Feasibility assessment of commercially available Unmanned Aerial Vehicle sensor and payload functions for crocodile population surveys

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Feasibility assessment of commercially available Unmanned Aerial Vehicle sensor and payload functions for crocodile population surveys

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Abstract. In recent years, there has been a growing interest in using Unmanned Aerial Vehicles (UAVs) for monitoring crocodile populations. We therefore assessed the feasibility and effectiveness of using commercially available UAV features for monitoring the population of critically endangered Siamese crocodiles (*Crocodylus siamensis*) in Crocodile Lake (Bàu Sấu), Nam Cat Tien National Park, Vietnam. The study deployed a DJI Mavic 2 Enterprise Advanced drone with a Smart Controller, a Thermal Infrared (TIR) sensor, a RGB visual camera, and a spotlight payload. The study conducted manual and pre-programmed systematic mission flights above Crocodile Lake to include heterogenous portions of the landscape and to assess variable crocodile detectability over areas of open land, vegetation, and open water. The results of our study show that systematic night flights at 20 m altitude using a DJI dual spotlight at a 45° downward angle, coupled with RGB and co-registered TIR sensors (with continuous gradient palettes on the flight controller) also set to 45° angle, are effective for crocodile population monitoring. Although brief, our study shows that conducting UAV flights in both day- and night-time conditions using TIR, RGB, and spotlight payloads can provide a comprehensive understanding of crocodile population given various strengths and limitations of each. Finally, our experience allows us to provide feasibility recommendations for the use of UAVs to monitoring of crocodile populations in a global context.

Key words. *Crocodylus siamensis*, drone, RGB camera, spotlight, thermal infrared

Introduction

For several decades, spotlight surveys from either boats or land (hereafter ground-based spotlight surveys, GSSs) using direct observations of eyeshine have been the standard for monitoring abundance and distribution of crocodile populations (Bayliss, 1987; Fukuda et al., 2013). These surveys are often conducted at night, when the eyeshine of crocodiles is more visible. However, GSSs have several limitations, including (1) the need to survey a large area by boat, on foot, or both, which takes significant human resources; (2) overcoming logistics with accessing the remote areas where crocodile surveys are often conducted, which can be physically difficult costly (e.g., petrol, personnel, and equipment costs); and (3) the lack of recorded footage that can be reviewed after the surveys.

In recent years, there has been a growing interest in using unmanned aerial vehicles (UAVs) for monitoring crocodile populations (Evans et al., 2015; Ezat et al., 2018; Black, 2019; Scarpa and Piña, 2019; Aubert et al., 2021; Sawan et al., 2023). UAVs, also known as drones, are small aircraft that can be flown remotely and can be equipped with a variety of sensors and payloads. These efforts have shown that sensors and payloads can be used to gather data on crocodile populations, including their size, distribution, habitat use, behaviours, and even thermal ecology.

The current study was conducted to assess the feasibility and effectiveness of using commercially available UAV features to optimize crocodile monitoring via drone flights above an isolated population of Critically Endangered Siamese Crocodiles, *Crocodylus siamensis* Schneider, 1801, in Crocodile Lake, Nam Cat Tien National Park, Vietnam (Bezuijen et al., 2012). The study focuses on the use of daytime Red Green Blue camera footage and still images (RGB), thermal sensor imagery, night-time RGB using a spotlight payload, and co-registered imagery to provide recommendations for the monitoring conservation and management of this species and other crocodilian monitoring programs globally.

Materials and Methods

Study Site. Crocodile Lake (Bàu Sấu) is an isolated lake within the 13,759 ha Nam Cat Tien RAMSAR Wetland complex of Cat Tien National Park, southern

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Vietnam (11.5°N, 107.4°E). The site is a key habitat for the last remaining sustained wild population of Siamese crocodiles in the country.

Drone model, sensors, and payloads. We deployed a DJI Mavic 2 Enterprise Advanced drone with a Smart Controller rated for 10 km HD transmission (Fig. 1). This drone incorporates co-registered thermal and RGB imaging functions and accessory payloads, including a 12-μm pixel pitch, an Uncooled VOx Microbolometer Thermal Infrared (TIR) sensor with a 8–14 μm spectral band, a 640 × 512-pixel resolution at a framerate of 30 Hz, a 35-mm lens with an 84° field of view, 16x digital zoom, a 48MP RGB camera with 32x digital zoom, and an attachable DJI dual spotlight accessory. In addition to the spotlight, the drone also has a fixed 90° spotlight beacon on its base that has a default trigger during take-off and landing but can be manually turned on from the Smart Controller during flights.

Flights. We conducted manual and pre-programmed systematic mission flights using the default DJI Pilot 2 app on the Smart Controller above Crocodile Lake, including both open water and vegetated habitats to capture and assess heterogenous portions of the landscape. A non-systematic daytime flight was conducted on 18 January 2023 for 10 min (17:48–17:58 h) at 20 m altitude covering a flown distance of ca. 399 m, and a simple square-shaped pre-programmed systematic mission flight was conducted at night for 8 min (19:43–19:51) at 20 m altitude covering a distance of 1195 m, with a manual flight at the end to briefly observe a location with a high density of crocodiles. For the day flight, flight conditions were calm with a temperature of 26.8°C, 63% relative humidity, and 2.6 m/s windspeed. Night-time conditions were similar, with a temperature of 25.2°C, 66% humidity, and 2.5 m/s windspeed. Both day- and night-time flights included co-registered TIR and RGB imagery. However, only the night-time flight employed the DJI dual spotlight accessory (facing downward at a 45° angle) and the spotlight beacon (with fixed position at a 90° angle). Still-images were taken on an ad-hoc basis. The dongle position was primarily set to 45° and 90° to test visibility at various points throughout the flights, but it was repositioned occasionally to check for improved or declining visibility of the target species.

Analysis. Visual (qualitative) analysis was conducted both during each flight and after flights via recorded footage and still images in Microsoft Photos. Thermal imagery was analysed using the DJI Thermal Analysis tool. We used the Point Thermometry tool to assess thermal signatures of crocodiles, and the Rectangular Thermometry tool to identify ranges of crocodiles against background water surface temperatures and comparably cooler average vegetation temperatures. We then tested various colour palettes with TIR still-images to determine which might be the most effective to detect crocodiles while conducting aerial drone surveys. Results include means ± standard deviation and ranges.

Results

Temperature. Crocodile body-surface temperatures above water ($\bar{x}$ = 25.0 ± 1.3°C; 23.4–27.3°C, n = 8) were, on average, colder than background water surface temperatures ($\bar{x}$ = 27.5 ± 0.9°C; 26.0–28.5°C, n = 8). The temperature of vegetation cover was similar to crocodile body surface temperature ($\bar{x}$ = 26.0 ± 1.7°C; 22.4–28.1°C, n = 8). Overall, the average difference between water

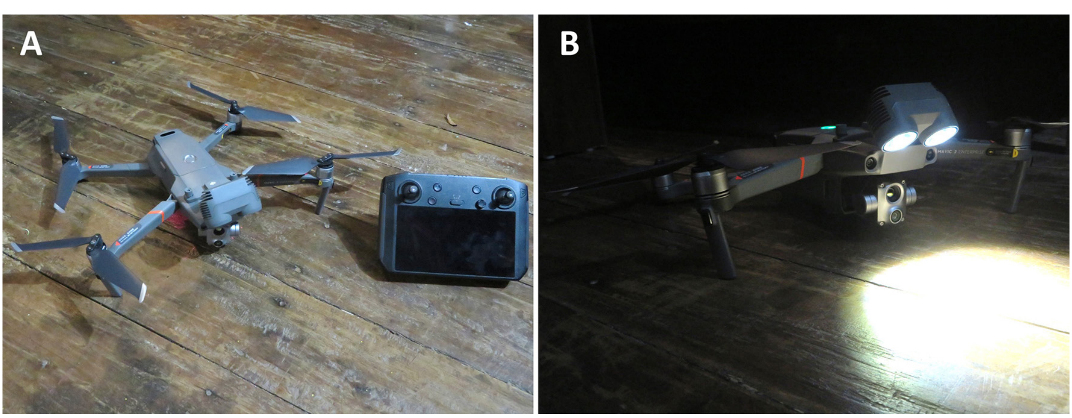

Figure 1. DJI Mavic 2 Enterprise Advanced drone. (A) Drone shown with RGB visual camera, thermal infrared (TIR) sensor, and an attachable DJI dual spotlight accessory set at a 45° downward angle. The Smart Controller is shown at right. (B) Drone with activated spotlight at night, as used in the current study.

surface temperature and above-water crocodile body temperature was 2.5°C, and between crocodile and vegetation cover only 1.5°C.

Daytime flight. Crocodiles were easily visible during the daytime flight both above and below the water in RGB (Fig. 2A, B). In TIR imagery, the water surface acted as a hot background, and when above the waterline, crocodiles showed up as a cold spot against the background (Fig. 2C). However, when submerged, the crocodiles' thermal signatures were completely masked by water temperature (Fig. 2D). In both RGB and TIR, crocodiles were more visible while swimming at both 45° and 90° camera angles. While crocodiles were easily detectable in open water, those seen inside the vegetation cover from ground level were not visible from drone imagery during daytime flights.

Night-time flight. During the night-time flight, crocodiles were visible with TIR sensors when above the water's surface (Fig. 3B) and also when the body was underwater (Fig. 3D). RGB images taken using the DJI dual spotlight accessory substantially increased detectability, even when crocodiles were not in the direct range of the spotlight, were moving, or were mostly underwater (Fig. 3C, D). Eyeshine was also visible when crocodiles were under vegetation, making night-time spotlight detections an improvement over daytime RGB and TIR.

Thermal imagery. We tested various colour palettes in the DJI Thermal Analysis Tool while post-processing still images with water, vegetation, and crocodiles in-frame (Fig. 4). While each of the palettes generally had the same effect of bringing out the cool surfaces over hot surfaces, crocodiles in continuous gradient palettes appeared more clearly than those in mixed spectrum palettes (excluding the Arctic palette). The gradient palettes with which crocodiles were detected most

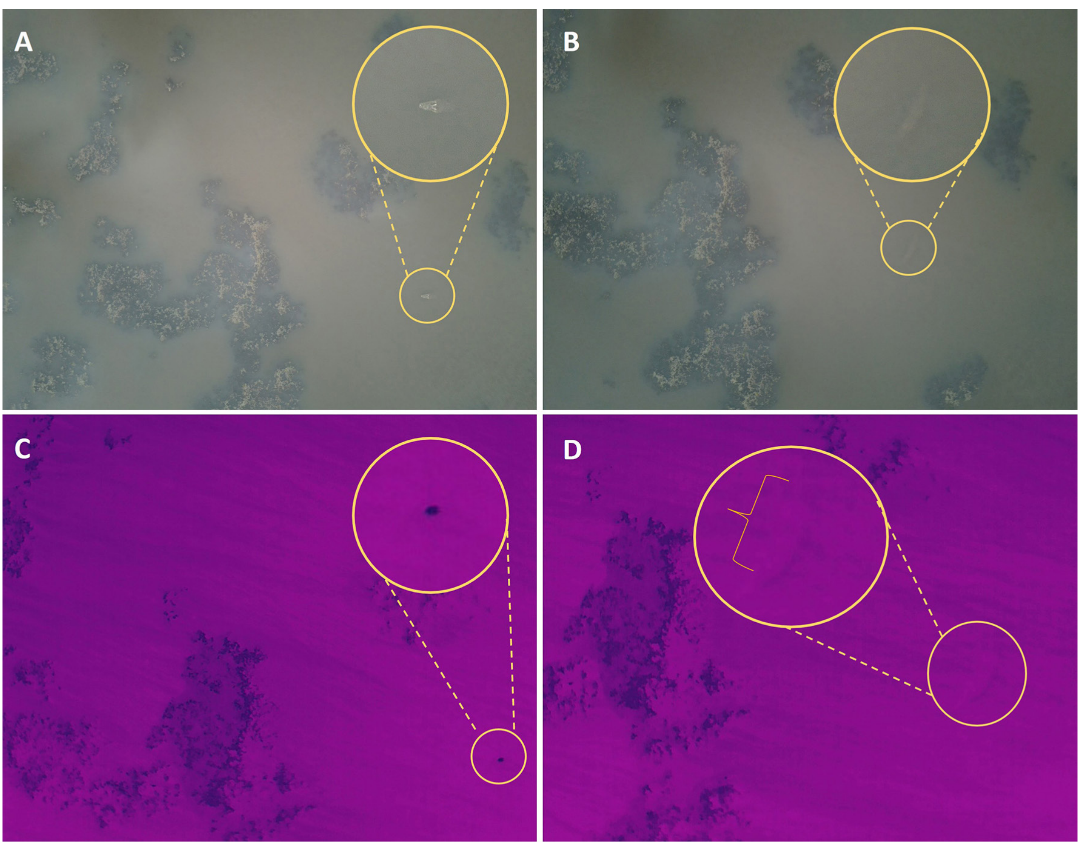

Figure 2. *Crocodylus siamensis* detection during a drone flight at 20 m altitude and 90° camera angle, showing a crocodile above and under water. The larger circles show enlargements of the crocodile in the original images (smaller circles). (A, B) Crocodile seen with RGB. (C, D) Crocodile shown using TIR imagery (temperature range of 25.8–28.8°C), revealing the crocodile's dark thermal signature present when above water (C), but not below (D).

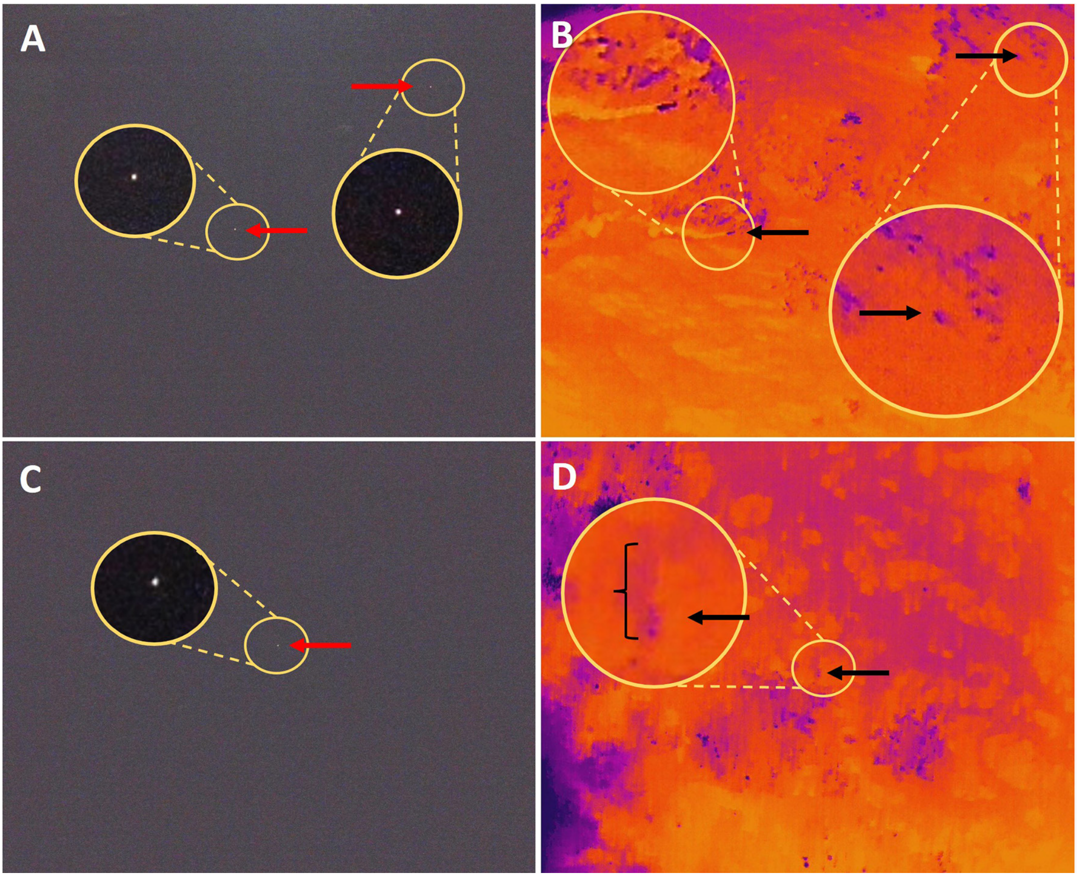

Figure 3. RGB spotlight surveys for *Crocodylus siamensis* using the DJI dual spotlight accessory set at a 45° downward angle with co-registered TIR images (temperature range = 20.8–26.8°C). Bright eyeshine identified by red arrows is revealed using RGB imagery (A, C), with the original image (smaller circles) enlarged for clarity (larger circles). Cold thermal signatures of the same crocodiles are shown when using TIR (B, D).

easily against the surface included IronRed/IronBow, Arctic, Fulgurite, Tint, Hot Iron, and WhiteHot. Palettes making crocodiles least visible against the background were Rainbow 1, Rainbow 2, and Medical.

Discussion

During this brief feasibility study using TIR imagery, RGB imagery, and spotlight payloads to conduct night surveys for crocodiles, we identified a few benefits and limitations of each part of the process. First, while RGB cameras may be effective during daytime hours for visually detecting crocodiles in open water, under water (on calm days), or on shorelines, their primary limitation is that they cannot detect crocodiles under the cover of vegetation. Additionally, when water is disturbed by wind, crocodiles can be difficult to detect, and when camera angle is set to 90° water reflectivity can also inhibit detection. RGB imagery would therefore be best used for daytime behavioural assessments, body size assessments, and general counts of crocodiles if conditions are calm and the sunlight is not directly overhead.

With TIR imagery, detecting crocodiles in open water is not inhibited by sunlight reflectivity, ripples or water roughness from wind, or camera angle. However, the main limitations of TIR imagery are that (1) water surface temperature masks crocodile body temperature when animals are submerged, and (2) crocodile body surface temperature above water may be too similar to vegetation temperature, meaning that crocodiles cannot be easily detected underneath or even on top of vegetation. While it is possible that body temperature may vary somewhat as thermal conditions during the day fluctuate, we conducted flights both during day- and night-time. The masking effect and body temperature of the crocodiles did not vary in regard to their visual appearance against the water as a backdrop nor in terms of their thermal signature, as evident in the daytime/night-time TIR image seen of a crocodile head (Fig. 3B; 20.8°C) and the daytime signature of

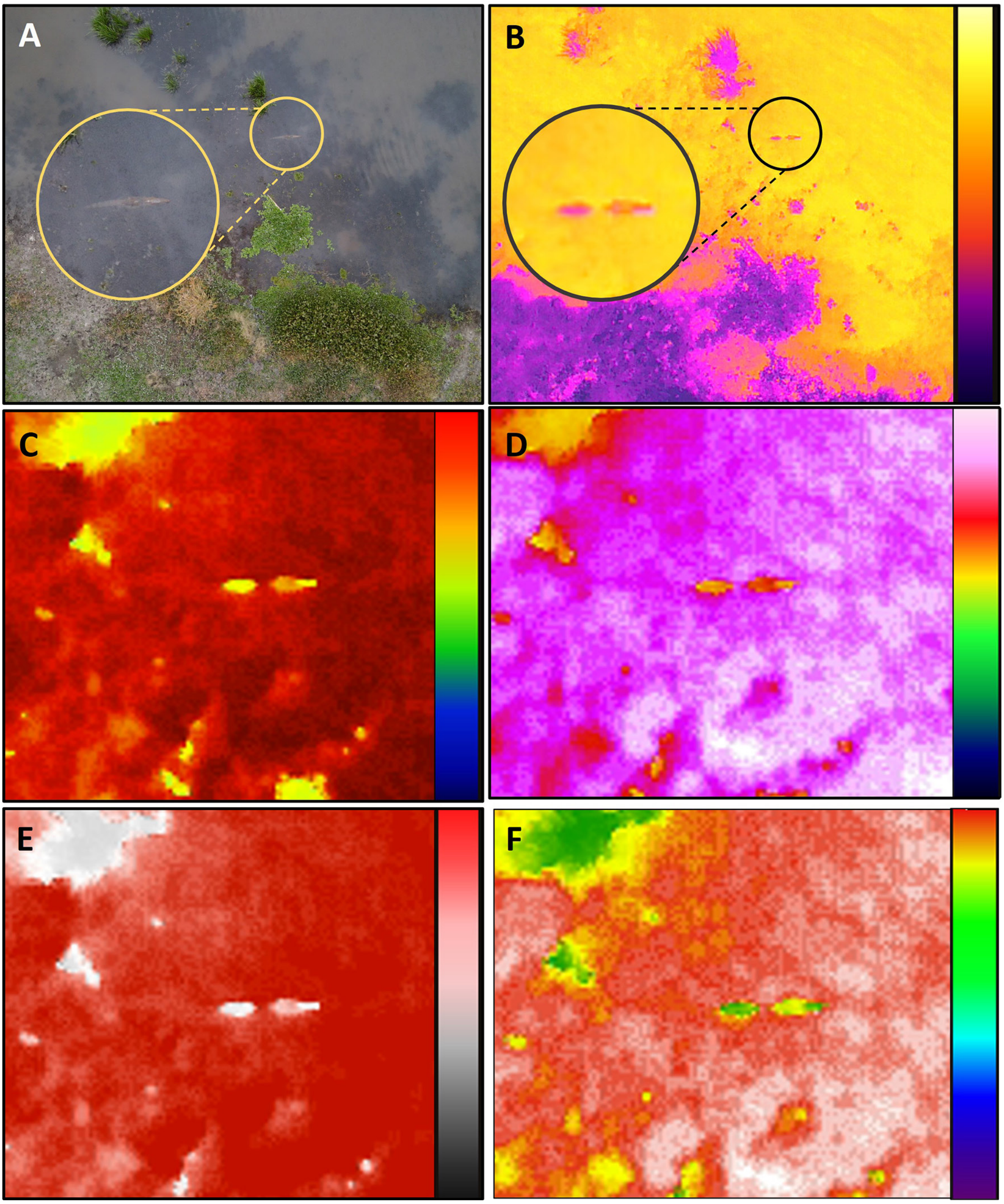

Figure 4. Examples of an RGB still image of a detected adult *Crocodylus siamensis* and comparisons using TIR colour palettes. The original RGB image (A) shows the crocodile in the small circle and an enlargement in the large circle. Images post-processed using recommended colour palettes are shown in (B), (C), and (E) which clearly show the crocodile's head and back on the background water. In contrast, post-processing with non-recommended colour palettes (D, F) does not provide the same level of clarity. Colour palettes used for post-processing include IronRed/IronBow (B), Arctic (C), Rainbow2 (D), Tint (E), and Rainbow1 (F). The thermal range of these images is 20.8–27.8°C.

the crocodile (Fig. 4; 20.8°C). Since the temperature of the water in each of the images in Figs. 2–4 was between 26.8°C and 27.8°C, any thermal signature below that temperature would be easily detectable. We conclude that TIR imagery is best used alongside RGB as a supplementary tool and not as a primary crocodile survey method.

Finally, spotlight accessories included with thermal drone models, such as the DJI dual spotlight on the DJI Mavic Enterprise Advances Thermal, are by far the most useful for accurate crocodile population counts. During our night flights, we were able to detect crocodile eyeshine above and below the water surface and inside and outside of vegetation. Furthermore, the spotlight enabled observers to detect crocodiles far off in the periphery, outside of the direct range of the spotlight, making the full camera view effective for detection. This was most effective at 45° camera angles and above. We should note, however, that using the fixed 90° angle spotlight meant for take-off and landing is not recommended, as it creates a reflection on the water's surface that inhibits detections. While our flight altitude was fixed at 20 m, we cannot make any recommendations for optimal flight height based on our surveys. However, we are confident that given the observed brightness of the spotlight and the resulting crocodile eyeshine, altitudes up to 50 m would likely still be effective in case emergent trees are present at the study site. For ease of crocodile detection, we nevertheless recommend flying at 20 m altitude or lower.

Other important features of the drone model used in the current study, as well as of many other DJI models, is the collection of spatiotemporal (date/time, GPS coordinates, UAV tracks) and environmental data (temperature, humidity, wind speed). Additionally, other payloads and sensors, such as LiDAR or multi-spectral sensors, could be incorporated into drone surveys to collect additional data on vegetation structure and crocodile population dynamics throughout the year.

Our recommendations for drone usage to conduct effective crocodile surveys therefore include use of a 45° downward-facing spotlight on a thermal drone (such as the DJI dual spotlight accessory), using co-registered TIR and RGB imagery during systematic night flights at a fixed 20-m altitude (or lower) to count crocodile populations via eyeshine on RGB footage, and to estimate body size through TIR. To improve detectability with TIR imagery, continuous gradient palettes are more useful for detecting crocodiles than mixed-spectrum palettes. As long as flight altitude is fixed throughout the survey, crocodile body sizes can be compared when reviewing TIR or daytime RGB footage. Researchers also need to ensure that during pre-programmed systematic flights the space between transect lines/flight paths is wider than the full view of the camera to prevent double counting crocodile detections. Finally, daytime flights can be used to reassess population body sizes of detectable individuals with more visual accuracy while also allowing monitoring of daytime behaviours. More studies should be carried out using and comparing daytime surveys with night-time spotlight surveys using UAVs to identify count and body size discrepancies.

As a side note, there were some events during our flights that should be taken into consideration during aerial drone surveys: (1) Some species of raptors (possibly night jars) emerged in the evening around 17:00 h, and during our daytime flight these birds swooped at the drone, leading us to interrupt the flight to prevent disturbance and a possible crash. (2) During our night flight, while flying over a vegetated area we heard a bird (likely a sleeping water bird) shrieking in the distance, possibly due to air movement or noise created by the drone. It is important to keep in mind the effect that drone usage may have on other animals than crocodiles. (3) Regarding flight altitude, it should be noted that previous research on behaviours of Saltwater Crocodiles, *Crocodylus porosus* Schneider, 1801, to UAVs yielded various crocodile responses, including submerging and fleeing drone activity below an altitude of 50 m, and responses from nesting birds were observed at altitudes below 60 m (Bevan et al., 2018). Only two individuals in the current study had any response to our 20-m altitude flights, these responses including flight and full-body submergence during daytime. Our results are consistent with the study by Jordaan (2021), who reported that standardized flights at 30 m altitude could be considered for counting *Crocodylus niloticus* Laurenti, 1768 while minimizing disturbance. We therefore recommend that researchers using drones to survey crocodiles make concerted efforts to understand behavioural responses of their target species to drones, and to check into nesting seasons for local avian species and activity periods of raptors and other birds before their surveys to reduce disturbances and stress of wildlife as much as possible.

We recognize that a quantitative analysis is necessary to determine the percentage of individuals that can be reliably detected and to establish correction factors for population counts based on thermal imagery. However, in this feasibility study, we aimed only to qualitatively assess the potential of thermal imaging of crocodile population sizes before trying out a full-fledged project. Subsequent to the completion of this feasibility study, we plan to conduct systematic flights and ground-level counts to compare the outcomes of traditional survey methods with the drone-based mapping using thermal imagery and aerial spotlight counts. We intend to present these findings in a separate manuscript that focuses specifically on the quantitative comparison between traditional surveys and drone-based population counts. We see the value in this feasibility study to produce a type of Standard Operating Procedure as a guide for other researchers since there are many recommendations in the literature to try and test thermal imagery for crocodile counts and no literature on its actual viability. These types of drones are quite costly (ca. EUR 6000) and we hope researchers can be better informed about the benefits and limitations from our experience.

Conclusion

UAVs are rapidly becoming a popular wildlife monitoring solution because they can provide rigorous survey data at low cost (Hodgson et al., 2018) and result in minimal disturbance of crocodiles compared with boat surveys. Most importantly, UAV surveys provide a permanent record of observations that can be reviewed at a later time to verify observations (Kelaher et al., 2019; Aubert et al., 2021). Our study found that using commercially available UAVs with various sensors and payloads can provide an effective and efficient way to monitor crocodile populations. The use of RGB and TIR imaging in conjunction with spotlight payloads can enable the gathering of valuable data on crocodile size, distribution, habitat use, and thermal ecology. Our study showed that the use of daytime RGB camera footage and still images, thermal sensor imagery, night-time RGB using a spotlight payload, and co-registered imagery can enable effective crocodile population surveys for the monitoring conservation and management of this species and other crocodilians globally.

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