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Measuring disturbance at swift breeding colonies due to the visual aspects of a drone: a quasi-experiment study

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Abstract

There is a growing body of research indicating that drones can disturb animals. However, it is usually unclear whether the disturbance is due to visual or auditory cues. Here, we examined the effect of drone flights on the behavior of great dusky swifts *Cypseloides senex* and white-collared swifts *Streptoprocne zonaris* in 2 breeding sites where drone noise was obscured by environmental noise from waterfalls and any disturbance must be largely visual. We performed 12 experimental flights with a multirotor drone at different vertical, horizontal, and diagonal distances from the colonies. From all flights, 17% caused <1% of birds to temporarily abandon the breeding site, 50% caused half to abandon, and 33% caused more than half to abandon. We found that the diagonal distance explained 98.9% of the variability of the disturbance percentage and while at distances >50 m the disturbance percentage does not exceed 20%, at <40 m the disturbance percentage increase to > 60%. We recommend that flights with a multirotor drone during the breeding period should be conducted at a distance of >50 m and that recreational flights should be discouraged or conducted at larger distances (e.g. 100 m) in nesting birds areas such as waterfalls, canyons, and caves.

Key words: *Cypseloides senex*, disturbance, drones, multirotors, *Streptoprocne zonaris*, unmanned aircraft systems

Multirotor drones are one of the most widely used drone platforms in the civilian environment and with the greatest commercial growth in recent years (Droneii 2019). The main growth factors for scientific, commercial, and recreational drone use are associated with a diversity of models relatively easy-to-use, vertical take-off/landing, and easy transport. The high maneuverability of multirotor drones and their ability to hover in the air make them the preferred option for filming and data collection in hard-to-access places (Bakó et al. 2014; Chabot et al. 2015). For these reasons, along with the affordability of commercial models, they are currently the most popular choice for recreational flyers (Rebolo-Ifrán et al. 2019), commercial services (Droneii 2019), and scientists (Chabot and Bird 2015; Jiménez López and Mulero-Pázmány 2019).

Within the scientific environment, the integration of drones as data-collection platforms has significantly facilitated vertebrate studies, mainly focused on birds and mammals (Wich and Koh 2018) to address a wide variety of topics, such as species monitoring (Rey et al. 2017; Hodgson et al. 2018); behavioral analysis (Canal et al.

2016; Mulero-Pázmány et al. 2017; Cliff et al. 2018); management (Mulero-Pázmány et al. 2014); habitat mapping (Castellanos-Galindo et al. 2019); and spatial ecology and wildlife diseases (Barasona et al. 2014; Mulero-Pázmány et al. 2015; Laguna et al. 2018). Some of the main advantages of using drones to study wildlife are the reduction of logistical difficulties; costs; risks; and disturbance on wildlife when compared with conventional methods such as manned aircraft surveys or researchers on the ground (Dulava et al. 2015; Christie et al. 2016).

The increase in drone use has raised concerns about the potential disturbance these systems can cause on wildlife (Bevan et al. 2018; Bennitt et al. 2019; Weston et al. 2020). There are a number of factors associated with drone characteristics (drone size, motor type, and flight pattern) and animals (species, life-history stage, and level of aggregation) that can be related to the level of disturbance caused by these systems (Mulero-Pázmány et al. 2017). The threshold of disturbance caused by a drone in a given species is often formed by a set of interconnected factors: the sound signature of the drone, the environmental noise level, the visual ability of the species, and the association degree of the drone with a threatening stimulus of the species (Bevan et al. 2018). Birds have acute visual perception, and therefore the visual stimuli generated by the drone can have a greater effect than the noise. Even though some studies that assessed drone disturbance in birds relating flight patterns and distances to the sound and visual aspects of the drone (McEvoy et al. 2016; Rümmler et al. 2016; Brisson-Curadeau et al. 2017; Reintsma et al. 2018), so far it has not been possible to analyze separately the disturbances caused by the visual stimuli of the sound stimuli coming from the drones.

Here, we describe an experiment in which we investigate responses from 2 species of swifts, great dusky swift *Cypseloides senex* and white-collared swift *Streptoprocne zonaris*, to drone flights in a scenario where noise is mainly masked by the background noise of waterfalls and the visual stimulus the main disturbance factor. We measured the disturbance caused by a multirotor drone at varying distances from swift colonies located in wet rocks walls next or behind waterfalls where the environmental noise is louder than the drone noise. Our aims were to 1) bring a new perspective of visual disturbance analysis caused by multirotor drones disassociated from the drone noise and 2) facilitate establishing guidelines that allow minimizing disturbance to bird colonies that use places such as rocks walls next or behind waterfalls, canyons, and caves around the world as resting and nesting sites, places with high probability of drone–bird interaction due to the increased recreational drone use and the tourist interest of such places.

Material and Methods

Study area and species

This study was conducted in Chapada das Mesas National Park, Maranhão, Brazil, in October, 2018. The park covers a total area of 1,600 km^2 within the Cerrado biome, that has various vegetation types, from "cerradão," which is a type of seasonal forest with dense tree vegetation to "campos limpos" that are open fields as savannas with few trees (Marques and Amorim 2014). The 2 breeding areas of the study species were: Cachoeira do Prata (6°59′36″S, 47°9′55″W) and Cachoeira de São Romão (7°1′11″S, 47°2′26″W). Both are located in the North of the park along different stretches of the "Farinha" river, a tributary of Araguaia/Tocantins basin, and are ~14 km away from each other in a straight line. The breeding areas are the 2 most voluminous waterfalls present within the park. The Cachoeira do Prata is formed by a set of falls that reach up to 18 m in height, and the Cachoeira de São Romão has falls of up to 25 m in height (Figure 1). The region has a humid tropical climate characterized by 2 well-defined seasons: dry, which runs from May to October and wet from November to April, with an annual temperature varying between 24°C and 26°C and an annual rainfall varying between 1,200 and 1,600 mm (IMESC 2008). The waterfalls are accessible to tourists but the number of visitors is low because the access is currently limited to 50 km of dirt road that can only be accessed by 4 × 4 vehicles.

The 2 study species were the great dusky and white-collared swifts. These are globally considered of least concern according to the Red List (IUCN 2020) with stable population for the great dusky swift and declining population for the white-collared swift population. The great dusky swift distribution is restricted to Argentina, Bolivia, Brazil, and Paraguay (Stopiglia and Raposo 2007) and the white-collared swift is distributed from the United States to Argentina (Chantler 1999). In Brazil, data for both species are sparse, leading to an inaccurate distribution map. Both species are strongly associated to areas with wet rocks walls next or behind waterfalls, canyons, and caves. These sites are used with great fidelity for breeding and nesting that occurs between October and November (Whitacre 1989; Stopiglia and Raposo 2007). The 2 species often share nesting sites (Pearman et al. 2010). In this study, most of the individuals identified in the nesting sites were the great dusky swift and few individuals of the white-collared swift.

Drone and experimental flights

The drone model used was a DJI Mavic Pro quad-copter, black color, with a diagonal size of 335 mm, 743 g weight, ±77 dB (decibel) noise level, maximum flight speed of 65 km/h, and 20 min average flight autonomy, that carried a camera with a 1/2.3″ CMOS (complementary metal-oxide semiconductor) and sensor with 12.35 effective megapixels. In each of the 2 swift breeding sites, we performed 6 experimental flights at varying heights above the ground and distances to the breeding rocks walls (Table 1).

All the swift nests were located in the rock wall at 10 ± 1 m above the ground in the Cachoeiras do Prata and 15 ± 1 m in the Cachoeiras de São Romão (Figure 2). Flights were conducted between 15 and 18 h local time. The drone was launched at a minimum distance of 100 m from the breeding site. During a pilot study conducted a week before the actual experiments, we checked that at this distance the drone did not lead to any noticeable reaction from the birds. Between the launch sites and the breeding areas, there was vegetation that prevented birds from viewing the drone's take-off. We approached the nesting sites horizontally at a speed between 14 and 21 km/h which in a previous study did not seem to influence bird behavior (Vas et al. 2015) and allows for good control of the drone. Once the drone reached the set point, which corresponds to the diagonal distance of each flight according to Table 1, it remained hovering stationary for a maximum time of 10 min or until we detected any swifts' behavioral reaction (flying away or mobbing). Once we detected any reaction, we kept the flight time no >5 min to minimize negative effects on the species. An experienced observer using a binocular (10 × 50) counted the number of birds that were present at the breeding site 5 min before the take-off of each flight and after the drone was landed. At both field sites, the observer was positioned between the nesting rocks walls and the drone, with free view to both. Due to the difficulty of approaching the nesting rocks walls and to avoid possible disturbance to the colony, the observer was positioned at a horizontal distance of 15–20 m from the base of

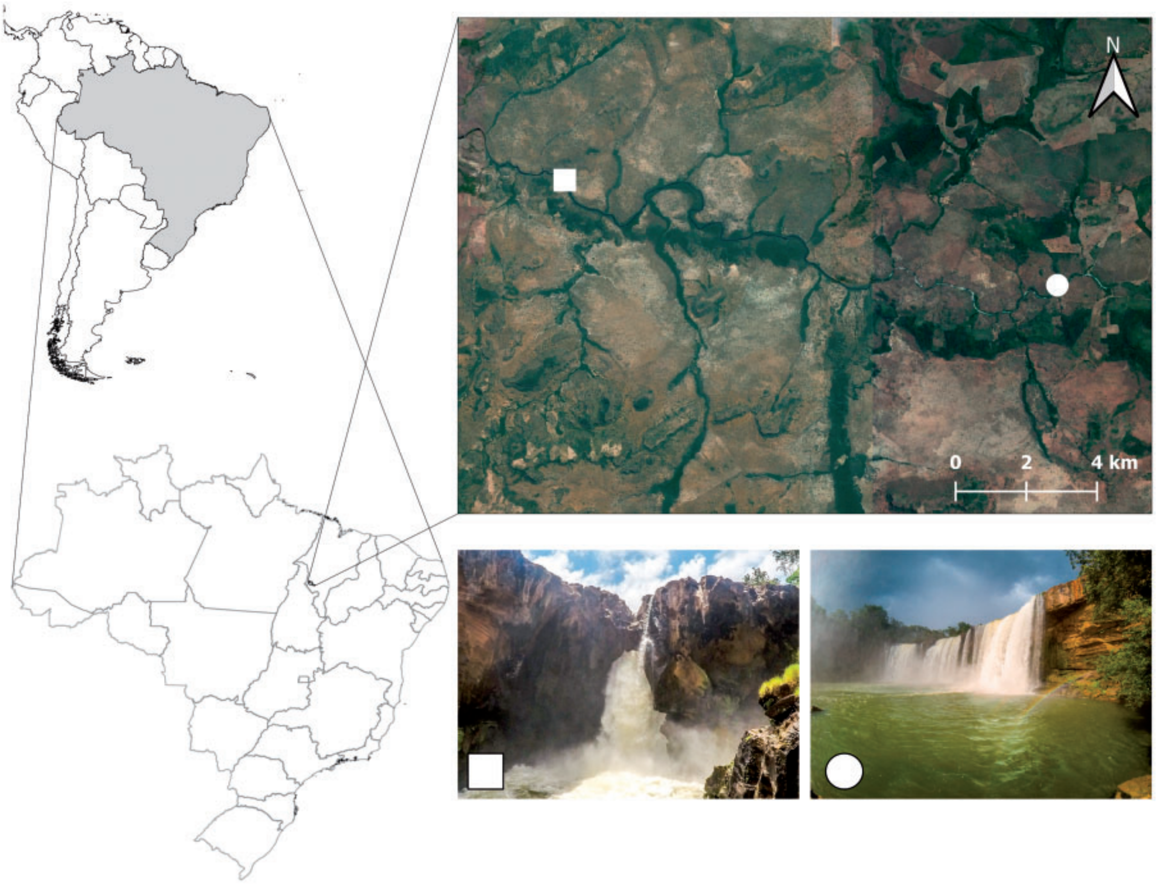

Figure 1. Location of the studied swift breeding sites in Chapada das Mesas National Park, Brazil. Cachoeira do Prata (white square) and Cachoeira de São Romão (white circle).

Table 1. Experimental flights parameters

Flight	Date	Time	Study site	Height nests	Flight altitude	Vertical distance	Horizontal distance	Diagonal distance
1	22 October 2018	16:00	Cachoeira do Prata	10	50	40	50	64.03
2	22 October 2018	17:30	Cachoeira do Prata	10	25	15	50	52.20
3	23 October 2018	16:00	Cachoeira de São Romão	15	50	35	50	61.03
4	23 October 2018	17:30	Cachoeira de São Romão	15	25	10	50	50.99
5	24 October 2018	16:00	Cachoeira do Prata	10	10	0	50	50.00
6	24 October 2018	17:30	Cachoeira do Prata	10	50	40	25	47.17
7	25 October 2018	16:00	Cachoeira de São Romão	15	10	−5	50	50.25
8	25 October 2018	17:30	Cachoeira de São Romão	15	50	35	25	43.01
9	26 October 2018	16:00	Cachoeira do Prata	10	25	15	25	29.15
10	26 October 2018	17:30	Cachoeira de São Romão	15	25	10	25	26.93
11	27 October 2018	16:00	Cachoeira do Prata	10.00	10	0	25	25.00
12	27 October 2018	17:30	Cachoeira de São Romão	15.00	10.00	−5	25	25.50

Note: Distances are in meters.

the rocks walls, hidden from the colony's line of sight. Because of the large number of individuals of the 2-species agglomerated and the low luminosity at the waterfalls, we could not determine the number of individuals of each of the 2 species at the breeding sites and therefore recorded the total number of birds. We established a minimum interval of 30 min after landing of each flight or until the birds regrouped in the breeding sites, and a maximum of 2 daily flights, to avoid major disturbances during the same day.

The visual analysis included an assessment of the spots size on the walls, which were agglomerations of the birds, and were used to define whether the birds had regrouped. This is, if the spot size returned to its original size, we assumed that the individuals had returned. For the visual analysis of spot sizes, we compare the spot sizes with rock wall features as atypical marks, deformations, or some plants. Due to the high environmental noise caused by the waterfalls, in all the experimental flights in the 2 studied places it

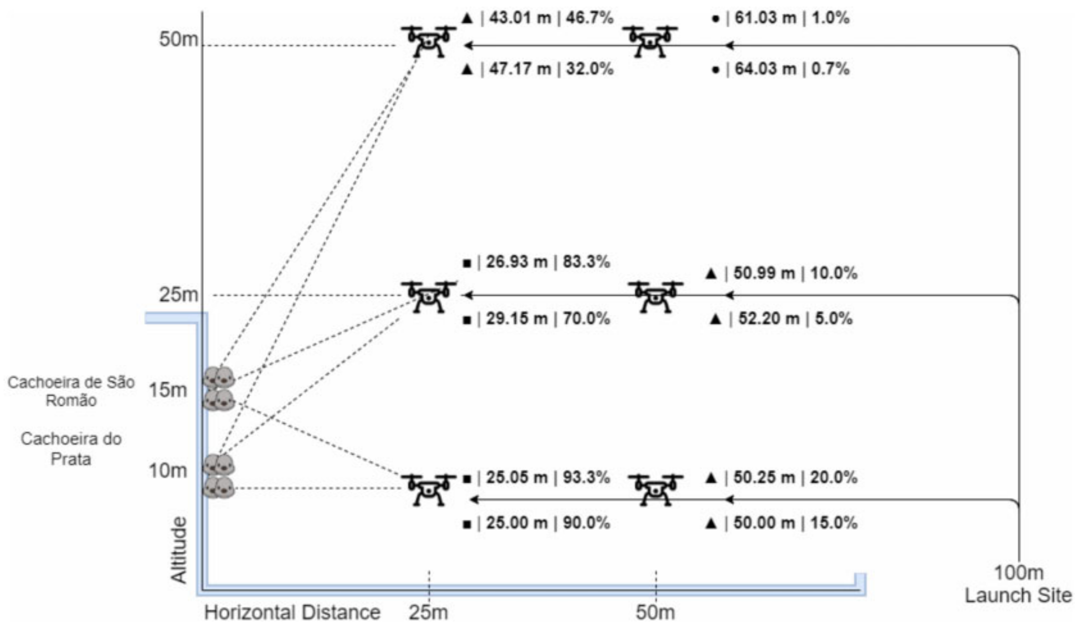

Figure 2. Design of experimental flights. Breeding group from "Cachoeira do Prata" and "Cachoeira de São Romão." Classification (circle, noticeable disturbance; triangle, moderate disturbance; and square, high disturbance), Diagonal distance (meters) and disturbance (%) for each drone flight.

was not possible to hear the drone noise by the observer who was positioned between the drone and the rock walls at a horizontal distance of 15–20 m from the base of the rocks walls.

Statistical analysis

As drone disturbance we considered the change in swifts' behavior (flying away or mobbing). We calculated this disturbance for each experimental flight as the percentage of birds present in the breeding colony 5 min before drone exposure minus the percentage of birds present after drone landing. Following Chabot et al. (2015), we classified the drone disturbance level in 3 categories based on the percentage of birds reacting: 1) noticeable disturbance, when the percentage does not exceed 1%; 2) moderate disturbance, when the percentage does not exceed 50%; and 3) high disturbance, when the percentage is >50%. For vertical distance, we considered the difference in height between the nest and the drone on each flight. The horizontal was measured from the projection of the drone to the ground to the colony and the diagonal distance (hereafter distance) was obtained through the Pythagorean theorem. We also calculated the return time of the individuals to the breeding sites after the drone had landed on each flight and the average time for each of the 3 categories of disturbance.

A previous descriptive scatter plot showed the possibility of a nonlinear association between variables in the 2 ran models. The first model with diagonal distance as a predictor variable and the disturbance percentage as a dependent variable, and the second model with the disturbance percentage as a predictor variable and the return time as a dependent variable. To choose the best models, we initially consider the nature of the variables and Akaike's information criterion (AIC). For model validation, we tested for normality test (Shapiro–Wilk), heteroscedasticity (Breusch–Pagan) and set the significance level at 0.05. All analyses and charts were made using "car" (Fox 2016), "drc" (Ritz et al. 2015), and "investr" (Greenwell and Schubert 2014) packages in R 3.6.2 with RStudio 1.2.5033 (R Core Team 2019).

Ethics Statement

This project was the authorized No. 64630-1 (scientific purpose) by the System of Authorization and Information on Biodiversity (SISBIO) in Brazil (art. 28 of IN 03/2014) from the Chico Mendes Institute for Biodiversity Conservation (ICMBio), and the flight drone was register certificate No. PP-019272726 by the National Civil Aviation Agency (ANAC).

Results

Twelve drone flights were performed at different distances from 2 swift breeding colonies. A maximum disturbance of 93.3% was recorded when the drone flew at 25.5 m distance from a bird's colony, and a minimum of 0.7% disturbance when the flight was conducted at 64.0 m distance (Table 2). During the 6 flights that produced moderate disturbance initially, a few swifts, ranging from 5 to 40 individuals, showed a mobbing behavior against the drone. However, the majority of other individuals who showed reactions just left the breeding sites and began to perform circular flights at a distance 20 ± 5 m above the drone. Flights performed at less than 29 m produced high disturbance, causing the departure of most of the colony of the breeding sites with just an average of 15.8% of the individuals remaining. In flights with high disturbance, we also recorded a larger number of individuals performing mobbing behavior toward the drone. In each of these flights, we landed as fast as possible.

The nonlinear Gompertz model is the one that presents a lower AIC, 80.16, and the distance from the drone to the colony explained 98.9% of the variability of disturbance percentage. Thus, while at distances >50 m the percentage of disturbances does not exceed 20%, at <40 m the disturbance percentage increase to >60%

Table 2. Percentage disturbed and classification of experimental flights

Classification	Flight	Date	Time	Study site	Diagonal distance (m)	Total swifts	Disturbed (%)	Return time (min)
1	1	22 October 2018	16:00	Cachoeira do Prata	64.03	3,000	0.7	1
1	3	23 October 2018	16:00	Cachoeira de São Romão	61.03	1,000	1.0	1
2	2	22 October 2018	17:30	Cachoeira do Prata	52.20	1,000	5.0	9
2	4	23 October 2018	17:30	Cachoeira de São Romão	50.99	3,000	10.0	9
2	5	24 October 2018	16:00	Cachoeira do Prata	50.00	1,000	15.0	12
2	6	24 October 2018	17:30	Cachoeira do Prata	47.17	2,500	32.0	15
2	7	25 October 2018	16:00	Cachoeira de São Romão	50.25	2,500	20.0	12
2	8	25 October 2018	17:30	Cachoeira de São Romão	43.01	1,500	46.7	16
3	9	26 October 2018	16:00	Cachoeira do Prata	29.15	1,000	70.0	20
3	10	26 October 2018	17:30	Cachoeira de São Romão	26.93	3,000	83.3	22
3	11	27 October 2018	16:00	Cachoeira do Prata	25.00	1,000	90.0	25
3	12	27 October 2018	17:30	Cachoeira de São Romão	25.50	3,000	93.3	25

Note: 1, noticeable disturbance; 2, moderate disturbance; and 3, high disturbance.

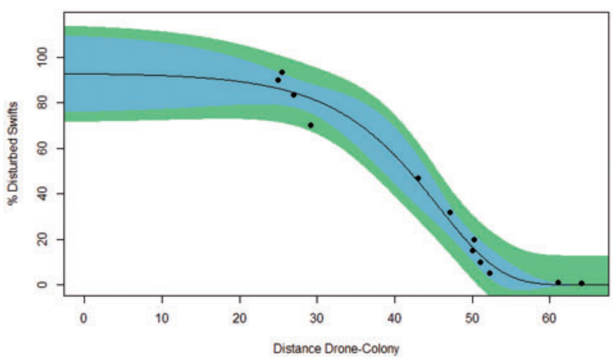

Figure 3. Nonlinear Gompertz regression between diagonal distance and % disturbed of swifts. Blue, 95% confidence band; green, prediction band.

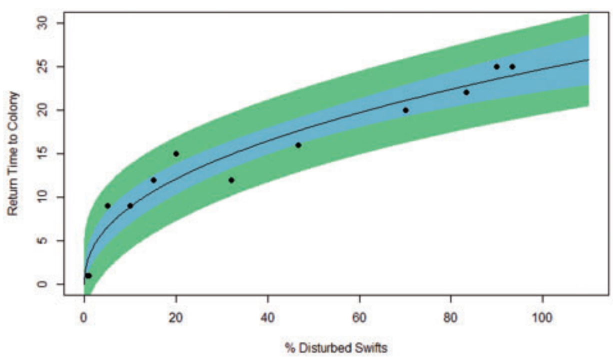

Figure 4. Nonlinear power regression between % disturbed of swifts and return time. Blue, 95% confidence band; green, prediction band.

(Figure 3). The relationship between the disturbance percentage and the return time, that is, the time it takes for the swifts to return to the colonies is better fitted to a nonlinear power model that explains 97.3% of the variability of return time, and it was the one that presents a lower AIC, 54.5 (Figure 4). On the 4 flights classified as high disturbance it took an average of 23.5 ± 2.4 min for all individuals in the colony to return to the breeding sites after the drone had landed. On flights classified as moderate disturbance this time was reduced to 12 ± 2.9 min, whereas on flights with just noticeable disturbance the individuals returned almost immediately after the drone landing.

Discussion

In this study, we measured the drone visual disturbance separate from the drone noise disturbance in birds breeding colonies from a quasi-experiment where the drone's noise is masked by environment noise, and we found that the response of birds to drone use follows a sigmoidal distribution with the diagonal distance from the drone to the colonies. Although our results are similar to studies that indicate that drone disturbance on birds increases as flight height decreases under different conditions and with different bird species (Rümmler et al. 2016; Mulero-Pázmány et al. 2017; van der Vliet et al. 2019), we found that the recommended minimum distance must be >50 m to avoid moderate and high disturbance in breeding sites, which is different from other studies, that were 15 m by common gulls and other species in the bird reserve island Langenwerder in the Baltic Sea (Grenzdörffer 2013) and at least 20 m with drones to survey cliff-nesting seabirds as murres (Brisson-Curadeau et al. 2017). However, unlike all the studies mentioned above, our results show that this reaction to the drone at a greater distance from the colony could be due to the idiosyncrasy of these species but it could also be a consequence of the fact that the drone, without any apparent sound is more similar to a natural situation of approach of a winged predator to the colony and trigger the defensive reaction earlier. The drone's sound could initially prevent the colony's reaction by being an artificial stimulus not associated with a winged predator, and only when the drone is close enough then triggers this defensive reaction.

The median bird hearing thresholds from 49 bird species suggest that the birds hear best at frequency between about 2 and 3 kHz, while humans generally have better auditory sensitivity with lower auditory thresholds and with wider bandwidth than typical birds (Dooling and Popper 2007). Therefore, if an observer was unable to hear the drone at 15 m, suppressed or muffled by waterfalls in this experiment, it is assumed that the swifts could not hear the drone at 25 m in the flight closest to the colony. This suggests that the drone noise may lose importance for the disturbance, while the visual aspects such as the shape or the flight pattern can be determinant for the swift's behavior change. Indeed, the drone visual stimulation was one of the possible causes of disturbances in colonies of greater crested tern *Thalasseus bergii* in a study that suggested that the noise emitted by multirotor drones may not be audible to colonies of this species (Bevan et al. 2018). However, the drone shape of our study eschews the classic "hawk/goose" rule (Schleidt et al. 2011) because a multirotor does not look like any potential swift predator. The new multirotor shape was one of the explanations for the lack of flight response in waterfowl at low flight altitudes in other studies (McEvoy et al. 2016). In contrast, we found that swifts showed mobbing behavior in flights near the nesting sites and may have recognized the multirotor drone as a potential predator. In the case of the great dusky swift and white-collared swift, the only known aerial predator is the peregrine falcon *Falco peregrinus* which has been observed near the others colony sites awaiting to catch swifts as they enter or leave the colony to feed and collect nest materials (Whitacre 1989). So even though the multirotor does not have a "hawk" shape, it is possible that the mobbing behavior of the swifts facing the drone can be elicited due to the drone being perceived as an unknown potential predator.

The time that swifts took to return to the colony after multirotor flights classified of high disturbance was about 2 times longer than those classified of moderate disturbance and about 20 times longer than those of low disturbance. This time between departure and return to the original location after the disturbance is also considered a way to measure an animal's response to a disturbance (van der Vliet et al. 2019). These types of responses can have a negative impact on the reproductive process in the case of birds in their breeding season, since it causes the individual to spend more energy, alters the incubation cycle and the care of altricial nestlings, and exposes them to possible predators. This negative impact caused by the return time to the nests was different from others bird studies that measured this time after drone disturbance in breeding colonies: ranging from 1 min to common terns *Sterna hirundo* (Reintsma et al. 2018), 1–3 min for Iceland gulls *Larus glaucoides*, and 5–10 min for thick-billed murres *Uria lomvia* (Brisson-Curadeau et al. 2017), while our experiment demonstrated much longer return time, whether on high disturbance flights, ranging from 20 to 25 min, or moderate disturbance flights, 9 to 16 min. This variability in return time suggests the need to carry out specific tests to know this effect in different species. Our experiment shows that this delay time in returning to the nesting site can cause very negative impacts on the reproductive process if the presence of these drones is intense over time.

Understanding the minimum operating distance at which drones can cause disturbance, which factors can cause them, and for which species each distance can be tolerated is critical, whether for the preparation of flight missions in scientific studies or to regulate the growing recreational use of drones in such environments. Despite the great diversity of responses to the drone use from different bird species due to the different types of ecological contexts in which they are found, almost always the greater the frequency and intensity of the disturbance, the greater the negative impacts on breeding bird populations. In this sense, the drone use, which is expanding in sites as bird nesting areas, such as this study, should be considered as a possible source of negative effects in certain colony birds. Therefore, we suggest the flight distance with multirotor drone to avoid high disturbance in the great dusky and white-collared swifts during the breeding period in nesting areas should be >50 m. We also recommend that recreational flights are generally discouraged or conducted at larger distances (e.g., 100 m) in areas where swifts occur such as waterfalls, canyons, and caves. This study serves as a basis both for the elaboration of new protocols for the use of drones over birds by researchers in conservation studies and for possible regulations for the recreational use of drones in areas where these species occur.

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Conflict of Interest statement

The authors declare that they have no competing interests.

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