# Effects of hunting frequency on wintering waterfowl abundance using UAVs

by

Brittany Hansey

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 6, 2023

Keywords: Wintering Waterfowl Abundance, Hunting Disturbance, UAVs, Survey Protocol

Approved by

Robert A. Gitzen, Chair, Associate Professor of Wildlife, College of
Forestry, Wildlife and Environment
William D. Gulsby, Co-chair, Associate Professor of Wildlife, College
of Forestry, Wildlife and Environment
Heath M. Hagy, Waterfowl Ecologist, U.S. Fish and Wildlife Service

# Abstract

Waterfowl managers must navigate trade-offs between providing sustainable waterfowl populations and hunting opportunities to establish effective waterfowl hunting regulations. Assessing these trade-offs requires information on how hunter disturbance affects wintering waterfowl use of hunted lands. Unmanned aerial vehicles (UAVs) are an emerging technology that can be utilized for surveying wintering waterfowl to meet various objectives. We implemented a study in the Tennessee River Valley (TRV) in North Alabama to quantify effects of hunting frequency on waterfowl relative abundance on state management units and provide a UAV survey protocol for future waterfowl research. We observed low relative abundances on hunted areas during both day and night compared to refuges. Our UAV survey protocol enabled us to obtain imagery with sufficient resolution to identify waterfowl during the day and detect and count individuals at night.

# Acknowledgments

Funding for this project was provided by the Alabama Department of Conservation and Natural Resources (ADCNR) Division of Wildlife and Freshwater Fisheries. I would like to thank ADCNR staff Seth Maddox, Amy Silvano, Austin LeCroy, Drew Able, and Courtnay Conring, and other ADCNR staff for their logistical and technical support for the project. Additionally, I would like to thank all of my technicians, Hunter Cleveland, Lauren Govekar, Amy Kopec, Blake Struthers, Justin Speicher, and Matthew Johnson for assisting me with data collection.

I would like to thank my advisors, Dr. Robert Gitzen and Dr. William Gulsby, for their impeccable guidance and inspirational mentorship throughout my long years of graduate study. They have provided me with numerous opportunities to expand my experience and knowledge in wildlife management practices and statistics. They truly are role models both as professionals and as human beings. I would also like to thank my committee member Dr. Heath Hagy for providing a wealth of knowledge on waterfowl survey design to the project, which has greatly increased my understanding of waterfowl management. I thank my fellow graduate students within the College of Forestry, Wildlife and Environment, for their support throughout my time in Auburn.

I would like to thank my family and friends in North Dakota for all the support and encouragement in pursuing my career goals. My previous experiences with you have shaped me into who I am today. I cannot express how thankful I am for all that you have done for me. Despite the long distance, you have all been there whenever needed.

## Table of Contents

List of Tables

## List of Figures

# CHAPTER 1

# EFFECTS OF HUNTING FREQUENCY ON WATERFOWL ABUNDANCE AND DISTRIBUTION IN THE TENNESSEE RIVER VALLEY

## ABSTRACT

State agencies must navigate the trade-offs between maximizing waterfowl hunter opportunity, ensuring a quality hunting experience, and providing waterfowl habitat. Assessing these trade-offs requires information on how hunter disturbance affects wintering waterfowl use of hunted lands. We implemented a study in the Tennessee River Valley (TRV) in Northern Alabama with the objective of quantifying the effects of hunting frequency on waterfowl relative abundance on state management units. Surveys included hunted units with varying regulations (i.e., hunted 4 vs. 7 days/week) and refuges (unhunted). During the winters of 2020-2021 and 2021-2022, we conducted day and night surveys before, during, and after the hunting season using a combination of unmanned aerial vehicles (UAV) surveys and ground counts. We compared total waterfowl relative abundances during each time period, across each unit type, and on hunt vs. non-hunt days during the hunting season. Daytime relative abundance of waterfowl was significantly greater on unhunted units than hunted units during the hunting season. Night-time relative abundance was generally lesser on hunted units than unhunted units during the season but did not differ statistically. We found no difference in relative abundance between hunt and non-hunt days during day or night. These results are consistent with our prediction that waterfowl relative abundance during the day would be greater on unhunted units during the hunting season. Our findings do not match our prediction that waterfowl would utilize hunted areas more at night and on non-hunt days. Reductions in hunter disturbance may be required to increase hunter opportunity and waterfowl use of our survey areas.

## INTRODUCTION

Balancing wintering waterfowl abundance with hunter opportunity requires knowledge of population size and the effects hunters have on waterfowl abundance and distribution (Nichols et al. 1995, Fox and Madsen 1997, Lancaster et al. 2015). Information on distribution and abundance of wintering waterfowl in response to hunting pressure helps guide managers to establish season frameworks that ensure sustainable populations while offering sufficient hunting opportunity (Johnson et al. 1997, Soulliere et al. 2013). Because waterfowl hunters are a key source of funding for wetland-wildlife habitat conservation and management, providing hunting opportunities is critical to maintain this source of funding (Schummer et al. 2020). However, in popular waterfowl hunting areas, like North Alabama's TRV, optimizing hunter opportunity can be difficult. Understanding the relationship between diurnal and nocturnal waterfowl abundance and hunting disturbance is important for assessing trade-offs between maximizing hunting opportunities (e.g., hours and days of open hunting on an area) vs. maximizing the number of birds seen or harvested by hunters, but the severity of these trade-offs depends partly on the degree to which hunter disturbance affects waterfowl use of hunted lands (Madsen and Fox 1995, Madsen 2001, Bregnballe and Madsen 2004, St. James et al. 2013).

The TRV provides important winter habitat for the greatest concentration of wintering waterfowl in Alabama, making it a prime location for waterfowl hunting (Wiebe 1946). It is an important, yet understudied, region for wintering waterfowl (Bellrose 1980), historically supporting >200,000 birds annually (USFWS 2007). Although this area provides waterfowl hunting opportunities in high demand on state and private lands, little is known about the impact hunting has on waterfowl in this region. Much of the TRV's historical waterfowl habitat has been lost or degraded via flood control, river channelization, agriculture, and urban expansion

(Phillips 2002, Dahl 2011). Consequently, wintering waterfowl abundance currently peaks at or near 100,000 birds according to state population counts (Seth Maddox, ADCNR, personal communication 2021). Waterfowl abundance and distribution are also affected by hunter disturbance in the TRV through direct (i.e., mortality) and indirect (i.e., shooting and boating) disturbance, which can affect hunter satisfaction (Korschgen and Dahlgren 1992, Madsen 1995, Madsen and Fox 1995, Bregnballe et al. 2004).

Waterfowl use of hunted areas partly depends on the degree of disturbance relative to resources available and energetic cost of movement  (Fox and Madsen 1997, Dooley et al. 2010, Webb et al. 2011, Hagy et al. 2017). Several management strategies exist to mitigate disturbance to waterfowl in attempt to maximize hunter satisfaction and maintain populations. For example, temporal restrictions that limit the number of hunt days or hours per week, and spatial refuges that are closed to all hunting activities, can sustain and often increase waterfowl abundance, influencing overall hunter success (Bellrose 1954, Madsen 1995, Fox and Madsen 1997, Evans and Day 2002, Bregenballe and Madsen 2004). Additionally, reducing hunter density in an area by limiting the number of hunters or hunting parties can also help minimize disturbance (Fox and Madsen 1997, St. James 2011). On Alabama state management units in the TRV, both temporal and spatial refuges exist. However, it is unknown how waterfowl utilize these lands in response to variable hunting frequencies dictated by temporal and spatial hunting restrictions, and whether waterfowl return to hunted areas when hunters are absent, such as at night or on closed days/hours.

Therefore, we quantified the effects of hunting frequency on waterfowl relative abundance and distribution on Alabama TRV state management units. This information will provide waterfowl managers with the information needed to establish regulations that optimize hunter opportunity and success, while maintaining sustainable populations. We hypothesized that hunting frequency would affect waterfowl relative abundance and distribution on state managed units in the TRV and predicted that 1) waterfowl relative abundance would be lesser on hunted areas during the hunting season, 2) waterfowl would utilize hunted areas more frequently on non-hunt days during the hunting season, and 3) waterfowl abundance would be greater at night than the day on hunted areas during the hunting season.

## METHODS

### Study Area

The TRV in North Alabama is considered an outer fringe of the Mississippi Flyway consisting of several reservoirs, impoundments, wildlife management areas (WMAs), state waterfowl refuges, and Wheeler National Wildlife Refuge. Substantial wetland loss and transformations have occurred in the TRV since the first dams were constructed in 1933 (USFWS 2007). Seasonally flooded backwaters and hardwood forests, which were likely rich in moist-soil seeds, tubers, invertebrates, and acorns, have been replaced by permanent reservoirs comprised primarily of open water with some submersed aquatic vegetation (SAV; USFWS 2007). Leveed impoundments within the National Wildlife Refuge and WMAs are gradually inundated in fall and winter, providing food for migrating and wintering waterfowl (USFWS 2007). Impoundments are flooded via pumping, gravity flow through water control structures, or through accumulation of precipitation (USFWS 2007).

Our study area was located within the floodplain of the Tennessee River and was flat or gently sloping but surrounded by the foothills of the Appalachian Mountains. Elevations ranged from 504–594 m above sea level (USFWS 2007, ADCNR 2015). The Lower Cumberland Tennessee Ecosystem typically experiences warm, humid summers (mean temperature > 20°C), mild winters (mean > 1°C), and rainfall is well-distributed seasonally (mean annual of 1,346 mm; USFWS 2007). Managed and natural wetlands within the study area include SAV, moist-soil vegetation, mudflats, open water, fields cultivated for row-crop agriculture, and isolated bottomland hardwood forests.

We focused on 7 state management units in the Alabama TRV, three of which had associated dewatering units (DWUs). Units in Jackson County included Crow Creek WMA (34.850444, -85.858056), Mud Creek WMA and DWU (34.754833, -85.9000556), Raccoon Creek WMA and DWU (34.817528, -85.811917), Crow Creek Waterfowl Refuge (34.840222, -85.831556) and North Sauty Waterfowl Refuge (34.591611, -86.097306). We also surveyed Swan Creek WMA and DWU (34.633056, -86.965278) in Limestone County, and Mallard Fox Creek WMA (34.682222, -87.137222) in Morgan and Lawrence counties. Combined, these areas provided >10,000 ha of natural and impounded wetlands managed primarily for migrating and wintering waterfowl. Swan Creek WMA was 3,590 ha and Mallard-Fox Creek WMA 705 ha. Crow Creek, Raccoon Creek, and Mud Creek management areas were 837, 3,443, and 3,239 ha, respectively. Crow Creek refuge was 1,354 ha and North Sauty refuge was 2,027 ha. Gasoline powered motors were not permitted on Raccoon Creek DWU North of Highway 117 or on Mud Creek DWU. Crow Creek and North Sauty Refuges had restricted access with the exception of boat and bank fishing.

Alabama waterfowl season dates during the two years of the study were from the last weekend of November to the last Sunday in January. A split season, during which waterfowl hunting was closed statewide, occurred on weekdays immediately following the last weekend in November to the first weekend in December. During the hunting season, WMAs were open to hunting 7 days/week and DWUs were open to hunting 4 days/week (closed Tuesdays-

Thursdays); the last 2 weeks of the season DWUs were open 7 days/week. Hunting was allowed on all WMAs and DWUs from 30 minutes before sunrise to sunset. Both North Sauty Refuge and Crow Creek Refuge were closed to hunting. Hunters in all management units were restricted to 25 shotshells/hunter in possession.

**Study Design**

From November to February 2020–2021 and 2021–2022, we surveyed three state management unit types including WMAs, DWUs, and refuges to assess dynamics of unit-scale abundance in relation to waterfowl hunting frequency. Each WMA and DWU was surveyed once per week while the two refuges were surveyed more frequently. Specifically, we conducted one daytime and one nighttime unmanned aerial vehicle (UAV) survey per week on each WMA and DWU, which was paired with a day and night refuge survey to monitor daily variations in abundance on hunted and unhunted areas. Survey areas for each unit type were first categorized based on expected levels of abundance (i.e., high, medium, or low) by Alabama Wildlife and Freshwater Fisheries Division biologists to ensure even representation of the system. Next, we conducted UAV trial flights to establish survey unit boundaries that complied with FAA line of sight regulations and created survey polygons within each unit based on this information. Within each polygon, we overlaid parallel transects spaced 100-m apart such that flight paths were comprised of long transects with minimal turns to reduce UAV flight time. We randomly selected 25% of these transects to survey, based on battery life and time limitations. We programmed those transects into the UAV remote-control system and surveyed the same transects in each polygon throughout the duration of the study.

We used a DJI Matrice 200 V2 (Shenzhen DJI Sciences and Technologies Ltd., Shenzhen, China) equipped with either a DJI Zenmuse X5S or DJI Zenmuse XT2 camera. The

Zenmuse X5S red-green-blue (RGB) camera was used while conducting surveys during the day and the Zenmuse XT2 thermal imaging camera was used during night-time surveys. We used a DJI Crystal Sky Monitor attached to the remote control to operate the UAV and set the desired flight specifications in DJI Pilot software. We set survey altitude and speed to maximize image quality and eliminate any overlap or gaps between images. Based on field calculations and test flights, the UAV was flown at ~48 m above ground level (AGL) and ~20.9 kph using a 7 second photo interval with the Zenmuse X5S, and ~48 m AGL and ~24.1 kph using a 5 second photo interval with the Zenmuse XT2 at a 90-degree angle. Camera settings for the Zenmuse X5S were set to shutter priority mode and automatic for the Zenmuse XT2.

Order of visitation to each WMA followed a systematic rotating design to produce balanced coverage of each WMA with respect to expected within-week variation in hunting frequency. Specifically, to reduce bias each polygon was surveyed an equal number of times on weekends and weekdays; during pre-hunt, hunt, and post-hunt seasons; on hunt days and non-hunt days; at different times of the day, and in different orders each time. A refuge survey was conducted every day and night in conjunction with a WMA survey to compare daily variation in relative abundance and distribution. Additionally, a single repeat polygon survey was conducted each day and night, also in a rotating order, to determine feasibility of modeling detection probability with repeat counts. Surveys were conducted only during periods of little to no precipitation and in winds less than ~32 kph to meet FAA guidelines. Day-time UAV surveys began around 0930 to reduce overlap between our surveys and prime hunting hours, and night-time surveys began around 2130 to allow waterfowl to settle after sunset. These times were also selected to provide enough time to recharge batteries between day and night surveys. The UAV was launched from >100 m away from the survey area and was not flown lower than 40 m to minimize disturbance of waterfowl (Vas et al. 2015, McEvoy et al. 2016). Additional data collected during flights included start and end times, weather conditions (i.e., wind speed and direction, temperature, cloud cover, and visibility), and hunter disturbance data (season, hunt days per week, weekday vs. weekend, hunt day vs. non-hunt day, and time since last hunt day). When the UAV was out of commission due to damage during Jan–Feb 2021, ground count methods were used as supplemental surveys; however, we were unable to conduct ground counts at night. Ground counts were conducted at sunrise and approximately within two hours before sunset, during peak waterfowl flight, because ground level visibility of our polygons was limited. Surveys were conducted at the same locations and in the same rotation used for UAV surveys. Using binoculars, total counts for each species observed were obtained for waterfowl visible within each polygon.

We classified land cover within each polygon using a combination of UAV imagery, satellite imagery, and water level maps provided by USGS to determine if waterfowl were selecting for a specific cover type. Specifically, each polygon was classified as either SAV, open water, or agriculture. SAV was considered any wetland area with ≤1 m of water with visible rooted aquatic vegetation in either the UAV or satellite imagery. Open water consisted of areas with >1 m of water with no visible aquatic vegetation. Agricultural wetlands included areas with water control structures that were planted with agronomic crops for waterfowl.

### Image Analysis

UAV imagery was analyzed by hand using the image processing software DotDotGoose (American Museum of Natural History, New York, NY). We uploaded images to the software and overlaid a grid to break the image into more manageable portions. For daytime images, each waterfowl species was designated a color that we used to mark each individual observed.

Running totals for each species were automatically counted in DotDotGoose. Species identification could not be determined from infrared images; therefore, all waterfowl observed during night surveys were pooled into one total count.

**Statistical Analysis**

We initially explored using an N-mixture modeling approach to account for variation in detection probability in analyses of hunter frequency effects. However, high variability in replicate counts was observed for each polygon, including those for which back-to-back repeated flights were conducted within the same day. Therefore, for all analyses, we modeled expected counts for a single survey based on survey-specific waterfowl counts per hectare (ha) to determine the effects of hunting frequency on waterfowl relative abundance and distribution. Although we acknowledge the possibility of missing some birds on polygons (e.g., divers under water, birds obstructed by vegetation), we believe that any effect of incomplete detectability was trivial compared to the magnitude of spatial-temporal variation and differences among unit types in observed counts.

We conducted all analyses in Program R (version 4.0.2; R Core Development Team 2022) using package glmmTMB (Brooks et al. 2017) to fit generalized linear mixed effects models, and library DHARMa ("DHARMa") to examine model fit via residual-simulation analyses. Based on initial analyses, we determined a hurdle model with a zero-inflation (logistic regression) component to account for the probability of counting zero waterfowl, and a conditional zero-truncated negative binomial component to model non-zero waterfowl expected counts, provided the best fit to our data, therefore we used it as the general model for all analyses. The general model included random effects of day, management unit, and polygon in the zero-inflation component of the model, while the conditional count model component included random effects of day and polygon; initial analyses indicated that adding additional random effects (e.g., date x unit interaction) led to convergence problems. We included an offset of log (surveyed area for the polygon) to account for variation in size of survey polygons, thus modeling expected counts in terms of mean density (number of waterfowl per ha). Temporal autocorrelation in polygon-level presence-absence and conditional counts was modeled with first-order autoregressive (AR [1]) correlation structures to control for repeated effects. Survey method (ground count, UAV) was included as a covariate in all daytime analyses. For reporting overall model-fitted expected counts, we calculated the non-conditional expected count as (1 – probability of zero count) x (expected conditional count).

For our first analysis, we compared zero-inflation and conditional counts per ha between each unit type and season (pre-hunt, hunt, and post-hunt) to test our prediction that waterfowl relative abundance would decrease on hunted areas and increase on unhunted areas during the hunting season. We used likelihood ratio tests to compare three models of the general form described above: a) a global model with an interaction of unit type and season in both the zero-inflation and conditional count components; b) a reduced model with main effects of unit type and season in each component; and c) a null model in which unit type was dropped from the model completely (but season retained). We ran the same set of analyses for night counts and compared counts during the day and at night to test our prediction that waterfowl relative abundance would differ between day and night.

For our second analysis, we compared zero-inflation and conditional counts during the hunting season between hunt days and non-hunt days on hunted areas (WMA and DWU) to test our prediction that waterfowl would utilize hunted areas more during non-hunted periods (i.e., mid-week closures and split season). We used likelihood ratio tests to compare three models including hunting pressure covariates: a) a global model with unit type, hunt day, weekend vs. weekday, and time since last hunt day in both the zero-inflation and conditional count components; b) a reduced model with main effects of unit type and hunt day in each component, and c) a null model in which hunt day was dropped from the model completely and unit type was retained. We ran the same analysis for night counts and compared results to daytime counts to test our prediction that waterfowl relative abundance would differ between day and night.

For our final analysis, we compared zero-inflation and conditional counts between land cover types to determine if habitat was driving patterns in relative abundance and distribution. We used likelihood ratio tests to compare a more complex model with season and cover type in both components of the model to a reduced complexity model including season only. The same analysis was conducted for night counts and compared to daytime results to determine if waterfowl were selecting for different cover types at night. All statistical tests were conducted at $\alpha = 0.05$.

## RESULTS

In total we surveyed 32 polygons, conducting 677 UAV surveys (396 daytime and 281 night-time) and 251 ground count surveys during our study. Combining UAV and ground count surveys, 171 daytime and 65 night-time surveys were conducted on the DWUs, 214 daytime and 90 night-time surveys were conducted on the WMAs, and 262 daytime and 126 night-time surveys were conducted on the refuges. We detected 17 waterfowl species with the UAV during daytime surveys, with Gadwall (*Mareca strepera*), Ring-necked ducks (*Aythya collaris)*, Mallards (*Anas platyrhynchos*), Green-winged teal (*A. crecca*) and Canvasbacks (*Aythya valisineria*) being the most common; however, unidentified species were the second greatest counts (Table 1.1). Overall, 266,589 waterfowl were counted during daytime surveys and 30,234 during night-time surveys throughout our study.

### Seasonal Change in Waterfowl Abundance and Distribution

#### Daytime Relative Abundance

The model with an interaction between unit type and season was supported over the reduced model with no interaction (likelihood ratio test statistic [LRT] = 17.7, df = 8, P = 0.02) and the null model (LRT = 35.7, df = 12, P < 0.001). For daytime counts, our results supported our prediction that waterfowl relative abundance would be lesser on hunted areas during the hunting season. Model-fitted expected counts during the pre-hunting, hunting, and post-hunting season consistently showed a greater number of waterfowl on unhunted areas than on hunted areas (Figure 1.1). Based on maximum-likelihood estimates from our interaction model, we were 39 (P = 0.01, CI 95% [2.53 – 606.76]; Table 1.2) times as likely to count zero waterfowl on WMAs than on the refuges and 66 (P = 0.01, CI 95% [3.45 – 1276.37]) times as likely to count zero waterfowl on the DWUs than on the refuges during the pre-hunting season. Conditional counts were not significantly different between hunted and unhunted areas. During the hunting season, we were 57 (P < 0.001, CI 95% [7.41 – 431.62]; Table 1.2) times as likely to count zero waterfowl on the WMAs than on the refuges and 73 (P < 0.001, CI 95% [7.83 – 678.96]) times as likely on the DWUs than on the refuges. Conditional counts showed there were 5 (P = 0.002, CI 95 % [1.82 – 14.65]; Table 1.2) times as many waterfowl on the refuges than on the WMAs and 4 (P = 0.02, CI 95% [1.29 – 15.27]) times as many on the refuges than on the DWUs. During the post-hunting season, we were 30 (P = 0.001, CI 95% [3.70 – 239.30]; Table 1.2) times as likely to count zero waterfowl on the WMAs than on the refuges and 33 (P = 0.003, CI 95%

[3.21 – 329.98]) times as likely on the DWUs than on the refuges. Conditional counts were not significantly different between hunted and unhunted areas post-hunting season.

## Night-time Relative Abundance

Results from model comparisons showed that an interaction between unit type and season was not statistically different than the reduced model with no interaction (LRT = 13.8, df = 8, P =0.09), but the interaction model was supported over the null model (LRT = 33.6, df = 10, P <0.001). For night-time counts, our results do not support our prediction that daytime and night-time waterfowl distribution would differ. Relative abundance compared between day and night generally followed the same patterns of distribution between each season; however, counts were somewhat lesser at night. Model-fitted expected night counts were highest on unhunted areas during the pre-hunting and hunting season and on the DWUs post-hunting season and were consistently least on the WMAs (Figure 1.2). Based on maximum-likelihood estimates from our interaction model, the probability of counting zero waterfowl during the pre-hunting season was significantly greater on the WMAs (P = 0.001; Table 1.3) than on the refuges; however, it was not significantly different between DWUs and refuges (P = 0.07). Conditional counts were greatest on unhunted areas but did not differ significantly from hunted areas. During the hunting season, we were 9 (P < 0.001, CI 95% [2.74 – 30.98]; Table 1.3) times as likely to count zero waterfowl on the WMAs than on the refuges and 7 (P = 0.01, CI 95% [1.60 – 30.26]) times as likely on the DWUs than on the refuges. Conditional counts were not statistically different between hunted and unhunted areas. During the post-hunting season, the probability of counting zero waterfowl and conditional counts were not significantly different between hunted and unhunted areas.

## Waterfowl Abundance and Distribution on Hunt Days vs. Non-hunt Days

## Daytime Relative Abundance

In our analysis of within season variation on hunted areas, results for daytime counts did not support our prediction that relative abundance during the hunting season would be greater on hunted areas on non-hunt days. Although model-fitted expected day counts on WMAs and DWUs were greatest on non-hunt days, the difference was not significant (Figure 1.3). Neither the probability of counting zero waterfowl (P = 0.55) nor conditional counts (P = 0.07) differed between hunt days and non-hunt days (Table 1.4).

## Night-time Relative Abundance

Results from model comparisons showed that the null model that included no hunting-related variables was not statistically different from the complex model including hunt day, weekend vs. weekday, and time since last hunt day as main effects (LRT = 3.0, df = 2, P = 0.23), or the reduced model with hunt day only (LRT = 0, df = 0, P = 1). Contrary to our prediction, we observed minimal difference in relative abundance and distribution between day and night counts. Model-fitted expected night counts on the DWUs and WMAs were insignificantly greater on hunt days than on non-hunt days during the hunting season (Figure 1.4). Neither the probability of counting zero waterfowl (P = 0.10) nor conditional counts (P = 0.90) differed between hunt days and non-hunt days (Table 1.5).

## Land Cover Type Waterfowl Abundance and Distribution

For daytime counts, results from model comparisons showed no statistical difference between the complex model including land cover type and the null model (LRT = 4.1, df = 4, P = 0.39). For night-time counts, results from model comparisons also showed no statistical difference between the complex model and the null model (LRT = 3.6, df = 4, P = 0.46). The probability of counting zero waterfowl and expected counts were not significantly different between SAV, agriculture, and open water for both daytime (Table 1.6) and night-time counts (Table 1.7).

## DISCUSSION

Waterfowl relative abundance was significantly lesser on hunted areas during the hunting season, supporting our hypothesis that hunting frequency would affect waterfowl relative abundance and distribution on state management units in the TRV. Our findings are consistent with other studies that have found hunting disturbance negatively affects waterfowl abundance on hunted areas during the hunting season (Korschgen et al. 1985, Fox and Madsen 1997). Results indicate that waterfowl were selecting refuge sites over hunted areas during the hunting season to avoid disturbance, but the reason behind their decision to use refuges during the pre- and post-hunting seasons is unknown. However, it was likely influenced by site fidelity exhibited in wintering waterfowl. High rates of site fidelity are common in many species of waterfowl during the breeding and non-breeding season because of their abilities to acquire knowledge of local food resources and predation risk (Rohwer and Anderson 1988, Anderson et al. 1992, Robertson and Cooke 1999). Furthermore, it has been suggested that waterfowl can also acquire knowledge of local disturbance caused by hunting and will therefore primarily utilize protected areas (Guillemain et al. 2002, Guillemain et al. 2007). If waterfowl in North Alabama have learned to return to the same wintering sites to avoid disturbance, opportunity for hunters to see and harvest birds may be negatively impacted, resulting in decreased hunter satisfaction (Slagle and Dietsch 2018, Bradshaw et al. 2019, Schroeder et al. 2019, Schummer et al. 2020). Adaptive management through manipulation of spatial refuges will be necessary to establish effective regulations that mitigate disturbance without negatively affecting hunter satisfaction.

Contrary to our hypothesis, we did not find a significant difference in waterfowl relative abundance between hunt days and non-hunt days during the hunting season, suggesting that neither the mid-week closures on DWUs nor the split season were effective at mitigating disturbance. Although some have found that short temporal refuges (Madsen 1998, Evans and Day 2002) or split seasons (Dooley et al. 2010, Lancaster et al. 2015) increased waterfowl abundance, our findings are consistent with St. James et al. (2013), Lancaster et al. (2015) and Hagy et al. (2017) who found that limiting hunting to two to four days per week, or splitting the season, was ineffective at reestablishing refuge on hunted areas. During our study, mid-week closures occurred from Tuesday to Thursday, and the split in the hunting season occurred from the last weekend in November to the first weekend in December. These closures were likely of insufficient length to restore waterfowl numbers and increase hunter harvest opportunity (Fox and Madsen 1997, Dooley et al. 2010) in North Alabama. The effectiveness of temporal closures and the duration of closure needed between periods of hunting to reestablish refuge have been widely debated but, when implemented, closures between hunting periods should be considered in weeks (i.e., 2-3 weeks) instead of days (Fox and Madsen 1997, Dooley et al. 2010, Hagy et al. 2017). Studies are lacking regarding the influence that restricted access to public lands has on hunter satisfaction. Gammonley and Runge (2022) found that restricted access did not have a strong influence on hunter satisfaction because these restrictions increased hunter success. However, in North Alabama, restricted access did not increase waterfowl use of hunted areas. Therefore, adaptive management on temporal closures will be necessary to determine effective regulations that mitigate disturbance without negatively affecting hunter satisfaction.

Daytime and nighttime waterfowl distribution generally followed the same seasonal pattern, which did not support our hypothesis that waterfowl would utilize hunted areas more at night during the hunting season. Similar to daytime results, waterfowl were primarily selecting refuge sites during each period at night. The only difference we observed was an increase in nighttime relative abundance on the DWUs during the post-hunting season, but these results were insignificant. We also found no significant difference in relative abundance and distribution between hunt and non-hunt days at night. Some studies have found that waterfowl will alter their diurnal activity patterns as a result of hunting pressure and become more active at night (Casazza et al. 2012, Dorak et al. 2017, Yetter et al. 2017), which was not observed during our study. It is unclear why waterfowl were avoiding our study sites at night, they may have been roosting in extensive areas of unsurveyed habitat available, primarily flooded row crops on nearby private property and flooded timber on state lands. Multiple studies suggest waterfowl prefer to roost in areas with sufficient cover and readily available food. For example, Euliss (1987) observed that the majority of waterfowl were found in areas of dense, emergent vegetation in all cropland types during nighttime surveys. Similarly, waterfowl may have been selecting for private property and flooded timber at night in our system, rather than more exposed areas on WMAs and DWUs.

Migratory waterfowl select various habitat types, but disturbances can alter their use of certain areas (Dooley et al. 2010, Pearse et al. 2012). We examined the possibility of habitat driving patterns of waterfowl abundance and distribution; however, we did not find that waterfowl were selecting for a particular land cover type within our survey units. Each polygon was categorized as either SAV, flooded row crops, or open water. WMA polygons consisted of primarily SAV, then open water, DWUs were flooded row crops, and refuges were SAV. Waterfowl were almost always observed in refuge polygons but not on other unit types consisting of the same habitat. Although some studies have shown that habitat type and complexity were more influential than sanctuaries on distributions of wintering ducks (Ephlick

2008, Pearse et al. 2012), our findings are consistent with Madsen and Fox (1995), Beatty et al. (2014), and McDuie et al. (2021) that waterfowl selected refuge sites even if equal or better habitat was nearby to avoid disturbance. Based on these results, the habitat covariates we had available during our study were not driving patterns in abundance or distribution, rather, hunting frequency was great enough to deter waterfowl away from hunted areas. As discussed previously, site fidelity may be driving abundance and distribution before and after the hunting season.

This study, among others, found that hunting disturbance had a negative effect on waterfowl abundance during the day, and that short temporal refuges were ineffective at increasing waterfowl use of these areas on non-hunt days. Additionally, we did not find that waterfowl utilized our study polygons more at night during the hunting season, suggesting other roost sites were available, such as Wheeler National Wildlife Refuge, flooded timber, and private lands. Waterfowl may benefit from short temporal restrictions during periods of low disturbance but when disturbance is excessive, waterfowl may benefit more if state managers prioritize spatial sanctuaries of sufficient size, although this may lead to decreased hunter satisfaction (Madsen, 1998, Hagy et al. 2017). Further research requiring manipulation of hunting activity is warranted to greater understand how waterfowl are responding to hunting frequency in the TRV of North Alabama to establish regulations that effectively minimize the impact of hunter disturbance without sacrificing hunter opportunity. Balancing trade-offs between providing hunting opportunities and a quality hunting experience will require adaptive management of waterfowl to sustain abundant populations for hunters to see and enhance their odds of harvesting birds.

Sources of potential bias in our estimates during daytime surveys included emergent vegetation blocking our view of individuals in select polygons and motion blur in imagery, when it occurred. Bias in our estimates for night-time surveys occurred when temperature contrast between the background environment and waterfowl varied significantly between night surveys. Additionally, when the UAV was out of commission from January to February 2021, we switched to ground counts in order to collect post-hunting season data, contributing to bias in our estimates because our perspective of survey areas changed, as well as start times for surveying; however, this affected all polygons equally and was accounted for in our analyses. Although we acknowledge the possibility of missing some birds on polygons (e.g., divers under water, birds obstructed by vegetation), we believe that any effect of incomplete detectability was trivial compared to the magnitude of spatial-temporal variation and differences among unit types in observed counts. The methods required to estimate detection probability are often seen to be expensive or difficult to implement in the field and in most ecological surveys, it is often unreasonable to expect detection probabilities to be constant due to environmental variables such as weather and habitat conditions, animal movement, and observer variability (Mackenzie and Kendall 2002). We found it difficult to measure detection probability using near simultaneous repeat polygon counts due to high variability between counts, therefore, focused on relative abundance.

## LITERATURE CITED

Alabama Department of Conservation and Natural Resources [ADCNR]. (2015). Alabama Wildlife Action Plan. ADCNR, Montgomery, AL, USA.

Anderson, M. G., Rhymer, J. M., and Rohwer, F. C. (1992). Philopatry, dispersal, and the genetic structure of waterfowl populations. Ecology and management of breeding waterfowl, 365-395. University of Minnesota Press, Minneapolis, MN.

Beatty, W. S., Kesler, D. C., Webb, E. B., Raedeke, A. H., Naylor, L. W., and Humburg, D. D. (2014). The role of protected area wetlands in waterfowl habitat conservation: implications for protected area network design. Biological Conservation, 176, 144-152.

Bellrose, F. C. (1954). The value of waterfowl refuges in Illinois. Journal of Wildlife Management, 18, 160-169.

Bellrose, F. C. (1980). Ducks, geese, and swans of North America. Third edition. Stackpole Books, Harrisburg, Pennsylvania.

Benedict, J.R. and Hepp, G.R. (2000). Wintering Waterbird Use of Two Aquatic Plant Habitats in a Southern Reservoir. Journal of Wildlife Management, 64, 269–78.

Bradshaw, L., Holsman, R. H., Petchenik, J., and Finger, T. (2019). Meeting harvest expectations is key for duck hunter satisfaction. Wildlife Society Bulletin, 43, 102-111.

Bregnballe, T., Madsen, J. and Rasmussen, P.A.F. (2004). Effects of temporal and spatial hunting control in waterbird reserves. Biological Conservation, 119, 93-104.

Bregnballe, T. and Madsen, J. (2004). Tools in waterfowl reserve management: Effects of intermittent hunting adjacent to a shooting-free core area. Wildlife Biology, 10, 261-268.

Browne, D. M. and Humburg, D. D. (2010). Confronting the challenges of climate change for waterfowl and wetlands. Ducks Unlimited, Inc., Memphis, TN.

Casazza, M. L., Coates, P. S., Miller, M. R., Overton, C. T., and Yparraguirre, D. R. (2012). Hunting influences the diel patterns in habitat selection by northern pintails *Anas acuta*. Wildlife Biology, 18, 1-13.

Dahl, T. E. (2011). Status and trends of wetlands in the conterminous United States 2004−2009. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C.

Dooley, J.L., Sanders, T.A. and Doherty, P.F. (2010). Mallard Response to Experimental Walk-In and Shooting Disturbance. Journal of Wildlife Management, 74, 1815-1824.

Dooley, J.L., Sanders, T.A. and Doherty, P.F. (2010). Effects of hunting season structure, weather, and body condition on overwintering mallard *Anas platyrhynchos* survival. Wildlife Biology, 16, 357-366.

Dorak, B. E., Ward, M. P., Eichholz, M. W., Washburn, B. E., Lyons, T. P., and Hagy, H. M. (2017). Survival and habitat selection of Canada Geese during autumn and winter in metropolitan Chicago, USA. The Condor: Ornithological Applications, 119, 787-799.

Elphick, C. S. (2008). Landscape effects on waterbird densities in California rice fields: taxonomic differences, scale-dependence, and conservation implications. Waterbirds, 31, 62-69.

Euliss, N.H. and Harris, S.W. (1987). Feeding Ecology of Northern Pintails and Green-Winged Teal Wintering in California. Journal of Wildlife Management, 51, 724–732.

Evans, D.M. and Day, K.R. (2002). Hunting disturbance on a large shallow lake: the effectiveness of waterfowl refuges. Ibis, 144, 2-8.

Fox, A.D. and Madsen, J. (1997). Behavioural and distributional effects of hunting disturbances on waterbirds in Europe: implications for refuge design. Journal of Applied Ecology, 34, 1-13.

Frederick, R.B., Clark,W.R. and Klass, E.E. (1987). Behavior, energetics, and management of refuging waterfowl: a simulation model. Wildlife Monographs, 96, 3-35.

Gammonley, J. H., and Runge, J. P. (2022). Duck hunter activity, success, and satisfaction on public hunting areas. Journal of Wildlife Management, 86, e22210.

Giroux, J-F. and Be´dard, J. (1988). Use of bulrush marshes by greater snow geese during staging. Journal of Wildlife Management, 52, 415-420.

Glick, P. (2005). The Waterfowlers' Guide to Global Warming. National Wildlife Federation, Washington, D.C.

Guillemain, M., Fritz, H., and Duncan, P. (2002). The importance of protected areas as nocturnal feeding grounds for dabbling ducks wintering in western France. Biological Conservation, 103, 183-198.

Guillemain, M., Fritz, H., Johnson, A. R., and Simon, G. (2007). What type of lean ducks do hunters kill? Weakest local ones rather than migrants. Wildlife Biology, 13, 102-107.

Hagy, H. M., Horath, M. M., Yetter, A. P., Hine, C. S., and Smith, R. V. (2017). Evaluating tradeoffs between sanctuary for migrating waterbirds and recreational opportunities in a restored wetland complex. Hydrobiologia, 804, 103-118.

Heyser, H. A. (2017). Want great hunting? What you need, in a word, is restraint. California Waterfowl Association, Roseville, CA.

Hockin, D.M., Ounsted, G.M., Hill, D., Keller, V. and Barker, M.A. (1992). Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. Journal of Environmental Management. 36, 253-286.

Johnson, F. A., Moore, C. T., Kendall, W. L., Dubovsky, J. A., Caithamer, D. F., Kelley Jr, J. R., and Williams, B. K. (1997). Uncertainty and the management of mallard harvests. Journal of Wildlife Management, 61, 202-216.

Kaminski, R. M., Pearse, A. T., Stafford, J. D., and Reinecke, K. J. (2005). Where have all the mallards gone. Delta Wildlife, 13, 23-26.

Korschgen, C. E., George, L. S., and Green, W. L. (1985). Disturbance of diving ducks by boaters on a migrational staging area. Wildlife Society Bulletin, 13, 290-296.

Korschgen, C. E., and Dahlgren, R. B. (1992). Human Disturbances of Waterfowl: Causes, Effects, and Management. Waterfowl Management Handbook, US Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Lancaster, J. D., Davis, J. B., Kaminski, R. M., Afton, A. D., and Penny, E. J. (2015). Mallard use of a managed public hunting area in Mississippi. Journal of the Southeastern Association of Fish and Wildlife Agencies, 2, 281-287.

Lehikoinen, A., and Jaatinen, K. (2012). Delayed autumn migration in northern European waterfowl. Journal of Ornithology, 153, 563-570.

MacKenzie, D. I., and Kendall, W. L. (2002). How should detection probability be incorporated into estimates of relative abundance?. Ecology, 83, 2387-2393.

Madsen, J. and Fox, A.D. (1995). Impacts of hunting disturbance on waterbirds. Wildlife Biology, 1, 193-207.

Madsen, J. (1995). Impacts of disturbance on migratory waterfowl. Ibis, 137, S67-S74.

Madsen, J. (2001). Can geese adjust their clocks? Effects of diurnal regulation of goose shooting. Wildlife Biology, 7, 213-222.

Mahaulpatha, D., Mahaulpatha, T., Nakane, K., and Fujii, T. (2002). Diurnal activity budgets and nocturnal movements of mallards (*Anas platyrhynchos*) wintering at the Hattabara Dam lake, Western Japan. Journal of the Yamashina Institute for Ornithology, 33, 176-188.

McDuie, F., Lorenz, A. A., Klinger, R. C., Overton, C. T., Feldheim, C. L., Ackerman, J. T., and Casazza, M. L. (2021). Informing wetland management with waterfowl movement and sanctuary use responses to human-induced disturbance. Journal of Environmental Management, 297, 113170.

McKnight, S. K. and Hepp, G. R. (1998). Diet selectivity of gadwalls wintering in Alabama. Journal of Wildlife Management, 62, 1533-1543.

Newton, I. (1998). Population limitation in birds. Academic Press, San Diego, CA.

Nichols, J.D., Johnson, F.A. and Williams, B.K. (1995). Managing North American waterfowl in the face of uncertainty. Annual Review of Ecology and Systematics, 26, 177-199.

Notaro, M., Schummer, M., Zhong, Y., Vavrus, S., Van Den Elsen, L., Coluccy, J., and Hoving, C. (2016). Projected influences of changes in weather severity on autumn-winter distributions of dabbling ducks in the Mississippi and Atlantic flyways during the twenty-first century. PLoS One, 11(12), e0167506.

Phillips, D. J. (2002). Discovering Alabama Wetlands. University of Alabama Press, Tuscaloosa, AL.

Roberts, A., Eadie, J. M., Howerter, D. W., Johnson, F. A., Nichols, J. D., Runge, M. C., and Williams, B. K. (2018). Strengthening links between waterfowl research and management. Journal of Wildlife Management, 82, 260-265.

Robertson, G. J. and Cooke, F. (1999). Winter philopatry in migratory waterfowl. The Auk, 116, 20-34.

Rohwer, F. C. and Anderson, M. G. (1988). Female-biased philopatry, monogamy, and the timing of pair formation in migratory waterfowl. Current ornithology, 5, 187-221.

Schroeder, S. A., Fulton, D. C., and Lawrence, J. S. (2006). Managing for preferred hunting experiences: A typology of Minnesota waterfowl hunters. Wildlife Society Bulletin, 34, 380-387.

Schroeder, S. A., Fulton, D. C., Cornicelli, L., Cordts, S. D., and Lawrence, J. S. (2019). Clarifying how hunt-specific experiences affect satisfaction among more avid and less avid waterfowl hunters. Wildlife Society Bulletin, 43, 455-467.

Schummer, M. L., Simpson, J., Davis, J. B., Shirkey, B., and Wallen, K. E. (2020). Balancing waterfowl hunting opportunity and quality to recruit, retain, and reactivate. Wildlife Society Bulletin, 44, 391-395.

Slagle, K. and Dietsch, A. (2018). National survey of waterfowl hunters: summary report Central Flyway. Report to the National Flyway Council from the Minnesota Cooperative Fish and Wildlife Research Unit, University of Minnesota and The Ohio State University, St. Paul.

Soulliere, G.J., Loges, B.W., Dunton, E.M., Luukkonen, D.R., Eichholz, M.W., and Koch, K.E. (2013). Monitoring waterfowl in the midwest during the non-breeding period: challenges, priorities, and recommendations. Journal of Fish and Wildlife Management, 4, 395-405.

St. James, E.A., Schummer, M.L., Kaminski, R.M., Penny, E.J. and Burger, L.W. (2013). Effect of weekly hunting frequency on duck abundances in Mississippi wildlife management areas. Journal of Fish and Wildlife Management, 4, 144-150.

U.S. Fish and Wildlife Service. (2007). Wheeler National Wildlife Refuge Complex Comprehensive Conservation Plan and Environmental Assessment. US Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Vas, E., Lescroël, A., Duriez, O., Boguszewski, G., and Grémillet, D. (2015). Approaching birds with drones: first experiments and ethical guidelines. Biology Letters, 11, 20140754.

Webb, E. B., Smith, L. M., Vrtiska, M. P., and Lagrange, T. G. (2011). Factors influencing behavior of wetland birds in the Rainwater Basin during spring migration. Waterbirds, 34, 457-467.

Wiebe, A.H. (1946). Improving conditions for migratory waterfowl on TVA impoundments. Journal of Wildlife Management, 10, 4-8.

Yetter, A. P., Hine, C. S., Gilbert, A. D., Blake-Bradshaw, A. G., Askren, R. J., Klimas, S. T., and Lancaster, J. D. (2017). Illinois Waterfowl Surveys and Investigations W-43-R-64 Annual Progress Report FY2017. Illinois Natural History Survey, Champaign, IL.

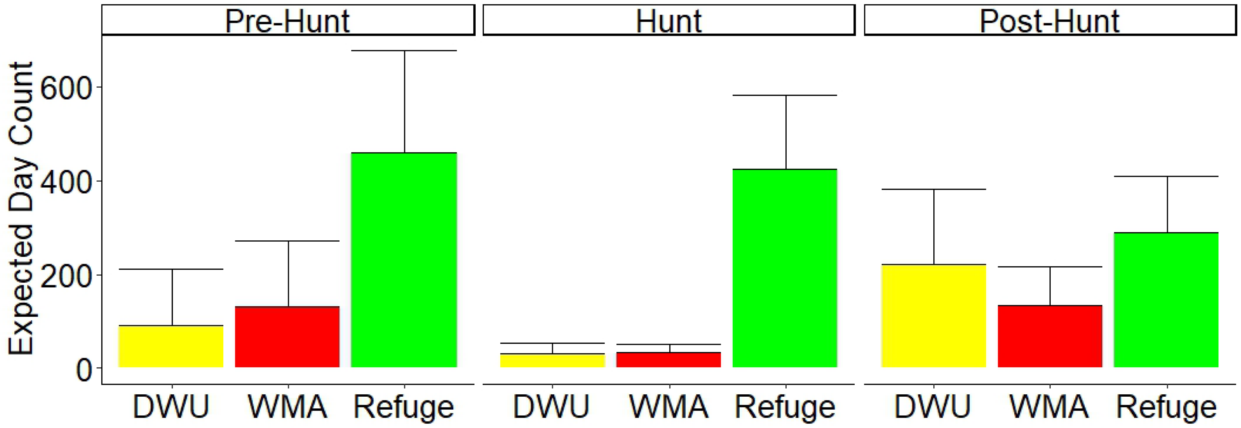

**Figure 1.1**. Expected (model-fitted; + 1 SE) day counts for a single survey of wintering waterfowl during the pre-hunting, hunting, and post-hunting seasons on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

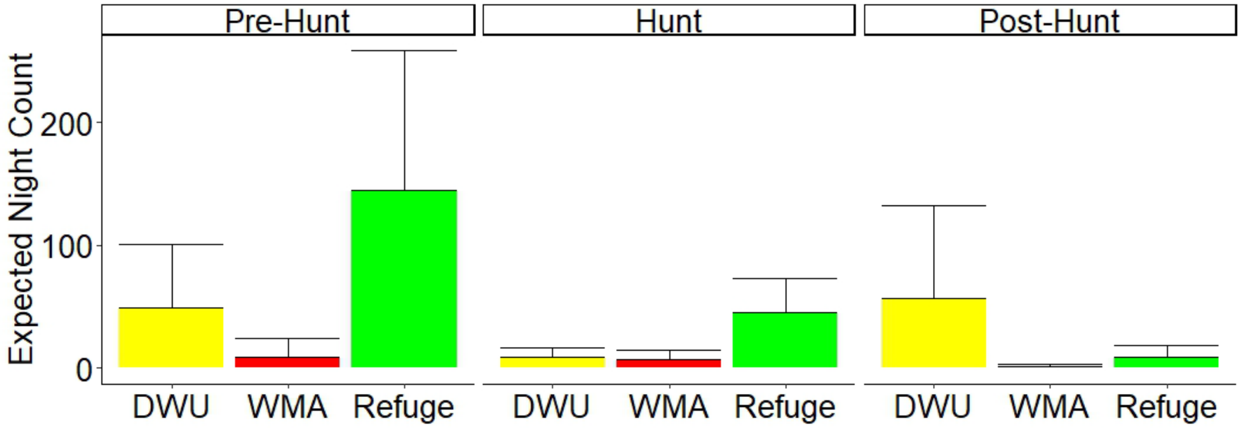

**Figure 1.2.** Expected night counts for a single survey of wintering waterfowl during the pre-hunting, hunting, and post-hunting season on the dewatering units (DWU), wildlife management areas (WMA), and Refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

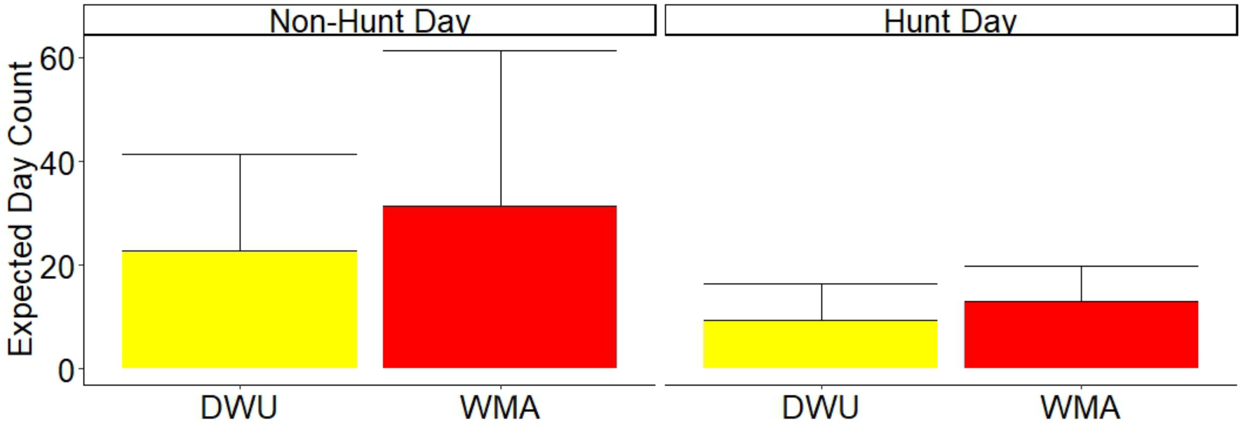

**Figure 1.3.** Expected day counts for a single survey of wintering waterfowl during hunting season on hunt vs. non-hunt days on the dewatering units (DWU) and wildlife management areas (WMA) in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

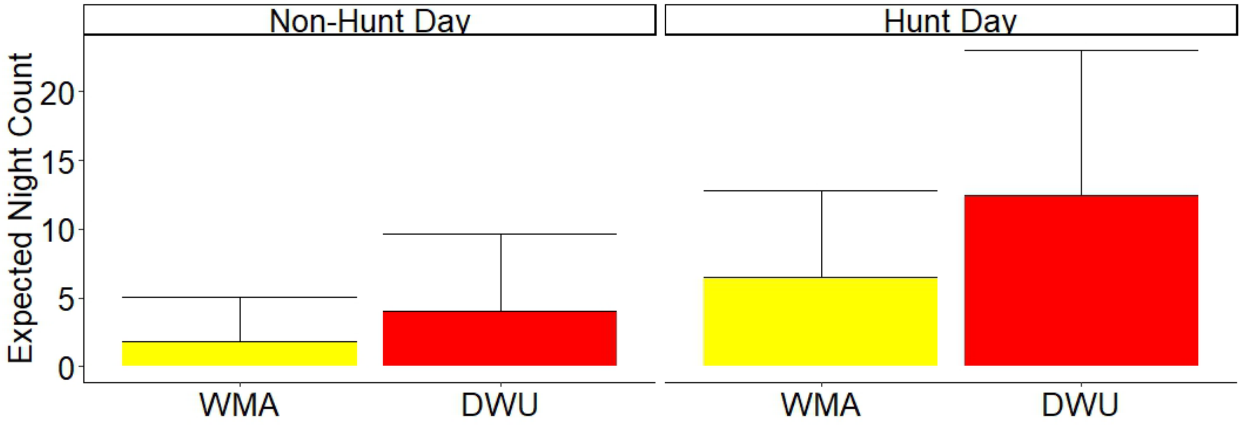

**Figure 1.4**. Expected night counts for a single survey of wintering waterfowl during hunting season on hunt vs. non-hunt days on the dewatering units (DWU) and wildlife management areas (WMA) in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

**Table 1.1.** Counts by species for daytime surveys and total counts for day and night surveys using UAV or ground based methods on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| *Species* | *Total* | *Species* | *Total* |
|---|---:|---|---:|
| American Wigeon | 1,256 | Northern Pintail | 1,437 |
| Black Duck | 41 | Northern Shoveler | 1,148 |
| Blue-Winged Teal | 99 | Redhead | 182 |
| Bufflehead | 1,239 | Ringneck | 41,607 |
| Canada Goose | 1,031 | Ruddy Duck | 46 |
| Canvasback | 3,170 | Scaup | 304 |
| Common Goldeneye | 23 | Wood Duck | 109 |
| Gadwall | 86,022 | Unknown | 50,564 |
| Green-Winged Teal | 5,664 | Total Day Counts | 266,589 |
| Mallard | 7,108 | Total Night Counts | 30,234 |

**Table 1.2.** Generalized linear mixed-effects hurdle model results comparing daytime counts using UAV or ground based methods on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) between the pre-hunting, hunting and post-hunting seasons from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-inflation model* | | | | | |
| Intercept* | -3.39 | 0.90 | -3.77 | 1.63E-04 | -2.00-0.30 |
| DWU | 72.93 | 1.14 | 3.77 | 1.64E-04 | 7.83-678.96 |
| WMA | 56.56 | 1.04 | 3.89 | 9.95E-05 | 7.41-431.62 |
| Post-Hunt | 1.39 | 0.59 | 0.56 | 0.57 | 0.44-4.41 |
| Pre-Hunt | 2.10 | 0.87 | 0.85 | 0.40 | 0.38-11.65 |
| DWU:Post-Hunt | 0.45 | 0.78 | -1.03 | 0.30 | 0.10-2.06 |
| WMA:Post-Hunt | 0.53 | 0.69 | -0.93 | 0.35 | 0.14-2.05 |
| DWU:Pre-Hunt | 0.91 | 1.20 | -0.08 | 0.94 | 0.09-9.55 |
| WMA:Pre-Hunt | 0.69 | 1.11 | -0.33 | 0.74 | 0.08-6.11 |
| *Conditional count model* | | | | | |
| Intercept | 3.81 | 0.37 | 3.61 | 3.12E-04 | 1.84-7.90 |
| Point Count | 0.11 | 0.29 | -7.62 | 2.54E-14 | 0.06-0.20 |
| DWU | 0.23 | 0.63 | -2.36 | 0.02 | 0.07-0.78 |
| WMA | 0.19 | 0.53 | -3.08 | 2.06E-03 | 0.07-0.55 |
| Post-Hunt | 0.69 | 0.28 | -1.33 | 0.18 | 0.40-1.19 |
| Pre-Hunt | 1.12 | 0.36 | 0.31 | 0.75 | 0.55-2.29 |
| DWU:Post-Hunt | 7.84 | 0.63 | 3.25 | 1.15E-03 | 2.27-27.15 |
| WMA:Post-Hunt | 5.02 | 0.59 | 2.75 | 5.88E-03 | 1.59-15.84 |
| DWU:Pre-Hunt | 4.51 | 0.99 | 1.52 | 0.13 | 0.64-31.59 |
| WMA:Pre-Hunt | 4.88 | 0.92 | 1.73 | 0.08 | 0.81-29.51 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

**Table 1.3.** Generalized linear mixed-effects hurdle model results comparing night-time counts using UAV or ground based methods on the on the dewatering units (DWU), wildlife management areas (WMA), and Refuges in North Alabama's Tennessee River Valley (TRV) between the pre-hunting, hunting and post-hunting seasons from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-Inflation Model* | | | | | |
| Intercept* | -0.49 | 0.51 | -0.96 | 0.34 | -0.66-0.22 |
| DWU | 6.95 | 0.75 | 2.58 | 0.01 | 1.60-30.26 |
| WMA | 9.21 | 0.62 | 3.59 | 3.33E-04 | 2.74-30.98 |
| Post-Hunt | 3.95 | 0.50 | 2.73 | 0.01 | 1.47-10.60 |
| Pre-Hunt | 0.39 | 0.56 | -1.68 | 0.09 | 0.13-1.17 |
| DWU:Post-Hunt | 0.09 | 0.88 | -2.72 | 0.01 | 0.02-0.51 |
| WMA:Post-Hunt | 0.24 | 0.91 | -1.54 | 0.12 | 0.04-1.46 |
| DWU:Pre-Hunt | 0.94 | 0.99 | -0.07 | 0.95 | 0.13-6.54 |
| WMA:Pre-Hunt | 2.38 | 0.95 | 0.91 | 0.36 | 0.37-15.35 |
| *Conditional Model* | | | | | |
| Intercept | -0.59 | 0.60 | -1.00 | 0.32 | 0.17-1.78 |
| DWU | 0.67 | 0.90 | -0.45 | 0.65 | 0.12-3.88 |
| WMA | 0.35 | 1.62 | -0.65 | 0.52 | 0.01-8.39 |
| Post-Hunt | 0.43 | 0.93 | -0.92 | 0.36 | 0.07-2.61 |
| Pre-Hunt | 2.52 | 0.61 | 1.53 | 0.13 | 0.77-8.26 |
| DWU:Post-Hunt | 7.37 | 1.42 | 1.41 | 0.16 | 0.46-119.15 |
| WMA:Post-Hunt | 0.31 | 2.00 | -0.58 | 0.56 | 0.01-15.80 |
| DWU:Pre-Hunt | 1.09 | 1.14 | 0.08 | 0.94 | 0.12-10.17 |
| WMA:Pre-Hunt | 0.43 | 2.05 | -0.42 | 0.68 | 0.01-23.74 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

**Table 1.4.** Generalized linear mixed-effects hurdle model results comparing daytime counts between hunt and non-hunt days using UAV or ground based methods on the dewatering units (DWU) and wildlife management areas (WMA) in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-Inflation Model* | | | | | |
| Intercept* | 0.21 | 0.67 | 0.73 | 0.46 | -0.36-0.78 |
| DWU | 0.92 | 0.73 | -0.11 | 0.91 | 0.22-3.86 |
| Non-Hunt Day | 1.51 | 0.68 | 0.60 | 0.55 | 0.39-5.77 |
| *Conditional Model* | | | | | |
| Intercept | 0.37 | 0.34 | -2.91 | 3.67E-03 | 0.19-0.72 |
| Point Count | 0.23 | 0.48 | -3.02 | 2.51E-03 | 0.09-0.60 |
| DWU | 0.69 | 0.56 | -0.67 | 0.51 | 0.23-2.07 |
| Non-Hunt Day | 3.19 | 0.64 | 1.81 | 0.07 | 0.91-11.20 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

**Table 1.5.** Generalized linear mixed-effects hurdle model results comparing night-time counts between hunt and non-hunt days using UAV or ground based methods on the dewatering units (DWU) and wildlife management areas (WMA) in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-Inflation Model* | | | | | |
| Intercept* | 5.00 | 0.61 | 2.66 | 0.01 | 1.52-16.4 |
| DWU | 0.48 | 0.68 | -1.09 | 0.28 | 0.12-1.82 |
| Non-Hunt Day | 4.76 | 0.95 | 1.65 | 0.10 | 0.74-30.57 |
| *Conditional Model* | | | | | |
| Intercept | 0.21 | 1.09 | -1.42 | 0.16 | 0.02-1.80 |
| DWU | 1.91 | 1.29 | 0.50 | 0.62 | 0.15-24.05 |
| Non-Hunt Day | 1.16 | 1.24 | 0.13 | 0.90 | 0.10-13.20 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

**Table 1.6.** Generalized linear mixed-effects hurdle model results comparing daytime counts between land cover type using UAV or ground based methods on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-Inflation Model* | | | | | |
| Intercept* | -0.16 | 1.19 | -0.13 | 0.9 | -1.08-0.95 |
| Agriculture | 1.60 | 1.32 | 0.36 | 0.72 | 0.12-21.29 |
| SAV | 0.66 | 1.27 | -0.33 | 0.74 | 0.06-7.87 |
| Post-Hunt | 0.82 | 0.35 | -0.56 | 0.57 | 0.41-1.63 |
| Pre-Hunt | 1.74 | 0.54 | 1.01 | 0.31 | 0.60-5.04 |
| *Conditional Model* | | | | | |
| Intercept | 0.46 | 0.62 | -1.27 | 0.2 | 0.14-1.53 |
| Point Count | 0.12 | 0.32 | -6.72 | 1.82E-11 | 0.06-0.22 |
| Agriculture | 2.30 | 0.73 | 1.14 | 0.26 | 0.55-9.67 |
| SAV | 3.30 | 0.66 | 1.82 | 0.07 | 0.91-11.90 |
| Post-Hunt | 1.61 | 0.25 | 1.9 | 0.06 | 0.98-2.64 |
| Pre-Hunt | 2.30 | 0.37 | 2.27 | 0.02 | 1.12-4.70 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

**Table 1.7.** Generalized linear mixed-effects hurdle model results comparing night-time counts between land cover type using UAV or ground based methods on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| Parameter | Value* | SE | Z-Value | P-Value | CI* |
|---|---|---|---|---|---|
| *Zero-Inflation Model* | | | | | |
| Intercept* | 1.15 | 0.69 | 2.19 | 0.03 | 0.16-2.87 |
| Agriculture | 0.36 | 0.72 | -1.42 | 0.16 | 0.09-1.47 |
| SAV | 0.49 | 0.7 | -1.02 | 0.31 | 0.12-1.94 |
| Post-Hunt | 1.60 | 0.36 | 1.3 | 0.19 | 0.79-3.27 |
| Pre-Hunt | 0.52 | 0.38 | -1.71 | 0.09 | 0.25-1.10 |
| *Conditional Model* | | | | | |
| Intercept | 0.16 | 1.14 | -1.61 | 0.11 | 0.02-1.49 |
| Agriculture | 4.85 | 1.37 | 1.15 | 0.25 | 0.33-71.22 |
| SAV | 1.99 | 1.21 | 0.57 | 0.57 | 0.19-21.42 |
| Post-Hunt | 0.86 | 0.63 | -0.24 | 0.81 | 0.25-2.98 |
| Pre-Hunt | 2.15 | 0.49 | 1.55 | 0.12 | 0.82-5.65 |

*ZI intercept is on the logit scale. All Betas and Confidence Intervals (CI) were exponentiated, giving estimated odds-ratio effects for the ZI model and proportional effects for conditional count model.

# CHAPTER 2

# USING UNMANNED AERIAL VEHICLES TO SURVEY WINTERING WATERFOWL

## ABSTRACT

Manned aerial surveys and ground count surveys are standard approaches for assessing waterfowl abundance and distribution, but each has limitations and drawbacks. Unmanned aerial vehicles (UAVs) are an emerging technology that can overcome many issues associated with traditional survey methods and are a tool that can be utilized for surveying wintering waterfowl to meet various objectives (i.e., assess habitat use, estimate abundance, etc.). However, UAV survey design requires a series of decisions on flight path, speed, altitude, image collection based on survey area, and target species. For effective UAV waterfowl surveys, it is critical to design surveys that result in adequate image resolution to detect birds and identify species, minimize disturbance to waterfowl, and accurately represent populations with appropriate spatial strategies. According to our literature review, wintering waterfowl surveys have not been previously conducted with multirotor UAVs on a scale covering hundreds of hectares (ha) per day (i.e., multiple state managed units). Additionally, information on using UAVs to survey waterfowl at night is lacking. We used UAVs to monitor changes in wintering waterfowl diurnal and nocturnal abundance and distribution in response to hunting pressure in North Alabama, and herein report on our approach, which is intended to serve as a model survey protocol for UAV waterfowl surveys. During the winters of 2020–2021 and 2021-2022, we conducted day and night UAV surveys using a DJI Matrice 200 V2 (Shenzhen DJI Sciences and Technologies Ltd., Shenzhen, China) equipped with a Zenmuse X5S camera for day surveys and a Zenmuse XT2 camera for night surveys. Based on field calculations and test flights, the UAV was flown at ~48 m above ground level (AGL) and ~20.9 kph using a 7 second photo interval with the Zenmuse

X5S, and ~48 m AGL and ~24.1 kph using a 5 second photo interval with the Zenmuse XT2. Overall, the UAV model and survey protocol we used enabled us to obtain imagery with sufficient resolution to identify 17 species of waterfowl during the day and detect and count individuals at night. During day and night surveys, we covered ~509 ha weekly of the ~5,401 ha of suitable waterfowl habitat in our study area. Major benefits of UAV surveys vs. manned aircraft surveys included repeated surveys obtaining extremely fine spatial and temporal resolution data, and zero risk to survey personnel. However, we faced multiple challenges including equipment and labor costs and requirements, obtaining high image resolution for reliable counts, constraints of landscape features, FAA regulations limiting our line of sight and access, issues with measuring detectability, and technical glitches and collisions. The magnitude of challenges associated with UAV operations determines feasibility of incorporating UAVs into waterfowl surveys. Our methodology used to monitor changes in wintering waterfowl abundance will help guide future UAV research on waterfowl, specifically on broad scales and in areas difficult to monitor with traditional methods.

## INTRODUCTION

Traditional aerial and ground count surveys are standard approaches for assessing waterfowl abundance and distribution, but there are several limitations of each method (Martinson and Kaczynski 1967, Caughley 1974, Smith 1995, Pearse et al. 2008, Kingsford and Porter 2009, Chabot and Bird 2012, Valle and Scarton 2020, Wen et al. 2021). For example, aerial surveys from manned aircraft may underestimate waterfowl abundance, depending on viewing conditions (e.g., land cover type, altitude, and speed), observer experience, conspicuousness of individuals, and density of birds (Gilbert et al. 2020). Ground count surveys can be hindered by limited visibility and restricted site access and often assume 100% detection probability which is probably seldomly reasonable (Caughley 1974, Bajzak and Piatt 1990, Pagano and Arnold 2009, Gonzalez et al. 2016, Valle and Scarton 2020). Regardless of methods used, accurate estimates of wintering waterfowl abundance and distribution are important to state and federal agencies for waterfowl conservation and management planning (Soulliere et al. 2013, Gilbert et al. 2021). Unmanned aerial vehicles (UAVs) are a promising tool to revolutionize the way abundance and distribution data are obtained in wildlife studies (Anderson and Gaston 2013, Christie et al., 2016, Brack et al. 2018). The emerging technology can overcome issues associated with traditional survey methods and have shown to be successful for surveying breeding and non-breeding waterbird populations (Chabot and Bird 2012, Chabot et al. 2015, Drever et al. 2015, Hodgeson et al. 2016, Afán and Díaz-Delgado 2018, Dundas et al. 2021).

The emerging use of UAVs in waterfowl research is partly owed to their ability to obtain fine spatial and temporal resolution data and provide a permanent record of bird counts that can be analyzed repeatedly with the potential to identify species and sex of birds in mixed species assemblages without using manned aircraft missions. These capabilities can result in significantly more accurate counts of waterbirds than standard fixed-wing aircraft and ground count surveys (Anderson et al. 2013, Hodgeson et al. 2016, Baxter and Hamilton 2018, Jarrett et al. 2020, Dundas et al. 2021). Additionally, because of improvements in UAV battery life, camera sensors and flight planning capabilities, potential access to remote areas, zero risks to human observers, and reduced disturbance, UAVs are a promising tool for surveying waterfowl populations (Abd-Elraham and Pearlstine 2005, Chabot and Bird 2012, Koh and Wich 2012, Watts et al. 2012, Anderson and Gatson 2013, Chabot and Bird 2015, Vas et al. 2015, Christie et al. 2016, McEvoy et al. 2016).

However, the utility of UAV surveys requires suitable survey design. The design process involves a series of decisions on flight path, speed, altitude, and image collection based on survey area, which depend on UAV capabilities and target species (Linchant et al. 2015, Baxter and Hamilton 2018, Lyons et al. 2019). For effective UAV waterfowl surveys, it is critical that survey design produce adequate image resolution to detect birds and identify species, minimize disturbance to waterfowl, and accurately represent populations with appropriate spatial strategies (Brown 1999, Jurdak et al. 2015, Baxter and Hamilton 2018). Constraints on UAV operation that must be considered in survey design are current Federal Aviation Administration (FAA) regulations on range, altitude, and line of sight (Hardin and Jackson 2005, Watts et al. 2010, Chabot and Bird 2012, Linchant et al. 2015), limited battery life, and weather factors that affect flight and resulting image quality (Sarda-Palomera et al. 2012, Campbell et al.2015).

Previous UAV waterfowl surveys have largely been limited to population counts during the breeding season, estimating flock size of geese, identifying nesting waterfowl, and conducting night-time nest searching and brood counts (Chabot and Bird, 2012, Bushaw et al. 2020, Stander et al. 2021). Although some UAV work has been completed during the non-breeding season, that work focused on determining wintering waterfowl habitat use or quantifying levels of disturbance caused by UAVs (Drever et al. 2016, McEvoy et al. 2016). According to our literature review, wintering waterfowl surveys have not been previously conducted using multirotor UAVs on a scale covering hundreds of hectares per day (i.e., multiple state managed units). We used UAVs to monitor changes in wintering waterfowl diurnal and nocturnal abundance and distribution in response to hunting pressure in North Alabama, and herein report on our approach, which is intended to serve as a model survey protocol for UAV waterfowl surveys.

## METHODS

### Study Area

The TRV is considered an outer fringe of the Mississippi Flyway consisting of several reservoirs, impoundments, wildlife management areas (WMAs), and waterfowl refuges. Substantial wetland loss and transformations have occurred in the TRV since the first dams were constructed in 1933 (USFWS 2007). Seasonally flooded backwaters and hardwood forests, which were likely rich in moist-soil seeds, tubers, invertebrates, and acorns, have been replaced by permanent reservoirs comprised primarily of submersed aquatic vegetation (SAV, USFWS 2007). Leveed impoundments within the refuges and WMAs are gradually inundated in fall and winter, providing food for migrating and wintering waterfowl (USFWS 2007). Impoundments are flooded via pumping, gravity flow through water control structures, or accumulation of precipitation (USFWS 2007).

Our study area was located within the floodplain of the Tennessee River surrounded by the foothills of the Appalachian Mountains. Elevations ranged from 504–594 m above sea level (USFWS 2007, ADCNR 2015). The Lower Cumberland Tennessee Ecosystem typically experiences warm, humid summers (mean temperature >20°C), mild winters (mean >1°C), and rainfall is well-distributed seasonally (mean annual of 1,346 mm; USFWS 2007). Managed and natural wetlands within the study area include SAV, moist-soil vegetation, mudflats, open water, fields cultivated for row-crop agriculture, and isolated bottomland hardwood forests.

We focused on 7 state management units in the Alabama TRV located within the Guntersville and Wheeler Reservoirs, three of which had associated dewatering units (DWUs). Units in Jackson County included Crow Creek WMA (34.850444, -85.858056), Mud Creek WMA and DWU (34.754833, -85.9000556), Raccoon Creek WMA and DWU (34.817528, -

85.811917), Crow Creek Waterfowl Refuge (34.840222, -85.831556) and North Sauty Waterfowl Refuge (34.591611, -86.097306). We also surveyed Swan Creek WMA and DWU (34.633056, -86.965278) in Limestone County, and Mallard Fox Creek WMA (34.682222, -87.137222) in Morgan and Lawrence counties. Combined, these areas provided >10,000 ha of natural and impounded wetlands managed primarily for migrating and wintering waterfowl. Swan Creek WMA was 3,590 ha and Mallard-Fox Creek WMA 705 ha. Crow Creek, Raccoon Creek, and Mud Creek management areas were 837, 3,443, and 3,239 ha, respectively. Crow Creek Refuge was 1,354 ha and North Sauty Refuge was 2,027 ha.

Alabama waterfowl season dates during the two years of the study were from the last weekend of November to the last Sunday in January. A split season, during which waterfowl hunting was closed statewide, occurred on weekdays immediately following the last weekend in November to the first weekend in December. During hunting season, WMAs were open to hunting 7 days/week and DWUs were open to hunting 4 days/week (closed Tuesdays-Thursdays); the last 2 weeks of the season DWUs were open 7 days/week. Hunting was allowed on all WMAs and DWUs from 30 minutes before sunrise to sunset. Both North Sauty Refuge and Crow Creek Refuge were closed to hunting.

### Study Design

We used UAVs to monitor changes in waterfowl relative abundance and distribution in response to hunting pressure in the TRV of North Alabama after deciding that using UAVs would be the most effective method due to their abilities to access remote areas and reduce disturbance to waterfowl. This purpose, as well as initial pilot work, dictated specific aspects of our survey design. We implemented a stratified-random sampling approach (Hennig et al. 2017) within our study area from November to February 2020–2021 and 2021–2022. We surveyed three state management unit types including WMAs, DWUs, and refuges to assess dynamics of unit-scale abundance in relation to waterfowl hunting disturbance during the day and at night. Each WMA and associated DWU were surveyed once per week while the two refuges were surveyed more frequently. Specifically, we conducted one daytime and one night-time UAV survey per week on each WMA and associated DWU, which was paired with a day and night refuge survey to monitor daily variations in abundance on hunted and unhunted areas. Survey areas for each unit type were first categorized based on expected levels of abundance (i.e., high, medium, or low) by Alabama Wildlife and Freshwater Fisheries biologists to ensure even representation of the system. Next, we conducted UAV trial flights to establish survey unit boundaries that complied with FAA line of sight regulations and created survey polygons within each unit based on this information. Within each polygon, we overlaid parallel transects spaced 100-m apart such that flight paths were comprised of long transects with minimal turns to reduce UAV flight time (e.g., Figure 2.1). We randomly selected 25% of these transects to survey, based on battery life and time limitations. We programmed those transects into the UAV remote-control system and surveyed the same transects in each polygon throughout the study.

We used a DJI Matrice 200 V2 (Shenzhen DJI Sciences and Technologies Ltd., Shenzhen, China) equipped with either a DJI Zenmuse X5S or a DJI Zenmuse XT2 camera and two TB55 intelligent flight batteries. The Matrice 200 V2 has a maximum flight time of 24 to 38 minutes depending on payload weight and maximum wind resistance of 43 kph. The Zenmuse X5S (5280×2970 resolution; DJI MFT 15mm lens) was used for daytime surveys and the thermal-capable Zenmuse XT2 (640 × 512 resolution; 19 mm lens) was used during night-time surveys. We attached a Freewell CPL filter (Freewell Industry Co Ltd, Kowloon, HK) to the Zenmuse X5S on clear and sunny days to reduce glare in our images. Attached to the remote control was a DJI Crystal Sky monitor used to operate the UAV and set the desired flight specifications in DJI Pilot software. Survey height and speed settings were chosen to reduce disturbance to waterfowl, maximize image quality, and eliminate any overlap or gaps between images to reduce double counting and undercounting. Based on field calculations and test flights, the UAV was flown at ~48 m above ground level (AGL) and ~20.9 kph using a 7 second photo interval with the Zenmuse X5S, and ~48 m AGL and ~24.1 kph using a 5 second photo interval with the Zenmuse XT2. Camera settings for daytime surveys were set to auto focus and shutter priority mode to reduce motion blur. On shutter priority mode aperture speed and ISO were automatically adjusted accordingly. Depending on weather conditions, the camera shutter speed was adjusted accordingly to improve image resolution. For night-time surveys, we used the white-hot filter in the DJI Pilot camera settings. For all surveys, the gimbal was adjusted to a 90-degree angle.

Order of visitation to each WMA followed a systematic rotating design to produce balanced coverage of each WMA with respect to expected within-week variation in hunting pressure (refer to Chapter 1 for details). Additionally, a single repeat polygon survey was conducted each day and night, also in a rotating order, to determine feasibility of modeling detection probability with repeat counts. Surveys were conducted only during periods of little to no precipitation and in winds less than ~32 kph to meet FAA guidelines. Day-time UAV surveys began around 0930 to reduce overlap between our surveys and prime hunting hours, and night-time surveys began around 2130 to allow waterfowl to settle after sunset. These times were also selected to provide enough time to recharge batteries between day and night surveys. The UAV was launched from >100 m away from the survey area to minimize disturbance of waterfowl (Vas et al. 2015, McEvoy et al. 2016). Additional data collected during flights included start and end times and weather conditions (i.e., wind speed and direction, temperature, cloud cover, and visibility) to determine total flight time by area and limitations of UAV operations under different weather conditions.

### Image Analysis

UAV imagery was analyzed manually using the image processing software DotDotGoose (Figure 2.2; American Museum of Natural History, New York, NY). We uploaded images to the software and overlaid a grid to break the image into more manageable portions. For daytime images, each waterfowl species was designated a color that we used to mark each individual observed. For female identification, if obvious identifying marks could not be seen, we located the nearest male, if applicable, then relied on size and shape of individuals in the photographs. Individuals were classified as unknown when image resolution was too low to confidently identify species. Running totals for each species were automatically counted in DotDotGoose. Species identification could not be determined from infrared images, so we relied on size and shape of individuals as well as rafting behavior and heat signatures generated from swimming motions to classify animals as waterfowl, and only total counts of waterfowl were determined for night-time surveys.

## RESULTS

### *Detectability*

Waterfowl were highly mobile within our study system, which resulted in high variability in replicate counts for both day and night counts. Therefore, we did not model detectability using count-based models. However, when zero waterfowl were counted during initial surveys, we also counted zero waterfowl during the repeat surveys. As the number of waterfowl present increased, variation increased.

### *Waterfowl Identification and Image Analysis*

In total, we surveyed 32 polygons within our study area. Figure 2.1 illustrates survey design within a unit depicting polygon boundaries, path of transects, and launch locations. We completed 677 UAV surveys (396 diurnal and 281 nocturnal) and counted 266,589 waterfowl during daytime surveys and 30,234 during night-time surveys throughout our study (Table 2.1). The number of photos taken per polygon ranged from 100s-1,000s. The maximum time spent analyzing photos for a single survey was ~4 hours for daytime surveys and ~1 hour for night-time surveys (e.g., Figure 2.2). We identified 17 species of waterfowl during daytime surveys, with Gadwall (*Mareca strepera*), Ring-necked ducks (*Aythya collaris)*, Mallards (*Anas platyrhynchos*), Green-winged teal (*A. crecca*) and Canvasbacks (*Aythya valisineria*) being the most common; however, unidentified species were the second greatest counts, making up 19% of total day counts (Table 2.1).

### *Time Surveyed by Area*

During day and night surveys, we covered ~509 ha weekly of the ~5,401 ha of suitable waterfowl habitat in our study area and ~5% to ~38% of each unit (Table 2.2). The maximum flight time with two TB55 intelligent flight batteries was ~24 minutes. With 6 sets of batteries, we spent ~144 minutes surveying every day and night which allowed us to cover ~102 ha/day on average.

## DISCUSSION

Our study did not include a control survey with a known number of waterfowl in our imagery, however, we observed minimal disturbance to waterfowl caused by the UAV, ground-truthed the presence or absence of waterfowl in survey polygons, where possible, and calculated low observer variability in total counts between six observers. Therefore, we assumed our imagery was an accurate representation of our study area and we were able to identify and detect waterfowl with minimal bias in our counts.

The UAV equipment and survey protocol we used enabled us to obtain imagery with sufficient resolution to identify waterfowl to the species level during the day and count individuals at night, while allowing broad coverage, access to isolated areas, and minimizing disturbance. Other studies have found UAV surveys to be effective for estimating abundance of waterfowl (Bushaw et al. 2020, Chabot and Bird 2012, Chabot and Bird 2015, Pöysä et al. 2018, Lyons et al. 2019, Dundas et al. 2021, Stander et al. 2021), but none have attempted on a similar spatial scale to our study using a multirotor UAV. Major benefits of utilizing a UAV for this study vs. manned aircraft surveys included repeated surveys obtaining extremely fine spatial and temporal resolution data, and zero risk to survey personnel. Advantages over ground counts included less technicians required to complete surveys and increased access to remote areas. Manned aircraft surveys would be more beneficial when surveying larger spatial areas less frequently (e.g., mid-winter surveys), while ground counts would be feasible on a smaller spatial scale requiring minimal equipment.

### *Cost and Labor Analysis*

The initial cost of UAV equipment can be high, as well as the associated labor requirements (Dundas et al. 2021, Pöysä et al. 2018), but UAVs are becoming increasingly affordable. Various types of UAVs are available at a range of prices to suit most budgets, but there are the additional costs of added equipment, training, and required permits (Christie et al. 2016, Jones et al. 2018, Linchant et al. 2015) that also must be considered. Our study required UAV equipment with the ability to generate high resolution imagery to accurately identify waterfowl. In general, the more expensive the UAV equipment, the better the image quality

(Dundas et al. 2021). Additional labor costs include training, planning flights, charging batteries, setting up and taking down the UAV, flying surveys, and especially commuting time and imagery analysis. The initial cost for equipment was ~$25,000 (~$0.82/ha), plus costs for FAA UAV certifications and labor to fly the UAV and process images that included four full-time technicians for four months equated to ~$53,000, but the UAV can be used for multiple seasons. Although costs for commuting time and technicians are also necessary for ground counts, total costs are likely to be higher for ground counts because of the number of observers required. For example, when Delta Waterfowl conducts ground nest and brood surveys, they usually hire 12 technicians for ~ 4 months, which cost ~$77,000 (Bushaw et al. 2020). UAVs have also proven to be more cost-effective compared to manned aircraft surveys, however our cost per hectare was higher than Hagy (2020) and Hagy et al. (2022) who estimated that the costs to fly wintering waterfowl surveys across various National Wildlife Refuges in the Southeast were ~$0.05 to $0.07/ha. Study area size and survey frequency will ultimately determine cost efficiency of UAV waterfowl surveys. With recent advances in deep machine learning used to estimate waterfowl abundance from UAV surveys, there is promise for future research to reduce costs of labor associated with image processing (Anderson and Gatson 2013, Dundas et al. 2021, Francis et al. 2020, Gonzalez et al. 2016, Hong et al. 2019). In a situation where commuting time would be significant, it is important to consider if purchasing two sets of equipment to allow simultaneous UAV operations would be worth the added costs to reduce commute time of an individual and maximize the amount of area surveyed.

### *Image Resolution*

For most waterfowl study objectives, UAV surveys need to generate high quality imagery to accurately identify and count waterfowl. Specifically, UAV surveys must balance area coverage with image resolution (Burke et al 2019). However, image resolution highly depends on equipment capabilities and flight speed, and the optimal flight speed to maximize image quality depends on flight altitude, weather conditions (e.g., cloudy vs. sunny; Figure 2.3), and camera shutter speed (Tang et al. 2021, Watts et al. 2010). Research providing recommendations for ideal weather conditions to maximize image resolution is limited, but similar to other studies, we found our imagery was of higher quality on clear days, cold nights, and in winds less ~32 kph (e.g., Figure 2.4; Barr et al. 2017, Dundas et al. 2021, Hodgson et al. 2018, Pöysä et al. 2018). When conducting UAV waterfowl surveys during the day, it is generally recommended to survey at altitudes of 40–60 m to reduce disturbance, and at slower speeds (i.e., 5–21.6 kph) to maximize image quality (Lyons et al. 2019, McEvoy et al. 2016, Pöysä et al. 2018, Ryckman et al. 2022). In addition, a high shutter speed is typically required (i.e., 1/2000 s; Dulava et al. 2015, Hodgson et al. 2017, McEvoy et al. 2016, Pöysä et al. 2018) to accurately identify waterfowl to species. Comparatively, we flew our surveys at 48 m altitude at ~20.9 kph with the Zenmuse X5S. With these flight specifications, we determined a shutter speed of 1/600 s produced the best imagery for waterfowl identification. Alternative flight specifications may require adjusting shutter speed.

According to our literature review, this study was the first attempt to demonstrate the utility of UAVs at night to monitor changes in waterfowl abundance and distribution on a broad scale. At an altitude of ~48 m and speed ~24.1 kph with the Zenmuse XT2 we were able to detect waterfowl at night but not identify them. We compared size and shape of ducks and coots in our daytime imagery to aid in night-time counts and differentiate between each (Figure 2.5). However, our resulting image resolution varied and, when low, differentiating between these groups was not feasible. Resolutions for thermal cameras are currently limited, and consequently require low altitude flights which result in longer flight times, reduction in spatial coverage, and the possibility of disturbance (Kays et al. 2019). Additionally, when using thermal equipment, the strength of the thermal signal is dependent on the temperature of the target object, its infrared reflectivity, and the characteristics of the background against the object (Ribeiro-Gomes et al. 2017). If the temperature of the surroundings is similar to that of the target object, or if the background is warmer than the target object, the contrast between the target and the background will be low (Burke et al. 2019). When ambient temperatures did not drop below ~4° C, contrast between waterfowl and the background environment was not great enough to produce clear images for reliable counts, which occurred for approximately 57% of our surveys. The internal and external temperature of an animal are rarely the same and animals can alter their skin temperature to prevent excess heat loss (McCafferty et al. 2015, Burke et al. 2019). As a result, animal temperatures may appear cooler during winter months, however it is still preferable to survey during colder times of day/night when temperatures between target object and the background are larger to maximize heat signal (Burke et al. 2019)

For both day and night surveys, our imagery contained some motion blur, likely because we flew at higher than most recommended speeds. However, this was necessary to cover the area required to meet our research objectives. Previous researchers successfully covered smaller study areas per day (i.e., 30–40 ha) using similar equipment and flight specifications (Drever et al. 2015, Francis et al. 2020, Pöysä et al. 2018). In contrast, we surveyed a total of ~102 ha per day. Overall, we were limited by the capabilities of our camera equipment and could not acquire adequate resolution imagery to identify or detect every individual across our study area, but we successfully identified various species of waterfowl during the day and were able to count them at night. For situations when acquiring more accurate counts is the objective, reducing speed and/or altitude will be necessary, at the cost of reduced coverage.

### *Topography and Land Cover*

Certain topographic features limited where and how much area we could survey. Surveying in or around trees often obstructed our view of the UAV, causing complications with line of sight requirements and limiting how much area and where we could survey. When surveying forested environments, we had to survey multiple smaller polygons vs. surveying in open landscapes, where we only had to survey one or two polygons to cover the area. Typically, surveying beyond ~1.6 km made it difficult to maintain sight of the UAV, but this depended on weather conditions, with it being most difficult to observe the UAV on sunny days. Additionally, access to many of our survey areas was limited, especially in Jackson County where the WMAs were primarily forested and surrounded by private lands with no appropriate place to launch or land a UAV. Depending on land cover type (SAV, open water, agriculture), image processing time varied based on density of cover, in which agriculture was greatest (Figure 2.6). In general, increased openness and access within a study area make UAVs more practical; the more impediments there are on line of site and access relative to the target population of interest, the lower the utility.

### *Detectability*

Because of the extensive area required to be surveyed daily to meet project objectives, we minimized overlap between transects. However, when acquiring imagery for UAV waterbird surveys it is recommended to design UAV flights with front and side overlap between images to create orthomosaics and improve detection rates due to bird movement (Afán et al. 2018, Lyons et al. 2019, Francis et al. 2020, Hodgson et al. 2017, Lyons et al. 2019, Pöysä et al. 2018). With our approach, we were unable to create orthomosaics to improve detection rates; however, we attempted to measure detectability by conducting repeat polygon flights. Unfortunately, our repeat surveys were unsuccessful because of high variability between counts. Within open systems, similar to our study area, it is difficult to measure detectability when counts are not conducted simultaneously (Brack et al. 2018). To measure detectability on a large scale, we recommend either conducting short temporal replicates via repeat surveys of a single transect or overlapping areas of subsequent images. If possible, combining images of flights with simultaneous thermal and common RGB photography can also produce accurate estimates of available individuals (Chrétien et al. 2016).

### *FAA Regulations*

According to FAA regulations, the remote pilot in command, the visual observer (if one is used), and the person manipulating the flight control of the small, unmanned aircraft system must be able to see the aircraft throughout the entire flight unaided, except by corrective lenses (FAA 2016). Consequently, we focused our surveys primarily in open landscapes and where trees did not obstruct our view, with the exception of a few large openings in flooded timber. The FAA also requires a minimum weather visibility of three miles from the control station (FAA 2016), which prevented us from conducting surveys during periods of dense fog. In wooded environments, FAA line of sight regulations are a major limiting factor and should be considered when selecting survey sites.

### *Technical and Hardware Issues*

As with any technology, there is always the possibility for technical issues, which take time to solve, especially in remote areas where troubleshooting can be challenging (Dundas et al. 2021). In our case, the connection between the remote control and UAV was occasionally disrupted when surveying around trees, powerlines, and other objects capable of interfering with the signal. Additionally, prior to launching the UAV, we often had to recalibrate the UAV and update software, which took ~5-30 minutes depending on magnitude of recalibration and update requirements. We also experienced hardware issues due to strenuous use and an accident after colliding with a bird. Bird strikes are a common cause of UAV collisions because birds of prey view them as a threat or prey (Lyons et al. 2018), and if a collision occurs and there is no option for a backup UAV, surveying will be halted until the UAV is repaired. The bird collision during our study required the UAV to be returned to the manufacturer for repair, which disrupted the remainder of our field season because the process took several months. Preventative maintenance and adhering to manufacturer guidelines when flying around sources of interference may improve UAV operations and reduce chances of technical issues. If budgets allow, purchasing a second set of equipment can ensure and are likely required for continued operations in the event of repairs.

### *Department of Defense (DoD) Restrictions*

Due to security concerns, purchases of foreign UAV and associated equipment by U.S. federal agencies were banned in the fiscal year 2020 and remain in effect. The Blue UAS program, established by the DoD, curates a roster of policy approved commercial UAVs that can be purchased with federal funds, but this list currently excludes DJI products. DJI products are popular within the field of wildlife management and conservation due to their advanced capabilities and lower costs. The DoD approved UAVs cost about four times as much as foreign UAVs. It is unclear how restrictions will impact the future of wildlife research relying on imported UAV technology, but with limited UAV options at higher costs and decreased capabilities, challenges will likely increase for federal agencies or for federally funded projects.

Biologists planning UAV studies need to consider the complications and limitations that may be faced if restrictions on UAV purchases with federal-source funds and on installation and use of critical software on restricted computers (e.g., university networks) continue.

### *Implications*

Effective UAV waterfowl surveys require a well-developed survey design to produce the minimal image resolution required to meet research objectives, minimize disturbance to waterfowl, and accurately represent populations with appropriate spatial strategies. Additionally, accounting for challenges associated with UAV operations, such as cost and labor requirements, environmental conditions, and FAA regulations is critical to determine feasibility of incorporating UAVs into waterfowl surveys. The methodology we used to monitor changes in wintering waterfowl diurnal and nocturnal abundance and distribution in response to hunting pressure in North Alabama will help guide future UAV research on waterfowl, specifically on broad scales and in areas difficult to monitor with traditional methods.

## LITERATURE CITED

Abd-Elraham, A. and Pearlstine, L.G. (2005). Development of pattern recognition algorithm for automatic bird detection from unmanned aerial vehicle imagery. Surveying and Land Information Science, 65, 37-45.

Afán, I., Máñez, M., and Díaz-Delgado, R. (2018). Drone monitoring of breeding waterbird populations: The case of the Glossy Ibis. Drones, 2, 42.

Alabama Department of Conservation and Natural Resources. (2015). Alabama Wildlife Action Plan. ADCNR, Montgomery, AL, USA.

Anderson, K. and Gaston, K.J. (2013). Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Frontiers in Ecology and the Environment, 11, 138-146.

Barr, J.R., Green, M.C., DeMaso, S.J. and Hardy, T.B. (2017). Surveying mixed-species waterbird colonies with unmanned aerial systems (UAS): visibility bias, disturbance, and protocol recommendations. Texas State University, San Marcos, TX.

Baxter, P. W. and Hamilton, G. (2018). Learning to fly: integrating spatial ecology with unmanned aerial vehicle surveys. Ecosphere, 9, e02194.

Brack, I.V., Kindel, A., and Oliveira, L.F.B. (2018). Detection errors in wildlife abundance estimates from unmanned aerial systems (UAS) surveys: Synthesis, solutions, and challenges. Methods in Ecology and Evolution, 9, 1864–1873.

Brown, J. A. (1999). A comparison of two adaptive sampling designs. Australian & New Zealand Journal of Statistics 41, 395–403.

Burke, C., Rashman, M., Wich, S., Symons, A., Theron, C. and Longmore, S. (2019). Optimising observing strategies for monitoring animals using drone-mounted thermal infrared cameras. International Journal of Remote Sensing, 40, 439-467.

Bushaw, J. D., Ringelman, K. M., Johnson, M. K., Rohrer, T., and Rohwer, F. C. (2020). Applications of an unmanned aerial vehicle and thermal-imaging camera to study ducks nesting over water. Journal of Field Ornithology, 91, 409-420.

Campbell, K. J., Beek, J., Eason, C. T., Glen, A. S., Godwin, J., Gould, F., and Baxter, G. S. (2015). The next generation of rodent eradications: innovative technologies and tools to improve species specificity and increase their feasibility on islands. Biological Conservation, 185, 47-58.

Caughley, G. (1974). Bias in aerial survey. Journal of Wildlife Management, 38, 921-933.

Chabot, D., and Bird, D. M. (2012). Evaluation of an off-the-shelf unmanned aircraft system for surveying flocks of geese. Waterbirds, 35, 170-174.

Chabot, D. and Bird, D.M. (2015). Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? Journal of Unmanned Vehicles Systems, 3, 137-155.

Chabot, D., Craik, S. R., and Bird, D. M. (2015). Population census of a large common tern colony with a small unmanned aircraft. PloS one, 10, e0122588.

Christie, K. S., Gilbert, S. L., Brown, C. L., Hatfield, M., and Hanson, L. (2016). Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. Frontiers in Ecology and the Environment, 14, 241-251.

Chrétien, L. P., Théau, J., and Ménard, P. (2016). Visible and thermal infrared remote sensing for the detection of white-tailed deer using an unmanned aerial system. Wildlife Society Bulletin, 40, 181-191.

Drever, M.C., Chabot, D., O'Hara, P.D., Thomas, J.D., Breault, A., and Millikin, R.L. (2015). Evaluation of an unmanned rotorcraft to monitor wintering waterbirds and coastal habitats in British Columbia, Canada. Journal of Unmanned Vehicle Systems, 3, 256-267.

Drever, M.C., Chabot, D., O'Hara, P.D., Thomas, J.D., Breault, A., and Millikin, R.L. (2016). Evaluation of an unmanned rotorcraft to monitor wintering waterbirds and coastal habitats in British Columbia, Canada. Journal of Unmanned Vehicle Systems, 3, 256-267.

Dulava, S., Bean, W. T., and Richmond, O. M. (2015). Environmental reviews and case studies: applications of unmanned aircraft systems (UAS) for waterbird surveys. Environmental Practice, 17, 201-210.

Dundas, S. J., Vardanega, M., O'Brien, P., and McLeod, S. R. (2021). Quantifying waterfowl numbers: comparison of drone and ground-based survey methods for surveying waterfowl on artificial waterbodies. Drones, 5, 5.

Federal Aviation Administration (FAA). (2016). Code of Federal Regulations (14 CFR) part 107. United States Department of Transportation, Washington, D.C.

Francis, R. J., Lyons, M. B., Kingsford, R. T., and Brandis, K. J. (2020). Counting mixed breeding aggregations of animal species using drones: lessons from waterbirds on semi-automation. Remote Sensing, 12, 1185.

Gilbert, A. D., Jacques, C. N., Lancaster, J. D., Yetter, A. P., & Hagy, H. M. (2021). Visibility bias of waterbirds during aerial surveys in the nonbreeding season. Wildlife Society Bulletin, 45, 6-15.

Gonzalez, L.F., Montes, G.A., Puig, E., Johnson, S., Mengersen, K., and Gaston, K.J. (2016). Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionizing wildlife monitoring and conservation. Sensors, 16, 97.

Hagy, H. M. (2020). Coordinated Aerial Waterfowl Surveys on National Wildlife Refuges in the Southeast during Winter 2020. U.S. Fish and Wildlife Service Report.

https://ecos.fws.gov/ServCat/DownloadFile/173702

Hagy, H. M., B. Van Druten, G. Wilkerson, S. Yates, P. Stinson, and J. Wortham. (2022). Midwinter Aerial Waterfowl Surveys on National Wildlife Refuges in the Southeast during 2022. U.S. Fish and Wildlife Service Report. https://ecos.fws.gov/ServCat/Reference/Profile/144230.

Hardin, P. J. and Jackson, M. W. (2005). An unmanned aerial vehicle for rangeland photography. Rangeland Ecology & Management, 58, 439-442.

Hennig, J. D., Benson, T. J., Stafford, J. D., Yetter, A. P., Hagy, H. M., and Stodola, K. W. (2017). An aerial grid-based sampling method to estimate nonbreeding duck abundance. Wildlife Society Bulletin, 41, 678-684.

Hodgson, A., Peel, D., and Kelly, N. (2017). Unmanned aerial vehicles for surveying marine fauna: assessing detection probability. Ecological Applications, 27, 1253-1267.

Hodgson, J. C., Mott, R., Baylis, S. M., Pham, T. T., Wotherspoon, S., Kilpatrick, A. D., and Koh, L. P. (2018). Drones count wildlife more accurately and precisely than humans. Methods in Ecology and Evolution, 9, 1160-1167.

Hong, S. J., Han, Y., Kim, S. Y., Lee, A. Y., and Kim, G. (2019). Application of deep-learning methods to bird detection using unmanned aerial vehicle imagery. Sensors, 19, 1651.

Jarrett, D., Calladine, J., Cotton, A., Wilson, M. W., and Humphreys, E. (2020). Behavioural responses of non-breeding waterbirds to drone approach are associated with flock size and habitat. Bird Study, 67, 190-196.

Jones, I. G. P., Pearlstine, L. G., and Franklin, H. (2006). Percival: An assessment of small unmanned aerial vehicles for wildlife research. Wildlife Society Bulletin, 34, 750-758.

Jurdak, R., Elfes, A., Kusy, B., Tews, A., Hu, W., Hernandez, E., and Sikka, P. (2015). Autonomous surveillance for biosecurity. Trends in biotechnology, 33, 201-207.

Kays, R., J. Sheppard, K. Mclean, C. Welch, C. Paunescu, V. Wang, G. Kravit, and M. Crofoot. (2019). Hot monkey, cold reality: surveying rainforest canopy mammals using drone mounted thermal infrared sensors. International Journal of Remote Sensing, 40, 407–419.

Kingsford, R. T., and Porter, J. L. (2009). Monitoring waterbird populations with aerial surveys–what have we learnt? Wildlife Research, 36, 29-40.

Koh, L. P. and Wich, S. A. (2012). Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. Tropical conservation science, 5, 121-132.

Linchant, J., Lisein, J., Semeki, J., Lejeune, P., and Vermeulen, C. (2015). Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. Mammal Review, 45, 239-252.

Lyons, M., Brandis, K., Callaghan, C., McCann, J., Mills, C., Ryall, S., and Kingsford, R. (2018). Bird interactions with drones, from individuals to large colonies. Australian Field Ornithology, 35, 51-56.

Lyons, M., Brandis, K., Wilshire, J., Murray, N., McCann, J., Kingsford, R., and Callaghan, C. (2019). A protocol for using drones to assist monitoring of large breeding bird colonies. Eco Evo Rxiv.

Martinson, R. K. (1967). Factors influencing waterfowl counts on aerial surveys, 1961-66. US Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, D.C.

Masto, N. M. (2019). Evaluation of aerial surveys to monitor fall-winter waterbird populations in South Carolina. Clemson University, Clemson, SC.

McCafferty, D. J., Gallon, S., and Nord, A. (2015). Challenges of measuring body temperatures of free-ranging birds and mammals. Animal Biotelemetry, 3, 1-10.

McEvoy, J. F., Hall, G. P., and McDonald, P. G. (2016). Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: disturbance effects and species recognition. PeerJ, 4, e1831.

Pagano, A. M., and Arnold, T. W. (2009). Detection probabilities for ground-based breeding waterfowl surveys. Journal of Wildlife Management, 73, 392-398.

Pearse, A. T., Gerard, P. D., Dinsmore, S. J., Kaminski, R. M., and Reinecke, K. J. (2008). Estimation and correction of visibility bias in aerial surveys of wintering ducks. Journal of Wildlife Management, 72, 808-813.

Pearse, A. T., Kaminski, R. M., Reinecke, K. J., and Dinsmore, S. J. (2012). Local and landscape associations between wintering dabbling ducks and wetland complexes in Mississippi. Wetlands, 32, 859-869.

Pöysä, H., Kotilainen, J., Väänänen, V. M., and Kunnasranta, M. (2018). Estimating production in ducks: a comparison between ground surveys and unmanned aircraft surveys. European journal of wildlife research, 64, 1-4.

Ribeiro-Gomes, K., Hernández-López, D., Ortega, J. F., Ballesteros, R., Poblete, T., and Moreno, M. A. (2017). Uncooled thermal camera calibration and optimization of the photogrammetry process for UAV applications in agriculture. Sensors, 17, 2173.

Sardà-Palomera, F., G. Bota, C. Viñolo, O. Pallarés, V. Sazatornil, L. Brotons, S. Gomáriz, and F. Sardà. (2012). Fine-scale bird monitoring from light unmanned aircraft systems. Ibis, 154, 177-183.

Smith, G. W. (1995). A critical review of the aerial and ground surveys of breeding waterfowl in North America. U.S. Fish and Wildlife Service, Washington, D.C.

Stander, R., D. J. Walker, F. C. Rohwer, and R. K. Baydack. 2021. Drone Nest Searching Applications Using a Thermal Camera. Wildlife Society Bulletin, 45, 371-382.

Tang, Z., Zhang, Y., Wang, Y., Shang, Y., Viegut, R., Webb, E., and Sartwell, J. (2021). sUAS and Machine Learning Integration in Waterfowl Population Surveys. Institute of Electrical and Electronics Engineers, 517-521.

U.S. Fish and Wildlife Service. (2007). Wheeler National Wildlife Refuge Complex Comprehensive Conservation Plan and Environmental Assessment. U.S. Fish and Wildlife Service, Atlanta, GA.

Valle, R. G., and Scarton, F. (2020). Drones improve effectiveness and reduce disturbance of censusing Common Redshanks Tringa totanus breeding on salt marshes. Ardea, 107, 275-282.

Vas, E., Lescroël, A., Duriez, O., Boguszewski, G., and Grémillet, D. (2015). Approaching birds with drones: first experiments and ethical guidelines. Biology letters, 11, 20140754.

Watts, A. C., Perry, J. H., Smith, S. E., Burgess, M. A., Wilkinson, B. E., Szantoi, Z., and Percival, H. F. (2010). Small, unmanned aircraft systems for low-altitude aerial surveys. Journal of Wildlife Management, 74, 1614-1619.

Watts, A. C., Ambrosia, V. G., and Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. Remote Sensing, 4, 1671-1692.

Wen, D., Su, L., Hu, Y., Xiong, Z., Liu, M., and Long, Y. (2021). Surveys of Large Waterfowl and Their Habitats Using an Unmanned Aerial Vehicle: A Case Study on the Siberian Crane. Drones, 5, 102.

**Table 2.1.** Counts by species for daytime surveys and total counts for day and night surveys using UAV or ground based methods on the dewatering units (DWU), wildlife management areas (WMA), and refuges in North Alabama's Tennessee River Valley (TRV) from November to February 2020-2021 and 2021-2022.

| *Species* | *Total* | *Species* | *Total* |
|---|---|---|---|
| American Wigeon | 1,256 | Northern Pintail | 1,437 |
| Black Duck | 41 | Northern Shoveler | 1,148 |
| Blue-Winged Teal | 99 | Redhead | 182 |
| Bufflehead | 1,239 | Ringneck | 41,607 |
| Canada Goose | 1,031 | Ruddy Duck | 46 |
| Canvasback | 3,170 | Scaup | 304 |
| Common Goldeneye | 23 | Wood Duck | 109 |
| Gadwall | 86,022 | Unknown | 50,564 |
| Green-Winged Teal | 5,664 | Total Day Counts | 266,589 |
| Mallard | 7,108 | Total Night Counts | 30,234 |

**Table 2.2**. Percent (%) area (ha) surveyed for each wildlife management area (WMA) and Refuge in North Alabama's Tennessee River Valley from November to February 2020-2021 and 2021-2022.

| *Management Unit* | *Area of Suitable Habitat* | *Polygon Area* | *Transect Area* | *% Suitable Habitat Surveyed* |
|---|---|---|---|---|
| Crow Creek WMA | 50 | 35 | 10 | 20% |
| Mud Creek WMA | 790 | 305 | 93 | 12% |
| Raccoon Creek WMA | 351 | 276 | 133 | 38% |
| Swan Creek WMA | 1739 | 818 | 112 | 6% |
| Mallard Fox Creek WMA | 602 | 202 | 28 | 5% |
| Crow Creek Refuge | 1354 | 300 | 73 | 5% |
| North Sauty Refuge | 654 | 459 | 60 | 9% |

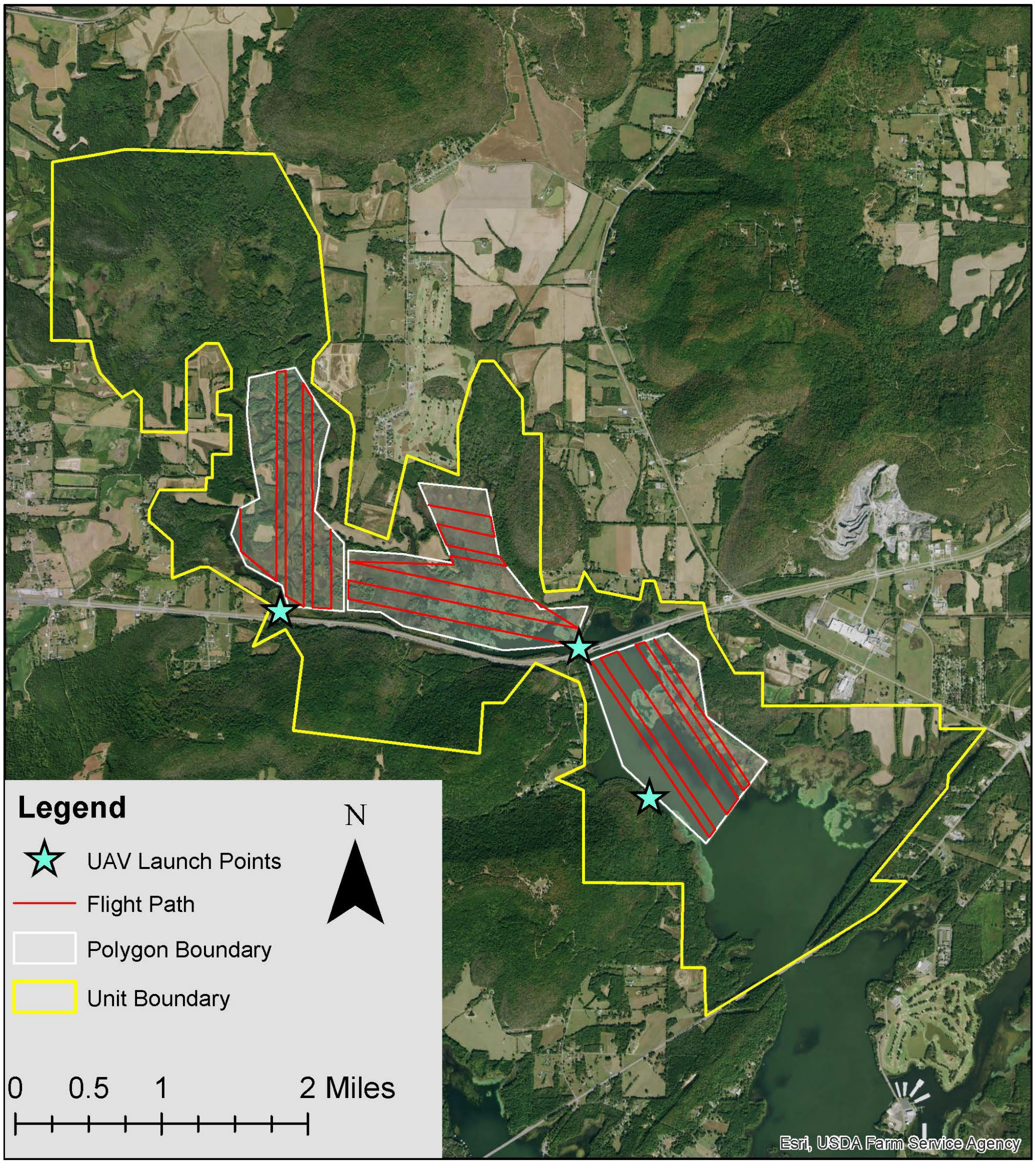

**Figure 2.1.** UAV survey polygon boundaries (white), flight paths (red), and launch points (indicated by blue star) on North Sauty Refuge (yellow) in Jackson County, Alabama from November to February 2020-2021 and 2021-2022.

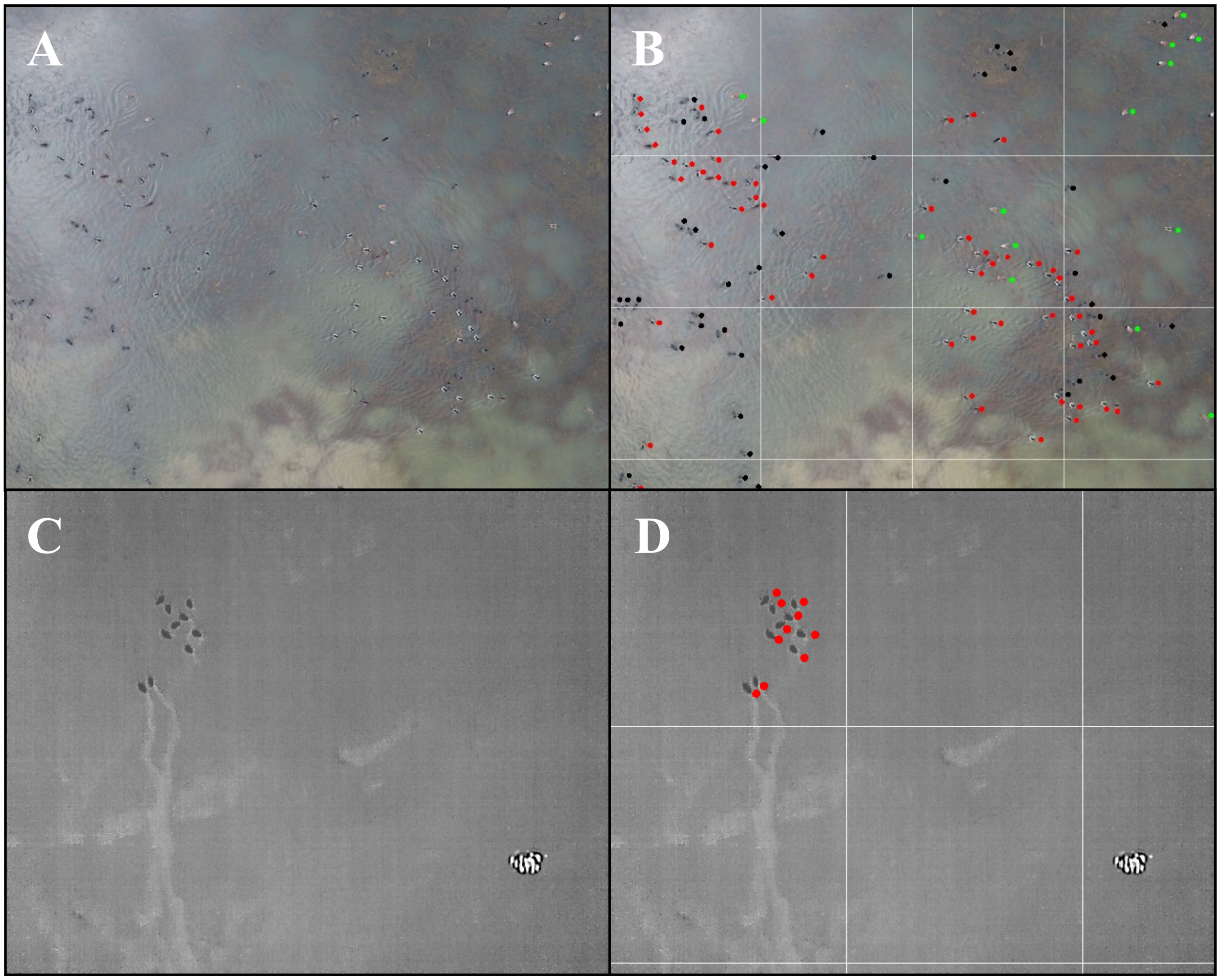

**Figure 2.2.** Example imagery captured with the Zenmuse X5S and Zenmuse XT2 as seen from the UAV and processed images in DotDotGoose during daytime (A,B) and night-time (C,D) surveys of wintering waterfowl in Northern Alabama.

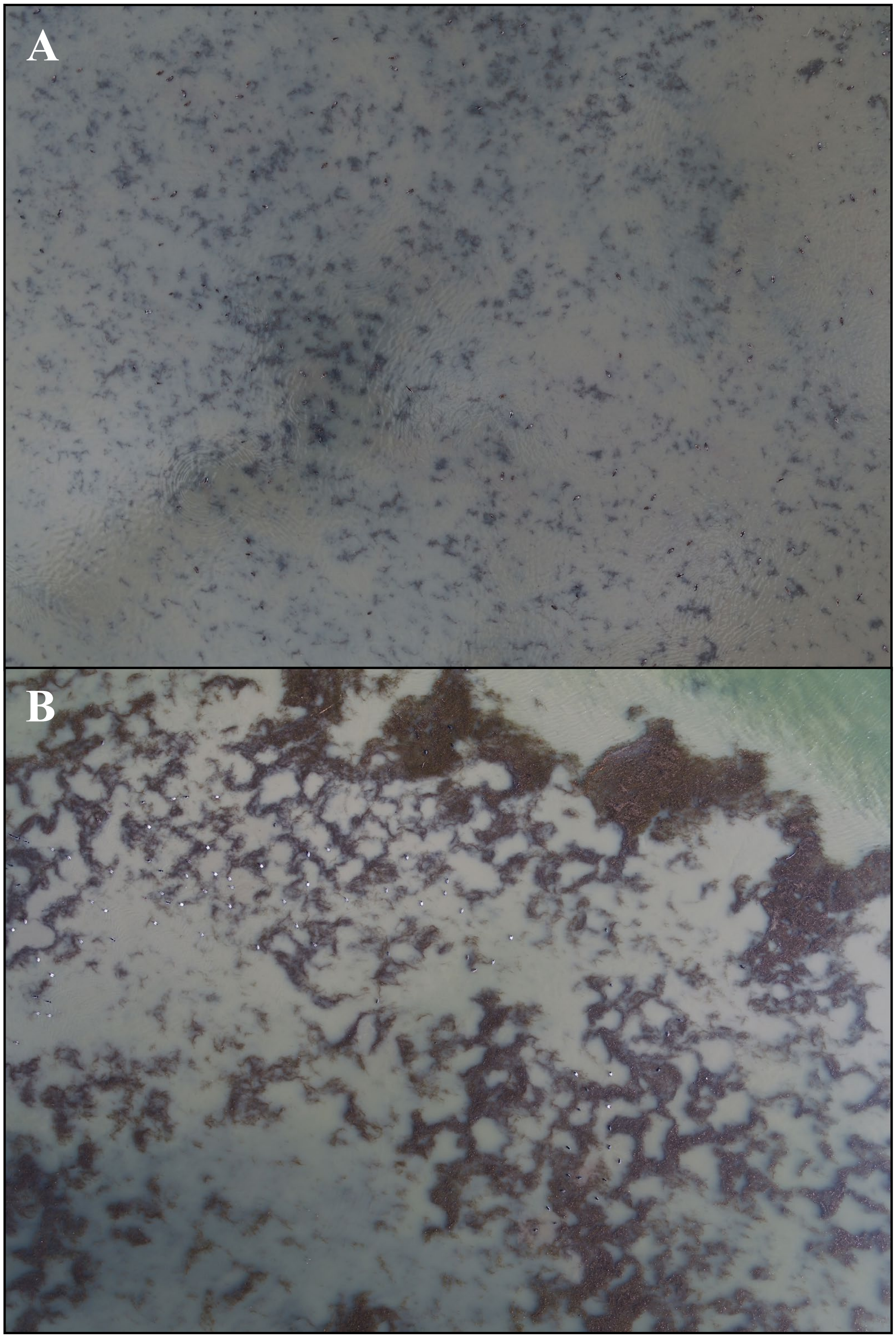

**Figure 2.3.** Example imagery captured with Zenmuse X5S in cloudy (A) vs. sunny (B) conditions.

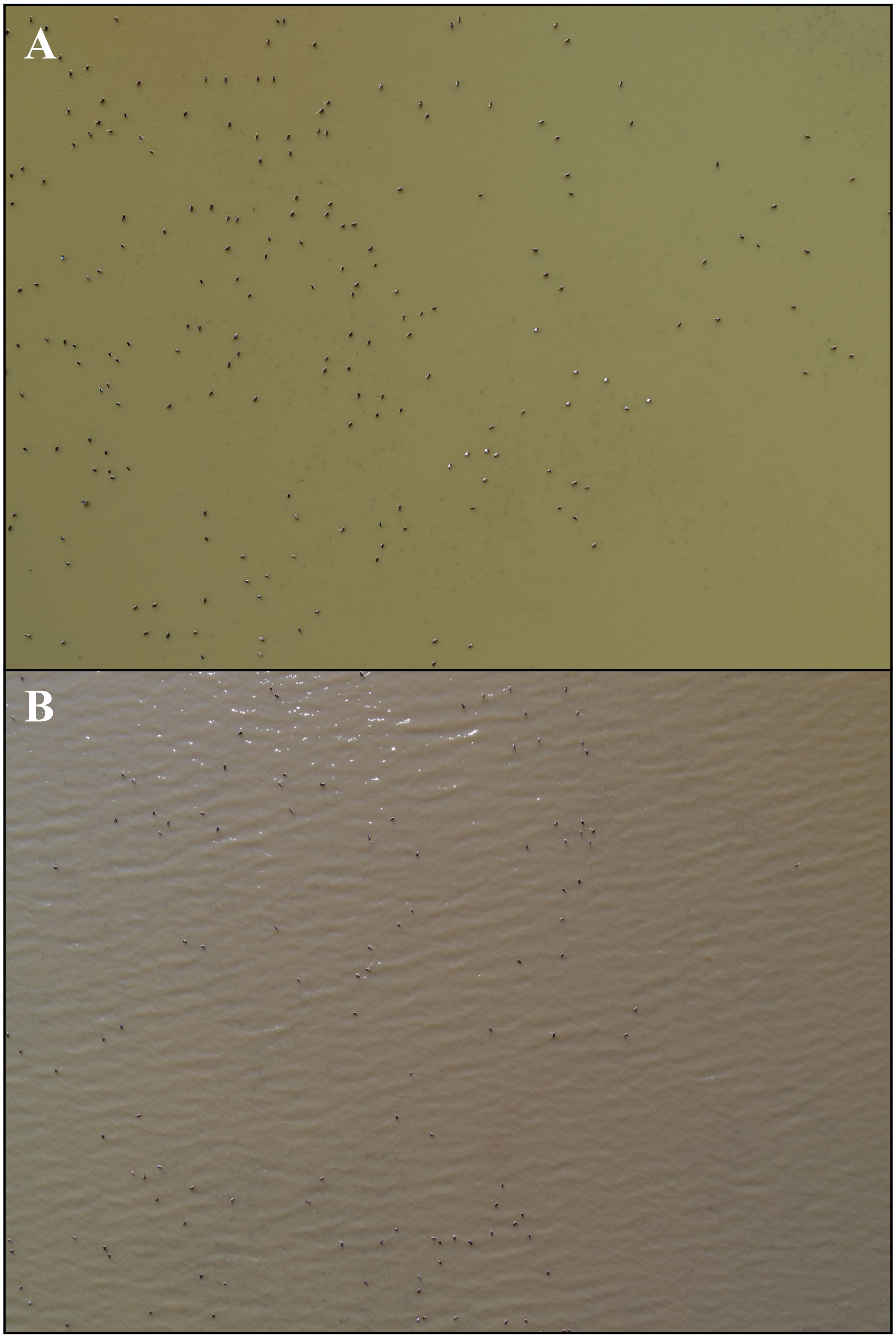

**Figure 2.4.** Example imagery captured with Zenmuse X5S in calm (A) vs. windy conditions (B).

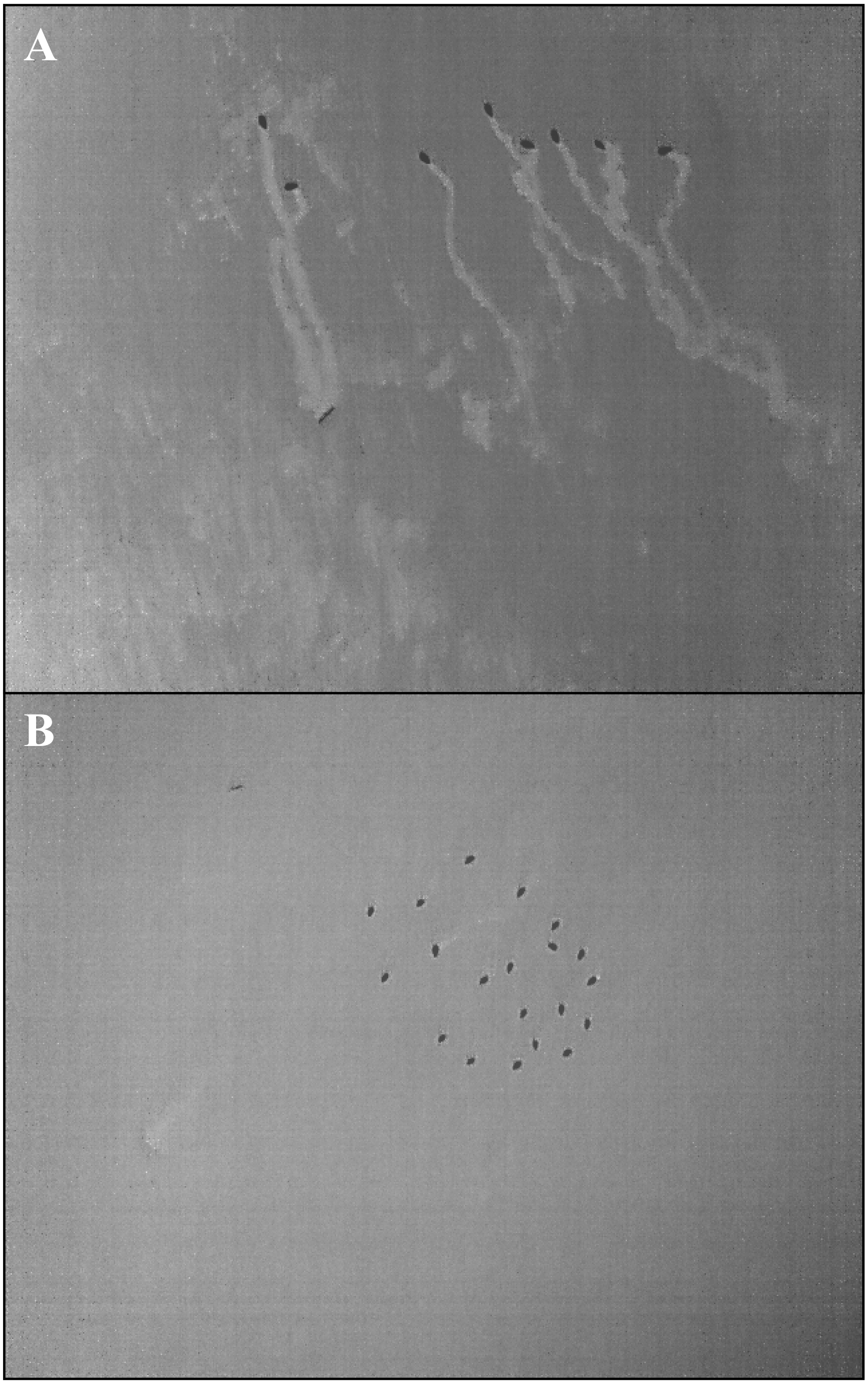

**Figure 2.5.** Example imagery captured with Zenmuse XT2 comparing ducks (A) vs. coots (B).

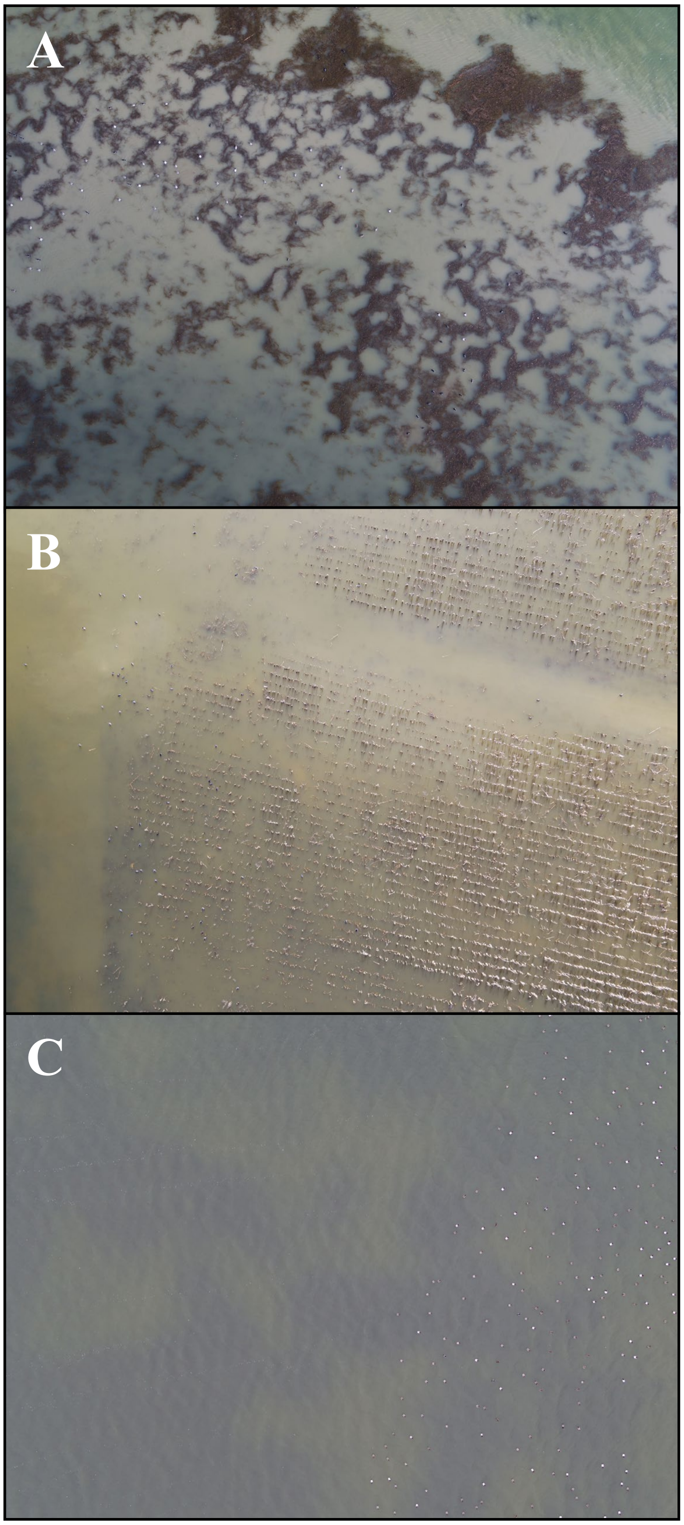

**Figure 2.6.** Example imagery captured with Zenmuse X5S in submerged aquatic vegetation (A) vs. agriculture (B) vs. open water (C) land cover types.