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Behavioral Responses Of Breeding Ducks To Unmanned Aerial Vehicle Surveys And Best Practices For Breeding Waterfowl Surveys Using Unmanned Aerial Vehicles

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BEHAVIORAL RESPONSES OF BREEDING DUCKS TO UNMANNED AERIAL VEHICLE SURVEYS AND BEST PRACTICES FOR BREEDING WATERFOWL SURVEYS USING UNMANNED AERIAL VEHICLES

by

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Bachelor of Science, Valley City State University 2016

A Thesis

Submitted to the Graduate Faculty

of the

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2022

This thesis, submitted by Mason Ryckman in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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PERMISSION

Title	Behavioral Responses of Breeding Ducks to Unmanned Aerial Vehicle Surveys and Best Practices for Breeding Waterfowl Surveys using Unmanned Aerial Vehicles (UAVs)
Department	Biology
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Mason Ryckman
May, 2022

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To my mother Sandy and dad Dan

ABSTRACT

Unmanned aerial vehicles (UAVs) have become a popular wildlife survey tool. As such, biologists are exploring the use of UAVs for surveying waterfowl, which are an important game species protected by the Migratory Bird Treaty Act. The most cited benefit of using UAVs over traditional methods is the idea of reduced disturbance, but this has had limited evaluation across species. However, responses of wildlife to UAVs are known to be species specific and vary with platform type. The objectives of this study were to investigate how breeding ducks respond to UAV surveys. First, we compared the behavioral responses of breeding blue-winged teal (*Spatula discors*) (n = 151) and northern shovelers (*Spatula clypeata*) (n = 46) on wetlands flown over with a rotary DJI Matrice 200 quadcopter and control wetlands without flights. Using a GoPro camera affixed to a spotting scope, we conducted focal individual surveys and recorded duck behaviors for 30 minutes before, during, and 30 minutes after UAV flights to determine if ducks flushed or changed in specific activities. We also conducted scan surveys during flights to examine flushing and movement on the entire wetland. Between 24 April and 27 May 2020, we conducted 42 paired (control and flown) surveys. Both teal and shovelers increased proportion of time engaged in overhead vigilance on flown wetlands from pre-flight to during flight (0.008 to 0.020 and 0.006 to 0.032 of observation time, respectively). Both species left the wetland more frequently during flights than ducks on control wetlands. Despite similarities between species, we observed marked differences in time each species spent on active (e.g., feeding, courtship, swimming), resting, and vigilant behaviors during flights. Overall, teal became less active during flights (0.897 to 0.834 of time) while shovelers became more active during this period (0.724 to

0.906 of time). Based upon scan surveys, ducks flushed in 38.1% of surveys while control wetlands only had a single (2.4%) flush during the flight time. We found launch distance was the most important predictor of whether ducks swam for cover or away from the UAV which could result in inaccurate counts. Secondly, we evaluated how nesting blue-winged teal and gadwall (*Mareca strepera*) females on nests respond to a fixed-wing UAV (80m AGL) and rotary UAV (35m and 80m AGL). We conducted 39 UAV flights over 61 nests and had an additional 12 control nests (no flights). Small surveillance cameras at each nest allowed us to obtain behavioral footage. Results showed that blue-winged teal surveyed with the rotary UAV at 35m increased in the proportion of time spent on active behavior from day before flight to day of flight (0.0825 to 0.2575) while the proportion of time spent on active for the rotary at 80m and fixed-wing decreased in time spent on active from day before to day of flight (0.1153 to 0.0927 and 0.1154 to 0.0902). On day of flights, both gadwall and blue-winged teal increased in a proportion of time spend on alert behavior from the before period to during the flight period and returned to preflight levels during the after period. Eight flushes of nesting females occurred during the 2020 field season. Three gadwall flushed when flown over with the rotary drone at 80m while 4 gadwall and 1 blue-winged teal flushed when flown over with the rotary at 35m. The fixed-wing drone didn’t flush any nesting females off of their nest. Ducks appear aware of UAVs during flights, but minimal behavioral shifts suggest negative fitness consequences are unlikely.

CHAPTER I BACKGROUND AND LITERATURE REVIEW

Early explorers of North America came across an abundant number of wildlife including waterfowl. As time progressed and settlers moved farther west, they started converting wetlands and prairie for agricultural or industrial purposes. Conservationists were seeing a rapid decline in wildlife including migratory birds which led to the passing of the Migratory Bird and Treaty Act of 1916. As a result of the importance of migratory birds in North America, a lot of effort has focused on monitoring annual reproductive rates for conservation, to set harvest regulations for game species, and monitor annual differences in climate and landscape change. For example, the U.S. Fish and Wildlife Service, along with the Canadian Wildlife Service, currently has two survey methods for estimating waterfowl breeding populations. These include the waterfowl breeding population and habitat survey (WBPHS), and the four-square mile breeding waterfowl survey (FSMS). The WBPHS is conducted by manned aircrafts that fly latitudinal transects. Altitude of the aircraft is 30-50m above ground level. The FSMS survey consists of point or ground counts of breeding pairs using wetlands in four square mile plots. It also uses remotely sensed data from satellite imagery to look at habitat characteristics.

While these surveys have a long history, there are challenges with each. For example, aerial surveys such as the WBPHS pose safety concerns. Airplane crashes have been identified as the leading cause of death among wildlife biologists (Sasse 2003). Another challenge is the quality of data acquired from the surveys. Long hours in an aircraft or conducting extensive ground counts can lead to observer fatigue, which ultimately causes errors in data (Hodgson et al. 2013). Also, according to Pagano and Arnold (2009), the assumption of detecting 100% of the waterfowl using a wetland during ground counts is false. They conducted independent double-observer pair surveys and found that population sizes were underestimated by 10-29% (Pagano and Arnold 2009). Further, accessibility to sites for ground counts can be a challenge in some areas due to remoteness or ground conditions limiting site access (Ellis-Felege et al. 2022).

In addition to population surveys, there is substantial interest in monitoring breeding effort and success in waterfowl (Anderson et al. 2018). By understanding nesting ecology of waterfowl species, managers can focus on conserving habitat that is crucial for nesting ducks (Stephens et al. 2005). A variety of approaches have been used to survey upland duck nests. The most common among these is the chain dragging method (Higgins et al. 1969). This method consists of a 15.88mm steel chain being dragged between two all-terrain vehicles (ATV). Another researcher, who is called a spotter, will try to identify the duck that flushes. Even though this method can be effective at finding nests, ATVs leave unwanted trails in the study area which predators can use to locate nests. There is also the possibility of driving over nests with the ATVs.

Unmanned Aerial Vehicles as a Survey Tool

Recently, unmanned aerial vehicles (UAVs) have been used to conduct a variety of wildlife surveys (Dulava et al. 2015, Linchant et al. 2015, Christie et al. 2016, Sardà-Palomera et al. 2017, Chabot 2018, Lyons et al. 2019). UAVs have been used to map dynamic changes in freshwater habitats (Marcaccio et al. 2016), detect poachers of Rhinoceros in Africa (Mulero-Pázmány et al. 2014), collect insects to monitor populations in rice fields (Kim et al. 2018), and to assess whale health by collecting “blow” through the nasal passages of whales (Pirotta et al. 2017).

One benefit of using UAVs over traditional surveys is the ability to access and collect data in rough terrain such as in the tundra biome and Arctic regions (Barnas et al. 2018). While much of the data UAVs collect are higher resolution than satellites can provide, another benefit to UAVs is the ability to time such remote sensing collections for ideal conditions (e.g., cloud cover, plant or breeding season phenology, etc.) (Anderson and Gaston 2013). Further, using UAVs for wildlife assessments results in the ability to rapidly collect a lot of data that can be archived. Archiving data will give researchers the ability to review previously analyzed datasets (McEvoy et al. 2016). However, these large datasets need to be reviewed and create a "data deluge" problem that requires storage and computational resources to manage (Bowley et al. 2019). Since analyzing footage and photos produced by UAVs is labor intensive, there is a need for computer automated detection. Chabot and Francis (2016) looked at computer automated detection software and found it effective for objects such as birds that contrast sharply with image backgrounds. A more complex software is warranted for thermal images where resolution isn't as high as the standard RGB (red green blue) sensors (Chabot and Francis 2016). Further, work has demonstrated the use of neural networks as a potential approach to estimating breeding snow geese (Bowley et al. 2018, 2019) and including citizen scientists as a way to develop training datasets for these automated approaches (Bowley et al. 2017). This is an area of future work as UAVs become more commonly used tools by wildlife biologists.

The most often cited benefit of using UAVs is the reduced disturbance compared to traditional surveys (Christie et al. 2016). However, research suggests that UAVs might not always be minimally invasive depending on animals' life history stage, size of UAV, flight altitude, and flight pattern (Mulero-Pázmány et al. 2017). One study on mammals in Botswana showed that elephants (*Loxodonta africana*) became vigilant or moved away from a VTOL (vertical take-off and landing) UAV when approached horizontally and vertically (Bennitt et al. 2019). In contrast, Vermeulen et al. (2013) showed that elephants exhibited no response when flown overhead with a fixed wing drone at 100m. Another UAV study suggests disturbances can negatively affect reproductive output and long-term physiological condition of Leach's storm-petrels (*Oceanodroma leucorhoa*) (Blackmer et al. 2004). Weimerskirch et al. (2018) concluded breeding adult king penguins showed an increased heart rate when approached by an UAV, while behavioral responses of stress were absent. Further, UAVs have been proposed as harassment tools for mitigating wildlife damage (Rhoades et al. 2019), suggesting that this technology may impact behavioral responses of animals in variety of ways depending on species of interest, platforms used, and flight approaches. Therefore, researchers should consider the impacts UAVs cause compared to traditional methods.

UAVs have also started to be tested as tools to survey waterfowl with some success over traditional ground surveys (Drever et al. 2015, Pöysä et al. 2018, Bushaw et al. 2020, Dundas et al. 2021, Stander et al. 2021). Pöysä et al. (2018) found that during brood surveys, UAVs found more ducklings than point count surveys. A study comparing UAV counts to ground counts of non-breeding waterfowl on artificial waterbodies concluded that UAV counts were more accurate than ground counts (Dundas et al. 2021). UAVs equipped with thermal cameras have been used to detect overwater nesting and upland nesting duck nests (Bushaw et al. 2020, Stander et al. 2021). During one field season, Bushaw et al. (2020) found that 19 overwater nests were abandoned from ground monitoring, compared to one nest abandonment by UAV monitoring. Stander et al. (2021) reported high false positive rates when nest searching for upland nesting ducks but future research at lower altitudes might perhaps mitigate the number of false positives.

While most studies evaluate detections rates of waterbirds using UAVs, few have accessed, or quantified disturbance caused by UAVs. Semi-captive mallards (*Anas platyrhynchos*) showed no reaction when approached at angles of 20°, 30°, and 60°, but showed a reaction for approaches at 90° using a quadcopter UAV, suggesting the approach of the UAV to the birds is important (Vas et al. 2015). Another study that examined responses of a variety of waterfowl species found a flight response was rarely observed but was present when the UAV was launched directly at a flock of birds or at a relatively low altitude of 10-15m (McEvoy et al. 2016). McEvoy et al. (2016) also reported that ducks were more disturbed by fixed-wing UAVs compared to rotary UAVs. Lesser snow geese (*Anser caerulescens caerulescens*) showed an increase in vigilance behavior during the UAV flight and geese would sometimes leave the nest prior to flight due to researcher presence (Barnas et al. 2018). Drever et al. (2015) concluded that responses of waterbirds to UAVs appeared to be species-specific and gulls were most likely to respond by flushing and not returning. Common Eiders (*Somateria mollissima*) showed no response or behavioral changes to fixed-wing UAV surveys (Ellis-Felege et al. 2022). To date, no research has been done that quantifies specific behaviors of nesting ducks on the prairie to UAV surveys.

While UAVs pose many benefits, there are still limitations to using them. Battery life is improving, but many platforms have limited flight times of 30 minutes or less (Christie et al. 2016). This results in limited spatial scale that can be covered. Resolutions for thermal/IR sensors are currently limited, resulting in low altitude flights which result in longer flight times, reduction in spatial coverage and the possibility of disturbances (Kays et al. 2019). Given the variety of platforms and sensors, there is a learning curve to ensuring researchers select the right sensors and platforms to meet project objectives. Restrictions on flying UAVs are improving but pilots in the U.S. still need to obtain an FAA Part 107 license. The UAV also has to stay within visual line of sight of the pilot or visual observer unless a special waiver is approved by the FAA (Vincent et al. 2015). Currently, there are still restrictions on flying UAVs over specific lands (e.g., Department of Interior owned). Researchers also should be aware that harassing or disturbing migratory birds should be avoided and requires additional permit considerations in the United States. This increases the need for best practices that inform the use of UAVs in research and monitoring wildlife (Barnas et al. 2020).

Study System

The Prairie Pothole Region (PPR), which spans across 5 US States and 3 Canadian Provinces, is one of the most unique wetland-grassland ecosystems in the world. Not only does the PPR provide habitat for an array of wildlife, it also provides a variety of ecological goods and services to our society including the storage of surface water which can reduce flooding, recharge groundwater, filter chemicals and contaminants, and mitigation of greenhouse gas emissions (Doherty et al. 2018). The PPR is the most important breeding area for waterfowl in North America and is estimated that it produces 50-80% of the continents duck population. During the waterfowl breeding population and habitat survey (WBPHS) in 2011, 29 million ducks were surveyed in the area. This makes the area an ideal location for monitoring and conducting research on ducks, which are an important game species and are protected under the Migratory Bird and Treaty Act. Common upland nesting ducks that nest in the PPR include mallard (*Anas platyrhynchos*), blue-wing teal (*Spatula discors*), gadwall (*Mareca strepera*), northern pintail (*Anas acuta*), northern shoveler (*Spatula clypeata*), American wigeon (*Mareca americana*) and lesser scaup (*Aythya affinis*). The three species we will be focusing on in this study include: blue-winged teal, northern shoveler, and gadwall. These three species are among the five of greatest interest to management and conservation in the region (Brice et al. n.d.).

Project Objectives

In the following chapters, I investigate how breeding ducks respond to UAV surveys in the Prairie Pothole Region (PPR) of North Dakota. In chapter II, I evaluate how breeding pairs on wetlands respond behavioral to a rotary UAV, flown as biologist would to survey waterfowl. I then assess behavioral responses of upland nesting ducks to 2 UAV platforms in chapter III. I use before-after-control-impact design to see how behaviors change before, during, and after UAV flights, along with the day before flights (chapter III). In the final chapter, I discuss limitations of using UAVS to survey waterfowl, management implications, and future research needs for UAV studies.

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CHAPTER II BEHAVIORAL REPSONSES OF BLUE-WINGED TEAL AND NORTHERN SHOVELER TO UNMANNED AERIAL VEHICLE

Introduction

Annual breeding bird population surveys are critical for understanding productivity, establishing conservation priorities, and setting harvest regulations for some species. Decision-making associated with these surveys requires having reliable and consistent data collection efforts that often employ low-flying aerial surveys or conducting intensive ground surveys. Aerial surveys can be prohibitively expensive and even dangerous to conduct. In fact, due to the low altitude and slow speeds, occupied aerial surveys accounted for 66% of job related mortality in wildlife researchers from 1937-2000 (Sasse 2003). Further, ground surveys can be labor intensive, inconsistent due to observer variation, and logistically difficult in remote areas (Jones et al. 2006, Anderson and Gaston 2013, Weissensteiner et al. 2015). As a result, wildlife professionals and scientists are increasingly interested in using unmanned aerial vehicles (UAVs) for surveys because of the safe and cost-effective alternatives they provide to traditional aerial surveys (Jones 2003, Linchant et al. 2015).

UAVs confer numerous advantages both in and out of the field for wildlife professionals. Using this technology, researchers can access terrain which would otherwise be inaccessible to ground observers. Their use can also help address the challenge of observer fatigue, which can bias the data being collected (Christie et al. 2016, Barnas et al. 2018). Outside of fieldwork, UAVs allow researchers to create an archive of data, giving researchers the chance to return to a dataset for multiple observers to verify estimates or even explore questions that may arise in the future (McEvoy et al. 2016). Also, UAVs provide high resolution imagery that can overcome problems of timing (e.g., plant and breeding season phenology) and suboptimal atmospheric conditions (e.g., cloud cover) that often hinder traditional satellite-based remotely sensed data (Anderson and Gaston 2013). Finally, one of the most cited benefits of UAVs is the reduced anthropogenic disturbance they provide compared to other survey techniques (Vas et al. 2015, Mulero-Pázmány et al. 2017). However, wildlife responses are often difficult to evaluate and until recently the benefit of reduced disturbance was based on anecdotal evidence. Advances in this field have demonstrated that responses to UAV disturbance are species-specific (McEvoy et al. 2016, Mulero-Pázmány et al. 2017) and that birds might exhibit higher sensitivity to UAVs than other wildlife (Mulero-Pázmány et al. 2017).

While the "birds eye view" captured by UAVs may help reduce bias in surveys, this benefit is contingent on the UAVs not disturbing the wildlife in question. Determining whether UAVs elicit negative behavioral responses such as escaping or leaving the area is important as these behaviors can reduce the time spent on fitness-enhancing activities such as feeding or mating (Frid and Dill 2002). Negative behavioral responses may also influence survey results if the individuals leave or move because of the survey method, causing a missed detection or double-count. Some studies have shown UAVs are capable of adversely impacting wildlife species by allowing aerial predators to depredate nests following a UAV flight or causing stress by increasing heart rates in individuals (Ditmer et al. 2015, Brisson-Curadeau et al. 2017). As Mulero-Pazmany et al. (2017) suggest, responses are often species-specific and depend on a variety of characteristics of the animal, landscape topography, and the UAV platform. Careful evaluation of life-history stage and level of aggregation of a species need to be evaluated.

One group of wildlife UAVs are being used to survey more frequently is waterfowl (Dulava et al. 2015, McEvoy et al. 2016, Bushaw et al. 2020). Traditional surveys, such as the

Waterfowl Breeding Population and Habitat Survey (WBPHS), are conducted via low-flying airplanes. The WBPHS surveys most of the North American breeding duck population and has been conducted annually since 1955 using a fixed-wing aircraft flying at an altitude of 30-50m above the ground. UAVs have been used thus far to survey nesting or breeding waterfowl (Pöysä et al. 2018, Bushaw et al. 2020) and also nonbreeding waterfowl (Drever et al. 2015, McEvoy et al. 2016, Jarrett et al. 2020, Dundas et al. 2021). The emphasis of UAV use in waterfowl research not only parallels the broader wildlife arena in its rapid growth but also in its limited information on behavioral responses of breeding ducks with only a few studies to some extent examining behavioral responses (McEvoy et al. 2016, Pöysä et al. 2018, Jarrett et al. 2020)

Here, we tested the assumption that UAVs do not alter behaviors such as vigilance and escape (e.g., flush, move to cover) by flying a rotary UAV over wetlands using altitudes and flight patterns that would be used to conduct actual breeding pair surveys. Specifically, we used a before-after-control-impact design to determine if breeding dabbling ducks flush, move to adjacent cover, or change in specific activities when flown over, and these flights were compared to control wetlands (no UAV flights) starting before flight and monitoring behaviors through post-flight period. From this research, we suggest guidelines for wildlife researchers conducting waterfowl surveys with UAVs that describe limitations of UAVs and illustrate approaches that minimize shifts in behavior responses while maximizing the quality of data generated.

Methods

Study Area and Study Species

Breeding duck surveys took place in the Prairie Pothole Region of North Dakota at two ranches: Coteau Ranch and Davis Ranch located in Sheridan County (Figure 1). Operations were based out of a location on the Coteau Ranch (N 47.401054, W -100.276947). The Coteau Ranch is currently owned by Ducks Unlimited and is approximately 1,214 ha. The Nature Conservancy owns the Davis Ranch which is approximately 2,931 ha. The ephemeral and semi-permanent wetlands of the area attract a variety of dabbling duck species to the study area. We chose to focus on northern shoveler (*Spatula clypeata*) and blue-winged teal (*Spatula discors*), which were the most common species present on wetlands within our survey area.

Behavior Monitoring and Point Counts

We conducted UAV flights over wetlands that had ducks present at the start of the entire survey and remained on the wetland through the first observation period. For each trial, we collected behavior data and duck counts at paired wetlands: a control and a flown. We defined a control wetland as a ponded wetland we identified prior to UAV flights that had ducks present and that we did not fly a UAV over or within 115 meters of, and it did not have a previous UAV flight on it. We acknowledge that depending upon wind and other weather characteristics, the sounds of setting up equipment or the UAV in flight may be able to be detected at a control wetland. Flown wetlands were those ponded wetlands that also had ducks present, and we flew over with a UAV to obtain counts. We did not fly over the same wetland twice; however, some control wetlands later became flown. Observers collected behavior data 30 minutes prior to the UAV flight, during flight (range: 6 – 29 minutes) and 30 minutes after the flight. During each flight, one observer was located on a flown wetland and the other on a control wetland. Both observers sat or kneeled in cover at vantage points where the whole wetland was visible or if the wetland exceeded UAV capabilities, the observer positioned themselves where they could see only the survey area covered by the flight. Observers selected the species based on the same species being present at the paired location. If multiple individuals of a species were present, observers prioritized pairs to be able to capture both male and females and maximize sample size. Due to the presence of pairs (male and female ducks in close proximity to one another), observers were commonly able to record observations for both individuals (pair). If multiple pairs existed, observers randomly selected a pair. These pairs are described hereafter as focal individuals or focal individual if only one duck was present on the wetland (Altmann 1974). Observers recorded observations of focal individuals using a GoPro Hero 4 mounted to either a Swarovski (STS 65) or Leica (APO-TELEVID 77) spotting scope. Each spotting scope was attached to a tripod (Zomei Q111, Cabelas 364/MG10) and each GoPro was attached to the spotting scope by using a phone scope attachment (C3-099-A, C3-022-1). GoPros were equipped with 16GB micro SD cards. Observation start and end times were coordinated via text messages among the two wetland observers and the UAV operator.

Flight Operations

The UAV operator conducted flights using a DJI Matrice 200 V2 (color: black, weight: 4.53kg, operating temp: -20°C to 40°C), a quad-rotary aircraft powered by lithium polymer batteries (22.8V, 7660 mAh). A Zenmuse X5S camera (RGB) was attached to the UAV. An Olympus lens with focal length of 45mm was attached to the camera. With this lens, the sensor has a ground sampling distance (GSD) of roughly 0.44cm per pixel at 45 m (150ft) above ground level (AGL). We chose 45m due to test flights that allowed pixel sizes (GSD of 0.44cm) capable for us to accurately identify ducks to species and sex. The camera was set to take still images to be used for counts, but these images were not used for any of the behavioral assessments. While counts are not reported, we report sensor parameters to contextualize actual survey parameters since we desired evaluating behaviors following actual breeding pair survey characteristics. The UAV operator preprogrammed flights using the DJI Pilot software (version 1.8.0). The flight path was a tangential approach grid (lawn-mower pattern). Research suggests this approach causes less disturbance than directly approaching birds from takeoff (McEvoy et al. 2016). The UAV operator flew the UAV at 5m/s which allowed us to collect data over larger wetlands compared to slower speeds, but still obtain images that were not blurry. Flight time with this aircraft is limited to 38 minutes or less so the UAV operator flew the UAV with a 60% forward and side-to-side overlap between adjacent images to allow for orthomosaics to be produced in future studies. Full details of flight operations and conditions are reported following Barnas et al. 2020 (S1 File). Permissions were provided by the North Dakota Game and Fish Department (GNF04912726, GNF05182785), UND Institutional Animal Care Use Committee A3917-01, Protocol #1904-2, and the UND Unmanned Aircraft Systems Research Compliance Committee Approval (Approved April 12, 2019).

Video Review and Individual Behavioral classifications from Focal Surveys

We retrieved micro-SD cards from the ground observer's GoPros after each flight and downloaded video files to a hard drive at the end of each survey day. To provide consistent behavioral evaluations, a single observer reviewed all video using Windows Media Player (Microsoft, Seattle, WA). This observer (MR) matched video files with start of survey times and classified behaviors from 30 minutes prior to takeoff until 30 minutes after the UAV has landed. The pre-flight period provided a baseline for behavioral comparisons that were individual or wetland specific. The post-period assessment provided an opportunity to determine if any residual behavior responses persisted after landing.

The observer classified behaviors of focal individuals into 5 broad categories: active, none, vigilant, overhead vigilance, and flush (Table 1). Active consisted of behaviors including preening, feeding, breeding (copulation, courtship displays), and swimming. The category none consisted of sleeping or resting behaviors. Head popping (described as high scan by Barnas et al.

(2018)) was the additional behavior for vigilant and described occasions when the duck extended its head away from the body to scan its surroundings. Overhead vigilance (classified as head cocking by Barnas et al. (2018)) was when a duck tilted its head to see what was up above it. Flush consisted of either territorial flushes or other flushes for which the cause was unknown, but the bird left the wetland.

Behavioral Classification from Scan Surveys

In addition to focal individual surveys, we conducted scan surveys where ground observers at both flown and control wetlands recorded if birds flushed at any time during the UAV flight. Similarly, the ground observers also recorded if ducks swam towards cover or away from the UAV. This gave us the opportunity to determine bird responses to UAV flights on a wetland perspective. Specifically, we were interested in determining if treatment (flown or control), wetland characteristics (cover type class as defined by Stewart and Kantrud (1971)), proximity of flight launch site or weather characteristics (wind speed, wind direction, temperature, and cloud cover) impacted responses of ducks across the wetland. Weather data (wind speed, temperature) was collected using Kestrel 3000 at 2 points during flight (start and end) and averaged to obtain one value.

Data Analysis

Focal Individual Responses

Our analysis of focal individual responses used a before-after-control-impact (BACI) design. In the model set, we looked at proportion of time spent in each of the five pre-defined behaviors. We constructed a generalized mixed model using Proc Glimmix in SAS Studio (Version: 9.4) assuming that each of our five behaviors (active, none, vigilant, overhead vigilance, flush) were drawn from a beta distribution representing the proportion of time spent in that behavior. Fixed effects included *species* (blue-winged teal, northern shoveler), *treatment* (flown or control), *flight period* (before, during, after), the 2-way interactions of *treatment* and *flight period*, *species* and *flight period*, and the 3-way interaction of *species*, *treatment*, and *flight period*. For a significant effect in a BACI design, we would expect to see a significant interaction between treatment and flight period. Random effects were *flight ID* and *bird ID*(species). P-values < 0.05 were considered statistically significant. We calculated the least square means (LSMeans) and report these estimates and their associated 95% confidence intervals.

Behavioral Responses from Scan Surveys

To evaluate general observations of ducks across the wetlands, we used a Fisher Exact test to compare flush levels (none, <50% of all birds flush, 50% - 99% of all birds flush, all individuals flush) for the two categories of treatment (wetland was flown over) and control (wetland did not have a flight). We considered P-values < 0.05 to be significant and provide summary statistics for each flush level by treatment (flown, control).

For our scan surveys, we wanted to know if birds might be moving away from the UAV or towards cover during surveys and if other factors may play a role in responses. We constructed a logistic regression using Proc Glimmix is SAS Studio (Version: 9.4) to model the binary response of ducks swimming away from UAV or to cover (1) versus no visible movement as ducks stayed in the relative same area throughout the flight period (0). Variables used in this model were *treatment* (flown or control), average *temperature* during survey time, average *wind* speed during survey, *cloud cover* (clear, partly cloudy, mostly cloudy, and overcast), *wind direction* (8 categories of N, S, E, W, NE, NW, SE, SW), wetland *cover type* (Stewart and Kantrud 1971), UAV *survey size* (area coverage of programmed flight) to represent wetland size, and *launch distance* (Euclidean distance of edge of wetland to UAV launch site). We included wind parameters because the UAV might have a higher noise output with high winds and birds might respond differently (Rischette et al. 2020). To explore if ducks responded differently to shadows produced from the UAV, we included cloud cover in the model. By including launch distance, we assessed whether the anthropogenic influence of the UAV launch operation is impacting how birds are behaving (Vas et al. 2015). We included cover type and survey area of the wetland because emergent vegetation and relative size could influence how birds respond to UAV flights. We used Akaike Information Criterion corrected for small samples sizes (AICc) to evaluate the simplest explanation for if birds swim to cover (Burnham and Anderson 2002). We calculated odds ratios from back transforming estimates to present how many times more or less likely the probability of swimming away was relative to the covariate of interest.

Results

We collected behavioral observations on control and flown wetlands for 42 flights between April 24th and May 27th, 2020. In a few cases (n = 3), technological failures, observer errors, or external disruptions (e.g. rancher drove ATV next to control wetland flushing all birds) rendered insufficient data for analysis. Initially, we obtained behavioral observations for 7 species of ducks, but due to difficulty in collecting adequate samples sizes of each, we focused efforts exclusively on blue-winged teal and northern shoveler. This translated to behavioral observations from 32 flights on 151 blue-winged teal and 13 flights on 46 northern shovelers. On average, we monitored 2.6 focal individuals/ flown wetland and 2.7 focal individuals/ control wetland. Average UAV flight duration was 18 min (range: 6 – 29 minutes).

Individual Duck Behavioral response to UAV flight

For active and none (sleeping or resting) behaviors, we found a statistically significant difference in behaviors ($P < 0.05$) for flight period and all the interactions (treatment × flight period, species × flight period, species × treatment × flight period; Table 2). Proportion of time spent on active behavior for blue-winged teal on flown wetlands decreased from pre-flight period when the UAV was overhead (0.897 to 0.834; Figure 2a; S2a Table). In other words, for a 10 minute observation period teal spent almost 9 minutes on average engaged in active behaviors prior to the flight, but reduced time spent in that behavior to 8.34 minutes during a 10-minute flight. In contrast, active behavior for northern shovelers on flown wetlands increased from pre-flight period when the UAV was overhead (0.724 to 0.906; Figure 2b). For a 10-minute pre- and during flight observation period, shovelers increased activity from 7.24 minutes to over 9 minutes during the flight. For both species, post-flight responses were similar to pre-flight responses (Figure 2). For vigilant behavior, the two-way interactions of treatment × flight period and species × flight period were statistically significant (Table 2). Vigilant behavior for blue-winged teal decreased from pre-flight period to when the UAV was overhead (0.012 to 0.008; Figure 3a) while northern shovelers increased from the pre-flight period to when the UAV was overhead (0.007 to 0.018; Figure 3b). This translated to teal spending approximately 7 seconds in vigilant behaviors during a 10-minute pre-flight observation to less 5 seconds during a 10-minute flight, while shovelers increased vigilance from about 4 seconds during the pre-flight period to over 10 seconds in vigilant behavior during a 10-minute flight period. Similar to active behaviors, vigilance appeared to return to similar pre-flight levels (Figure 3). We found statistically significant results for treatment, flight period, the two-way interaction of treatment × flight period, and the three-way interaction of species × treatment × flight period for the proportion of time spent in overhead vigilance behavior (Table 2). Blue-winged teal and northern shovelers both exhibited increases in overhead vigilance from pre-flight period to when the UAV was overhead (0.008 to 0.020 and 0.006 to 0.032), but these levels returned to pre-flight levels during the post-flight period (Figure 4).

Scan Surveys Behavioral Responses

We observed more events of ducks flushing on flown wetlands than at control wetlands (Table 3). For all observations when all ducks flushed on the flown (n=2 flights) and control wetlands (n=1 flight), there was only 1 pair of ducks on the wetland at the time of the flight. Results from the Fisher's Exact test indicated there was a significant difference between flush levels for wetlands that were flown over and wetlands that were not flown (p-value < 0.01).

Based on summary statistics, if birds were to swim away from the UAV or into cover, this occurred more often on flown wetlands (Table 4). However, the most parsimonious model (lowest AICc score) explaining the binary response of ducks swimming towards cover during surveys was the additive model of intercept + launch distance (distance from edge of wetland to UAV lauch site: S2b Table). This model possessed >98% AICc weight. Based on our top model, we found the probability of ducks swimming away from the UAV or towards cover was about 1.4 times less (OR =exp(-0.003*100)) likely for each 100 m increase in distance between the edge of wetland and the launch site (Intercept = 0.535, SE = 0.613; $B_{distance\ from\ pad} = -0.003$, SE = 0.002).

Discussion

With an increased interest in quantifying behavioral responses of wildlife to UAVs, our study is the most detailed and systematic behavioral evaluation of breeding ducks relative to a multi-rotor UAV. Our flight methods followed procedures that researchers would use to conduct breeding pair surveys using UAVs. We used a BACI design to evaluate changes in behaviors of focal individuals. We observed a quantifiable behavioral change on flown wetlands for blue-winged teal and northern shovelers across the flight periods (before, during, after). On flown wetlands, the proportion of time spent on overhead vigilance increased during the flight period and decreased back to pre-flight levels during the post-flight period for both species. This finding suggests both species of ducks were detecting the aircraft above them. These results are similar to a study looking at behavior changes of lesser snow geese (*Anser caerulescens caerlescens*) to UAV flights (Barnas et al. 2018) and also noted in other waterfowl species surveyed with UAV models (McEvoy et al. 2016). Further, other species of Antarctic birds have been documented engaging in aerial vigilance in response to UAVs (Rümmler et al. 2015, Weimerskirch et al. 2018). As Barnas et al. (2018) noted, the time spent in this behavior overall is a very small proportion of total time and therefore unlikely to have a large biological impact. We agree that for the ducks we surveyed, it is interesting that they notice the UAV in flight like other species of wildlife, but that this should not limit the use of UAVs as a sampling tool. Further, many other survey approaches such as observers approaching a wetland on foot or manned aviation likely draw the same vigilance response if not more since the birds may flush.

While active behaviors (swimming, breeding, feeding, preening) decreased a small amount for blue-winged teal during the flight, northern shovelers had an increase in active behavior. We acknowledge that we were unable to disentangle in focal birds if the swimming was suggesting a disturbance type response or simply just swimming as ducks do and that these were small proportions of time relatively speaking. However, it is worth noting that some birds do tend to become more active in response to UAVs such as those that are generally being disturbed by UAVs (Egan et al. 2020), while others tend to hold still (Ellis-Felege et al. 2022). Thus, it can be difficult to discern the motivation of an active behavior such as swimming. Further, we saw similar patterns for the proportion of time spent on vigilant behavior (head is extended away from body) for both species. Interestingly, both flown birds and control birds had the same pattern suggesting birds may be using their auditory stimuli to detect the aircraft. Blue-winged teal might be decreasing active and vigilant behavior as an anti-predatory response to the perceived threat of the UAV as a predator (Frid and Dill 2002). Perhaps most importantly, our findings demonstrate that during the post-flight period, ducks were resuming pre-flight levels of the behaviors, meaning these shifts in behavior were not sustained after the UAV landed. The species-specific responses in activity and vigilance were interesting given the two species are similar in size, and likely would have similar risks from aerial predators. However, it is worth noting that the two species have different life history patterns in diet and foraging ecology (shovelers are more filter feeders compared to teal) and likely different harvest pressure with teal being a more sought after game species than shovelers that may impact responses to potential threats.

During our scan surveys where we explored flushing of birds across the wetland, we found that ducks more often flushed on flown wetlands compared to control wetlands. Although the instances where all ducks flushed were few, this only occurred when the number of ducks on the wetlands (flown = 2, control =1) were a lone pair. While we didn't explore group size in detail and this warrants further investigation, our results from anecdotal evidence suggest ducks are more likely flush in response to UAVs on small wetlands with few ducks. This contrasts with past research that noted larger groups of ducks tend to flush during UAV surveys compared to smaller group sizes (Mulero-Pázmány et al. 2017).

We also found from our scan surveys, that ducks were more likely to swim towards cover or away from the UAV during the flight on flown wetlands. While that behavior was also apparent on control wetlands (14%), there are a few possible explanations for our model results.

First, due to UAV battery life limiting flight durations and to reduce the proximity of the UAV to a control wetland, we set up launch sites closer to flown wetlands (average = 319 m) than control sites (average = 537 m). Second, birds are likely responding to disturbance caused by researchers setting up equipment for UAV surveys which could lead to responses based on proximity to launch site. This has also been noted in past research of waterfowl species (Vas et al. 2015, Barnas et al. 2018). Barnas et al. (2018) reported that if snow geese were to leave their nest, it most often occurred before the UAV was even launched. Vas et al. (2015) recommended launch sites be greater than 100 meters from the wetland to minimize disturbances. Given most of our launch sites were greater than 100 m and averaged 428.18 m, we suggest even greater distances from launch sites to wetland may be warranted.

When examining the overall findings from this work, we did observe behavioral shifts in ducks reacting to UAV but responses were minimal in overall proportion of time and relatively rapid returns to pre-flight behaviors. These behavioral responses were unlikely to have major fitness consequences on breeding ducks and should not dissuade their use as a potential tool for breeding pair surveys. However, it is unknown if repeated flights over wetlands may result in habituation or increased disturbances that could have negative implications for breeding productivity. If birds are constantly flushed or increasing movement with avoidance behaviors such as swimming to cover, this could have energetic costs (Bélanger and Bédard 1990). Current survey protocols for breeding waterfowl typically have limited visits (two per survey period) so this is unlikely to be a major concern, but if other questions or monitoring efforts require intense, repeated surveys, this should be considered.

Our study was designed to evaluate behavioral responses that would mimic a survey for estimating breeding pairs. As a result, we used a sensor that enabled us to be at 45 m (150 ft)

AGL. Many off-the-shelf cameras may not have this resolution and result in a need to fly at a lower altitude. In fact, much of the research to date has been conducted at very low altitudes (e.g. 31m, 40m) in order to obtain accurate information on breeding birds (McEvoy et al. 2016, Bushaw et al. 2020). We highly encourage consideration of sensors and UAV platforms that maximize altitude while still meeting image resolution needs (Barnas et al. 2018, Duffy et al. 2020). Thus, altitudes lower than 45 m may result in very different behavioral responses than we found in our study.

The primary motivation of this work was to understand if we were to adopt UAVs as a tool for breeding pair surveys, are UAVs going to negatively impact breeding birds and would changes in behavior cause challenges in obtaining accurate counts. Our work suggested that UAV flights can cause flushes and this may result in missing ducks in counts compared to ground counts where an observer can take note of this in the field if it were to occur. We found ducks swam away from the incoming UAV, possibly perceiving it as a threat, and such movements can result in double counting or missing ducks entirely during a survey. Further, ducks moving away from the UAV or towards cover may reduce their ability to be detected depending on the type and resolution of the sensor. However, ground observers may also move birds or be unable to detect birds for these same reasons, thus creating some similar detection challenges. The benefit of a UAV is the ability to attach different sensors such as dual sensors equipped with a Red, Green, Blue (RGB; also known as an electrical optical sensor) and thermal or potentially even ultraviolet sensor on a UAV platform. This may aid in improving the detection of ducks in vegetation or along wetland edges that would be missed otherwise when using just an RGB camera (Helvey 2020). Technological advances in sensors and automation of imagery to obtain accurate counts will be critical next steps in the adoption of UAVs for duck counts (Tabak et al. 2019, Helvey 2020). Furthermore, future research is needed to understand the actual counts obtained from UAV imagery compared to traditional ground counts to determine what bias may exist as a result of behavioral responses to UAV flights.

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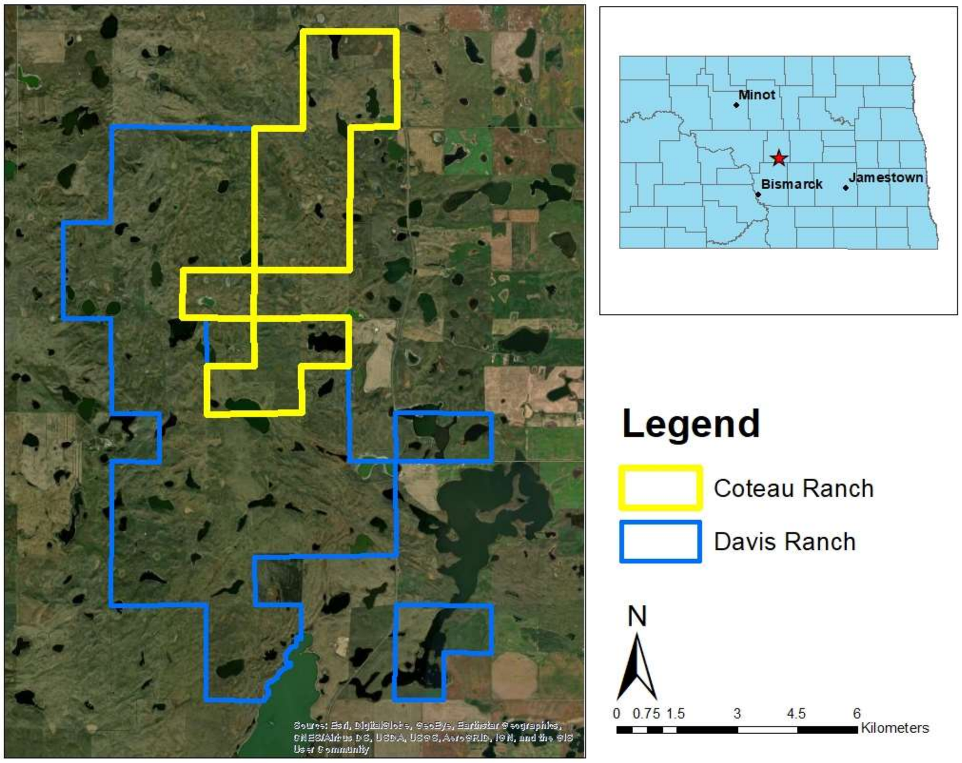

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1 Map of Coteau and Davis ranches in Sheridan County, North Dakota.

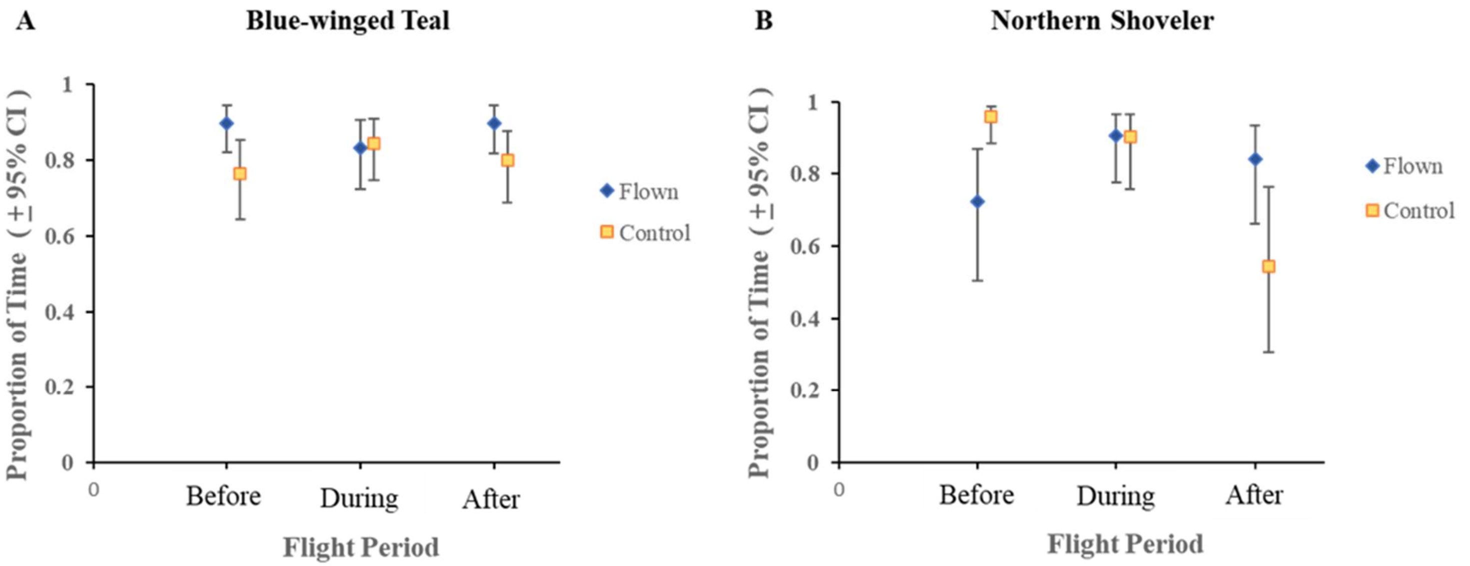

Figure 2 Least square means and 95% confidence intervals of proportion of time spent on active behavior for blue-winged teal (A) and northern shoveler (B) within treatments groups (Flown vs. Control). Additional behaviors for active are feeding, breeding, preening, and swimming.

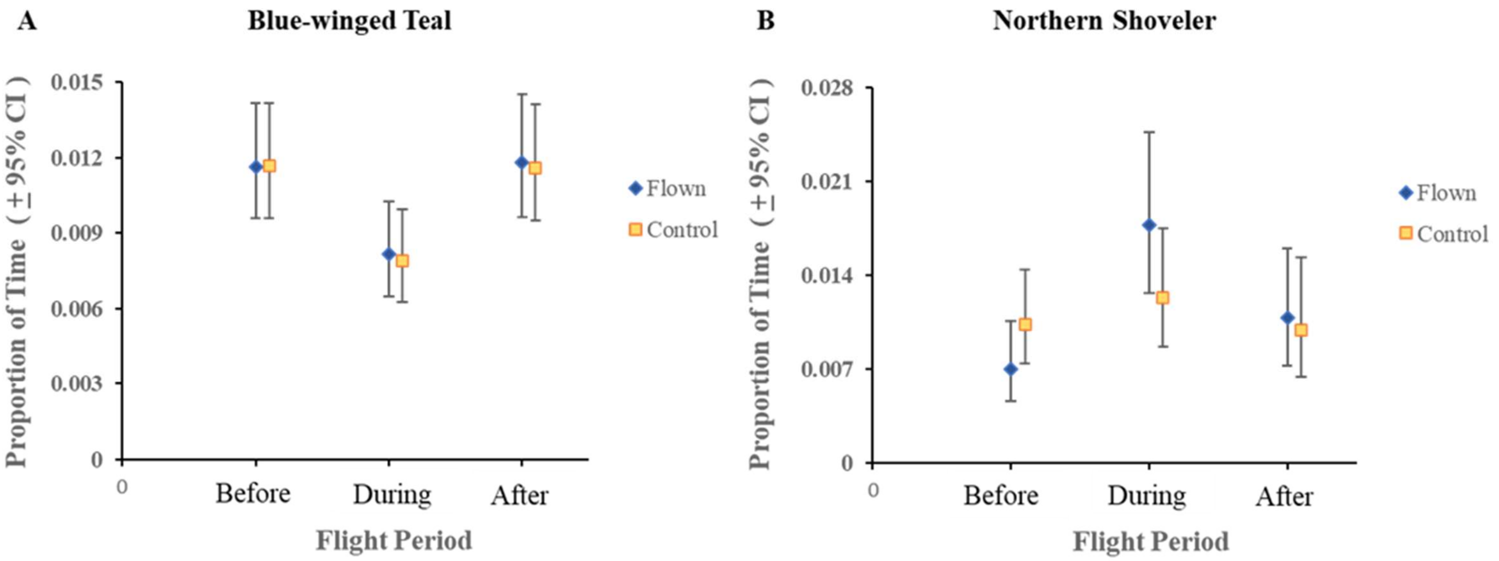

Figure 3 least square means and 95% confidence intervals of proportion of time spent on vigilant behavior for blue-winged teal (A) and northern shoveler (B) wihtin treatments groups (Flown vs. Control). This behavior consisted of the ducks fully extending their head away from the body to scan for intruders.

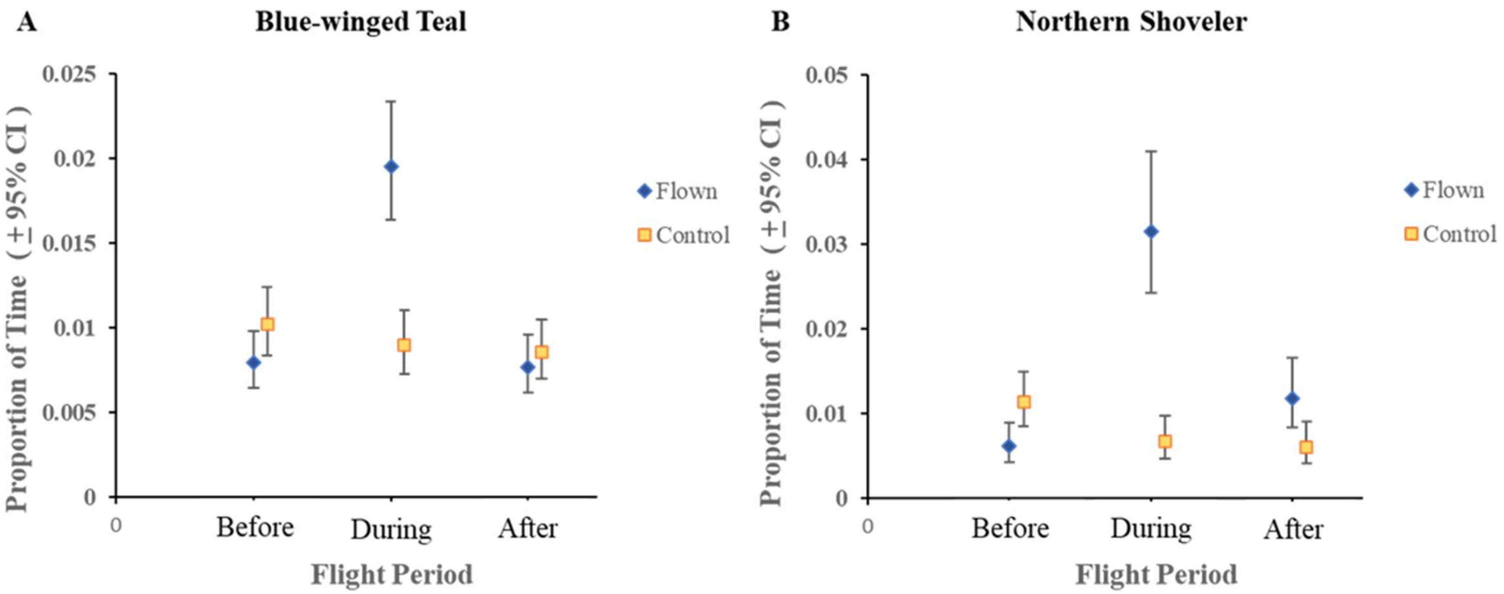

Figure 4 Least square means and 95% confidence intervals of proportion of time spent on overhead vigilance behavior for blue-winged teal (A) and northern shoveler (B) within treatments groups (Flown vs. Control). This behavior consisted of the ducks tilting their head to look at the UAV above them.

Table 1. Categories and types of behaviors for focal behavior surveys on breeding duck pairs conducted in Sheridan County, North Dakota during the spring of 2020.

Categories	**Additional Behaviors**
Active	Preening, Feeding, Breeding, Swimming
None	Sleeping, Resting
Vigilant	Head Popped
Overhead Vigilance	Head Cocked/tilted
Flush	Flush territorial, Flush other, Offshore flush

Table 2. Model results for proportion of time spent on each behavior. Fixed effects include *species* (blue-winged teal and northern shoveler), *treatment* (flown and control), *flight period* (before during after), and the interactions (*treatment* × *flight period*, *species* × *flight period*, *species* × *treatment* × *flight period*). Bold highlights denote statistical significance.

Behavior	DF	F-value	P-value
Active			
species	1	0.02	0.9011
treatment	1	0.35	0.5525
flight period	**2**	**5.73**	**0.0037**
treatment × flight period	**2**	**10.55**	**<0.0001**
species × flight period	**2**	**8.24**	**0.0003**
species × treatment × flight period	**3**	**10.00**	**<0.0001**
None			
species	1	0.01	0.9146
treatment	1	1.08	0.2989
flight period	**2**	**7.14**	**0.0010**
treatment × flight period	**2**	**11.34**	**<0.0001**
species × flight period	**2**	**10.02**	**<0.0001**
species × treatment × flight period	**3**	**11.13**	**<0.0001**
Vigilant			
species	1	0.25	0.6184
treatment	1	0.02	0.8787
flight period	2	0.85	0.4279
treatment × flight period	**2**	**3.08**	**0.0475**
species × flight period	**2**	**19.00**	**<0.0001**
species × treatment × flight period	3	1.70	0.1664
Overhead Vigilance			
species	1	0.03	0.8683
treatment	**1**	**12.95**	**0.0004**
flight period	**2**	**32.02**	**<0.0001**
treatment × flight period	**2**	**63.83**	**<0.0001**
species × flight period	**2**	0.80	0.4515
species × treatment × flight period	**3**	**7.59**	**<0.0001**

Table 3. Summary statistics for a multinomial classification of flushes on a whole wetland perspective basis. We conducted a total of 42 flights during the spring and early summer of 2020.

Flush Category	**Flown**	**Control**	**Total**
None Flushed	26	41	67
< 50% Flushed	12	0	12
50-99% Flushed	2	0	2
All Flushed	2	1	3
Total	**42**	**42**	**84**

Table 4. Summary statistics for the binary response of birds swimming away or towards cover during the UAV flight on a whole wetland perspective basis. We conducted a total of 42 flights during the spring and early summer of 2020.

Swam Description	**Flown**	**Control**	**Total**
Did not swim away or towards cover	23	36	59
Swam away/ towards cover	19	6	25
Total	**42**	**42**	**84**

CHAPTER III EVALUATING DRONE PLATFORM AND ALTITUDE ON UPLAND NESTING DUCK BEHAVIORS

Introduction

Many North American duck species nest on the ground in upland habitats. Traditional methods of searching for upland duck nests include behavioral observations, systematically walking transects disturbing vegetation with a sweeping stick, or most commonly the chain-drag method (Higgins et al. 1969). The chain-drag method consists of a chain or rope being dragged between two all-terrain vehicles (ATVs), which flushes the female duck from her nest and reveals the nest to watching researchers. Such techniques cause disturbances that could increase risks to predation or increase nest abandonment. More recently, Unmanned Aerial Vehicles (hereafter UAVs) have been used as research tools to locate duck nests (Bushaw et al. 2020, Stander et al. 2021). UAVs may be an alternate method of nest searching and monitoring that is less impactful to the study species, as well as the environment they inhabit.

The use of UAVs for wildlife surveys has been steadily increasing in ecology in recent years (Chabot 2018). Benefits of using UAVs compared to traditional methods of surveying wildlife include the collection of high spatial and temporal resolution imagery (Xiang and Tian 2011), low operational costs, increased safety compared to manned aerial surveys (Linchant et al. 2015), the ability to produce archivable data (Hodgson et al. 2013), and the assumption of reduced impact on wildlife and their habitats compared to traditional methods of data collection (Christie et al. 2016). However, UAVs are also being used as hazing tools to handle human – wildlife conflicts, suggesting they can also induce anti-predator responses (Wandrie et al. 2019, Wang et al. 2019, Egan et al. 2020). This leaves the last assumption of less impact in question. Given the variety of responses of species to UAVs, there is a need to evaluate how individual species respond to different platforms as they would be flown for conducting actual surveys.

Reactions or response of animals to UAVs seem to be variable and depend on the UAV attributes such as flight pattern, engine type, and shape and size of aircraft (Mulero-Pázmány et al. 2017). Mulero-Pazmany et al. (2017) suggest that responses are species-specific and depend on species-specific characteristics (e.g., life history, social patterns), as well as landscape level variables such as topography and habitat type. Terrestrial mammals moved away from a vertical take-off and landing rotary UAV when the UAV approached 80 to 100 meters away while impalas and giraffes would flee the area when the aircraft was 40 to 50 meters away (Bennitt et al. 2019). Sea turtles such as green turtles (*Chelonia mydas*) and flatback turtles (*Natator depressus*) showed no physical response to an overhead rotary UAV flying at 20 - 30m AGL (above ground level) while saltwater crocodile (*Crocodylus porosus*) responded to the UAV by fleeing, producing lateral movements and completely submerging themselves as the UAV flew below 50m AGL. Fixed-wing UAVs are thought to cause greater disturbances to birds than rotary-wing drones (McEvoy et al. 2016). Barnas et al. (2018) found that behavioral responses of lesser snow geese (*Anser caerulescencs*) to a high altitude fixed-wing UAV are minimal, but geese clearly noticed the aircraft. Research on breeding ducks on wetlands found blue-winged teal had different responses than northern shovelers (Ryckman et al. 2022). Northern shovelers became more active during the UAV flight while blue-winged teal decreased in active behavior during the UAV flight (Ryckman et al. 2022). Large flocks of non-breeding waterfowl are more likely to respond to UAV surveys than small flocks and at a greater distance from the drone (Jarrett et al. 2020). A few studies have found closer proximity between the UAV launch site to ducks results in more behavioral responses (Ryckman et al. 2022, Vas et al. 2015, McEvoy et al. 2016). To date, there has not been any studies looking at behavioral responses of upland nesting ducks to UAV surveys.

We provide a baseline for future research approaches using UAVs to examine ground-nesting birds by evaluating the behavioral response of blue-winged teal and gadwall from miniature surveillance cameras placed at the nest to four UAV scenarios that represent survey approaches for nesting and habitat assessments of waterfowl including: fixed-wing at 80m, rotary wing at 80m, rotary wing at 35m, and control (received no overhead flight)(Barnas et al. 2019, Bushaw et al. 2020, Stander et al. 2021). Ultimately, we seek to provide recommendations for researchers seeking to minimize the disturbance caused by UAVs to breeding waterfowl during nest searches or habitat assessments.

Methods

Study Area and Study Species

As part of a larger study monitoring breeding ducks and their behaviors, we conducted UAV flights in the Prairie Pothole Region at two ranches: Coteau Ranch and Davis Ranch located in Sheridan County, North Dakota (centroid: N 47.401054, W -100.276947). Collectively, the ranches total 4,145 hectares. Both ranches are in mixed-grass prairie and managed using grazing (both) and prescribed fires (Davis). We collected nesting behavior data for two of the most abundant species breeding in the area: blue-winged teal (*Spatula discors*) and gadwall (*Merica strepera*) (Prairie Pothole Joint Venture. 2017).

Behavior Monitoring

Researchers conducted nest searches from approximately 15 May – 15 July in 2019 and 2020. We conducted nest searching using the ATV chain drag method (Higgins et al. 1969) and plots were searched every 14 days. Once a female flushed, researchers located the nest and recorded the clutch age using the candling technique (Weller 1956). We placed video surveillance cameras equipped with 24 LEDs and 4.3mm lenses (Jet Security USA, Buena Park, CA, USA) on metal rebar stakes within 0.5 meter of the nest once incubation has started, which we determined using the candling technique. Each camera was connected to a 25m cable which we attached to a box with a Digital Video Recorder (DVR; Advanced Security, Bellevue, IL, USA) and battery (12-V, 36amps; Burr et al. 2017). Using a 32 GB SD card, we recorded video of nesting behaviors. The DVR box and battery were located away from the nest, allowing researchers to change the batteries and SD cards every 3 – 4 days without disturbing the incubating female on the nest. If we could not see the female using an LCD monitor (i.e., tote vision) at the DVR box, we approached the nest to confirm if the female was away on recess or the nest had been destroyed by predators. Cameras were left at the nest until hatch or failure or in a few cases moved prior to cattle grazing to avoid trampling. All research was approved by the University of North Dakota Institutional Animal Care and Use Committee A3917-01 (Protocols: 2012-4C, 1904-2), the North Dakota Game and Fish Department (GNF04912726, GNF05182785), and UND Unmanned Aircraft Systems Research Compliance Committee Approval (Approved April 12, 2019).

Flight Operations

We conducted flights over nests that were not physically disturbed by researchers $\geq$ 36 hours using two UAV platforms: a fixed-winged Trimble UX5 (hereafter UX5) and a rotary DJI Matrice 200 (hereafter M200). For each surveyed nest, we identified a control nest which received no overhead flight. We placed a surveillance camera at each control nest as well. Two FAA Remote Pilot certified operators, S. Ellis-Felege and M. Ryckman conducted all flights.

The UX5 is a rear propelled aircraft, powered by removable lithium polymer batteries (14.8 V, 6000 mAh). It has a weight of 2.9kg and a 1-m wingspan. A catapult is used to launch the aircraft and completes the flight by belly landing (slowly bouncing or skidding on the ground). The endurance of the UX5 is rated for 50 minutes with a cruise speed of roughly 85 kph. The UX5 is limited to flights at a cruising altitude of 75 m above ground level (AGL) or higher except for take-off and landings. The M200 has four rotaries and can vertically takeoff and land. The weight of the M200 is approximately 4.53kg. Two TB55 lithium polymer batteries powered the M200. SEF and MR flew both UAVs at an altitude of 80m to evaluate behavioral responses between platforms. Pilots flew a subset of nests at an altitude of 35m using the M200 as the platform (Helvey et al. 2020, Bushaw et al. 2020). The UX5 was excluded from this altitude as fixed wing aircrafts are rarely used to conduct thermal nest searches and this platform also has a minimal flight altitude of 75m from its takeoff location.

Pre-programmed flights for the UX5 were created using Trimble Access Aerial Imaging (Version 2.0) and DJI pilot (Version 1.8.0) for the M200. These two software packages allowed operators to determine the flight path, altitude, and degree of image overlap. The UAV operators used the tangential approach grid (i.e., lawn mower) for flight paths since this grid is assumed to cause less disturbance than directly approaching birds after takeoff (McEvoy et al. 2016) and would most closely mimic that of an actual nest searching (Bushaw et al. 2020, Stander et al. 2021), or habitat assessment (Barnas et al. 2019, Ellis-Felege et al. 2022) flight.

Video Review and Behavioral classifications

We retrieved SD cards during regular nest checks or battery exchanges and backed-up video onto hard-drives. MR reviewed behavioral footage from 2019 and CI from 2020 with training and verification from MR. Specifically, we reviewed behaviors on days with (day of) and without (day before) flights across flight process for 30 minutes before (before) the flight, during the flight, (during), and 30 minutes after the flight (after). We classified female behavior under four broad categories: no activity, active, alert, and off-nest (Table 5). Active behaviors included nest maintenance, preening, or egg turning. The no activity category consisted of sleeping or resting. We classified vigilant behaviors such as overhead vigilance or head-popping into the alert category. Overhead vigilance or head-cocking occurs when the female tilts her head to look skyward (described in Barnas et al. (2018)). Head popping occurred when the female extended her neck to scan the surrounding area. Off-nest included occasions when the female duck was away from the nest and out of the camera field of view.

Data Analysis

Our analysis of nesting duck responses used a before-after-control-impact (BACI) design. Thus, we had observations of ducks before, during, and after treatments (UAV flights) and for controls (never flown over). We expected that if the UAV altered behaviors, the result would appear as a significant interactive term.

Specifically, we looked at the proportion of time spent on each pre-defined behavior described above the day before the flight, day of the flight, and across the three flight periods (before, during, after). We constructed a generalized mixed model using Proc Glimmix in SAS Studio (Version: 9.4) assuming that each of our five behaviors were drawn from a beta distribution representing the proportion of time spent in each behavior (active, no activity, alert, off nest). Fixed effects included *treatment* (UX5, M200-80m, M200-35m, control), *flight process* (before, during, after), *day* (day before, flight day), the 2-way interactions of *treatment* and *flight process*, *treatment* and *day*, *flight process* and *day*, and the 3-way interaction of *treatment*, *flight process*, and *day*. Where we had data to allow a 3-way interactive term, we conducted it.

However, for some situations (species) we only had sufficient data to conduct 2-way interactions. We modeled blue-winged teal and gadwall separately to explain how each species responds across all treatment types. Specifically, we wanted to determine if there are any differences among platforms, are they shifting behaviors from day before to day of the flight, and how do behaviors change across the three flight periods (i.e., before, during, and after the flight) on day of the flight. Random effects included *nest ID* and *flight ID*. P-values < 0.05 were considered statistically significant. We calculated least square means (LSMeans) for any statistically significant interactions and reported their estimates and associated 95% confidence intervals graphically.

Flush Observations and Distance Evaluation

We provide summary statistics for flush events that occurred during the UAV flight and calculated the distance between focal nests (control or treatment) and the launch site. Nest distance was measured by using the Euclidian distance measure tool in ArcMap 10.7.1. We provide summary statistics for treatment and control nests.

Results

We conducted a total of 39 UAV flights over 61 nests and had 12 control (no flights) nests in 2019 and 2020. Due to logistic and technical difficulties, not all nests and UAV flights were included in the analysis. Specifically, 4 nests were depredated, 8 camera failures, and 10 females went on recess before the observation period started. This resulted in behavior data collected from 51 (39 treatment and 12 control) nests across 23 UAV flights (Table 6). Five nests served as controls on multiple days/flights.

Blue-winged teal and gadwall behavioral response to UAV flights

For blue-winged teal, we found a significant change in proportion of time spent on the active behavior for *day* and the interactions (*treatment* × *day*, *flight process* × *day*; Table 7). The proportion of time spent on active behavior for blue-winged teal surveyed with the M200 at 35m increased from the day before to flight day (0.0825 to 0.2575; Figure 5a). Blue-winged teal surveyed with the M200 at 80m and UX5 slightly decreased in time spent on active behavior (0.1153 to 0.0927 and 0.1154 to 0.0902). The behavior no activity for blue-winged teal resulted in statistical significance in the interaction of *treatment* × *day* (Table 7). While blue-winged teal surveyed with the M200 at 80m increased in time spent on no activity behavior from the day before to flight day (0.7184 to 0.845), blue-winged teal surveyed with the M200 at 35m decreased in proportion of time spend on no activity from day before flight to flight day (0.873 to 0.736; Figure 5b). The proportion of time blue-winged teal surveyed with the UX5 spent on the no activity behavior remained relatively stable from day before, to flight day (0.841 to 0.874; Figure 5b). The fixed effects of flight process and interactions (*flight process* × *day*, *treatment* × *flight process* × *day*) were statistically significant for the proportion of time blue-winged teal spent on alert behavior (Table 7). Although the proportion of time blue-winged teal spent on alert behavior is a very small proportion of total observed time (0.000086 - 0.0014), there is a statistical shift for blue-winged teal surveyed with the M200 at both 35m and 80m. On flight day, blue-winged teal that were surveyed with the M200 at 35m increased in time spent on alert behavior from the before flight period 0.0004 to during flight 0.0103 and decreased to 0.00012 after the flight (Figure 6a). For a 30-minute pre and 30-minute flight period, blue-winged teal increased in alert behavior from 0.72 seconds pre-flight to 18.54 seconds during the flight period. Similar patterns were observed for blue-winged teal surveyed with the M200 at 80m as time spent on the alert behavior on flight day increased from 0.00009 before flight to 0.0079 during flight and returned to 0.00009 (Figure 6b). In other words, blue-winged teal spent 0.16 seconds on alert behavior during a 30-minute pre- flight period and increased to 14.22 seconds during a 30-minute UAV flight. The off-nest behavior for blue-winged teal resulted in no fixed effects showing statistical significance (P > 0.05).

For gadwall, the proportion of time spent on active behavior resulted in the fixed effects of *day* and interaction (*flight process* × *day*) having statistical significance (Table 8). On day before flight, the proportion of time gadwall spent on active behavior increased from before period to during period and decreased for the after period while on flight day, we saw opposite shifts where gadwall decreased in time spent on active behavior during the flight period. (Figure 7a). *Flight process*, *day*, and the interaction (*treatment* × *day*) all showed statistical significance for the proportion of time gadwall spend on no activity behavior (Table 8). Gadwall surveyed with the M200 at 35m and 80m both decreased in proportion of time spent on no activity behavior from the day before, to flight day (0.934 to 0.463, 0.835 to 0.605; Figure 8) while gadwall surveyed with the UX5 increased in proportion of time from day before to flight day (0.826 to 0.876). The interaction (*flight process* × *day*) is the only fixed effect that resulted in statistical significance for the proportion of time gadwall spent on alert behavior (Table 8.) Like blue-winged teal, the proportion of time spent on alert behavior was a relatively small proportion of time compared to the overall observed time. On flight day, we saw an increase in the proportion of time spent on alert behavior from the before period to during flight period and back to the after period (0.0007 to 0.0223 to 0.0008; Figure 7b). This translates to gadwall spending approximately 1.26 seconds on alert behavior during a 30-minute pre-flight period to 40.14 seconds during a 30-minute UAV flight. Like blue-winged teal, the fixed effects for the proportion of time gadwall spent on off-nest behavior showed no statistical significance (P > 0.05).

Flush Observations and Distance Evaluation

The presence of females flushing or moving off nests during flights only occurred during the 2020 field season (n=8 females) (Table 9). Three gadwall flushed while being surveyed with the M200 at 80m altitude. One blue-winged teal and four gadwall flushed at 35m with the M200. No flushing occurred during the UX5 flights. The average distance between nests that were surveyed, and control nests is 5,206.7 meters (min = 584.6, max = 11,839.8).

Discussion

Our study represents the only research to date formally examining behavioral responses of upland nesting ducks to UAV surveys. We conducted flights using four different scenarios which represent current day sensor capabilities (35 m AGL) and future capabilities (80 m AGL). While we had small sample sizes, we were still able to detect significant effects in the interactive terms suggesting behaviors were shifting in response to platform types and UAV altitude. Our findings also suggest species appear to respond differently to UAV surveys and that current methodology might limit how researchers conduct nest surveys for waterfowl.

We found blue-winged teal surveyed with the UX5 and M200 at 80m were less active on flight days compared to the day before flights. This pattern is similar to blue-winged teal pairs and nesting common eiders when exposed to UAV flights and might be an antipredator response (Ellis-Felege et al. 2022, Ryckman et al. 2022). However, blue-winged teal surveyed with the rotary M200 at 35m increased in active behavior on flight days suggesting at lower altitudes, females could be detecting the UAV using their visual stimuli and changing in behavior. The noise of the four rotors also could be alarming the nesting blue-winged teal as the noise intensity is greater at lower altitudes. Gadwall surveyed with the rotary M200 at both altitudes (80m and 35m), decreased in amount of time spent on no activity or inactivity during flight days. The gadwall females are increasing in activity when surveyed with the rotary drone. Interestingly, gadwall surveyed with the fixed wing UX5 increased slightly in time spent on no activity during flight days compared to non-flight days. Mulero-Pázmány et al. (2017) suggests that species may respond differently due to differences in the visual and auditory stimuli of species. Both species increased in amount of time spent on alert behavior from the before period to during flight period and back to normal levels at the after period on the day of the UAV flight. While the amount of time spent (seconds) on the alert behavior for both species was a very small proportion of total observed time, we observed increases during the flight period meaning the females were most likely detecting the UAVs. This alert or vigilant behavior has also been reported in other species during UAV flights, but these are unlikely to be biologically detrimental given the brevity of the behaviors (Barnas et al. 2018, Ryckman et al. 2022).

Shape of the UAV is also known to cause differences in how birds respond to UAV flights (Mulero-Pázmány et al. 2017). Red-wing blackbirds (*Agelaius phoeniceus*), for example, perceived a fixed wing drone modified to look like a predator riskier than a normal fixed fixed-wing UAV that resembles an airplane (Egan et al. 2020). In our case, the fixed-wing UX5 resembles an aerial predator more than the quadcopter M200. Since we didn't see an increase in active behavior for both blue-winged teal and gadwall when surveyed with the fixed-wing UX5 at 80m, this suggests that flying at lower altitudes may cause an increase of response to UAV flights.

There were 8 off-nest events or flushes that occurred during the UAV flight periods and all took place during the 2020 field season. Seven of the 8 occurrences were by gadwall surveyed with the rotary M200 (4 at 35m and 3 at 80m AGL). Our sample size for 2019 was relatively small for nests surveyed (17% of total). We didn't survey any gadwall nests with the rotary M200 and only 2 gadwall nests with the UX5 during the 2019 field season. No nesting females flushed or left the nest during the flight period when surveyed with the fixed-wing UX5 at 80m AGL. While the one-propeller UX5s shape resembles an aerial predator, it is noticeably quieter than the 4-propeller rotary M200. This differs than the findings of McEvoy et al. (2016) that proposed the fixed wing UAVs may lead to increased disturbances. Gadwall could be detecting the aircraft by using the visual stimuli. Body size is shown to influence how birds respond as larger mass ducks have a stronger visual acuity than smaller bodied birds (Kiltie 2000). Anecdotally, we noticed from nest searching by chain drag method, that gadwall females were more skittish or "flighty" compared to blue-winged teal. Most gadwalls would flush before the chain would get close to their nest. One study found when conducting a nest visit on foot, larger body mass ducks such as gadwall, on average, would flush at farther distances than smaller bodies ducks such as blue-winged teal (Dassow et al. 2012). The one occurrence of a blue-wing teal getting off the nest during the UAV flight period was surveyed with the M200 at 35m. However, it should be noted that although we observed occurrences of ducks flushing from the nest, when using traditional chain-drag methods, the ducks always flush and flushes are used to locate the nests.

For other nesting studies on waterfowl, there were shifts in behaviors but rarely, if ever, were flushes observed during flight activities (Barnas et al. 2018 and Ellis-Felege et al. 2022). Our research suggests caution should be used with low-level drone flights, especially with the use of rotary-wing UAVs, over some species of nesting ducks. In the United States, if UAVs are to be adopted for nest searches that are conducted by non-state or federal agency biologists or permitted researchers, there needs to be an understanding of disturbances to migratory birds to avoid harassment violations. Our work was permitted by North Dakota Game and Fish Department (GNF04912726, GNF05182785) in an effort to evaluate methods for drone survey development that could guide best practices. With the eagerness of researchers and managers to use UAVs, there may need to be additional considerations in the use of rotary wing aircraft for migratory birds such as ducks. We have to be sure disturbances are minimized and are compared to the responses UAVs elicit to currently accepted practices, as UAVs become more commonly utilized in wildlife surveys.

We conclude nesting female ducks could change in behaviors to UAV surveys and flushing might occur. The fixed-wing UX5 seemed to cause less impact, but it has a limited flight altitude of 80m so our study was unable to determine if lower flights would result in increased disturbance. Due to limitations of current UAV thermal sensors for nest searching, it is likely that biologists are going to have to fly at lower altitudes to gain accurate data or attach additional sensors to detect nests (Helvey et al. 2020), and this could lead to disturbances, especially since most of these sensors are flown on rotary wing UAVs which we found to be most disruptive to nesting gadwall. Research has shown that detectability varies with site and weather variation and can produce high false positive rates (Stander et al. 2021). As such, researchers should try to conduct nest surveys using UAVs when weather and site conditions are ideal to reduce the number of false positives. Additional work should be conducted on behavioral responses of upland ducks to night operations for UAV nest searching. This approach would likely lead to increased nest detections using thermal sensors, but may be perceived differently by ducks and warrants future research. Our approaches followed traditional survey methods that may be used for searching for nests or conducting habitat assessments, and while we did observe changes in behavior, most of these behaviors are likely to be minimal or at least no more disruptive than current ground-based survey methods for locating duck nests.

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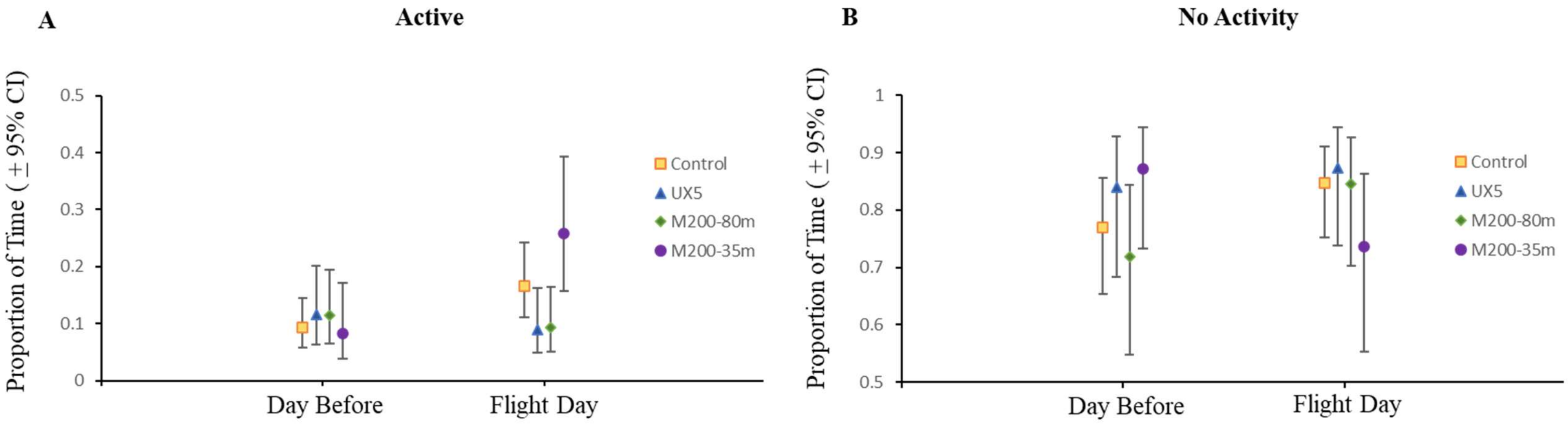

Figure 5. Least square means and 95% confidence intervals of proportion of time spent on active behavior (A) and no activity behavior (B) for blue-wing teal across all treatments (M200-35m, M200-80m, UX5, Control) on Day Before and Flight Day.

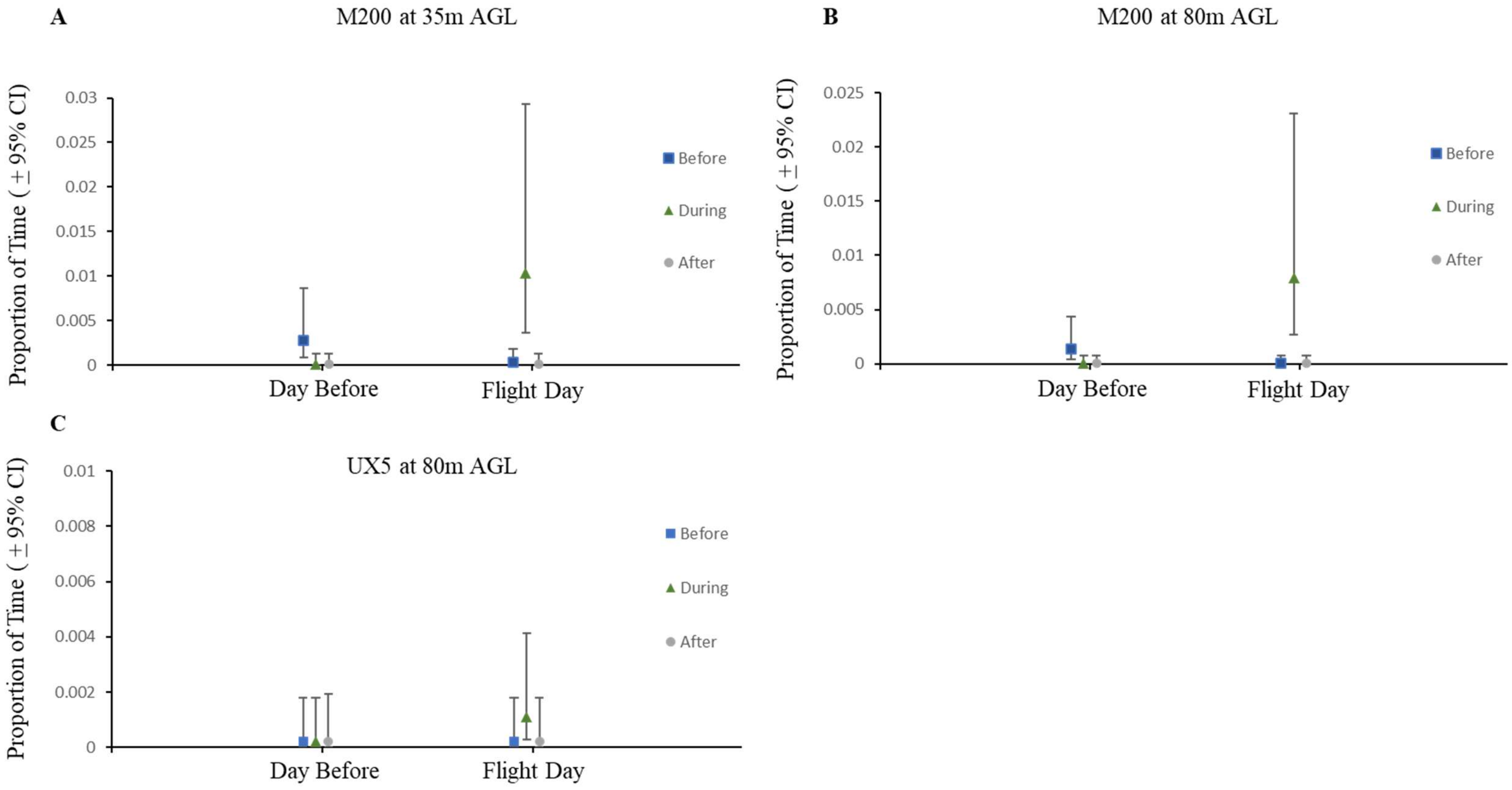

Figure 6. Least squared means and 95% confidence intervals of proportion of time spent on alert behavior for blue-winged teal surveyed with the M200 at 35m above ground level (A), the M200 at 80m above ground level (B) and the fixed-wing UX5 (C) across the flight processes (Before, During, After) on Day Before and Flight Day.

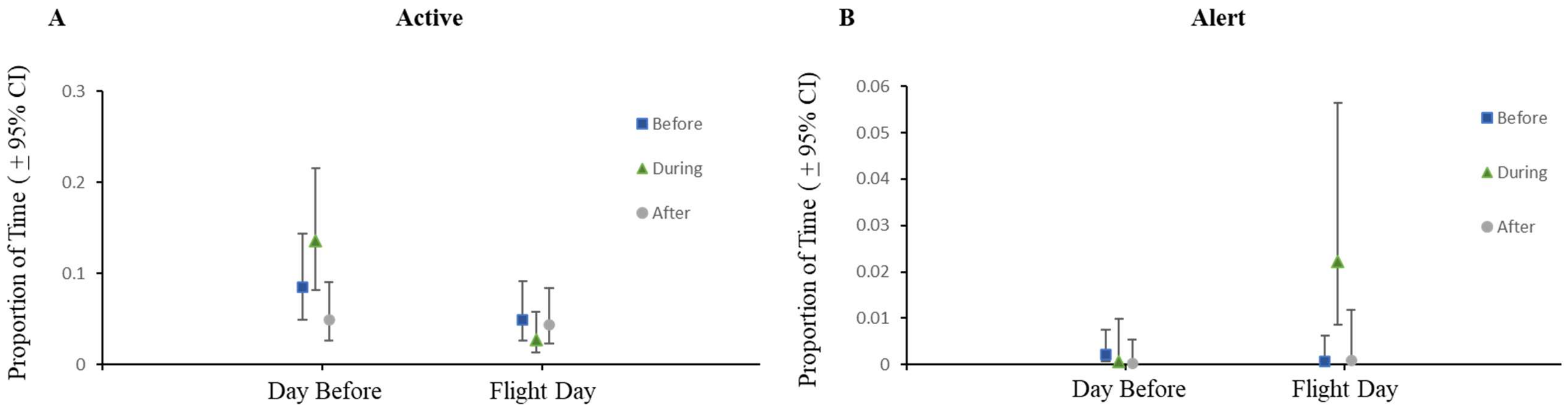

Figure 7. Least square means and 95% confidence intervals of proportion of time spent on Active (A) and Alert (B) behavior for gadwall by all treatments for the flight processes (Before, During, After) on Day Before and Flight Day.

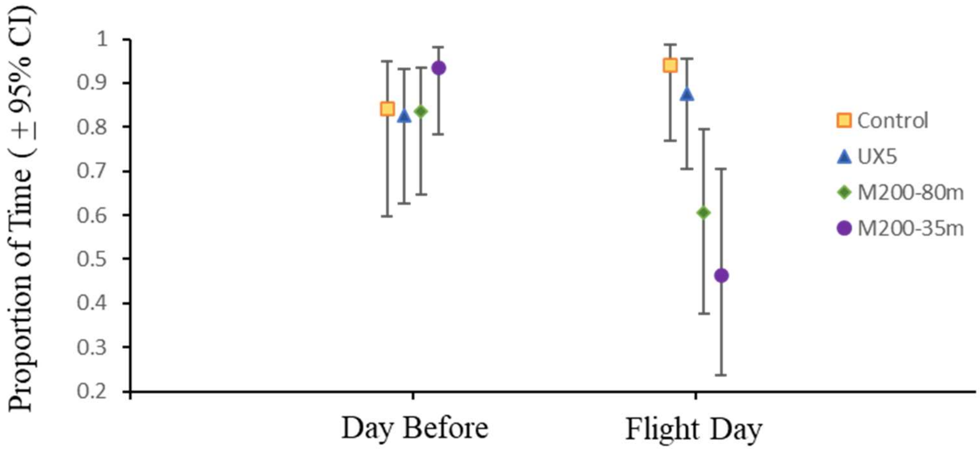

Figure 8. Least squared means and 95% confidence intervals of proportion of time spent on no activity behavior for gadwall across all treatments (M200-35m, M200-80m, UX5, Control) on Day Before and Flight Day.

Table 5. Classifications and details of behaviors of blue-winged teal (*Spatula discors*) and gadwall (*Mareca strepera*) in response to UAV surveys at the nest.

Category	Additional behavior	Event	Description
None	**Sleeping or Resting**	Sleeping Resting	Head is tucked back and down and eyes are visibly closed or head us tucked under wing. Bird has head tucked back and down but has eyes open.
Active	**Nest Activities**	Nest Maintenance Preening Egg turning	Bird is pulling vegetation to cover nest for camouflage. Moving vegetation litter and feathers to fill nest bowl. Plucking feathers or down to put in nest bowl. Bird stands up, turns eggs with beak and returns to sit on nest.
Alert	**Vigilant**	Overhead Vigilance/Head popping	Bird's head is out and away from body. Bird seems to be aware of drone.
Off-nest	**Off Nest**	Out of frame Flushes	Bird may or may not cover nest with vegetation litter or feathers and leaves. Bird apparently flushes from nest without covering eggs

Table 6. Combined sample size of nesting footage we collected during the 2019 and 2020 field seasons. We obtained nesting footage for blue-winged teal (BWTE) and gadwall (GADW).

	UX5	**M200**			
	80 m	**35m**	**80m**	**Control**	**Total**
BWTE	8	6	8	9	31
GADW	6	5	6	3	20
Total	14	11	14	12	51

Table 7. Model results for proportion of time spent on each behavior for blue-winged teal. Fixed effects include treatment (M200-80m, M200-35m, UX5, Control), flight process (before, during, after), day (before, during) and the interactions (aircraft × flight process, aircraft × day, flight process × day, aircraft × flight process × day). Bold highlights denote statistical significance (P<0.05).

Behavior	**DF**	**F-value**	**P-value**
Active			
Treatment	3	0.52	0.6698
Flight Process	2	0.37	0.6901
Treatment × Flight Process	6	1.01	0.4231
Day	**1**	**5.44**	**0.0207**
Treatment × Day	**3**	**5.19**	**0.0018**
Flight Process × Day	**2**	**3.51**	**0.0318**
Treatment × Flight Process × Day	6	1.26	0.2797
None			
Treatment	3	0.33	0.8005
Flight Process	2	0.64	0.5297
Treatment × Flight Process	6	1.24	0.2874
Day	1	0.57	0.4514
Treatment × Day	**3**	**2.75**	**0.0438**
Flight Process × Day	2	1.05	0.3536
Treatment × Flight Process × Day	6	0.96	0.4509
Alert			
Treatment	3	0.44	0.7213
Flight Process	**2**	**6.48**	**0.0019**
Treatment × Flight Process	6	1.18	0.3175
Day	1	3.01	0.0841
Treatment × Day	3	0.25	0.8620
Flight Process × Day	**2**	**19.60**	**<0.0001**
Treatment × Flight Process × Day	**6**	**3.60**	**0.0021**
Off-nest			
Treatment	3	0.31	0.8162
Flight Process	**2**	0.17	0.8442
Treatment × Flight Process	6	1.52	0.1725
Day	1	0.44	0.5062
Treatment × Day	3	0.09	0.9641
Flight Process × Day	2	0.01	0.9853
Treatment × Flight Process × Day	6	0.61	0.7253

Table 8. Model results for proportion of time spent on each behavior for gadwall (**GADW**). Fixed effects include treatment (M200-80m, M200-35m, UX5, Control), flight process (before, during, after), day (before, during) and the interactions (aircraft × flight process, aircraft × day, flight process × day, aircraft × flight process × day). Bold highlights denote statistical significance. Behaviors with an (*) represent only the 2-way interaction and did not include the 3-way interaction due to data limitations.

Behavior	**DF**	**F-value**	**P-value**
***Active**			
Treatment	3	0.27	0.8443
Flight Process	2	1.36	0.262
Treatment × Flight Process	6	1.3	0.2647
Day	**1**	**15.87**	**0.0001**
Treatment × Day	3	2.33	0.0786
Flight Process × Day	**2**	**6.32**	**0.0026**
***No activity**			
Treatment	3	0.98	0.4036
Flight Process	**2**	**4.45**	**0.0141**
Treatment × Flight Process	6	1.37	0.2355
Day	**1**	**4.47**	**0.037**
Treatment × Day	**3**	**7.54**	**0.0001**
Flight Process × Day	2	1.12	0.3293
Alert			
Treatment	3	2.07	0.1091
Flight Process	2	1.90	0.1552
Treatment × Flight Process	6	0.44	0.8493
Day	1	2.03	0.1571
Treatment × Day	3	0.06	0.9809
Flight Process × Day	**2**	**3.77**	**0.0266**
Treatment × Flight Process × Day	6	0.73	0.6278
***Off-nest**			
Treatment	3	0.88	0.4561
Flight Process	2	0.06	0.9432
Treatment × Flight Process	6	1.56	0.1674
Day	1	0.5	0.4822
Treatment × Day	3	1.67	0.1781
Flight Process × Day	2	0.06	0.9443

Table 9. Number of flushes or off-nest events relative to total nests by blue-winged teal (BWTE) and gadwall (GADW) during the 23 UAV flights occurring in 2019 and 2020. No flushes were observed during the 2019 field season. UAV operators flew the UX5 at an altitude of 80m and the M200 at two altitudes (35m and 80m) AGL.

	UX5		**M200 35m**		**M200 80m**	
	Flush	**Total**	**Flush**	**Total**	**Flush**	**Total**
BWTE	0	8	1	6	0	8
GADW	0	6	4	5	3	6

CHAPTER IV CONCLUSION AND MANAGEMENT IMPLICATIONS

Wildlife biologists, including waterfowl biologists, are increasing their interest in using UAVs as a research tool to estimate populations and access reproductive rates. The use of UAVs for wildlife studies is increasing rapidly in the literature (Chabot et al. 2018). While there has been a large push to determine effectiveness at obtaining counts using UAVs, less is known about how these aircrafts impact wildlife. Most research on behavioral responses of wildlife to UAVs is based on anecdotal evidence and most studies lack a structured study design evaluating responses as UAVs would be used in the field. Wildlife responses to UAVs are known to depend on UAV attributes (e.g., engine type, size and flight pattern of aircraft) and characteristics of the animals (e.g., life history stage and level of aggregation) (Mulero-Pázmány et al. 2017).

We sought to evaluate behavioral responses of breeding ducks at two life-stages, breeding pairs (Chapter 2) and nesting females (Chapter 3), to UAV surveys in North Dakota. During the summer of 2020, we monitored blue-winged teal and northern shoveler pairs using GoPros attached to spotting scopes and evaluated how these pairs responded to a rotary UAV flown at 45m. McEvoy et al. (2016) found mixed species of waterfowl showed little or no response to a rotary UAV flown at 40m above individuals and we found during test flights that at 45m above ground level, we were able to identify sex and species. Observers operating cameras to record individual duck behaviors also conducted a scan survey to determine how all birds on the wetland responded to the UAV. Our analysis of behaviors followed the Before-After-Control-Impact (BACI) design in which we categorized behaviors for a time period before the flight, duration of UAV flight, and for a time period after the flight. Blue-winged teal pairs decreased in active behaviors (swimming, preening, breeding, feeding) during the UAV flight, while northern shovelers became more active during the UAV flight. Both species increased in time spent on overhead vigilance and vigilant behaviors from preflight period to flight period and dropped to preflight levels after the flight. Overhead vigilance behaviors include the ducks tilting their heads to look up at the aircraft. This behavior has been noted in other waterfowl species as well (McEvoy et al. 2016, Barnas et al. 2018). Vigilant behaviors include head-popping and is when the ducks extend the head away from the body to scan for intruders. Results from scan surveys suggest ducks are swimming towards cover or away from the incoming UAV and flushing is minimal but seems to occur on small wetlands with few ducks present.

During the summer of 2019 and 2020, we monitored nesting blue-winged teal and gadwall nests using nest cameras and accessed how females responded to 4 different survey scenarios (fixed-winged aircraft at 80m, rotary aircraft at 80m, rotary at 35m, and control). These altitudes were chosen due to current day sensor, platform capabilities and similar altitudes were used in previous waterfowl surveys for nest detections (Bushaw et al. 2020, Stander et al. 2021) and habitat assessments (Barnas et al. 2019). Like our previous analysis, we followed the BACI design in which we categorized behaviors before the flight, during the UAV flight, after the flight, and during the same timeframe the day before the flight. Nesting blue-winged teal became less active during the flight period when surveyed at 80m with the fixed-wing UX5 and the Rotary M200 but increased in activity when flown over with the M200 at 35. Active behaviors for nesting females include preening, egg turning, and pulling vegetation over the nest to camouflage. Nesting gadwall females showed an increase in inactivity or no activity behavior when flown over with the UX5 at 80m but increased in activity when flown over with the rotary M200 at both 80m and 35m. Both species increased in alertness or vigilant behavior during the flight period compared to pre or post flight periods. This increase in vigilant behavior is unlikely to cause biological impacts due to the brevity of this behavior, mere seconds. There was a total of 8 off-nest events or flushes that occurred during UAV flights for nesting females. Seven of the 8 were gadwalls and 4 occurred when flown over with the rotary UAV at 35m while the other 3 occurred when flown over with the rotary UAV at 80m. The one blue-winged teal flushed during the flight when flown over with the rotary UAV at 35m.

We found that breeding pairs and nesting females are noticing the aircraft, but negative fitness impacts are unlikely, and responses should not dissuade researchers from using UAVs for waterfowl surveys in the future. Such observations are likely common among ground surveys approaches as well as researchers approaching wetlands, where birds often move away or flush in response to ground surveyor presence. Some protocols for surveying ducks on wetlands with dense emergent vegetation even call for researchers to actively flush the wetland to confirm all birds have been counted (e.g., Four Square Mile Survey). It is worth noting that while we observed flushing behavior in some birds, when traditional chain drag methods are used (Higgins et al. 1969), birds are always flushed from the nest for researchers to locate them. However, researchers must be cautious that their approaches do not harass migratory birds from an aircraft, including UAVs, and requires working with federal and state agencies to insure all permits and precautions are in place to limit disturbances.

In summary, we found breeding ducks notice the UAV as has been found in some research (Barnas et al. 2018) but also some species such as blue-winged teal exhibited other anti-predator behaviors (e.g., holding still) which has also previously been documented in species such as common eiders (Ellis-Felege et al. 2022). We conducted aerial surveys following protocols in waterfowl research. Further, our aim was not to harass the birds or to determine how close the UAV could approach before birds were disturbed through evaluations of metrics such as flight initiation distance (FID) as many studies have conducted to determine behavioral responses (Egan et al. 2020, Pfeiffer et al. 2021), but rather behavioral evaluations of standard flight protocols that might be conducted for counting wildlife or mapping vegetations across the landscape that have been reported in the literature. Finally, the observations of behaviors observed are equal or less than those of ground surveys regularly conducted by researchers and managers. As the use of UAVs increase and technology advances, UAVs have the potential to be an effective survey tool for waterfowl researchers conducting counts and nest searching.

Future Research

Future research on conducting waterfowl pair surveys using UAVs should examine if any biases in counts obtained from imagery occur and how to overcome those biases. If ducks are flushing from the UAV flight, they could be missed in counts. Along with flushing, if ducks swim away from the drone or towards cover, they could perhaps get double counted or missed entirely. Dual sensor combinations such as an RGB (Red, Green, Blue) paired with a thermal sensor might detect more ducks, such as cryptic colored females in emergent vegetation. There has also been some research using ultraviolet sensors for detecting birds which could perhaps increase detection rates as well (Helvey 2020). Another future step would be to develop convolutional neural networks for automated detection of ducks from high resolution imagery (Chabot and Francis 2016, Bowley et al. 2018). These UAV flights produce enormous amounts of data and a computer automated process will make the process less time consuming.

Next steps for conducting nest surveys using UAVs include finding a proper platform/altitude combination that allows for higher altitudes and longer battery duration to more efficiently search large grids, mitigating false positive detections, and developing computer automated processes for duck detections. From our research, we found that the rotary M200 caused a greater behavioral response in nesting females than the fixed-wing UX5 which debunks previous research that suggests fixed-wing UAVs cause a greater behavioral response in waterfowl (McEvoy et al. 2016). We were limited in flight altitude with our fixed-wing UAV, but other fixed-wing UAVs can perform flights at lower altitudes. Current thermal sensor resolutions limit the effectiveness of detecting nests. Decreasing in altitude produces greater resolution, but the image footprint decreases which limits the overall survey area. Stander et al. (2021) reported high false positives rates (60-95%) using a thermal sensor which had a ground sampling resolution of 4.1 cm/pixel at 46m AGL. Thermal sensors use relative temperature for target detections so conducting surveys before environmental objects hit equilibrium is essential. Environment equilibrium often occurs shortly after sunrise, so it is recommended to conduct thermal surveys before sunrise (Stander et al. 2021). Behaviors of nesting females should be evaluated before sunrise as they might respond differently than what we found when conducting surveys during the daytime. FAA part 107 restrictions have relaxed, making night flights easier to conduct than historically where a waiver needed approval. As was the case with pair surveys, these nest surveys produce large amounts of imagery to be reviewed and a computer automated process of thermal detections will greatly reduce times spent going through imagery and may be able to discern false positives better than the human eye. We anticipate that as technology increases efficiencies, UAVs may serve as an alternative tool for surveying breeding ducks.

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