Biological Conservation 223 (2018) 76–81

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Use of an unmanned aerial vehicle (drone) to survey Nile crocodile populations: A case study at Lake Nyamithi, Ndumo game reserve, South Africa

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ARTICLE INFO

Keywords:
Observer bias
Aerial survey
Unmanned aerial vehicles (drones)
Diurnal survey
Crocodile survey methods

ABSTRACT

Observer bias and inexperience are challenging aspects of crocodile survey methods for determining population numbers and structure. Aerial surveys with either a helicopter or a fixed winged aircraft are generally preferred methods to ground surveys; however, the high cost of the former is a limiting factor. Recently unmanned aerial vehicles (UAVs) or drones have been proposed for surveys because of their potential of improving over traditional techniques of wildlife monitoring and as they have relatively lower costs. We investigated of the suitability of a UAV to determine numbers and structure of the Nile crocodile, *Crocodylus niloticus*, population during winter at Lake Nyamithi, Ndumo Game Reserve in South Africa. We used the UAV for eight flights covering ~132 ha. We also conducted a diurnal ground survey of crocodiles for comparison. Using the UAV, 287 crocodiles were identified and body length measured accurately for size class allocation whereas only 211 crocodiles were counted in the diurnal ground survey. Consequently, the UAV aerial survey recorded 26% more crocodiles. The potential of using UAVs to estimate crocodile population size and measure the total length (TL) of individuals accurately and precisely at a relatively low cost should improve management actions, enable monitoring of the crocodile populations annually and importantly avoid observer bias. Implications of this may facilitate improved crocodilian survey techniques.

1. Introduction

The Nile crocodile, *Crocodylus niloticus*, as other crocodilian species, is considered a keystone species in its aquatic habitat because of its essential ecological role as the largest semi-aquatic predator representing the top of the food chain (Leslie and Spotila, 2001; Ross, 1998). The Nile crocodile is widely distributed on the African continent, and found in 42 different countries (Leslie and Spotila, 2001). Between the 1950s and 1960s Nile crocodile populations in Africa declined dramatically, and faced a series of major threats such as the over-hunting for skin and habitat loss or degradation (Botha, 2006; Champion and Downs, 2017; Combrink, 2004; Cott and Pooley, 1972; Jacobsen, 1984; Pooley and Gans, 1976; Pooley, 1982; Warner et al., 2016). According to the International Union for the Conservation of Nature (IUCN) Red List, the Nile crocodile population in much of Africa is still vulnerable and in South Africa is classified as threatened (Marais, 2014). Currently, it is still necessary to manage Nile crocodile populations in order to ensure its persistence.

Although unmanned aerial vehicles (UAVs) or drones have been used for military purposes for decades, it is more recent that civilian applications were developed (Linchant et al., 2015). UAVs are able to approach fixed or moving objects relatively closely, which enables exploration of places that were previously difficult to reach (Martin et al., 2012). UAVs are able to do the similar tasks as helicopters or fixed-wing aircraft, often more reliably and at relatively lower cost (Ogden, 2013). Recently UAVs, have become an important tool for conservation management because of their potential of greatly improving traditional techniques of wildlife monitoring (Evans et al., 2016; Hodgson et al., 2016, 2018). UAVs have been used for monitoring the surface of particular habitats to generate 3D maps, and for animal population censuses (Mukwazvure and Magadza, 2014; Koh and Wich, 2012). UAVs have been used increasingly in anti-poaching programs for various species (Mulero-Pázmány et al., 2014). Management objectives of crocodilian populations range in emphasis from conservation to regulation of populations. Irrespective these objectives require suitable survey methods to reliably determine the species' distribution and abundance and monitor changes in these with time (Bayliss, 1987). Historically there are generally two main techniques to count or estimate crocodile

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https://doi.org/10.1016/j.biocon.2018.04.032
Received 29 January 2018; Received in revised form 18 April 2018; Accepted 20 April 2018

populations, namely ground and aerial surveys. As crocodiles are more visible from above especially in some habitats, this initiated and developed the aerial survey technique to count crocodiles (Graham, 1987). Aerial surveys of crocodiles are generally considered more accurate and precise than day-count or spotlight ground survey methods in the same area (Graham, 1987; Jacobsen, 1984). However, aerial surveys have certain prominent short comings. For example, it is almost impossible to reliably count hatchlings and very small crocodiles from the air, and the relatively high cost of aerial surveys is a limiting factor, especially for the long-term monitoring programs. Recently, UAVs have been used to observe and map the nests of crocodilian species in North America and Asia and examine behavioral aspects of their nesting (Elsey and Trosclair III, 2016; Evans et al., 2015). In addition, UAVs have been successfully piloted to identify and measure an individual American alligator *Alligator mississippiensis* in Lake Okeechobee, USA (Martin et al., 2012). However, no studies appear to have used a UAV to survey crocodile populations.

In Africa, surveys and population estimates of Nile crocodiles have a long history of supporting management programs (Fergusson, 2010). Ndumo Game Reserve (NGR) located in KwaZulu-Natal Province, South Africa, has one of the longest Nile crocodile monitoring programs. It has been running since the early 1960s and is based on aerial and/or ground surveys (Calverley and Downs, 2014a, 2014b; Pooley, 1982), however, the precision and accuracy of the estimates are affected by fluctuating water levels and use of different observers (Calverley and Downs, 2014a). Calverley and Downs (2014a) predicted a potential decline of the NGR Nile crocodile population due to natural processes as well as the effects of anthropogenic crocodile harvesting and destruction of nesting habitat. They recommended annual surveys of Nile crocodiles in NGR during the austral winter when the crocodiles are more visible due to their basking behaviour. Therefore, the present study was conducted in the winter. In this study, we assessed the possibility of using a UAV to conduct accurate and precise aerial surveys and determine size and age classes of the Nile crocodile population at Lake Nyamithi as a cost-effective alternative to the annual surveys proposed by Calverley and Downs (2014a).

2. Methods

2.1. Study area

Our study was carried out at Lake Nyamithi (26°53′38.26″S, 32°17′33.50″E, WGS84) in NGR, KwaZulu-Natal Province, South Africa, between April and June 2017. Lake Nyamithi is the largest permanent lake in the Pongola floodplain and it has the highest density of Nile crocodiles in NGR (Calverley and Downs, 2014a). Lake Nyamithi extends about 4.2 km from east to west and about 700 m at its widest point along the north-south axis (Calverley and Downs, 2014b). Water levels vary between ~5 m deep during summer to < 1 m deep during winter (Pooley, 1982).

2.2. Aerial survey using unmanned aerial vehicles (UAVs)

Aerial surveys for this study were carried out using a DJI Phantom 3 Standard Drone with 2.7 K Camera and 3-Axis Gimbal. This UAV was preferred because its camera shoots 12 megapixel JPEG files and has a 1/2.3″ sensor, fast f/2.8 prime lens, and a preset focus optimized for aerial images, and has a battery life of up to 22 min.

DroneDeploy (www.Dronedeploy.com) is a drone mapping software platform that captures aerial data as images and processes those images into maps and 3D models. In this study, DroneDeploy was used to create a predefined flight plan over the target area and flights in autopilot mode were then deployed to capture aerial imagery of Lake Nyamithi. A significant overlap between photographs is needed to create a geo-referenced mosaic map of sufficient quality to allow objects on the ground to be identified accurately (Koh and Wich, 2012). Increasing both the side-lap and front-lap to > 50% creates this significant overlap between the photographs. Side-lap represents the percentage of the overlap between each leg of the flight and the front-lap represents the percentage of overlap between one image and the next. Additionally, the correct camera settings were vitally important to ensure the quality of each captured image.

2.3. Experimental flights

Three pilot flights were conducted between 9:00 and 12:30 on 23 April 2017 in a grid pattern over 12 ha of the study area. The UAV was programmed to fly at various test altitudes (40, 55, 70 m) in each flight mission, taking into account that the overlaps between the images were fixed (70% side-lap and 60% front-lap). The aim of these flights was to determine the optimal altitude to fly the UAV at during surveys and to allow coverage to be produced of the entire study area (Lake Nyamithi).

On 16 June 2017, eight UAV flight missions were conducted between 9 h:00 to 13 h:00 with the total time required for the aerial survey being ~113 min for a grid flight path that covered Lake Nyamithi (~132 ha). The total flight time excluded drone takeoff and landing and ferrying back and forth between the starting point and the survey grid. The drone was launched a distance from the lake in nearby bush to avoid possible disturbance of the crocodiles.

2.4. Data processing

Despite the existing number of software or third-party platforms that can process UAV data, it is critical to understand the flow of the processing via managing the aerial imagery correctly when the output quality is essential for the purpose of the project. Processing the data means stitching the geo-tagged images together, and this can be summarized in three different stages: 1) Data calibration which refers to syncing up of points on an aerial image with a geographical point on the ground; 2) Point cloud replacement; A point cloud is a set of points in a coordinate system that visualizes the geographical area (These data points correlate with the ground points) and 3) The exported output is the final visual format, an ortho-mosaic, 3D Model, or Digital Elevation Model etc. (https://pix4d.com/). This exported visual format was used to study the objects (crocodiles). ArcMap 10.5 (ArcGIS, ESRI Redlands, California, USA) was used to mark and measure the individual crocodiles in the ortho-mosaic (2D) geo-referenced produced map. A free trial version of DroneDeploy, online platform, and Pix4Dmapper Pro, desktop software, were used to process the generated data that consisted of 3017 geo-tagged images captured from eight flights.

The pilot flight plan at 55 m altitude determined the area of the lake cover as ~12 ha (Fig. 1). The flights were flown in a grid form that allowed for a predefined percentage of image overlap (Fig. 1). Based on the experimental flights, an aerial survey plan conducted to cover Lake Nyamithi and survey the crocodile population was developed.

We first attempted to design a predefined flight pathway in order to capture aerial geo-referenced imagery at known altitude. These aerial images were stitched together to produce a geo-referenced 2D map. The experimental flights were conducted assessing a sub-area of Nyamithi Lake. Images were captured at 40, 55, and 70 m altitude. In light of these flights, the total time required to cover the entire lake was calculated for each altitude and the geo-tagged imagery was stitched to determine the quality of the produced maps. Following the pilot flights, images captured at 55 m altitude provided the most sufficient stitched collages in order to survey the crocodile population in Lake Nyamithi (Fig. 2). The resulting geo-referenced 2D quality map was 2 cm/pix detail. An altitude of 55 m was also sufficient due to the total number of flights needed to cover the target area, the resolution quality of the produced maps, the ability to locate the individual crocodiles and measure their size. In addition, the total time expected for flights corresponded to the expected time of the presence of crocodiles on the shores of the lake (Fig. 1).

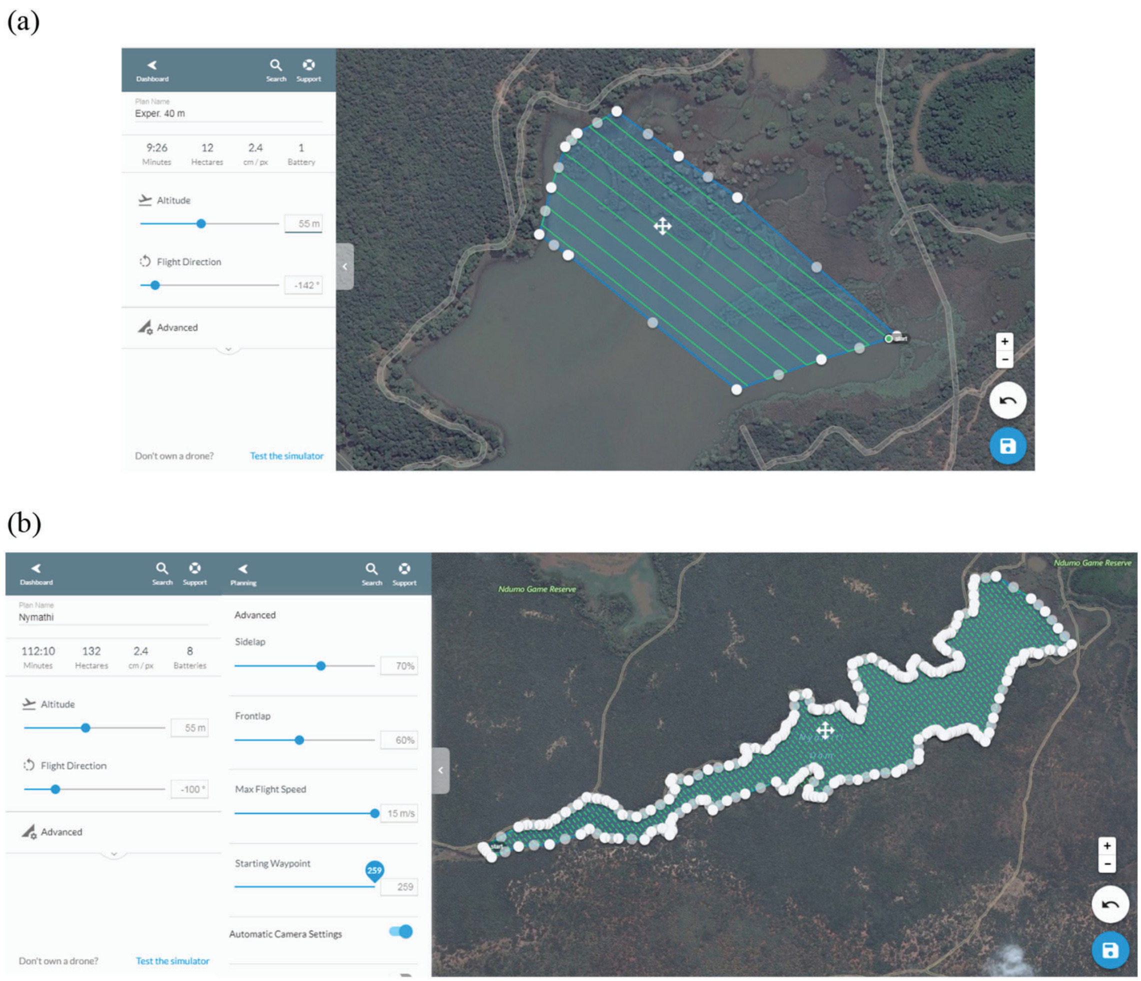

Fig. 1. An example of the UAV crocodile survey flight plan using the DroneDeploy platform where (a) is the flight test plan using the DroneDeploy platform at 55 m altitude (only a portion of the lake is shown in this example); and (b) the grid mission at ~55 m above the ground at Lake Nyamithi, Ndumo Game Reserve.

Following the pilot aerial surveys, a complete aerial survey was conducted at 55 m altitude in order to determine the numbers and size of Nile crocodiles in Lake Nyamithi between 9 h:00 and 12 h:30. This UAV survey enabled high-resolution identification of crocodile individuals (Fig. 2). Eight size categories were classified according to the respective crocodile total lengths (TL) determined. These size categories ranged from 0.5 to 4 m TL. Additionally, an "eye only" (EO) class represented individuals not measured because of an obstacle hindering a correct measurement (either hiding behind a tree or totally/partly submerged).

2.5. Ground survey

A diurnal ground survey of Nile crocodiles was carried out after the aerial survey on 18 June 2017 at Lake Nyamithi. The ground survey was conducted at the same time of the day as the UAV aerial survey and started at 9 h:00 until 12 h:45 where a vehicle was driven at low speed (~10 km) around Lake Nyamithi while an observer counted and sized the crocodiles observed using the size classes described above. Binoculars (DENALI 10 × 42) were used to observe the crocodile individuals and estimate their respective size classes.

2.6. Statistical analyses

Descriptive statistics and Chi^2 for homogeneity test were conducted to evaluate the equality of crocodile size classes among UAV and ground survey results. Our null hypothesis was that a percentage of crocodile size classes was homogeneous or equal with respect to the two methods (UAV and ground).

3. Results

The UAV data allowed precise mapping of Nile crocodile numbers and distribution in Lake Nyamithi and each individual's TL to be measured. This was possible using the extensive details in the orthomosaic together with the mapping tools to make accurate measurements and to pinpoint all crocodiles in the image which could be further double checked. This alleviated observer bias associated with ground surveys of the crocodiles. Out of 3017 geo-tagged images stitched together, 287 crocodiles were successfully identified and measured at Lake Nyamithi as shown in Fig. 3.

Our UAV survey enabled high-resolution accurate identification of individual crocodile length (Fig. 2). After measurement and allocation to the respective size classes, the highest number of crocodiles was in the 2.0–2.5 m TL size class. This represented 39% of the total crocodiles counted in the aerial survey using a UAV (Fig. 4). Based on the ground survey 211 crocodiles were counted and their size classes estimated at Lake Nyamithi. The highest number of crocodiles was in the range of 1.5–2.0 m and 2.0–2.5 m TL size classes respectively (Fig. 4). These represented 28% and 26% respectively of the total number of Nile crocodiles counted using this method.

Comparison of the two survey methods showed the total count using the aerial UAV survey identified more crocodiles (287 individuals) compared with the ground survey (211 individuals). Consequently, the

Fig. 2. Stitched image of 12 ha pilot flight flown at 55 m, where the produced 2D map quality is 2 cm/pix. The total length (TL) of the individual crocodiles observed were measured.

aerial UAV survey recorded 26% more crocodiles. In addition, a significant difference in the percentage of Nile crocodiles in the respective size classes using the UAV aerial and ground survey methods was found (Chi^2 for homogeneity test, $P < 0.001$, Fig. 4). Size class estimation with the UAV survey was more accurate than the estimation during the ground survey. The ground survey result overestimated individuals in the size class ranges between 0.5 and 2 m in TL and of individuals > 2 m TL. Also, 16 crocodiles (5%) were classified in the EO category with the UAV aerial survey compared with 24 crocodiles (11%) in the ground survey. Therefore, using the aerial UAV survey gave a more accurate and precise estimate of the crocodile population size class structure. In the UAV survey only one individual TL was measured to be < 1 m (hatchling) while six individuals from the same size class were counted during the ground survey.

4. Discussion

We confirmed the suitability and ability of UAV technology to survey crocodile populations accurately and precisely. It has the potential to become one of the standard methods to determine crocodile population numbers. Furthermore, it is an efficient method to measure the correct size of each individual crocodile observed, allowing each to be correctly allocated to the appropriate size class. These applications coupled with their relatively low cost enhances the further potential for use in size determination and understanding of crocodile populations, especially with repeated annual counts for long-term studies. In comparison, the high costs of aerial surveys using helicopters or fixed-wing aircraft is a challenge for viable long-term monitoring programs.

Our results showed that the UAV aerial survey yielded significantly (26%) more crocodiles than the ground survey at Lake Nyamithi. However, as highlighted by Bayliss (1987) there are difficulties in identifying small crocodiles (hatchlings) during aerial surveys. Lake Nyamithi is in the Phongola River floodplain where crocodiles will move with changing water levels (Henein and Merriam, 1990; Taylor et al., 1993). Higher crocodile numbers exist in Lake Nyamithi, especially during the winter (Calverley and Downs, 2014a, 2014b). The most recent crocodile survey (diurnal ground) conducted at Lake Nyamithi between 2009 and 2012 found the number of Nile crocodiles reach a peak of 273 (SE ± 13.5) in August (Calverley and Downs, 2014a, 2014b) while our diurnal ground survey counted 211 individuals in July 2017. Although our UAV survey confirmed a minimum of 278 Nile crocodiles in Lake Nyamithi, further UAV surveys are recommended to determine the status of the Nile crocodile population at Lake Nyamithi. Although our ground survey results of Nile crocodiles in Lake Nyamithi supported Calverley and Downs' (2014a) predicted decline in the NGR Nile crocodile population, our UAV results showed little change in the population numbers with time at Lake Nyamithi. Furthermore, our age class results continue to support that it is an aging population.

Previous work has shown that estimating crocodile size is affected by observer bias and experience (Combrink, 2004; Woodward and Moore, 1993). Aerial surveys using UAVs may help reduce observer bias over the long-term annual monitoring program of the Nile crocodile population at NGR. UAV based aerial surveys make accurate and precise measurements of each individual Nile crocodile observed possible and therefore improve the size class categorization of individual crocodiles. To launch effective management of crocodilian habitat, it becomes important to understand the spatial and temporal use of different habitats by crocodilians (Botha, 2006). Long-term monitoring is essential to implement management actions to conserve Nile crocodile populations. The use of UAVs to monitor crocodile populations can lead to better informed management decisions based on accurate data instead of relying on observer experience which in turn will contribute greatly to the conservation of crocodilian species and their habitats.

Fig. 3. An overall 2D map with a resolution of 2 cm/pix as a result of the aerial survey using a drone showing the number and distribution of Nile crocodiles in Lake Nyamithi.

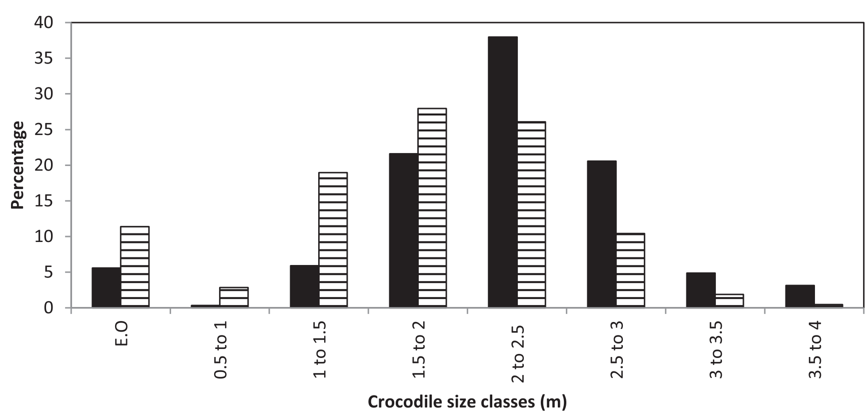

Fig. 4. Percentages of Nile crocodiles in the respective size classes using the aerial drone (dark bars) compared with ground surveys (hatched bars) at Lake Nyamithi.

Further research is required to assess whether UAV surveys will deliver the same positive results in open ended habitats like river systems or large impoundments where the surface area can be in the thousands of hectares instead of just over a 150 ha as in the present study.

UAV technology has the potential to survey crocodile populations accurately at relatively low cost and over a much shorter time even in areas that are difficult to access. Moreover, our UAV aerial survey has implications for future research and management strategies for Nile crocodiles.

Acknowledgments

We are grateful to the European Commission through the program Erasmus Mundus Master Course-International Master in Applied Ecology (EMMC-IMAE) (EPA 532524-1-FR-2012-ERA MUNDUS-EMMC), IUCN-SSC Crocodile Specialist Group's Student Research Assistance Scheme (SRAS), the National Research Foundation (ZA) and the University of KwaZulu-Natal for funding. We thank C. Price for fieldwork assistance. We are most grateful for the constructive comments of the reviewers.

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