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Manned, aerial surveys are an important tool for wildlife managers, but they are dangerous to conduct, expensive and difficult to replicate. Interest is increasing in using small unmanned aerial systems [sUAS] due to concerns associated with traditional manned, aerial surveys. To assess the potential of sUAS technology for grouse lek surveys, we examined the behavioral response of sharp-tailed grouse *Tympanucus phasianellus* to a quadcopter sUAS platform in the Northern Great Plains. We conducted 43 surveys at 19 leks between 9 April and 3 May in 2018 and 2019. We found altitude and wind speed were informative at explaining the behavioral response of grouse following sUAS exposure. We observed an increase in flush responses during low altitude surveys (≤30 m above ground level) during periods of low to high wind speeds. In contrast, flush responses were mitigated when survey altitude increased to 121 m above ground level with moderate wind speeds. Further investigation into sUAS for lek surveys should explore altitudes >121 m above ground level, using more advanced sUAS platforms.

Keywords: drone, grouse, small unmanned aerial systems, survey, *Tympanuchus phasianellus*

Wildlife surveys are important to the management and conservation of animal populations globally. Annual surveys can provide indices of local populations (Autenreith 1982) or can help identify trends across larger landscapes (Sauer et al. 2013). Wildlife agencies often use methods such as point counts on foot or roadside counts from automobiles to conduct surveys (Ralph et al. 1995, Rabe et al. 2002). Rugged and roadless terrain makes ground surveys unfeasible in many areas, making aerial surveys the only means for assessing wildlife populations. Aerial surveys can provide more precise population information than ground based surveys (Schroeder et al. 1992), but a major problem with manned, aerial surveys is the associated risk to observers. Survey protocols may require flying aircrafts at reduced speeds and at low altitudes to collect data (Certain and Bretagnolle 2008, Laake et al. 2008), putting pilots and observers at risk of injury or death (Wiegmann and Taneja 2003). Recent technological advances and changes to Federal Aviation Administration rules associated with small unmanned aerial systems (hereafter, sUAS [FAA § 107]) have made them a possible alternative for wildlife managers, yet little is known about their efficacy for surveying many wildlife species.

Small unmanned aerial systems may provide a safer, cheaper and more reliable means for collecting survey data on wildlife. However, before their implementation, methodologies need to be explored and the responses from wildlife determined. Because wildlife surveys often occur during important life history stages (e.g. nesting, lekking), it is important that any survey method be evaluated to minimize negative impacts to the species. Wildlife researchers have begun to evaluate the use of sUAS during aerial surveys, but greater information on species-specific behavior in response to sUAS is still needed (Christie et al. 2016). Previous research demonstrates that some wildlife exhibit both behavioral and physiological responses to sUAS flights (Ditmer et al. 2015, Weissensteiner et al. 2015, Brisson-Curadeau et al. 2017, Weimerskirch et al. 2018), which can be both detrimental to the wildlife of interest and inhibit accurate data collection. Therefore, before protocols can be developed to best implement this new technology, greater investigation into individual species response to sUAS exposure is necessary.

Prairie grouse *Tympanuchus* spp. are distributed throughout the central and western United States and are of high

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conservation concern (Johnsgard 2002). Wildlife professionals commonly use aerial surveys with manned aircraft to monitor grouse and develop population indices by counting males each spring on centralized display areas known as leks. These surveys commonly provide more accurate data then ground-based road surveys alone (McRoberts et al. 2011). However, because of the dangers (Sasse 2003) and costs (McRoberts et al. 2011) associated with manned, aerial surveys, sUAS may present a realistic alternative. However, for sUAS to be effective, they need to collect accurate counts of individual grouse through imagery. Research using sUAS on greater sage-grouse *Centrocercus urophasianus* suggests still imagery are of sufficiently high resolution to detect individual males on leks (Hanson et al. 2014, Forbey et al. 2017). Prairie grouse *Tympanuchus* spp. are smaller than sage-grouse and often are found in denser vegetation. For these reasons, observers using manned, aerial surveys find flushed prairie grouse easier to count while quantifying populations (Lehmann and Mauermann 1963, Schroeder et al. 1992). Conversely, if sUAS trigger the flushed behavioral response it could inhibit the ability to capture prairie grouse in sUAS imagery (Gillette et al. 2013), and thus render the images useless for population estimation.

In addition to specific behavioral responses to sUAS, there are still much logistical uncertainty about the use of sUAS for wildlife surveys (e.g. altitude, weather conditions). Given the gap in sUAS knowledge and the major need for safer survey methods in remote landscapes, we designed a study to evaluate the potential use of sUAS to survey sharp-tailed grouse *Tympanucus phasianellus* (hereafter, grouse) on leks in remote areas of South Dakota. Our study objectives were to 1) assess behavioral responses of lekking grouse to sUAS exposure, and 2) discuss labor, technical requirements, and logistical challenges associated with sUAS wildlife surveys. By addressing these objectives, we will provide guidance for future applications of sUAS in grouse lek surveys.

Methods

Study area

We conducted aerial surveys using sUAS during the spring of 2018 and 2019 in the Grand River National Grassland in Perkins County, South Dakota. This area is located within the semiarid, unglaciated portion of the Missouri Plateau. The Grand River National Grassland (GRNG; 45°45′0″N, 102°30′11.52″W) was 626.4 km^2, and dominated by mixed grass prairie and hardwood river bottoms. Topographic features of the GRNG include gently rolling hills, steep grassy buttes and broad river plains.

Small unmanned aerial system

We used DJI's Phantom 4 quadcopter (hereafter, quadcopter (DJI, Shenzhen, China, Fig. 1)), which weighs 1.38 kg with camera on board. This platform has a plastic shell body and a diagonal wingspan of 35 cm. This quadcopters propulsion comes from four motors mounted on the tip of each wing, allowing speeds up to 72 km h^{-1}. Power comes from a 5870 mAh battery, which allows approximately 30 min of flight and is fitted with a 20 megapixel 3-axis-stabalizing gimbal camera.

Figure 1. Quadcopter small unmanned aerial systems (sUAS) by DJI with controls.

Small unmanned aerial system flights

We carried out aerial lek surveys between dawn and 09:30 h MST in correspondence to typical ground surveys of leks (Autenreith 1982). To avoid disturbance during pre-takeoff, we launched the sUAS at a minimum distance of 200 m from leks (Vas et al. 2015, Rümmler et al. 2016). To investigate behavior response by grouse at extreme flight–height gradients we flew the sUAS at 30 m and 121 m above ground, levels [hereafter, AGL]. Flights were designed to cover the entire lek and its proximity using linear flight paths. A visual observer accompanied the remote pilot during all controlled flights, as specified by the FAA § 107-31. The visual observer also took notes on labor and technical requirements to provide a general understanding of the logistics that accompany surveys.

Prior to takeoff, a third observer stationed at a concealed vantage point near the lek, counted grouse and noted behavior before, during and after each sUAS survey using a spotting scope. Lek observers arrived at concealed vantage points 20 min prior to each survey. Monitoring grouse prior to sUAS exposure allowed us to get a baseline on their behavior. We 'scored' sUAS response behavior into four categories: no response, acknowledgement, flush and total disruption. Behavior for no response included continuing to display, preening and foraging. Acknowledgement meant the birds stopped displaying and turned attention toward the sUAS or sought cover. We defined a flush score when at least one, but not all birds flushed from the lek. Total disruption signified a lek entirely abandoned (i.e. all birds flushed) after sUAS exposure. Following surveys, the lek observer stayed in position for 15 min to document post exposure behavior of grouse.

Statistical analysis

To assess response behavior, we categorized scores by No flush (i.e. no response and acknowledgement) or Flush (i.e.

flush and total disruption) (Rümmler et al. 2016, Weimerskirch et al. 2018). We examined univariate, binomial generalized linear mixed models (GLMM) with a link function (Bates et al. 2014), using package lme4 in R statistical environment (<www.r-project.org>, Bates et al. 2015). Univariate models were based on a priori variables of interest and categorized into three predetermined groups. The best models from each group were used to create a best model set on the basis of Akaike's information criterion (AIC) corrected for small sample sizes, AIC_c (Burnham and Anderson 2002).

We first assessed variables for multicollinearity using Pearson's correlation, retaining one variable from any highly correlated variable pairs ($r > 0.7$; Coppedge et al. 2008). We then created three model groups based on weather, study design and biological variables. This resulted in six weather, three study design and three biological models. Variability in climatic conditions and lek tenacity was assessed by comparing both linear and quadratic trends of temperature, wind speed and survey date. All covariates including a quadratic trend also included a linear term. We nested lek identification as a random effect within all univariate models, null model (intercept only) and combination models for each step to account for repeated measures. We ran univariate models for all variables within the three groups and ranked them based on their AIC_c values and in comparison to a null model (Burnham and Anderson 2002). Univariate models from each group with greater relative importance than the null model, and within 2 AIC_c units of the best model were considered supported and were included in the 'best' model set (Hovick et al. 2015). The best model set included all supported univariate models, all possible combinations of those variables, and a null model (intercept only), to determine the relative importance of each variable (Loss and Blair 2011). We calculated model-averaged parameter weights for each supported variable by summing their AIC_c weights *(w)* in all models within the best model set, then dividing the sum by the total number of models in which that variable occurred within that set (Burnham and Anderson 2002, Hovick et al. 2015). This method allowed us to determine the most informative parameters from multiple competitive models. We calculated confidence intervals for variables in the top model from the final model set to gauge their effect.

Results

We visited 19 leks and conducted 43 sUAS surveys between 9 April and 3 May in 2018 and 2019. Collectively, eight leks were surveyed once, six leks were surveyed twice, five leks were surveyed three times, and two leks were surveyed four times. The number of grouse present on surveyed leks varied, with males averaging 6.3 ± 0.3 (SE) and females averaging 1.0 ± 0.3. Pre-survey behavior of grouse consisted of resting birds or displaying males. Post-survey observations noted that of 14 leks that scored total disruption, eight had birds returning to leks within an average of 4.4 min ± 1.0, one had birds return while the sUAS was still in flight, and five had no birds return during the sampling period. Grouse behavior on leks without a total disruption score included, five where birds returned to displaying within 3.02 min ± 1.48 of sUAS departure, 10 had birds that continued to display during the flight duration, three had birds displaying immediately following sUAS departure, and five never had birds display again while the lek was being observed. There were six leks where birds remained present but did not display at any given point throughout the sUAS survey.

There was no evidence of correlation between predictor variables of interest. We found altitude and wind speed were most informative at explaining the behavioral response of grouse during sUAS surveys (Table 1). Altitude (parameter importance weight = 0.48) and the quadratic of wind speed (parameter importance weight = 0.48) both occurred in the best model. We observed lower flush scores when we increased survey altitude to 121 m AGL ($\beta_{altitude} = -116.80$, 95% CI: −29.94 to −1.32, Fig. 2, 3). The quadratic trend of wind speed suggested lower flush scores when surveys occurred at intermediate wind speeds ($\beta_{windspeed} = -15.36$, 95% CI = 0 to −0.46; $\beta_{windspeed}{}^2 = 24.22$, 95% CI = 4.11 to 0, Fig. 2, 4).

Discussion

Our main research findings suggest that grouse flushed from lek locations less often when sUAS were flown at greater altitudes and during days with moderate wind speeds. Specifically, we observed lower flush scores from grouse as we increased survey altitude from 30 m to 121 m AGL. One or more grouse flushed from leks 83.3% of the time following sUAS exposure at 30 m AGL and 35.1% at 121 m AGL. Additionally, we found wind speeds ≥ 6 kph and < 13 kph to be best at minimizing grouse flushing and recommend wind be considered in future surveys using sUAS. Despite the behavior response from grouse we observed with our sUAS platform, our experience with sUAS suggest there is potential for their use in aerial lek surveys by improving access to remote locations (Jones et al. 2006) and alleviating dangers associated with manned, aerial surveys. However, it may require more advanced sUAS and sensors that allow for higher altitude observations and greater imagery resolution.

Our results suggest that higher survey AGLs should be considered in future sUAS evaluation but due to FAA restrictions we were unable to survey altitudes >121 m AGL. Flights at similar altitudes to those we evaluated have triggered greater-sage grouse to flush during manned, aerial surveys (Gillette et al. 2013). Small unmanned aerial systems flown at 80 m AGL and lower, have triggered both a behavioral and physiological response to both waterfowl and nesting Artic sea birds (McEvoy et al. 2016, Weimerskirch et al. 2018). Protocols and changes to FAA regulations, or an exemption permit that allow for increased sUAS survey altitudes >121 m AGL could alleviate this response from grouse and other birds (Hanson et al. 2014). However, identifying less conspicuous grouse (i.e. female greater sage grouse and sharp-tailed grouse) in still imagery at ≥121 m AGL becomes increasingly difficult with sensors rated at ≤ 20 megapixel (Breckenridge et al. 2011, Fig. 5). Small unmanned aerial systems with greater weight capacity would allow for more sophisticated sensors with greater ability to detect grouse at higher altitudes. However, investigators using larger platforms could risk higher detectability from

Table 1. Model selection results for sharp-tailed grouse behavioral responses during small unmanned aerial systems surveys conducted in South Dakota during the springs of 2018–2019.

Model	K^a	ΔAIC$_c$^{b}	w^c	log-likelihood^d
Weather models				
Wind speed^2	4	0.00	0.68	−22.63
Cloud cover	3	3.51	0.12	−25.60
Null	2	4.21	0.08	−27.11
Temperature^2	4	5.94	0.03	−25.60
Precipitation	3	6.18	0.03	−26.94
Temperature	3	6.32	0.03	−27.01
Wind speed	3	6.43	0.03	−27.06
Study design models				
Altitude	3	0.00	0.81	−24.01
Null	2	3.89	0.12	−27.11
Survey date	3	6.21	0.04	−27.11
Survey date^2	4	6.21	0.04	−25.90
Biological models				
Null	2	0.00	0.42	−27.11
Number of males	3	0.77	0.29	−26.34
Number of females	3	1.92	0.16	−26.91
Pre-flight behavior	3	2.31	0.13	−27.11
Best models				
Altitude + wind speed^2	5	0.00	0.91	−18.34
Altitude	3	6.34	0.05	−24.01
Wind speed^2	4	6.01	0.04	−22.63
Null	2	10.23	0.01	−27.11

[a] No. of model parameters.
[b] Difference in AIC$_c$ value between models and the strongest supported model.
[c] AIC$_c$ weights.
[d] Natural logarithm of the maximum likelihood for model.

grouse compared to smaller quadcopters (Watts et al. 2010, Sardà-Palomera et al. 2012).

We found a quadratic trend of wind speed, being that at low (< 6 kph) and high (≥ 13 kph) wind speeds more flush scores were recorded than at moderate (≥ 6 kph and < 13 kph) wind speeds. We speculate that during low wind speeds the operating noise produced by the sUAS traveled more efficiently to grouse from the lack of atmospheric distortion. During periods of high wind speeds, the body of the sUAS was forced to increase its flight angle to keep its linear flight path. This resulted in the sUAS's airfoils trailing edge to produce larger amounts of low frequency noise (Brooks et al. 1989). Low frequency anthropogenic noise can influence bird behavior (Goodwin and Shriver 2010), and could explain grouse behavior during surveys at high wind speeds. Alternatively, grouse become more alert during

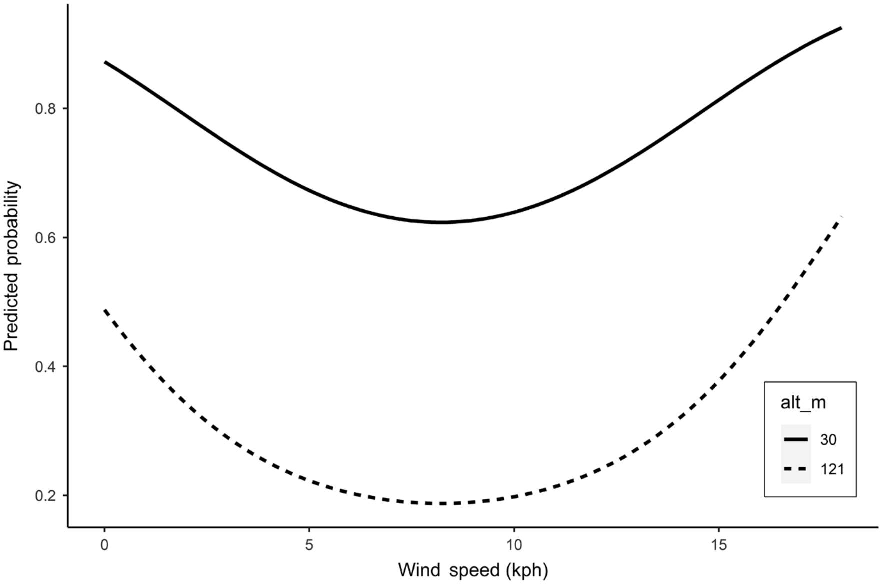

Figure 2. Predicted probability of sharp-tailed grouse producing a flush response relative to above ground levels (altitude at 30 and 121 m) and wind speed (kph) during small unmanned aerial systems (sUAS) lek surveys in South Dakota during the springs of 2018–2019.

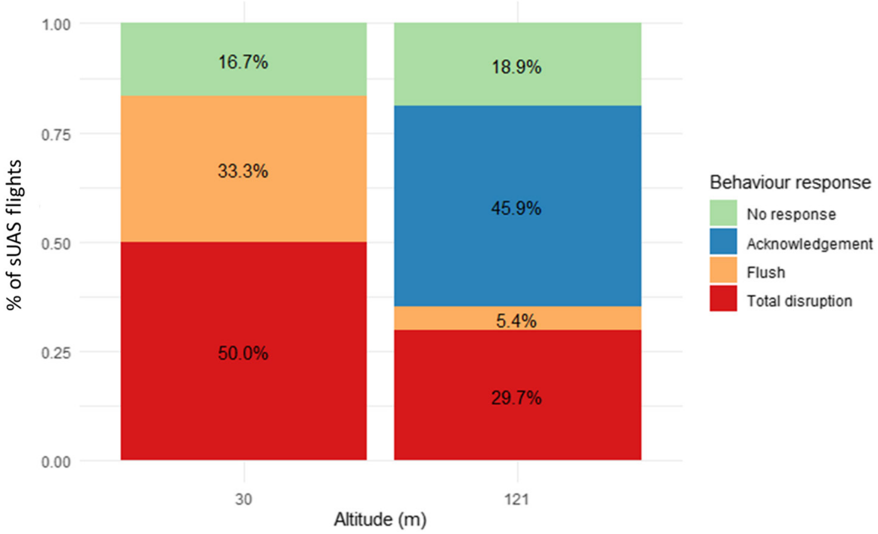

Figure 3. Sharp-tailed grouse flush response to survey altitude (m) during small unmanned aerial systems (sUAS) surveys in South Dakota during the springs of 2018–2019.

high wind speeds, which can make approaching them difficult under those conditions.

We noted that the majority of birds that remained on the lek either sought shelter in the nearest tall vegetation or crouched closer to the ground. This behavioral response could lead to a broken silhouette of grouse in still or video imagery (Chabot et al. 2015). Small unmanned aerial system based thermal imagery presents a potential solution to this problem with wildlife researchers finding them particularly useful for depicting animals in imagery (Potvin and Breton 2005, Carr et al. 2012, Israel 2012, Hanson et al. 2014). Although, this is dependent on wildlife not vacating an area before imagery is able to capture them (Gillette et al. 2013).

Surveys were easy to replicate between leks with DJI's user friendly software, which allowed for easy uploading of preprogrammed linear flight paths. We experienced technical difficulties on several surveys when the sUAS was not calibrating its compass properly. This however did not restrict our ability to complete surveys at any particular lek after the remote pilot began to systematically recalibrate the compass before each sUAS survey.

Small unmanned aerial systems show promise to alleviate concerns with manned, aerial surveys with ease of deployment and alleviate risks during aerial surveys. The Phantom 4 quadcopter was able to survey leks at 32.2 km h^{-1} allowing for an average flight duration of 7.6 min ± 0.3. We found no difference between flight times for sUAS surveys conducted at 30 m AGL and 121 m AGL. Conversely, we did find a difference between labor times between the two altitudes, but this can largely be attributed to adjustments made after the first year of this study that allowed for more efficient surveys. On three separate occasions we experienced communication difficulties between the sUAS navigation software and remote pilot, but DJI's failsafe sys-

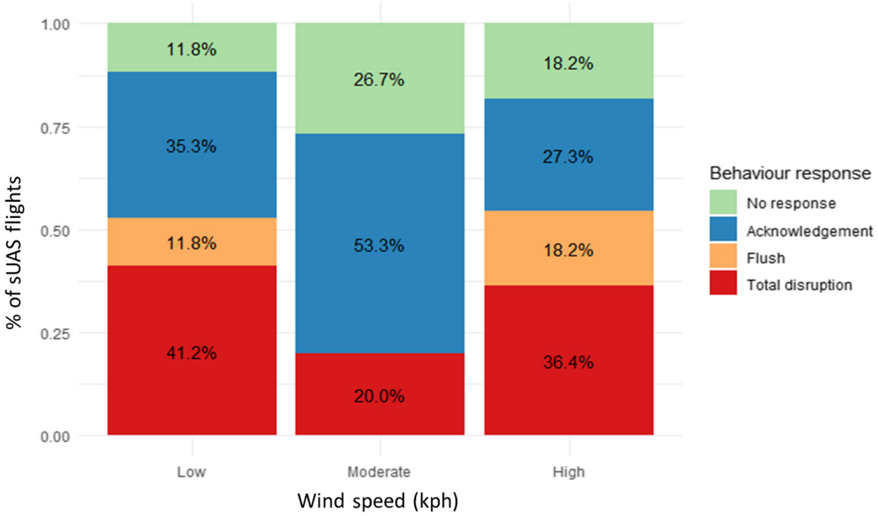

Figure 4. Sharp-tailed grouse behavioral response to wind speed (kph) during small unmanned aerial systems (sUAS) surveys in South Dakota during the springs of 2018–2019. Wind speed (kph) is categorized into Low (< 6 kph), Moderate (≥ 6 kph and < 13 kph) and High (≥ 13 kph).

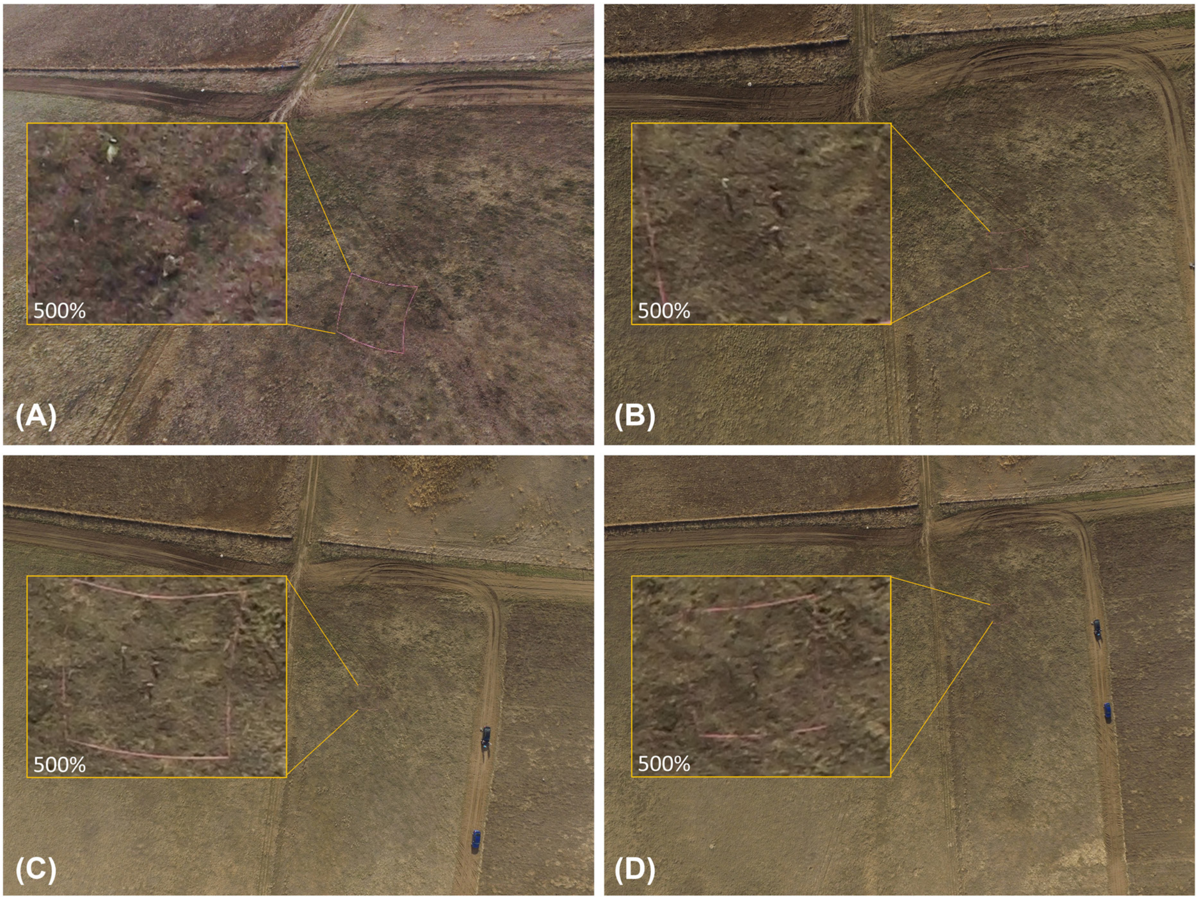

Figure 5. Images taken of sharp-tailed grouse *Tympanucus phasianellus* decoys using DJI's Phantom 4 quadcopters 20 megapixel gimbal camera at four above ground levels (A: 30 m AGL, B: 60 m AGL, C: 91 m AGL, D: 121 m AGL). Inset images are shown at 500% magnification.

tem was efficient at preventing damaging accidents. Overall, our sUAS was easy to deploy, autonomously controlled, and cost efficient. Our research suggests that this sUAS is well suited as an unmanned aircraft in terms of logistics for lek surveys (Hodgson et al. 2010). However, it was frequently detected by grouse at altitudes ≤ 121 AGL during variable wind speeds.

Our findings suggest that low altitude (≤ 121 m AGL) restrictions to sUAS surveys may limit the potential of sUAS as a substitute for manned, aerial surveys. Despite this, sUAS show promise to alleviate concerns with manned, aerial surveys with ease of deployment, potentially lower operation cost (Wing et al. 2014), and alleviated risks. We extend caution when deploying sUAS on prairie grouse and call for future research in sUAS methodology to identify and alleviate behavioral responses grouse express towards sUAS to determine appropriate sUAS survey protocols. Future research should explore various survey altitudes > 121 m AGL to determine disturbance thresholds for sUAS lek surveys. This will likely require exemption permits or changes to current sUAS regulations set by the FAA. Increasing survey altitude will require more advanced sUAS platforms, so additional sUAS models should be evaluated. Though much remains unknown about sUAS and wildlife research, our study outlines concerns that need consideration during future research and we hope it will be useful to other researchers that are exploring the use of sUAS in grouse lek surveys.

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