



Technical Note

# Assessing the Behavioural Responses of Small Cetaceans to Unmanned Aerial Vehicles

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**Abstract:** Unmanned Aerial Vehicles (UAVs), or drones, have recently emerged as a relatively affordable and accessible method for studying wildlife. Vertical Take-off and Landing (VTOL) UAVs are appropriate for morphometric, behavioural, abundance and demographic studies of marine mammals, providing a stable, nonintrusive and highly manoeuvrable platform. Previous studies using VTOL UAVs have been conducted on various marine mammal species, but specific studies regarding behavioural responses to these devices are limited and scarce. The aim of this study was to evaluate the immediate behavioural responses of common (*Delphinus delphis*) and bottlenose (*Tursiops truncatus*) dolphins to a VTOL UAV flown at different altitudes. A multirotor (quadcopter) UAV with an attached GoPro camera was used. Once a dolphin group was located, the UAV was flown at a starting height of 50 m directly above the group, subsequently descending 5 m every 30 s until reaching 5 m. We assessed three behavioural responses to a VTOL UAV at different heights: (i) direction changes, (ii) swimming speed and (iii) diving. Responses by *D. delphis* (n = 15) and *T. truncatus* (n = 10) groups were analysed separately. There were no significant responses of *T. truncatus* to any of the studied variables. For *D. delphis*, however, there were statistically significant changes in direction when the UAV was flown at a height of 5 m. Our results indicate that UAVs do not induce immediate behavioural responses in common or bottlenose dolphins when flown at heights > 5 m, demonstrating that the use of VTOL UAVs to study dolphins has minimal impact on the animals. However, we advise the use of the precautionary principle when interpreting these results as characteristics of this study site (e.g., high whale-watching activity) may have habituated dolphins to anthropogenic disturbance.



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## 1. Introduction

Unmanned Aerial Systems (UASs) have recently emerged as a relatively inexpensive and accessible method for studying wildlife [1–3]. These systems consist of an Unmanned Aerial Vehicle (UAV or drone), a launch and recovery system, a video camera payload mounted to the UAV and a ground control system [4]. These devices constitute an alternative to manned aerial surveys, having both improved manoeuvrability and less intrusion than manned aircraft, while also providing high-resolution video with lower risk to human life and at a potentially reduced financial cost [1,5–7]. Vertical Take-off and Landing (VTOL) UAVs are a category of UAS that are usually smaller and have the ability to hover in flight and take-off and land without a runway [1]. This provides a stable, nonintrusive and highly manoeuvrable platform for the detailed study of an individual or small groups of animals [1,2]. Nonetheless, in comparison to boats, manned aerial surveys and fixed-wing

UASs, some limitations of VTOL UAVs include limited battery life, rarely exceeding 20 min in commercial off-the-shelf variants, and reduced payloads [1,5,6].

Notwithstanding, VTOL UAVs are an excellent platform for aerial studies of marine mammals, having been used in studies of morphometrics, behaviour, demographics and relative abundance [6–12]. While many of these studies have focused on pinnipeds [2,10,11], others have also focused on cetaceans including humpback whales (*Megaptera novaeangliae*) [13,14]; grey whales (*Eschrichtius robustus*) [15]; southern right whales (*Eubalaena australis*) [16]; blue (*Balaenoptera musculus*), fin (*B. physalus*) and sperm (*Physeter macrocephalus*) whales [17]; killer whales (*Orcinus orca*) [12]; bottlenose dolphins (*Tursiops truncatus*) [18]; dusky dolphins (*Lagenorhynchus obscurus*) [7] and finless porpoise (*Neophocaena asiaeorientalis*) [19].

According to Smith et al. [2], two main factors can cause disturbance to marine mammals from UAVs: acoustic and visual cues. However, research regarding behavioural responses of marine mammals to VTOL UAVs has been relatively scarce and limited to a few species [1,2,4,18,20]. Pinnipeds such as harbour seals (*Phoca vitulina*), spotted seals (*P. largha*), ribbon seals (*Histiophoca fasciata*) and grey seals (*Halichoerus grypus*) have been recorded exhibiting stress or avoidance behaviours when confronted by either visual or acoustic effects from VTOL UAVs [2,10,11]. This may be due to association with avian predators that cast a shadow of similar size to the UAVs when at certain altitudes [2].

However, visual and acoustic effects from VTOL UAVs may have little impact on cetaceans. First, VTOL UAVs have a relatively small acoustic signature [2,5,21]. For example, Christiansen et al. [3] used underwater microphones to conclude that small UAVs flown at altitudes > 10 m are virtually inaudible to both mysticetes and odontocetes at depths of 1 m in coastal areas. Unlike pinnipeds, the cetacean ear is no longer adapted for hearing in air thus potentially reducing the perceived auditory impact of UAVs on cetaceans, even at the surface [22]. Second, the relatively small size of VTOL UAVs provides a visual signature that, even if perceived at all, could potentially be discarded as nonthreatening due to the lack of cetaceans' natural aerial predators [23]. In fact, there is anecdotal evidence for bottlenose dolphins playing with the shadow cast by one of these devices [2,20]. The few existing studies on the behavioural responses of cetaceans to UAVs indicate that some cetaceans appear to be relatively undisturbed by them [1,2]. However, restriction of these studies to cetaceans of relatively large size (> 6 m) [2] leads to limitations in the generalisability of these findings to smaller cetacean species such as bottlenose [18,20] and common (*Delphinus delphis*) dolphins.

The aim of the present study was to evaluate the immediate behavioural responses of common and bottlenose dolphins to a VTOL UAV. To test the null hypothesis of no response, we measured changes in direction, swimming speed and diving behaviour of dolphin groups to a VTOL UAV flown at different heights.

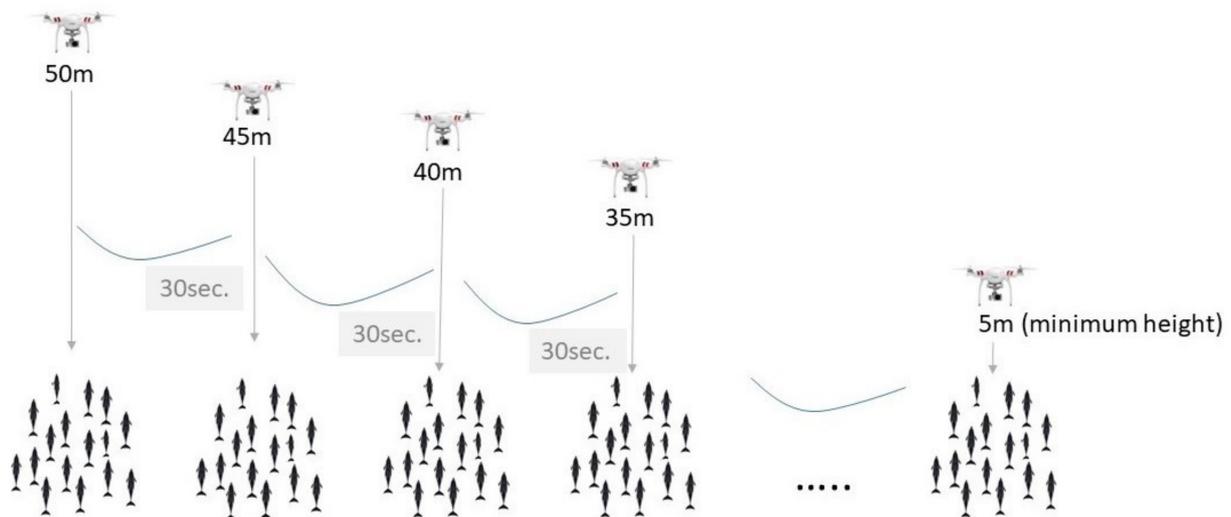
## 2. Materials and Methods

A multirotor (quadcopter) VTOL UAV (DJI Phantom 2; 35 cm diameter, 1 kg, plastic propellers, <http://www.dji.com>) with an attached GoPro HERO4 camera was used. A radio antenna system installed on the UAV allowed live-streaming of video during flight. The study site was located in the Algarve region in the south coast of Portugal, between Cape St. Vicente (37°1.35'N, 8°59.81'W) and Olhão (37°1.56'N, 7°50.54'W) at a maximum distance of 25 nautical miles (nm) from shore. In this region, several species of cetaceans occur year-round, posing a potential hotspot for species such as common and bottlenose dolphins [24,25]. It is also a region where both dolphin species are the focus of commercial whale-watching tours [26,27]. This study was conducted under the authorisation of the Portuguese Conservation Institute (ICNF–AOC/17/2016).

During the summer months of 2017, random surveys were conducted to locate common and bottlenose dolphin groups. Once a group was sighted, the research vessel (a 7 m RHIB with 4-stroke 135 hp outboard engine) approached at a distance of approximately 30 m, unless the animals approached the vessel more closely. In an effort to habituate

the group of dolphins and minimise possible impacts of the research vessel, the group was followed for  $\geq 15$  min prior to launching the UAV. During sampling, the research vessel maintained a distance of 30–100 m from the group. These distances were intended to be a compromise between the capability of observing the group closely and minimising the impact of the vessel on the behaviours of the animals. The 30 m distance is also the approach limit to an individual or group of cetaceans, according to the Portuguese Law (Decreto-Lei n.º 9/2006). All sampling was conducted with no other boats present within a 1 nm radius, Beaufort Sea state of  $\leq 3$ , swell of  $< 0.5$  m and visibility  $\geq 5$  km. These sampling criteria were established to control for the effect of environmental conditions (since they can largely determine the acoustic effects of the UAV on dolphins [2]) and to ensure suitable conditions for observing the group and accurately determining changes in the variables being tested.

The research team consisted of a boat driver, UAV pilot and dolphin observer(s). Once the UAV was aloft, it was flown towards the dolphin group at an initial height of 70–100 m. When the group was inside the UAV's field of view, it was slowly lowered to a height of 50 m directly above the dolphin group. The UAV subsequently descended 5 m every 30 s until reaching 5 m above sea level (Figure 1), resulting in 10 sampling periods. The time span of 30 s was chosen because: (i) we wanted to limit the amount of potential disturbance to the animals and (ii) we considered this an appropriate time interval to measure the animals' immediate responses to the VTOL UAV [18]. Trials were performed once a day, with three exceptions when a total of two trials occurred on the same day. However, to prevent group resampling and thus pseudoreplication, in these cases the second trial was conducted  $\geq 1$  h after having navigated  $\geq 1$  nm in the opposite direction of the previously sampled group.



**Figure 1.** Experimental design used to test the immediate behavioural responses of *Delphinus delphis* and *Tursiops truncatus* to a Vertical Take-off and Landing Unmanned Aerial Vehicle.

Before the start of each flight, the species, group size and behavioural state (Table 1) of the group were recorded. A “group” was defined following the 10 m chain rule and coordinated activity [28,29]. To examine the immediate behavioural responses of dolphins to the UAV, the following behavioural changes were considered: (i) direction—a change was considered to have occurred when the majority of the group exhibited a direction change of  $\geq 45^\circ$  with respect to the previous heading; (ii) swimming speed—a change was considered to have occurred when the speed of the group exceeded that of the vessel travelling at the same speed of the group and (iii) diving—when the majority of the group dove (i.e., individuals arched their back at the surface and increased their angle of re-entrance, diving vertically) synchronously for longer intervals than was previously observed. These

variables were chosen because wild animals, including cetaceans, often perceive human activities as a predation threat and may consequently respond to anthropogenic disturbance by engaging in antipredation behaviours such as fleeing, increasing vigilance or altering habitat use [30–32]. Specifically, cetacean antipredation behaviours include changes in movement patterns [33–35], increases in swimming speed [33–36] and longer interbreath intervals [37].

All data were collected in real-time through visual observation from the research vessel (i.e., not through post hoc analysis of the UAV video). This method was used because optimal video recording can be affected by environmental variables (e.g., sun glare), which preclude the UAV from being flown directly above the dolphins. Each behavioural change was recorded as a binary measurement (i.e., “yes” or “no”) during each sampling interval. To avoid bias, the same person flew the UAV (A. Cid), and the same observer recorded behavioural data (J. Castro) throughout the study.

Statistical analysis was conducted using SPSS Statistics v. 25 (IBM, Armonk, NY). Heterogeneity between trials was assessed for each response variable (i.e., direction, speed, diving) to ensure assumptions of the statistical test were met. A Cochran’s Q test was performed to determine if dolphins exhibited immediate behavioural changes according to UAV height. Both species were tested separately, and the two-tailed significance level was set at  $\alpha = 0.05$ . When significant, the Cochran’s Q test was followed by a Dunn’s post hoc test to determine at which heights the differences occurred.

**Table 1.** Definitions of behavioural states for *Delphinus delphis* and *Tursiops truncatus*.

Behavioural State	Definition
Foraging	Searching for or consuming prey, as indicated by long, deep dives followed by loud forceful exhalations (“chuffs”) and directionless movement; may include coordinated “burst swims” (rapid bursts of speed), “clean” noiseless headfirst re-entry leaps, coordinated clean leaps and tail slaps
Resting	Slow directionless movement at speeds of < 3 knots close to the surface with low activity level; often includes slow surfacing and floating near the surface
Socialising	Interacting with each other or inanimate objects; usually directionless movement and may include body and pectoral fin rubbing, rolling, belly-up swimming, spyhops, splashing at the surface, chasing, leaping, mating and playing with seaweed
Travelling slow	Steady movement in one direction at speeds of < 3 knots
Travelling average	Steady movement in one direction at speeds of 3 to 5 knots
Travelling fast	Steady movement in one direction at speeds of > 5 knots

### 3. Results

Data were collected on 15 and 10 groups of *D. delphis* and *T. truncatus*, respectively, from May to September 2017. For common dolphins, the majority (53%) of groups exhibited an initial behavioural state of travelling slow prior to each flight (Table 2). In contrast, the most common initial behavioural states of bottlenose dolphins were travelling average and socialising (both 40%). Average group sizes for common and bottlenose dolphins were  $20.6 \pm 19.3$  SD and  $13 \pm 12.5$  SD, respectively.

**Table 2.** Initial behavioural state for *Delphinus delphis* (n = 15) and *Tursiops truncatus* (n = 10) groups prior to the start of each Vertical Take-off and Landing Unmanned Aerial Vehicle flight.

Species	Travelling Slow (%)	Travelling Average (%)	Travelling Fast (%)	Socialising (%)	Feeding (%)
<i>Delphinus delphis</i>	53.3	13.3	20.0	6.7	6.7
<i>Tursiops truncatus</i>	20.0	40.0	0	40.0	0

Common dolphins did not exhibit changes in diving behaviour or swimming speed with decreasing UAV height (Table 3). However, common dolphins did exhibit significant changes in direction. Specifically, *D. delphis* were observed performing significantly more direction changes when the UAV was at a height of 5 m ( $Z = 2.791$ ,  $p = 0.005$ ) compared to other heights, with the exception of 20 and 30 m. No other significant differences were observed for any of the other pairwise comparisons for *D. delphis*. *T. truncatus* showed no significant behavioural responses to the UAV; direction changes were not analysed since there was no response variation in this variable across all 10 observations (Table 3).

**Table 3.** Results of Cochran’s Q tests performed to determine behavioural responses of *Delphinus delphis* and *Tursiops truncatus* to the vertical approach of a Vertical Take-off and Landing Unmanned Aerial Vehicle (significant values shown in bold).

Species	Behavioural Response	N	Cochran’s Q	df	p-Value
<i>Delphinus delphis</i>	Diving	15	14.27	9	0.113
	Direction change	15	18.00	9	<b>0.035</b>
	Swimming speed	15	13.09	9	0.159
<i>Tursiops truncatus</i>	Diving	10	13.05	9	0.161
	Swimming speed	10	9.00	9	0.437

#### 4. Discussion

The present study evaluated the immediate behavioural responses of common and bottlenose dolphins to a UAV flown at different heights. While previous research examined the impact of UAVs on bottlenose dolphins [18,20], to our knowledge, this is the first study to assess the impact of VTOL UAVs on common dolphins. The UAV did not cause a significant change in diving behaviour or swimming speed for either species.

For common dolphins (but not bottlenose dolphins), however, there were significant changes in direction when the UAV was flown at a height of 5 m. This suggests that common dolphins may be more sensitive than bottlenose dolphins to the effects of a UAV flown at very low heights. Our results indicated that common dolphins also responded to the UAV at heights of 20 and 30 m. One potential explanation is that the dolphins detected some level of risk or disturbance from the UAV at these heights and responded briefly by changing direction before developing a short-term habituation to the UAV. Overall, however, these results indicate that UAVs do not induce immediate behavioural responses when flown at heights of  $\geq 10$  m for common dolphins or  $\geq 5$  m for bottlenose dolphins.

These results demonstrate the feasibility of using UAVs as a non-invasive research tool in dolphin research. Using a UAV for behavioural studies can, for example, potentially reduce the impacts of the research vessel on the dolphins and reduce biased observations. It also allows the possibility of gathering high-quality videos, allowing a more detailed behavioural analysis and the opportunity to review the footage several times [7,20]. These devices also present a different and possibly more advantageous perspective on cetacean behaviour, with the possibility of observing subsurface behaviours [7,20]. In fact, Weir et al. [7] concluded that UAVs are better platforms than small research vessels for behavioural data collection on dusky dolphins, particularly when determining group spacing and interindividual interactions. In this same study, a UAV was used to quantify mother–calf behaviour (e.g., calf respiration and suckling rates), data that would be challenging to obtain via other methods. UAVs can also aid in assessing cetacean morphology and size [12,38], collecting biological samples such as respiratory blow [17] and measuring group composition, size and cohesion [7,14,20].

Fettermann et al. [20] reported that resting bottlenose dolphins reacted to the presence of a VTOL UAV when flown at a height of 10 m. Specifically, these individuals increased the number of reorientation and tail slap events at this height but exhibited no significant behavioural response at UAV heights  $\geq 25$  m. Similarly, Würsig et al. [39] found that small delphinids tend to be more sensitive to aerial disturbances of small research aircraft when

milling or resting. In the present study, however, none of the sampled bottlenose dolphin groups displayed resting behaviour. This could explain the lack of any significant response to the UAV even at lower heights for this species.

Although bottlenose dolphins were not observed to change their behaviour with respect to UAV height, they were observed several times exhibiting an apparent visual interest (i.e., side swimming and side floating) under the UAV during sampling. Unfortunately, this was not recorded consistently and is based on anecdotal observations. Fettermann et al. [20] also reported observation of an individual bottlenose dolphin performing side floating behaviour just after the UAV's shadow passed over its body, although they could not confirm this was a response to the UAV itself. However, a study conducted by Ramos et al. [18] identified that side floating/side roll events were the main responses exhibited by bottlenose dolphins towards the UAV, suggesting that measuring the incidence of side turning behaviours may be a useful way to detect responses to UAVs in some cetacean species.

Dolphin reactions may vary according to the behavioural state, size and composition of the dolphin group at the time of exposure to the UAV. For example, groups that are socialising or foraging may change direction, speed and diving behaviour more frequently than groups that are resting or travelling, making behavioural responses to the UAV difficult to discern. Further, groups that are smaller (vs. larger) or contain calves (vs. lack calves) may be more reactive, as observed in previous studies when cetaceans were exposed to aircraft [8]. Unfortunately, due to the small sample size in the present study, it was not possible to include these factors as independent variables in the model. However, these and other potentially confounding factors such as age, sex and biological state [11] should be considered in future studies.

The results reported in this study are based on observations of visible changes to dolphin behaviour in response to the UAV. It is also important to examine other potentially relevant indicators of disturbance (e.g., changes in the type and frequency of vocalisations, stress hormone levels) with respect to UAVs. Future research on the impact of UAVs on cetaceans should consider such traits as have been studied in other vertebrate species (e.g., black bears (*Ursus americanus*) [40], African elephants (*Loxodonta africana*) [41] and orangutans (*Pongo abelii*) [42]).

## 5. Conclusions

The results of this study indicate that UAVs are a powerful tool for cetacean research. While both *D. delphis* and *T. truncatus* exhibited few immediate behavioural responses to the UAV, the significant response by common dolphins should not be neglected. Caution should be taken when extrapolating these results to other regions since the high level of whale-watching activity at our study site may have habituated the dolphins to anthropogenic disturbance making it possible that they are less reactive compared to more secluded populations, which inhabit more remote areas [43]. In addition, the UAV used in this study was a small VTOL platform, and variation in size and power of other VTOLs could elicit different responses [2,11,20]. Further, it is possible that UAVs may induce unwanted and yet-to-be-determined impacts. As there could be species-specific responses [18], a “one-size-fits-all” approach may not be applicable [2]. Therefore, until further research reveals if and how UAVs affect the species of interest [3,44], the precautionary principle should be employed. Finally, it is imperative to develop and implement guidelines to minimise the potential impact of UAVs [44]. The present study intends to contribute towards this goal.

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**Conflicts of Interest:** The authors have no conflicts of interest to declare.

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