Habituation of White-tailed Deer (*Odocoileus virginianus*) in an Urban/Suburban Environment to an Unmanned Aircraft System (UAS) quad copter

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ABSTRACT: The use of remote control Unmanned Aircraft Systems (UAS) with photographic instrumentation has the potential to be a useful tool for various aspects of wildlife management. However, if the presence of an UAS significantly alters normal behavior, use of these devices may be limited. Therefore, the objective of this study was to evaluate behavioral changes of white-tailed deer (*Odocoileus virginianus*) when repeatedly exposed to a commercially available UAS. We hypothesized that white-tailed deer in an urban/suburban environment would rapidly become habituated to the presence of an UAS. Deer in two hay fields on the Berry College campus were subjected to 1 UAS flight per day for 10 consecutive days. Each flight consisted of 2 overhead passes by the UAS at an initial height of 50 m above the ground followed by 2 passes at 40 m, 30 m, and 20 m altitude. Digital camcorder recordings at ground level were obtained during each flight from a minimal distance of 100 m from the deer. Behavior of deer during 12 predefined, 10 sec components of each flight, within the field of view of the digital camcorder, were categorized as Passive (no altered behavior), Alert (actively observing and/or listening toward the UAS), Active (slow to moderate movement away from area), or Flight (running away from area). The average number of deer observed during each flight was similar ($P \geq 0.05$) at each respective location (12.1 ± 3.9; 12.8 ± 5.6). There was an increase in Passive Behavior ($P \leq 0.05$) and a corresponding decrease in Alert Behavior ($P \leq 0.05$) of deer as the number of flights and subsequent exposure to the UAS increased. Too few observations of Active or Flight Behavior were recorded to provide meaningful interpretation. The results of this study indicate white-tailed deer in an urban/suburban environment can readily become habituated to the presence of an UAS with repeated exposure.

Key Words: behavior, habituation, UAS, white-tailed deer

INTRODUCTION

The rapid advancement and availability of various platforms of Unmanned Aircraft Systems (UAS) have resulted in a proliferation of potential uses for these devices. Classification of the different types of vehicles available for civilian use has primarily been a result of application of military descriptions based on size, endurance, capabilities, and physical conformations of the vehicles (Watts et al. 2012). Terminology used to describe different platforms also continues to evolve, including Remotely Piloted Vehicle (RPV), Unmanned Aircraft (UA), Unmanned Aerial Vehicle (UAV), and the more recent term of Unmanned Aircraft System (UAS) (Watts et al. 2012, Gupta et al. 2013). An UAS is described as an air vehicle and associated equipment that does not carry a human operator and flies by autonomous control or remote piloting (Gupta et al. 2013). Regardless of classification, the primary civilian use at this time is for surveillance.

Over the past decade, there has been a proliferation of proposed and documented use of various UAS platforms for environmental monitoring. Unmanned aircraft system imaging has been used for monitoring vegetation, including rangeland (Quilter and Anderson 2001, Rango et al. 2006, Laliberte et al. 2011) and various types of forests (Tomlins and Lee 1983, Paneque-Galvez et al. 2014). Agricultural applications documented suggest that UAS have been useful for evaluating soil erosion (d'Oleire-Oltmanns et al. 2012), vineyard status (Baluja et al. 2012), and detection of diseases of citrus trees (Garcia-Ruiz et al. 2013). Monitoring the status of fires (Ambrosia et al. 2003), avalanche zones (Watts et al. 2012) and oil spills (Allen and Walsh 2008) has also been reported as a use of these devices. It should also be noted that UAS have significant use and potential for human surveillance such as law enforcement and border patrol efforts (Gupta et al. 2013).

The potential of UAS applications for wildlife management objectives, particularly those typically involving low-altitude aerial surveys using conventional aircraft, are evident. According to Wiegman and Taneja, (2003) crashes of light aircraft while conducting aerial surveys are the leading cause of death for wildlife researchers. Manned aerial surveys also tend to have a high cost/hour flight for the aircraft operation, and significant additional expenses related to personnel and logistic considerations such as working within airport constraints (Watts et al. 2010). Watts et al. (2010) further reported problems with survey repeatability, restrictions due to climatic conditions, and challenges with small special scales or area access when conducting surveys with conventional aircraft.

Application of capturing aerial images of wildlife in the 1990s through the early 2000s primarily involved modification of recreational remote control aircraft (Thome and Thome 2000, Abd-Elgrahman et al. 2005, Jones et al. 2006). As various UAS platforms became available from commercial sources, classifications and availability of these vehicles as well as considerations for particular use also expanded (Watts et al. 2012).

Surveillance of wildlife species using UAS technology is becoming more widespread. There are reports of using various UAS platforms to survey wading birds (Abd-Elrahman et al. 2005, Jones et al. 2006), black-headed gulls (*Chroicocephalus ridibundus*) (Sarda-Palomera et al. 2011), Canada geese (*Branta canadensis*) and Snow geese (*Chen caerulescens*) (Chabot and Bird 2012), and assessing bird risk hazards in power lines (Mulero-Pazmany et al. 2013).

Use of unmanned aircraft to survey marine mammals has been considered successful (Koski et al. 2009, Hodgson et al. 2013). Unmanned aircraft systems have also been used for detection of Roe deer (*Capreolus capreolus*) (Israel 2011), and monitoring disease transmission in Red deer (*Cervus elaphus*) and Fallow deer (*Dama dama*) (Barasona et al. 2014). Vermeulen et al. (2013) examined the use of UAS to survey populations of African elephants (*Loxodonta africana*).

While the use of UAS platforms for wildlife surveillance is evident, the influence on animal behavior while being subjected to the presence of the vehicles is unclear. Vermeulen et al. (2013) reported no observable reaction by African elephants when the UAS utilized for survey purposes was maintained at an altitude of 100 m. Various wetland bird species reacted more to vertical approaches from a UAS compared to approaches at other angles (Vas et al. 2015). While the use of remote control UAS platforms with photographic instrumentation has the potential to be a useful tool for various aspects of wildlife management, if the presence of the vehicle significantly alters normal behavior, the use of these devices may be limited. Therefore, the objective of this study was to evaluate behavioral influence of white-tailed deer (*Odocoileus virginianus*) in an urban/suburban environment when repeatedly exposed to a commercially available UAS.

STUDY AREA

We conducted our study on the 1,215 ha Berry College Wildlife Refuge (BCWR) within the 11,340 ha Berry College campus in northwestern Georgia, USA. The BCWR was within the Ridge and Valley physiographic province with elevations ranging from 172 m to 518 m (Hodler and Schretter 1986). The BCWR was characterized by campus-related buildings and facilities for the 2,100 student body, interspersed with expansive lawns, hay fields, pastures, woodlots, and larger forested tracts. Forested areas were dominated by pines (*Pinus* spp.), oaks (*Quercus* spp.) and hickories (*Carya* spp.). The two test areas used for this study were characterized as a transition zone from campus lawn to agricultural hayfields. Lawn areas consisting of orchard grass (*Dactylis glomerata*), fescue (*Schedonorus phoenix*), and white clover (*Trifolium repens*) extended from buildings used for housing, approximately 100 m into hayfields predominantly composed of Bermuda grass (*Cynodon dactylon*). Each hayfield immediately adjacent to the campus buildings used as test sites were approximately 8 ha (Deer Field Hall (DF)) and 13 ha (Rollins Hay Field (RF)). Unmanned aircraft system flights initiated were within 100 m of a campus building and typically within 100 m of the same location at each site for each flight.

The BCWR had a deer population estimated at 25 deer/km^2 (D. Booke, Georgia Department of Natural Resources, personal communication). Due to significant contact with humans and lack of hunting pressure, deer on the college campus are highly habituated to the presence of humans. Approaching some animals to within a 10 m distance is common.

METHODS

We used a commercially available UAS (Phantom 2 Vision, DJI North America, Los Angeles, CA, USA). This platform was classified as a small UAS quad copter, capable of vertical take-off and landing. The UAS is operated by a portable remote control unit, with a range of 300 m and a typical flight time of up to 25 min per battery charge. This UAS is reported to have the ability for ascent at 6 m/s, descent at 2 m/s and a maximum flight speed of 15 m/s. The vehicle, operated by four electric propeller driving motors, weighs 1.2 kg, including battery and a factory-included camera. The camera is capable of still photos (14-megapixels) and high definition video recording (HD 1080/p30 or 1080/60i) with a panoramic (120^{o}) field of view. Live video feed of the camera view, camera angle, and flight information data is displayed by use of a smart phone application that connects to the UAS via a unique WI-FI signal generated by the flight control unit (Phantom 2 Vision – Specifications. DJI North America, Los Angeles, USA. http://www.dji.com/product/phantom-2-vision/spec.). To minimize potential variation in the designated flight sequence, there was a single operator of the UAS for all flights.

Groups of deer located within the two hay fields, Deer Field Hall (DF) and Rollins Hay Field (RF) on the Berry College campus, were subjected to 1 UAS flight per day (with multiple passes per flight; see below) for 10 consecutive days, typically between 0700 hr – 1000 hr, from 8 July – 17 July 2014. Criterion for a flight to occur required at least five mature deer within the field of view of the digital camcorder used for recording behavior. A flight of the UAS was initiated at a minimum of 100 m from the group of deer that were within the operating range of the UAS (300 m), as determined by use of a range finder (Rangemaster 900, Leica Camera Inc. Allendale, NJ, USA). Climatic conditions including temperature, relative humidity and wind speed were recorded prior to each flight (Skymaster SM-28, Speedtech Instruments, Great Falls VA, USA). At the initiation of each flight, the UAS ascended vertically to an altitude of 50 m directly over the operator. Each flight consisted of two overhead passes by the UAS, between the operator to the approximate center of the group of deer at the initial height of 50 m, followed by the same number of passes at 40 m, 30 m, and 20 m altitude. The UAS then completed a vertical landing within 3 m of the operator/take-off location.

Digital camcorder (Handycam DCR-SX63, SONY Corp. of America, New York, NY, USA) video recordings at ground level for each flight were obtained for at least 5 min prior to UAS take-off and continued for at least 5 min post-landing. Twelve, 10-second periods for each phase of each flight were examined using video playback software (VLC Media Player for Windows, VideoLAN, Paris, France). Time periods for behavioral evaluation were determined by identifying specific digital recording periods, based upon audio descriptions provided by the UAS operator and recorded by the digital camcorder during each flight. These time periods were determined by the UAS operator without input or disclosure to the video reviewing personnel. Specific time stamps for designated periods to be evaluated were identified and provided as reference points to the two individuals evaluating behavior. The 12 periods within each flight evaluated included 1-min before take-off (Pre-Flight); initiated at take-off (Take-Off); when the UAS was directly overhead of the deer for each of the two overhead passes made at altitudes of 50 m, 40 m, 30 m and 20 m; during the UAS landing (Landing); and 1 min post-landing (Post-Flight). Reviewers categorized behavior as number of seconds, within the 10 sec observation period, that deer exhibited passive (no altered behavior), alert (the animals ears and face pointing toward the UAS), active (slow to moderate movement away from area), or flight (running away from area). Each deer within the field of view during each 10 sec behavioral observation period received an individual behavioral analysis. Deer entering or leaving the field of view during the prescribed 10 sec period were included by observation for the appropriate number of seconds prior to entering or after leaving the field of view to reach a total of 10 sec evaluation.

Sound recording of decibel (dB) level was obtained using a hand-held sound meter (Extech Model 407732, Extech Instruments Corp., Nashua, NH, USA). Sound intensity levels (dB) were recorded in one of the test areas (RF) approximately 14-days following collection of behavioral data. Three sound intensity levels (dB) were initially recorded during a 5 sec period, without the operation of the UAS to obtain background sound levels. Three sound intensity levels were recorded in a similar manner when the UAS was being operated at altitudes of 1 m, 10 m, 20 m, 30 m, 40 m and 50 m directly over the operator utilizing the hand-held sound meter.

A spectrum frequency profile software (Spectrum View, Oxford Wave Research Ltd., UK) operated on an iPad (Model A1395, Apple, Cupertino CA, USA) was utilized to record sound produced by the UAS. A 1 min recording was obtained using the iPad, at a distance of 50 cm from the UAS, while hovering over a concrete surface at an altitude of 1.3 m.

Animal use procedures were approved by the Berry College Institution Animal Care and Use Committee (IACUC No - 2013-14-013).

Data Analysis

The linear model for the passive behavior or alert behavior data, y_{ijklm}, is given by: $y_{ijklm} = \mu + \alpha_i + \beta_j + \tau_k + \delta_l + e_{ijklm}$ where μ denotes the overall mean, α_i denotes the effect of location *i* (*i*=Morgan, Hayfield), β_j denotes the effect of technician *j* (*j*=1, 2), τ_k denotes the effect of flight *k* (*k*=1,..,10), δ_l denotes the effect of period *l* (*l*=pre, takeoff, pass1_50m, pass2_50m, pass1_40m, pass2_40m, pass1_30m, pass2_30m, pass1_20m, pass2_20m, landing, post) and e_{ijklm} denotes the error term, assumed to be normally distributed with mean 0 and with variance-covariance matrix Λ. The variance-covariance matrix Λ is assumed the same for all subjects. Individual observations at each period interval from all data sets were treated as repeated measurements of the corresponding experimental unit. In R-project, the function *gls* (generalized least squares) within the *nlme* library (R Development Core Team 2014) was used to fit a linear model with several different structures for the correlations among measurements. The optimal covariance structure for the variance-covariance matrix was determined using Schwarz's Bayesian Criterion (Littell et al. 1997). The passive behavior and alert behavior data sets were analyzed using the first-order autoregressive covariance structure where correlations increase as the time interval decreases (Littell et at. 1997). After significant effects were identified, differences between least squares means were considered significant at 0.05 based on the Tukey adjustment Type I error rate.

Analysis of decibel intensity was conducted using one-way ANOVA analysis procedures of IBM SPSS 22.0 (SPSS 22.0 2013) and Duncan Multiple Range Analysis to determine differences among different altitudes as treatments at the 0.05 significance level.

RESULTS

There were no differences ($P \geq 0.10$) in behavioral analysis parameters observed between the two independent reviewers of the digitally recording data. The number of deer observed in digital recordings observed during each flight were similar ($P \geq 0.05$) at the DF (12.1 ± 3.9) and RF (12.8 ± 5.6) location, ranging from 5 – 23 animals per flight. However, there was an overall difference in behavioral response of white-tailed deer exposed to the UAS treatment between the two locations. Deer exposed to the UAS platform exhibited less ($P \leq 0.001$) Passive Behavior (7.45 sec ± 0.08) in DF compared to RF (7.99 sec ± 0.08) across all 10-sec observation periods and flights. Conversely, more ($P \leq 0.004$) time exhibited as Alert Behavior was observed in deer in the DF (2.41 sec ± 0.08) versus the RF (2.08 sec ± 0.08) location. The average flight time required to complete a flight were 13.53 min ± 0.59 in the DF field and 11.63 min ± 0.32 in the RF area.

The average number of seconds white-tailed deer exhibited Passive and Alert Behavior occurring with the 10 sec observation sequences, across the 12 defined periods of each flight, indicated a progressive pattern of increasing acceptability of the presence of the UAS upon repeated exposure (Table 1). During the first flight white-tailed deer exhibited the least ($P \leq 0.05$) Passive Behavior (5.65 sec ± 0.17) and the most Alert Behavior (4.18 sec ± 0.17). There was a general progression of increasing ($P \leq 0.05$) amount of time observed as Passive Behavior and a decrease in Alert Behavior as more exposure to the UAS occurred during the 10 consecutive flights. The exception to this progression occurred during the 9th of the 10 flights. During this flight, Passive Behavior and Alert Behavior was characterized as being more similar to flights 1-2 as compared to later flights. Temperature (22.19 C ± 0.42), humidity (60.0% RH ± 3.40) and wind velocity (0.80 m/s ± 0.60) were relatively consistent across most treatment days. However, during the morning of the 9th flight, temperature dropped to 18.33 C with wind velocity gusting to 7.6 m/s as an impending thunderstorm approached. This storm resulted in 9.4 mm^3 precipitation. It is likely that the impending weather condition had significant impact on the deer behavior as opposed to the presence of the UAS.

Table 1. Mean time (sec) white-tailed deer exhibited Passive and Alert Behavior during the 10-sec observation time frames recorded during the 12 predefined distinct periods within each UAS flight.

Flight	Mean Passive Behavior ± SE	Mean Alert Behavior ± SE
1	5.65 ± 0.17^{a}	4.18 ± 0.17^{a}
2	7.00 ± 0.18^{b}	2.54 ± 0.18^{c}
3	7.69 ± 0.20^{c}	2.28 ± 0.19^{c}
4	7.47 ± 0.16^{c}	2.46 ± 0.16^{c}
5	8.33 ± 0.16^{d}	1.64 ± 0.16^{d}
6	8.28 ± 0.20^{d}	1.74 ± 0.20^{d}
7	8.77 ± 0.15^{e}	1.25 ± 0.15^{e}
8	8.56 ± 0.23^{de}	1.82 ± 0.22^{d}
9	6.64 ± 0.19^{b}	3.34 ± 0.19^{b}
10	8.83 ± 0.19^{e}	1.21 ± 0.19^{e}

Mean ± SE within same column with different superscripts differ ($P \leq 0.05$)

White-tailed deer exhibited a consistent pattern of Passive and Alert Behavior during the 10 sec observation time frames, within the 12 predefined flight periods, occurring during the 10 consecutive flights (Table 2). As expected, deer exhibited the most Passive and least Alert Behavior during the pre-flight period, prior to initiation of a flight. Deer on the campus are habituated to the presence of humans. Filming and preparation of each UAS flight, at a minimum distance of 100 m from the animals, induced virtually no visible response.

Table 2. Mean time (sec) white-tailed deer exhibited passive and alter behavior during the 10-sec observation time frames recorded during the 12 predefined distinct periods across all UAS flights.

Flight Period	Mean Passive Behavior ± SE	Mean Alert Behavior ± SE
Pre-Flight	9.57 ± 0.17^{a}	0.47 ± 0.17^{a}
Take-Off	7.37 ± 0.17^{e}	2.62 ± 0.17^{ef}
1st Pass 50 m	6.65 ± 0.18^{f}	3.42 ± 0.17^{g}
2nd Pass 50 m	7.16 ± 0.17^{e}	2.74 ± 0.16^{f}
1st Pass 40 m	7.14 ± 0.17^{e}	2.91 ± 0.17^{f}
2nd Pass 40 m	7.79 ± 0.18^{cd}	2.19 ± 0.17^{cd}
1st Pass 30 m	7.48 ± 0.18^{de}	2.34 ± 0.18^{de}
2nd Pass 30 m	8.27 ± 0.17^{b}	1.72 ± 0.17^{b}
1st Pass 20 m	7.35 ± 0.18^{e}	2.58 ± 0.19^{d}
2nd Pass 20 m	7.83 ± 0.19^{c}	2.08 ± 0.19^{bc}
Landing	8.01 ± 0.19^{bc}	1.97 ± 0.19^{bc}
Post-Flight	8.07 ± 0.18^{bc}	1.93 ± 0.18^{bc}

Mean ± SE within same column with different superscripts differ ($P \leq 0.05$)

Take-off of the UAS decreased ($P \leq 0.05$) Passive Behavior and increased ($P \leq 0.05$) Alert Behavior compared to the pre-flight period. Typically, the take-off and filming location was between 100 m – 150 m away from the deer. However, it was during the initial pass at 50 m altitude, culminating when directly overhead of the animals, that elicited the greatest decrease in Passive Behavior and increase Alert Behavior (P $\leq$ 0.05) compared to the pre-flight activity.

Sound intensity in decibels (dB) indicated that the amplitude produced by the UAS from altitudes of 1 m to 50 m directly overhead was greater ($P \leq 0.05$) than background noise levels

(Table 3). The sound spectrum frequency profile obtained while the UAS was hovering at a height of 1.3 m produced predominant peaks ranging from 200 Hz – 4,000 Hz. In addition to the behavioral observation of deer suggesting auditory response, these frequencies (Hz) and intensities (dB) are within the range of hearing reported for white-tailed deer (D'Angelo et al. 2007). It should be noted that during any form of rapid acceleration, in any direction, there is a distinct increase in frequency (Hz) and intensity (dB) of sound produced by the UAS.

Table 3. Mean intensity of sound (dB) produced by the UAS operated at different altitudes (m).

Altitude	Mean Decibel Level (dB) ± SE
1	73.10 ± 1.50^{a}
10	58.13 ± 1.34^{b}
20	54.17 ± 0.93^{c}
30	50.43 ± 0.73^{d}
40	52.70 ± 0.50^{c}
50	48.70 ± 0.23^{e}
Background Level	44.87 ± 0.92^{f}

Mean ± SE within same column with different superscripts differ ($P \leq 0.05$)

DISCUSSION

The flight protocol utilized in this study was intended to provide a progressively increasing source of stimulus and exposure by decreasing the altitude of the UAS during the two-pass process from 50 m to 20 m, in 10 m increments. Because of the presence of power poles and transmission lines reaching a maximum height of 11 m in the RF area, it was not considered safe to fly at an altitude below 20 m. Regardless, it was during the initial pass at 50 m altitude, culminating when directly overhead of the animals, that elicited the greatest decrease in Passive Behavior and increase Alert Behavior compared to the pre-flight activity. This response is likely due to the initial approach of the UAS toward the deer creating a brief period of threat assessment. Subsequent passes resulted in a consistent trend of increasing Passive Behavior with the corresponding decrease in Alert Behavior. This suggests deer did not consider the UAS a substantial threat after initial exposure even though altitude during subsequent passes continued to decrease from 50 m to 40 m, 30 m and finally 20 m, before landing. Based upon the behavioral responses elicited by white-tailed deer when subjected to the flight protocol, habituation to the presence of an UAS appeared to be evident over the 10 day treatment period.

Research utilizing UAS platforms to quantify animal abundance continues to expand. However, behavioral influence as a result of the presence of the UAS in operation is only beginning to emerge. Various wetland bird species exhibited minimal reactions when approached by different colored UAS platforms from an initial altitude of 30 m, when approach angles were from 20° – 60° (Vas et al. 2015). However, birds reacted more to the UAS when a vertical approach (90°) was initiated. Vermeulen et al. (2013) reported no observable reaction in elephants was recorded when a UAS was operated at 100 m altitude. However, no information of the potential amplitude or frequency of sound from the UAS was presented. Additionally, it was reported that medium and small mammals could not be observed at that height (100 m). Thus, utility of the UAS-camera combination used as the height of 100 m was effective to count elephants, but yielded little other information. The UAS-camera combination used in our study has a relatively wide field of view (120°) that is useful for panoramic viewing of the environment and providing ease of orientation since environmental landscapes are clearly visible. However, this camera configuration might limit visual information of a target individual without flying the UAS in close proximity, which in turn could alter the animals' behavior. Conversely, utilization of a camera with higher focal power tends to decrease the field of view, potentially resulting in difficulty finding specific target animals or identifying environmental features and locations.

There are a number of potential applications of the UAS for wildlife related issues. However, significant consideration in selection of the type of UAS and camera configuration must be considered to be effective for any given objective. It should also be recognized that the UAS may not be an ideal tool or necessarily more effective than other options. Vermeulen et al. (2013) reported that while the UAS was effective and accurate for counting elephants, it cost approximately 10x more to operate compared to conventional aircraft due to limited amounts of land that could be observed over a given period of time. A study comparing the use of images produced by a UAS to conventional ground counts of flocks of geese produced varying results. The number of Canada geese was lower based on UAS information compared to humans counting from the ground. However, counts of snow geese by UAS images were 60% higher compared to ground counts (Chabot and Bird 2012). It was suggested that contrast in feather color between the birds and the environment contributed to the different results. The proliferation of commercial and private operation of UAS vehicles may enhance human-wildlife conflicts by increasing collisions with birds as airspace becomes more crowded (Lambertucci et al. 2015).

White-tailed deer observed in the current study were habituated to the presence of humans on the college campus. Deer under other conditions, particularly those receiving hunting pressure by humans, may not habituate as readily. Currently, there are also significant challenges related with operation of UAS as the Federal Aviation Administration (FAA) continues to develop regulatory policies for recreational, research and commercial applications. With careful consideration of research objectives, environmental and regulatory limitations, the UAS will likely continue to evolve and provide another tool for wildlife related objectives.

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