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# Conservation Letter: The Use of Drones in Raptor Research

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## INTRODUCTION

Drones are increasingly used as tools to facilitate wildlife research and conservation. The use of drones in raptor research has the potential to benefit conservation and management through improved knowledge of nesting, productivity, hazards, diet, etc. However, drones may also pose risks to raptors at nest sites, potentially leading to reduced reproductive rates. This Conservation Letter provides an overview of actual and potential impacts on and benefits when using drones to study raptors and concludes by highlighting lessons learned and potential guidelines for use. This letter is not intended as an exhaustive literature review. Rather, the intent of the Raptor Research Foundation (RRF) in publishing this letter is to provide readers with enough evidence-based examples that readers can appreciate the scope and prevalence of raptor interactions with drones and understand the potential effects as well as the challenges associated with addressing these effects across regions and species.

Information about nest occupancy, nestling or fledgling status, and breeding success is essential for monitoring bird populations (Newton 2013). For birds of prey, nest monitoring has been traditionally conducted with ground-based surveys (direct observation and nest climbing) or using crewed aircraft (fixed-wing and helicopter) for large or inaccessible remote areas (Andersen 2007, Pagel and Thorstrom 2007, Steenhof and Newton 2007). These methods are often expensive and time consuming and include significant safety issues. To address some of these issues, the use of drones in wildlife research has increased significantly over the last two decades due to technological advances in drones, their software, batteries, and associated sensors (e.g., camera, multispectral, infrared) and substantial reductions in costs. Drones are now widely used in wildlife management and research to map and assess habitat, and to determine the distribution and density of wildlife species. Data collection by drones overcomes the spatial and temporal resolution and cost problems associated with traditional ground-based, and occupied aircraft data collection methods, as well as the safety issues associated with crewed aircraft surveys (Sasse 2003). Drones enable surveys of wildlife with greater user control and reproducibility, greater image resolution compared to satellites, reduced disturbance of target species, and increased accessibility of difficult-to-access areas, at significantly reduced costs and logistics (Chabot and Bird 2015, Hodgson et al. 2016, Canal and Negro 2018, Gallego and Sarasola 2021, Wirsing et al. 2022). Drones also allow a greener alternative to crewed aircraft.

What are technically known as unoccupied, uncrewed, or unmanned aircraft systems or vehicles (UASs/UAVs), or remotely piloted aerial or aircraft systems (RPAS), but are more commonly

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called drones, come in a variety of sizes and configurations (fixed-wing or multi-rotor). This review is limited to the use of small UAVs, which are aircraft weighing <25 kg on takeoff; this includes multi-rotor vertical takeoff and landing aircraft (e.g., tricopter, quadcopter, hexacopter, and octocopter) and fixed-wing aircraft (Federal Aviation Administration [FAA] 14 Code of Federal Regulations 107.3). Drones heavier than 25 kg are typically outside the price range of most researchers and also require additional specific licensing in the USA. In addition, all of the published studies we found regarding the use of drones in raptor research used a multi-rotor drone. None used fixed-wing drones, which are more suitable for collecting vegetation or landscape data along transects and not site-specific nest data.

Drones have been used to study a variety of wildlife species including ungulates, primates, marsupials, bats, marine mammals, reptiles, seabirds, waterfowl, shorebirds, and raptors (e.g., Junda et al. 2016, Aniceto et al. 2018, Howell et al. 2021, McMahon et al. 2021, Piel et al. 2021, Stander et al. 2021, Yaney-Keller et al. 2021, Castenschiold et al. 2022, Kuhlmann et al. 2022, Edney et al. 2023). However, based on a database of approximately 1100 references from 2003 through 2024, drones have been used more often to study birds than other wildlife groups, with 429 (39%) of the papers addressing avian species, 297 (27%) addressing terrestrial mammals, 264 (24%) addressing marine mammals, and the remainder addressing reptiles, amphibians, fish, and invertebrates (R. Spaulding unpubl. data).

## DRONES IN AVIAN AND RAPTOR RESEARCH

At the time of this writing, the use of drones in avian research is a young issue, as there are few studies that specifically assess the impact of drones on birds. Drones have been used during the breeding period for a variety of purposes, such as to count nests and/or colonies (Chabot and Bird 2015, Sardà-Palomera et al. 2012, 2017, Chabot et al. 2015, Hodgson et al. 2016) to monitor nest status (Potapov et al. 2013, Weissensteiner et al. 2015, Gallego and Sarasola 2021), or to determine population status and productivity, particularly for threatened and endangered species (Fig. 1). Although the majority of studies have found little to no disturbance to birds from the use of drones, some disturbance has been documented (e.g., Dulava et al. 2015, Brisson-Curadeau et al. 2017, Lyons et al. 2018, Egan et al. 2020), including in raptors (e.g., Junda et al. 2016, Lyons et al. 2018). Specifically, the use of drones to study wildlife may affect individuals' behavior and reduce their reproductive output, thereby altering species' fitness and biasing research results (Grenzdörffer 2013, Borrelle and Fletcher 2017). Although the aforementioned studies have provided information regarding the behavioral disturbance to birds from drones, very few studies, and none for raptors, have looked at potential short- and long-term physiological impacts (Wulf and Pietsch 2021, Geldart et al. 2022).

Raptors are particularly suitable for monitoring nesting activities using drones because raptors typically nest in remote areas or in inaccessible places that are difficult or impossible to view from the ground such as treetops, rocky outcrops, coastal cliffs, power poles, or wetland areas, which are typically easy to view with a drone. Drone surveys provide significant advantages over traditional survey techniques such as helicopter or fixed-wing aircraft and climbing into the nests of tree- or cliff-nesting species. In addition to the reduced costs, the use of drones to monitor nests avoids safety hazards associated with crewed aircraft and with tree or nest climbing by researchers, and also avoids damage to nest trees. Drone surveys are also typically much faster than other methods, further reducing disturbance.

Although most scientific studies of nestlings still require researchers to enter a nest (with the associated disturbance of adults and young), the use of a drone removes the need to enter a nest to check on the status of the young prior to banding, thereby reducing the number of times and duration that a nest would be disturbed (Gallego and Sarasola 2021). In addition, monitoring by drone removes the potential for predators to follow the track made by researchers during nest checks of ground-nesting species such as harriers (Kilic and Purckhauer 2016).

However, the use of drones for research purposes should always be carefully evaluated. Studies using drones should minimize any risk of death or injury to birds either by accidental collisions or deliberate attacks and should minimize the disturbance or alteration of birds' behavior that would result in nest failure (Junda et al. 2015, Weston et al. 2020). These conditions must be observed for any research involving drones, but especially when species of conservation concern are the foci of a study.

## EFFECTS OF DRONES ON RAPTORS

Based on a review of the literature, a total of 20 papers have been published in peer-reviewed journals, agency reports, or conference abstracts that address the effects of drones on raptors (Table 1). Although these 20 studies cover 31 species, the

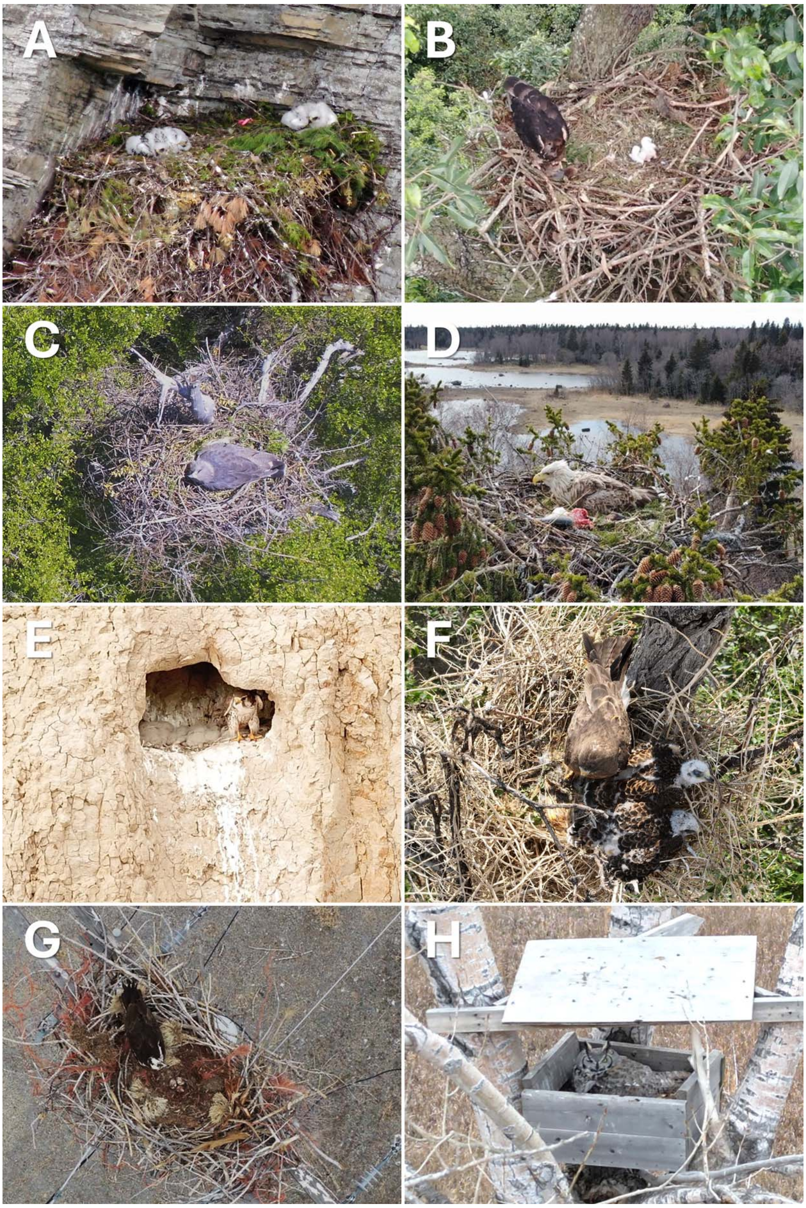


Figure 1. Raptor nest statuses documented via drones. None of the raptors in these images departed their nests during the inspections. RRF recommends that all drone operations follow local, state/province, and federal regulations regarding drone use. (A) Golden Eagle (*Aqulia chrysaetos*) nestlings in Canada. Photo G. Tremblay; (B) Crowned Eagle (*Stephanoaetus coronatus*) adult and nestlings in South Africa. Photo S. Sumasgutner; (C) Chaco Eagles (*Buteogallus coronatus*) incubating eggs in Argentina. Photo J. Sarasola; (D) Adult White-tailed Eagle (*Haliaeetus albicilla*) in Finland. Photo T. Osala; (E) Prairie Falcon (*Falco mexicanus*) in Canada. Photo D. Zazelenchuk; (F) Swainson's Hawk (*Buteo swainsoni*) in the United States. Photo anonymous; (G) Osprey (*Pandion haliaetus*) incidentally observed incubating eggs during a power line inspection in Colorado. Photo J. Dwyer; (H) Great Horned Owl (*Bubo virginianus*) in Canada. Photo D. Zazelenchuk.

Table 1. Publications that include discussion of disturbance effects of drones on raptors.

| Common Name (Scientific Name) | Source(s) |
| --- | --- |
| Osprey (*Pandion haliaetus*) | Junda et al. (2015, 2016); Doring and Mitterbacher (2022); Murphy (2023) |
| Chaco Eagle (*Buteogallus coronatus*) | Gallego and Sarasola (2021) |
| Golden Eagle (*Aquila chrysaetos*) | Fessenden (2015); Sustainability and Environmental Group (2021); Charbonneau et al. (2024) |
| White-bellied Sea Eagle (*Haliaeetus leucogaster*) | Radiansyah et al. (2017) |
| Bald Eagle (*Haliaeetus leucocephalus*) | Junda et al. (2015, 2016); Craig (2017) |
| Steller's Sea Eagle (*Haliaeetus pelagicus*) | Potapov et al. (2013) |
| Wedge-tailed Eagle (*Aquila audax*) | Lyons et al. (2018) |
| Ferruginous Hawk (*Buteo regalis*) | Junda et al. (2015, 2016) |
| Red-tailed Hawk (*Buteo jamaicensis*) | Junda et al. (2015, 2016) |
| Rufous-tailed Hawk (*Buteo ventralis*) | Rivas-Fuenzalida et al. (2020) |
| Common Buzzard (*Buteo buteo*) | Doring and Mitterbacher (2022) |
| Swainson's Hawk (*Buteo swainsoni*) | Junda et al. (2015) |
| Brown Goshawk (*Accipiter fasciatus*) | Lyons et al. (2018) |
| Whistling Kite (*Haliastur sphenurus*) | Lyons et al. (2018) |
| Black Kite (*Milvus migrans*) | Lyons et al. (2018); Doring and Mitterbacher (2022) |
| Red Kite (*Milvus milvus*) | Doring and Mitterbacher (2022) |
| Montagu's Harrier (*Circus pygargus*) | Kilic and Purckhauer (2016); Kronberg and Bauer (2017); Wagner and Mitterbacher (2022) |
| Swamp Harrier (*Circus approximans*) | Stone and Parker (2022) |
| Striated Caracara (*Phalcoboenus australis*) | Galimberti and Sanvito (2020) |
| Eurasian Hobby (*Falco subbuteo*) | Potapov et al. (2013) |
| Eleonora's Falcon (*Falco eleonorae*) | Hadjikyriakou et al. (2020) |
| Brown Falcon (*Falco berigora*) | Lyons et al. (2018) |
| American Kestrel (*Falco sparverius*) | Bird et al. (2024) |
| Nankeen Kestrel (*Falco cenchroides*) | Lyons et al. (2018) |
| New Zealand Falcon (*Falco novaeseelandiae*) | Stone and Parker (2022) |
| Peregrine Falcon (*Falco peregrinus*) | McIntosh et al. (2018); Charbonneau et al. (2024) |
| Merlin (*Falco columbarius*) | Junda et al. (2015) |
| Bearded Vulture (*Gypaetus barbatus*), Egyptian Vulture (*Neophron percnopterus*), Cinereous Vulture (*Aegypius monachus*), Griffon Vulture (*Gyps fulvus*) | Zink et al. (2023) |
| Turkey Vulture (*Cathartes aura*) | Pfeiffer et al. (2021) |

majority (23) of the species are only addressed in a single study. Of the remaining species, six are addressed in two studies, and two species (Bald Eagle [*Haliaeetus leucocephalus*] and Osprey [*Pandion haliaetus*]) are addressed in three and four studies, respectively. This illustrates the paucity of data on the potential disturbance effects on individual species across multiple studies. In addition, although 14 of the studies included either a horizontal or vertical distance from the drone to the subject species, six of the studies provided no context with respect to distance from the drone to the species or any observed disturbance to the species. Lastly, the above-mentioned studies all utilized a quadcopter type drone, which is known to be less disturbing to birds than fixed-wing drones (e.g., Egan et al. 2020, Pfeiffer et al. 2021).

The primary use of drones in avian research is to conduct nest monitoring, including the majority of raptor studies with drones (e.g., Potapov et al. 2013, Junda et al. 2015, 2016, Radiansyah et al. 2017, Hadjikyriakou et al. 2020, Gallego and Sarasola 2021, Charbonneau et al. 2024). Other studies include incidental encounters with raptors while conducting other drone-related surveys (e.g., Komenda-Zehnder and Zehnder 2010, McIntosh et al. 2018). In general, most papers addressing the use of drones for nest/population monitoring compare (and even highlight) their utility over traditional techniques such as tree/cliff climbing and/or ground-based observations (Potapov et al. 2013, Junda et al. 2016, Kilic and Purckhauer 2016, Gallego and Sarasola 2021, Charbonneau et al. 2024).

A recent study involved using a small off-the-shelf drone to take photos of the nest contents of cavity-nesting American Kestrels (*Falco sparverius*; Bird et al. 2024).

The first published study using drones to monitor the breeding season of a raptor was by Potapov et al. (2013), in which the authors successfully used a drone to check Steller's Sea-Eagle (*Haliaeetus pelagicus*) nests in Russia. Adults showed no reaction to the drone, although in one case an individual briefly approached the drone but did not interact with it. Additionally, the drone was approached twice by a Eurasian Hobby (*Falco subbuteo*) that apparently was interested in the drone but showed no aggressive behavior. Distances to the drone were not provided.

Ospreys have shown varied reactions to drones. Junda et al. (2016) tested the nest defense behavior of four different raptor species toward a small quadcopter drone at 3–6 m above the nest in Saskatchewan, Canada. Drone surveys were conducted over 2 yr and involved 51 Osprey nests. Of the four species studied, Ospreys showed the highest degree of nest defense, with birds circling at nest height and within 50 m of the nest; however, the birds quickly returned to the nest when the drone moved away. An Osprey was the only species to strike a drone during the study: the bird was unharmed although the drone was destroyed (Junda et al. 2016). Researchers using a drone to conduct nest checks of Ospreys in Finland since 2014 have not observed any instances of an Osprey attacking the drone or showing any significant negative behavioral responses to the drone. However, while the banders were at the nest, they were aggressively attacked by the adult Ospreys (T. Osala pers. comm.). Murphy et al. (2024) found that adult Ospreys spent more time away from the nest, called more often, and engaged in defensive behaviors when the nest was approached by a climber compared to a drone. In addition, when a drone was flown 10–30 m over the nest, the female was more likely to remain on the nest or, if flushed, return to the nest during the drone surveys. In one instance in the study by Junda et al. (2016), a pair of Ospreys actually left their nest containing young with a rotary drone (i.e., a novel intruder) hovering right over it to fly almost a kilometer away to attack a Bald Eagle, a known enemy. Ospreys were also observed copulating during a drone survey (N. Murphy pers. comm.). The summary of the varying responses by Ospreys to a drone illustrates the potential for species-specific, or even individual-specific, differences in responses to a drone.

During drone surveys of Ferruginous Hawk (*Buteo regalis*) and Red-tailed Hawk (*Buteo jamaicensis*) nests, both species showed similar responses, increased their call rates while the drone was present, and often circled 50–100 m above the nest (Junda et al. 2016). Neither species made any aggressive approaches toward the drone.

Bald Eagles in general did not react negatively to drones during nest surveys. During the Junda et al. (2016) study, Bald Eagles showed the lowest nest defense behavior, often only flying once over the nest during the approach of the drone, and no individual dove towards the drone. Negative reactions or aggressive approaches to the drone have not been observed during surveys of more than 200 Bald Eagle nests in Saskatchewan, Canada (E. Dzus pers. comm.). Researchers using drones to survey Bald Eagles in Surrey, British Columbia, observed similar results, even when the drone was 5–7 m above the nest, with only a few flybys of the drone by adults (M. Lamont pers. comm.). Craig (2017) observed similar reactions by Bald Eagles during nest surveys near Anchorage, Alaska, USA. With the drone at approximately 5 m above the nest, the adults remained perched away from the nest and showed no apparent interest in or concern for the drone, while nestlings were also not disturbed by the drone. During drone surveys of 12 Bald Eagle nests in Newport News, Virginia, USA, over two seasons, adults reacted by flying 10–12 m above the drone, alarm-calling; nestlings showed a minimal response by only looking in the direction of the drone (J. Cooper pers. comm.). The presence of drones did not alter typical nest defense responses from adults compared to a biologist climbing to the nest, as Bald Eagles typically do not respond aggressively to nest visits either.

Kilic and Purckhauer (2016) compared the monitoring of Montagu's Harrier (*Circus pygargus*) ground nests by a person on foot versus a hexacopter or octocopter drone. The altitude of the drone over the nest during a nest check was 2–5 m. The female harrier attacked the drone during 4 of 22 drone flights and did not attack a person during 19 nest checks. The female left the nest and called while flying around the nest area during 9 of 23 drone flights but left the nest and called during 17 of 19 nest checks by a person. The mean durations for the female to return to the nest after a nest check by drone and by a person on foot were 13 and 16 min, respectively. In addition, during a 2015 study, females attacked the drone during only 2 out of 40 flights. Although the authors acknowledged that sample sizes were small and more research is needed, they found no significant differences between the two nest check methods with respect to disturbance of the female and ultimate success of a brood (Kilic and Purckhauer 2016).

Lyons et al. (2018) documented several encounters of drones with raptors. In general, response levels were very low. For instance, Wedge-tailed Eagles (*Aquila audax*), Black Kites (*Milvus migrans*) and Whistling Kites (*Haliastur sphenurus*) showed no interest at all in the drone, and a Nankeen Kestrel (*Falco cenchroides*) carried out a successful hunting event in the presence of the drone. However, as a fixed-wing drone passed within 5–10 m of a perched Brown Falcon (*Falco berigora*), the falcon attacked the drone, causing it to crash with no harm to the falcon. Whether the falcon was nesting nearby was not provided. The falcon may have perceived the fixed-wing drone as a threat, particularly given how close it was to the perched falcon.

Rivas-Fuenzalida et al. (2020) used a drone to confirm the presence of two Rufous-tailed Hawk (*Buteo ventralis*) nestlings in a nest in Chile. Adults did not react to the drone, and the paper's authors suggested this was probably because the birds were more concerned by the presence of the researchers on the ground.

The use of a quadcopter drone to monitor the nest status of endangered Chaco Eagles (*Buteogallus coronatus*) during five consecutive breeding seasons in central Argentina was found to be more efficient and less disturbing than the use of traditional monitoring techniques (e.g., tree climbing or focal observation; Gallego and Sarasola 2021). Therein, no attacks on a drone were recorded, and only one adult (out of 38 trials) flew away from the nest when the drone approached. The rest of the adults remained vigilant or paid no attention to the drone. Additionally, the breeding performance of the birds whose nests were monitored with the drone did not differ from that of the pairs monitored in past years with traditional techniques.

Charbonneau et al. (2024) conducted drone surveys of three Golden Eagle (*Aquila chrysaetos*) nests and 11 Peregrine Falcon (*Falco peregrinus*) nests in Quebec, Canada, to compare the assessment of nest occupation, including number and age of young, by traditional ground survey methods (i.e., binoculars and spotting scope) and drone surveys. No aggressive behavior was observed for either species during drone surveys, which were conducted at 100 m from the nest. The majority of nestlings of both species were indifferent to the drone. Two Golden Eagle adults departed the nest upon the approach of the drone, one was indifferent, and although the majority of adult falcons were indifferent to the drone, some individuals made alarm calls, and only one adult left the nest upon the approach of the drone. Both the adult eagles and falcons typically quickly returned to the nest after the drone departed. The study also found that the assessment of nest status was almost three times faster using a drone compared to ground monitoring. An assessment of surveys of Golden Eagle nests by a ground observer compared to a drone found that the drone user was able to survey approximately twice as many nests each week than the ground observer in both years of the study (Sustainability and Environmental Group 2021). In addition, given the distance at which a ground observer could inspect a nest vs. a drone, the ground observer was not as accurate at determining nest occupancy compared to a drone.

Lastly, Zink et al. (2023) reviewed the potential for disturbance from drone operations on four vulture species: Bearded Vulture (*Gypaetus barbatus*), Egyptian Vulture (*Neophron percnopterus*), Cinereous Vulture (*Aegypius monachus*), and Griffon Vulture (*Gyps fulvus*). The recommended distance from the nest to the drone was >100 m for the Griffon Vulture, >300 m for the Bearded and Egyptian Vultures, and <500 m for the Cinereous Vultures (Zink et al. 2023). However, these recommended distances were based on studies on ground disturbance susceptibility and not specifically on studies of reactions of the vulture species to a drone flight. Hausheer (2016) reported that a survey of 33 Cinereous Vulture nests in Mongolia would have normally taken a week on foot, while all nests were surveyed by drone in 2 d; responses of the nesting vultures to the drone were not provided.

## RECOMMENDED BEST PRACTICES TO AVOID AND MINIMIZE IMPACTS TO RAPTORS FROM DRONE OPERATIONS

Drones may cause disturbance to raptors due to noise of the drone, shape (e.g., fixed-wing vs. multirotor), flight speed, flight height, approach angle, and possibly color. In addition, time of day, nest type (i.e., ground, tree, artificial platform, or cliff), and nesting stage when the survey is conducted may influence whether a drone survey will have negative effects on adults and young. Based on the available published data, it is challenging to dictate exact guidelines on the use of drones when conducting nest monitoring of the diversity of raptor species. Research has focused on several issues (e.g., behavioral experiments, nest monitoring, picture attainment), during different periods (i.e., nest building stage, incubation phase, and nestling rearing) and has covered a wide array of species, from large eagles to small falcons. Furthermore, many studies have not provided the distance from the drone to the target species or nest to provide context as to what approach distance is best to minimize potential impacts to adults or young. Based on the available

Table 2. Recommended best practices to avoid and minimize impacts to raptors from drone operations.

| Topic | Recommendation |
|---|---|
| Mission planning | |
| Local, state/province, and federal regulations | All drone operations must follow local, state/province, and federal regulations regarding drone use. For example, all drone operators must be FAA Part 107 certified pilots in the USA. |
| Permits/land access/airspace authorization | Appropriate permits or permission to access any lands that will be flown over must be obtained prior to drone operations, if applicable. The remote pilot in command (RPIC) should consult the FAA's B4UFLY app or a current aeronautical chart (faa.gov) of the area of drone operations to determine if they may be operating in controlled airspace. Drone operations in controlled airspace require prior authorization from air traffic control. |
| Site assessment | A site assessment should be completed to determine if a drone is suitable for the proposed work. A site assessment should determine the visibility of the object of interest (e.g., what is the best angle from which to obtain the desired view into a nest), the safest and most efficient flight corridor for the drone that is free of obstacles (e.g., trees, power poles, and lines), if there are other activities within the area that may be impacted by drone flight (e.g., other nesting species, public activities) or that might impact the drone (e.g., other nesting species such as corvids that may pursue the drone), potential emergency landing areas, and the location of the launch/land site (see below). |
| Survey personnel | Nest-focused drone operations should have at a minimum two survey personnel: RPIC and spotter (e.g., Potapov et al. 2013, Junda et al. 2015, 2016, Gallego and Sarasola 2021, Charbonneau et al. 2024). This approach reduces the risk of accidents with the drone and the target species, and it gives the researchers the opportunity to monitor the reaction of the target species to the approach of the drone. In addition, the RPIC should have experience flying a drone in the proximity of raptor nests. It is recommended that the RPIC have a minimum of 4 hr of flying time around inactive raptor nests, prior to flying around active nests. RPIC experience is key to reducing drone flight time over raptor nests and therefore avoiding and minimizing potential disturbance of the target raptors (e.g., Junda et al. 2015, Gallego and Sarasola 2021). It is imperative that the RPIC and the spotter(s) not only be able to communicate effectively during the flight but also have in place an "abort" plan (e.g., immediate withdrawal and landing), should the raptors behave aggressively toward the drone (see below, Reaction of Target Species to Drone). |
| General drone operations | Drones should be operated within the manufacturer's specified safe operating limits with regards to temperature of the drone and battery, wind speed, and the ability of the RPIC to have full control of the drone at all times. |
| Drone platform | Given that the size, shape, and flight attributes of a fixed-wing drone can be perceived as raptorial by the target raptor species and hence a potential threat, we recommend that fixed-wing drones not be used in raptor or nest inspections. Multi-rotor drones are also easier to transport, launch, and recover, and are more maneuverable (e.g., able to hover or move horizontally/vertically to optimize the view of the target), and can be less expensive to maintain. |
| Drone launch-and-land location | For most raptor species that have been studied to date with drones, the drone launch-and-land location should be >100 m from the targeted nest (Vas et al. 2015, Weston et al. 2020, Charbonneau et al. 2024). However, the distance will vary greatly by species, terrain, and habitat. Launch and land locations will also depend on the accessibility of a launch/land site in proximity to the nest such that both nest and launch/land site are visible. |

Table 2. Continued.

| Topic | Recommendation |
| --- | --- |
| Flight operations | |
| Distance of drone from focal species/nest | The distance from the drone to the target nest during a drone flight should be as great as possible to obtain the necessary data. With the current availability of high-resolution cameras with excellent zoom capabilities standard on many drones, a minimum vertical and horizontal separation distance of 50 m generally allows excellent quality photographs and video while minimizing disturbance (e.g., Vas et al. 2015, Weston et al. 2020, Cantu de Leija et al. 2023, Edney et al. 2023). However, the distance will vary greatly by species and possibly even by individual bird or nest geometry within a substrate. For example, Charbonneau et al. (2024) kept all drone flight operations >100 m from the Golden Eagle and Peregrine Falcon nests in their study. Although the reactions by the raptors to the drone in their study were mild, some individuals did react thereby reinforcing the need to monitor the behavior of individuals at and around the nest for all raptor species at all times for negative reactions to the drone. |
| Flight height and approach angle | The flight parameters, which are tightly associated with the noise from the drone, are important considerations. Vertical approaches of a nest are more disturbing than horizontal approaches as the noise from the rotors is greater when the drone is directly overhead (Vas et al. 2015, Duporge et al. 2021). Flight height should be determined by distance from the drone to the nest. |
| Flight time | The time to conduct the survey to collect the necessary data should be the absolute minimum. RPIC skill is important in reducing flight time to accomplish the necessary data collection (e.g., Junda et al. 2015, 2016, Gallego and Sarasola 2021). Flight time within 50 m of a nest should be limited to a maximum of 3 min or less. |
| Site conditions and time of day | Site conditions and time of day should be considered prior to drone operations. For example, there should be no nest predators or other disturbances in the survey area, there should be no precipitation, and air temperatures should be between 5–29°C (e.g., Junda et al. 2015). |
| Reaction of target species to drone | The research team should have a predefined set of criteria that provide specific guidance regarding those raptor responses that would cause the abort of the drone survey. These include responses from adults, nestlings, and/or fledglings. Responses may include but should not be limited to an adult flying within 2 m of the drone, actively pursuing or swooping on the drone, and fledglings becoming agitated with obvious signs of stress. If the RPIC and/or spotter observe any of these predefined response criteria from the target animals, then the drone flight will be aborted. |
| Nest status | Breeding season is the most important and sensitive period in a raptor's life cycle. If any negative reactions by a raptor to a drone are observed, the drone should be immediately withdrawn in the opposite direction from the raptor. If a raptor pursues the drone, the drone should be landed as soon and as safely as possible to avoid a collision with the bird. As the presence of a drone near a nest may cause a nestling to prematurely fledge, drone surveys during the critical pre-fledgling period should be avoided. |
| Nest location | Other habitat characteristics that could complicate drone surveys and should be accounted for in flight plans include a nest being obscured by tree canopy or overhanging cliff, nest height, nest location (i.e., ground, cliff, tree, human-made structure), and overall habitat characteristics (e.g., open vs. forested). |

Table 2. Continued.

| Topic | Recommendation |
| --- | --- |
| Post-flight reporting | |
| Standardized reporting protocol | All surveys of raptor nests utilizing drones should include, at a minimum, supplementary material that provides details regarding the model of drone used; pre-launch and flight operations, including total time of all operations; the reactions of all raptor species to the drone flights, including but not limited to, vertical and horizontal distance from drone to raptor; behavioral responses of raptors in flight, on the nest, or perched in the vicinity of the nest; nesting stage; time of day; length of time over the nest; model of drone; nest type; height of nest; and time of day of drone flights. All publications should include the list of the predefined abort criteria based on raptor responses to the drone (see above, Reaction of target species to drone) and how many surveys had to be aborted because the raptor response reached the criteria level. Barnas et al. (2020) provides an excellent standardized protocol that should be followed for all drone-wildlife operations. Documenting and publishing details regarding raptor responses to a variety of drone types, locations, nest types, and most importantly by species, will provide invaluable knowledge for other raptor biologists considering the use of a drone for the same or similar species. |

published literature regarding the use of drones with raptors and other avian species (e.g., Junda et al. 2015, 2016, Vas et al. 2015, Weissensteiner et al. 2015, Weston et al. 2020, Cantu de Leija et al. 2023, Edney et al. 2023, Charbonneau et al. 2024), Table 2 presents recommended best practices for the use of drones when conducting nest monitoring of raptors.

The current literature regarding the use of drones to study and monitor raptors has shown drones to be an efficient, cost-effective, less disturbing, and safe survey method for both the subject species and the researchers compared to traditional methods. The time at the nest to determine nest status, number of eggs, status of young, etc. has been reduced from 30–150 min based on the traditional method of climbing to a cliff or tree nest to 1–3 min when utilizing a drone. This alone significantly reduces the level of disturbance at a raptor nest, and also removes significant safety risks to survey personnel associated with climbing or flying in helicopters or aircraft.

To our knowledge, there are no published records of nest abandonment or mortality of individual raptors due to the use of drones to conduct nest monitoring. However, the use of drones has been limited to very few raptor species. Of the 304 diurnal raptorial species and 178 nocturnal species, only a handful have been studied with regard to monitoring their nests with drones. Therefore, caution must be exercised when using a drone to monitor the nest of a raptor species where potential effects from drone operations have not been reported. Some species are far more aggressive toward intruders. For example, American Goshawks (*Accipiter atricapillus*) are particularly aggressive in the defense of their nests, but to date, we know of no published studies on using drones to monitor their nests. In addition, it should be stressed that a response to a drone by an individual or nesting pair may vary greatly within a species even if there are no published negative effects on the species from previous drone surveys.

Although drones have been used in raptor research for over a decade, the published literature is limited to a relatively few species and with limited assessment of drone type, flight parameters, and species response. Further research is needed regarding the potential impact of the actual drone such as physical size and number of motors, type (multi-rotor vs fixed-wing), color, and noise levels; flight parameters (e.g., approach height, angle, and speed; duration of flight); and how impacts from drone activities may vary based on the nest location for the same species (e.g., cliff, tree, power pole). In addition, researchers need to provide more detail in their publications regarding raptor responses to drones so that this information can generate an evidence base to provide refined guidelines for the use of drones while conducting raptor research and monitoring activities. Future research should also consolidate information on avian responses to drones across avian taxa, not only raptors.

Many federal, state, and local agencies regulate the use of drones. RRF recommends that researchers identify and follow the rules and laws governing drone use in their study areas.

As a leading professional society for raptor researchers and raptor conservationists, the RRF is dedicated to the accumulation and dissemination of scientific information about raptors, and to resolving raptor conservation concerns (RRF 2021). Raptor interactions with drones are an emerging conservation concern, requiring development of and adherence to a clear and consistent set of guidelines. Based on the science summarized here, resolving the factors associated with raptor conflicts with drones will allow long-term co-occurrence of raptor populations with researchers using drones.

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