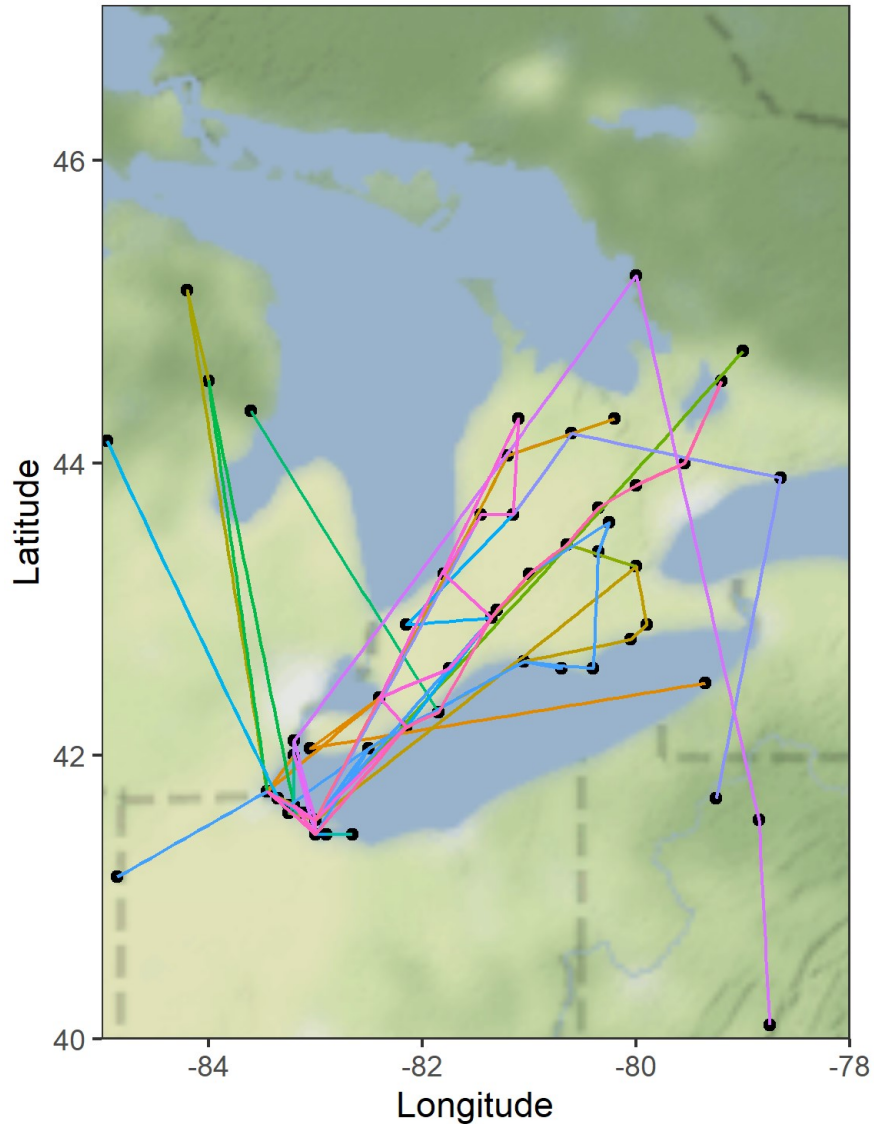


Figure 1.8. Detections of Virginia rails fitted with pulse-coded VHF radio transmitters at Motus Wildlife Tracking System automated telemetry towers within the Great Lakes region, USA during April – October in 2018 and 2019. Colored lines represent straight-line movements between telemetry towers (black dots) where individual Virginia rails were detected.

## Departure Probability

*Rail traits, time, wetland management, and weather condition effects, 2016 – 2019*

I applied extended Cox proportional hazards (CPH) survival analysis methods to model probabilities of departure for adult Virginia rails and soras that were captured and fitted with frequency-coded VHF radio transmitters and pulse-coded VHF radio transmitters at WPM ( $n = 406$ ). Final extended CPH models were determined for the pre-nesting, nesting, and post-breeding stages with the 4-year dataset. The cut-off dates for extended CPH models in each stage were 21 May for the pre-nesting stage, 15 July for the nesting stage, and the field season end dates (i.e. 30 September 2016, 28 September 2017, 28 August 2018, and 30 August 2019) for the post-breeding stage.

The highest-ranked extended CPH models predicting probability of departure for radio-marked rails in the 4-year dataset included different sets of predictors for each stage. Wetland unit grade and year were highly correlated with management type and capture date, respectively, so these variables were excluded from the highest-ranked pre-nesting and post-breeding models. The proportional hazards assumption with  $\alpha > 0.01$  was not violated in the final pre-nesting ( $P = 0.028$ ) and post-breeding ( $P = 0.330$ ) models but was violated in the nesting model ( $P = 0.005$ ) due to capture date. This means the hazard ratios cannot be interpreted as constant estimates but as estimates of the hazard on average during the nesting stage so the 95% confidence intervals are not valid (Stensrud and Hernán 2020).

The final pre-nesting model predicting probability of departure (likelihood ratio test = 66.6,  $df = 7$ ,  $P \leq 0.001$ ,  $n_{events} = 204$ ) included species, management type, capture

date, atmospheric pressure, wind direction change, wind speed, and the interaction between wind direction change and wind speed (Table 1.2). Virginia rails and lower atmospheric pressure were associated with lower probability of departure while hemi-marsh management and later capture dates were associated with higher probability of departure (hazard ratio ( $HR_{\text{species}}$ ) = 0.59, 95% CI = 0.44, 0.81;  $HR_{\text{pressure}}$  = 0.37, 95% CI = 0.15, 0.92;  $HR_{\text{management}}$  = 1.77, 95% CI = 1.08, 2.89;  $HR_{\text{capture date}}$  = 1.03, 95% CI = 1.02, 1.05). The interaction between wind direction change and wind speed showed northward shifts in wind direction and higher wind speeds also were associated with higher probability of departure ( $HR_{\text{wind direction change}}$  = 0.62, 95% CI = 0.43, 0.89;  $HR_{\text{wind speed}}$  = 0.94, 95% CI = 0.90, 0.98;  $HR_{\text{interaction}}$  = 1.05, 95% CI = 1.00, 1.10). Cumulative pre-nesting departure probability increased linearly for 15 days approaching 0.50 probability. The departure curve slowly increased thereafter over the next 25 days before leveling off slightly below 1.00 (Figure 1.9A).

Table 1.2. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the pre-nesting stage in 2016 – 2019. The number of parameters ( $K$ ), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding pre-nesting sub-models during 2016 – 2019.

Pre-nesting models	$K$	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
~ species + grade*management + capture date*year + wind direction change*wind speed + pressure	11	-911.74	1846.86	0.00	0.41
~ species + grade*management + capture date*year + wind direction change*wind speed	10	-913.21	1847.56	0.70	0.29
~ species*condition + grade*management + capture date*year + wind direction change*wind speed + pressure	13	-910.64	1849.20	2.33	0.13
~ species + grade*management + capture date*year + wind direction change + wind speed	9	-915.48	1849.88	3.02	0.09
~ species*sex*condition + grade*management + capture date*year + wind direction change*wind speed + pressure	17	-906.34	1849.98	3.12	0.09
null	0	-959.91	1919.81	72.95	0.00

The final nesting stage model predicting likelihood of departure (likelihood ratio test = 36.27,  $df = 5$ ,  $P \leq 0.001$ ,  $n_{events} = 152$ ) included capture date, wind speed, atmospheric pressure, humidity, and visibility (Table 1.3). Lower wind speeds, atmospheric pressure, and humidity were associated with lower probability of departure while later capture dates and greater visibility were associated with higher probability of departure ( $HR_{wind\ speed} = 0.91$ , 95% CI = 0.86, 0.97;  $HR_{pressure} = 0.14$ , 95% CI = 0.04, 0.54;  $HR_{humidity} = 0.98$ , 95% CI = 0.97, 1.00;  $HR_{capture\ date} = 1.01$ , 95% CI = 1.01, 1.02;

$HR_{\text{visibility}} = 1.27$ , 95% CI = 0.95, 1.70). The nesting stage departure curve showed large increases in cumulative departure probability each day through day 45 of the field season after which the curve leveled off around 0.90 for approximately 20 days but never reached 1.00 (Figure 1.9B).

Table 1.3. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the nesting stage in 2016 – 2019. The number of parameters ( $K$ ), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding nesting sub-models during 2016 – 2019.

Nesting models	$K$	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
~ capture date + wind speed + pressure + humidity + visibility	5	-651.05	1312.50	0.00	0.41
~ sex + capture date + wind speed + pressure + humidity + visibility	6	-650.43	1313.44	0.94	0.26
~ capture date + wind speed + pressure + humidity	4	-652.71	1313.70	1.20	0.22
~ sex + management + capture date + wind speed + pressure + humidity + visibility	7	-650.15	1315.08	2.58	0.11
null	0	-669.18	1338.37	25.86	0.00

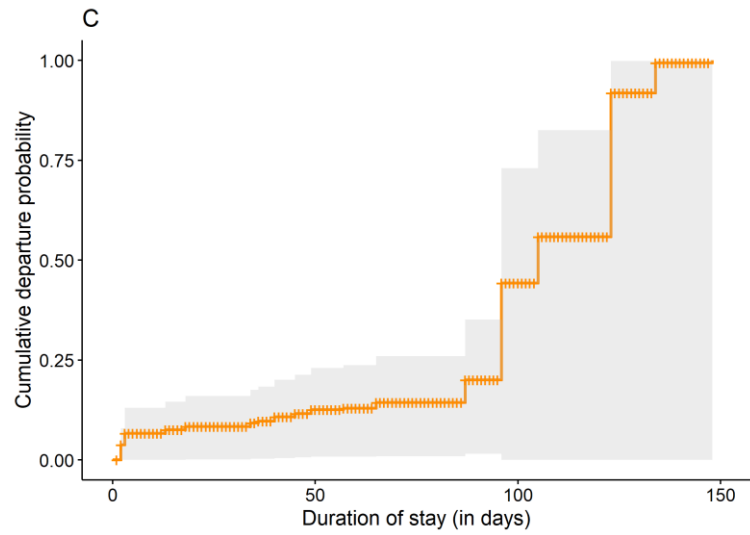
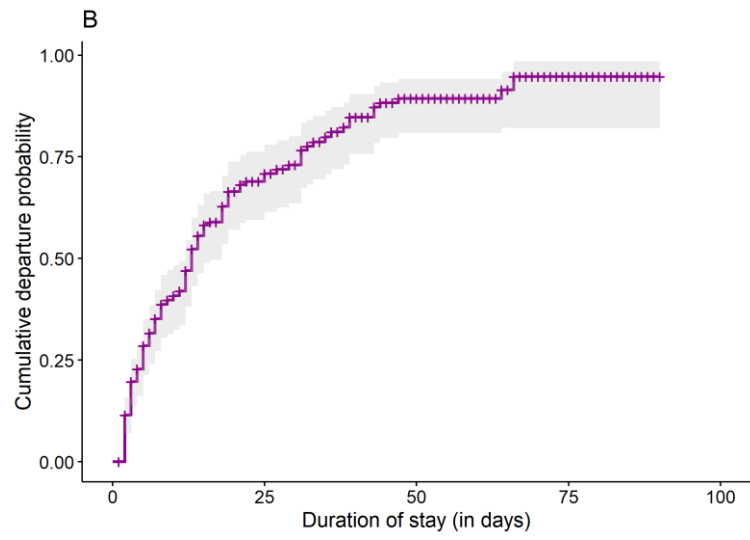
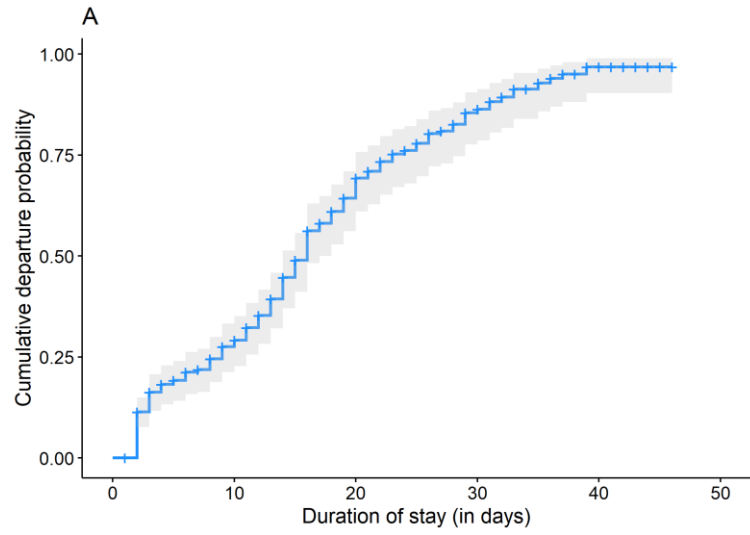
Management type, capture date, and visibility were the only predictors in the post-breeding model in 2016 – 2019 (likelihood ratio test = 29.15,  $df = 3$ ,  $P \leq 0.001$ ,  $n_{\text{events}} = 25$ ; Table 1.4). Hemi-marsh management and lower visibility were associated with lower departure probability and later capture dates had higher probability of departure ( $HR_{\text{management}} = 0.65$ , 95% CI = 0.26, 1.65;  $HR_{\text{visibility}} = 0.57$ , 95% CI = 0.42,

0.77;  $HR_{\text{capture date}} = 1.05$ , 95% CI = 1.02, 1.08). Post-breeding cumulative departure probability was  $<0.20$  during the first 90 days of the field season and then increased in large increments each day or two for 10-20 days until reaching 1.00 at about 135 days (Figure 1.9C).

Table 1.4. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the post-breeding stage in 2016 – 2019. The number of parameters ( $K$ ), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding post-breeding sub-models during 2016 – 2019.

Post-breeding models	$K$	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
~ grade*management + capture date + visibility	5	-58.57	130.30	0.00	0.79
~ species + grade*management + capture date + visibility	6	-58.35	133.37	3.07	0.17
~ species + condition + grade*management + capture date + visibility	7	-58.22	137.03	6.74	0.03
~ grade*management + visibility	4	-64.11	138.22	7.93	0.01
~ species + condition + grade*management + capture date + pressure + visibility	8	-58.21	141.41	11.12	0.00
null	0	-78.90	157.80	27.51	0.00

Figure 1.9. Daily probabilities of departure for frequency-coded and pulse-coded Virginia rails and soras that were present during pre-nesting (A), nesting (B), and post-breeding (C) stages as predicted by extended Cox proportional hazards models. A departure event was defined as when a radio-marked rail departed Winous Point Marsh, Ottawa County, Ohio, USA for the first time after capture during 2016 – 2019. Shaded areas represent 95% confidence intervals.



### *Water level effects, 2018 – 2019*

I applied extended Cox proportional hazards (CPH) survival analysis methods to analyze departure dates of adult radio-marked Virginia rails and soras ( $n = 243$ ) using the 2-year dataset with additional water level variables. Final extended CPH models were determined for the pre-nesting, nesting, and post-breeding stages. The cut-off dates for extended CPH models in each stage were 21 May for the pre-nesting stage, 15 July for the nesting stage, and the field season end dates (i.e. 28 August 2018, and 30 August 2019) for the post-breeding stage.

Models applied to the 2-year dataset specifically included water level variables but only the highest-ranked pre-nesting model included a variable related to water level. Management type was limited to hemi-marsh management in 2018. Management type and water level were highly correlated in the top pre-nesting model, but water level was eliminated when model comparisons ranked the management type model with a higher AIC<sub>c</sub> score. The proportional hazards assumption was not violated in the final pre-nesting ( $P = 0.193$ ), nesting ( $P = 0.460$ ), or post-breeding ( $P = 0.970$ ) models.

The final pre-nesting model predicted the likelihood of departure (likelihood ratio test = 73.92,  $df = 8$ ,  $P \leq 0.001$ ,  $n_{\text{events}} = 141$ ) with species, water level change, management, capture date, year, atmospheric pressure, wind direction change, and precipitation as variables (Table 1.5). Virginia rails, declining water levels, year, lower atmospheric pressure and amounts of precipitation, and southward shifts in wind direction were associated with lower probability of departure ( $HR_{\text{species}} = 0.63$ , 95% CI = 0.43, 0.91;  $HR_{\text{water level change}} = 0.81$ , 95% CI = 0.63, 1.05;  $HR_{\text{year}} = 0.52$ , 95% CI = 0.35,

0.77;  $HR_{\text{pressure}} = 0.42$ , 95% CI = 0.12, 1.46;  $HR_{\text{precipitation}} = 0.12$ , 95% CI = 0.01, 1.08;  $HR_{\text{wind direction change}} = 0.82$ , 95% CI = 0.67, 1.02). Hemi-marsh management and later capture dates were associated with higher probability of departure ( $HR_{\text{management}} = 1.48$ , 95% CI = 0.62, 3.53;  $HR_{\text{capture date}} = 1.07$ , 95% CI = 1.04, 1.09). The pre-nesting cumulative departure probability increased linearly and reached approximately 0.50 after 15 days. Thereafter, cumulative departure probability increased slowly over the next 30 days of the field season before leveling off slightly below the maximum of 1.00 (Figure 1.10A).

Table 1.5. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the pre-nesting stage in 2018 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding pre-nesting sub-models during 2018 – 2019.

Pre-nesting models	K	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
~ species + water level + water level change + management + capture date + year + pressure + wind direction change + precipitation	9	-544.28	1107.94	0.00	0.20
~ species + water level + management + capture date + year + wind direction change + precipitation	7	-546.58	1108.00	0.06	0.20
~ species + water level + management + capture date + year + pressure + wind direction change + precipitation	8	-545.58	1108.24	0.30	0.17
~ species + water level*water level change + management + capture date + year + pressure + wind direction change + precipitation	10	-543.43	1108.55	0.60	0.15

Continued

Table 1.5. Continued

~ species + water level + management + capture date + year + precipitation	6	-548.15	1108.93	0.99	0.12
~ species + water level*water level change + management + capture date + year + pressure + wind direction change + precipitation + cloud cover change	11	-542.68	1109.40	1.46	0.10
~ species + water level*water level change + management + capture date + year + wind speed*pressure + wind direction change + precipitation + visibility*cloud cover change	15	-538.80	1111.45	3.51	0.04
~ species + water level*water level change + management + capture date + year + pressure + wind direction change + precipitation + visibility*cloud cover change	13	-542.44	1113.75	5.80	0.01
~ species + water level*water level change + management + capture date + year + wind speed*pressure + wind direction change + precipitation + temperature change + visibility*cloud cover change	16	-538.76	1113.90	5.95	0.01
null	0	-584.15	1168.30	60.35	0.00

Capture date and wind direction change were the only predictors for the final nesting stage model of predicted departure probability (likelihood ratio test = 19.52, df = 2,  $P \leq 0.001$ ,  $n_{\text{events}} = 75$ ) (Table 1.6). Later capture dates had a higher probability of departure and southerly shifts in wind direction were associated with lower probability of departure ( $HR_{\text{capture date}} = 1.02$ , 95% CI = 1.01, 1.03;  $HR_{\text{wind direction change}} = 0.67$ , 95% CI = 0.52, 0.87). The nesting stage cumulative departure curve increased quickly during the first 8 days of the field season reaching 0.50 probability after 15 days then continued to increase during the next 30 days before leveling off at ~0.90 (Figure 1.10B).

Table 1.6. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the nesting stage in 2018 – 2019. The number of parameters ( $K$ ), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding nesting sub-models during 2018 – 2019.

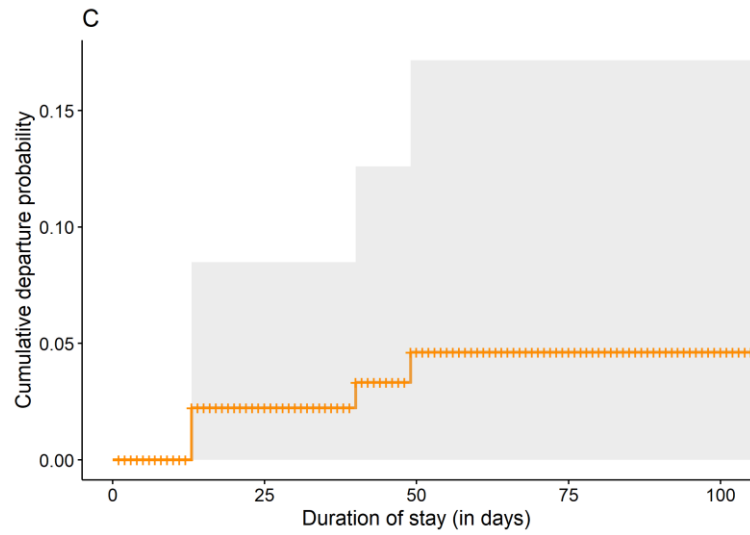
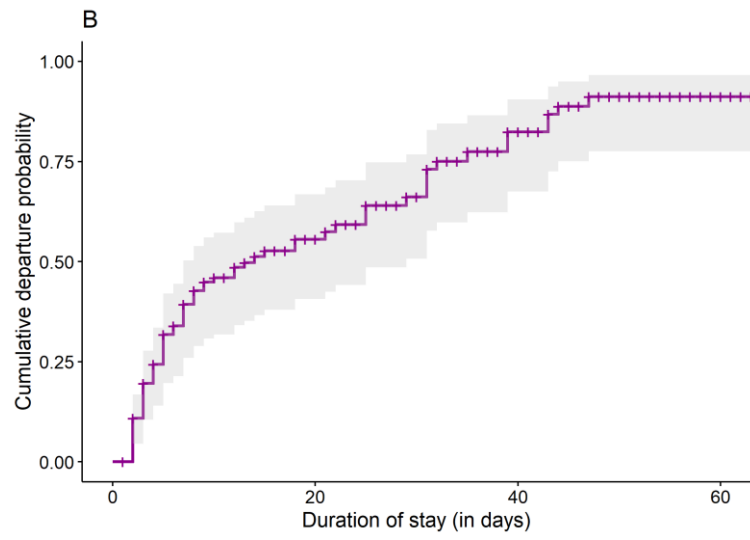
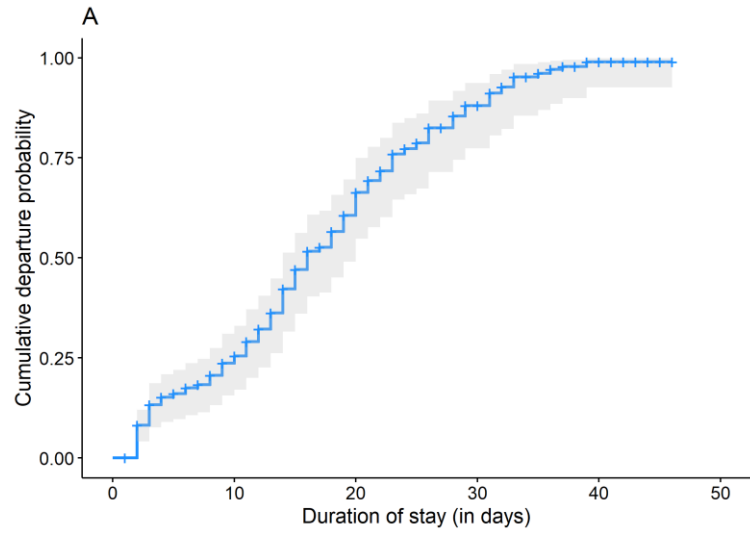
Nesting models	$K$	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
capture date + wind direction change	2	-259.05	522.27	0.00	0.37
management + capture date + wind direction change + visibility	4	-257.15	522.88	0.60	0.27
management + capture date + wind direction change	3	-258.36	523.06	0.79	0.25
management*water level + capture date + wind direction change + visibility	6	-255.89	525.01	2.73	0.09
capture date	1	-263.88	529.82	7.54	0.01
null	0	-268.82	537.63	15.36	0.00

The final post-breeding model of departure probability during the post-breeding stage included wind direction change, wind speed, and their interaction (likelihood ratio test = 4.46,  $df = 3$ ,  $P = 0.2$ ,  $n_{events} = 3$ ) (Table 1.7). The interaction between wind direction change and wind speed showed southerly wind shifts and higher wind speeds were associated with lower probability of departure ( $HR_{wind\ direction\ change} = 6.99$ , 95% CI = 0.10, 472.93;  $HR_{wind\ speed} = 0.74$ , 95% CI = 0.34, 1.60;  $HR_{interaction} = 0.52$ , 95% CI = 0.20, 1.32). Post-breeding cumulative departure probability remained at 0.00 for the first 13 days, increased twice for extended periods of time during the field season before increasing and leveling off slightly below 0.05 until the end of the stage (Figure 1.10C)

Table 1.7. Ranking of extended Cox proportional hazards models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the post-breeding stage in 2018 – 2019. The number of parameters ( $K$ ), Log-Likelihood score, corrected Akaike Information Criterion ( $AIC_c$ ), the difference in  $AIC_c$  from the lowest  $AIC_c$  of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model. See Appendix A for all corresponding post-breeding sub-models during 2018 – 2019.

Post-breeding models	$K$	Log-likelihood	$AIC_c$	$\Delta AIC_i$	$w_i$
~ wind direction change*wind speed	3	-5.51	-6.97	0.00	0.92
~ water level change + wind direction change*wind speed	4	-5.50	-1.00	5.97	0.05
~ water level change + year + wind direction change*wind speed	5	-5.50	1.00	7.97	0.02
~ water level*water level change + year + wind direction change*wind speed	7	-5.46	2.52	9.49	0.01
~ water level*water level change + capture date*year + wind direction change*wind speed	9	-5.40	3.08	10.05	0.01
null	0	-7.75	15.49	22.46	0.00
~ wind direction change	1	-6.69	19.39	26.36	0.00

Figure 1.10. Daily probabilities of departure for frequency-coded and pulse-coded Virginia rails and soras that were present during pre-nesting (A), nesting (B), and post-breeding (C) stages as predicted by extended Cox proportional hazards models. A departure event was defined as when a radio-marked rail departed Winous Point Marsh, Ottawa County, Ohio, USA for the first time after capture during 2018 – 2019. Shaded areas represent 95% confidence intervals.



## **DISCUSSION**

There was a consistent pattern of departures across all 4 years during the time when Virginia rails and soras should have been breeding. After the high number of departures during 2016 – 2017 and intensive ground and aerial search efforts led to few individuals being found, I sought to confirm that rails were indeed moving beyond the western basin and not going undetected because of failed transmitters or mortality. Detections of Virginia rails by the Motus Wildlife Tracking System, confirmed that departing Virginia rails continued north to Michigan and southern Ontario before and during the nesting season. Pulse-coded VHF radio transmitters were purposefully only attached to Virginia rails because there was evidence that Virginia rails nested in the area during 2016 – 2017 but sora did not, so I presumed that soras moved beyond the western basin to breed. Confirming the high number of departures led to implications for population monitoring due to the lack of population closure during the Standardized North American Marsh Bird Monitoring Protocol survey windows. While a majority of rails used WPM as migratory stopover, others dispersed to surrounding wetland complexes for varying lengths of time and some stayed at WPM after capture and attempted to breed.

### **Breeding Chronology**

The date ranges that I observed for stages of the breeding season aligned with dates from published literature on the timing of arrivals and departures of rails in northern Ohio (Bent 1926, Campbell 1968, Andrews 1973, Fournier et al. 2015). Virginia rails were present throughout the pre-nesting and nesting stages and into the post-breeding

stage, while soras moved through the area before Virginia rails began nesting and reappeared after nesting. Andrews (1973) and Campbell (1968) similarly remarked that movement of soras through the western Lake Erie basin in spring was followed by few soras after May. The timing of the different stages, therefore, does not necessarily apply to soras as the entirety of the nesting evidence was based on Virginia rails. Historically, Virginia rails appeared to be present throughout the summer months as well; however, no Virginia rails were seen after 19 July 1971 despite later departure dates previously observed in fall (Campbell 1968, Andrews 1973).

Establishing the precise timing of nesting was limited by the small number of nests found during this study. The apparent lack of soras at WPM during the nesting season and no observations of sora nests suggests that soras are an uncommon breeder in the coastal marshes of northwest Ohio. Andrews (1973) found limited evidence of nesting soras and noted the scarcity of soras at WPM during summer as well. The only evidence of nesting during 2016 – 2019 was by Virginia rails with 9 nesting records, fledged young from only 2 of those nests, and 3 captures of hatch-year birds. The number of failed nests indicates Virginia rail nesting success may be low which could account for the low proportion of nesting birds as many nesting attempts were likely undetected. High probabilities of departure during the pre-nesting and nesting stages and limited evidence of nesting suggests that while there are large number of rails that move through the western Lake Erie marshes during pre-nesting stage, most rails do not use the area for nesting.

The obvious difference in numbers of radio-marked rails present during pre-nesting and nesting is problematic considering the current timing of the ODW secretive marsh bird survey windows. These surveys are timed to occur during peak breeding season (Conway 2011); however, the first two survey windows overlapped with pre-nesting when there were high departure rates. The First Ohio Breeding Bird Atlas similarly noted that Virginia rail vocalizations during 20 April – 20 May could be from either migrant or resident birds and, therefore, were not included in the Atlas project data (Peterjohn and Rice 1991). The extensive overlap in the timing of the pre-nesting and nesting stages strongly indicates that surveyed populations in Lake Erie coastal marsh complexes are not closed, a violation of a central assumption of estimating occupancy and abundance (Royle 2004, Dénes et al. 2015). Emerging methods that use *N*-mixture models assume the sampled population is closed to immigration, emigration, births, and deaths during the survey period and biased population estimates could result if the assumption is violated (Royle 2004, Dénes et al. 2015). Thus, estimates of occupancy and abundance of breeding rails are likely to be over-estimated particularly for soras which move through northwest Ohio and breed farther north.

### **Departure Probability**

High departure rates were seen throughout the pre-nesting and nesting stages resulting in few rails within the area until the start of the post-breeding stage. Departure behavior of frequency-coded and pulse-coded rails appeared to be affected by several covariates that varied among pre-nesting, nesting, and post-breeding stages. Water levels did not appear to directly influence departure probabilities in 2018 and 2019 as only the

pre-nesting model included a water level variable. Other environmental conditions including wind direction and speed did not have consistent effects on rail departure probability; however, tailwind, a value determined partially by wind direction and speed, has been important in departure probability for other migratory bird species (Dossman et al. 2016, Wright et al. 2018). Rail body condition was not an important variable in the CPH models; however, body condition has been associated with probability of departure in other species (Wright et al. 2018). Further research into environmental and body conditions of rails pre- and post-crossing is needed to assess the role of impounded coastal wetlands within the southwestern shores of Lake Erie on rail northerly migration.

The pre-nesting CPH curves for the 4-year and 2-year datasets showed a dramatic increase in departure probability within short periods of time. This pattern appears consistent with continued arrival and northerly spring migration movements during the approximate 2-month long pre-nesting stage. The continued high rate of rail departures during nesting could be attributed to the overlap of peak pre-nesting and nesting activity but also to failed nesting attempts after which those rails departed the area.

The post-breeding CPH curve for the 4-year dataset visually portrayed a movement pattern consistent with rails remaining at WPM after attempting to breed. This movement pattern was more true for Virginia rails as soras were largely absent after pre-nesting but reappeared during post-breeding before leaving again during fall migration. Onset of fall migration is likely the driving cause in the rise of departure probability through the later period of post-breeding. The post-breeding model for the 2-year dataset did not significantly predict the likelihood of departure and had wide

confidence intervals because I was likely pushing the limitations of the model due to a limited sample size with only three departure events occurring.

### **Regional Movements and Migration**

The high numbers of departures from WPM during pre-nesting and nesting without subsequent detections or relocation within the surrounding area for a brief period reveal that most rails only used WPM and the surrounding area as a migratory stopover in spring and summer. Rails are generally considered weak flyers so the extent of open water Lake Erie presents might necessitate stopping to refuel before crossing or migrating around the lake.

Post-breeding detections in Illinois, Pennsylvania, North Carolina, South Carolina, Georgia, and Florida suggested several potential migratory routes both within and across the Mississippi and Atlantic Flyways. Detections in Illinois likely follow a Mississippi Flyway route while the detections in other states suggest cross-flyway routes and wintering areas within the Atlantic Flyway. Wintering areas near the northern Atlantic coast and on the southern Atlantic coast are possible based on detections in Pennsylvania and detections in the Carolinas, Georgia, and Florida, respectively. It should be noted that the quality of Motus detection data is only as good as the location and number of automated telemetry towers; therefore, areas with more telemetry towers will likely detect more individuals than a sparsely covered landscape. While the telemetry tower infrastructure was already in place around the western basin of Lake Erie and farther north in Michigan and Canada, there were fewer telemetry towers within the

Mississippi Flyway south of Ohio in comparison to within the Atlantic Flyway coastal region during 2018 – 2019.

In addition to movements beyond the western Lake Erie basin, the pulse-coded data revealed other previously unknown local movement patterns. The nocturnal forays that were witnessed would not have been possible without the use of the automated radio telemetry towers. These nightly movements suggest rails might inspect other locations before making long-term movements.

Evidence that WPM and the surrounding marshes are used as fall migration stopover areas was found with a few radio-marked rails that departed during pre-nesting or nesting stages and then reappeared during the post-breeding stage. Consistent with these observations, there was a noticeable decrease in rail captures during the nesting stage each year followed by an increase in July. Virginia rails and soras are known to concentrate in larger wetlands in late summer and early fall before migration (Bent 1926, Pospichal and Marshall 1954, Giese et al. 1980). Fall pre-migratory concentrations are thought to result from decreasing water levels at smaller breeding wetlands and high abundance of food at larger wetlands (Bent 1926, Pospichal and Marshall 1954, Giese et al. 1980).

### **Local Movements and Home Ranges**

Some rails remained within the western Lake Erie basin for varying periods of time (1 day up to ~5 months). A few rails were relocated at surrounding wetland complexes for extended periods (1 day up to ~4 months) after dispersing from their capture sites during pre-nesting and nesting. While the off-site relocations varied in

length from a few days to several months, 3 rails established 3 home ranges and one successfully fledged a nest at Ottawa NWR suggesting that some Virginia rails stopover at WPM then disperse to nest elsewhere in the Lake Erie coastal marsh region. Some rails stayed at WPM after capture, established home ranges, and attempted to nest and remained through the post-breeding stage.

Mean home range sizes of Virginia rails and soras were smaller than reported home range sizes of king rails (Pickens and King 2013, Kolts and McRae 2017) but comparable to clapper rails (*Rallus crepitans*) (Rush et al. 2010). Smaller rail species (i.e. Virginia rails and soras) may, therefore, require less space and have more centralized movements within established areas than larger rail species (i.e. king rails). Clapper rails in saltmarshes along the Gulf Coast have smaller home ranges in areas associated with greater densities of fiddler crabs (*Uca* spp.), a main food source, during the breeding season (Rush et al. 2010). The small home range sizes observed for Virginia rails in particular due to the presence of breeding individuals could be associated with areas with higher quantities of food sources. The small size of the home ranges also fit within one wetland unit. Future examination of rail home range sizes and locations in response to changing water levels and vegetation structure and cover within an impounded unit is therefore possible. Overlapping home ranges were not uncommon, suggesting absence of interspecific and intraspecific territoriality. This was similarly seen in a study of breeding Virginia rails and soras in Colorado (Glahn 1974).

## **Conclusions**

Determining the seasonal movements of Virginia rails and soras is important for the monitoring efforts and habitat management performed by wildlife agencies. Presence of breeding Virginia rails and soras in northwest Ohio was largely based on limited historical data that was mostly anecdotal; however two comprehensive surveys were conducted during the first and second Ohio breeding bird atlases during 1982-1987 and 2006-2011 (Peterjohn and Rice 1991, Rodewald et al. 2016). My study showed limited breeding was occurring in the area with few records of breeding Virginia rails and none of soras. Almost all attempts at breeding by Virginia rails resulted in failure with several breeders leaving the area after failing.

Annual secretive marsh bird surveys completed by ODW currently estimate marsh bird occupancy and abundance during the breeding season, but the timing of those surveys mostly overlapped with migratory movements of rails through the area and not entirely of breeding rails. The lack of population closure during the survey period violates statistical assumptions of methods used to estimate occupancy and abundance and results in bias estimates. It would be advisable for ODW to consider shifting the timing of their survey windows to begin in early June so as to capture as many breeding rails as possible and not migrant individuals and to increase the accuracy of rail population estimates in Ohio.

The large movement of rails through the area in the spring and fall and the apparent lack of breeding rails indicts habitat management during the spring and fall could be equally as important for migrating rails as it is believed to be for breeding rails.

The pattern of rail departures could be part of normal rail behavior with spring and fall migrants, non-nesting and failed nesting individuals, and post-fledging dispersals. The high number of rail departures might also be associated with lack of quality wetland habitat within the area which forces Virginia rails and soras to continue north for more suitable nesting habitat. Investigations of microhabitat selection of Virginia rails and soras is needed to determine if managed wetlands to produce food and cover for waterfowl is beneficial for migrating and breeding rails.

## Chapter 2. Microhabitat Selection of Virginia Rails and Soras within Impounded Coastal Wetlands of Northwest Ohio

### INTRODUCTION

Across North America 57% of Rallidae species are in decline (Rosenberg et al. 2019). A dependence on wetlands combined with extensive wetland loss has been attributed to this decline of rail populations across the United States (Eddleman et al. 1988, Conway et al. 1994, Lor and Malecki 2002). The Midwest is among the areas with the greatest percentage loss of wetlands (Tiner, Jr. 1984). Gottgens et al. (1998) reported that less than five percent of the original western Lake Erie basin marshes remain. Additionally, the remaining wetlands are mostly impounded and managed for waterfowl through the manipulation of water levels. While managed wetlands are vital habitat for rails in northwest Ohio, it is not well understood if wetlands managed for waterfowl create suitable habitat for migrating and breeding rails.

Information on the habitat requirements of each species throughout their ranges is necessary to make habitat management recommendations that would benefit rails (Bolenbaugh et al. 2011). Virginia rails (*Rallus limicola*) and soras (*Porzana carolina*) are two North American rail species that migrate through and breed in northern Ohio (Rodewald et al. 2016, Conway 2020, Melvin and Gibbs 2020). Threatened by habitat loss and population decline, Virginia rails and soras are listed as species of concern in Ohio. The loss of wetland habitat could be the main contributing factor to uncertainties in rail populations in Ohio emphasizing the need to better understand habitat selection by rails.

Wetland habitat selection by rails is thought to be influenced by a combination of water level fluctuations, vegetation structure, and vegetation species composition. Water depths and hydrologic regime directly influence vegetation species composition and abundance, which in turn influences food availability and nesting, thermal, or escape cover for marsh birds (Murkin et al. 1997). Wetlands with lower water levels might, for example, have fewer fish which could result in higher invertebrate abundance (Baschuk et al. 2012). Rails also have a tendency to nest in emergent vegetation above or adjacent to standing water which may lead to flooding but help with predator deterrence (Darrah and Krementz 2009). Despite the perceived importance of water depths, past studies have found differing results on the influence of water depths on the presence of marsh birds (Johnson and Dinsmore 1986b, Darrah and Krementz 2009, Baschuk et al. 2012, Pickens and King 2013, 2014, Kolts and McRae 2017).

Wetland vegetation structure may also be more important than vegetation species composition since species composition can vary across the range of a marsh bird (Rundle and Fredrickson 1981, Darrah and Krementz 2009). A wetland with diverse stands of emergent vegetation and wetland seed producers as well as a moderate level of interspersed vegetation cover to water might be the ideal habitat characteristics for Virginia rails and soras (Johnson and Dinsmore 1986b, Conway 2020). Conversely, woody vegetation has been shown to have a negative effect on the presence of rails (Darrah and Krementz 2009, Bolenbaugh et al. 2011).

Virginia rails and soras are known to inhabit the impounded coastal wetlands of northern Ohio during the spring, summer, and fall (Bent 1926, Campbell 1968, Andrews 1973, Fournier et al. 2015). At Winous Point Marsh in northwest Ohio, 81% of radio-marked Virginia rails and soras ( $n = 440$ ) used only the wetland unit they were captured in (Chapter 1). Furthermore, estimated home ranges of radio-marked rails were mostly centralized within one wetland unit

(Chapter 1). This extensive use of one wetland unit allowed me to examine rail movement patterns in response to changing water levels and vegetation structure and cover. Previous marsh bird studies focused on overall use of vegetation cover types within study areas (Benoit and Askins 2002, Bolenbaugh et al. 2011, Baschuk et al. 2012) at specific times during the breeding season (Johnson and Dinsmore 1986*b*, Bolenbaugh et al. 2011, Willard 2011, Harms and Dinsmore 2013, Alexander and Hepp 2014). I focused mostly on microhabitat characteristics including water depths, vegetation cover, and distances to open water and cover type edges, along with abundance and interspersed of key cover types throughout pre-nesting, nesting, and post-breeding seasons. By expanding the measurement types and sampling period, my research could provide clarity to the habitat use patterns of Virginia rails and soras.

The goal of this study was to describe and distinguish microhabitat characteristics of sites used by Virginia rails and soras in impounded wetlands managed principally to provide waterfowl habitat and hunting opportunity. Impounded coastal wetlands in the western Lake Erie basin are often managed by manipulating water levels to promote growth of native plants to provide food and cover for fall migrating waterfowl. Managers often assume that managing vegetation to attract waterfowl will also benefit other marsh birds that use the same general cover types as ducks. I hypothesized that Virginia rails and soras would exhibit different patterns of selection within dense stands of emergent vegetation interspersed with open water or other vegetation cover types. I further hypothesized that the hydrology of sites used by rails would differ from the general hydrology of the impoundments they inhabited. Therefore, the objectives of my study were to 1) evaluate the effects of fluctuating water depths on rail movements, and 2) compare cover type use and microhabitat characteristics between Virginia rails and soras during spring and summer. Microhabitat characteristics measured at known locations of radio-marked

rails will allow for comparisons of water and vegetation measurements at rail locations and available wetland habitat, thereby revealing wetland habitat characteristics that Virginia rails and soras select for and providing more detailed information on the habitat requirements of these rail species.

## **STUDY AREA**

I conducted research during 2018 – 2019 at a coastal wetland site located within the western Lake Erie basin in northwest Ohio, USA. My research site was Winous Point Marsh (WPM), Ottawa and Sandusky Counties, Ohio, USA (41.461° N, 82.998° W; Figure 2.1). Winous Point Marsh was nearly 2,023 ha including 1,214 ha of managed coastal wetlands. Muddy Creek Bay separated the northern (Ottawa County) and southern (Sandusky County) marshes of WPM. My research mainly focused on managed marsh units north of Muddy Creek Bay (Figure 2.2) comprising 12 impounded wetland units that were separated by levees and equipped with staff gauges and water control structures for manipulation of water levels. Surrounding land uses were primarily traditional row crop fields and flooded agricultural fields managed for waterfowl hunting.

All wetland units were managed with varying degrees of intensity each year to manipulate water depths and subsequent vegetation growth and to control spread of invasive plant species. Hard drawdowns occurred in actively managed units to create moist-soil conditions, while passively managed units had minimal water manipulation that produced hemi-marsh (Weller and Spatcher 1965) conditions (B. T. Shirkey, Winous Point Marsh Conservancy, personal communication). The resulting vegetation community provided food, cover, and hunting opportunities for fall migrating waterfowl.

The wetland units consisted of a mosaic of open water and vegetated areas with most units having a channel of deep water between levees and the interior of the wetland unit. Areas

of standing water typically supported submergent aquatic vegetation (SAV) and floating-leaf vegetation. Common SAV included water milfoils (*Myriophyllum* spp.), coontail (*Ceratophyllum demersum*), and pondweeds (*Potamogeton* spp.). Duckweeds (*Lemna* spp.) were the most prevalent floating-leaf vegetation species. Woody vegetation was typically found along the dikes and infrequently the shallowest areas within wetland units. Shrubs and trees were mostly dogwoods (*Cornus* spp.), buttonbushes (*Cephalanthus occidentalis*), black willows (*Salix nigra*), eastern cottonwoods (*Populus deltoides*), and box elders (*Acer negundo*).

Emergent vegetation communities were interspersed throughout the wetland units and included persistent and non-persistent emergent macrophytes. Persistent emergent vegetation was dominated by narrowleaf (*Typha angustifolia*) and hybrid (*T. × glauca*) cattail, swamp rose mallow (*Hibiscus moscheutos*), and reed canary grass (*Phalaris arundinacea*). Giant bur-reed (*Sparganium eurycarpum*), purple loosestrife (*Lythrum salicaria*), swamp loosestrife (*Decodon verticillatus*), common reed (*Phragmites australis*), and small, scattered stands of broadleaf cattail (*T. latifolia*) were also present in wetland units. Non-persistent emergent species included broadleaf, sedge, rush, and grass species. Broadleaf arrowhead (*Sagittaria latifolia*), pickerelweed (*Pontederia cordata*), and smartweeds (*Polygonum* spp.) were the most common broadleaf species. Sedges, rushes, and grasses species included flowering rush (*Butomus umbellatus*), river bulrush (*Bolboschoenus fluviatilis*), softstem bulrush (*Schoenoplectus tabernaemontani*), common spikerush (*Eleocharis palustris*), and grasses (*Echinochloa* spp.). Narrowleaf and hybrid cattail, reed canary grass, purple loosestrife, common reed, and flowering rush were all non-native, invasive species.

Secondary research sites included wetland units across the Ottawa National Wildlife Refuge Complex, Ottawa and Lucas Counties, Ohio, USA (ONWRC; 41.607° N, 83.210° W;

Figure 2.1). The wetland units at ONWRC were separated by levees and equipped with water control structures for the manipulation of water levels similarly to WPM. The Ottawa NWRC had pockets of open water and vegetation dispersed throughout the units with similar vegetation species as WPM except for European frogbit (*Hydrocharis morsus-ranae*), an invasive floating-leaf species that was not present at WPM but abundant throughout the refuge. Secondary sites were also managed to produce suitable habitat for migrating and breeding waterfowl.

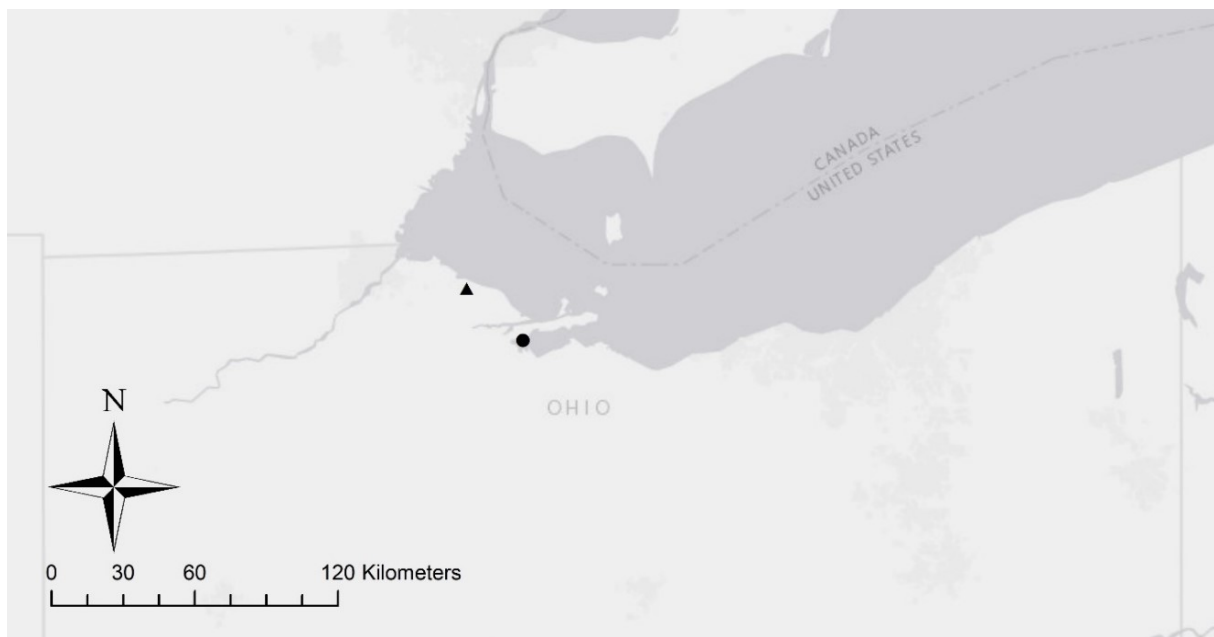


Figure 2.1. Location of Winous Point Marsh (circle) and Ottawa National Wildlife Refuge Complex (triangle), Ottawa, Sandusky, and Lucas Counties, Ohio, USA.

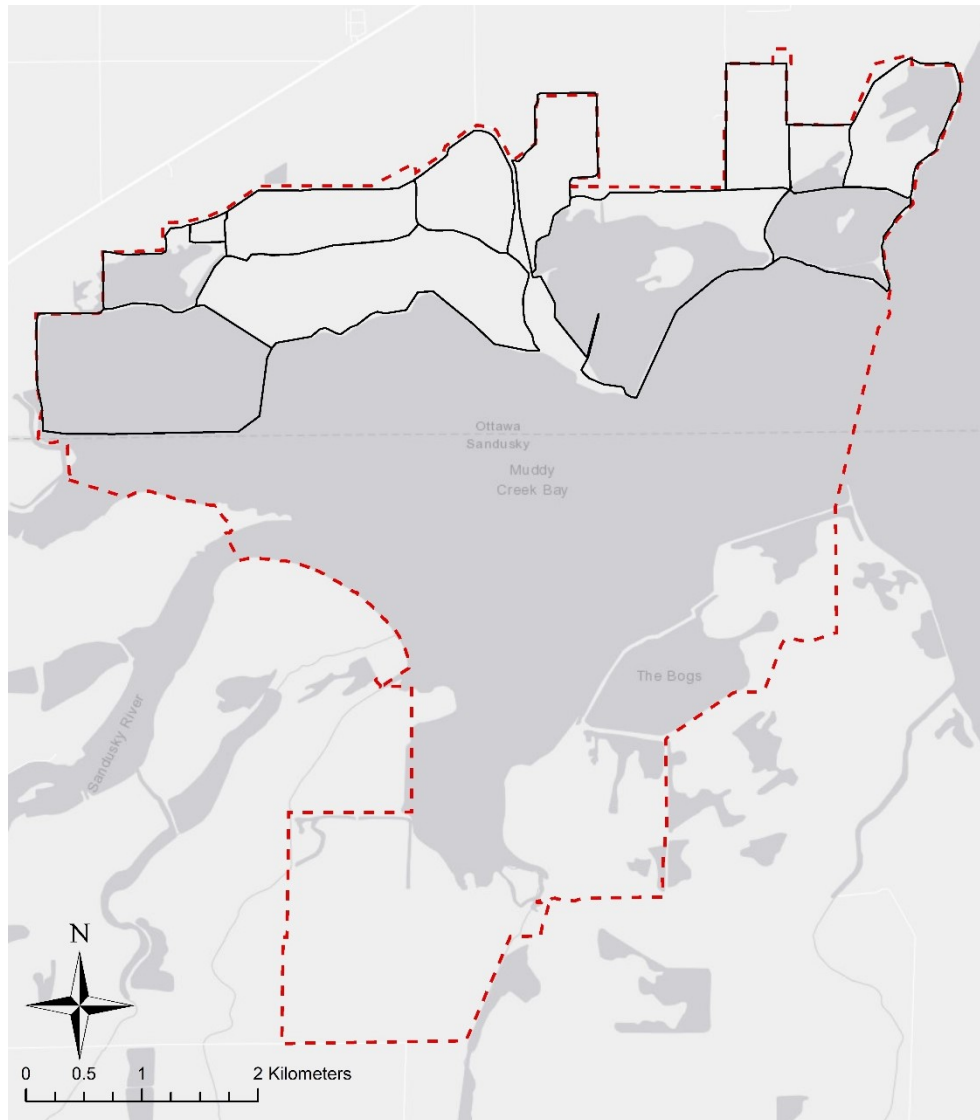


Figure 2.2. Boundary of Winous Point Marsh (red dashed line) in Ottawa and Sandusky Counties, Ohio, USA. The primary research sites are the 12 impounded wetland units outlined in black.

## METHODS

### Capture and Tracking

I captured Virginia rails and soras during late March through late July during 2018 – 2019 at WPM. I used walk-in funnel traps equipped with an audio lure of Virginia rail and sora vocalizations that continuously played from dusk to dawn 5 – 7 nights a week to capture rails

(Kearns et al. 1998, Fournier et al. 2015). I processed all captured rails following banding and handling techniques described in Chapter 1. I fitted captured Virginia rails (>60 g) with a frequency-coded VHF radio transmitter (model A1050, Advanced Telemetry Systems, Inc., Isanti, MN, USA) or a pulse-coded VHF radio transmitter (model NTQB2-6-1 and ANTCW-M6-1, Lotek Wireless Inc., Newmarket, Ontario, Canada) using a leg-loop harness (Rappole and Tipton 1991). I similarly fitted captured soras (>60 g) with a frequency-coded VHF radio transmitter. Tracking of radio-marked rails began one day after capture and continued until the signals were lost or the rail was found dead. I obtained locations of radio-marked rails determined by homing (White and Garrott 1990) each week to ascertain live/dead status and for conducting microhabitat assessments. In Chapter 1, I detailed additional tracking efforts. All capture, handling, and marking methods were approved by The Ohio State University Institutional Animal Care and Use Committee (2015A00000028-R1).

## **Microhabitat Measurements**

### *Water depths and distance to open water*

I located radio-marked Virginia rails and soras weekly during 1 April – 18 August 2018 and 14 April – 31 August 2019. I used a use-availability sampling design to compare microhabitat measurements between use-points where radio-marked Virginia rails and soras were located by homing (hereafter homing points) and availability-points located 25 m from homing points at randomly selected azimuths (hereafter random points). Using a GPS, I recorded homing points of radio-marked Virginia rails and soras. I measured water depth at the homing point and at 5 m in each of four cardinal directions and recorded nearest distance to open water from the homing point with a range finder or GPS unit. I defined open water as at least 1 m<sup>2</sup> of exposed surface water.

I established paired random points 25 m from the homing point at a randomly selected azimuth. I skipped azimuths that led me to an unsuitable location (e.g. channel surrounding a wetland unit, dike, another wetland unit). I marked the random point with a GPS unit and measured water depths and distance to open water using the same protocol as for homing points; 1 depth measurement at plot center and 4 depth measurements 5 m distant in 4 cardinal directions.

I also measured water depths from staff gauges purposively placed in accessible areas of wetland units used by radio-marked Virginia rails and soras. I recorded staff gauge readings in each unit 1 – 5 times per week (i.e. the same day water depths were recorded, after rain events, and whenever time allowed) during 13 April – 22 August 2018 and 15 April – 30 August 2019. I imputed missing daily staff gauge readings in each unit after smoothing with Generalized Additive Models (GAM) with the use of package ‘mgcv’ (Wood 2017) in program R (R Version 4.0.2, <https://www.R-project.org>, accessed 22 Jun 2020). The staff gauge locations did not represent a particular elevation of any unit in which they were placed. I only collected readings to measure daily changes in water depths in units where I tracked radio-marked rails.

#### *Vegetation cover, composition, and structure*

I navigated back to homing and random points to measure vegetation cover, structure, and distance to nearest habitat edge within one week after water depths and distance to open water were measured. Vegetation measurements included distance to edge, visual obstruction, percent cover by habitat class (Appendix B), and interspersions. I recorded distance to edge from homing and random points with a range finder or GPS. I defined edge as the nearest distance to where the cover type surrounding the waypoint changed to a different cover type.

I measured visual obstruction using a modified Robel pole placed at homing and random points. The modified Robel pole consisted of telescoping PVC pipes. The outer pole was 2 m in length and marked with alternating 10-cm colored sections numbered 1 – 20. I inserted the inner pole into the substrate to stabilize the outer pole whose height was adjusted with a hose clamp so that visual obstruction measurements were standardized to a baseline at the water surface. I recorded the last visible band on the outer pole at a distance of 5 m from the pole with my eye at 1 m height in the 4 cardinal directions (Robel et al. 1970, Uresk and Benzon 2007). If no bands of the pole were visible, I recorded a visual obstruction measurement of 21.

I recorded percent habitat cover from ocular estimates within a 10 m radius of homing and random points based on methods adapted from the U.S. Fish and Wildlife Service Integrated Waterbird Management and Monitoring program (Loges et al. 2014). I identified all vegetation to species, noted the presence of water and unvegetated (exposed mud) areas, and categorized everything into 1 of 5 habitat classes (Appendix B) including : 1) water, 2) bare ground, 3) emergent vegetation, 4) scrub-shrub, and 5) forest (Cowardin et al. 1979, Loges et al. 2014). The water habitat class included standing water, submerged aquatic vegetation (SAV), or floating-leaf vegetation. Bare ground was unvegetated soil with no surface water. Emergent persistent and non-persistent vegetation were included in the emergent habitat class. Scrub-shrub and forest habitat classes were shrubs and tree species, respectively. I then estimated the percent cover of each species and/or area type (i.e. water or unvegetated) so that percent cover estimates summed to 100% across all habitat classes (Loges et al. 2014).

I defined interspersed as the extent to which water and bare ground areas were present compared to vegetated areas within a 10-m radius survey plot surrounding the homing and random points (Loges et al. 2014). I considered vegetated areas as areas previously categorized

into emergent, scrub-shrub, and forest habitat classes. Potential interspersion classifications for a survey plot were high, low, or intermediate based on whether the water/bare ground patches were large and connected, small and disconnected, or somewhere in between, respectively (Suir et al. 2013, Loges et al. 2014). I calculated the total sum of percent water and bare ground patches. I categorized survey plots that summed to >60% water and bare ground as high interspersion (Suir et al. 2013, Loges et al. 2014). Survey plots with <60% water and bare ground, I determined large, medium, or small interspersion based on the observed size of water/bare ground patches dispersed throughout the survey plot.

I categorized all surveys into 1 of 12 cover types based on the survey plot's most abundant habitat class. Each habitat class had at least one cover type that specified a vegetation species or the presence of water/unvegetated areas (Appendix B). The highest percent cover recorded for a vegetation species or water/unvegetated area became the assigned cover type for the survey plot.

### **Data Summary**

I summarized water depths, nearest distances to open water and edge, visual obstruction measurements, and habitat cover percentages to prepare for statistical analyses. I averaged the 5 water depth measurements (center and 4 cardinal directions) from each homing and random point to create a single mean plot value. I also created an outer water depth by averaging the measurements from the 4 cardinal directions of each survey plot.

I combined percent cover for the scrub-shrub and forest habitat classes to create a percent wooded cover variable and converted all habitat cover percentages to proportions. Since I recorded visual obstruction measurements as the last visible band (i.e. 1 as 0% obstructed and 21 as 100% obstructed), I subtracted 1 from all raw visual obstruction measurements and divided by

20 to convert to proportions. I then averaged the 4 visual obstruction measurements (4 cardinal directions) to create a single mean plot visual obstruction proportion. I collapsed vegetation cover classes to their mid-point.

I was interested in comparing temporal patterns and magnitudes of change in daily water depths among wetland units, homing points, and random points. Consequently, I normalized (observed / (maximum – minimum)) water depth measurements separately by year, species, and measurement type (unit, homing, random). I also calculated variances from the raw plot water depths and plot visual obstruction measurements by year, species, and measurement type (homing and random only).

Water levels and vegetation cover and structure changed throughout the period over which I conducted multivariate analyses of microhabitat selection. Consequently, I calculated residuals for plot water depth, distance to open water, distance to edge, and plot visual obstruction by fitting third-degree polynomial regression models with independent variables Julian date and year for homing and random points. This had the effect of removing temporal trends in water levels, vegetation growth, and cover type development that occurred during April – August when microhabitat variables were measured. Thus, the multivariate analysis results represented overall selection for shallower versus deeper water levels and less versus more vegetation cover independent of temporal trends in water levels and vegetation cover development.

## **Statistical Analysis**

### *Water depths*

Transformations of raw water depth measurements require explanation with respect to the aims of my statistical analyses of water level changes at homing and random points relative to

daily changes in the wetland units inhabited by radio-marked Virginia rails and soras.

Normalizing water depth measurements removed the arbitrary main effect associated with purposive placement of staff gauges relative to the more meaningful water depths at homing and random points. Normalization of water depth measurements had two outcomes. First, the magnitudes of change at unit and homing and random points could be considered on comparable scales, regardless of differences in the range of variation caused by differences in raw water depths among unit, homing, and random measurement points. The normalized residual water depth values thus focused my analyses on temporal changes in water depths at homing and random points relative to daily variation in water levels in the impounded units they inhabited. Second, normalizing the residuals produced positive values that were more easily interpreted.

I hypothesized that if rails differentially selected water depths relative to the overall water depths in the wetland units they occupied, normalized water depths at homing points would differ ( $\alpha = 0.05$ ) and be more right-skewed than normalized water depths at wetland unit or random points. Positive effects for homing and random measurement types indicated that rails selected deeper water levels, while negative effects indicated selection for shallower water depths relative to normalized unit measurements. Alternatively, if rails did not select shallower or deeper water depths in units they occupied, the residual values would be similar and not differentially skewed among unit, homing, and random points. The normalized residual water depths at homing and random points were plotted by date to compare “hydrographs” at unit vs. homing vs. random measurement points on the same scale.

I used GAMs to compare weekly patterns of normalized water depths among wetland units used by radio-marked Virginia rails and soras and normalized water depths at homing and random points of radio-marked rails during 4 April – 22 August 2018 and 15 April – 30 August

2019. I did this with package ‘mgcv’ (Wood 2017) in program R. I analyzed the relationship between normalized water depths by measurement type and year for Virginia rails and soras separately.

I used generalized additive models to estimate and test the significance of both fixed effects (e.g. overall differences in normalized water depths among species, years, and measurement types) and non-systematic of a spatial or in this case temporal variable (i.e. date). I examined both fixed and main effects (i.e. species, year, measurement type) and the interaction of the smoothed effect of date with the fixed effect of measurement type. Coefficient estimates of the former were used to test the significance of overall differences independent of the effect of date (e.g. were water levels shallower or deeper at unit vs. homing vs. random measurement types). By examining the estimated degrees of freedom (edf; number of knots) of the latter effects (i.e. date:unit, date:homing, date:random) I compared complexity and significance of the temporal pattern of the date effect on normalized water depths among unit, homing, and random points.

#### *Vegetation cover, composition, and structure*

I used multivariate analyses implemented in program R to discriminate microhabitat measurements taken at homing and random points for both species. I constructed multivariate models that included water depth and vegetation variables, but I did not use all variables measured in the field in the multivariate analyses. I inspected distributions of potential variables, tested for patterns of multicollinearity, and included those variables in a set that most closely met assumptions of multivariate normality and equality of groups dispersions which I tested with R packages ‘MVN’ and ‘vegan’ (Korkmaz et al. 2014, Oksanen et al. 2020). To improve multivariate normality and group homogeneity, I applied arcsin square root transformations to

variables measured as proportions and log transformations to variables measured as other quantities.

I mean-centered and scaled to unit variance all transformed variables. Using canonical discriminant analysis with package ‘candisc’ (Friendly and Fox 2020) in program R, I examined the overall separation of groups in multivariate space and tested for significance of discrimination among groups (SORA homing, SORA random, VIRA homing, VIRA random) with multivariate analysis of variance (MANOVA). Bivariate pairs of microhabitat variables that contributed most to separating the four groups were identified with R package ‘heplots’ (Fox et al. 2020).

## **RESULTS**

### **Capture and Radio-tracking**

A total of 293 Virginia rails and 100 soras were captured at WPM during 2018 – 2019. A subset of Virginia rails ( $n = 141$ ) and soras ( $n = 64$ ) were fitted with frequency-coded VHF radio transmitters. Additional Virginia rails ( $n = 83$ ) were fitted with pulse-coded VHF radio transmitters. Rails were captured and tracked in 9 of 21 impounded wetland units across WPM (Appendix A).

### **Microhabitat Measurements**

Microhabitat measurements were completed in 11 wetland units at WPM and 3 wetland units at ONWRC. I conducted a total of 512 water depth surveys and 322 vegetation surveys at known locations of frequency-coded and pulse-coded rails and paired random locations each week during 4 April – 15 August 2018 and 15 April – 28 August 2019. Rails were mostly located in emergent vegetation (80%) and no rail homing locations were recorded in scrub-shrub or forested areas (Table 2.1).

Table 2.1. Numbers and classification of homing and random points by habitat class and cover types for radio-marked Virginia rails and soras at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019.

Habitat class – cover type	Number of homing points		Number of random points		Total
	2018	2019	2018	2019	
Water – unvegetated	14	4	20	5	43
Water – submergent aquatic vegetation	2	0	3	2	7
Water – floating-leaf vegetation	10	2	9	2	23
Bare ground – unvegetated	0	0	2	0	2
Emergent – cattail/bur-reed	52	28	40	23	143
Emergent – rose mallow/reed canary	27	5	35	6	73
Emergent – loosestrife	2	0	2	0	4
Emergent – common reed	8	2	3	2	15
Emergent – broadleaf	1	0	2	1	4
Emergent – sedges, rushes, and grasses	2	2	1	2	7
Scrub-shrub – scrub-shrub	0	0	0	0	0
Forest – forest	0	0	1	0	1
Total	118	43	118	43	322

### *Water depths*

As expected, raw water depths recorded from staff gauges purposively placed in wetland units were smaller and far less variable than water depths recorded at homing and random points for both species each year (Figure 2.3). Normalized water depth values for Virginia rails were larger at unit points compared to homing and random points for Virginia rails both years (Figure 2.3). These patterns were more evident in 2018 than in 2019. Similar patterns were evident in the raw water depths measured at unit, homing, and random points for soras, but normalized water depths for soras were only similar to Virginia rails for unit and homing points in 2018 (Figure 2.3).

The normalized water depths for units were approximately normally distributed, while the distributions of normalized water depths at Virginia rail homing and random points were considerably right-skewed (Figure 2.4). The normalized water depths for soras were sparse and

had a generally uniform distribution. The normalized unit water depths were similar but not identical between Virginia rails and soras, as both species were not necessarily observed in the same wetland units with the same frequencies (Figure 2.4).

I could not estimate the effects of date, species, year, and measurement type with a single global GAM model due to the paucity of sora radio-locations. Consequently, I fit a GAM model that combined homing and random points for each species to examine the effects of species (including unit) and year (with interaction), along with the smoothed effects of date:unit, date:VIRA, and date:SORA. I found no fixed main effect of species ( $P = 0.780$ ) but there was an effect of year ( $P = 0.042$ ) and interaction of year with unit ( $P = 0.780$ ). The smoothed effects of date:unit and date:VIRA were significant ( $P < 0.001$ ) but the smoothed effect of date:SORA was not ( $P = 0.694$ ). The complexity of the smooth was higher for date:VIRA (edf = 7.285), followed by date:unit (edf = 6.881), and date:SORA (edf = 1.002). Considering these results, I chose to compare normalized water depths by year and measurement type with separate GAM models for each rail species.

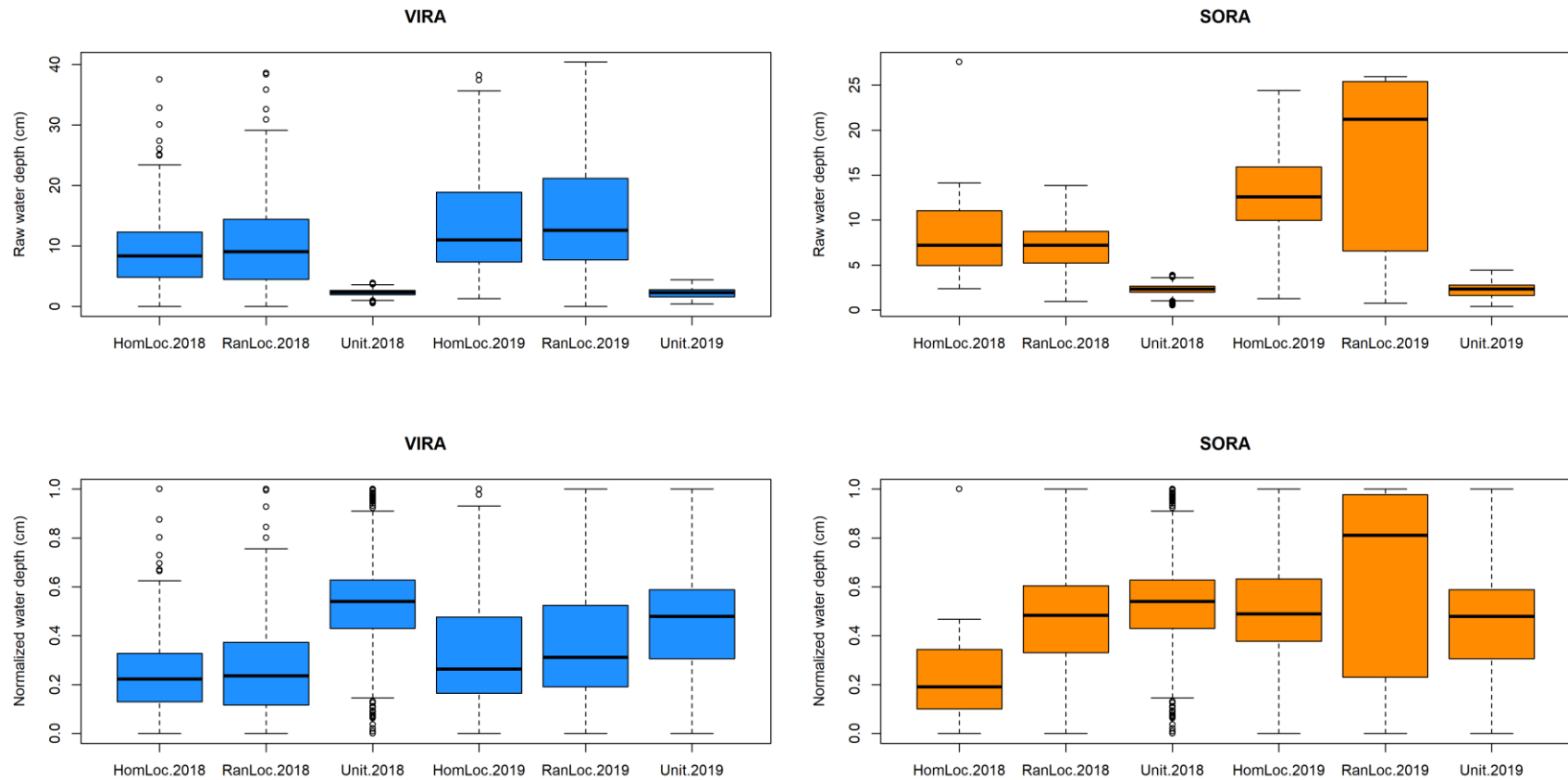


Figure 2.3. Mean raw and normalized water depths for homing points (HomLoc), nearby random points (RanLoc), and wetland units (Unit) associated with radio-marked Virginia rails (VIRA) and soras (SORA) at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019.

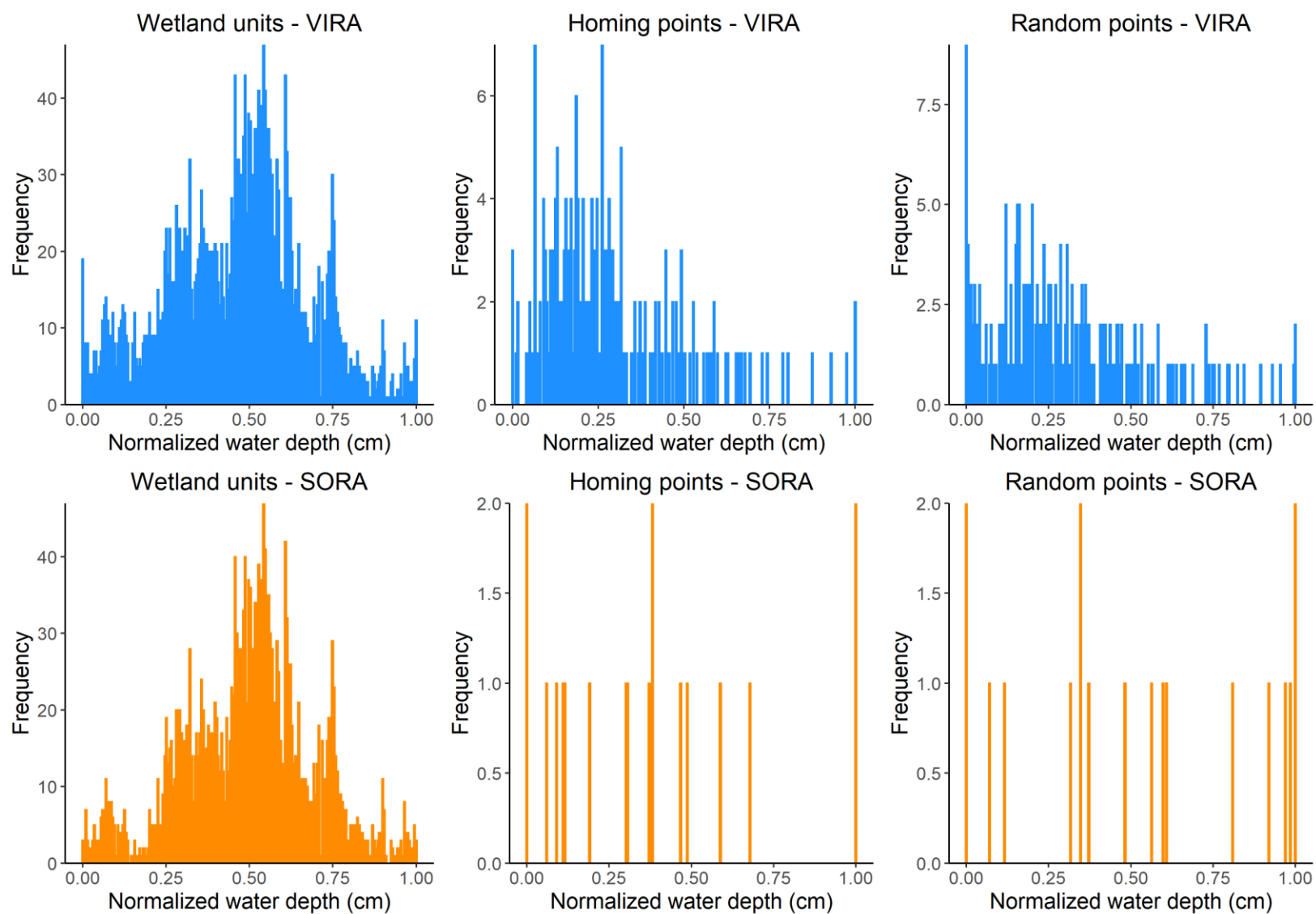


Figure 2.4. Frequency of normalized water depths for wetland units and paired homing and random points associated with radio-marked Virginia rails (VIRA) and soras (SORA) at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019.

The fixed effects of year, point, and year:point were all significant ( $P \leq 0.005$ ) for Virginia rails (Table 2.2). The smoothed effects of date:unit, date:homing and date:random also were significant ( $P < 0.001$ ), and date:homing had the lowest complexity (estimated degrees of freedom). The smoothed fit date:unit was nearly constant until a steep decline in the middle of the nesting stage, while the smoothed fit of date:homing displayed a bi-modal pattern with peaks midway through pre-nesting and near the end of nesting. Random locations were more variable with 3 peaks within the pre-nesting and nesting stages (Figure 2.5). All three hydrographs showed a declining trend starting before post-breeding that continued through the midpoint before showing an increase at the end of post-breeding.

Table 2.2. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type and year for radio-marked Virginia rails at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.540	0.053	10.203	$\leq 0.001$
2019	-0.067	0.006	-11.768	$\leq 0.001$
Homing point	-0.250	0.062	-4.036	$\leq 0.001$
Random point	-0.248	0.062	-4.008	$\leq 0.001$
2019:homing point	0.128	0.046	2.795	0.005
2019:random point	0.161	0.046	3.504	$\leq 0.001$
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	6.912	7.976	122.953	$\leq 0.001$
s(julian date):homing point	5.754	6.830	5.121	$\leq 0.001$
s(julian date):random point	6.999	7.995	5.438	$\leq 0.001$
s(frequency)	69.311	83.000	21.380	$\leq 0.001$

I also fit separate GAMs for 2018 and 2019 (Tables 2.3 and 2.4). The fixed and smoothed interaction effects were all significant ( $P < 0.001$ ) in 2018, but only the smoothed interaction effects were significant ( $P < 0.028$ ) in 2019. Complexities (estimated degrees of freedom) of the hydrographs were higher in 2018 than in 2019, and also highest for date:unit, followed in order by date:random, and date:homing. These results were evident in the hydrographs for unit, homing, and random points in 2018 and 2019 (Figure 2.6). Normalized water depths at unit points were relatively stable through pre-nesting until a steep decline midway through nesting and the entirety of post-breeding in 2018. A similar period of slowly declining normalized water levels was observed through pre-nesting, followed by a mildly steeper decline through post-breeding in 2019. Bimodal hydrographs at homing points were observed in 2018 compared to a more unimodal hydrograph for homing points in 2019. More strongly bimodal or trimodal hydrographs were observed at random points in 2018 compared to 2019.

Table 2.3. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type for radio-marked Virginia rails at Winous Point Marsh, Ottawa County, Ohio, USA during 2018.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.541	0.046	11.797	≤ 0.001
Homing point	-0.281	0.053	-5.257	≤ 0.001
Random point	-0.285	0.053	-5.328	≤ 0.001
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	8.148	8.792	125.700	≤ 0.001
s(julian date):homing point	6.422	7.436	12.160	≤ 0.001
s(julian date):random point	7.487	8.334	14.690	≤ 0.001
s(frequency)	52.158	58.000	50.140	≤ 0.001

Table 2.4. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type for radio-marked Virginia rails at Winous Point Marsh, Ottawa County, Ohio, USA during 2019.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.469	0.062	7.595	≤ 0.001
Homing point	-0.108	0.077	-1.400	0.162
Random point	-0.071	0.077	-0.922	0.356
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	6.694	7.801	110.773	≤ 0.001
s(julian date):homing point	3.506	4.251	2.752	0.028
s(julian date):random point	4.763	5.755	2.411	0.020
s(frequency)	29.321	33.000	53.476	≤ 0.001

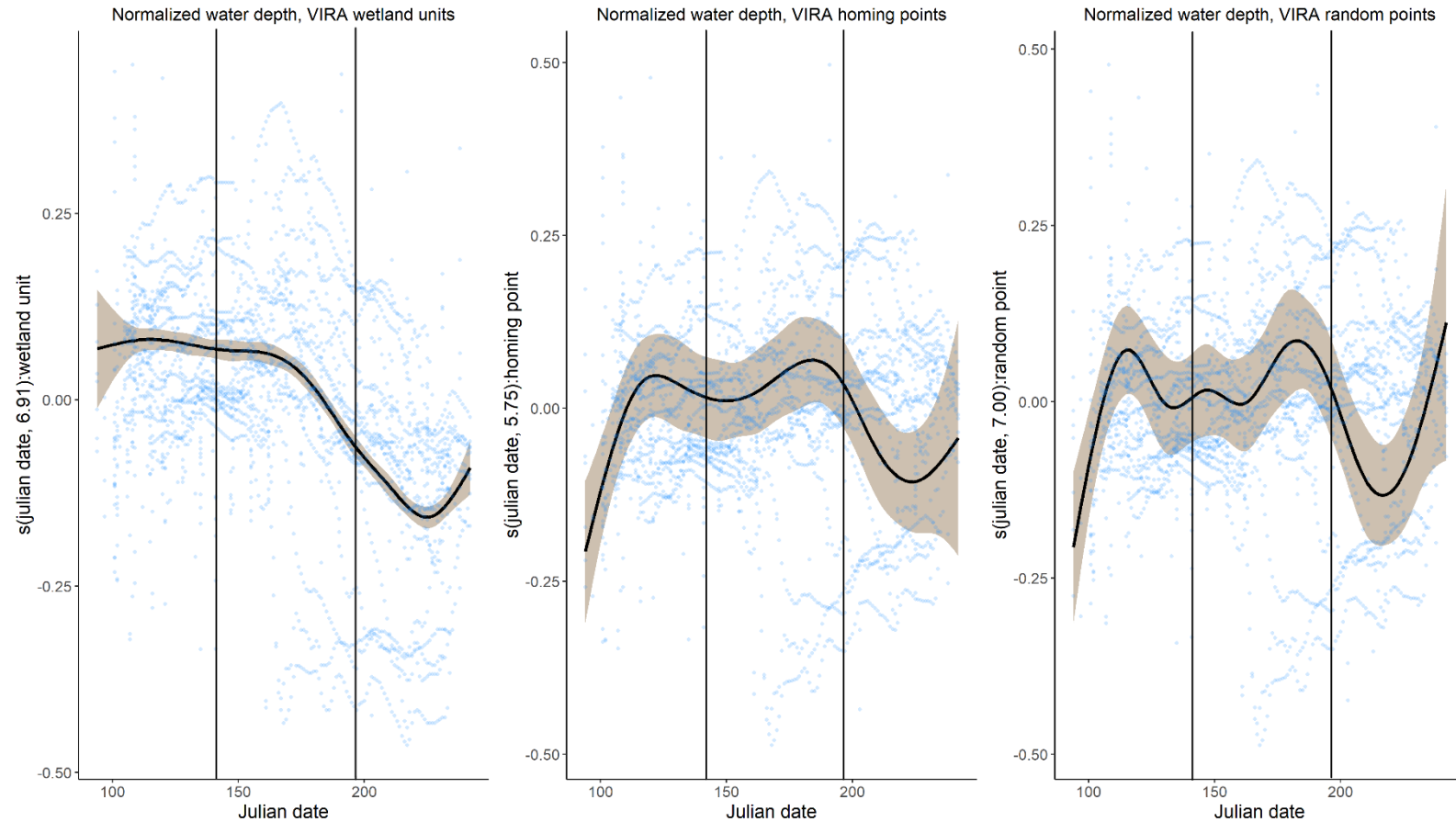


Figure 2.5. Generalized additive models of normalized water depths for wetland units and paired homing and random points associated with radio-marked Virginia rails at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019. Shaded area represents the 95% confidence interval of the smoothed coefficients, the points are the recorded normalized water depths, and the black vertical lines show cut-off dates for pre-nesting, nesting, and post-breeding.

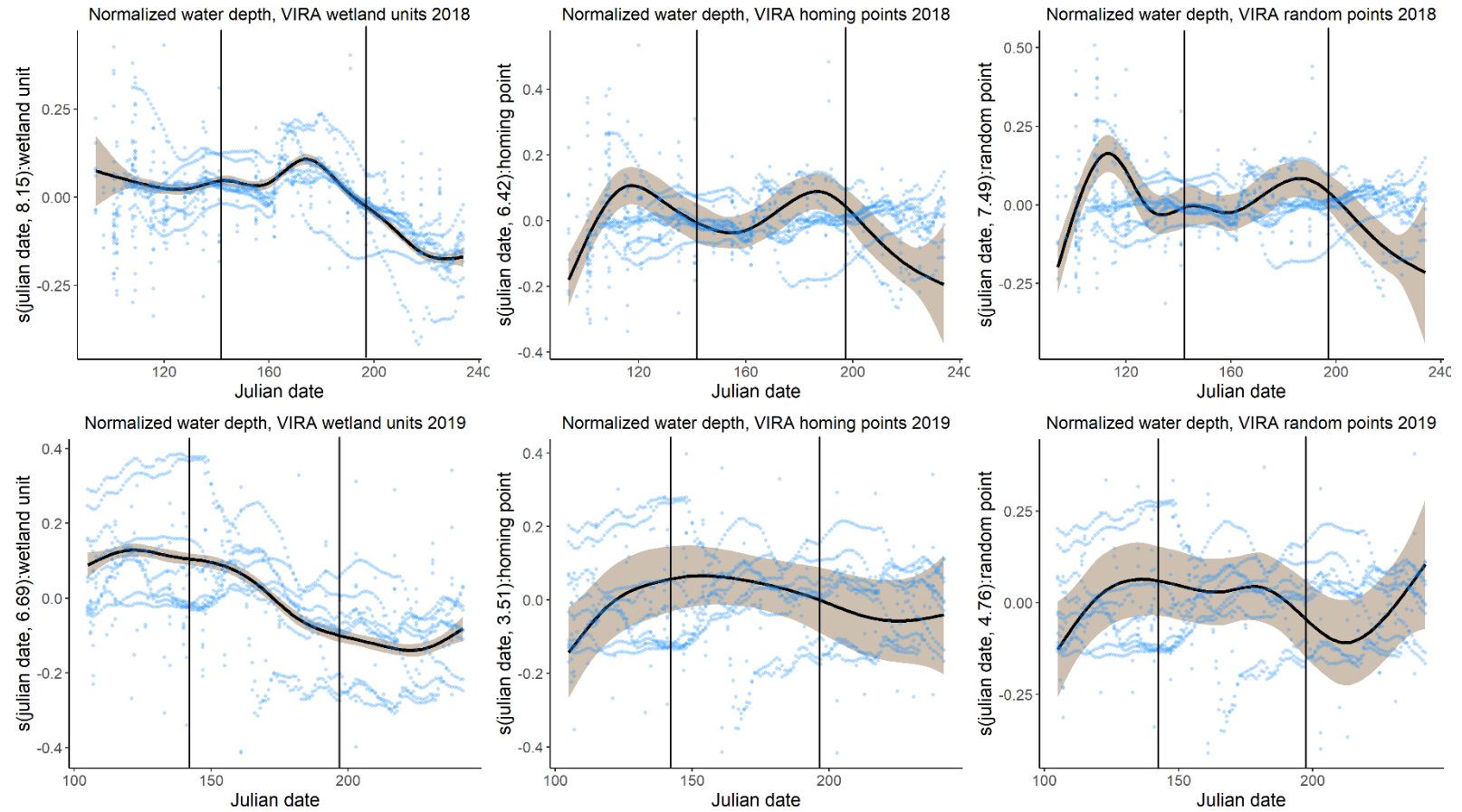


Figure 2.6. Generalized additive models of normalized water depths for wetland units and paired homing and random points associated with radio-marked Virginia rails at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 and 2019. Shaded area represents the 95% confidence interval of the smoothed coefficients, the points are the recorded normalized water depths, and the black vertical lines show cut-off dates for pre-nesting, nesting, and post-breeding.

Water depth measurements for homing and random locations associated with soras were sparse. Only the fixed effect of year and the smoothed effect of date:unit were significant ( $P \leq 0.001$ ) for soras (Table 2.5). The smoothed fit date:homing and date:random were relatively stable with a gradual increase over time (Figure 2.7). The smoothed fit date:unit for soras was very similar to the trend for the smoothed fit date:unit associated with Virginia rails in that normalized water depths at unit points were relatively stable through pre-nesting until a steep decline midway through nesting into post-breeding (Figure 2.7).

Table 2.5. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type for radio-marked soras at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.535	0.075	7.120	$\leq 0.001$
2019	-0.067	0.006	-11.951	$\leq 0.001$
Homing point	0.325	3.888	0.084	0.933
Random point	0.434	2.216	0.196	0.845
2019:homing point	0.408	0.153	2.661	0.008
2019:random point	0.144	0.149	0.961	0.337
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	6.990	8.063	125.540	$\leq 0.001$
s(julian date):homing point	2.381	2.647	0.450	0.628
s(julian date):random point	1.808	2.045	0.080	0.860
s(frequency)	18.958	22.000	68.810	$\leq 0.001$

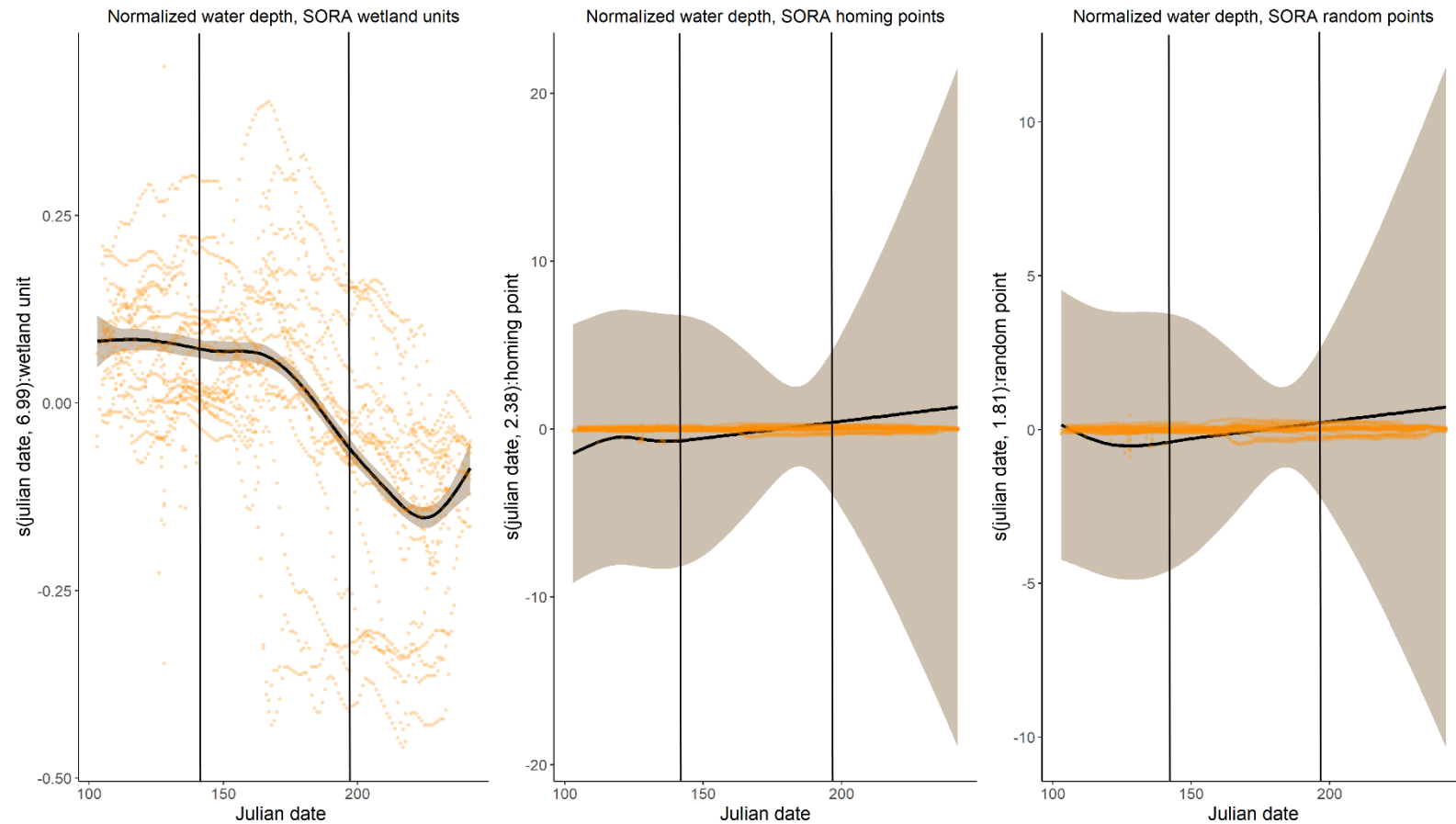


Figure 2.7. Generalized additive models of normalized water depths for wetland units and paired homing and random points associated with radio-marked soras at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 – 2019. Shaded area represents the 95% confidence interval of the smoothed coefficients, the points are the recorded normalized water depths, and the black vertical lines show cut-off dates for pre-nesting, nesting, and post-breeding.

The effect of year on normalized water depths where radio-marked soras were located was examined with individual GAMs for 2018 and 2019 (Tables 2.6 and 2.7). A difference in normalized water depths was found between homing points in 2018 ( $P \leq 0.001$ ) but not 2019. The smoothed effect of date:unit was significant ( $P \leq 0.001$ ) both years, and date:homing was significant in 2018 ( $P = 0.001$ ) but not 2019. In 2018, the smoothed fit date:homing for soras decreased drastically over time while in 2019, the smoothed fit increased continually (Figure 2.8). The random locations had the opposite trend with an increase in 2018 and slight decrease in 2019 (Figure 2.8). The smoothed fit date:unit for soras once again mirrored the trend seen for the smoothed fit date:unit associated with Virginia rails (Figure 2.8).

Table 2.6. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type for radio-marked soras at Winous Point Marsh, Ottawa County, Ohio, USA during 2018.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.536	0.064	8.403	$\leq 0.001$
Homing point	-1.387	0.336	-4.123	$\leq 0.001$
Random point	2.174	5.119	0.425	0.671
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	8.331	8.876	171.567	$\leq 0.001$
s(julian date):homing point	1.000	1.000	11.554	0.001
s(julian date):random point	1.930	2.028	1.546	0.366
s(frequency)	15.342	16.000	215.603	$\leq 0.001$

Table 2.7. Summary table for generalized additive model examining the relationship between normalized water depths by measurement type for radio-marked soras at Winous Point Marsh, Ottawa County, Ohio, USA during 2019.

Parametric coefficients	Estimate	Standard error	<i>t</i> -value	<i>P</i> -value
Intercept	0.467	0.077	6.062	$\leq 0.001$
Homing point	0.273	0.451	0.605	0.546
Random point	-2.589	11.308	-0.229	0.819
Smoothing terms	Estimated degrees of freedom	Reference degrees of freedom	<i>F</i>	<i>P</i> -value
s(julian date):wetland unit	6.881	7.962	119.006	$\leq 0.001$
s(julian date):homing point	1.001	1.001	0.305	0.583
s(julian date):random point	2.844	2.972	1.820	0.143
s(frequency)	12.234	13.000	137.313	$\leq 0.001$

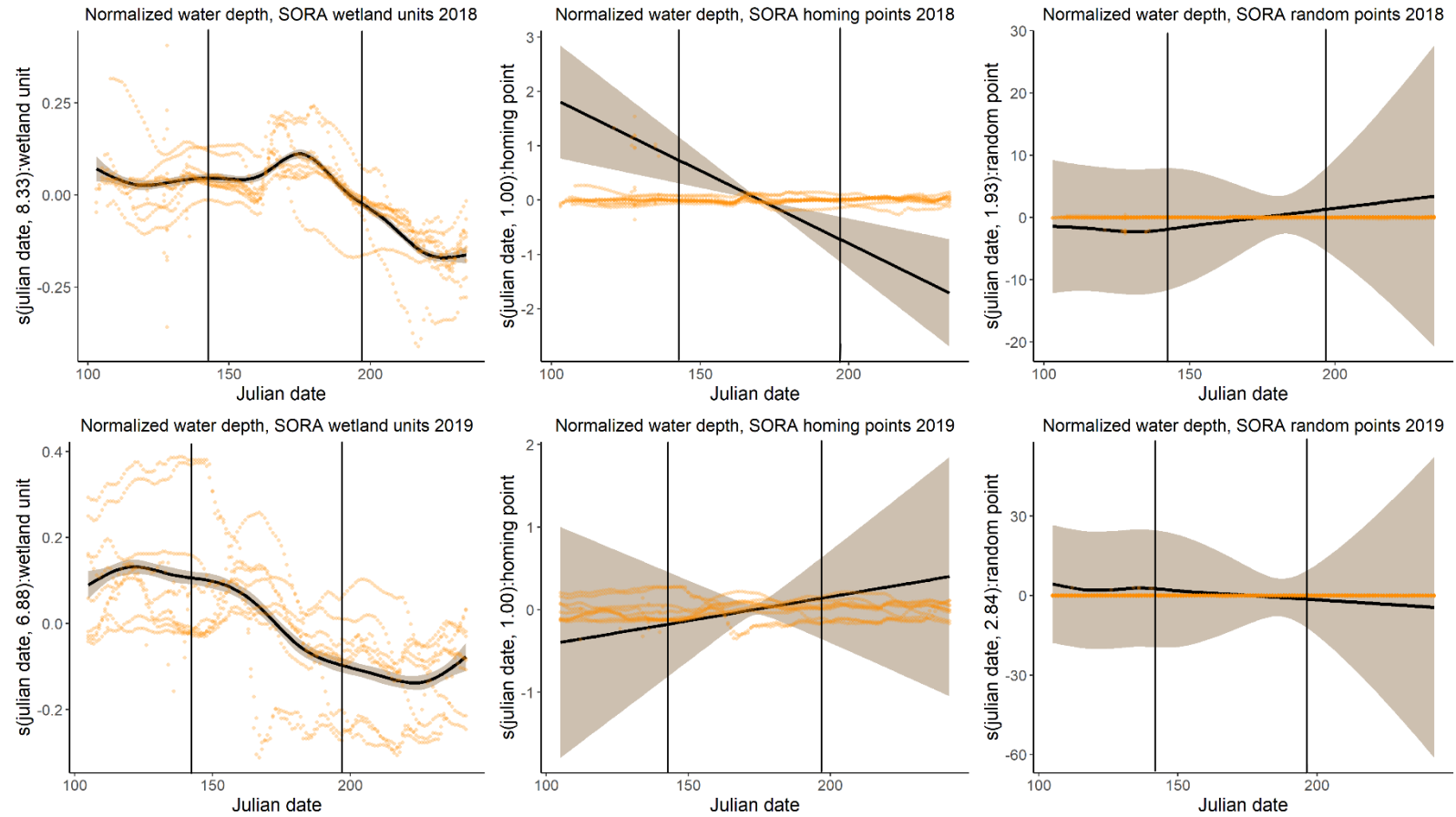


Figure 2.8. Generalized additive models of normalized water depths for wetland units and paired homing and random points associated with radio-marked soras at Winous Point Marsh, Ottawa County, Ohio, USA during 2018 and 2019. Shaded area represents the 95% confidence interval of the smoothed coefficients, the points are the recorded normalized water depths, and the black vertical lines show cut-off dates for pre-nesting, nesting, and post-breeding.

*Multivariate analyses of species and location type microhabitat characteristics*

Nine variables were selected which I hypothesized were most likely to differ between homing and random points for Virginia rails and soras after inspecting distributions and intercorrelations of all microhabitat variables measured in the field (Appendix B). These included total vegetation cover class mid-point, proportion of herbaceous emergent cover, proportion of wooded cover, residual water depth, residual distance to open water, residual distance to cover class edge, residual visual obstruction, and variances of water depth and visual obstruction measurements (not residuals). Multivariate analysis of variance models with these variables did not meet assumptions of multivariate normality before ( $HZ = 4.279, P \leq 0.001$ ) or after ( $HZ = 2.175, P \leq 0.001$ ) data transformations, though the transformations markedly improved multivariate normality and reduced skewness of the individual variables. The homogeneity of group dispersions assumption also was not met ( $F = 4.548, P = 0.004$ ) with the transformed microhabitat variables. A pairwise permutation test revealed that the overall difference was mostly due to differences in dispersions of homing and random points of Virginia rails ( $P = 0.010$ ), and secondarily to differences between Virginia rail homing and sora random points ( $P = 0.080$ ). Intercorrelations of the 9 variables were  $< 0.6$  for all variables except proportion emergent cover and total vegetation cover class mid-point which had a large correlation ( $-0.821$ ). Both variables were retained, however, because of their hypothesized importance.

Canonical analysis of discriminant showed that the four groups were separated along one significant ( $P = 0.005, R^2 = 0.095$ ) canonical axis that accounted for 64% of

total inertia. The second axis was not significant ( $P = 0.400$ ,  $R^2 = 0.038$ ) and accounted for an additional 24% of inertia. The first axis was dominated by wooded cover (factor loading = 0.614) and water depth (factor loading = -0.334) variables and was interpreted as a gradient from higher to lower water depths where wooded vegetation was dominant (Figure 2.9). The second axis was dominated by visual obstruction (factor loading = -0.636), distance to open water (factor loading = -0.567), and percent emergent cover (factor loading = 0.504) and was interpreted as a gradient from low overall vegetation cover near open water to high vegetation cover distant from open water (Figure 2.9). Soras occupied a somewhat wider range of microhabitat conditions represented on the first axis, particularly where water depths were lower than for Virginia rails (Figure 2.9). Not unexpectedly, homing sites had a narrower range of microhabitats conditions than random sites for both species along both axes (Figure 2.9). Neither axis separated homing and random points within or across species.

Multivariate analysis of variance found that the 9 microhabitat variables discriminated the four groups of species and location type, (Pillai's test,  $F_{27,936} = 3.661$ ,  $P = 0.005$ ). Proportion of wooded cover was the only significant ( $F_{3,318} = 4.265$ ,  $P = 0.006$ ) univariate comparison and showed that wooded cover was higher at sora homing and random points than at Virginia rail homing and random points ( $P = 0.049$ ). Despite the globally significant MANOVA, I found no differences between groups when comparisons were coded orthogonally to compare all Virginia rail vs sora points ( $P = 0.332$ ), all homing vs random points ( $P = 0.876$ ) and the interaction of species and location type ( $P = 0.850$ ). However, hypothesis-error plots showed that bivariate pairs of

the proportion wooded cover, water depth, and variance of water depth produced significant or nearly significant ( $P = 0.05$ ) separation of species and or location types (Figure 2.10).

The hypothesis and error sums-of-squares-and-products plot for proportion wooded cover and water depth demonstrated that soras were found in areas with more woody cover and shallower water depths compared to Virginia rails (Figure 2.11). Similarly, random points also had more woody cover and shallower water depths compared to homing points within species (Figure 2.11). The difference between groups was less obvious in the bivariate plot of water depth with water depth variance (Figure 2.12). Soras again selected areas with shallower water depths than Virginia rails but also areas with greater variability in water depths (Figure 2.12). Random sites were located in shallower water depths than homing points within species as well (Figure 2.12).

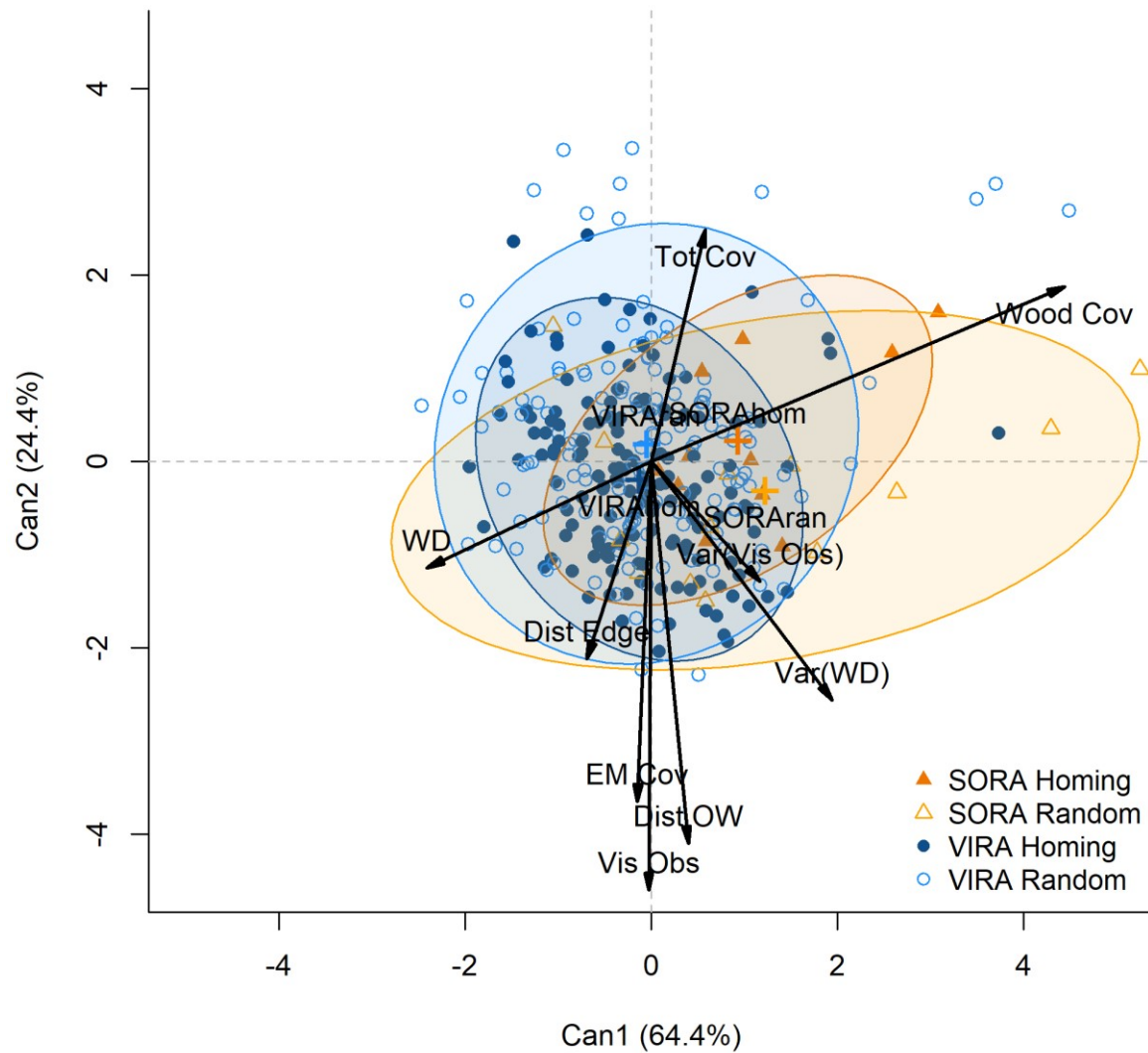


Figure 2.9. Canonical analysis of discriminant of the 9 multivariate analysis of variance variables measured during rapid and detailed assessments at homing and random points associated with radio-marked Virginia rail (VIRA) and sora (SORA) at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019.

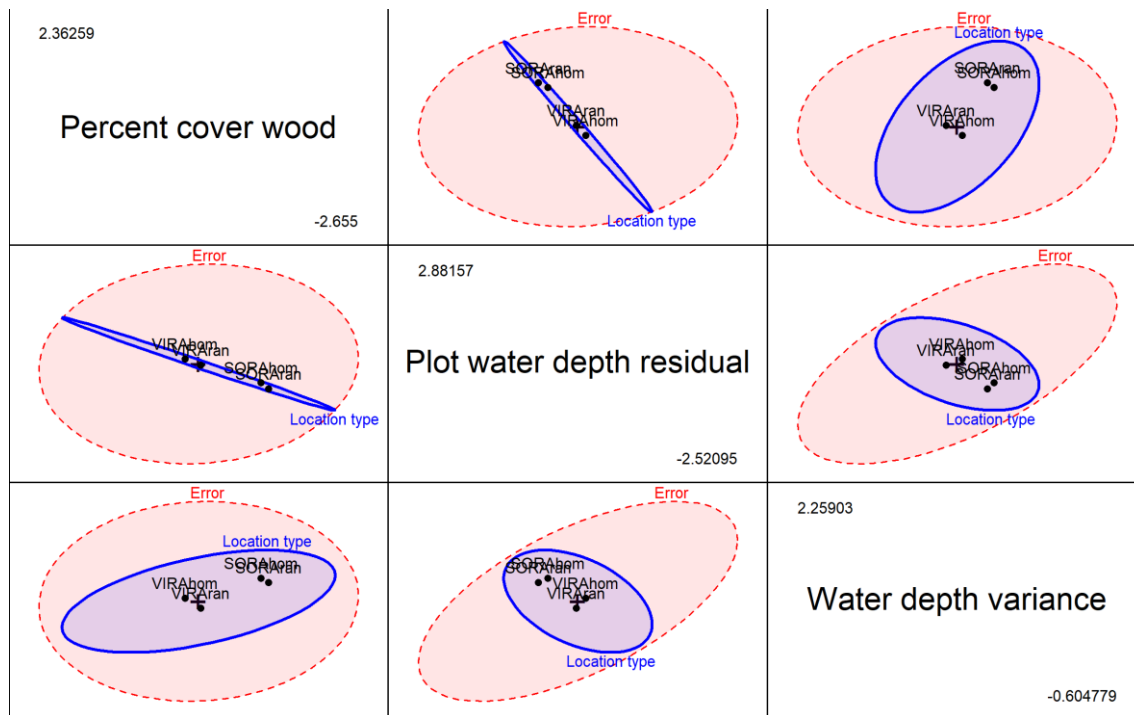


Figure 2.10. Pairwise hypothesis and error sums-of-squares-and-products plots for multivariate analysis of variance for habitat variables at homing and random points associated with radio-marked Virginia rail (VIRA) and sora (SORA) at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019. If the blue hypothesis ellipse extends outside the red error ellipse, then the bivariate pair significantly ( $P < 0.05$ ) discriminated the groups whose centroids are inside the hypothesis ellipse.

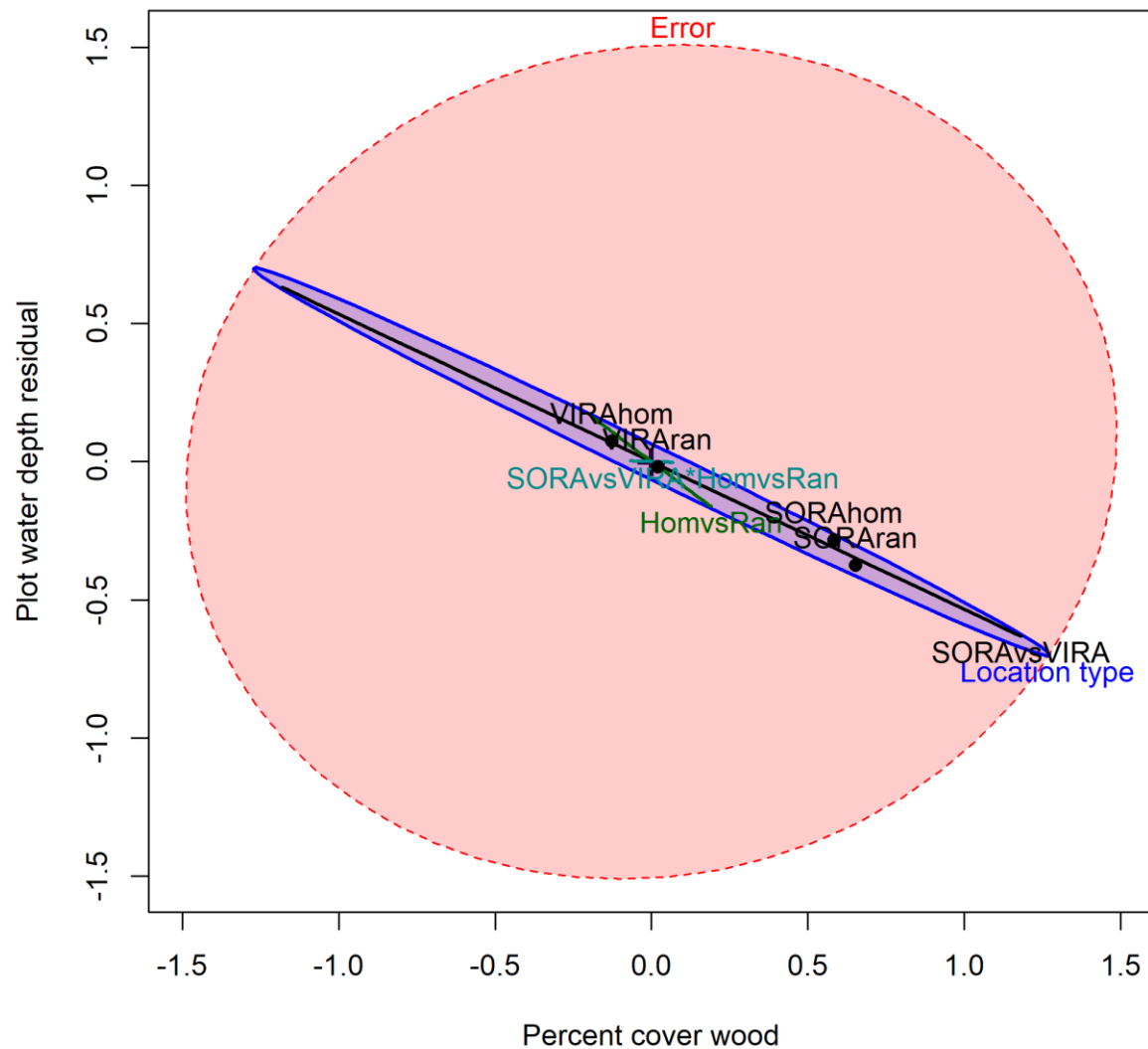


Figure 2.11. Two-dimensional hypothesis and error sums-of-squares-and-products plots for multivariate analysis of variance for percent cover wood and plot water depth residual at homing and random points associated with radio-marked Virginia rail (VIRA) and sora (SORA) at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019. If the blue hypothesis ellipse extends outside the red error ellipse, then the bivariate pair significantly ( $P < 0.05$ ) discriminated the groups whose centroids are inside the hypothesis ellipse.

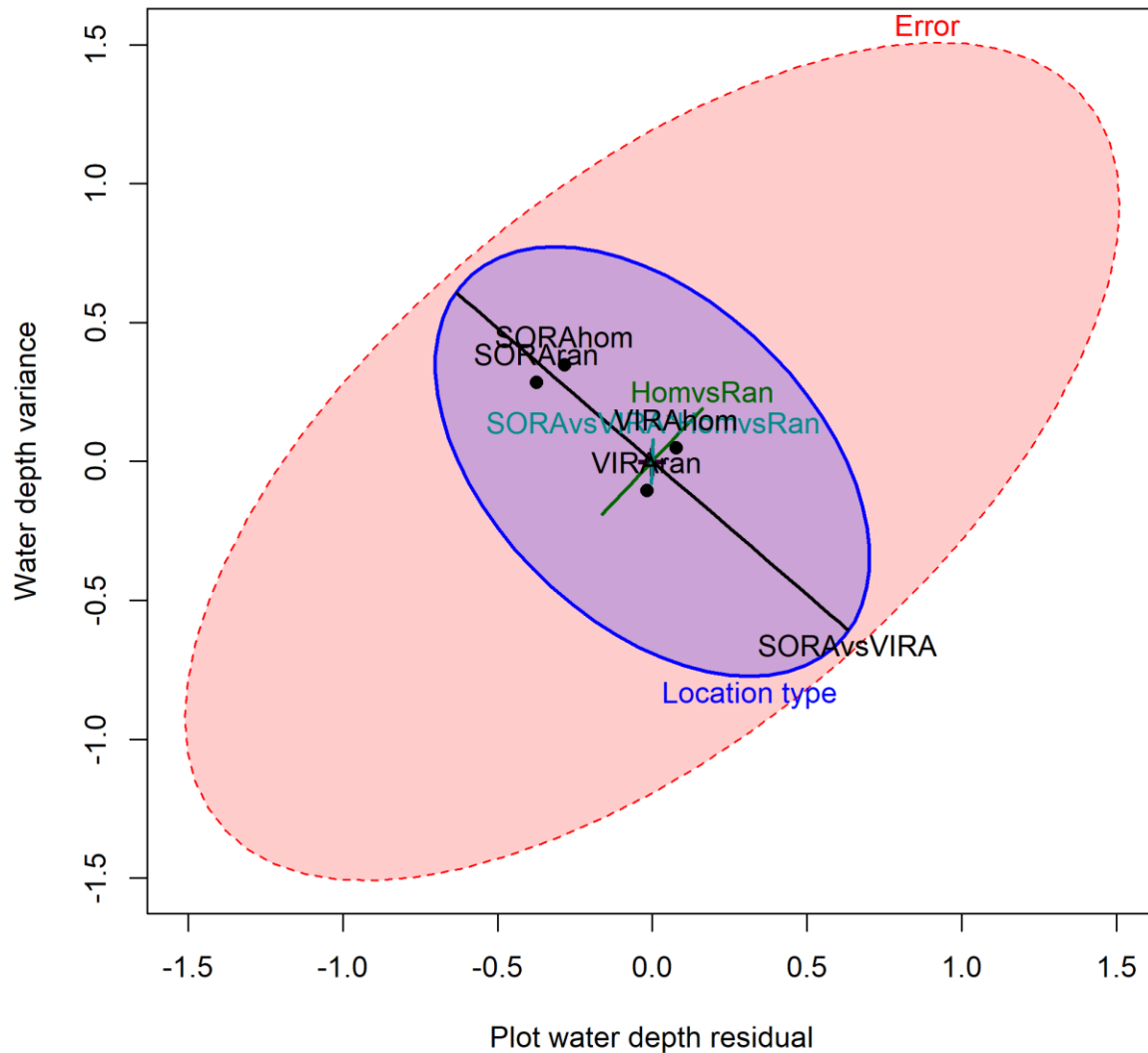


Figure 2.12. Two-dimensional hypothesis and error sums-of-squares-and-products plots for multivariate analysis of variance for plot water depth residual and water depth variance at homing and random points associated with radio-marked Virginia rail (VIRA) and sora (SORA) at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019. If the blue hypothesis ellipse extends outside the red error ellipse, then the bivariate pair significantly ( $P < 0.05$ ) discriminated the groups whose centroids are inside the hypothesis ellipse.

## DISCUSSION

There is an intrinsic connection between water depths and vegetation structure and composition that has focused attention on water depth and vegetation measurements in numerous marsh bird habitat selection studies (Johnson and Dinsmore 1986*b*, Willard 2011, Harms and Dinsmore 2013, Pickens and King 2014, Kolts and McRae 2017). This connection arises from the understanding that changing water depths directly affects vegetation growth which has subsequent effects on food availability, and nesting, thermal, and protective cover (Murkin et al. 1997). Studying microhabitat selection by marsh birds during spring and summer is challenging because the variables hypothesized to be important vary over large ranges of values during pre-nesting, nesting, and post-breeding stages of the breeding cycle. My approach sought to circumvent this problem by normalizing water depths in GAM models used to compare hydrographs among unit, homing, and random points. I also used residuals to “factor out” temporal trends in water levels and vegetation cover throughout the breeding season for Virginia rails and soras.

The GAM models and hydrographs of normalized water depths revealed that Virginia rails apparently adjusted their selection of wetland use areas in response to changing water levels throughout pre-nesting, nesting, and post-breeding stages. Virginia rails selected shallower water depths compared to water depths in units they occupied, particularly during pre-nesting, and moved to deeper areas at the end of the nesting period. With evidence of breeding Virginia rails documented at WPM during 2018 - 2019 (Chapter 1), the variable temporal pattern of water depth selection could be indicative of movements made by Virginia rails to select suitable nesting and brood-rearing habitat.

Waterbird nest success has been positively correlated with water depth at or adjacent to nests (Darrah and Krementz 2009). Kolts and McRae (2017) reported that king rails (*Rallus elegans*) selected shallow water during the brood-rearing period and large movements from nest sites to brood-rearing areas. Selection for deeper water depths by Virginia rails compared to the declining wetland unit water depths at the end of the nesting stage could be an effort to maintain stable water levels or movements made once chicks were independent. During post-breeding, Virginia rail water depth selection mirrors the temporal pattern of wetland unit water depths each year which further supports the idea that breeding Virginia rails selected water depths as habitat needs change during different parts of the breeding season.

Numbers of radio locations and radio-marked individuals were sparser for soras, so temporal patterns and differences between Virginia rails and soras were more difficult to discern because of exceptionally wide confidence limits. Nevertheless, it appeared that soras were more flexible in their capacity to use sites with more consistent water depths relative to the units they inhabited compared to Virginia rails. This difference could be related to the fact that some Virginia rails attempted to nest and raise young at WPM, while we found little or no evidence of nesting activity by soras. Pickens and King (2013) similarly found no selection for water depths by king rails; however, one year of the study occurred during a severe draught, so most water depth measurements were zero. Different results may have resulted if rainfall amounts had been more normal during their study. The varying results between individual years for both species also suggested that

the strength of selection might depend on the magnitude of variation in water levels in impounded wetland units.

Multivariate analyses of microhabitat variables found little or no differences between Virginia rail and sora homing and random points suggesting that microhabitat selection occurs at a scale  $> 25$  m if at all. Numerous studies have used call-broadcast surveys to link marsh bird occupancy and abundance to wetland habitat characteristics (Johnson and Dinsmore 1986b, Benoit and Askins 2002, Rehm and Baldassarre 2007, Bolenbaugh et al. 2011, Willard 2011, Baschuk et al. 2012, Harms and Dinsmore 2013, Alexander and Hepp 2014, Pickens and King 2014); however, by design these studies examined habitat characteristics at large survey plot scales including at the wetland level scale. I selected a 25-m scale to differentiate homing and random points because I primarily wanted to discern micro- as opposed to macro-habitat characteristics. King rail studies previously used a 50-m scale for microhabitat assessments (Pickens and King 2013, Kolts and McRae 2017), and one of the studies showed microhabitat selection at the 50-m scale demonstrating that rails may select habitat characteristics at a finer spatial scale (Pickens and King 2013).

Though the separation of group centroids between homing and random points was not significant, random plots encompassed a wider range of microhabitat conditions than homing points for both species. Consequently some level of differentiation between homing and random points was evident in the multivariate tri-plot of microhabitat conditions that reflected tolerance for shallow water and woody vegetation. Soras were more tolerant of areas with higher proportions of wooded cover and shallower water

depths compared to Virginia rails. Woody vegetation was previously shown to negatively affect the presence of king rails (Darrah and Krementz 2009, Bolenbaugh et al. 2011) as mammalian predators may use wooded wetland areas as foraging habitat or corridors to gain access to wetland prey such as rails (Darrah and Krementz 2009). Kolts and McRae (2017) observed the opposite and had several king rails use wooded wetland areas overwinter and for short time periods during brood-rearing. Baschuk et al. (2012) showed the presence of breeding Virginia rails and soras was not affected by water depth at both the plot and wetland level scale. On the other hand, call-broadcast surveys conducted in Johnson and Dinsmore's study (1986b) on breeding Virginia rails and soras had no responses from areas without standing water. Management implications for that study indicated that water levels should be held at depths that maximize the edge between moist-soil sites and shallow marsh whereas lowering water levels to expand moist-soil conditions would adversely affect breeding rails (Johnson and Dinsmore 1986b).

## **Conclusions**

Wetland managers typically manipulate vegetation structure and composition of wetlands by raising and lowering water levels at critical times of the year for germination, growth, and decomposition of vegetation species that provide food and cover resources for fall- and spring-migrating waterfowl. As opposed to migrant waterfowl, rails and other marsh birds inhabit northern temperate wetlands during the summer and rely on vegetation for protective cover, nest sites, and residual seeds and invertebrate or small vertebrate prey. Marsh birds typically inhabit shallower areas that are more densely vegetated compared to areas where waterfowl forage during fall and

spring migration (Figure 2.13). Thus, the habitat requirements of breeding marsh birds are vastly different from those of migrating waterfowl, creating a potential conflict in managing wetlands for multiple bird guilds.

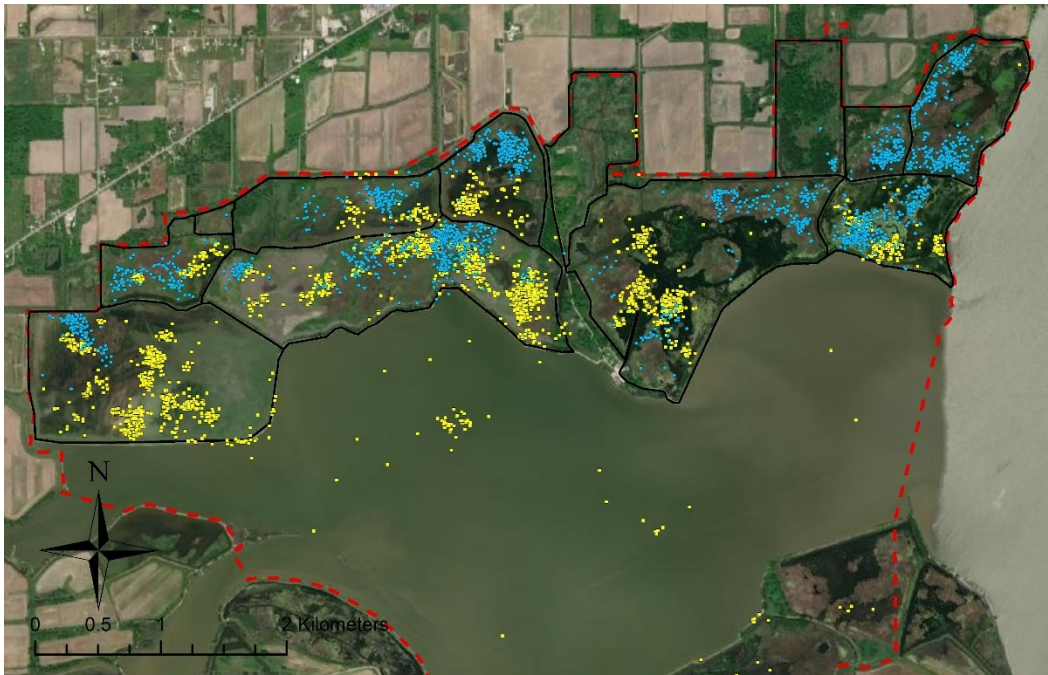


Figure 2.13. Spatial and habitat overlap of Virginia rail and sora radio-locations during April – September 2016 – 2018 and satellite locations of mallards marked with PTT tags during October – February 2015 – 2016 at Winous Point Marsh (WPM), Ottawa County, Ohio, USA. Virginia rail and sora locations are shown in blue and mallard locations in yellow. The boundary of WPM is marked by the red dashed line, and the 12 impounded wetland units of the northern marshes are outlined in black.

Water levels in coastal marshes of Lake Erie are typically managed by planned spring or early summer drawdowns to promote growth of desirable waterfowl food plants, or by retaining high water levels to control invasive species or create open hemi-marsh conditions that favor waterfowl and facilitate access for hunting in fall. Both of

these strategies could be detrimental to rails and other marsh birds during their breeding season.

I concluded that Virginia rails adjusted their habitat use patterns as water levels changed within managed and impounded coastal wetlands in northwest Ohio. Though I lacked specific comparisons with migrating waterfowl, I described and documented the habitat conditions used by Virginia rails and soras on impounded coastal wetlands near the western basin of Lake Erie. These species used mostly robust emergent vegetation cover types near habitat edges associated with open water and submergent or floating leaf vegetation cover types. Virginia rails and soras used very similar microhabitats, although soras were more tolerant of shallower water depths and woody vegetation cover.

With knowledge of habitat characteristics of areas used by rails pre-nesting, nesting, and post-breeding seasons, managers can adjust their habitat management plans to retain shallow water depths in vegetated cover types that are preferred by Virginia rails and soras. Rails may seemed to have capacity to adjust their selection of microhabitats within a minimum of a 25-m radius area. Best wetland management practices for either rail species would be beneficial for both species and possibly other marsh birds. I also found some flexibility for Virginia rails and soras to select shallower water depths as water levels varied in impounded wetland units so that annual water level management strategies if not too severe, may not be detrimental to rails and other marsh birds. Marsh bird responses to habitat change and management actions are sometimes monitored with point counts (Baschuk et al. 2012, Hansen 2019, Bradshaw et al. 2020). My radio-telemetry data showed that marsh birds may select certain habitat characteristics at a

larger spatial scale than I studied, potentially comparable to what may be represented by point counts surveys with call-broadcasts. Future work should examine microhabitat selection at multiple larger spatial scales than I used to determine if the scale of microhabitat selection by marsh birds matches the scale of detection probability from active and passive point count surveys.

## Literature Cited

- Alexander, B. W., and G. R. Hepp. 2014. Estimating Effects of Habitat Characteristics on Abundances of Three Species of Secretive Marsh Birds in Central Florida. *Waterbirds* 37:274–285.
- Andrews, D. A. 1973. Habitat utilization by sora, Virginia rails and king rails near southwestern Lake Erie. Thesis, The Ohio State University, Columbus, USA.
- Baschuk, M. S., N. Koper, D. A. Wrubleski, and G. Goldsborough. 2012. Effects of Water Depth, Cover and Food Resources on Habitat Use of Marsh Birds and Waterfowl in Boreal Wetlands of Manitoba, Canada. *Waterbirds* 35:44–55.
- Beers, T. W., P. E. Dress, and L. C. Wensel. 1966. Notes and observations: aspect transformation in site productivity research. *Journal of Forestry* 64:691–692. Oxford Academic.
- Benoit, L. K., and R. A. Askins. 2002. Relationship between habitat area and the distribution of tidal marsh birds. *Wilson Bulletin* 114:314–323.
- Bent, A. C. 1926. Life histories of North American marsh birds. Bulletin 135, U.S. National Museum, Washington, D.C.
- Bolenbaugh, J. R., D. G. Krementz, and S. E. Lehn. 2011. Secretive Marsh Bird Species Co-Occurrences and Habitat Associations Across the Midwest, USA. *Journal of Fish and Wildlife Management* 2:49–60.

- Bradshaw, T. M., A. G. Blake-Bradshaw, A. M. V. Fournier, J. D. Lancaster, J. O'Connell, C. N. Jacques, M. W. Eichholz, and H. M. Hagy. 2020. Marsh bird occupancy of wetlands managed for waterfowl in the Midwestern USA. PLOS ONE 15:e0228980. Public Library of Science.
- Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Second edition. Springer-Verlag, New York. <<https://www.springer.com/gp/book/9780387953649>>. Accessed 15 Sep 2020.
- Calenge, C. 2006. The package “adehabitat” for the R software: A tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519. Elsevier, Amsterdam.
- Campbell, L. 1968. Birds of the Toledo area. The Blade, Toledo, Ohio.
- Conway, C., W. Eddleman, and S. Anderson. 1994. Nesting success and survival of Virginia rails and soras. Wilson Bulletin 106:466–473.
- Conway, C. J. 2011. Standardized North American Marsh Bird Monitoring Protocol. Waterbirds 34:319–346.
- Conway, C. J. 2020. Virginia Rail (*Rallus limicola*), version 1.0. In Birds of the World. A. F. Poole and F. B. Gill, editors. Cornell Lab of Ornithology, Ithaca, New York, USA. <<https://doi-org.proxy.lib.ohio-state.edu/10.2173/bow.virrai.01>>. Accessed 23 Jul 2020.
- Conway, C. J., and J. P. Gibbs. 2005. Effectiveness of call-broadcast surveys for monitoring marsh birds. Auk 122:26–35.

- Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31. Washington, DC.
- Crewe, T. L., Z. Crysler, and P. Taylor. 2020. Motus R Book. <<https://motus.org/MotusRBook/>>. Accessed 1 May 2021.
- Darrah, A. J., and D. G. Krementz. 2009. Distribution and Habitat Use of King Rails in the Illinois and Upper Mississippi River Valleys. *Journal of Wildlife Management* 73:1380–1386.
- Dénes, F. V., L. F. Silveira, and S. R. Beissinger. 2015. Estimating abundance of unmarked animal populations: accounting for imperfect detection and other sources of zero inflation. *Methods in Ecology and Evolution* 6:543–556.
- DeSante, D. F., K. M. Burton, P. Velez, D. Froehlich, D. Kaschube, and S. Albert. 2015. MAPS Manual: 2015 Protocol. The Institute for Bird Populations, Point Reyes Station, CA.
- Dossman, B. C., G. W. Mitchell, D. R. Norris, P. D. Taylor, C. G. Guglielmo, S. N. Matthews, and P. G. Rodewald. 2016. The effects of wind and fuel stores on stopover departure behavior across a migratory barrier. *Behavioral Ecology* 27:567–574. Oxford Academic.
- Eddleman, W. R., F. L. Knopf, B. Meanley, F. A. Reid, and R. Zembal. 1988. Conservation of North American rallids. *Wilson Bulletin* 100:458–475.

- Fournier, A. M. V., M. C. Shieldcastle, T. Kashmer, and K. A. Mylecraine. 2015. Comparison of Arrival Dates of Rail Migration in the Southwest Lake Erie Marshes, Ohio, USA. *Waterbirds* 38:312–314.
- Fox, J., M. Friendly, and G. Monette. 2020. heplots: Visualizing Tests in Multivariate Linear Models. R package version 1.3-7. <<https://CRAN.R-project.org/package=heplots>>.
- Friendly, M., and J. Fox. 2020. candisc: Visualizing Generalized Canonical Discriminant and Canonical Correlation Analysis. R package version 0.8-3. <<https://CRAN.R-project.org/package=candisc>>.
- Gibbs, J. P., and S. M. Melvin. 1993. Call-response surveys for monitoring breeding waterbirds. *The Journal of Wildlife Management* 57:27–34. [Wiley, Wildlife Society].
- Glahn, J. F. 1974. Study of Breeding Rails with Recorded Calls in North-Central Colorado. *The Wilson Bulletin* 86:206–214.
- Gottgens, J. F., B. P. Swartz, R. W. Kroll, and M. Eboch. 1998. Long-term GIS-based records of habitat changes in a Lake Erie coastal marsh. *Wetlands Ecology and Management* 6:5–17.
- Grange, S. 2014. Technical note: averaging wind speeds and directions.
- Griese, H. J., R. A. Ryder, and C. E. Braun. 1980. Spatial and temporal distribution of rails in Colorado. *The Wilson Bulletin* 92:96–102. Wilson Ornithological Society.

- Hansen, J. M. 2019. Survey methods and habitat associations of secretive marsh birds in coastal wetlands of the western Lake Erie basin. Thesis, The Ohio State University, Columbus, USA.
- Harms, T. M., and S. J. Dinsmore. 2013. Habitat Associations of Secretive Marsh Birds in Iowa. *Wetlands* 33:561–571.
- Johnson, R. R., and J. J. Dinsmore. 1985. Brood-Rearing and Postbreeding Habitat Use by Virginia Rails and Soras. *The Wilson Bulletin* 97:551–554.
- Johnson, R. R., and J. J. Dinsmore. 1986*a*. The Use of Tape-Recorded Calls to Count Virginia Rails and Soras. *The Wilson Bulletin* 98:303–306.
- Johnson, R. R., and J. J. Dinsmore. 1986*b*. Habitat Use by Breeding Virginia Rails and Soras. *The Journal of Wildlife Management* 50:387–392.
- Kaufmann, G. W. 1987. Growth and Development of Sora and Virginia Rail Chicks. *The Wilson Bulletin* 99:432–440. Wilson Ornithological Society.
- Kaufmann, G. W. 1989. Breeding ecology of the sora, *Porzana carolina*, and the Virginia rail, *Rallus limicola*. *Canadian Field-Naturalist* 103:270–282.
- Kearns, G. D., N. B. Kwartin, D. F. Brinker, and G. M. Haramis. 1998. Digital playback and improved trap design enhance capture of migrant soras and Virginia rails. *Journal of Field Ornithology* 69:8.
- Kearns, L. 2018. Ohio Marshbird Survey Instructions Booklet 2018. Ohio Division of Wildlife.
- Kleinbaum, D. G., and M. Klein. 2012. Extension of the Cox proportional hazards model for time-dependent variables. Pages 241–288 *in* D. G. Kleinbaum and M. Klein,

- editors. *Survival Analysis: A Self-Learning Text*, Third Edition. Statistics for Biology and Health, Springer, New York, New York, USA.
- Kolts, J. R., and S. B. McRae. 2017. Seasonal home range dynamics and sex differences in habitat use in a threatened, coastal marsh bird. *Ecology and Evolution* 7:1101–1111.
- Korkmaz, S., D. Goksuluk, and G. Zararsiz. 2014. MVN: An R Package for Assessing Multivariate Normality. *The R Journal* 6:151–162.
- Loges, B. W., B. G. Tavernia, A. M. Wilson, J. D. Stanton, J. H. Herner-Thogmartin, J. Casey, J. M. Coluccy, J. L. Coppen, M. Hanan, P. J. Heglund, S. K. Jacobi, T. Jones, M. G. Knutson, K. E. Koch, E. V. Lonsdorf, H. P. Laskowski, S. K. Lor, J. E. Lyons, M. E. Seamans, W. Stanton, B. Winn, and L. C. Ziemba. 2014. National protocol framework for the inventory and monitoring of nonbreeding waterbirds and their habitats, an Integrated Waterbird Management and Monitoring Initiative (IWMM) approach. Natural Resources Program Center, Fort Collins, CO.
- Lor, S., and R. A. Malecki. 2002. Call-response surveys to monitor marsh bird population trends. *Wildlife Society Bulletin* 30:1195–1201.
- Manci, K. M., and D. H. Rusch. 1988. Indices to distribution and abundance of some inconspicuous waterbirds on Horicon Marsh. *Journal of Field Ornithology* 59:67–75.
- Melvin, S. M., and J. P. Gibbs. 2020. Sora (*Porzana carolina*), version 1.0. In *Birds of the World*. A. F. Poole, editor. Cornell Lab of Ornithology, Ithaca, New York, USA.

<<https://doi-org.proxy.lib.ohio-state.edu/10.2173/bow.sora.01>>. Accessed 23 Jul 2020.

Murkin, H. R., E. J. Murkin, and J. P. Ball. 1997. Avian Habitat Selection and Prairie Wetland Dynamics: A 10-Year Experiment. *Ecological Applications* 7:1144–1159.

National Oceanic and Atmospheric Administration. 2020*a*. Local climatological data station details: Carl R Keller Field Airport, OH US. National Centers for Environmental Information. <<https://www.ncdc.noaa.gov/cdo-web/datasets/LCD/stations/WBAN:00468/detail>>. Accessed 15 Apr 2020.

National Oceanic and Atmospheric Administration. 2020*b*. Local climatological data station details: Toldeo Metcalf Field, OH US. National Centers for Environmental Information. <<https://www.ncdc.noaa.gov/cdo-web/datasets/LCD/stations/WBAN:04848/detail>>. Accessed 15 Apr 2020.

Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O’Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, and H. Wagner. 2020. *vegan*: Community Ecology Package. R package version 2.5-7. <<https://CRAN.R-project.org/package=vegan>>.

Peterjohn, B. G., and D. L. Rice. 1991. *The Ohio Breeding Bird Atlas*. Ohio Department of Natural Resources, Division of Natural Areas and Preserves.

Pickens, B. A., and S. L. King. 2013. Microhabitat Selection, Demography and Correlates of Home Range Size for the King Rail (*Rallus elegans*). *Waterbirds* 36:319–329.

- Pickens, B. A., and S. L. King. 2014. Multiscale Habitat Selection of Wetland Birds in the Northern Gulf Coast. *Estuaries and Coasts* 37:1301–1311.
- Pospichal, L. B., and W. H. Marshall. 1954. A field study of sora rail and Virginia rail in central Minnesota. *The Flicker* 26:2–32.
- Rappole, J. H., and A. R. Tipton. 1991. New Harness Design for Attachment of Radio Transmitters to Small Passerines. *Journal of Field Ornithology* 62:335–337.
- Rehm, E. M., and G. A. Baldassarre. 2007. The influence of interspersed marsh on bird abundance in New York. *Wilson Journal of Ornithology* 119:648–654.
- Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. *Rangeland Ecology & Management / Journal of Range Management Archives* 23:295–297.
- Rodewald, P. G., M. B. Shumar, A. T. Boone, D. L. Slager, and J. McCormac. 2016. *The Second Atlas of Breeding Birds in Ohio*. Penn State University Press.
- Rosenberg, K. V., A. M. Dokter, P. J. Blancher, J. R. Sauer, A. C. Smith, P. A. Smith, J. C. Stanton, A. Panjabi, L. Helft, M. Parr, and P. P. Marra. 2019. Decline of the North American avifauna. *Science* 366:120–124. American Association for the Advancement of Science.
- Royle, J. A. 2004. N-Mixture Models for Estimating Population Size from Spatially Replicated Counts. *Biometrics* 60:108–115.
- Rundle, W. D., and L. H. Fredrickson. 1981. Managing Seasonally Flooded Impoundments for Migrant Rails and Shorebirds. *Wildlife Society Bulletin (1973-2006)* 9:80–87.

- Rush, S. A., R. Mordecai, M. S. Woodrey, and R. J. Cooper. 2010. Prey and Habitat Influences the Movement of Clapper Rails in Northern Gulf Coast Estuaries. *Waterbirds* 33:389–396.
- Stensrud, M. J., and M. A. Hernán. 2020. Why test for proportional hazards? *JAMA* 323:1401–1402. American Medical Association.
- Suir, G. M., D. E. Evers, G. D. Steyer, and C. E. Sasser. 2013. Development of a reproducible method for determining quantity of water and its configuration in a marsh landscape. *Journal of Coastal Research* 110–117. Coastal Education & Research Foundation, Inc.
- Taylor, P. D., T. L. Crewe, S. A. Mackenzie, D. Lepage, Y. Aubry, Z. Crysler, G. Finney, C. M. Francis, C. G. Guglielmo, D. J. Hamilton, R. L. Holberton, P. H. Loring, G. W. Mitchell, D. R. Norris, J. Paquet, R. A. Ronconi, J. R. Smetzer, P. A. Smith, L. J. Welch, and B. K. Woodworth. 2017. The Motus Wildlife Tracking System: a collaborative research network to enhance the understanding of wildlife movement. *Avian Conservation and Ecology* 12:8.
- Therneau, T. M. 2020. A Package for Survival Analysis in R. R package version 3.2-7. <<https://CRAN.R-project.org/package=survival>>.
- Tiner, Jr., R. W. 1984. Wetlands of the United States: Current Status and Recent Trends. United States Department of Interior, Fish and Wildlife Service, National Wetlands Inventory. <[http://www.fwspubs.org/doi/suppl/10.3996/092015-JFWM-085/suppl\\_file/092015-jfwm-085.s7.pdf](http://www.fwspubs.org/doi/suppl/10.3996/092015-JFWM-085/suppl_file/092015-jfwm-085.s7.pdf)>. Accessed 22 Oct 2017.

- Uresk, D. W., and T. A. Benzon. 2007. Monitoring with a modified Robel pole on meadows in the central Black Hills of South Dakota. *Western North American Naturalist*. 67(1): 46-50. <<https://www.fs.usda.gov/treesearch/pubs/29068>>. Accessed 28 Oct 2020.
- Weller, M., and C. Spatcher. 1965. Role of habitat in the distribution and abundance of marsh birds. Special Report. <<https://lib.dr.iastate.edu/specialreports/42>>.
- White, G. C., and R. A. Garrott. 1990. *Analysis of Wildlife Radio-Tracking Data*. Academic Press, San Diego.
- Willard, K. L. 2011. *Habitat Associations of Breeding Marsh Birds within the Glaciated Region Of Ohio, USA*. Thesis, The Ohio State University, Columbus, USA.
- Wood, S. N. 2017. *Generalized Additive Models: An Introduction with R*, Second Edition. CRC Press.
- Wright, J. R., L. L. Powell, and C. M. Tonra. 2018. Automated telemetry reveals staging behavior in a declining migratory passerine. *The Auk* 135:461–476. American Ornithological Society.

## Appendix A. Chapter 1 Supplemental Materials

Table A.1. Grading scale for yearly wetland management grades at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019.

Letter grade	Percent grade
A	95
B+	88
B	85
C+	78
C	75
D+	68
D	65

Table A.2. Nesting data for Virginia rails (VIRA) and soras (SORA) at Winous Point Marsh (WPM) and Ottawa National Wildlife Refuge (ONWR), Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019.

Species	Year	Location	Date found	Status when found	Date final status	Final status
VIRA	2016	WPM	20 June	2 hatchlings	21 June	successful
VIRA	2017	WPM	15 May	7 eggs	19 May	failed
VIRA	2017	WPM	24 July	6 eggs, incubating	7 August	failed
VIRA	2018	WPM	1 May	4 eggs	11 May	failed
VIRA	2018	WPM	15 May	2 eggs	24 May	failed
VIRA	2018	WPM	28 May	6 eggs	30 May	failed
VIRA	2018	ONWR	19 June	5 eggs	25 July	successful
VIRA	2018	WPM	22 June	3 eggs	27 June	failed
VIRA	2018	WPM	23 July	7 eggs	26 July	failed

Table A.3. Summary table of capture results and movements of Virginia rails (VIRA) and soras (SORA) by wetland unit at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2016. “Captured” refers to all rail capture events including initial captures, recaptures, and trap mortalities. “Radio-marked” refers to all rails that were fitted with a frequency-coded VHF radio transmitter or pulse-coded VHF radio transmitter.

	2016 Units												Total
	A	B	C	D	E	F	H	I	J	K	M	Unknown	
Captured													
VIRA	9	4	5	6	25	4	15	6	13	5	28	124	244
SORA	2	0	4	4	20	3	15	1	6	0	8	24	87
Banded													
VIRA	8	2	5	3	18	4	13	3	11	5	25	120	217
SORA	2	0	4	4	18	3	13	1	4	0	8	23	80
Radio-marked													
VIRA	7	4	3	6	19	1	11	6	5	2	0	0	64
SORA	2	0	4	0	14	0	10	1	3	0	0	0	34
Proportion of radio-marked rails that used only 1 unit													
VIRA	1.00	1.00	0.67	0.83	1.00	1.00	0.60	1.00	0.25	1.00			0.85
SORA	1.00		1.00		1.00		0.89	1.00	1.00				0.97
Proportion of radio-marked rails that departed $\leq 10$ days after capture													
VIRA	0.43	0.25	0.33	0.83	0.28	0.00	0.40	0.40	0.25	0.50			0.38
SORA	0.00		0.25		0.50		0.22	1.00	1.00				0.42
Mean home range size													
VIRA		13.39			2.78		0.81	8.07					5.49
SORA					0.54		1.42						0.98

Table A.4. Summary table of capture results and movements of Virginia rails (VIRA) and soras (SORA) by wetland unit at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2017. “Captured” refers to all rail capture events including initial captures, recaptures, and trap mortalities. “Radio-marked” refers to all rails that were fitted with a frequency-coded VHF radio transmitter or pulse-coded VHF radio transmitter.

	2017 Units										Total
	A	B	D	E	F	H	I	J	K	Unknown	
Captured											
VIRA	5	4	18	20	20	3	20	0	14	1	105
SORA	0	0	8	7	4	1	7	1	1	0	29
Banded											
VIRA	5	4	17	19	17	2	19	0	13	0	96
SORA	0	0	8	7	4	0	7	1	1	0	28
Radio-marked											
VIRA	4	3	16	17	16	2	18	0	12	0	88
SORA	0	0	8	7	3	0	3	1	1	0	23
Proportion of radio-marked rails that used only 1 unit											
VIRA	1.00	0.67	0.69	0.92	0.86	0.50	0.75		1.00		0.82
SORA			0.88	0.86	1.00		0.67	0.00	1.00		0.83
Proportion of radio-marked rails that departed $\leq 10$ days after capture											
VIRA	0.50	0.33	0.77	0.50	0.43	0.50	0.69		0.30		0.54
SORA			0.88	1.00	0.67		0.67	0.00	1.00		0.83
Mean home range size											
VIRA		5.13		3.57	6.76		16.66		4.99		7.14
SORA				3.46	0.59				0.45		1.50

Table A.5. Summary table of capture results and movements of Virginia rails (VIRA) and soras (SORA) by wetland unit at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2018. “Captured” refers to all rail capture events including initial captures, recaptures, and trap mortalities. “Radio-marked” refers to all rails that were fitted with a frequency-coded VHF radio transmitter or pulse-coded VHF radio transmitter.

	2018 Units								Total
	A	D	E	H	I	J	K	L	
Captured									
VIRA	20	35	19	22	52	5	19	0	172
SORA	8	12	10	2	14	1	3	0	50
Banded									
VIRA	20	28	15	21	37	5	12	0	138
SORA	7	12	10	2	14	1	3	0	49
Radio-marked									
VIRA	19	27	15	18	35	4	11	0	129
SORA	7	8	4	0	10	1	2	0	32
Proportion of radio-marked rails that used only 1 unit									
VIRA	0.56	0.91	0.93	0.88	0.61	1.00	0.70		0.76
SORA	1.00	0.71	1.00		0.50	1.00	0.50		0.73
Proportion of radio-marked rails that departed $\leq 10$ days after capture									
VIRA	0.63	0.45	0.93	0.56	0.39	0.33	0.50		0.54
SORA	1.00	0.43	0.50		0.40	1.00	0.00		0.53
Mean home range size									
VIRA	1.62	2.63	0.82	4.85	0.26	3.66	3.52	0.13	3.07
SORA									

Table A.6. Summary table of capture results and movements of Virginia rails (VIRA) and soras (SORA) by wetland unit at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2019. “Captured” refers to all rail capture events including initial captures, recaptures, and trap mortalities. “Radio-marked” refers to all rails that were fitted with a frequency-coded VHF radio transmitter or pulse-coded VHF radio transmitter.

	2019 Units								Total
	A	D	E	H	I	J	K	M	
Captured									
VIRA	24	12	3	28	38	8	6	2	121
SORA	14	6	1	10	18	0	1	0	50
Banded									
VIRA	22	9	3	25	30	8	6	2	105
SORA	13	6	1	10	14	0	1	0	45
Radio-marked									
VIRA	20	8	2	24	27	7	6	1	95
SORA	9	3	1	7	11	0	1	0	32
Proportion of radio-marked rails that used only 1 unit									
VIRA	0.83	0.75	1.00	1.00	0.76	0.57	0.50	1.00	0.81
SORA	0.75	1.00	1.00	1.00	0.64		0.00		0.80
Proportion of radio-marked rails that departed $\leq 10$ days after capture									
VIRA	0.42	0.75	0.50	0.38	0.33	0.71	0.83	0.00	0.47
SORA	0.25	0.33	1.00	0.71	0.73		0.00		0.57
Mean home range size									
VIRA	5.22	2.23		1.18	1.46	3.60			2.66
SORA									

Table A.7. Summary table of capture results and movements of Virginia rails (VIRA) and soras (SORA) by wetland unit at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019. “Captured” refers to all rail capture events including initial captures, recaptures, and trap mortalities. “Radio-marked” refers to all rails that were fitted with a frequency-coded VHF radio transmitter or pulse-coded VHF radio transmitter.

	2016 – 2019 Units													Total
	A	B	C	D	E	F	H	I	J	K	L	M	Unknown	
Captured														
VIRA	58	8	5	71	67	24	68	116	26	44	0	30	125	642
SORA	24	0	4	30	38	7	28	40	8	5	0	8	24	216
Banded														
VIRA	55	6	5	57	55	21	61	89	24	36	0	27	120	556
SORA	22	0	4	30	36	7	25	36	6	5	0	8	23	202
Radio-marked														
VIRA	50	7	3	57	53	17	55	86	16	31	0	1	0	376
SORA	18	0	4	19	26	3	17	25	5	4	0	0	0	121
Proportion of radio-marked rails that used only 1 unit														
VIRA	0.77	0.86	0.67	0.82	0.96	0.87	0.87	0.71	0.57	0.79		1.00		0.81
SORA	0.88		1.00	0.83	0.96	1.00	0.94	0.60	0.80	0.67				0.84
Proportion of radio-marked rails that departed $\leq 10$ days after capture														
VIRA	0.67	0.33	0.50	0.78	0.57	0.46	0.51	0.62	0.88	0.64		0.00		0.49
SORA	0.57		0.25	0.73	0.68	0.67	0.47	1.00	1.00	0.50				0.57
Mean home range size														
VIRA	2.65	9.26		2.50	2.95	6.76	3.48	10.56	3.65	4.55	0.13			4.77
SORA					2.00	0.59	1.42			0.45				1.29

Table A.8. Gender of frequency-coded and pulse-coded Virginia rails (VIRA) and soras (SORA) captured at Winous Point Marsh, Ottawa and Sandusky Counties, Ohio, USA during 2016 – 2019.

Year	Species	Male	Female	Unknown
2016	VIRA	31	24	9
	SORA	2	27	5
2017	VIRA	51	33	4
	SORA	5	18	0
2018	VIRA	89	39	1
	SORA	21	11	0
2019	VIRA	66	28	1
	SORA	19	10	3
Total		284 (57.1%)	190 (38.2%)	23 (4.6%)

Table A.9. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the pre-nesting stage in 2016 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Pre-nesting candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta AIC_i$	$w_i$
<b>Rail traits</b>					
~ species*sex*condition	7	-942.47	1899.50	0.00	0.56
~ species*condition	3	-948.50	1903.12	3.62	0.09
~ sex*condition + species	4	-947.58	1903.36	3.86	0.08
~ species	1	-950.93	1903.89	4.39	0.06
~ species*condition + sex	4	-948.15	1904.50	4.99	0.05
~ species + condition	2	-950.25	1904.55	5.05	0.05
~ species*sex	3	-949.30	1904.72	5.22	0.04
~ species*sex + condition	4	-948.72	1905.64	6.14	0.03
~ species + sex	2	-950.89	1905.84	6.33	0.02
~ species + sex + condition	3	-950.08	1906.27	6.77	0.02
~ sex*condition	3	-956.84	1919.80	20.29	0.00
null	0	-959.91	1919.81	20.31	0.00
~ sex	1	-959.18	1920.38	20.87	0.00
~ sex + condition	2	-958.22	1920.49	20.99	0.00
~ condition	1	-959.26	1920.53	21.03	0.00
<b>Time</b>					
~ capture date*year	3	-935.68	1877.48	0.00	1.00
~ capture date + year	2	-942.71	1889.48	12.00	0.00
~ capture date	1	-946.75	1895.52	18.03	0.00

Continued

Table A.9. Continued

null	0	-959.91	1919.81	42.33	0.00
~ year	1	-959.63	1921.28	43.80	0.00
<hr/> Wetland management <hr/>					
~ grade*management	3	-954.33	1914.77	0.00	0.85
null	0	-959.91	1919.81	5.04	0.07
~ grade	1	-959.57	1921.16	6.39	0.03
~ management	1	-959.64	1921.29	6.52	0.03
~ grade + management	2	-959.26	1922.59	7.81	0.02
<hr/> Weather conditions <hr/>					
~ wind direction change*wind speed + precipitation*pressure	6	-936.50	1885.43	0.00	0.37
~ wind direction change + wind speed + precipitation*pressure	5	-938.01	1886.33	0.90	0.24
~ wind direction change*wind speed + precipitation*pressure + visibility	7	-936.19	1886.95	1.52	0.17
~ wind direction change*wind speed + precipitation + pressure	5	-938.76	1887.83	2.40	0.11
~ wind direction change*wind speed + precipitation*pressure + visibility + cloud cover change	8	-936.01	1888.75	3.32	0.07
~ wind direction change*wind speed + precipitation*pressure + visibility*cloud cover change	9	-935.99	1890.91	5.48	0.02
~ wind direction change*wind speed + precipitation*pressure + temperature change + visibility*cloud cover change	10	-935.82	1892.78	7.35	0.01
~ wind direction change + wind speed + pressure + precipitation + temperature change + humidity + visibility + cloud cover change	8	-939.52	1895.78	10.35	0.00
~ wind direction change*wind speed*pressure + precipitation*pressure + temperature change*humidity + visibility*cloud cover change	15	-931.84	1896.24	10.81	0.00

Continued

Table A.9. Continued

~ wind direction change*wind speed + pressure	4	-944.55	1897.31	11.88	0.00
~ precipitation*pressure	3	-949.84	1905.81	20.38	0.00
~ visibility*cloud cover change	3	-955.01	1916.13	30.70	0.00
null	0	-959.91	1919.81	34.38	0.00
~ temperature change	1	-959.02	1920.06	34.63	0.00
<hr/>					
Wind					
<hr/>					
~ wind direction change*wind speed + pressure	4	-944.55	1897.31	0.00	0.24
~ wind direction change + wind speed + pressure	3	-945.76	1897.64	0.33	0.20
~ wind speed + pressure	2	-947.31	1898.68	1.37	0.12
~ wind direction change*pressure + wind speed	4	-945.32	1898.84	1.53	0.11
~ wind speed*pressure + wind direction change	4	-945.48	1899.17	1.86	0.10
~ wind direction change*wind speed*pressure	7	-942.72	1900.01	2.70	0.06
~ wind speed*pressure	3	-947.11	1900.33	3.02	0.05
~ wind direction change*wind speed	3	-947.33	1900.79	3.48	0.04
~ wind direction change + wind speed	2	-948.45	1900.96	3.65	0.04
~ wind speed	1	-949.82	1901.67	4.36	0.03
~ wind direction change	1	-956.32	1914.67	17.36	0.00
~ wind direction change + pressure	2	-955.89	1915.84	18.53	0.00
~ wind direction change*pressure	3	-955.25	1916.62	19.31	0.00
null	0	-959.91	1919.81	22.50	0.00
~ pressure	1	-959.72	1921.45	24.14	0.00
<hr/>					
Precipitation					
<hr/>					
~ precipitation*pressure	3	-949.84	1905.81	0.00	0.69

Continued

Table A.9. Continued

~ precipitation	1	-953.31	1908.64	2.84	0.17
~ precipitation + pressure	2	-952.44	1908.95	3.14	0.14
null	0	-959.91	1919.81	14.01	0.00
~ pressure	1	-959.72	1921.45	15.65	0.00
<hr/>					
Temperature					
<hr/>					
null	0	-959.91	1919.81	0.00	0.37
~ temperature change	1	-959.02	1920.06	0.25	0.33
~ humidity	1	-959.89	1921.80	1.99	0.14
~ temperature change + humidity	2	-959.02	1922.10	2.28	0.12
~ temperature change*humidity	3	-959.01	1924.14	4.33	0.04
<hr/>					
Sky					
<hr/>					
~ visibility*cloud cover change	3	-955.01	1916.13	0.00	0.48
~ visibility	1	-957.73	1917.48	1.35	0.25
~ visibility + cloud cover change	2	-957.31	1918.68	2.55	0.14
null	0	-959.91	1919.81	3.68	0.08
~ cloud cover change	1	-959.18	1920.38	4.25	0.06
<hr/>					

Table A.10. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the nesting stage in 2016 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Nesting candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta AIC_i$	$w_i$
<b>Rail traits</b>					
~ sex	1	-668.04	1338.10	0.00	0.24
null	0	-669.18	1338.37	0.27	0.21
~ species	1	-668.88	1339.78	1.68	0.10
~ sex + condition	2	-668.00	1340.09	1.99	0.09
~ species + sex	2	-668.02	1340.13	2.03	0.09
~ condition	1	-669.18	1340.39	2.29	0.08
~ sex*condition	3	-667.78	1341.72	3.62	0.04
~ species + condition	2	-668.87	1341.83	3.73	0.04
~ species + sex + condition	3	-667.99	1342.14	4.04	0.03
~ species*sex	3	-668.02	1342.21	4.11	0.03
~ sex*condition + species	4	-667.73	1343.74	5.64	0.01
~ species*condition	3	-668.87	1343.90	5.80	0.01
~ species*condition + sex	4	-667.98	1344.24	6.14	0.01
~ species*sex + condition	4	-667.98	1344.24	6.14	0.01
~ species*sex*condition	7	-665.70	1346.19	8.09	0.00
<b>Time</b>					
~ capture date	1	-660.56	1323.16	0.00	0.59
~ capture date + year	2	-660.50	1325.08	1.92	0.22
~ capture date*year	3	-659.63	1325.43	2.27	0.19

Continued

Table A.10. Continued

null	0	-669.18	1338.37	15.21	0.00
~ year	1	-669.16	1340.34	17.18	0.00
<hr/> Wetland management <hr/>					
~ management	1	-668.14	1338.31	0.00	0.32
null	0	-669.18	1338.37	0.05	0.31
~ grade + management	2	-667.98	1340.05	1.73	0.13
~ grade*management	3	-667.04	1340.25	1.94	0.12
~ grade	1	-669.13	1340.29	1.97	0.12
<hr/> Weather conditions <hr/>					
~ wind speed + pressure + humidity + visibility	4	-656.85	1321.97	0.00	0.41
~ wind speed + pressure + visibility	3	-658.21	1322.58	0.61	0.30
~ wind speed*pressure + humidity + visibility	5	-656.48	1323.37	1.39	0.20
~ wind speed*pressure + precipitation + humidity + visibility	6	-656.48	1325.54	3.56	0.07
~ wind direction change + wind speed + pressure + precipitation + temperature change + humidity + visibility + cloud cover change	8	-655.99	1328.98	7.01	0.01
~ wind direction change*wind speed*pressure + precipitation*pressure + temperature change*humidity + visibility*cloud cover change	15	-649.61	1332.75	10.78	0.00
~ visibility	1	-665.42	1332.87	10.90	0.00
~ wind speed*pressure	3	-663.41	1332.98	11.01	0.00
~ humidity	1	-667.82	1337.66	15.69	0.00
~ precipitation	1	-668.10	1338.22	16.25	0.00
null	0	-669.18	1338.37	16.39	0.00

Continued

Table A.10. Continued

Wind					
~ wind speed + pressure	2	-663.97	1332.02	0.00	0.20
~ wind speed	1	-665.32	1332.67	0.65	0.15
~ wind speed*pressure	3	-663.41	1332.98	0.97	0.12
~ wind direction change*wind speed + pressure	4	-662.51	1333.29	1.28	0.11
~ wind direction change + wind speed + pressure	3	-663.71	1333.59	1.57	0.09
~ wind direction change*wind speed	3	-663.82	1333.80	1.78	0.08
~ wind direction change + wind speed	2	-665.08	1334.23	2.21	0.07
~ wind direction change*pressure + wind speed	4	-663.10	1334.48	2.46	0.06
~ wind speed*pressure + wind direction change	4	-663.13	1334.52	2.50	0.06
~ wind direction change*wind speed*pressure	7	-660.26	1335.29	3.28	0.04
null	0	-669.18	1338.37	6.35	0.01
~ wind direction change	1	-668.37	1338.77	6.75	0.01
~ pressure	1	-668.88	1339.79	7.77	0.00
~ wind direction change + pressure	2	-668.00	1340.09	8.07	0.00
~ wind direction change*pressure	3	-667.30	1340.77	8.75	0.00
Precipitation					
~ precipitation	1	-668.10	1338.22	0.00	0.31
null	0	-669.18	1338.37	0.14	0.29
~ precipitation + pressure	2	-667.51	1339.11	0.88	0.20
~ pressure	1	-668.88	1339.79	1.57	0.14
~ precipitation*pressure	3	-667.49	1341.14	2.92	0.07

Continued

Table A.10. Continued

Temperature					
~ humidity	1	-667.82	1337.66	0.00	0.34
null	0	-669.18	1338.37	0.70	0.24
~ temperature change*humidity	3	-666.29	1338.75	1.08	0.20
~ temperature change + humidity	2	-667.80	1339.67	2.01	0.13
~ temperature change	1	-669.11	1340.25	2.59	0.09
Sky					
~ visibility	1	-665.42	1332.87	0.00	0.59
~ visibility + cloud cover change	2	-665.41	1334.91	2.03	0.21
~ visibility*cloud cover change	3	-664.77	1335.69	2.82	0.14
null	0	-669.18	1338.37	5.49	0.04
~ cloud cover change	1	-669.17	1340.36	7.49	0.01

Table A.11. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the post-breeding stage in 2016 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta\text{AIC}_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Post-breeding candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta\text{AIC}_i$	$w_i$
Rail traits					
null	0	-78.90	157.80	0.00	0.19
~ species	1	-77.93	158.04	0.24	0.17
~ condition	1	-77.99	158.16	0.36	0.16
~ sex	1	-78.33	158.83	1.03	0.11
~ species + condition	2	-77.17	158.88	1.08	0.11
~ species + sex	2	-77.51	159.57	1.77	0.08
~ sex + condition	2	-77.67	159.88	2.08	0.07
~ species + sex + condition	3	-76.92	160.98	3.18	0.04
~ species*condition	3	-77.17	161.47	3.67	0.03
~ sex*condition	3	-77.20	161.55	3.75	0.03
~ sex*condition + species	4	-76.35	162.70	4.89	0.02
~ species*condition + sex	4	-76.91	163.81	6.01	0.01
Time					
~ capture date	1	-70.02	142.21	0.00	0.70
~ capture date + year	2	-70.02	144.58	2.37	0.22
~ capture date*year	3	-69.72	146.58	4.36	0.08
null	0	-78.90	157.80	15.59	0.00
~ year	1	-77.89	157.95	15.74	0.00

Continued

Table A.11. Continued

Wetland management					
~ grade*management	3	-70.14	147.42	0.00	0.99
~ management	1	-77.79	157.76	10.34	0.01
null	0	-78.90	157.80	10.38	0.01
~ grade	1	-78.89	159.96	12.54	0.00
~ grade + management	2	-77.76	160.07	12.64	0.00
Weather conditions					
~ pressure + visibility	2	-70.93	146.40	0.00	0.53
~ pressure + precipitation + visibility	3	-70.26	147.66	1.25	0.29
~ visibility	1	-73.95	150.08	3.68	0.08
~ precipitation + pressure	2	-75.30	155.14	8.73	0.01
~ pressure	1	-77.28	156.74	10.33	0.00
null	0	-78.90	157.80	11.40	0.00
~ wind direction change + wind speed + pressure + precipitation + temperature change + humidity + visibility + cloud cover change	8	-68.72	162.44	16.04	0.00
~ wind direction change*wind speed*pressure + precipitation*pressure + temperature change*humidity + visibility*cloud cover change	15	-67.20	217.74	71.33	0.00
Wind					
~ pressure	1	-77.28	156.74	0.00	0.27
null	0	-78.90	157.80	1.07	0.16
~ wind direction change + pressure	2	-76.87	158.29	1.55	0.12
~ wind speed + pressure	2	-77.27	159.08	2.34	0.08
~ wind speed*pressure	3	-76.13	159.39	2.66	0.07
~ wind speed	1	-78.68	159.54	2.80	0.07

Continued

Table A.11. Continued

~ wind direction change	1	-78.73	159.63	2.90	0.06
~ wind direction change*pressure	3	-76.54	160.23	3.49	0.05
~ wind direction change + wind speed + pressure	3	-76.78	160.71	3.97	0.04
~ wind direction change + wind speed	2	-78.38	161.31	4.58	0.03
~ wind speed*pressure + wind direction change	4	-75.77	161.54	4.80	0.02
~ wind direction change*pressure + wind speed	4	-76.40	162.81	6.07	0.01
~ wind direction change*wind speed + pressure	4	-76.78	163.56	6.83	0.01
~ wind direction change*wind speed	3	-78.34	163.83	7.09	0.01
~ wind direction change*wind speed*pressure	7	-75.42	171.43	14.69	0.00
<hr/> Precipitation <hr/>					
~ precipitation + pressure	2	-75.30	155.14	0.00	0.37
~ precipitation	1	-76.96	156.10	0.96	0.23
~ pressure	1	-77.28	156.74	1.60	0.17
~ precipitation*pressure	3	-74.99	157.13	1.99	0.14
null	0	-78.90	157.80	2.67	0.10
<hr/> Temperature <hr/>					
null	0	-78.90	157.80	0.00	0.54
~ temperature change	1	-78.84	159.85	2.05	0.19
~ humidity	1	-78.86	159.90	2.10	0.19
~ temperature change + humidity	2	-78.80	162.15	4.35	0.06
~ temperature change*humidity	3	-78.75	164.64	6.84	0.02

Continued

Table A.11. Continued

Sky					
~ visibility	1	-73.95	150.08	0.00	0.57
~ visibility + cloud cover change	2	-73.36	151.27	1.19	0.31
~ visibility*cloud cover change	3	-73.16	153.46	3.37	0.10
null	0	-78.90	157.80	7.72	0.01
~ cloud cover change	1	-78.85	159.87	9.79	0.00

Table A.12. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the pre-nesting stage in 2018 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Pre-nesting candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta AIC_i$	$w_i$
<b>Rail traits</b>					
~ species	1	-578.48	1159.00	0.00	0.41
~ species + condition	2	-578.48	1161.05	2.06	0.15
~ species + sex	2	-578.48	1161.05	2.06	0.15
~ species*condition	3	-578.17	1162.51	3.51	0.07
~ sex*condition + species	4	-577.26	1162.81	3.81	0.06
~ species + sex + condition	3	-578.48	1163.14	4.14	0.05
~ species*sex	3	-578.48	1163.14	4.14	0.05
~ species*condition + sex	4	-578.16	1164.62	5.63	0.02
~ species*sex*condition	7	-575.09	1165.02	6.02	0.02
~ species*sex + condition	4	-578.48	1165.26	6.26	0.02
null	0	-584.15	1168.30	9.30	0.00
~ condition	1	-584.02	1170.07	11.07	0.00
~ sex	1	-584.15	1170.32	11.33	0.00
~ sex*condition	3	-582.50	1171.18	12.18	0.00
~ sex + condition	2	-584.01	1172.11	13.11	0.00
<b>Time</b>					
~ capture date + year	2	-558.80	1121.69	0.00	0.73
~ capture date*year	3	-558.80	1123.77	2.09	0.26

Continued

Table A.12. Continued

~ capture date	1	-564.17	1130.37	8.69	0.01
~ year	1	-580.83	1163.69	42.01	0.00
null	0	-584.15	1168.30	46.61	0.00
<hr/> Wetland management <hr/>					
~ water level*water level change + management	4	-575.42	1159.14	0.00	0.59
~ grade*water level	3	-577.76	1161.70	2.55	0.16
~ management*water level	3	-577.85	1161.87	2.73	0.15
~ management*water level*water level change	7	-574.80	1164.45	5.31	0.04
~ grade*water level*water level change	7	-575.66	1166.16	7.01	0.02
null	0	-584.15	1168.30	9.16	0.01
~ water level	1	-583.29	1168.60	9.46	0.01
~ water level change	1	-583.32	1168.67	9.52	0.01
~ grade*management	2	-582.37	1168.82	9.68	0.00
~ grade + management	2	-582.37	1168.82	9.68	0.00
~ grade	1	-583.46	1168.95	9.81	0.00
~ management	1	-583.49	1169.00	9.86	0.00
~ water level*water level change	3	-581.77	1169.71	10.57	0.00
~ grade*water level change	3	-582.51	1171.19	12.05	0.00
~ water level*water level change + grade	4	-581.59	1171.48	12.34	0.00
~ management*water level change	3	-582.69	1171.56	12.42	0.00
<hr/> Weather conditions <hr/>					
~ wind direction change + wind speed + pressure + precipitation + temperature change + humidity + visibility + cloud cover change	8	-566.15	1149.39	0.00	0.54

Continued

Table A.12. Continued

~ wind speed*pressure + wind direction change + precipitation + temperature change + visibility*cloud cover change	9	-565.78	1150.94	1.55	0.25
~ wind direction change + precipitation	2	-575.11	1154.32	4.93	0.05
~ pressure + wind direction change + precipitation	3	-574.09	1154.36	4.97	0.04
~ precipitation	1	-576.27	1154.56	5.17	0.04
~ precipitation + pressure	2	-575.30	1154.68	5.29	0.04
~ pressure + wind direction change + precipitation + visibility	4	-573.68	1155.65	6.26	0.02
~ pressure + wind direction change + precipitation + visibility*cloud cover change	6	-572.58	1157.79	8.40	0.01
~ wind speed*pressure + wind direction change	4	-575.20	1158.70	9.31	0.01
~ visibility*cloud cover change	3	-576.34	1158.85	9.46	0.00
~ pressure + wind direction change + precipitation + temperature change + visibility*cloud cover change	7	-572.55	1159.94	10.55	0.00
~ temperature change	1	-583.01	1168.05	18.66	0.00
null	0	-584.15	1168.30	18.91	0.00
<hr/>					
Wind					
~ wind direction change + wind speed + pressure	3	-575.53	1157.24	0.00	0.22
~ wind direction change + wind speed	2	-576.92	1157.93	0.69	0.16
~ wind speed + pressure	2	-577.30	1158.69	1.45	0.11
~ wind speed*pressure + wind direction change	4	-575.20	1158.70	1.46	0.11
~ wind speed	1	-578.36	1158.74	1.50	0.10
~ wind direction change*pressure + wind speed	4	-575.30	1158.88	1.65	0.10
~ wind direction change*wind speed + pressure	4	-575.52	1159.34	2.10	0.08

Continued

Table A.12. Continued

~ wind direction change*wind speed	3	-576.89	1159.96	2.72	0.06
~ wind speed*pressure	3	-577.08	1160.34	3.10	0.05
~ wind direction change*wind speed*pressure	7	-573.61	1162.07	4.83	0.02
~ wind direction change	1	-581.23	1164.48	7.24	0.01
~ wind direction change + pressure	2	-580.96	1166.01	8.77	0.00
~ wind direction change*pressure	3	-580.86	1167.89	10.65	0.00
null	0	-584.15	1168.30	11.06	0.00
~ pressure	1	-584.10	1170.23	12.99	0.00
<hr/> Precipitation <hr/>					
~ precipitation	1	-576.27	1154.56	0.00	0.51
~ precipitation + pressure	2	-575.30	1154.68	0.12	0.48
null	0	-584.15	1168.30	13.73	0.00
~ pressure	1	-584.10	1170.23	15.66	0.00
<hr/> Temperature <hr/>					
~ temperature change	1	-583.01	1168.05	0.00	0.32
null	0	-584.15	1168.30	0.25	0.28
~ temperature change*humidity	3	-581.62	1169.41	1.36	0.16
~ humidity	1	-583.96	1169.95	1.90	0.12
~ temperature change + humidity	2	-582.99	1170.06	2.01	0.12
<hr/> Sky <hr/>					
~ visibility*cloud cover change	3	-576.34	1158.85	0.00	0.78
~ visibility	1	-580.04	1162.11	3.26	0.15
~ visibility + cloud cover change	2	-579.99	1164.08	5.22	0.06
null	0	-584.15	1168.30	9.45	0.01
~ cloud cover change	1	-584.14	1170.31	11.45	0.00

Table A.13. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the nesting stage in 2018 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Nesting candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta AIC_i$	$w_i$
<b>Rail traits</b>					
null	0	-268.82	537.63	0.00	0.31
~ sex	1	-268.77	539.60	1.97	0.12
~ species	1	-268.78	539.61	1.97	0.12
~ condition	1	-268.82	539.69	2.05	0.11
~ sex*condition	3	-266.87	540.07	2.44	0.09
~ species*condition	3	-267.58	541.49	3.86	0.04
~ species + sex	2	-268.75	541.66	4.02	0.04
~ sex + condition	2	-268.77	541.70	4.07	0.04
~ species + condition	2	-268.77	541.72	4.08	0.04
~ sex*condition + species	4	-266.86	542.30	4.67	0.03
~ species*sex	3	-268.48	543.30	5.67	0.02
~ species*condition + sex	4	-267.56	543.68	6.05	0.02
~ species + sex + condition	3	-268.74	543.82	6.18	0.01
~ species*sex*condition	7	-264.89	545.45	7.82	0.01
~ species*sex + condition	4	-268.46	545.49	7.86	0.01
<b>Time</b>					
~ capture date	1	-263.88	529.82	0.00	0.61
~ capture date + year	2	-263.62	531.40	1.58	0.28
~ capture date*year	3	-263.55	533.44	3.62	0.10

Continued

Table A.13. Continued

null	0	-268.82	537.63	7.81	0.01
~ year	1	-268.77	539.59	9.78	0.00
<hr/> Wetland management <hr/>					
~ water level change	1	-267.61	537.28	0.00	0.19
~ management*water level	3	-265.61	537.56	0.28	0.16
null	0	-268.82	537.63	0.35	0.16
~ management	1	-268.05	538.16	0.88	0.12
~ water level	1	-268.36	538.78	1.50	0.09
~ grade	1	-268.80	539.66	2.38	0.06
~ grade + management	2	-268.03	540.23	2.95	0.04
~ grade*water level change	3	-267.04	540.42	3.14	0.04
~ water level*water level change	3	-267.16	540.66	3.38	0.03
~ management*water level change	3	-267.22	540.77	3.49	0.03
~ grade*water level	3	-267.49	541.31	4.03	0.02
~ grade*management	3	-267.78	541.90	4.62	0.02
~ water level*water level change + management	4	-266.74	542.05	4.77	0.02
~ water level*water level change + grade	4	-267.12	542.81	5.53	0.01
~ management*water level*water level change	7	-264.07	543.82	6.54	0.01
~ grade*water level*water level change	7	-264.98	545.64	8.36	0.00
<hr/> Weather conditions <hr/>					
~ wind direction change + visibility	2	-262.51	529.18	0.00	0.37
~ wind direction change	1	-264.18	530.41	1.23	0.20
~ wind direction change + visibility + cloud cover change	3	-262.20	530.75	1.56	0.17

Continued

Table A.13. Continued

~ wind direction change + visibility*cloud cover change	4	-261.19	530.95	1.77	0.15
~ wind direction change + temperature change + visibility*cloud cover change	5	-260.58	532.03	2.85	0.09
~ temperature change	1	-266.97	536.00	6.82	0.01
~ visibility*cloud cover change	3	-265.17	536.68	7.50	0.01
null	0	-268.82	537.63	8.45	0.01
<hr/>					
Wind					
~ wind direction change	1	-264.18	530.41	0.00	0.40
~ wind direction change + pressure	2	-264.02	532.20	1.79	0.16
~ wind direction change + wind speed	2	-264.05	532.27	1.87	0.16
~ wind direction change + wind speed + pressure	3	-263.95	534.23	3.82	0.06
~ wind speed*pressure + wind direction change	4	-262.89	534.35	3.94	0.05
~ wind direction change*pressure	3	-264.02	534.37	3.96	0.05
~ wind direction change*wind speed	3	-264.05	534.44	4.03	0.05
~ wind direction change*wind speed + pressure	4	-263.94	536.45	6.05	0.02
~ wind direction change*pressure + wind speed	4	-263.95	536.46	6.05	0.02
null	0	-268.82	537.63	7.22	0.01
~ wind speed	1	-268.30	538.66	8.25	0.01
~ pressure	1	-268.45	538.95	8.54	0.01
~ wind speed + pressure	2	-268.09	540.35	9.94	0.00
~ wind speed*pressure	3	-267.25	540.83	10.42	0.00
~ wind direction change*wind speed*pressure	7	-262.65	540.98	10.57	0.00

Continued

Table A.13. Continued

Precipitation					
null	0	-268.82	537.63	0.00	0.66
~ pressure	1	-268.45	538.95	1.31	0.34
Temperature					
~ temperature change	1	-266.97	536.00	0.00	0.43
null	0	-268.82	537.63	1.63	0.19
~ temperature change + humidity	2	-266.85	537.87	1.86	0.17
~ temperature change*humidity	3	-266.05	538.44	2.43	0.13
~ humidity	1	-268.77	539.60	3.59	0.07
Sky					
~ visibility	1	-267.07	536.20	0.00	0.30
~ visibility*cloud cover change	3	-265.17	536.68	0.48	0.23
~ visibility + cloud cover change	2	-266.37	536.91	0.71	0.21
null	0	-268.82	537.63	1.43	0.14
~ cloud cover change	1	-267.95	537.95	1.74	0.12

Table A.14. Extended Cox proportional hazards candidate models predicting departure probability of Virginia rails and soras marked with frequency- and pulse-coded transmitters at Winous Point Marsh, Ottawa County, Ohio, USA during the post-breeding stage in 2018 – 2019. The number of parameters (K), Log-Likelihood score, corrected Akaike Information Criterion (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> from the lowest AIC<sub>c</sub> of the model set ( $\Delta AIC_i$ ), and Akaike weight ( $w_i$ ) were reported for each model.

Post-breeding candidate models	K	Log-likelihood	AIC <sub>c</sub>	$\Delta AIC_i$	$w_i$
<b>Rail traits</b>					
null	0	-7.75	15.49	0.00	0.95
~ condition	1	-7.73	21.46	5.97	0.05
<b>Time</b>					
~ capture date*year	3	-7.65	-2.70	0.00	1.00
null	0	-7.75	15.49	18.19	0.00
~ year	1	-7.67	21.34	24.04	0.00
~ capture date	1	-7.71	21.42	24.12	0.00
~ capture date + year	2	-7.65	Inf	Inf	0.00
<b>Wetland management</b>					
~ water level*water level change	3	-7.66	-2.68	0.00	0.20
~ water level*water level change + management	3	-7.66	-2.68	0.00	0.20
~ management*water level*water level change	3	-7.66	-2.68	0.00	0.20
~ grade*water level change	3	-7.67	-2.66	0.02	0.20
~ grade*water level	3	-7.74	-2.53	0.15	0.19
~ water level*water level change + grade	4	-7.66	3.32	6.00	0.01
~ grade*water level*water level change	7	-7.38	6.36	9.03	0.00
null	0	-7.75	15.49	18.17	0.00
~ management	0	-7.75	15.49	18.17	0.00

Continued

Table A.14. Continued

~ water level change	1	-7.68	21.36	24.03	0.00
~ management*water level change	1	-7.68	21.36	24.03	0.00
~ grade	1	-7.74	21.48	24.16	0.00
~ grade*management	1	-7.74	21.48	24.16	0.00
~ grade + management	1	-7.74	21.48	24.16	0.00
~ water level	1	-7.74	21.48	24.16	0.00
~ management*water level	1	-7.74	21.48	24.16	0.00
<hr/> Weather conditions <hr/>					
~ wind direction change*wind speed	3	-5.51	-6.97	0.00	0.74
~ temperature change*humidity	3	-6.85	-4.31	2.67	0.20
~ wind direction change*wind speed + humidity	4	-5.15	-1.70	5.27	0.05
~ wind direction change*wind speed + temperature change*humidity	6	-5.05	1.10	8.07	0.01
null	0	-7.75	15.49	22.46	0.00
~ wind direction change	1	-6.69	19.39	26.36	0.00
<hr/> Wind <hr/>					
~ wind direction change*wind speed	3	-5.51	-6.97	0.00	0.46
~ wind direction change*pressure	3	-6.07	-5.87	1.11	0.27
~ wind direction change + wind speed + pressure	3	-6.59	-4.83	2.14	0.16
~ wind speed*pressure	3	-7.47	-3.06	3.91	0.07
~ wind direction change*wind speed + pressure	4	-5.45	-1.11	5.86	0.02
~ wind direction change*pressure + wind speed	4	-6.04	0.09	7.06	0.01
~ wind speed*pressure + wind direction change	4	-6.48	0.95	7.93	0.01
null	0	-7.75	15.49	22.46	0.00

Continued

Table A.14. Continued

~ wind direction change	1	-6.69	19.39	26.36	0.00
~ pressure	1	-7.58	21.17	28.14	0.00
~ wind speed	1	-7.71	21.43	28.40	0.00
~ wind direction change + wind speed	2	-6.69	Inf	Inf	0.00
~ wind direction change + pressure	2	-6.59	Inf	Inf	0.00
~ wind speed + pressure	2	-7.56	Inf	Inf	0.00
<hr/> Precipitation <hr/>					
null	0	-7.75	15.49	0.00	0.94
~ pressure	1	-7.58	21.17	5.68	0.06
<hr/> Temperature <hr/>					
~ temperature change*humidity	3	-6.85	-4.31	0.00	1.00
null	0	-7.75	15.49	19.80	0.00
~ humidity	1	-7.14	20.27	24.58	0.00
~ temperature change	1	-7.41	20.82	25.13	0.00
~ temperature change + humidity	2	-6.86	Inf	Inf	0.00
<hr/> Sky <hr/>					
null	0	-7.75	15.49	0.00	0.75
~ cloud cover change	1	-6.04	18.07	2.58	0.21
~ visibility	1	-7.72	21.44	5.95	0.04
~ visibility + cloud cover change	2	-6.02	Inf	Inf	0.00

## Appendix B. Chapter 2 Supplemental Materials

Table B.1. Breakdown of 5 habitat classes and 12 cover types used to categorize and summarize detailed assessments from homing locations of radio-marked Virginia rails and soras and nearby random locations at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019.

	Habitat class				
	Water	Bare ground	Emergent	Scrub-shrub	Forest
Cover type			cattail / bur-reed		
	unvegetated		rose mallow / reed canary		
	submergent aquatic vegetation	unvegetated	loosestrife	scrub-shrub	forest
	floating-leaf vegetation		common reed		
			broadleaf		
			sedges, rushes, and grasses		

Table B.2. Mean raw values of multivariate analysis variables from radio-marked Virginia rail (VIRA) and sora (SORA) homing and random points at Winous Point Marsh and Ottawa National Wildlife Refuge Complex, Ottawa, Sandusky, and Lucas Counties, Ohio, USA during 2018 – 2019.

Multivariate variable	Mean (standard deviation) raw value			
	VIRA		SORA	
	Homing points	Random points	Homing points	Random points
Plot water depth	10.457 (7.813)	10.902 (8.678)	9.923 (8.259)	9.231 (7.848)
Residual plot water depth	0.013 (6.858)	0.463 (7.702)	-2.369 (8.085)	-3.044 (6.462)
Plot water depth variance	21.420 (31.624)	20.093 (30.390)	23.655 (20.576)	18.848 (11.988)
Distance to open water	13.098 (15.944)	13.351 (17.431)	4.923 (3.861)	12.538 (10.829)
Distance to edge	7.051 (9.091)	6.939 (9.290)	3.231 (3.516)	6.077 (5.908)
Proportion emergent cover	0.730 (0.215)	0.692 (0.236)	0.665 (0.252)	0.742 (0.237)
Proportion wooded cover	0.002 (0.017)	0.008 (0.050)	0.027 (0.073)	0.031 (0.078)
Cover class mid-point	0.309 (0.198)	0.342 (0.217)	0.338 (0.233)	0.338 (0.233)
Plot visual obstruction	50.228 (29.405)	44.552 (31.207)	22.115 (9.304)	28.462 (19.679)
Residual plot visual obstruction	2.737 (21.980)	-2.931 (25.584)	-2.183 (11.288)	4.395 (20.618)
Plot visual obstruction variance	285.177 (495.637)	259.614 (377.459)	165.705 (142.323)	244.551 (314.382)