Ornithological Council
Guidelines to the Use of Wild Birds in Research
2018 Supplement

Summary of literature reporting use of drones to study birds

Note for ornithologists who plan to use drones or model aircraft to study or monitor birds in the United States: The Airborne Hunting Act may prohibit the use of drones to study or monitor wildlife in the United States, except for state and federal agency personnel or their agents (i.e., someone who is working under contract to or in collaboration with state or federal agencies) or under a permit issued by one of those agencies. However, the USFWS will not issue such permits and only four states allow the use of drones for research. The Ornithological Council has asked the Office of the Solicitor of the Department of the Interior to determine if the use of SUA to study wildlife is subject to the AHA. Anticipating that the Solicitor will determine that the AHA does apply, The Ornithological Council has also filed a petition for rulemaking asking the USFWS to issue permits. Read more on this situation on OrnithologyExchange.org.

Also note the FAA registration requirements.

<u>Introduction</u>

Piloted aircraft have been used to survey birds and other wildlife, primarily for census purposes, since at least 1935, when the USFWS began its wintering ground surveys of waterfowl. The Waterfowl Breeding Population and Habitat Survey began experimentally in 1947 and became operational in 1955. Drawbacks include cost, inability to access some parts of the survey area, inability to fly low enough and at a low enough low speed to get accurate counts, and injury to or loss of life of pilots and researchers.

Cost

Fixed-wing aircraft and helicopters and the fuel and the cost for a pilot are the largest components of the cost of aerial survey. In one study that compared the cost of efficacy of wildlife counts, the cost of 58 hours of aerial survey of 91 plots totaled 23,500 € (about $2800 USD) for the aircraft, fuel, and pilot (including ferrying). Ground-based surveys of 1200 plots took 240 hours but cost only 7,000 € (about $830 USD), including travel (Månsson, J. et al. 2011). A 2013 study by the Bureau of Ocean Energy Management of the Department of the Interior compared the cost of piloted aircraft to that of drones to survey marine birds, marine mammals, and sea turtles. As a result, the Department of the Interior's Office of Aviation Services has developed a strategy to integrate unmanned aircraft systems "into DOI's government-owned and commercially contracted aircraft fleet to support DOI missions for which UAS may be better suited than manned aircraft, achieving superior science, safety, savings." That plan notes that, "The cost to operate small UAS (sUAS, under 55 pounds) currently employed by DOI are less expensive than manned aircraft for certain missions. For example, FWS and USGS estimated the cost to survey Sandhill Cranes is about $2,500 using sUAS.

Estimates to fly a similarly equipped manned aircraft for that mission range from $40,000-$50,000" (DOI Unmanned Aircraft Integration Strategy 2015-2020).

Fatalities resulting from manned aerial surveys

A 2003 study of 91 job-related fatalities among wildlife biologists found that 60 (66%) deaths between 1937 and 2000 involved aviation accidents (Sasse, D.B. 2003). Mortality continued in subsequent decades. In 2003, two marine biologists and their pilot were killed when censussing right whales; the plane crashed eight miles offshore. In 2008, three researchers from Florida Atlantic University and their pilot were killed as they flew at low altitude to study wading birds. Another Florida researcher and his pilot died in 2008 while censussing black bears. An Alaska wolf biologist dies in Denali in October 2009 while monitoring wolf packs by air. In January 2010, three California Department of Fish and Game biologists and a pilot were killed when their helicopter crashed in the Sierra National Forest where they were surveying wildlife. Two USFWS biologists died that same month while conducting waterfowl surveys in Oregon. In 2011, a wildlife biologist and a pilot were killed in a Montana crash while surveying prairie dogs.

Transitioning to unmanned aerial systems

It was inevitable that researchers would see the potential in using small, unmanned aircraft in lieu of piloted aircraft as a means to save lives and money. Other benefits soon emerged. Nest searches, which are difficult and sometimes impossible at inaccessible sites, could also be achieved with drones (Chabot and Bird, 2015). In addition, the images obtained from drones allows for the identification of individual species, which is far more difficult with images taken from manned aircraft (McEvoy et al. 2016). Studies comparing remotely sensed data from drones with data collected by human researchers found that the drone-based data are more accurate, both because the drones can access areas that humans conducting ground surveys and manned aircraft can't reach and because drones can fly lower and slower than piloted aircraft (Jones et al. 2006). More recently, researchers in Australia created several artificial colonies of sea duck decoys to compare the accuracy of drone counts versus traditional ground-based counts. On average across all colonies, RPAS-derived counts were between 43% and 96% more 205 accurate than ground counts, depending on the height of the drone above the colonies. Accuracy did not increase at altitudes under 90 m, suggesting that the benefit is realized at an altitude that is likely to minimize impact on the birds (Hodgson et al. 2017).

The impact on wildlife, however, would not be known until researchers began to use the devices for that purpose in approximately 2006. The earliest published study focused on feasibility of flight and detection and identification of wading birds. It mentioned impact on the birds only briefly. "It generally has been our experience that wading birds were not disturbed by the noise of the UAV passing overhead as long as the aircraft was launched in a direction away from the birds and brought to altitude (typically >10 m) before passing over the birds (Jones et al. 2006). As the devices became lighter, smaller, and less expensive, interest grew. In the United States, when the FAA issued its final rule governing drone use (81 FR 124; 28 June 2016), researchers assumed that they had the "all-clear" signal, not realizing that the Airborne Hunting Act (AHA) might limit use.

General summary of key research through 2017

Although the early studies focused on feasibility, researchers were also concerned about the impact of drones on wildlife. For this reason, nearly every study included some assessment of the reaction of the wildlife and some studies were conducted for the express purpose of determining impact. From these studies, certain drone characteristics and flight practices that minimize disturbance have been identified. Following a review of studies that focused on impact, those characteristics and practices are summarized.

Population estimates

In 2012, researchers used an off-the-shelf UAS to survey flocks of Canada Geese (*Branta canadensis*) and Snow Geese (*Chen caerulescens*) during spring migration (Chabot and Bird, 2012). While transects were flown over the flocks at an altitude of 183 m, an observer with a spotting scope monitored the birds and saw none flushing, leaving, or joining the flocks.

U.S. Geological Survey researchers studied Greater Sage-Grouse (*Centrocercus urophasianus*) by flying a fixed-wing drone over two leks (Hanson et al. 2014). This ground-dwelling species displays in the open and is vulnerable to raptor predation. It was expected that the birds would flush in response to the aircraft. In fact, one of the two leks had experienced depredation by Golden Eagles (*Aquila chrysaetos*) and the researchers assumed that the response by the birds at this lek might differ from that of the first lek. As observers watched from blinds, flights over the lek and circling flights were flown over the first lek at altitudes between 60 m and 75 m AGL. On a different date, transects were flown at 61 m AGL. At the second lek, three flights circled the lek at 61 m AGL and a set of transect flights were flown at 37 m AGL and 61 m AGL. There was no long-term reaction to the flights regardless of flight altitude or pattern and no birds flushed from the leks. Some displaying males, however, paused or crouched momentarily while the aircraft flew over. Females continued to forage. The birds seemingly habituated as they showed little to no response to the later flights. At the second lek, the aircraft noise increased as it gained altitude and the birds stopped displaying for approximately 35 s. At this site, the females crouched briefly as the aircraft circled nearer to the center of the lek.

A 2015 study explored the relationships between flight altitude, imagery resolution, and waterbird identification, using two different drones – one, a gas-powered vertical take-off-and-landing craft, and the other, a fixed-wing, battery-powered craft (Dulava et al. 2015). The aircraft were flown at altitudes ranging from 15 – 120 m AGL. Researchers studied the images taken during the flights, looking for flushing behavior, defined as flight or dives that produced large splashes (larger than splashes associated with feeding dives). Evidence of flushing was found in 38 of 583 images and in 11 of 34 flocks. The rate of flushing was defined as the mean proportion of birds exhibiting flushing behavior per image. The rate was highest for the lowest altitude flights, with a rate of 0.0074 for flights at 16 – 27 m AGL. At altitudes between 33 - 79 m AGL, the index decreased to 0.0056. At altitudes of 85 – 106 m AGL, the index dropped to 0.0032. At the highest altitude (133-146 m AGL) the index was 0.0049. As the study methods apparently did not employ human observers, there was apparently no means of detecting avian predators or other sources of disturbance at the time(s) of the observed flights or dives of the waterbirds.

Using a single-rotor helicopter-style drone, researchers tested the response of wintering waterbirds at two coastal sites in British Columbia (Drever et al. 2015). They also flew the drone to map habitat. Autonomous flights for mapping and surveying birds took a grid pattern at 61 m, 91 m, and 122 m AGL. The manual flights to assess bird reactions began at 91 m AGL, flew directly over the birds, and gradually descended to a minimum altitude of 20 m AGL. Reactions were mixed. With the drone at 122 m AGL and 91 m AGL, Dunlin (*Calidris alphina*) flushed but returned to the same spot within a minute. Gulls were more likely to flush and sometimes did not return. At altitudes of 20 – 91 m AGL, ducks rarely reacted, though they would occasionally flush. The response of seabirds was difficult to interpret; they dove but it could not be determined if that was normal foraging behavior or a response to the drone. The authors suggested it would be necessary to determine foraging dive rates (versus time normally spent at the surface) by species to determine if the diving rates observed in the presence of a drone exceeded normal dive rates. If so, the additional diving could be attributed to the drone.

By 2015, ethical guidelines for the use of drones to study birds were proposed (Vas et al. 2015). The researchers used a quadricoptor to approach three species of non-breeding waterbirds, including Mallards (*Anas platyrhyncus*) that lived in a zoo but that were unconfined, flamingos (*Phoenicopterus roseus*) and Greenshanks (*Tringa nebularia*). After launching at 50 – 100 m from the birds, the drone ascended to 30 m and then approached the birds at different angles (20°, 30°, 60°, and 90° from the horizontal and at different speeds. An observer noted reactions: (type 1): no reaction, brief head and tail movement followed by movement away from the drone (type 2), or flight (type 3). Mallards did not react in 72% of the flights but showed type 2 or type 3 responses when the drone came within 4- 8 m of the birds. The pattern was much the same with flamingos except that reactions occurred when the drone came within 5-30 m of the birds. Greenshanks did not react in 87% of the cases and reactions occurred when the drone was within 4-10 m of the birds. Of all the variables studied - bird behaviour prior to approach, approach speed, drone color, and angle of approach – only angle of approach had a significant impact. In all three species, most reactions occurred when the drone approached at 90°.

The researchers suggested that drones be launched at least 100 m from the birds, that the birds not be approached vertically, and that approach distance should be adjusted according to species (requiring test flights prior to conducting the actual studies). They also suggested studying impacts on captive birds so that physiological responses such as heart rate and stress hormones could be measured and compared to responses to other approaches by humans or other motorized vehicles.

Canadian researchers used a drone to census a Common Tern (*Sterna hirundo*) colony (Chabot et al. 2015). The colony had been censused by ground-based researchers on foot, causing significant disturbance and damage. The drone study was conducted to compare the count results of the two methods and to assess reaction to the drones. The flights were launched about 275 m from the colony and transects were flown at 91 m and then 122 m. Behavior during the flights was recorded by an observer who also recorded behavior for the same duration 10 min after the flights ended. Disturbance was scored as "0"for no noticeable disturbance, "1" for moderate disturbance such as local flushing or visible agitation, and "2" for high disturbance (flushing throughout most or all of the island or panic flight (birds fell silent, flew rapidly from the colony, then called). There was no statistically significant difference between behaviour during the flight than during the control periods when the drone was not airborne. Only eight upflights were observed during the aircraft flights, compared to four during the control periods. The researchers noted that those eight upflights during aircraft overflight took place immediately following takeoff of the first flight and each of the first two survey days, which they interpreted to mean that there was some disturbance but also rapid habituation.

Reactions of Adélie Penguins (*Pygoscelis adeliae*) to an Octocopter in horizontal flight, vertical flight, and short-term habituation flights were studied during the breeding season in 2015 (Rümmler et al. 2015). For one group of birds, the vehicle was launched 50 m from the group, ascended to 50 m and, for the vertical flight moved down to 10 m. For the horizontal flight, the aircraft descended in transect-like steps to 10 m. The habituation flights over a different group of birds started at 30 m from the group and the aircraft was flown back-and-forth at 10 m above the birds. Behaviours were observed and classified into five categories: comfort resting, vigilance, agonistic, and escape. Two humans – the pilot and the cameraman – stood about 15 m from the birds and apparently did not use a blind, though they attempted to minimize disturbance by being quiet and moving slowly. Both the horizontal and vertical flights resulted in statistically significant increases in disturbance, starting at takeoff and increasing as the drone descended. Vertical flights provoked more reaction than did horizontal flights. When the drone descended to 10 – 20 m, disturbance reached the highest level, with almost all individuals reacting. For the short-term habituation flights, no decrease in disturbance levels was observed.

A study (McEvoy et al. 2016) of the impact of drones on mixed-species flocks of waterfowl found no disturbance when the aircraft were flown at least 60 m above the water level, using fixed wing aircraft, or at least 40 m about individuals (using multirotor aircraft). This study was intended, in part, to compare reactions to the five different types of aircraft - three fixed-wing with different wing styles and two multirotor aircraft. Launch sites ranged from 10 m from the lagoon shore to 300 m from the water's edge, to a site 500 m from the shore and out of sight of the birds. Flight altitude ranged from a minimum of 40 m to 120 m above the water and altitudes were tested in both ascending and descending order. Disturbance was monitored by two observers who could see the entire water body. Reactions were characterized as no discernible response; ceased foraging and orienting or looking towards the aircraft or swimming away; or took flight. Flight was rarely observed but when it did occur, it followed a direct launch at the birds or low altitude (10 – 15 m) during takeoff. This observed response entailed short flights, unlike responses to raptors, which provoked large flocks to take more prolonged flights. The shape of the aircraft and the wing seemed to influence the birds' response in that the delta wing design cause more disturbance and fleeing behavior when it launched directly at the birds or approached directly rather than tangentially or banking, which resembled the banking flight of raptors. The smaller multirotor aircraft could descend to 15 m before birds swam away; the larger multirotor Acraft provoked no response except, when at 40 m, roosting birds tilted their heads back to look at the aircraft. Generally, there was little disturbance so long as the launch and landing occurred out of sight of the birds and the aircraft reached survey altitude before it came into view of the birds. The multirotor aircraft were quieter but the fixed wing aircraft proved superior for collecting aerial photographer and were more practical for larger scale surveys.

Nest monitoring

The nest defense behavior of four raptor species in response to drones was studied by Junda et al. (2016). The study compared reactions among the four species– Osprey (*Pandion haliaetus*), Bald Eagle (*Haliaeetus leucocephalus*), Ferruginous Hawk (*Buteo regalis*), and Red-tailed Hawk (*Buteo jamaicensis*) – to nest checks conducted by drones and also compared reactions to drones to reactions to ground surveys. For Osprey (*Pandion haliaetus*), the drones were also used to assess responses to nest checks across the nesting cycle, from the egg incubation stage to the nestling stage.

The foot surveys started from between 30 – 200 m from the nest but the preferred distance, when feasible, was 100 m from the nest. At 20 m from the nest, the drone was launched. A spotter on the ground monitored and reported behaviour of the adult birds to the pilot. The spotter reported flushing, direction and type of flight, calls and alarms, and the adult's distance from and height above the nest. After the adult left the nest, the aircraft was flown near the nest and the spotter checked to be sure it was at a height above the nest; it was then placed over the nest to hover for a total of 6 s and flown quickly away. If the adult returned while the aircraft was near the nest, the aircraft was moved away and if the adult pursued the aircraft aggressively, the aircraft was set down on the ground. After the nest checks were complete, the aircraft was returned to the ground and the pilot and spotter removed it and left the area, continuing to monitor and record the behaviour of the adult. Among 110 flights, one collision occurred when an adult dove on the aircraft and knocked it out of the air. Reactions recorded were call rates and defensive behaviours on the part of the adult birds, ranging from sitting silently in a tree in sight of the nest to diving on the aircraft and, at the extreme, striking the aircraft or the researcher.

All species reacted defensively, peaking during the at-nest stage, but the reactions differed among species, with Osprey showing the highest level of nest defense and Bald Eagles being the least defensive during both the approach and at-nest stages. Overall, none of the four species were more aggressive to the drone in flight than to humans conducting ground surveys. However, there were differences among species. For instance, Ospreys showed no significant difference in the call rate or defense rate during the approach stage or the at-nest stage but Bald Eagles called at a statistically significant higher rate during the approach stage and the increase in the defense index was statistically significant during the at-nest stage.

For the Osprey, there were no statistically significant differences between call rates or defense indices during the approach and at-nest stages as between the egg stage and the nestling stages. An Osprey was the only species to strike the drone (one incident), causing the drone to crash but leaving the bird unharmed.

The researchers concluded that the aerial nest surveys caused no more disturbance to the nesting birds than did ground surveys. The Osprey quickly returned to the pre-survey behaviour when the researchers withdrew but the Bald Eagles did not return to the nest while the researchers were present. Ferruginous Hawks sometimes followed the researchers as they left the area and did not return to the nests while the researchers were present. Red-tailed Hawks generally remained near the nests as the researchers left the area. The birds did become more aggressive as the breeding season progressed. The researchers were unaware of any birds abandoning nests after a visit from a drone.

Junda et al. (2016) also commented on the novelty factor of drones. They described an observation of a pair of Ospreys ceasing their nest defense behavior in response to a hovering drone to chase after a Bald Eagle, a known nest predator, flying by almost a half-mile away.

Based on this same study, Junda et al. (2015) suggested proper techniques for observation of raptor nests. Anticipating contact with aggressive raptors, the aircraft selected had plastic break-away rotors, anti-strip motors that would cause the motor to shut down rapidly if resistance was met), and four rotors to distribute the force generated by an impact. The researchers also planned to investigate the use of a cowl or screening around the rotors to minimize damage from an impact with a bird, and also considered adding an object atop the aircraft, as raptors typically attempt to strike the topmost part of an intruder. They also remarked that pilots must be prepared to crash land the aircraft to avoid bird collisions. Finally, the researchers emphasized that it is important to refrain from nest surveys or any form of disturbance during the late-nesting season when nestlings may fledge prematurely.

The response truly seems to be species-specific. Certain raptors are known to be fiercely aggressive around their nests, including Northern Goshawks (*Accipiter gentilis*) and some of the larger owl species. Test flights can ascertain how any given species might react. For instance, test flights involving two nests of Swainson's Hawk (*Buteo swainsonii*) and Merlin (*Falco columbarius*) nest found that adults did not approach within 100 m of the aircraft while it was over their nests.

A similar study used a quadcopter to survey nests of Hooded Crows (*Corvus cornix*), again with a ground monitor guiding a pilot (Weissensteiner et al. 2015). Take-off apparently started at or near the nest trees. The aircraft was flown to a height of 5 m above the nest and then slowly lowered closer to the nest. In this study, the researchers included fully-feathered nestlings as well as eggs, newly hatched birds, and young with down. In several cases, adults and young birds gave alarm calls and adults flew repeatedly over the nests. The young cowered and remained still. In other cases, no adults were observed near the nests. Aggressive behavior occurred in only one instance; the adult dive-bombed the drone and called intensively. Half the nests were also later surveyed by climbers and in three cases, the number of eggs had decreased but the species is vulnerable to very high nest predation rates. The responses were similar to those resulting from climbing but the aerial surveys were much faster so the period of stress was much shorter.

Breeding colonies

Spanish researchers monitoring temporal changes in breeding population size of the Black-headed Gull (*Chroicocephalus ridibundus*) colony used drones specifically to minimize disturbance. They knew that accurate counts required repeated visits to the colony and that human visits would cause disturbance. Using a drone, they hoped to obtain adequate data while minimizing disturbance. With two flights on each of three days, at an altitude of 30-40 m above ground, the researchers succeeded in obtaining the data they needed. They also observed that the birds showed no notable response to the drones (Sardà-Palomera et al. 2011).

A paper in press (Brisson-Curadeau et al.) reports surveys of four species of Arctic cliff-nesting seabirds: Glaucous Gull (*Larus hyperboreus*), Iceland Gull (*Larus glaucoides*), Common Murre (*Uria aalge*) and Thick-billed Murre (*Uria lomvia*). The Thick-billed Murre colonies were studied for the nest failure rate, behavioral responses, and habituation in addition to colony counts. Because Glaucous Gulls nested among the Thick-billed Murre colonies, their behavior in response to the aircraft flights was also assessed and aerial counts were conducted and compared to the results of ground surveys. Common Murres flushing behavior was assessed. The Iceland Gull colony was surveyed to compare results to a ground-based count. In all but one location, breeding birds rarely flushed in response to the drone. At the site where eagles were present, Common Murres flushed in response to the drone and often lost eggs. Generally, most Iceland Gulls (which generally scold predators) flushed from the nests but returned within three minutes. Among the other three species, non-breeders were more likely to flush than breeding birds. However, flushing was reduced by launching the aircraft from a greater distance from the top edge of the cliff. Angle of approach seemed to have no effect, contra to Vas (2015), perhaps because cliff-dwelling birds are less likely to be attacked from above than are the wetlands birds studied by Vas. The gulls seemed to habituate after 3 min but the murres did not habituate either short-term or long-term. There was one instance of a collision between a bird and a drone. After completing a mission to take photos of murre nests on Gull Island and returning to home base, a rotary drone was struck by a Herring Gull (*L. argentatus)* with such force so as to cause the machine to lose control and fall into the water as a total write-off. The bird was unharmed. While Herring Gulls are known to be extremely aggressive in the immediate area of their ground nests, sometimes striking humans in the head, seabird biologists who witnessed the gull strike on the drone were surprised by the attack.

The authors recommended that baseline tests be conducted to determine if the species disperses in response to the aircraft, especially in areas where predators are common. Determining response addresses not only ethical concerns but also influences study design. While ethical concerns take priority, there is no point in using methods that reduce the ability to obtain the data needed to answer the study questions. *If data collection is insufficient to complete the study, then no matter how minimal the impact, the study is not justified.* From studies described here and others not discussed but included in the references, below, the following elements emerge as significant considerations in minimizing impacts when using birds to study birds.

Previous literature reviews and compilations

In a 2017 review assessed literature reporting wildlife response to drones (used for various purposes, including habitat surveys, anti-poaching efforts, depredation control and airport safety, recreation, and research) covered 36 published studies and 17 unpublished field campaigns that reported information about wildlife reactions (Mulero-Pázmany et al. 2017). Among all wildlife, birds showed the highest sensitivity, with flightless and large flying birds showing greater response that smaller flying birds, but the differences were not statistically significant. Individuals were less responsive during breeding stages and when in small groups or solitary. The larger aircraft caused greater reactions at higher altitudes than did smaller aircraft. Target-oriented flights, such as those used for photography and nest inspection, provoked more reaction than "lawn-mower" pattern flights, which are typically flown at higher altitudes. Fuel engines, which are louder than electric engines, seemed to provoke more reactions, as did changes in noise levels. This particular study did not assess the impact of the shape of the vehicle, time of day, habitat type, or angle of approach. The authors speculated that physiological or behavioral responses might result in higher energy expenditures, decreases in reproduction and survival, and space-use changes (such as territory abandonment) but they did not address the issue of habituation. Based on this review, the authors made a number of suggestions which are incorporated into the recommendations, below.

A 2017 study assessed and compared the behavioral response of 11 southern seabird species to drone approaches at specific altitudes. The behavioral responses differed between species depending on the altitude of the drone approach. At 50 m of altitude, only one species showed a detectable reaction, but at 10 m, most species showed strong behavioral postures of stress. Adult penguins breeding in large colonies, and some albatross species showed little behavioral response even when the drone was as close as 3 m, but other species such as Giant Petrels or cormorants appeared highly sensitive to drone approaches. Incubating adult King Penguins, showed little signs of behavioral stress, but non-breeding adults and fledglings exhibited strong behavioral responses to the drone approach. Monitoring the heart rates of the King Penguins confirmed the expected link between physiological and behavioral response in chicks, and also showed that the breeding adults – which showed no behavioral sign of stress - had a significant increase in heart rate, the relative increase being higher than in chicks (Weimerskirch et al. 2017).

Other uses

A novel use of drones, pairing bioacoustics and aerial detection to count songbirds, was attempted in 2016 (Wilson et al. 2017). Recording equipment was suspended from a quadrocopter that was flown over 51 count stations at an altitude of 58 m for three min. Point counts by human observers were conducted at the same stations but at least 20 minutes apart. To determine if the aircraft affected the amount of bird song output, the researchers also used ground-based recorders at 30 of the count stations and recorded for 3 min prior to the aircraft flight, during the aircraft flight, and 3 min after the aircraft departed. They found a very small dip in song bird output when the aircraft was overhead, approaching, or departing but the drone noise masked bird song to some extent. The researchers were confident that such behavioral impacts were modest among the species in the study area.

<u>Overall recommendation</u>

Conduct trial flights before initiating the study or survey. Use spotters to assess and record behavior before, during, and after the trial flights. Assumptions about reactions may prove inaccurate. For instance, it was assumed that Greater Sage-Grouse, which lek in the open and are vulnerable to raptor predation, would react strongly to drones but in fact, they did little more than crouch for a few seconds (Hanson et al. 2014). Aquatic species sharing the same habitat reacted very differently to drones (McEvoy et al. 2016). Trial flights might lead to habituation in some species which might aid in interpreting results of the study flights.

1. Know your species

Review the literature to determine if drones have been used to study that species. Use the responses described to select type of aircraft, launch distance, approach altitude, approach direction (vertical vs. horizontal) and angle, and other flight attributes.

If the species has not previously been studied or surveyed by drone, review the literature to determine the reaction of that species to human approach on foot and by boat, piloted aircraft, and avian predators. To distinguish between reaction to the drone and normal behavior, review the literature and/or conduct preliminary observations. For instance, does the species normally vocalize in response to perceived threats? If so, how much? What type of vocalization? If a diving species, does the species dive more frequently in response to perceived threats?

If studying raptors that have been found to be aggressive towards drones, fly early in the day or on cool days when diurnal raptors are more likely to be in flight, unless the birds are on nests and are likely to flush at the approach of a drone, leaving eggs or chicks vulnerable to cold temperatures. When studying species that will pursue predators, it might be worthwhile to distract such birds with a known threat (using a decoy) prior to conducting a nest survey. Junda et al. (2016) observed that Ospreys abandoned a chase of a drone to pursue a Bald Eagle. Distracting aggressive birds might also avert the destruction of drones; such attacks by Wedge-tailed Eagles and other raptors, gulls, and other large birds have been documented.

Do not assume that species within a taxa will respond the same way. Some species use different types of habitat and may react differently as a result. For instance, some species are adapted to suburban landscapes and may be more habituated to human presence than individuals of the same species that dwell in more remote areas. Birds that are accustomed to aircraft overflight may show less response to drones than birds of the same species that rarely experience aircraft overflight.

Some authors have suggested testing for physiological responses but doing so would usually necessitate repeated capture and handling, which would be an additional source of disturbance and stress. In some cases, devices that can be read remotely via transmitting sensors in nests or at feeding stations might be feasible. Such devices can be used to detect heart rate but not other key physiological indicators of stress such as corticosteroids.

2. Determine the presence of predators

Studies show that species vary in their reactions to drones and not necessarily in a manner consistent with their vulnerability to avian predators. However, the presence of predators should be noted if the study or survey method results in adults leaving nests. Some predators may not avoid drones, which means unattended nests will be vulnerable to predation, and particularly to predators that do not react to drones. Outside the nesting season, attention to a drone may leave a bird more vulnerable to a predator.

3. During the breeding season, determine the nesting stage

Unless the study or survey pertains to some aspect of breeding, avoid flights during the breeding season. During the breeding season, avoid flights on cold days, as the adult may flush from the nest, leaving eggs or chicks unprotected from temperature extremes. Be alert to the timing of the breeding cycle so as to avoid nest checks when the young are close to fledging, so as to avoid provoking premature fledging. If an adult becomes aggressive towards the drone, manoeuver it away or take it to the ground as quickly as possible.

4. Use a spotter

When using a drone to study nests, a spotter is essential to assure that the drone is at the correct altitude and to warn of the approach of the adults so the drone can be moved away and landed, if necessary.

For surveys and other studies, a spotter is needed to assess and record behavioral responses.

To distinguish between reactions to the spotters and reactions to the drone, attempt to use a blind or observe from as distant a point as possible.

5. Size of aircraft

Smaller aircraft may seem less like a predator but are more vulnerable to wind conditions, which can cause the aircraft to be unstable and can make it more difficult to obtain good images.

6. Shape

Fixed-wing aircraft and especially those with “swept” or “delta” wings may more closely resemble avian predators.

7. Type (fixed wing vs. rotary)

8. Engine type (gasoline-powered vs. electric)

Electric engines are quieter but do not have the range of gasoline-powered engines. Survey flights over large colonies may be problematic,

9. Distance at launch

Launch out of sight of the birds if possible and at a distance of 100-300 m, if possible.

10. Altitude and angle of approach

Fly or hover at the highest altitude possible to obtain the needed images. Literature reviews and test flights will be particularly useful to make this determination.

Ascend prior to approach and attempt to approach at a level altitude. Conduct banking turns away from the study animals. Avoid vertical descent. If descending in sight of the study animals, descend slowly. Descend after flying some distance from the study animals.

12. Habituation flights starting at higher altitudes, then gradually lower, could allow the birds to habituate, which would reduce impact.

13. Maintain the aircraft in good condition and test it before trial flights and survey and study flights. Be sure to have a supply of batteries and other spare parts and if feasible, have a back-up aircraft in case of failure or damage to the aircraft.

14. Obtain adequate experience flying the aircraft. If required by government authorities, obtain the relevant license or certificate. Basic piloting abilities should be guaranteed, either by a certificate issued by the authorities or evaluated with flying manoeuvres such as flying in straight lines, making turns, circles, avoiding obstacles, hovering and landing on predetermined sites (see also Kakaes *et al.* 2015 Appendix 2 for a safety pre and post-flight check list).

15. Avoid flight near or over sensitive species in the study area.

16. Include methods and behavioral observations in papers and research reports and publish the results and/or present them at conferences to share with others.

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