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Brief Report

Attenuation of Responses of Waterbirds to Repeat Drone Surveys Involving a Sequence of Altitudes and Drone Types: A Case Study

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Abstract: Remotely piloted aircraft systems (RPAS, or 'drones' hereafter) have potential for surveying waterbird species and habitats, but there is a risk that the disturbance from drones could compromise count accuracy and bird welfare. We examined the response of 16 waterbird species to repeated up-and-back overhead drone flights (n = 50 flights) at multiple flight heights (80, 60, 40 and 20 m) using three common drone platforms (DJI Matrice 300, DJI Mavic 2 Enterprise Advanced and DJI Phantom 4). A ground observer scored the species' responses to overhead drone flights, which ranged from no response (no change to initial behavior), vigilance (head turning and tracking), movement within the site (swimming, diving, flight into or on the water) and substantial flight resulting in departure from the pond (fleeing). A total of 280 waterbird encounters with overhead drones were observed. The most common response across all flights was no response (70.7%), followed by vigilance (27.5%), whereas more intense responses were comparatively rare (1.8%). The responses were of higher intensity during earlier overhead drone flights, before moderating substantially during later flights. Thus, our case study provides the first unambiguous evidence of the attenuation of responses of bird species to drones.

Keywords: drones; habituation; birds; wildlife disturbance

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1. Introduction

Many applications of drones offer promising outcomes for wildlife and wildlife habitat monitoring; however, the continued uptake of drones as a wildlife monitoring tool will increase the number of drone–wildlife encounters (e.g., drones moving through the airspace used by some wildlife species or drones operating at low flight heights near terrestrial or marine wildlife [1,2]). Encounters between a drone and a wildlife species (or group of species) may or may not evoke a response on the part of the wildlife [1,3]. Wildlife responses are nuanced, complex, and sophisticated, and can be influenced by the proximity of a stimulus and by a variety of internal and environmental factors [4–6]. Where and when they occur, wildlife responses to human activities (including their machines) are hierarchical, often commencing with vigilance (the cessation of normal activities to monitor a potential threat), before sometimes escalating to either attack or, more commonly, escape [1,7,8]. A disruption to the behavioral or physiological states of wildlife evoked by people and their machines is considered 'disturbance' [4]. Compromised energy and time budgets or the stress responses of animals associated with frequent disturbance or disturbance at sensitive life history stages (e.g., when breeding or during pre-migratory fattening) represent an ethical, a welfare and potentially a conservation problem for wildlife monitoring and management approaches [9].

Although the responses of wildlife species to drones are poorly understood, despite increasing research efforts [2], the response of species to drones follows several of the above-mentioned basic principles of wildlife disturbance to non-drone stimuli. For example, responses will often involve vigilance but may escalate to be aggressive or centered around escape, and the probability of a response occurring is influenced by proximity (e.g., flight height [1,8,10,11]). In addition, wildlife responses to drones are influenced by internal or extrinsic factors (e.g., they differ between species [1,12], by sociability or by animal group size [8]), as well as by the attributes of the stimulus (e.g., drone size and flight characteristics [1,13]).

The prospect of drone disturbance to wildlife species remains controversial and contested [14], and many aspects of wildlife responses to drones remain unstudied. One process, 'habituation', which refers to a reduction in the occurrence or intensity of a response with repeated encounters with benign stimuli [6], has been documented in wildlife responding to humans in general (e.g., through proxies such as urbanization [15]). For example, the habituation of Australian Magpies (*Cracticus tibicen*) to the noise of an approaching aircraft has been observed in birds inhabiting airfields [16]. The habituation of waterbirds to overhead drone flights has not been formally investigated or reported. Habituation is critical because even if disturbance occurs, habituation may buffer animals against ongoing effects. This is particularly important for waterbirds, as drones show promise as a survey tool to help manage and monitor waterbird populations, and therefore, may experience further uptake [17–19].

When using drone technology to monitor waterbird species (or any other wildlife) there will be trade-offs between image quality and the resolution required for automated or manual species identification (which is heavily influenced by the payload and platform size, as well as flight height) and the need to avoid wildlife responses, which could: (1) risk the drone, (2) cause particular animals to escape before they can be counted (thus biasing and/or compromising population counts and detection) or (3) raise ethical or legal problems [20]. Although multi-site, randomized studies offer promising insights into any disturbance caused by drones [2] and are clearly needed, they remain relatively few in number, whereas case studies [21,22] also offer valuable insights.

We present one such case study, which involves a relatively small number of individual waterbirds (n = 63) across 16 species, which were monitored intensively for disturbance during 50 repeat overhead drone flights. We used an ordinal scale of responses, from no response to substantial flight responses and fleeing the survey site, to observe and code disturbance for the full sequence of flights using a descending order of flight heights and three unique drone types. The size of the survey site meant that we were able to track the same group of waterbirds for the entire study period. Overall, we found that disturbance was minimal across all flights. Most responses were absent or of low intensity. The more intense responses were rare and, when they did occur, occurred early in the sequence of flights. Critically, our case study also suggests, for the first time, the attenuation of bird responses to a sequence of overhead drone flights. This was uniquely possible because we constantly monitored the same group of birds over the entirety of the sequence and had confidence that the study population remained the same.

2. Materials and Methods

2.1. Study Site

We surveyed waterbirds on a discrete section of a pond system (~300 m in length) at the Williamstown Rifle Range (also known as Jawbone Coastal Reserve), Melbourne, Victoria, Australia (−37.861215, 144.875422; Figure 1). The site was positioned in a transition zone between a suburb and a coastal off-limits reserve, with a nearby bicycle and walking track ~60 m away. Watercrafts are never used in the site (M.A.W pers. comm.). Light aircrafts and helicopters occasionally pass over the wetland, and, after the study period, we encountered a small recreational drone being flown over the site. Birds generally inhabited the open water or the bank on the far side away from human activity. The personnel involved in this study were positioned ~50 m away (at −37.861365, 144.876200) in the public park area between the survey pond and the bicycle and walking track (Figure 1).

Figure 1. Map of the study area at the Williamstown Rifle Range (also known as Jawbone Coastal Reserve), Melbourne, Victoria, Australia. The approximate center of the survey pond is located at −37.861215, 144.875422. The map depicts the perimeter of the survey pond (Flight Area), the flight path used for repeat overhead drone flights (Flight Line), the location of ground personnel for piloting drones and monitoring waterbird responses (Standing Area) and the location that the drone was launched from (Takeoff Location). The map was generated by T.A.D. using ArcGIS Pro 3.0.3, Redlands, CA, USA.

2.2. Drone Flights

Before broad-scale, ongoing, drone-based surveys of birds commence, it is helpful to undertake a preliminary sequence of overflights using different platforms at descending altitudes to assess bird responsiveness to drones, which can involve escape and movement out of the surveyed area, thereby confounding raw count data [11]. We conducted 50 repeat drone flights over a 4 h and 9 min period (between 09:38:00 and 13:47:00) using three drone platforms at a series of flight heights (Figure 2). Simultaneously, we monitored waterbird responses to these repeat overhead drone flights (see Section 2.3). All the drone flights were conducted on 17 June 2022 and the weather conditions were fine but overcast (consistently 90–100% cloud cover and wind speeds did not exceed 27 km/h).

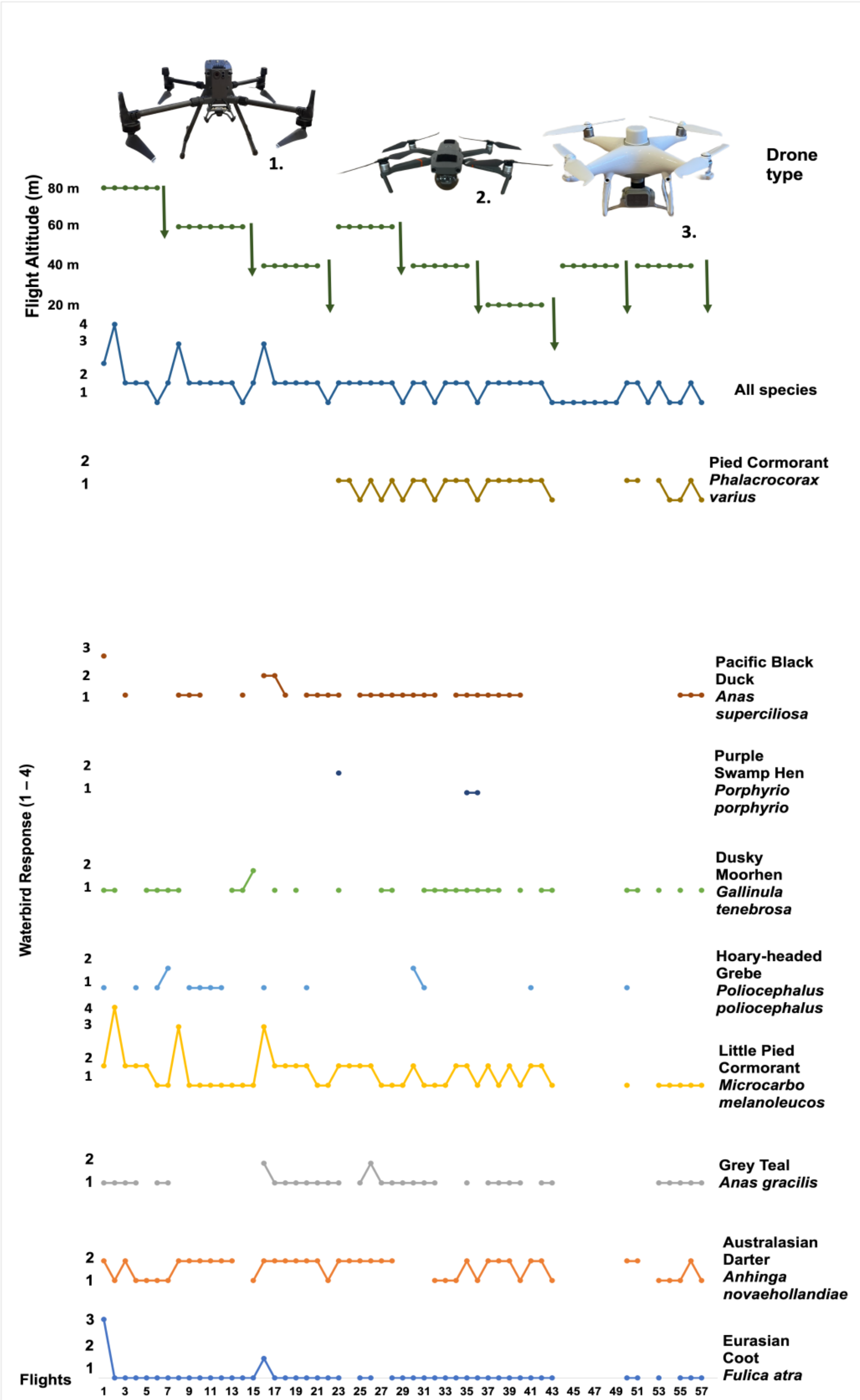

Figure 2. Maximal response of waterbird species (n = 9) to a sequence of repeated up-and-back overhead drone flights (n = 50) using three drone platforms (1 = DJI Matrice 300; 2 = DJI Mavic 2 Enterprise Advanced; 3 = DJI Phantom 4) at multiple flight heights (80, 60, 40 and 20 m). Responses were rated using a 1–4 scale. The flight speed was consistent (~5 m/s). The downward arrow represents drone landings which are included in the overall tally for visualization. The sequence of descending flight heights is summarized as follows: DJI Matrice 300, 80, 60 and 40 m; DJI Mavic 2 Enterprise Advanced, 60, 40, 20 and 40 m; DJI Phantom 4, 40 m).

All the drones used in this study were quad-rotor aircrafts. The sequence of drone flights involved two drones (the DJI Matrice 300 and the DJI Mavic 2 Enterprise Advanced), flown at descending flight heights (80, 60, 40 and 20 m above ground level). We also conducted a single flight at 40 m using a DJI Phantom 4 (Figure 2). The DJI Matrice 300 has a weight of ~6.3 kg (with two batteries) and dimensions of 810 × 670 × 430 mm when unfolded and without a payload (https://www.dji.com/au/matrice-300/specs, accessed 10 January 2023). With the payload used for this study (Zenmuse P1; https://enterprise.dji.com/zenmuse-p1/specs, accessed 10 January 2023), the DJI Matrice 300 had a weight of ~7.1 kg. The DJI Mavic 2 Enterprise Advanced has a weight of 909 g and dimensions of 322 × 242 × 84 mm when unfolded (https://www.dji.com/au/mavic-2-enterprise-advanced/specs, accessed 10 January 2023). The DJI Phantom 4 has a weight of 1388 g without the camera and is 350 mm in length from motor hub to motor hub (https://www.dji.com/au/phantom-4-pro/info, accessed 10 January 2023).

At each flight height, a session of between 6 and 7 repeat up-and-back overhead flights was conducted. On average, there was a 2 min and 10 s interval between up-and-back overhead flights (1–7 min; mean ± SD, 2 min and 10 s ± 53 s). There was an average interval of 20 min and 43 s between sessions at a new flight height (13–27 min; mean ± SD, 20 min and 43 s ± 4 min and 47 s). The sequence of descending flight heights can be summarized as follows: DJI Matrice 300, 80, 60 and 40 m; DJI Mavic 2 Enterprise Advanced, 60, 40, 20 and 40 m; DJI Phantom 4, 40 m). Before each session at a new flight height, a manual drone take-off was performed ~55 m from the survey pond to minimize the chance of disturbance during take-off ([1] proposed that responses to drone take-offs reduce substantially when the drone take-off is >40 m away) (Figure 1). The drone was flown vertically until the desired flight height was reached before being flown manually parallel with the survey pond to the starting point. The drone was kept over land during this period and the ~55 m distance from the survey pond was maintained where possible to minimize any disturbance prior to the formal overhead drone flights. After each session of 6–7 up-and-back overhead drone flights, the drone was manually flown away from the pond and over land to the take-off point before it was landed manually (a total of 8 drone landings throughout the survey period). The average actual flight time of the overhead drone flights was 1 min and 13 s (37 s–1 min 17 s; mean ± SD, 1 min and 13 s ± 9 s; based on a sample of 24 typical overflights when accurate timing was collected from video data). All the drones were flown manually and were consistently flown at ~5 m/s, with the exception of the first flight, which was flown at ~6.5 m/s while the pilot adjusted to the flight style required.

2.3. Monitoring Waterbird Response

During all the drone events (50 overhead flights interspersed with 8 drone landings; see Section 2.2) an on-ground observer (M.A.W) observed and categorized the response of 16 waterbird species (Figure 2). The waterbird species included in this study and the maximum number of individual animals present for each species were as follows: Eurasian Coot (*Fulica atra*; n = 7), Australasian Darter (*Anhinga novaehollandiae*; n = 1), Grey Teal (*Anas gracilis*; n = 4), Little Pied Cormorant (*Microcarbo melanoleucos*; n = 5), Hoary-headed Grebe (*Poliocephalus poliocephalus*; n = 2), Dusky Moorhen (*Gallinula tenebrosa*; n = 5), Black Swan (*Cygnus atratus*; n = 1), Purple Swamphen (*Porphyrio porphyrio*; n = 1), Silver Gull (*Chroicocephalus novaehollandiae*; n = 22), Pacific Black Duck (*Anas superciliosa*; n = 2), Hardhead (*Aythya australis*; n = 1), Musk Duck (*Biziura lobata*; n = 1), Chestnut Teal (*Anas castanea*; n = 2), Pied Cormorant (*Phalacrocorax varius*; n = 5), Australasian Shoveler (*Anas rhynchotis*; n = 1) and Australasian Grebe (*Tachybaptus novaehollandiae*; n = 3) (Figure 2). The authors note that drone-derived imagery was not used for species identification and that all species identification was performed by the on-ground observer. All the birds sampled were not breeding (breeding type and stage can influence avian responses to drones [23]).

The on-ground observer monitored waterbirds from ~50 m from the closest bank of the survey pond (Figure 1) using binoculars (Bushnell range finding binoculars, ×10). The constant monitoring of waterbirds present in the pond ensured that we observed the same population during all the overhead drone flights and drone landings (apart from one departure; see Section 3); however, individuals were not individually identifiable. At times, some waterbirds were not in view by the on-ground spotter, and thus could not be assigned response codes, but they were known to be in the pond. We used an ordinal four-point scale for assigning the response of each waterbird to each overhead drone flight:

1. No response (no change to initial behavior);
2. Vigilance (head turning and tracking);
3. Movement within the site (swimming, diving, or flight into or on the water);
4. Substantial flight resulting in departure from the pond (fleeing).

No attacks were observed, and no other stimuli were active during overflights.

All the flights were approved under Deakin University's remotely piloted aircraft operator's certificate (ReOC; number CASA.ReOC.6496 Revision No.: 5). All personnel involved in the drone flights had a Remote Pilot License (RePL) under the Australian Government Civil Aviation Safety Authority (CASA). This study was conducted under animal ethics protocol B08-2022, administered by the Animal Ethics Committee Wildlife Burwood (AECW-B; License Number 20346).

2.4. Data Analysis

Data were ordinal in nature, and so changes with sequential overhead drone flights were analyzed using nonparametric correlation tests (Spearman rank). To test the responses between species (all flights), a nonparametric alternative to a one-way ANOVA (Kruskal–Wallace test) was performed. We present some analyses for all the species combined, recognizing that the process of counting waterbirds by drones inevitably involves overflying mixed-species associations.

3. Results

A total of 280 waterbird responses to all the overhead drone flights were observed across sixteen species. The most common response to overhead drone flights of any platform or height was no response (70.7%; n = 198 counts of no response), vigilance (27.5%; n = 77), movement within the study area (swimming, diving or flight into or on the water; 1.4%; n = 1 swimming; n = 1 diving; n = 2 flight within the survey pond) or substantial flight resulting in departure from the pond (0.36%; n = 1, Little Pied Cormorant). Seven species showed no response at all to any of the overhead drone flights, regardless of drone type or flight height (Black Swan, Silver Gull, Musk Duck, Chestnut Teal, Australasian Shoveler, Australasian Grebe, and Hardhead). Because individual waterbirds could not be identified, yet the same pool of individuals of each species was consistent across all the overhead drone flights, we pooled the species responses for the nine species that exhibited responses and present the maximal response for any species (Figure 2).

The one instance of a Little Pied Cormorant departing the survey pond occurred in the first half of the flight sequence (in the 2nd flight of 50 overhead flights) (Figure 2). All observations of movement within the site (swimming, diving, or flight into or on the water) also occurred in the first half of the overhead flight sequence (Figure 2). Overall, for most species and for all the species combined, response intensity was generally low and decreased as the sequence of overhead drone flights continued (Figure 2). This was supported by correlations, which suggests that the maximal avian response for all the waterbird species that responded decreased as the sequence of overhead drone flights progressed ($r_{Spearman} = -0.495$, $p < 0.001$; excluding the waterbird which flew away from the area, $r_{Spearman} = -0.495$, $p < 0.001$). At the end of the sequence of overhead drone flights (from flight 20 onwards until the final overhead drone flight), no response (no change to initial behavior; 71.4% of observed responses) or vigilance (head turning and tracking; 28.6%) were the only responses recorded for any species (Figure 2).

We have not analyzed by platform or height because our design was non-random and unsuitable for such approaches. However, all species experienced the same sequence of overflights, enabling inter-species comparisons. Species (where ≥10 responses were scored) differed in the types of responses observed (Kruskal–Wallis $\chi^2 = 114.733$, df = 9, $p < 0.001$), with median responses scored as vigilance (head turning and tracking) for Australasian Darter and Little Pied Cormorant species and medians scored as no response (no change to initial behavior) for the other eight species (Chestnut Teal, Dusky Moorhen, Eurasian Coot, Grey Teal, Hoary-headed Grebe, Pacific Black Duck, Pied Cormorant and Silver Gull) (Figure 2).

4. Discussion

The responses by the 16 bird species observed in this case study to overhead drone flights were entirely absent for nearly half of all the species observed. For the species that showed some response to drones, the responses were infrequent and almost entirely of low intensity. Intense responses made up only a small proportion of the total responses observed. For example, movement responses within the pond accounted for 1.4% of the responses coded, and only one individual fled the survey pond due to drone flyover. The predominance of low-intensity responses is not surprising and accords with other studies of wildlife disturbance, including disturbance induced by drones (see [24]). More intense responses can displace wildlife and, if frequent enough, disrupt energy balances and habitat use [3]. Even low-intensity or subtle responses may be problematic if frequent enough [3], and physiological responses may occur during low-intensity responses or even when behavioral responses are not evident [25,26]. For example, at times, vigilance may come at the cost of a substantial reduction in other essential activities [27], diminished capacity to detect predators and other risks [28] and increases in the secretion of stress hormones [29], among other possible deleterious effects. We note that some species (Australasian Darter and Pied Cormorant; Figure 2) continued to become vigilant during drone flights late in the sequence of overflights, and so might conceivably realize some of these costs. These two species are two of the largest species we observed, and larger species often exhibit higher levels of responsiveness to humans and their machines than smaller species [4,30].

To the best of our knowledge, we present the first unambiguous observations of the attenuation of responses to drones by birds. The moderation of responses over time can result from 'filtering', whereby the most sensitive species depart an area [31]. We observed only one departure across our sequence of drone flights by the most responsive species (Little Pied Cormorant in the second flight). This site departure occurred early, and more intense responses continued in this species early in the sequence (i.e., two flight responses within the site) because the first model of drone, which was also the largest and loudest, stepped down in altitude. These observations were consistent with neophobia and the increased responsiveness of birds with closer drone proximity [1,8,10]. However, overall, the responses appeared to reduce for all the remaining birds as the flight sequence continued, albeit from a low level of early and initial response (usually vigilance). This pattern is attributable to reduced responsiveness within individuals with repeated exposure to the drone, i.e., learning. To our knowledge, this has not been unambiguously demonstrated previously for overhead drone flights and birds (but see [32] for evidence of habituation in a bird species to videos of drones). Habituation has been demonstrated in bears, as they exhibited decreased responsiveness to repeated drone overflights [33]. Although various studies of drone–wildlife interactions cautiously suggest habituation as a possible explanatory factor for the observed patterns, they are unable to demonstrate the identity of the animals between flights and, therefore, are unable to conclude that habituation occurred [19,34]. This issue is partially overcome in our case study, as the survey site allowed constant monitoring of the population and any waterbird departures from the site.

We acknowledge that the birds in our case study (which was not replicated across sites) were exposed to humans and could have been exposed to drones and other aircrafts probably in low and modest frequencies, respectively. We also highlight that our flight paths stepped down flight heights and so provided the opportunity to habituate. The flight paths were predictable and benign, with modest intervals between flights so that any learning could be readily maintained. All these factors could have promoted habituation in our study birds and may not apply to other contexts. We also note that some birds continued occasional vigilance, even at the end of the sequence, and that one fled the study area, and so would not have been countable by later flights (assuming the drone flights were being used to count birds).

Information Gaps and Future Research

Further multi-site studies of drone–waterbird interactions are required, and these could incorporate repeated flights over various intervals to assess the capacity for, and duration of, any habituation. We also note that many other factors that were not examined here may influence waterbird responses to drones and could be incorporated into future multi-site research. Such factors include:

1. The biological, ecological, or social contexts of the waterbirds subject to overflights. Further multi-site studies may provide more robust insights into the responses of waterbird congregations of varying size to drone overflights (larger group sizes may be positively related to greater responsiveness [35]). A limitation of the present study is the relatively small congregation of individuals. Therefore, further tests over a greater variety of group sizes are required. Other contexts, such as breeding status and stage, may also influence responsiveness [1,23]. In this study, we exclusively sampled non-breeding waterbirds. Species clearly differed in their responsiveness to drones (as in [1,23,36]), and more remote sites than those studied here may harbor additional, more sensitive species. Species also differ in terms of their use of different escape modalities (e.g., swim, dive, run on water, fly, etc.) and some may even become aggressive to drones (e.g., mobbing and swooping [7]). Thus, sampling a wider variety of species will assist with understanding how generalizable the current results are to other waterbirds.
2. The exposure of waterbirds to previous human activity. Further tests at locations with fewer agents of disturbance (e.g., fewer humans, aircraft and recreational drones) may reveal greater responsiveness than reported here, based on the capacity to adapt to human activity and the degree to which waterbirds generalize their responses to different anthropogenic stimuli [37]. In particular, waterbird hunting, which is common throughout many parts of the world, may increase the responsiveness of birds to human activity (see [38]) and this may vary between sites/populations.
3. The cues offered by drones, as perceived by waterbirds, to judge risk associated with a given drone overflight. Drones are perceived by waterbirds based on the cues they offer (e.g., visual, and acoustic cues), which may vary with environmental factors, such as light levels and wind, as well as according to the platform and flight characteristics. Altering and comparing other flight parameters, which may differ across survey approaches (e.g., transect sampling or site census using lawnmower patterns), such as the flight length, flight speed and number of repeats across the same survey site, may affect the probability and nature of bird responses to drones and warrants further investigation. In addition, research attention should be given to the responses of birds to other drone platforms, including both larger and smaller drones associated with different noise and visual profiles.

We focused on the behavioral responses of waterbirds to drones because these are likely to influence the number of birds available to be counted by an overflying drone. However, we recognize that non-behavioral responses (e.g., physiological responses) of birds to drones can also occur, sometimes in the absence of behavioral responses [36]. The consequences of the responses (behavioral or otherwise) of birds are generally unknown, but the possibility of difficult-to-detect physiological responses exists, and these could have implications for stress and energy balance [25]. Thus, although we describe the attenuation of behavioral responses to drones, we recognize that some possible physiological responses were undetectable.

In conclusion, the case study presented here apparently provides the first documented attenuation of responses of bird species to drone overflights. This was possible due to a unique set of circumstances (i.e., the ability to monitor all individuals in the study site and to quantify site departures). Although limited in scope and based on a small number of individuals, this case study offers valuable insights into the potential for the attenuation of bird responses to drones and will hopefully be a catalyst for further studies of attenuation potential.

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Data Availability Statement: All data used in the analysis are provided and appear in the submitted article.

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