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Routine and Safe Operation of Remotely Piloted Aircraft Systems in Areas with High Densities of Flying Birds

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Abstract: Remotely Piloted Aircraft Systems (RPASs), or drones, have had a rapid uptake for scientific applications and are proving particularly valuable for data collection in the natural world. The potential for bird strikes presents a real hazard in these settings. While animal welfare is a primary consideration when planning and executing RPAS operations, the safe operation and return of RPASs is the key to successful flight missions. Here, we asked if RPASs can be routinely and safely implemented to meet data collection requirements in airspaces with high densities of flying birds. We flew quadcopter RPASs over breeding seabird colonies in tropical island settings. A dedicated spotter adjacent to the pilot recorded all interactions between flying seabirds and the RPAS unit while aerial population surveys were being undertaken. Over 600 interactions were recorded for nine species of seabirds. We flew over 100 flights totaling 2104 min in airspace routinely occupied by dense aggregations of seabirds without a single collision. We demonstrate a high capacity to undertake safe and successful RPAS operations in airspaces that contain high densities of flying seabirds. While bird collisions remain possible, such outcomes are clearly rare and should be placed in context with routine disturbances by ground surveys to meet the same objectives. RPASs routinely offer the least invasive method for collecting ecological data compared to traditional field methods and can be undertaken with relatively low risk to the successful completion of the operation.

Keywords: drone; interaction; airspace; monitoring; seabird

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1. Introduction

Remotely Piloted Aircraft Systems (RPASs), or drones, have become an important tool for an array of scientific applications. These applications are extremely varied, including infrastructure impact assessments [1], detecting and tracking wildfires [2], monitoring fishing activity in marine protected areas [3], and surveying wildlife populations [4]. In many instances, the use of RPASs provides a more practical, cost-effective, and robust method for collecting data when compared to traditional methods [5,6]. These tools are proving especially valuable for collecting data in the natural world, yet interactions with birds and the potential for bird strikes present a real hazard [7]. These hazards are multifaceted, posing risks to both birds and the safe operation of RPASs. The use of RPASs for ecological research raises particular concerns as operation in airspaces with high densities of flying birds becomes increasingly common [8,9].

These concerns are typically addressed by adhering to ethical flight guidelines and detailed protocols [9–11]. This ensures that animal welfare remains a key consideration when planning and executing RPAS operations. To uphold safe operational practices, a precautionary approach should be adopted, aiming to minimize wildlife disturbance [12,13]. Strategies for mitigating RPAS-related impacts on animals include: Testing species- and location-specific disturbance distances prior to formal surveys; increasing take-off distances from animals; and flying small aircraft (i.e., <2 kg) in an automated flight path of survey transects at relatively slow speeds to reduce noise-related disturbance [8,11,14]. These operational best practices have been well established in the literature, and a thorough understanding is encouraged when considering RPASs as a tool for data collection.

Even when adhering to ethical flight practices, a disturbance response from some animals will still occur. In particular, birds have the propensity to negatively respond to RPASs more than other animal taxa [15–17]. In some settings, bird strike is a limiting factor for the safe application of RPASs [18]. Despite this, RPASs still regularly offer the least invasive method for collecting ecological data compared with traditional field methods [19–22]. Ultimately, the safe operation of RPASs in busy airspace is the key to successful missions. In this study, safe operation of RPASs refers to the safety of the RPAS unit itself and not wildlife safety.

Previous studies have not quantified the safe operation of RPASs in airspace with a high density of flying seabirds. Many of these studies focus on the behavioral responses of grounded or perched birds. Given that welfare considerations are well established, we ask a different question: Can RPASs be routinely and safely implemented to meet data collection objectives in areas with high densities of flying birds? We sought to answer this question by quantifying all interactions between RPASs undertaking routine surveys of seabird colonies, where flying seabirds create highly congested airspaces. We focused on the specific interactions surrounding the aircraft during flights and not birds at rest, which are often the focus of disturbance-based studies.

2. Materials and Methods

Given our primary aim was to establish whether RPASs can safely operate amongst high densities of flying seabirds, we quantified attributes that might influence the capacity to complete missions without collision or loss of units in congested airspaces. In this study, RPAS units were flown over nesting seabirds to obtain population estimates. While a dedicated RPAS pilot completed the mission, a spotter standing adjacent to the pilot monitored all seabird interactions with the RPAS unit to quantify risk and document any contact or collisions. Monitored flights were completed over three survey periods: December 2019 and February 2020 on Pulu Keeling (Cocos (Keeling) Islands) (11°49′ S, 96°49′ E), and May 2021 on Christmas Island (10°29′ S, 105°35′ E). All flights were undertaken with a lightweight white quadcopter RPAS (1.39 kg; DJI Phantom 4 Pro or DJI Phantom 4 RTK, Dà-Jiāng Innovations (DJI), Shenzen, China) along pre-programmed flight paths (using Pix4Dcapture for the Phantom 4 Pro, https://www.pix4d.com/product/pix4dcapture, accessed on 1 December 2019, or using the 'terrain awareness' mode in GS RTK for the Phantom 4 RTK). All flights were undertaken by a licensed pilot (holder of an Australian Civil Aviation Safety Authority-issued Remote Pilot Licence). Between take-off and landing, a survey height of between 50–70 m above ground level was maintained for all flights. Take-off distance from the breeding colony edge varied (range = 5–150 m) based on topography and site accessibility.

An interaction between a seabird and the RPAS was classified as any instance where the air gap between a seabird and the RPAS was ≤15 m. For all RPAS flights, seabird interactions were further categorized by type (approach, follow, swoop, circle, close approach, with a close approach involving interactions at <2 m from the RPAS) (Figure 1, Appendix A Table A1). These interaction categories differ from other disturbance-based studies as our focus was on the interactions surrounding the aircraft and not the disturbance caused to birds at rest. In some instances, interactions involved a clear behavioral response by a bird where the flight path was modified to approach or maintain proximity to a RPAS unit (notably, the interaction categories 'follow', 'swoop', and 'circle' represent active interaction). In other instances where a more extended bird flight path intersected with the 15 m air gap of the RPAS unit on a pre-programmed flight, interactions appeared to be passive (a portion of 'approach' and 'close approach' interactions were in this class). The number of seabirds involved per interaction and the nearest approach distance by any one seabird to the RPAS were estimated in meters. As the specific motion of the RPAS (forward, changing direction, ascending, descending, hovering) may influence the probability of an interaction, this was also recorded at the time of the interaction (Figure 1). All observations, including the seabird species involved, were made with the assistance of binoculars or a spotting scope by the dedicated observer. The number of birds in the airspace of the flight was also recorded prior to take-off for each flight.

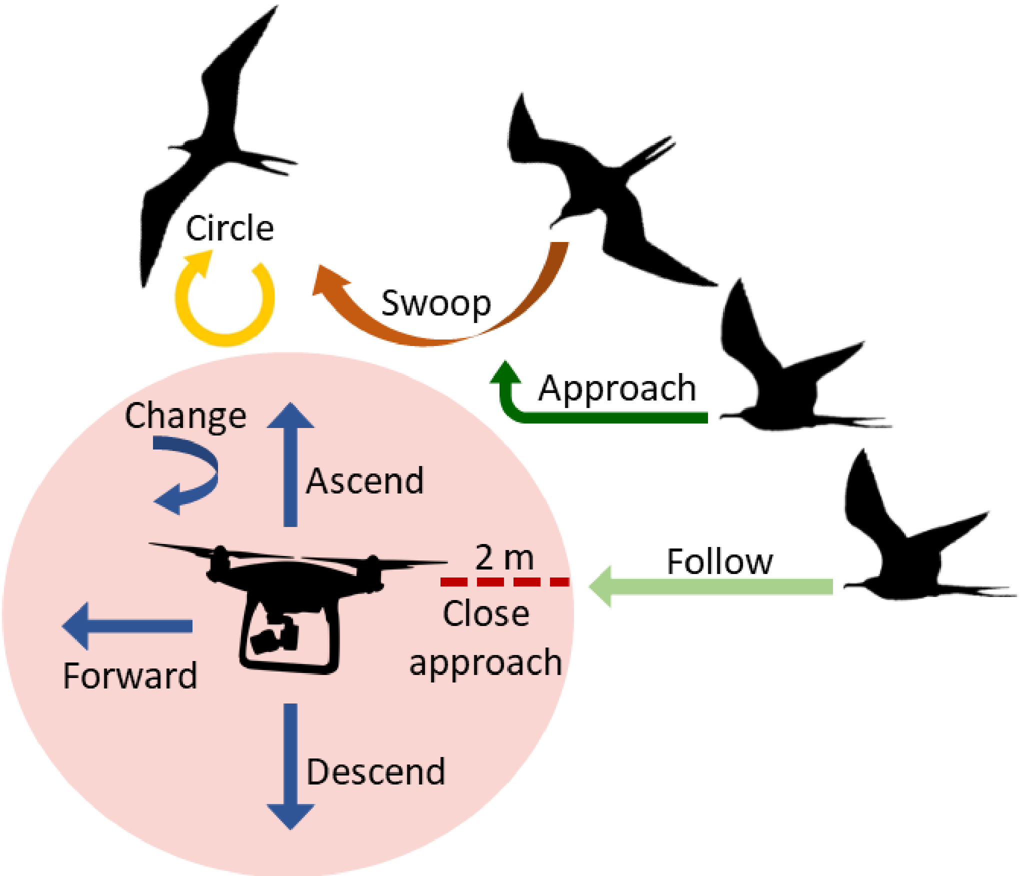

Figure 1. Visual representation of Remotely Piloted Aircraft System (RPAS) flight types (blue arrows surrounding the aircraft) and seabird behavioral response interactions (yellow, orange, and green arrows, and a red dotted line). Bird silhouettes derived from Menkhorst et al. (2017) [23] with permission from CSIRO Publishing. Artist: Jeff Davies.

The amount of time the RPAS spent in each flight motion was quantified using flight logs downloaded from the RPAS controller. The format of the flight logs is such that one row of data accounts for 100 milliseconds of flight activity. A series of thresholds were set to assign each row of data to a flight state (forward, changing direction, ascending, descending, hover). If the height value changed by more than 1.83 m (6 feet) when compared to the value 20 rows prior (2 s), it was assigned to be either 'ascending' or 'descending' depending on the direction of change. The horizontal speed of the RPAS is captured in x and y speeds, and the vertical speed is represented by the z speed. The sum of the absolute values of the x speed and y speed shows when the RPAS was moving horizontally in the air. This value approaches/reaches zero as the RPAS slows down to change direction/come to a stop. When this value was less than 4.8 km/h, the flight state was assigned as 'change of direction'. When x, y, and z speeds all equalled zero, the flight state was assigned as 'hover'. All other states were assigned to 'forward' motion. The percentage of time the RPAS spent in each state was then calculated and compared with the proportion of interactions that occurred during each flight state. To test whether interactions were proportionate to the amount of time the RPAS spent in each flight state and to determine the rate of interactions per minute, we used a generalized linear model (GLM, 'stats' base package) with a Poisson family. Significance was tested at a $p < 0.05$ level. All data analysis was performed using R and RStudio [24].

3. Results

A total of 108 RPAS flights of varying duration, totaling 2104 min of flight time, were undertaken on Christmas Island (1105 min) and Pulu Keeling (999 min) in the tropical Indian Ocean. Sampling occurred across 18 days and in a range of weather conditions, with wind speeds varying from calm to ~20 kts. No collisions between seabirds and the RPASs were recorded during monitored flights. During these same flights, 87 close approaches (i.e., air gaps < 2 m; Christmas Island: 72; Pulu Keeling: 15) along with an additional 569 interactions (i.e., air gaps of 2–15 m; Christmas Island: 508, Pulu Keeling: 61) between the RPAS and flying seabirds were recorded (Table 1). One or more interactions were recorded during 82 of the 108 flights (75.9%); there were no seabird-RPAS interactions during the remaining 24.1% of flights.

Table 1. Counts of all seabird-RPAS interactions that occurred during monitored RPAS flights among high densities of flying seabirds over seabird colonies. Flights were completed at Pulu Keeling National Park in November and December 2019 and February 2020 and Christmas Island in May 2021. The RPAS flight action during the interaction was recorded, and the seabird interaction behavior was categorized. The minimum approach distance (m) of any one individual to the RPAS was estimated per encounter.

	RPAS Flight Type *		Bird Interaction Behavior *			Minimum Distance from RPAS (m)			
	Christmas	Pulu Keeling		Christmas	Pulu Keeling	Christmas		Pulu Keeling	
	Number of Interactions			Number of Interactions		Mean (SD)	Range	Mean (SD)	Range
Forward	486	52	Approach	364	8	6.33 (3.73)	1–15	6.84 (3.28)	0.5–15
			Circle	-	1				
			Follow	39	33				
			Close approach	64	5				
			Swoop	19	5				
Ascend	30	5	Approach	25	1	6.10 (3.64)	2–15	3.00 (1.87)	1–5
			Circle	-	1				
			Close approach	5	3				
Descend	30	5	Approach	26	2	6.73 (3.50)	2–15	3.60 (2.51)	2–8
			Follow	1	-				
			Close approach	1	2				
			Swoop	2	1				
Change	24	13	Approach	21	4	6.54 (2.75)	2–10	4.38 (2.47)	2–10
			Circle	-	2				
			Follow	1	1				
			Close approach	1	5				
			Swoop	1	1				
Hover	10	1	Approach	9	1	7.2 (3.79)	2–15	4 (0)	4
			Close approach	1	-				

* RPAS flight types and bird interaction behaviors are described in Appendix A Table A1 and shown in Figure 1.

Flying seabirds were present during all flights, and flights were undertaken with a mean of 103 and 164 flying seabirds in the same airspace as the RPAS for Christmas Island (range = 20–200) and Pulu Keeling (range = 10–630), respectively. Species that were numerically dominant in RPAS interactions included the Christmas Island Frigatebird *Fregata andrewsi* (52.0%) and Great Frigatebird *F. minor* (33.8%) on Christmas Island, and the White Tern *Gygis alba* (48.7%) and Red-footed Booby *Sula sula* (22.4%) on Pulu Keeling (Table 2). Species of seabirds that were present during monitored flights but did not interact with the RPASs included the Sooty Tern *Onychoprion fuscata*, Abbott's Booby *Papasula abbotti*, and Brown Booby *S. leucogaster*. However, these species were often only present in small numbers (Table 2).

Table 2. Summary of all seabird species that interacted with the RPAS during monitored flights over active seabird colonies. Flights were completed at Pulu Keeling National Park in November and December 2019 and February 2020 and at Christmas Island in May 2021. The average approach distance (m) of any one individual to the RPAS is presented for each species.

Species	Christmas			Pulu Keeling		
	Number of Interactions	Average Distance (m)	Percentage (%)	Number of Interactions	Average Distance (m)	Percentage (%)
Christmas Island Frigatebird *Fregata andrewsi*	302	6.64	52.0	N/A	N/A	N/A
Great Frigatebird *Fregata minor*	196	5.56	33.8	1	8	1.3
Lesser Frigatebird *Fregata ariel*	2	9.00	0.3	10	6.2	13.2
Frigatebird sp.	29	5.55	5	6	7.5	7.9
Red-footed Booby *Sula sula*	31	6.77	5.3	17	4.82	22.4
Masked Booby *Sula dactylatra*	N/A	N/A	N/A	2	5.5	2.6
Red-tailed Tropicbird *Phaethon rubricauda*	1	15.00	0.2	-	-	-
White-tailed Tropicbird *Phaethon lepturus*	18	9.28	3.1	2	4	2.6
Common Noddy *Anous stolidus*	1	5.00	0.2	1	2	1.3
White Tern *Gygis alba*	N/A	N/A	N/A	37	6.24	48.7

There were fewer interactions relative to the available opportunity between birds and the RPAS when the flight state was changing direction, ascending or descending (GLM, $p < 0.05$ in all cases, Table 3). Interactions were proportionate to flight states when the RPAS was flying forward or hovering (GLM, $p > 0.05$ for both, Table 3).

Table 3. Percentage of time RPAS units spent in each flight state and the corresponding percentages of total seabird interactions, and the number of interactions per minute for each flight state.

RPAS Flight State	Time Spent in State (%)	Total Interactions (%)	Interactions per Minute
Forward	69.8	82.0	0.87
Ascending	9.9	5.3	0.40
Descending	11.9	5.3	0.33
Change of direction	6.3	5.6	0.67
Hover	2.1	1.7	0.58

4. Discussion

We demonstrate that RPASs can be safely and effectively operated in airspaces with high densities of flying seabirds. We flew over 100 flights totaling 2104 min in airspace routinely occupied by considerable aggregations of seabirds without a single collision. Furthermore, despite hundreds of interactions, most of these were at a distance >2 m from the RPAS (87% of all interactions). Therefore, they were not detrimental to the completion of the flight operation. There were 87 instances where a seabird interaction resulted in an air gap of <2 m with the RPAS. While there is a temptation to label each of these as a near miss, none of these interactions resulted in contact between the seabird and RPAS. This demonstrates that these were, in effect, not near misses (where a near miss represents a substantial increase in the probability of a collision). Moreover, no singular flight state led to greater than expected interactions between the RPAS and seabirds. A key conclusion of this study is that there is a high capacity to undertake safe and successful RPAS operations in airspaces that may otherwise be relatively crowded by flying seabirds.

Although all survey flights were completed successfully, seabirds sharing the same airspace as the RPAS occasionally caused disruptions to automated flight plans. On a small number of occasions, seabirds flew close enough (whether intentionally or accidentally) to the aircraft to trigger the obstacle avoidance systems. These interactions demonstrate very close approaches to a RPAS in flight, albeit without any collisions. In these instances, the survey flight trajectories were interrupted, and the aircraft came to a halt mid-air. The pilot then manually overrode the obstacle avoidance once the bird had moved away to a safe distance/was no longer interacting with the aircraft to resume normal survey flight. As we were undertaking surveys to capture images for orthomosaic generation, seabirds that occupied the airspace between the RPAS and the surface area being photographed (e.g., the tree canopy) were often captured in images. Because these flying birds were mostly close to the canopy, very little of the image was obstructed. Furthermore, any small obstructed area was invariably visible in the previous/following images, meaning these events did not impede data collection.

Outside of this study, our research group has flown similar aircraft (e.g., DJI Phantom 2–4) for hundreds of additional flights where bird interactions have been unmonitored. Across all of these flights, we have detected just one contact between a bird and RPAS. This contact occurred at a tropical seabird colony when the outermost wing tip of a juvenile Red-footed Booby made contact with the DJI Phantom 4 Pro propeller. This contact generated an audible 'tick' that was heard by both the pilot and the spotter. As neither the RPAS nor the Red-footed Booby showed any deviation in flight, this was only characterized as minor contact with a primary feather. The bird appeared to have not seen the aircraft when the RPAS was ascending vertically during take-off, rather than engaging in an active interaction where the RPAS was targeted.

There is a growing body of literature on interactions between RPASs and various avian species. However, many of these studies focus on the disturbance of birds caused by RPASs where the birds are perched or at rest (on the ground, in trees, or on a water surface) but not in flight, for instance [17,18,25]. For example, penguins display increasingly agitated behavior toward RPASs, with different species showing varied sensitivity tolerances [14,26]. Yet many waterbirds, including waterfowl and shorebirds, tend not to show strong adverse reactions to RPASs with appropriate flight height selection [17,27]. Here, we focused on the specific interactions surrounding the aircraft during flights and not on birds at rest. Despite recording 656 interactions, all planned RPAS operations were successfully completed. Our findings and other studies support the conclusion that RPASs remain an appropriate tool for flying over and among colonially breeding species.

While behavioral responses to RPASs are frequently reported in the scientific literature, there are very few mentions of birds actively targeting RPASs [17,28]. Reports of 'attacks' on RPASs by raptors are more common in grey literature [16]. Other species, including the Australian Magpie *Gymnorhina tibicen* during the breeding season, have been recorded flying towards a RPAS, where an evasive maneuver performed by the pilot prevented collision [9]. There is also an example of an attack on a fixed-wing RPAS by a falcon species, where a collision resulted in the loss of the aircraft while the bird flew off apparently unharmed [9]. Here, we routinely flew within seabird colonies in relatively busy airspaces, generally without the need for pilot intervention, even when close approaches were occurring. At other locations, discretion should be used based on an understanding of the propensity of different species to aggressively respond to the RPAS unit. It may be that at sites with 'higher risk' species, such as the approach of a raptor toward a RPAS, would lead to the grounding of operations until that bird had left the airspace.

Here, we have flown with DJI Phantom airframes, so our results should not be generalized to other airframes. We have not tested other multi-rotor units available in a range of sizes, colors, and rotor diameters, nor have we tested fixed-wing aircraft, all of which may influence interaction behaviors. Larger airframes have been found to elicit a stronger behavioral response in wildlife [15], whereas color does not appear to influence disturbance for some waterbird species [8]. Additionally, wildlife responses also vary with flight pattern, with typical mapping and wildlife census flights that follow a regular trajectory (as in this study) resulting in reduced reaction responses [15]. Generally, the more closely an aircraft resembles a predator (in appearance and flight pattern) and is perceived as a threat, the greater the likelihood of a disturbance response [29,30]. As RPAS miniaturization continues, it is possible that smaller units may be prone to higher collision risk, in part because detection by birds might be delayed relative to the airframe used in this study. Conversely, smaller airframes may reduce interactions if wildlife does not perceive the risk as readily as they would with a larger airframe. We also did not test interactions with RPASs traveling at speeds above 49 km/h. One would presume there is a threshold response for the airspeed of the RPAS, above which collisions are generated by the inability of flying birds to appropriately detect and/or respond to an impending collision in the available time. This study did not account for the time of day, given the ubiquitous presence of birds during daylight hours. However, this may be an important direction for future studies to understand if there is an increased likelihood for birds to interact with RPASs at certain times of the day. These variables should all be carefully considered when planning RPAS operations around wildlife.

While bird collisions with RPASs do remain a possibility, and with routine operations, it is perhaps not a question of ‘if’ but ‘when’, we demonstrate that intervals between collisions are likely to be substantial. In this study, over 2100 min of flight time were recorded with interactions between the aircraft and birds. Additionally, there have been many more unmonitored flights by these pilots. No damage to airframes or injury to birds has occurred in any of these instances. While a collision between a RPAS and a bird could potentially result in the loss of the RPAS and/or the injury or death of the bird [31], such outcomes are clearly rare. This risk of collision should also be placed in context with routine terrestrial survey operations targeting the same data. One example of this is the impact of on-ground monitoring on seabird colonies. Researchers entering a breeding colony of Common Tern *Sterna hirundo* resulted in birds flushing from nests, whereas birds were not flushed from nests when RPASs were flown at sufficiently high altitudes [32]. Similarly, Greater Snow Geese *Chen caerulescens atlantica*, that were flushed off the nest by researchers had an increased probability of nest predation. Furthermore, birds left their nests uncovered and exposed to predators, where they would otherwise cover nests for protection prior to departing the nest [29,33]. In most settings, RPASs eliminate the risk of burrow collapse by fieldworkers moving through burrow-nesting seabird colonies on foot [34]. Some species are extremely sensitive to human disturbance from ground-based surveys alone and can have severe negative impacts. An example is the Southern Giant Petrel *Macronectes giganteus*, where researchers visiting breeding colonies caused nest failures, which in turn contributed to long-term declines in populations [35,36]. A transition to a RPAS-based monitoring program for this species has resulted in a clear reduction in visible behavioral disturbance to nesting birds [37]. In this context, monitoring programs for breeding bird colonies that use RPASs, even with the risk of rare to occasional collisions, are likely to generate fewer negative impacts on wildlife populations than traditional ground-based surveys that require researchers to traverse colonies.

5. Conclusions

Our findings confirm that RPAS technology is a valuable scientific tool, even in airspaces with high densities of flying birds. While interactions did occur between the RPAS units and seabirds, no collisions occurred, and all flights were successfully completed, suggesting that the risk of damaging an airframe and/or injuring a bird is very low. Many other studies have focused on animal welfare considerations associated with RPAS operations. While we acknowledge that data collection should always strive to meet best practices for reducing disturbance to wildlife, we demonstrate that airspaces congested with birds should not necessarily preclude RPAS operation.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Appendix A

Table A1. Descriptions of seabird behavior response categories and flight motion of the RPAS during interactions.

Seabird Behavior	
Approach	A bird flies toward the aircraft, then deviates away.
Follow	A bird flies toward the aircraft and maintains proximity within 15 m.
Swoop	A bird dives at the aircraft.
Circle	A bird actively flies around above the aircraft.
Close approach	Any interaction where the bird came within 2 m of the aircraft.
RPAS Flight Motion	
Ascend	Aircraft gains altitude vertically without movement in the horizontal plane.
Descend	Aircraft loses altitude vertically without movement in the horizontal plane.
Forward	Aircraft flies in a straight line, e.g., along a straight-line transect. It may have a shallow ascent or descent, but the overall motion is forward flight.
Change of direction	Aircraft turns with forward movement to fly along a new course, e.g., at the end of a transect.
Static hover	Aircraft holds position without movement along the vertical or horizontal planes.

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