Nonbreeding Waterfowl Behavioral Response to Crewed and Uncrewed Aerial Surveys on Conservation Areas in Missouri

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Abstract: Monitoring waterfowl populations provides the basis for improving habitat quantity and quality, establishing harvest regulations, and ensuring sustainable waterfowl populations through appropriate management. Waterfowl biologists currently use a variety of population and habitat monitoring methods ranging from informal ground observations to low-level occupied aircraft surveys. Unoccupied aerial systems (UAS) may provide safer and more precise alternatives to traditional aerial survey techniques that are less disturbing to waterfowl, but there is limited information on how waterfowl in winter respond to UAS. Therefore, we compared the behavioral responses of waterfowl to helicopters and UAS on Missouri Department of Conservation wetland conservation areas October–February 2021–2022. Helicopter surveys were flown using an Airbus H125 helicopter at heights of 100–350 m, with UAS surveys flown using a DJI Mavic 2 Pro UAS at 15–90 m. Waterfowl behavior was categorized as alert, swim, fly, or abandonment using flock-scan surveys recorded for 10-min periods before, during, and after the surveys. The percentage of time flocks spent in each behavior during- or post-survey were compared to time spent in those behaviors pre-survey. Waterfowl increased time spent swimming, flying, and abandonment in response to helicopter flights, whereas UAS flights did not influence overall waterfowl behavior. Additionally, waterfowl did not change behavior in response to UAS flights regardless of waterfowl guild (mallard, other ducks, or goose) or hunting season (open or closed). Waterfowl did increase flight behavior during UAS flights at 30 m, however, there was no change in behavior at all other UAS survey altitudes. Use of UAS may be a good alternative to traditional waterfowl survey methods and is not likely to affect waterfowl distributions or energy expenditures during the survey periods.

Key words: aerial survey, disturbance, drone, duck, goose

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Information collected from waterfowl surveys is used to monitor waterfowl populations, establish harvest regulations, inform management decisions, provide the basis for improving waterfowl habitat quantity and quality, and ensure the sustainability of the resource for the future (Williams et al. 1996, Johnson and Williams 1999, Nichols et al. 2007, Soulliere et al. 2013). Localized surveys allow wetland managers to evaluate waterfowl response to habitat conservation and management decisions as a form of Adaptive Resource Management (Williams et al. 1996, Johnson and Williams 1999, Nichols et al. 2007). Waterfowl biologists use a variety of population monitoring methods ranging from informal ground observations to more systematic approaches, including low-level crewed aerial surveys and structured ground counts (Stancill and Leslie 1990). Historical and existing methods for monitoring waterfowl abundance are expensive, risk crew safety, and contain logistical and observational challenges that can result in inaccurate or imprecise abundance estimates (Martinson 1967, Stancill and Leslie 1990, Smith 1995, Pagano and Arnold 2009). Observational challenges during ground surveys include visual obstructions, such as standing vegetation, and high abundances of birds that make accurate counting difficult (Martinson 1967, Pagano and Arnold 2009). Aerial surveys often result in imprecise estimates due to challenges with estimating density of birds from the air and limited time for counting tens of thousands of birds in the short time they are in view of the aircraft (Martinson 1967, Pagano and Arnold 2009). Aerial surveys conducted from fixed-wing aircraft

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are also expensive, flown at extremely low altitudes (<150 m) and inherently dangerous, making them the leading cause of work-related mortalities among wildlife biologists (Sasse 2003).

Current low-level aerial surveys impact resting waterfowl, causing disturbance and increasing energetic expenditure (Pease et al. 2005, Gilbert et al. 2020). Lesser snow, Ross', and greater white-fronted geese (*Anser caerulescens, Anser rossii, and Anser albifrons*, respectively) may abandon the survey area even prior to arrival of the aircraft (Soulliere et al. 2013, Wang et al. 2019, Gilbert et al. 2020). Harlequin ducks (*Histrionicus histrionicus*) increase disturbance-related behaviors and decrease comfort behaviors during exposure to aircraft (Goudie 2006). Previous research found that survey methodology (crewed aircraft versus ground surveys) did not result in different rates of disturbance, including wetland abandonment, with both methods resulting in approximately 14% of waterfowl disturbed and 3% of individuals abandoning the wetland and with geese exhibiting more disturbance behaviors than ducks (Gilbert et al. 2020). Refuge status, or lack of hunting pressure, can also impact waterfowl response to aerial surveys, with ducks and geese showing 2.2 times greater response to aircraft disturbance on areas closed to hunting (Hagy et al. 2017, Gilbert et al. 2020). Disturbance level of harlequin ducks differs depending on the type of aircraft (military jets, single-engine fixed-wing, and helicopter), indicating smaller and quieter aerial systems such as unoccupied aerial systems (UAS) may cause lower disturbance than crewed aircraft (Goudie 2006, Wang et al. 2019).

In recent years, UAS have emerged as a new technology for monitoring wildlife populations that may provide a safer alternative to current ground and low-level aerial survey techniques (Linchant et al. 2015, Pimm et al. 2015, Lyons et al. 2019, Elmore et al. 2023). Over time, aerial platforms have increased in technological ability and versatility, including improvements in sensor quality and capabilities, and the price of data acquisition and processing has decreased, allowing broader use of UAS to monitor wildlife populations (Linchant et al. 2015, Pimm et al. 2015, Lyons et al. 2019, Elmore et al. 2023). In many cases, UAS are more cost-efficient and provide more flexibility in use than traditional methods, and may allow the integration of technology to monitor and inform daily management decisions in real time (Marchowski 2021). Although UAS have been demonstrated as effective in wildlife monitoring and population surveys, there is limited research on the effect of UAS on non-breeding avifauna (Marchowski 2021, de Leija et al. 2023). Disturbance levels among wildlife may vary based on UAS shape, size, color, noise-level produced, and flight pattern design, with smaller, quieter UAS flown at steady altitudes and speeds generally causing less disturbance (McEvoy et al. 2016, Mulero-Pázmány et al. 2017, de Leija et al. 2023). Overall, UAS may provide less disturbance to wildlife than traditional ground and aerial surveys. For example, limited disturbance of colonial-nesting waterbirds was observed with UAS flown at or above 50 m above ground (Barnas et al. 2018, Barr et al. 2020, de Leija et al. 2023). Several studies have evaluated the ability of UAS to identify nesting waterfowl and the disturbance of UAS surveys on nesting avifauna, but more research is needed to determine disturbance impacts to waterfowl during non-breeding seasons (McEvoy et al. 2016, Barnas et al. 2018, Barr et al. 2020, Ryckman et al. 2022, Elmore et al. 2023). Thus, objectives of this study were to (1) evaluate the impacts of UAS compared to crewed aircraft on waterfowl behavior during non-breeding season surveys, and (2) identify factors influencing behavioral response of waterfowl to UAS surveys to reduce potential bias due to waterfowl response to the surveys.

Study Area

We conducted waterfowl observations at ten intensively managed wetland Conservation Areas (hereinafter, areas) within the Upper Mississippi River Conservation Priority Area across Missouri from October 2021 through January 2022 (Figure 1). Areas were Missouri Department of Conservation (MDC) properties, all with a management emphasis of providing migrating waterfowl

Figure 1. Study sites located on intensively managed wetland conservation areas in Missouri where we conducted waterfowl behavior response surveys to helicopter and unoccupied aerial system surveys during October–February 2021–2022.

habitat and hunting opportunities, ranging from 1518 to 5637 ha. All areas contained portions of waterfowl refuge that were closed to any form of human recreational use 15 October–1 March, with the remaining portions of the areas open to waterfowl hunting during the state hunting season through a controlled lottery system or available for walk-in hunting. The areas all contained water pumping capabilities and various water-control structures, which allowed water levels to be managed in smaller units or pools (approximately 40–160 ha) within the larger conservation areas. Vegetation cover types present in refuge and hunting pools included moist-soil vegetation (smartweeds [*Persicaria* spp.], millets [*Echinochloa* spp. and *Leptochloa* spp.], and others), open water, shrub-scrub (buttonbush [*Cephalanthus occidentalis*], black willow [*Salix nigra*], and swamp privet [*Foresteria acuminata*]), wooded (oak species [*Quercus* spp.], bald cypress [*Taxodium distichum*], water tupelo [*Nyssa aquatica*]), flooded harvested crop (corn [*Zea mays*], soybeans [*Glycine max*], and wheat [*Triticum* spp.]), and flooded standing crop (corn, soybeans, and wheat). Waterfowl numbers on the areas ranged from approximately 25,000 to 200,000 ducks, with up to an additional 50,000 geese during peak times of migration.

Methods

Waterfowl Surveys

MDC personnel conducted waterfowl abundance surveys using an Airbus H125 helicopter (Airbus, Leiden, Netherlands) at altitudes of 100–350 m above ground level (AGL) from October 2021–January 2022. Helicopter surveys were flown weekly by region, surveying three to five areas during each flight, resulting in 12 observed helicopter flights. For each flight, one wetland pool within the survey was selected for monitoring waterfowl behavior based on waterfowl abundance, species present, and viewing capabilities. We conducted UAS surveys with a DJI Mavic Pro 2 (Da-Jiang Innovations, Shenzhen, Guangdong, China), a multi-rotor style UAS, using software developed in-house and installed on a DJI Smart Controller (Da-Jiang Innovations) for automated flight path planning in a lawnmower transect flight pattern. We flew UAS surveys over the same wetland pool as was monitored during the helicopter flight. UAS surveys were initiated on the backside of the levee, 50–500 m from the perimeter of the wetland, so that waterfowl behavior was not influenced by the takeoff and landing portions of the surveys (Barnas et al. 2018). The UAS surveys were flown at ground speeds of 10 m sec^{-1} for flights at 60 and 90 m AGL and 5 m sec^{-1} at flights at 15 and 30 m AGL, to reduce image blurriness due to flight speed and simulate actual flight conditions of UAS abundance surveys (Tang et al. 2021). Image overlaps were set to 30% frontal overlap and 10% side (horizontal) overlap. UAS surveys were spatially and temporally paired with each helicopter survey and occurred ≥30 min before or after completion of the helicopter flight, to allow recovery time for birds following any potential response to the helicopter flight (McEvoy et al. 2016, Barnas et al. 2018, Barr et al. 2020). Additional UAS surveys were flown twice weekly (weather permitting) October 2021–January 2022 at areas selected based on waterfowl abundance, species present, weather conditions, and vegetation cover type present. All UAS flights were conducted under a Special Use Permit from the Missouri Department of Conservation and followed the regulations set forth in 14 Code of Federal Regulations Part 107 Small Unmanned Aircraft Systems (14 CFR Part 107).

All surveys (UAS and helicopter) were flown over pools designated as refuge and closed to any anthropogenic activity, starting no earlier than 2 h after sunrise and ending by 1300 h. We randomized UAS survey altitude (15, 30, 60, and 90 m) order and terminated any flight in which the waterfowl flushed and left the pool (abandonment). We included a 30-min rest/recovery period between UAS flights at different altitudes to allow recovery time for birds following any potential response to the previous UAS flight (McEvoy et al. 2016, Barnas et al. 2018, Barr et al. 2020).

Monitoring Waterfowl Behavior

We recorded waterfowl behavior using a Canon T2i camera (Canon Inc., Tokyo, Japan) on video recording mode attached to a Vortex Skyline 80ED (20–60x80) spotting scope (Vortex Optics, Barneveld, Wisconsin) from a vantage point >100 m from the flock under observation, allowing us to view a portion of birds in a visible portion of the wetland with enough detail to identify individual bird behaviors while not impacting behavior (Barr et al. 2020, Ryckman et al. 2022, de Leija et al. 2023). We defined the beginning of a survey as the time the UAS took flight, or the helicopter entered auditory range and the end of a survey as when the UAS landed, or the helicopter exited auditory range. Video recordings began 10 min prior to each survey (pre-survey behavior), continued for the duration of the survey (during survey behavior), and ended 10 min after the survey ended (post-survey behavior). The time at which the UAS or helicopter was directly over the waterfowl flock in the video frame was also recorded during surveys. The period beginning up to 5 min before through up to 5 min after the helicopter or UAS was directly over the portion of birds under observation was extracted for the survey time period. Thus, each survey consisted of 3 parts, each 10 min long: pre-survey, survey, and post-survey. The pre-survey period allowed us to establish baseline behavior, whereas the post-survey period allowed us to examine any residual effects surveys had on waterfowl flock behavior.

Videos were reviewed by a single observer in Windows Media

Player (Microsoft, Seattle, Washington), and waterfowl were classified into one of three taxonomic guilds: geese (Canada [*Branta canadensis*], greater-whited fronted, lesser snow, and Ross' geese), mallards (*Anas platyrhynchos*), and other ducks (northern pintail [*Anas acuta*], northern shoveler [*Spatula clypeata*], American wigeon [*Mareca americana*], gadwall [*Mareca strepera*], American green-winged teal [*Anas crecca carolinensis*], and ring-necked ducks [*Aythya collaris*]). Although our study areas contain many mixed-species flocks, we were uncertain if one species response in a mixed-species flock would be independent of the response of other waterfowl species present in the flock. Unlike mallards, which were encountered in flocks not containing other species, we did not encounter individual species flocks of species in the other duck guild to analyze these species individually. Therefore, we analyzed the combination of all species in that flock as one guild, (i.e., other duck). The same was true for geese, in that we did not encounter them enough in individual species flocks but using mixed-species flocks we had a large enough sample to analyze them as a separate guild. Each video was assigned a time of year, either before, during, or after hunting season, depending on the date of the survey and season dates for that conservation area.

While reviewing videos, we recorded the greatest disturbance behavior most exhibited by the waterfowl flock at the beginning of the video (i.e., if birds were alert but also swimming, their behavior was recorded as swimming). When the behavior most exhibited by the flock changed, the new behavior and time was recorded. We classified waterfowl flock behavior into one of seven behavioral categories as defined in Barr et al. (2020) and Ryckman et al. (2022): abandonment, flight, swim, alert, maintenance, courtship, aggression, resting, and feeding/foraging. These seven behaviors were then condensed to five disturbance response categories for analysis: none (maintenance, courtship, aggression, resting, and feeding/foraging), alert, swim, fly (flight), and abandonment, with the assumption that these behaviors represented a continuum of increasing disturbance response from none to abandonment.

Evaluating Waterfowl Response

To analyze waterfowl disturbance response to survey method, all waterfowl guilds, UAS altitudes, and times of year were analyzed together, and waterfowl flock was used as the sampling unit (McEvoy et al. 2016, Barr et al. 2020). We calculated the percentage of time a flock spent in each behavior before, during, and after a survey. Most of the flock frequently exhibited no behavior in one or all disturbance categories during behavioral observations, creating zero-inflated data. We fit zero-inflated Bayesian beta regression models using Markov Chain Monte Carlo (MCMC) approaches in R (R Core Team 2022) through package zoib (Liu and Kong 2015). We generated Bayesian posterior distributions of estimates for each waterfowl flock disturbance behavior to identify differences in percentages of time the flock spent in each behavior in response to survey period and aircraft type (before, during helicopter or UAS survey, and after) in a before-treatment-after design. The distribution of the percentages of time a flock spent in each behavior pre-survey was used as a moderately informative prior for the Bayesian analysis (McCarthy and Masters 2005, Choy et al. 2009). We also fit zero-inflated Bayesian beta regression models to evaluate differences in waterfowl flock response based on waterfowl guild, UAS survey height, and time of year. We ran all models on two chains for 150,000 iterations with a burn-in period of 50,000 iterations and a thinning interval of 10 (McGrath et al. 2018, Weston et al. 2020). MCMC chain plots were then visually inspected for model convergence and biological significance was determined using the 95% credible intervals derived from MCMC estimates of model coefficient beta estimates, where parameters with intervals not crossing zero were considered significantly different from pre-survey waterfowl behavior (McGrath et al. 2018, Weston et al. 2020). All models included wetland pool as a random effect, nested within area.

Results

Behavioral observations were collected for 12 helicopter flights with 48 paired UAS flights ($n = 12$ flights per UAS altitude) and 86 additional unpaired UAS flights. Across all 134 UAS surveys, we observed 11 species of waterfowl during behavior observations with sample sizes of 72 mallard surveys, 51 other duck surveys, and 11 goose surveys. While evaluating waterfowl responses to UAS surveys, we did not observe abandonment as a response during pre-survey, during, or post-survey and thus excluded abandonment from the analyses evaluating responses to UAS surveys.

Waterfowl Behavioral Response to Survey Method

Waterfowl exhibited behavioral responses to helicopter surveys, with differences detected in percentage of time spent in all disturbance behaviors (alert, swim, fly, and abandonment) between the pre-survey and survey periods (Figure 2). We also observed differences in the percentage of time waterfowl spent in alert and swimming behaviors during the pre-survey and post-survey periods for helicopter surveys (Figure 2). Compared to the pre-survey period, mean percent of time alert decreased during (5.6 ± 4.2% [SE]) and post (10.2 ± 5.9%) helicopter surveys, whereas mean percent of time swimming (44.7 ± 6.6%), flying (29.4 ± 6.5%), and abandonment (12.9 ± 7.5%) increased during the helicopter surveys (Table 1; Figure 2). Percentage of time the flock exhibited swimming behavior in response to helicopter surveys only differed between pre-survey and post-survey periods, with flocks spending a greater percent of time swimming during the post-survey period (38.1 ± 5.2%; Table 1; Figure 2). For UAS surveys, we observed no difference in the percentage of time ducks spent in any disturbance behaviors during pre-survey, survey, and post-survey periods, indicating that they were not disturbed by the UAS surveys (Figure 2).

Waterfowl Behavioral Response to UAS Surveys

Waterfowl did not exhibit a behavioral response to UAS surveys, with no differences in percentage of time spent in disturbance behaviors during the different survey periods. There were no differences in the behaviors of combined duck species (mallards plus other ducks) during any survey period at UAS survey altitudes of 15, 60, and 90 m, except percent of time spent in flight behavior increased (9.5 ± 1.5%) during surveys at 30 m compared to the percentage of time the flock spent in pre-survey flight behavior (Table 2; Figure 3). We found no difference in behaviors of any waterfowl guild (mallard, other duck, and geese) in the pre-survey, survey, or post-survey periods (Table 3; Figure 4). We also observed no difference in the waterfowl response to UAS surveys among time periods relative to hunting season (pre-hunting season, during hunting season, or after the close of hunting season; Table 4; Figure 5).

Table 1. Mean (± SE) proportion of time waterfowl spent in each disturbance-behavior category (alert, swim, fly, abandonment) for the pre-, survey, and post-survey periods for unoccupied aerial system (UAS) and helicopter surveys conducted October–February 2021–2022 at intensively managed wetland conservation areas in Missouri. All means with asterisks (*) have 95% beta coefficient credible intervals that do not overlap mean pre-survey behavior and therefore can be interpreted as biologically significant.

Disturbance Behavior	Pre-Survey		Helicopter Survey		Post Helicopter Survey		UAS Survey		Post UAS Survey	
Alert	0.12	±0.03	*0.06	±0.04	*0.10	±0.06	0.19	±0.05	0.17	±0.06
Swim	0.27	±0.03	*0.45	±0.07	*0.38	±0.05	0.28	±0.04	0.31	±0.04
Fly	0.08	±0.01	*0.30	±0.07	0.02	±0.01	0.03	±0.02	0.02	±0.02
Abandonment	not observed		*0.13	±0.08	0.01	±0.03	not observed		not observed	

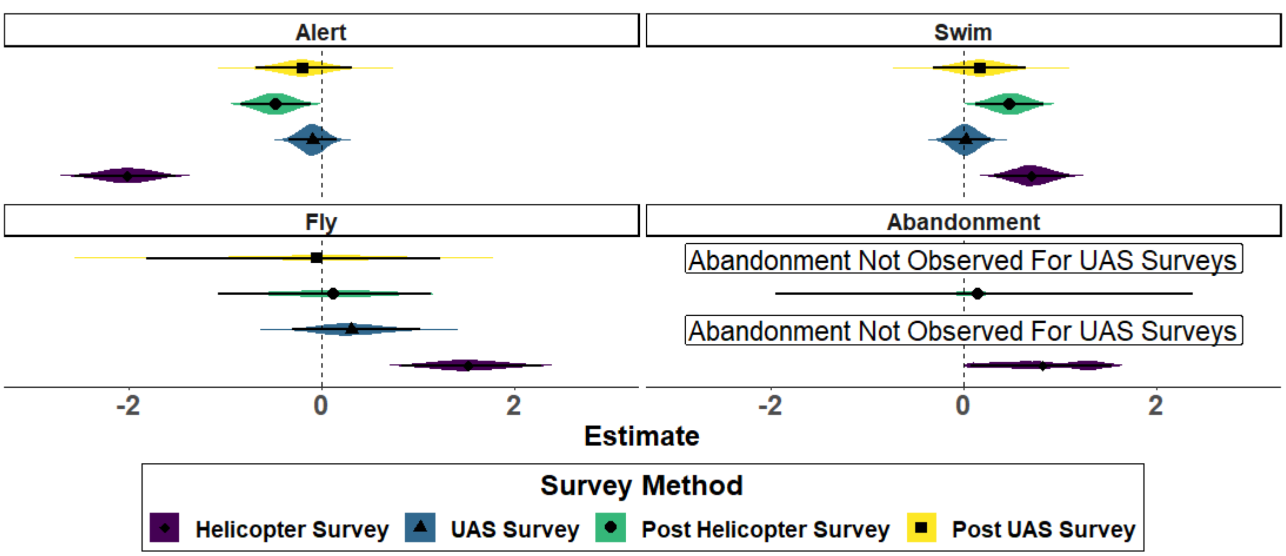

Figure 2. Beta coefficient estimates for percentage of time waterfowl flocks spent in disturbance behaviors (alert, swim, fly, and abandonment) in response to survey methodology (unoccupied aerial system [UAS] survey, post-UAS survey, helicopter survey, and post-helicopter survey). Data were collected from wetland conservation areas in Missouri, October–February 2021–2022, and analyzed using Bayesian generalized linear mixed models. The vertical dashed line ($x = 0$) represents percentage of time spent in behavior pre-survey with the 95% credible intervals represented for during- and post-survey estimates; 95% credible interval not crossing 0 was deemed significant.

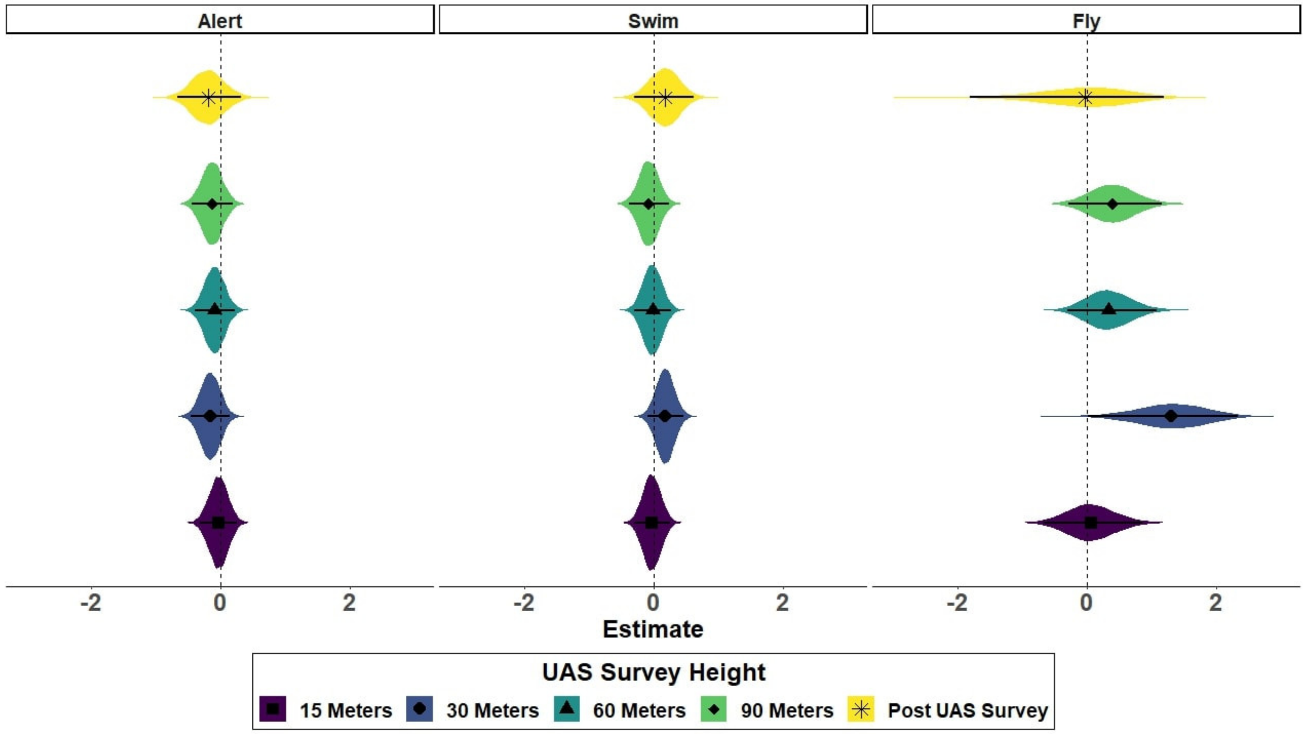

Figure 3. Beta coefficient estimates for the percentage of time waterfowl flocks spent in disturbance behaviors (alert, swim, and fly) in response to unoccupied aerial system (UAS) survey height (15, 30, 60, and 90 m). Data were collected from wetland conservation areas in Missouri, October–February 2021–2022, and analyzed using Bayesian generalized linear mixed models. The vertical dashed line ($x = 0$) represents percentage of time spent in behavior pre-survey with the 95% credible intervals represented for during- and post-survey percentages in behaviors; 95% credible interval not crossing 0 was deemed significant.

Table 2. Mean (± SE) proportion of time waterfowl spent in each disturbance-behavior category (alert, swim, fly) for the pre-survey, unoccupied aerial system (UAS) survey, and post-survey periods for different UAS survey heights conducted October–February 2021–2022 at intensively managed wetland conservation areas in Missouri. All means with asterisks (*) have 95% beta coefficient credible intervals that do not overlap mean pre-survey behavior and therefore can be interpreted as biologically significant.

Survey Method and Height	Alert		Swim		Fly	
Pre-survey	0.172	±0.029	0.265	±0.023	0.017	±0.010
UAS 15 m	0.101	±0.051	0.272	±0.040	0.028	±0.024
UAS 30 m	0.177	±0.041	0.313	±0.037	*0.095	±0.015
UAS 60 m	0.192	±0.037	0.273	±0.038	0.050	±0.020
UAS 90 m	0.179	±0.051	0.268	±0.047	0.053	±0.026
Post-survey	0.170	±0.055	0.309	±0.040	0.021	±0.017

Table 3. Mean (± SE) proportion of time spent in each disturbance-behavior category (alert, swim, fly) for the pre-survey, unoccupied aerial system (UAS) survey, and post-survey periods for different waterfowl guilds (geese, mallard, and other ducks) conducted October–February 2021–2022 at intensively managed wetland conservation areas in Missouri.

Disturbance Behavior	Survey Method	Geese		Mallard		Other Ducks	
Alert	Pre-survey	0.181	±0.019	0.190	±0.032	0.125	±0.023
	UAS survey	0.174	±0.061	0.182	±0.043	0.100	±0.049
	Post-survey	0.196	±0.027	0.125	±0.076	0.116	±0.025
Swim	Pre-survey	0.220	±0.019	0.291	±0.024	0.235	±0.020
	UAS survey	0.289	±0.051	0.290	±0.040	0.267	±0.042
	Post-survey	0.304	±0.027	0.338	±0.053	0.280	±0.027
Fly	Pre-survey	0.023	±0.018	0.020	±0.011	0.013	±0.010
	UAS survey	0.038	±0.024	0.028	±0.020	0.045	±0.027
	Post-survey	0.043	±0.021	0.038	±0.024	0.034	±0.023

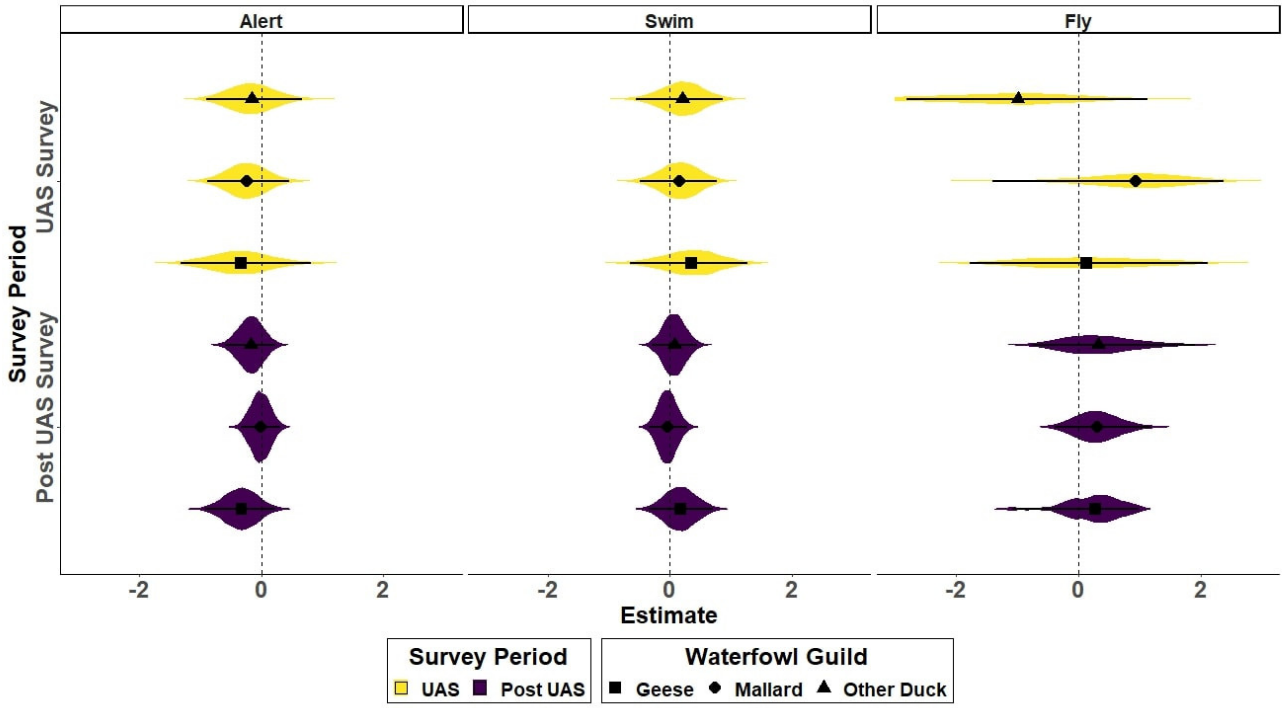

Figure 4. Beta coefficient estimates for the percentage of time waterfowl flocks spent in disturbance behaviors (alert, swim, and fly) in response to unoccupied aerial system (UAS) surveys dependent on waterfowl guild (geese, mallard, or other ducks). Data were collected from wetland conservation areas in Missouri, October–February 2021–2022, and analyzed using Bayesian generalized linear mixed models. The vertical dashed line ($x = 0$) represents percentage of time spent in behavior pre-survey with the 95% credible intervals represented for during- and post-survey percentages in behaviors; 95% credible interval not crossing 0 was deemed significant.

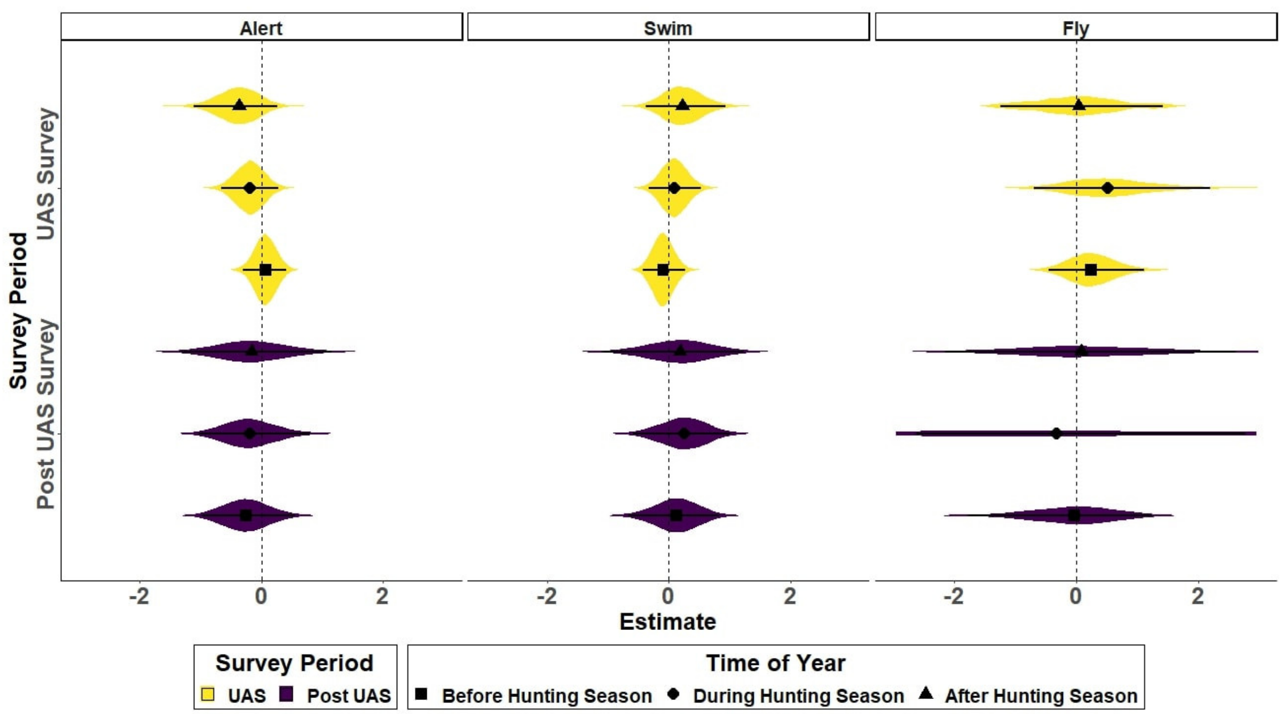

Figure 5. Beta coefficient estimates for the percentage of time waterfowl flocks spent in disturbance behaviors (alert, swim, and fly) in response to unoccupied aerial system (UAS) surveys dependent on time of year with hunting season (before, during, and after). Data were collected from wetland conservation areas in Missouri, October–February 2021–2022, and analyzed using Bayesian generalized linear mixed models. The vertical dashed line ($x = 0$) represents percentage of time spent in behavior pre-survey with the 95% credible intervals represented for during- and post-survey percentages in behaviors; 95% credible interval not crossing 0 was deemed significant.

Table 4. Mean (± SE) proportion of time waterfowl spent in each disturbance-behavior category (alert, swim, fly) for the pre-survey, unoccupied aerial system (UAS) survey, and post-survey periods for different hunting season periods (before, during, and after) conducted October–February 2021–2022 at intensively managed wetland conservation areas in Missouri.

Disturbance Behavior	Survey Method	Before Hunting Season		During Hunting Season		After Hunting Season	
Alert	Pre-survey	0.184	±0.032	0.142	±0.025	0.164	±0.024
	UAS survey	0.194	±0.044	0.188	±0.049	0.170	±0.048
	Post-survey	0.110	±0.091	0.196	±0.027	0.123	±0.032
Swim	Pre-survey	0.289	±0.024	0.248	±0.022	0.236	±0.024
	UAS survey	0.278	±0.041	0.282	±0.040	0.295	±0.042
	Post-survey	0.334	±0.065	0.304	±0.027	0.278	±0.032
Fly	Pre-survey	0.027	±0.013	0.011	±0.009	0.041	±0.024
	UAS survey	0.036	±0.024	0.030	±0.022	0.035	±0.024
	Post-survey	0.056	±0.026	0.042	±0.027	0.052	±0.034

Discussion

Numerous studies on occupied and unoccupied aircraft disturbance reported a range of factors can influence waterfowl, including aircraft type, speed, altitude, vegetation characteristics, refuge status, and individual breeding status (Goudie 2006, Brisson-Curadeau et al. 2017, Mulero-Pázmány et al. 2017). Avifauna during the breeding season are more easily disturbed by rotorcraft-type aircraft at lower altitudes over areas with less dense vegetation, however, it is unclear whether and to what extent results of these studies apply to avifauna responses during the non-breeding season (Goudie 2006, Mulero-Pázmány et al. 2017, de Leija et al. 2023). One study found that non-breeding waterfowl exhibit similar responses as breeding waterfowl, but non-breeding waterfowl were less responsive to rotor-type aircraft than fixed-wing aircraft (McEvoy et al. 2016). Although numerous studies have demonstrated crewed aircraft surveys disturb waterfowl during all times of the year, our results indicate nonbreeding waterfowl behavioral response to UAS are minimal and that UAS surveys result in substantially less disturbance to waterfowl than those conducted by helicopter. Anecdotally, the response of the waterfowl during the helicopter surveys was abrupt and drastic, particularly for geese, with most waterfowl responding before or right as the helicopter entered human aural range and before it was visually accessible (typically approaching from behind trees). Geese would commonly abandon wetland pools before the helicopter was in visual line-of-sight, suggesting that the helicopter produced sufficient noise to be perceived as a threat even prior to visual detection by birds. Those birds that had not abandoned the wetland prior to the helicopter's arrival would often abandon or fly once the helicopter entered visual range, suggesting that they were responding to combination of auditory and visual cues.

Unoccupied aerial systems that mimic raptors may cause more disturbance to small avifauna, such as waterfowl, compared to UAS which do not resemble raptors or appear to exhibit raptor-like behaviors (McEvoy et al. 2016, Mulero-Pázmány et al. 2017). Although the UAS used in our study and the flight patterns did not resemble raptors, we did observe a slight increase in the frequency of waterfowl flight behaviors during UAS surveys conducted at 30 m AGL. Previous studies found birds engage in alert behaviors in response to raptor overflights and UASs, however, the time spent in these behaviors is usually a small percentage of time and biologically insignificant even if time spent in alert behaviors increases (Barnas et al. 2018, Ryckman et al. 2022). Compared to other studies, we found that waterfowl spent a greater percentage of time in alert behaviors during the pre-survey period (10–18% in our study vs. < 1–6%; Barnas et al. 2018, Ryckman et al. 2022). This alert behavior may be due to the numerous (50–250) bald eagles (*Haliaeetus leucocephalus*) present at our study sites, which may have affected the behavior of waterfowl. This may also explain the increase in flight behavior in waterfowl at survey altitudes of 30 m, as eagles may hunt waterfowl at this height, and objects flying at this altitude may cause waterfowl to flee due to a perceived predation threat (Dekker 1984, Folk 1992).

Previous research found differences in behavioral response to UAS among avifauna species, hypothesizing that differences in behavioral response was due to different life history traits and strategies, with greater responses observed in species that were hunted or heavily targeted compared to those that were not hunted (McGrath et al. 2018, de Leija et al. 2023). We found no difference in the behavioral response among waterfowl guilds to UAS surveys in our study, potentially because waterfowl species tend to show more similar life history traits and strategies during the non-breeding season, aggregating in the large mixed-species flocks that we observed (Anderson and Batt 1983, Ackerman et al. 2006). Most surprisingly, we found no behavioral response among geese to our UAS surveys while previous studies found that geese were most responsive to disturbance, particularly during aerial surveys, including UAS surveys (Barnas et al. 2018, Gilbert et al. 2020). Most studies evaluating waterfowl species-specific behavioral response to UAS primarily occurred during the breeding season, whereas our study occurred during the non-breeding season, and we saw an overall lower behavioral response to UAS surveys than in the previous UAS breeding studies (Brisson-Curadeau et al. 2017, Barr et al. 2020, Ryckman et al. 2022). Avifauna have been shown to exhibit different responses to predators and disturbance during different life-history stages, with more response exhibited during the breeding season, possibly to protect eggs or teach young escape techniques, and this may explain why geese were less responsive during our study (Piratelli et al. 2015, Mikula et al. 2018). Additionally, we may have found differences in response to UAS surveys in our study compared to those on the breeding grounds due to many mixed-species flocks comprised of over 50,000 birds. Previous work on the non-breeding grounds found that larger flock sizes typically reduced responses to UAS flights (McEvoy et al. 2016, Brisson-Curadeau et al. 2017, Gilbert et al. 2020, Weston et al. 2020, de Leija et al. 2023).

The presence of refuge has been shown to decrease avifauna response to UAS or other aerial survey methods, and while most previous studies have focused on breeding avifauna, limited studies have shown that the same disturbance patterns occur in avifauna during the non-breeding season (Mulero-Pázmány et al. 2017, McGrath et al. 2018, Gilbert et al. 2020). We hypothesized that waterfowl disturbance would be greater on refuges during the non-hunting season than during the hunting season due to the perceived higher risk of mortality from birds leaving the refuge than tolerating the UAS. However, our results showed that there were no behavioral differences in response to UAS before, during, or after the hunting season. This finding suggests that waterfowl did not perceive the UAS as a substantial threat and that the energetic costs of avoiding or moving away from the UAS may have exceeded the risk imposed by the UAS. The perceived risk of the UAS by waterfowl may have also been reduced due knowledge of the refuge areas from previous years and perceived hunting pressure (regardless of the opening or closing of seasons) on the surrounding areas (Hagy et al. 2017, McGrath et al. 2018, Gilbert et al. 2020). We consider it unlikely that the reduction in disturbance was due to habituation of disturbance from UAS or other anthropogenic sources, as the refuges in our study were closed to all anthropogenic use and waterfowl response did not decrease throughout the year as additional UAS flights were conducted.

Management Implications

Our study was designed to increase the understanding of the feasibility of using UAS as a tool for monitoring non-breeding waterfowl abundance and the impacts of UAS surveys on waterfowl disturbance behavior. By comparing the percentage of time spent in seven behavioral categories prior to, during, and post-survey, we determined that there was no change in behavior during or post-survey period with UAS surveys, indicating UAS are unlikely to result in disturbance responses that could lead to an inherent bias in abundance survey estimates (Ryckman et al. 2022, de Leija et al. 2023). Although most birds in the flock did not respond negatively to the UAS during our observations, we only recorded the behavior exhibited by most of the flock. While the flock as a majority did not respond to the UAS surveys, some individuals may have responded negatively to the UAS. However, we did not observe instances in which the behaviors of a few birds were drastically different than most of the flock. Our results suggest that the appropriate combination of aerial platform and survey altitude may allow for use of UAS to monitor non-breeding waterfowl abundance with minimal disturbance. Additional work across other UAS platforms and target fauna for planned surveys would allow evaluation of the level of disturbance or impacts that may be expected prior to launching full implementation of surveys.

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