drones

Brief Report

Estuary Stingray (*Dasyatis fluviorum*) Behaviour Does Not Change in Response to Drone Altitude

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Abstract: The use of drones to study the behaviours of marine animals is increasing, yet the potential effects of drones on natural behaviours are poorly understood. Here, we assessed if a small consumer drone produced behavioural changes in a ray common to New South Wales, Australia, the estuary stingray (*Dasyatis fluviorum*). A drone was flown directly above a total of 50 individual stingrays, the altitude above that ray was progressively reduced, and any behavioural changes were recorded. While stingrays demonstrated a range of behaviours, these behaviours rarely changed during drone observations (n = 6 or 12% of flights), and no change in the type of behaviour or number of behavioural changes was observed as the altitude decreased. These results suggest that consumer drones have little visible impact on stingray behaviour but do not exclude potential physiological responses. As a result, we recommend that when conducting drone-based stingray research, operators fly at the highest altitude possible that allows monitoring of features of interest, and we conclude that drones are effective tools for assessing natural stingray behaviours.

Keywords: stingray; drone; UAV; impacts; behaviour; response

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1. Introduction

The contemporary use of drones in ecological research has contributed to distinct opportunities in animal observation and habitat assessment [1–3]. Despite the comprehensive use of drones to examine other marine animals [2,4,5], however, their use in ray studies has lagged behind other charismatic marine fauna. Habitat destruction as a result of coastal development is a developing threat that is influencing rays by modifying their habitats [6], and in conjunction with fisheries' impacts, the risk of extinction for rays has increased over the last half century [7,8]. It is therefore concerning that so few studies have adopted drones as a tool to study these threatened animals.

Unoccupied aerial vehicles have numerous applications that can make them useful for studying rays. Drones can monitor the size of rays that can be otherwise difficult to measure in situ [1,9]. Ray bioturbation of sediments is an important ecosystem service, and drones can be used to assess the scale of bioturbation [10]. Moreover, observing rays without disrupting their natural behaviour contributes to a better understanding of numerous biotic and abiotic factors [1] that can affect movement. Fine-scale ray movement remains an understudied area of research, though it presents a great potential to determine drivers of behaviour and habitat use [11]. Therefore, knowledge on ray habitats, demography and behaviours will inform management strategies at all scales, and drones are a promising tool to obtain this.

Drones have more of a potential to disturb animals than other aerial survey methods due to their capacity to fly and hover at very low altitudes above the target species [12,13], and understanding the impacts of drones on wildlife is a key research objective [14–16]. Several studies have examined the disturbance that drones pose to pinniped and dolphin populations [17–20], yet the impact on elasmobranch behaviour is not understood. Christiansen et al. [18] suggested that elasmobranch species will not be prone to disturbance effects caused by drones, as frequency and loudness of noise travel poorly through water. While many elasmobranch experts who have used drones believe the impact to be low [21], no formal studies have directly assessed this. Chronic impacts of the use of drones are of biological and ethical concern, especially if they are used in wildlife surveys designed to minimally disturb animals [12]. Without first evaluating the influences of drones on target animals, the advantages of decreasing observer presence may be ineffective, and thus, with the rise of drone surveys in wildlife research, it is imperative to understand whether this technology has the potential to alter elasmobranch behaviour.

This study assessed whether the presence of drones altered the behaviour of a common stingray species, the estuary stingray *Dasyatis fluviorum.* This species is found in many Eastern Australian estuaries and is listed as near threatened by the IUCN Red List. We also assessed whether flying the drone at lower altitudes was more likely to affect ray behaviour, since lower altitudes increase the relative visual footprint of the drone as well as increasing any noise stimulus. We expected that disturbance levels would be low but that flying at lower altitudes would be more likely to produce an altered change in the response of the target animal, especially towards threat avoidance behaviours like hiding or resting in the substrate. These results could be used to inform minimum flight altitudes for studies on this species or similar elasmobranchs.

2. Materials and Methods

2.1. Field Site

Research was conducted in accordance with University of Newcastle Animal Ethics Committee approval A-2012-238 in October 2020 to March 2021. All flights were conducted above the waters to the east of Woy Woy, NSW, Australia in the Brisbane Water estuary (Figure 1). This area is an estuarine system with water alternating between marine, brackish and, in extreme flood situations, fresh water. It is surrounded by dense residential housing (Gosford, NSW population 178,000) with a shallow bathymetry (<2 m), abundant seagrass meadows (*Zostera* spp.) and sandy intertidal flats known to be used by these stingrays for feeding and resting. The area is frequently used for recreational activities like fishing or kayaking, and many of the fringes of this site have commercial pearl oyster leases.

2.2. Drone and Flight Patterns

An off-the-shelf DJI Mavic Platinum Pro® drone (739 g, 93 dB sound levels) was used, flown in GPS mode with the DJI GO 4 app on an iPad Mini. The stock camera carried by this drone has an f/2.2 lens with a 78.8-degree field of view capable of recording footage at 3840×2160 pixels at 30 frames per second. To reduce reflections on the surface of the water, a polarised lens was fitted to the camera. Weather and wind patterns were monitored one week prior to entering the field, with ideal winds below 10 km h^{-1} and a maximum of 20 km h^{-1}. Various vantage points were selected at Woy Woy to ensure that the drone was within the visual line of sight throughout each flight. The drone was manually piloted over the research zone in an "S" search pattern at an altitude of 30 m (the safe altitude from other species in Fiori et al. [4]) until a ray was spotted. As many surveys as possible were conducted on each sampling day, with a maximum of seven flights conducted on a single day. Aside from visibility limitations with reduced light before sunrise and after sunset, the Civil Aviation Safety Authority of Australia restricts pilots conducting flights to daylight hours only, limiting flight times to during the day, so no successful tracks of *D. fluviorum* were conducted in the evening. Additionally, wind at this site generally increased in the afternoon, so the main observation period was morning/early afternoon (9 am~2 pm) under a variety of tidal conditions.

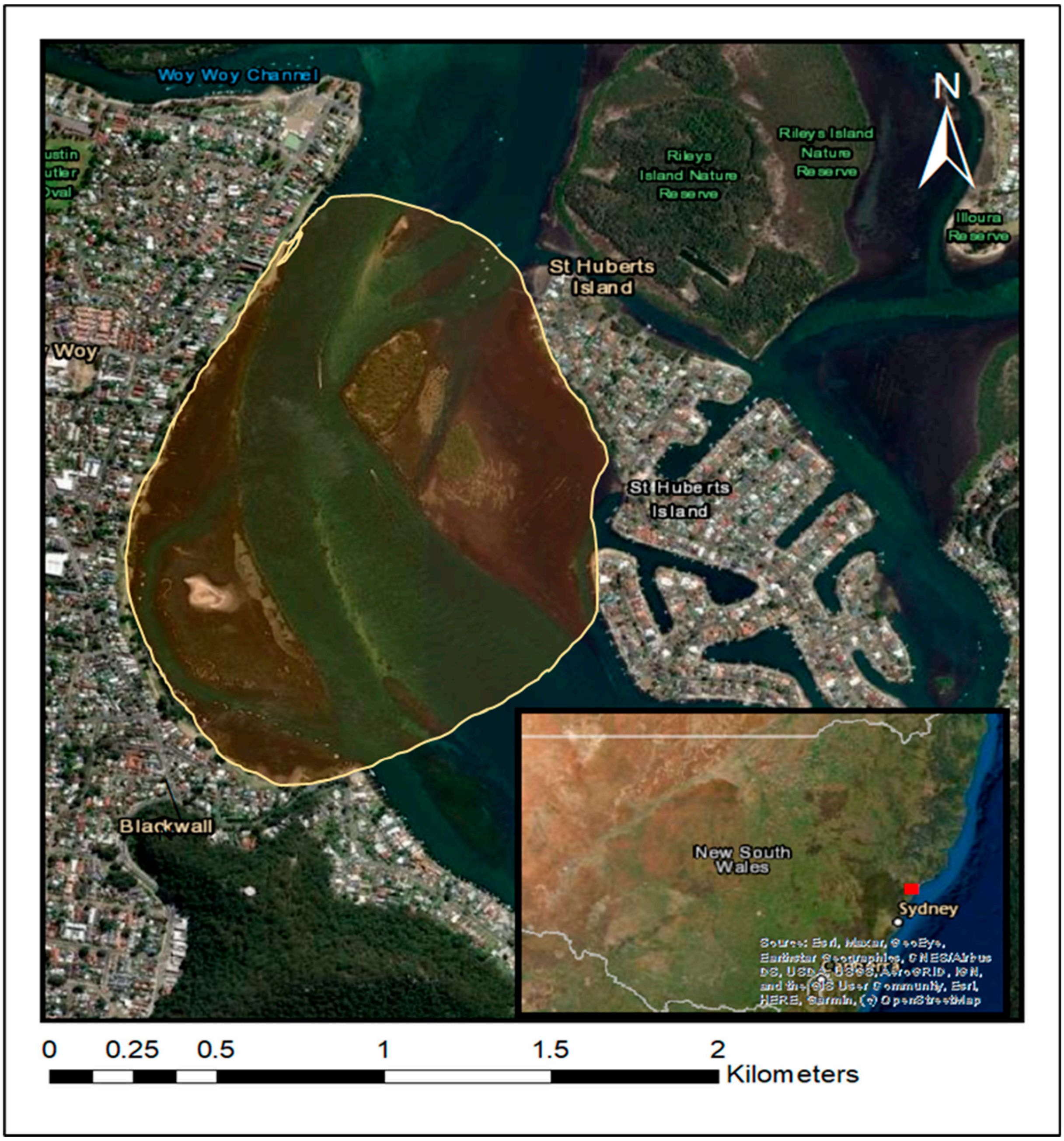

Figure 1. Satellite imagery showing New South Wales and indicating the location of Woy Woy, within Brisbane Water estuary. The specific study area is shaded in orange. Source: Esri Inc. (2016).

To determine the effect of tracking altitude on *D. fluviorum* behaviour, an approach used by Fettermann de Oliveira [22] was implemented. Flying at high altitudes (>30 m) with fixed-lens drones like the one used here was unrealistic for *D. fluviorum*, as rays were not clearly visible. Thus, the drone began at 30 m from the surface of the water and spent 30 s at each altitude, reducing altitude at 5 m intervals at a speed of 1 m/s to a minimum altitude of 5 m above sea level (Figure 2). Each video was, therefore, approximately 3 min long. Once the assessment of an individual completed, the drone continued searching the area of interest along the “S” pattern until the next individual was spotted. Once 50 videos were collected, the data were used to identify the appropriate altitude that should be used.

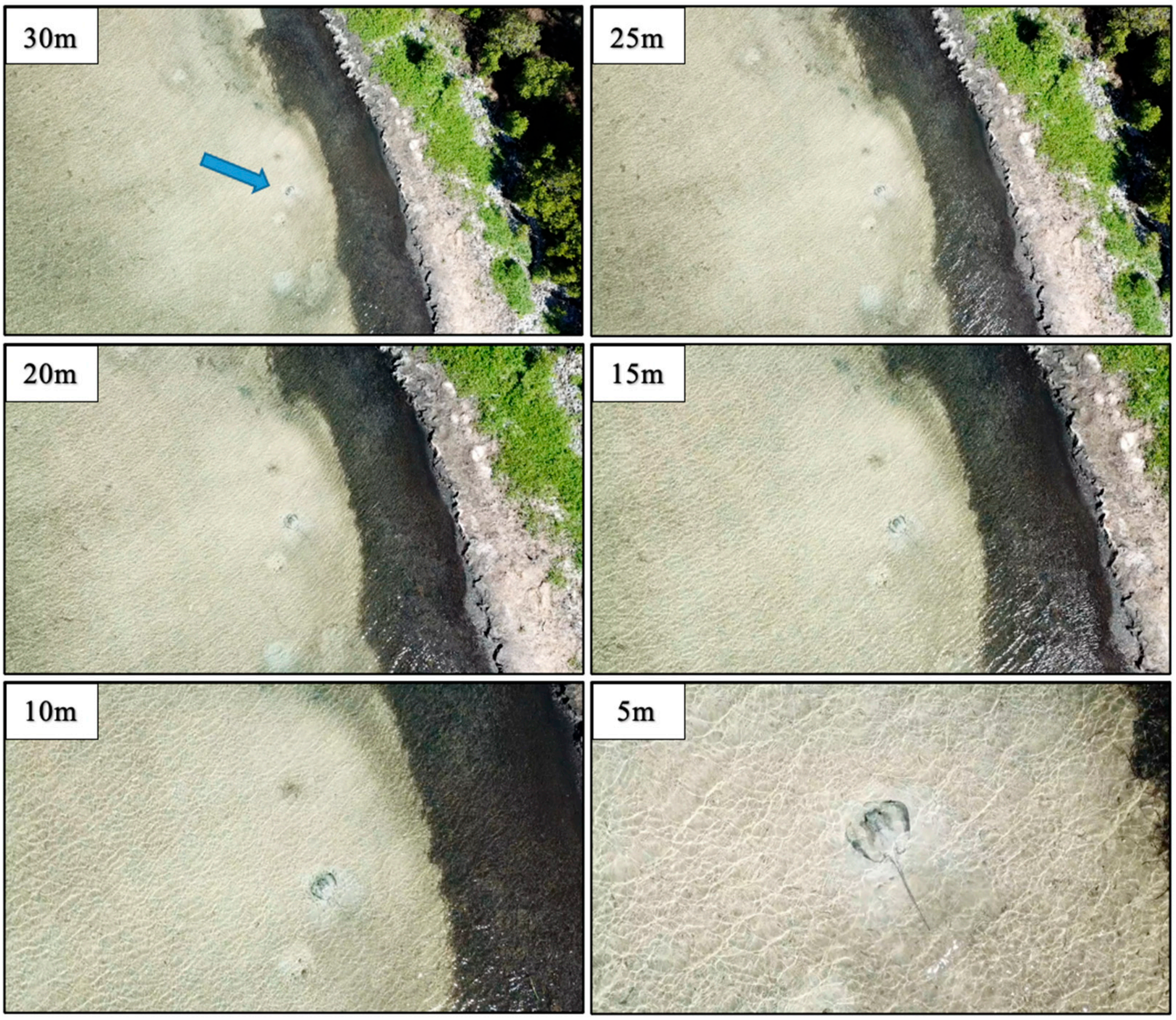

Figure 2. Aerial view from the drone while assessing behaviour of D. fluviorum at altitudes of 30 m, 25 m, 20 m, 15 m, 10 m and 5 m; the ray is indicated by the blue arrow in the first image.

2.3. Video Analysis

The 'mp4' footage files were downloaded from the SD card of the drone and reviewed on a computer. To measure and record behavioural observations, instantaneous sampling was used (behaviours were observed and recorded every 30 s). Behavioural events were defined as a series of body movements that could be unambiguously identified as a unit and could be observed every time they occurred. In this study, three exclusive behaviour events were recorded (Table 1).

Table 1. Definition of behaviours recorded during drone flights.

Behaviour	Definition
Swimming	Moving through the water
Foraging	Looking or searching for food or provisions/ingesting food; flapping pectoral fins to excavate food off seafloor
Resting	Lying motionless on the substrate

2.4. Data Analysis

A generalised linear mixed effects model (GLMM) was used to examine changes in the group behavioural state in relation to decreasing altitude, with the expectation that a decreased altitude would result in more changes to the behavioural state. The data were modelled with a GLMM in the 'lme4' package [23] for R Studio and R V 4.2.2 [24,25]. The model used a response variable for behaviour change that was binary (i.e., a behavioural change was coded as 'Change', and no change was coded as 'No Change'). Consequently, our GLMM used a binomial family for the response variable, altitude as the determinant, and a logit link function.

3. Results

We tracked the behavioural response of 50 stingrays during the duration of the experiment (Table 2). *D. fluviorum* did not exhibit increased changes in behaviour with decreasing drone altitudes ($p = 0.61$, $z = 0.5$; $dF = 298$; Figure 3). Of the 50 individuals, only two demonstrated a change in behaviour after a change in drone altitude: one individual changed behaviours twice, at 25 and 15 m, and another individual changed behaviours at 5 m. The only change in behaviour alternated between foraging and swimming, and none of these changed from swimming or foraging to resting. Overall, from these assessments it was concluded that there was no significant change in behavioural responses with the drone decreasing in altitude.

Table 2. Summary of behaviours recorded during drone flights.

Altitude (m)	Number of Individuals Exhibiting Behaviour		
	Swimming	Foraging	Resting
30	27	15	8
25	25	17	8
20	25	17	8
15	25	17	8
10	23	19	8
5	19	23	8

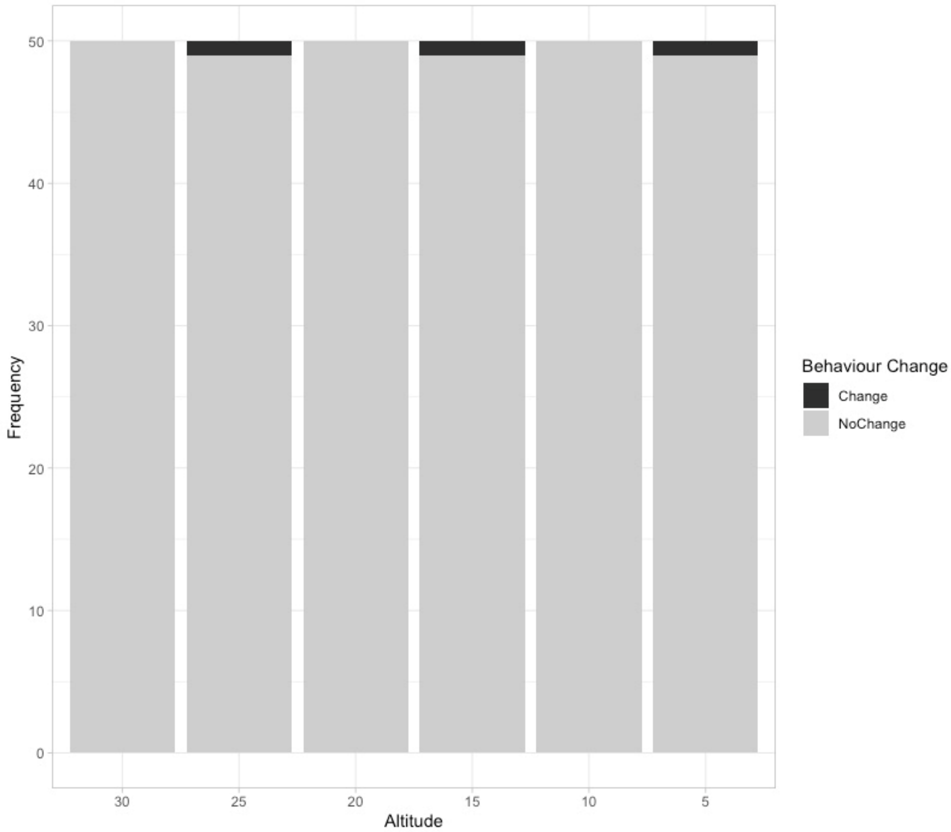

Figure 3. Counts of behaviour change or no change across the 50 stingray observations at different altitudes.

4. Discussion

The presence of the drone did not cause a significant change in swimming, foraging or resting behaviour for this particular species, regardless of the altitude flown. This result contrasts with other studies that suggest that some marine animals change their behaviour in the presence of a light weight drone flying at 30 m and below [19,26]. Ramos et al. [27] assessed the behavioural response of Antillean manatees (*Trichechus manatus manatus*) to a drone (DJI Phantom) and identified a change in response in 24% of all sightings, and fleeing responses were observed from a 6 to 52 m altitude. The authors suggest that this change in behaviour may be a result of manatees being intensively hunted until the late nineteenth century, pressures that can sometimes cause manatees to shift their activity to avoid human detection [27]. Bottlenose dolphins (Tursiops spp.) also show an increased behavioural response at lower altitudes [20]. Similarly, Bevan et al. [28] assessed the response of crested terns (*Thalasseus bergii*) resting on a sandbank to a small drone and found that flyovers elicited a display of disturbance behaviours (e.g., flight response) when the drone was flown below a 60 m altitude. From this, they concluded that the birds may be associating the approach of the drone with a predator attack. However, in the same study, sea turtles in nearshore waters off nesting beaches or in foraging habitats exhibited no evasive behaviours (e.g., rapid diving) in response to a drone at or above a 20–30 m altitude, as was the case for juvenile green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) at or above a 10 m altitude. In contrast, Durban et al. [29] did not observe evidence of behavioural responses in killer whales (*Orcinus orca)* exposed to a drone flying at a 35 m altitude, and several species of baleen whales and sperm whales *(Physeter microcephalus*) have been approached by a drone flying lower than a 10 m altitude with no reaction of the targeted animals being noted [30]. Thus, there is clearly a species/taxa-specific response to drones, with the rays studied here appearing to be less sensitive to their presence. Further research is required to assess whether other species of rays respond in a similar manner, as drones can capture species-specific behaviours (Raoult et al., 2018), and some responses of patterns of ray behaviour may be more susceptible to drone interference than others.

The differing results between studies indicate that there may be a variety of factors that determine the intensity of a behavioural response in an animal and that stingrays may be less prone to these stressors. Characteristics of the disturbing agent produced by drones may include size, noise emitted, angle of approach, speed and distance, which all affect the perception of risk by an animal [31,32]. Further, the larger and nosier the approaching agent is, the stronger the anti-predator responses will be [33], with species that are naturally threatened by aerial predators (e.g., birds) reacting more than other animal types, such as large terrestrial mammals and fully aquatic species. This is why the type of aircraft used (e.g., fixed-wing vs. multi-rotor), the flight patterns (e.g., hovering or active-search) and the proximity of the aircraft to animals may all affect species differently [19,33]. *D. fluviorum* typically does not have aerial predators and is not fished by humans in the area, which could be the reason why there were no significant changes of behaviour in this study. Additionally, pelicans frequently fly in the area where the research occurred, which could suggest that the stingrays were accustomed to having objects fly over them, thus not responding to the presence of a drone. Environmental conditions could also contribute to sensitivity to drone disturbance; however, in this case, conditions were similar across all sampling events (mornings, low wind, low-to-mid tide) and were unlikely to explain the few behavioural changes observed. Individual characteristics relating to personality and experiences of individuals within a population can also potentially drive differences in responses [34,35]. Thus, the characteristics and context of the animal exposed to the disturbance may impact the degree of its behavioural response.

The species, age, level of aggregation, life history stage, habitat and season may also contribute to an animal's susceptibility to responding to drones [31,32]. Rebolo-Ifrán et al. [13] found that wildlife that use aerial and terrestrial habitats are more likely to show a behavioural response to drones than those occupying aquatic habitats. Furthermore, Smith et al. [36] suggested that animals living in water may be less affected because acoustic and visual aerial signals occur with less intensity underwater. However, this seems to be inaccurate for marine mammals that have been observed responding in a significant manner to drones [27], and it is still unclear as to why there is such a difference. The drone model used here produces 93 dB, and this noise level is often considered a cause for disturbance in marine mammals. While marine mammals are known to be sensitive to sound [37], there is comparatively little that is known about the auditory capabilities of elasmobranchs [38] and whether they would be capable of hearing a drone stimulus. For the elasmobranch species that have been studied, there appears to be large species-specific differences in auditory ability, especially for higher frequencies produced by drones. These results outline that the auditory capabilities of elasmobranchs warrant further research to better determine the cause, if any, of drone disturbance. Additionally, responses to drones are potentially altered by the reproductive status. Since gravid females might have decreased movement capabilities, individuals in parental care may prioritize the safety of their offspring to their own survival [33], and it is possible that some of the observed rays were gravid but did not respond to the drone. Gravid rays can often be identified by large dorsal 'humps' that result from well-developed embryos, though this can be difficult to differentiate with certainty from a drone. These findings indicate that the approach distance is unlikely to cause observable behavioural changes in *D. fluviorum*; however, the flight altitude should be dictated by the size of the target species, the complexity of the habitat and the potential for obstacles to impede the flight path at different altitudes when monitoring rays [39]. Associated species that are not targeted by the study but could be affected should also be considered [14] to be able to assess broad environmental impacts of drones in marine ecosystems.

Currently, there is insufficient knowledge on the physiological and long-term consequences of drone disturbances. However, it is possible that drones might cause non-visible effects [33]. Ditmer et al. [40] found no behavioural changes in animals subjected to close distances of drones; however, they discovered that there was an increase in physiological stress. The physiological stress potentially caused by drone disruption may induce decreases in reproduction and survival, higher energy expenditures and space-use changes, which may jeopardise the average fitness or even viability of certain populations [41]. The results in this study are based on observations of visible changes to *D. fluviorum* behaviour in response to a drone. Other potentially relevant indicators of disturbance are glucose concentration levels and changes in the type and frequency of vocalisations. Previous studies have used glucose levels to assess physiological stress related to post-release effects in elasmobranchs [42–44]; however, there have been no studies assessing the effects of drones on elasmobranch physiology. Further research is required to gain knowledge on the effect of non-visible factors and the potential consequences of drone exposure in elasmobranchs. However, the lack of response to drones shown in this study is a good first step towards a better understanding of the effects that drone flights have on the behaviour of *D. fluviorum.*

Researchers using drones to study marine animals should always adhere to the precautionary principle and fly at the highest possible altitude, even if there are no observable changes in behaviour due to the presence of the drone [14,21]. With this model of a consumer drone, at 10 m the drone has a clearer visual range of the individual, whilst still being close enough to observe behavioural cues. Given the capabilities of this model (DJI Mavic Platinum Pro), which has a fixed lens and a lower resolution (2.7 K) than that available in more current models (up to 6 K and/or a telescopic lens attachment), we suggest a minimum flight altitude of 10 m when observing rays of this size. Aircraft with a higher resolution (and by association, digital zoom) or telescopic lenses may choose to fly at altitudes above 10 m to further reduce the odds of any behavioural impacts. In establishing optimal drone-use protocols, resource managers are challenged with balancing the quality and type of data needed with the level of disturbance inflicted upon a variety of species [14]. This study has demonstrated the feasibility of using drones as a non-invasive research tool when studying *D. fluviorum* and provides foundational knowledge to address the uncertainty of drone disturbance as it relates to this species and potentially to rays more generally.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/drones7030164/s1. Excel file containing the data used for analyses.

Author Contributions: E.B., V.R., J.E.W. and T.F.G. conceived the study. E.B. and V.R. conducted the fieldwork. E.B. analysed the data. E.B. wrote the first draft of the manuscript. E.B., V.R., J.E.W. and T.F.G. produced the final version of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data are available as Supplementary Material.

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Conflicts of Interest: The authors declare no conflict of interest.

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