Validating the use of drones for monitoring the abundance and behaviour of juvenile green sea turtles in mangrove creeks in The Bahamas

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Introduction

Over the past decade, Unoccupied Aerial Vehicles (UAVs), also known as drones, have been widely incorporated into many ecological studies (Allan et al. 2015). These devices, which are now available 'off-the-shelf' and are becoming increasingly affordable, can collect accurate visual imagery over ranges that can extend up to tens of kilometres in almost any habitat (Duffy et al. 2018). As such, they are suited to monitor species that may be difficult to view on foot or by vehicle but can be readily spotted from an aerial vantage point (Linchant et al. 2015). For this reason, UAVs are incredibly beneficial for monitoring many marine species, such as sea turtles (Schofield et al. 2019).

Before the recent commercialization of drone technology, most researchers employed boats or low-flying aircraft to conduct rapid in-water population assessments for sea turtles (Eguchi et al. 2007; Seminoff et al. 2014). During these surveys, human spotters were generally used to identify the presence and abundance of turtles within the survey area. These studies provided valuable insights into the abundance and distribution of sea turtles and many other marine species (Pollock et al. 2006; Rowat et al. 2009; Williams et al. 2017); however, they also had their limitations (Colefax et al. 2018). For example, procuring a boat or aircraft can be prohibitively expensive and logistically challenging for many projects, especially when repeat surveys are required. In addition, the human spotters used in these surveys may vary considerably in their observational abilities. In turn, this could influence the accuracy of the data collected and can lead to problems with standardising monitoring efforts between surveys (Hone 2008).

Considering these issues, drone-based surveys can serve as a viable alternative for rapid in-water monitoring of sea turtles (Rees et al. 2018). One of the benefits of drone surveys over boat- or aircraft-based surveys is that a single drone can be flown repeatedly without incurring additional costs, making them suitable for long-term studies over prolonged timeframes. Secondly, drone surveys are generally more straightforward in terms of logistics, only requiring a single person with the relevant permits. Thirdly, drones can overcome the human error associated with opportunistic visual surveys as the field of view of the drone's cameras can be easily calculated and the footage can be viewed post-hoc as many times as necessary (Hodgson et al. 2018). In addition to these benefits, drones are also capable of undertaking more flexible flight paths than manned aircrafts, allowing drone pilots to remain focussed on a specific individual or environment for as long as the battery lasts. This raises some interesting possibilities for the observation of animal behaviour that might be challenging to witness with more conventional methods.

Here, we tested the potential for drones to support in-water monitoring of juvenile green sea turtles (*Chelonia mydas*) in the waters of southern Eleuthera, The Bahamas. This area hosts populations of several sea turtle species, although the most abundant are the juvenile green turtles that inhabit several of the local shallow-water (<5m) mangrove creek systems. A sea turtle tagging programme has been active in these creeks since 2011 and has provided valuable data on abundance and behaviour of the local turtle populations. Yet due to many of the aforementioned limitations associated with boat-based surveys, we foresaw important benefits to validating the use of drones to survey the turtles in these habitats. To achieve this, we aimed to (1) evaluate the feasibility of using a small commercially available drone, the DJI Phantom 4 Pro, to rapidly and reliably assess the numbers of turtles that can found in several mangrove creek systems in Eleuthera and (2) determine whether this drone could also provide a useful technique for monitoring the undisturbed behaviour of individual turtles.

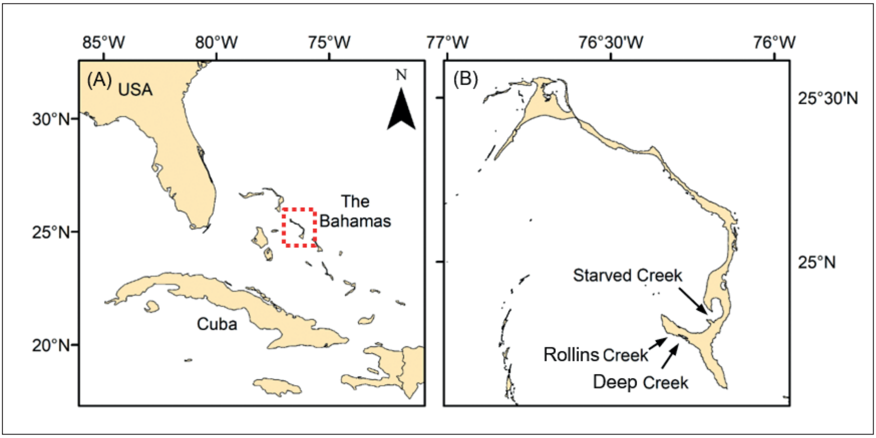

Fig. 1. (A) Map indicating the location of Eleuthera as highlighted by the dotted red square. (B) Close-up map of Eleuthera indicating the location of the three mangrove creeks surveyed in this study.

Methods

Study sites

The study was conducted at the south-western end of the island of Eleuthera, The Bahamas, in three mangrove creeks: Rollins Creek, Deep Creek and Starved Creek (Fig. 1). These creeks host extensive beds of turtle grass *Thalassia testudinum* and manatee grass *Syringodium filiforme,* which are fringed by *Rhizophora mangle* and *Avicenna germinans* mangroves. These shallow-water habitats (<2m deep) are subject to a semi-diurnal tidal cycle, with a maximum semi-diurnal tidal range of 80cm, which means that often much of the mangrove habitats are fully exposed at low tide. The benthic substrate varies between sand, rock and mud.

Abundance surveys

To survey each creek in a repeatable and standardised manner, we designed automatable flight pathways for the three creeks using the autopilot software Litchi. To determine the drone's pathways, we chose routes that were known to both be sea turtle habitats and be inundated at all tidal states. This latter factor would ensure that surveys could be conducted whenever possible. The total length of each survey was constrained by the maximum flight time of the drone (25 min). For Rollins and Deep Creek, the flight path was 1.41km and 1.75km long respectively and primarily followed the deepest channel in both creeks. In Starved Creek, the flight path was 2.23km long and followed the perimeter of the bay area at the mouth of the creek (Fig. 2).

In each of the three creek systems, we conducted three separate drone surveys on different dates using a DJI Phantom 4 Pro. Surveys were

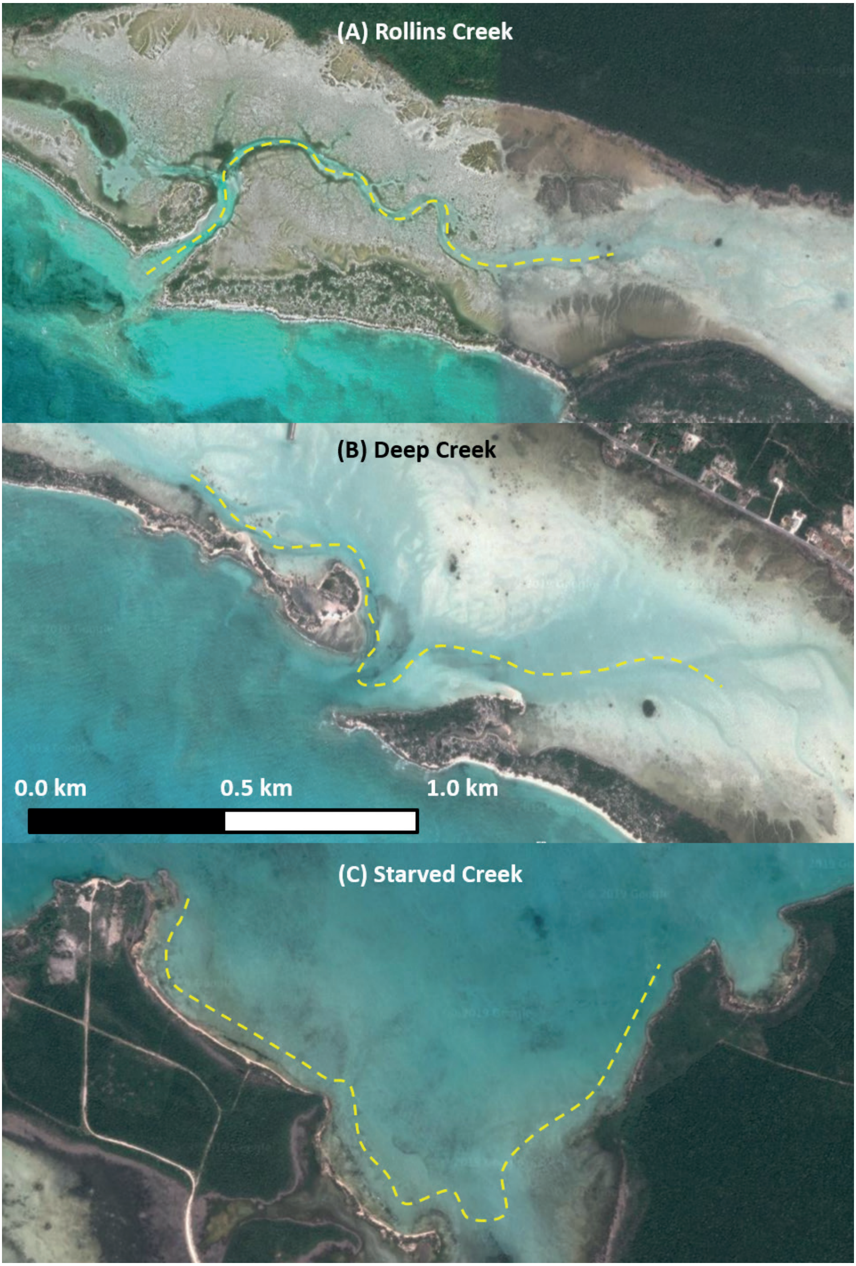

Fig. 2. Satellite imagery of the 3 study sites: (A) Rollins Creek, (B) Deep Creek, and (C) Starved Creek. Yellow dashed lines represent the pathway flown by the drone during automated surveys.

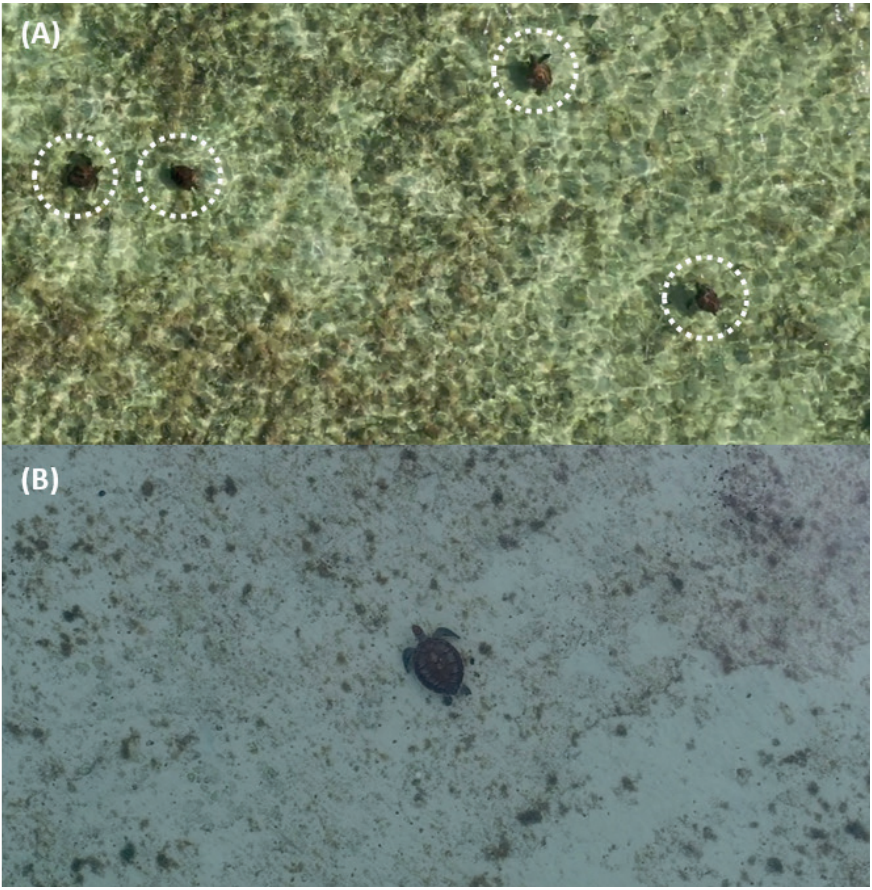

Fig. 3. (A) An example still from footage collected during an abundance survey in Starved Creek. Turtles are highlighted using dotted white circles to aid visualization. (B) An example of a resting turtle observed during the behavioural surveys.

conducted at an altitude of 30m and at a speed of ~7.5km h^{-1}. Total survey flight times at this speed were 10.01min, 12.29, and 15.52 for Rollins Creek, Deep Creek and Starved Creek respectively. We chose this speed as it kept the survey duration safely under the maximum flight duration of the drone, while being sufficiently slow to enable accurate identification of any observed turtles. During each survey, the drone recorded continuous video footage at a resolution of 4k with the drone's camera facing perpendicular (90°) to the water.

To analyse the footage generated on the drone surveys (Fig. 3A), each survey was reviewed by at least three of the co-authors. These reviewers would then independently record every sea turtle they spotted during the survey. To compare the abundance of turtles between each creek, the number of turtles seen on each survey was divided by the length of the survey area. It should be noted that this gives a value of turtles per m and not turtles per m^2, as would be preferable; however, survey paths in Rollins and Deep Creek did not entirely consist of potential turtle habitat as sections of the survey areas were either covered by dense mangroves or became exposed at low tide. Because of these limitations, reporting assessment of turtle density per metre was deemed more accurate.

Behavioural surveys

To record sea turtle behaviour by drone, the drone was opportunistically flown in each of the three creeks at an altitude of 30m, using the real-time visual feed to look for the presence of sea turtles. Once a sea turtle was spotted, the drone was lowered to an altitude of 15m above the chosen individual. Recording then began with the drone remaining above the same individual until the battery was low enough to necessitate recovery (Fig. 3B). Upon drone recovery, its batteries were replaced and a following survey was conducted until we ran out of batteries. To ensure that a different turtle was recorded each time, the search was begun in an area at least 200m away from the last observed location of the previous turtle. Using these methods, the behaviour of three turtles in each of the three study creeks was recorded.

To analyse the footage generated by the behavioural surveys, the observed behaviour was divided into six different categories, recording the amount of time each individual spent exhibiting each behaviour. The behavioural categories were: (1) swimming – identified by active use of the front flippers in a swimming motion; (2) surface breathing – identified as the time spent by the individual at the surface both breathing and resting in between breaths; (3) resting on the seafloor – identified as time spent motionless on the seafloor; (4) foraging – identified as time spent actively foraging on seagrass or algae; (5) interacting with conspecifics; and (6) other – any behaviour not covered by the other categories.

Results

Abundance surveys

Turtles were observed by each reviewer on all three drone surveys conducted in each creek system (minimum two turtles per survey, maximum eight turtles per survey) (Fig. 4). Only on two surveys, the first and third conducted in Rollins Creek, did all three reviewers record the same number of turtles for a single survey. For five other surveys, specifically the second in Rollins Creek, the first and third in Deep Creek, and the second in Starved Creek, two of the reviewers recorded the same number of turtles, while the remaining reviewer

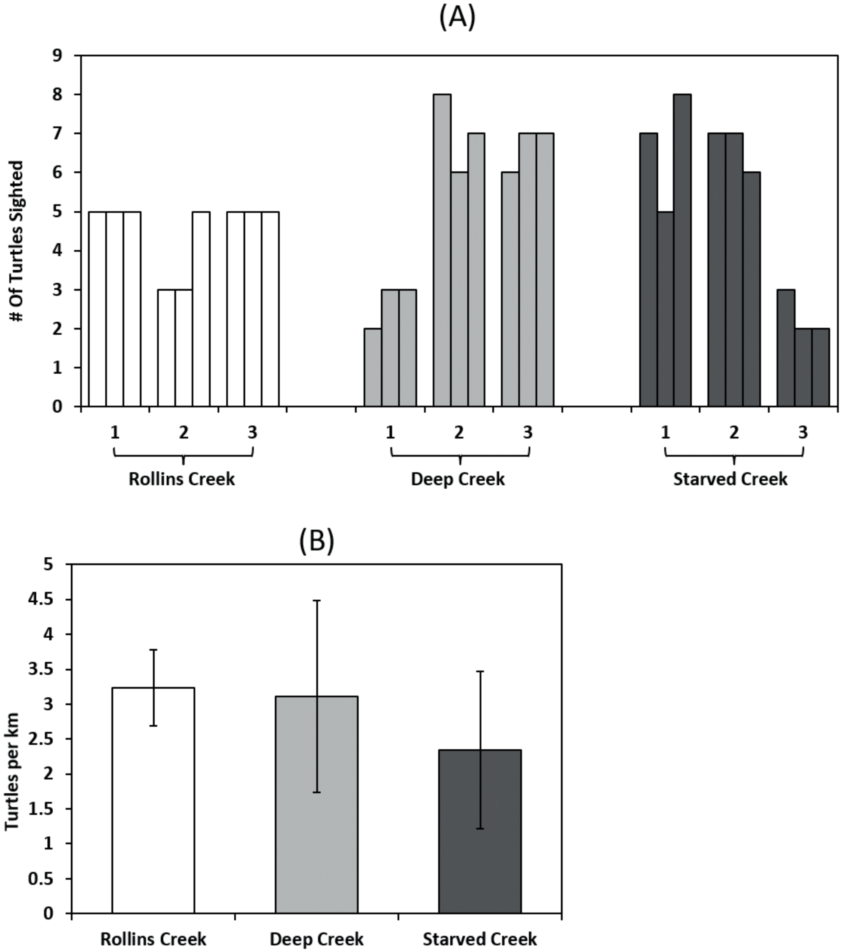

Fig. 4. (A) Average density of turtles recorded in each creek over the three surveys. (B) Number of turtles recorded after reviewing footage from drone surveys in Rollins, Deep and Starved Creek. Individual bars represent the number of turtles spotted by each of three reviewers from each of the three surveys in each creek.

was different in their result by either one or two individuals. For the remaining two surveys, the second in Deep Creek and the first in Starved Creek, all three reviewers recorded different numbers of turtles and the largest discrepancy between reviewers was recorded for the first survey in Starved Creek. The mean number of turtles spotted during each survey was highest in Rollins Creek (3.2 per km ± 0.5 SD), slightly lower for Deep Creek (3.1 per km ± 1.3 SD) and lowest for Starved Creek (2.3 per km ± 1.1 SD).

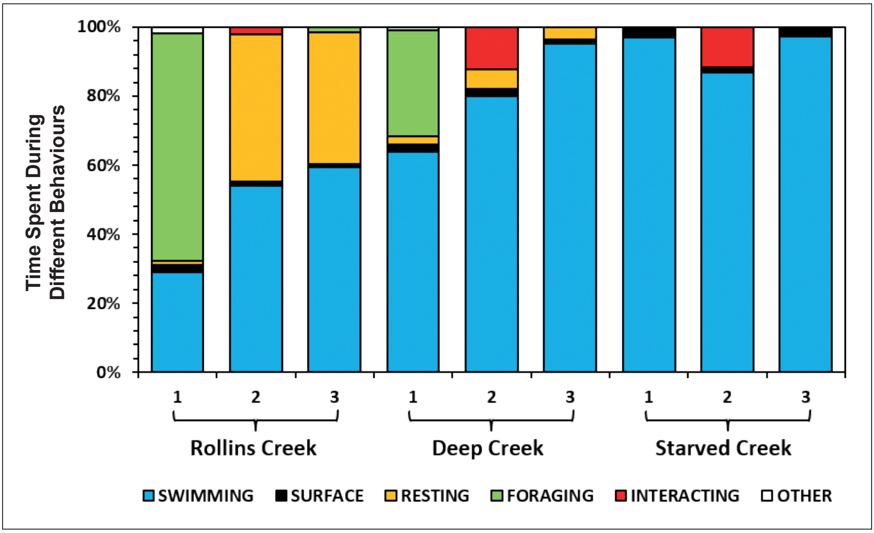

Fig. 5. Percentage of the time observed conducting different behaviours for three juvenile green sea turtles in either Rollins, Deep or Starved Creek.

Behavioural surveys

Over the 9 behavioural surveys, we recorded over 127 min of footage or an average of 14.2 min per individual (range: 8.7-16.8 min) (Fig. 5). The most observed behaviour for all but the first individual was swimming, which occupied between 29.0 and 97.2% of the total observed time for each individual. The sole exception for this was the first turtle recorded from Rollins Creek, which only spent 29.0% of its time swimming but 65.8% of its time foraging. Foraging was observed in three of the nine turtles recorded and only six of the nine were observed resting on the seafloor. Interestingly, four of the nine turtles were observed spending time socializing with other turtles, albeit for a relatively small period of their recorded time (2.0-12.3% of the time).

Discussion

Drones are now being used to answer an increasingly diverse range of ecological questions for sea turtles (Rees et al. 2018; Schofield et al. 2019). Yet as the practicality of using drones is strongly dependent on the environment in which they are being used (Duffy et al. 2018), there is a need to validate the use of drones across the various habitats that are utilized by sea turtles. Here, we aimed to assess the practicality of drone use for the monitoring of green turtles in the shallow-water mangrove creeks of The Bahamas.

Specifically, we aimed to see if the small, commercially-available DJI Phantom 4 Pro was a suitable device, in terms of image resolution and battery-life, to provide valuable data on the abundance and behaviour of juvenile green turtles in three mangrove creeks in Eleuthera. The data we have collected in this study have confirmed that these devices are indeed practical tools for the monitoring of local sea turtle populations in these environments. Furthermore, our initial experiences in conducting this study have provided us with several important insights that have highlighted potential directions for future studies.

During the abundance surveys, we successfully monitored areas up to 2.23km in length and turtles were sighted on every survey. However, it must be noted that even though the numbers of turtles sighted per survey was relatively small, ranging from two to eight turtles per survey, these numbers varied when the same footage was reviewed by different people. Indeed, only in two of the nine surveys conducted did all three independent reviewers count the same number of turtles. This highlights the potential for error in drone count data, even when dealing with small surveys with low numbers of individuals.

This variability between reviewers was likely to be due to a combination of two factors: surface ripples and the colouration/heterogeneity of the seafloor. Surface ripples understandably obscure the outline of a turtle below the surface, making turtles difficult to discern. To address this issue, researchers could choose to only conduct drone surveys when wind speeds are nominal and thus reduce the potential for surface ripples. Nevertheless, this may only be feasible in those cases when it is possible to delay survey dates until suitable weather conditions occur. In other cases, a more practical solution may be to develop a method to quantify ripple intensity during the survey and then factor this into account when determining the potential for error in the count data.

Concerning the colouration/heterogeneity of the seafloor, it is easy to consider that when the background is made up of patchy substrates, such as seagrass or algae that may be a similar colour to a turtle's, this can lead to both false positives and false negatives being recorded. One way to address this issue would be to only conduct surveys above substrates that provide a high contrast, e.g. sand, over which turtles can be easily spotted. However, this would self-evidently limit the habitats that can be surveyed and this may not be suitable in all cases. Instead, a more practical solution may be to once again account for this error by quantifying the potential for error when surveying these habitats. One method to achieve this would be to place known numbers of 'artificial turtles', which mirror live turtles in shape and colour, throughout these habitats and then run trial surveys to determine how often reviewers are able to accurately identify artificial turtles. Such methods for quantifying errors in aerial surveys have already been used successfully when conducting abundance surveys for sea turtles via low-flying manned aircraft (e.g. Fuentes et al. 2015).

Beyond count data, we also showed that the DJI Phantom 4 Pro is a useful tool for short-term monitoring of sea turtle behaviour in Bahamian mangrove creeks. At the predefined altitude of 15m, we were able to identify the turtle behaviours while still being high enough that the drone's propellers did not create obscuring ripples. Furthermore, as these are shallow-water habitats (<2m deep) and the water clarity is high enough to see the seafloor at all times, we were able to continually follow a single turtle for an extended period of time without loss of sight with relative ease. That said, it should also be mentioned that the duration of time that can be spent following an individual was not just limited by the battery-life of the drone itself but also by the time needed to sight the turtle in the first place. In most instances, we required around five minutes to locate a turtle, which will clearly vary between sites, and this search time directly reduces the amount of time that can then be spent following that individual. Because of this, despite the battery-life for the DJI Phantom 4 Pro being approximately 25 min, the longest continual video recorded from a single individual was 16.8 min.

The behavioural data collected in this study, admittedly with a relatively small sample size for a behavioural study, showed that turtles were predominantly recorded swimming. This was interesting as there was plenty of food available in the form of algae and seagrass, a primary diet of green turtles (Gillis et al. 2018) and almost no turtle predators were observed. Having abundant food and little risk of predation, it might be expected that these turtles would spend the majority of their time either feeding or resting. One explanation for this could be that our method of opportunistically recording the first turtle sighted via the drone is biased towards recording swimming animals. Indeed, swimming animals are easier to spot than stationary individuals and so they were more likely to be sighted and then filmed. Alternatively, it could be that the continuous swimming was an avoidance behaviour in response to the nearby presence of the drone. We believe this is unlikely as we never observed any rapid flight behaviour from the turtles when approached by the drone at a height of 15m, and other studies have similarly noted that no immediate avoidance behaviour is observed when drones are flown above 10m altitude (Bevan et al. 2018). Nevertheless, this does still warrant further research. A study to address this potential impact could compare turtle behaviour filmed by drones at different heights. By comparing the percentage of time spent displaying different behaviour such as swimming or feeding, such study may provide a more sensitive measure of whether sea turtles are affected by the nearby presence of a drone than simply looking for rapid avoidance behaviour.

In conclusion, the DJI Phantom 4 Pro appears to be a practical and versatile tool for monitoring sea turtles in Bahamian mangrove systems. Nevertheless, to ensure that we gain the maximum possible insights from these devices, we need to carefully consider multiple factors, including human error associated with interpreting visual data as well as how sea turtles are influenced by the nearby presence of drones. If we are able to account for these issues, we believe that drones will become an increasingly useful tool for sea turtle biologists worldwide.

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