Drone Systems and Applications

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# An assessment of survey techniques using unmanned aerial vehicles to monitor Nile crocodiles (*Crocodylus niloticus*)

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## Abstract

Monitored populations of the Nile crocodile *Crocodylus niloticus* at the southern end of its distribution, in the KwaZulu-Natal province of South Africa, are largely in decline. Trophy hunting of wild Nile crocodiles is only permitted at Pongolapoort Dam in the province, and monitoring of this population is required to enable the setting of annual hunting quotas. The aims of this study were to determine the feasibility of using drones to count and measure Nile crocodiles in the inlet to the dam and evaluate the utility of photomosaics, individual photographs, and videos for this purpose. A total of 16.5 km of shoreline was surveyed and 183 sub-adult and adult crocodiles observed, averaging 10.74 crocodiles per kilometer. The use of drones was cost-effective compared to traditional survey methods even though a higher number of person hours were required for data collection and processing. We recommend that drones be used to acquire video footage, supplemented by photomosaics in areas where large aggregations of crocodiles occur, to regularly monitor this crocodile population.

**Key words:** drone, aerial survey, Pongolapoort Dam inlet, monitoring

## 1. Introduction

The Nile crocodile *Crocodylus niloticus* is widely distributed in sub-Saharan Africa (Fergusson 2010) and reaches the southern end of its current global distribution in South Africa where it is regionally classified as vulnerable on the IUCN Red List (Turner and Marais 2017). All wild populations of this apex freshwater predator in the province of KwaZulu-Natal, South Africa, that have been monitored for about a decade or longer are declining (Combrink et al. 2011; Calverly and Downs 2014; Ezemvelo KZN Wildlife, unpublished data). However, the wild Nile crocodile population at Pongolapoort Dam, north-eastern KwaZulu-Natal, appeared to have increased between two surveys in 2009–2010 and 2015, from a minimum number of 281 to 549, respectively (Summers 2015; Champion and Downs 2017). Owing to their large size and predatory habits, crocodiles are hunted as trophies in various parts of the world. However, unregulated harvesting (e.g., for skins) can lead to severe declines in wild crocodilian populations (e.g., Fukuda et al. 2011).

On the other hand, a well-regulated harvest of crocodilians in large wild populations can ensure that these populations do not decline over time (Velasco et al. 2003; Joanen et al. 2021). Joanen et al. (2021) showed that harvest quotas, set using current and recent population size indicators and environmental data, in combination with protection of breeding females and strict law enforcement, ensured that a wild American alligator population did not decline and in fact increased over a 35-year period, while at the same time realizing sizable economic benefit. Length measurements were obtained from the harvested skins, which enabled size-class percentages to be calculated, and the data indicated that the average size of the harvested alligators increased over time without affecting the overall population size structure (Joanen et al. 2021). Velasco et al. (2003) found that the harvest of large male caimans led to increases in the density and relative abundance of large males in harvested relative to nonharvested populations in most of the regions studied.

Ezemvelo KZN Wildlife, the provincial conservation agency in KwaZulu-Natal, follows the principle of sustainable use of wildlife. Although trade in Nile crocodile skins in KwaZulu-Natal emanates from crocodile farms, trophy hunting of large Nile crocodiles can also bring in economic benefit. A wild Nile crocodile population in KwaZulu-Natal that could potentially sustain a certain amount of trophy hunting owing to its potentially increasing in size is the Pongolapoort Dam population. However, this population has not been monitored regularly and so its status was unknown when the first applications to hunt adults from this population were received by Ezemvelo KZN Wildlife. Since a well-regulated harvest requires recent data on population size and population size-class structure (e.g., Joanen et al. 2021), Ezemvelo KZN Wildlife needed to start a monitoring programme for this population. Nile crocodile surveys in KwaZulu-Natal in the past have used spotlight counts (from boats or motor vehicles) or aerial surveys using fixed-wing aircraft and helicopters (e.g., Combrink et al. 2011; Calverley and Downs 2014; Downs et al. 2015; Summers 2015; Champion and Downs 2017); each of these methods have their own advantages and disadvantages, but all have the constraint of not being able to measure the length of the crocodiles accurately.

The use of drones, or unmanned aerial vehicles (UAVs), is helping with the monitoring of some threatened and invasive species to obtain accurate population estimates (Gonzalez et al. 2016). The use of drones to monitor Nile crocodile populations in certain situations in KwaZulu-Natal was suggested by Ezat et al. (2018), who used a drone for a once-off survey of Nile crocodiles at Nyamithi Pan in the Ndumo Game Reserve, northern KwaZulu-Natal. More Nile crocodiles were recorded using the drone than during a ground survey from a vehicle at the same time of day 2 days later, and the crocodiles could be more accurately assigned to half-metre size classes using the drone footage in comparison to the length estimates from the ground survey (Ezat et al. 2018). Elsewhere, Thapa et al. (2018) demonstrated that the mean number of gharial *Gavialis gangeticus* counted using a UAV did not differ significantly from the number counted previously in a replicated diurnal survey from boats.

The Nile crocodiles at the Pongolapoort Dam concentrate in the Pongola River inlet section during winter for mating and breeding purposes (Champion and Downs 2017). This suggests that monitoring of the crocodile population there annually in winter could provide a suitable index to ascertain the status and trend of the population at the dam over time. The aims of the current study were to (1) determine whether drones could be used to count and measure the Nile crocodiles in the Pongola River inlet region and (2) evaluate the differences in utility between photomosaics and individual photographs and video captured by the drones in monitoring the crocodile population and for the purpose of setting annual crocodile hunting quotas.

## 2. Materials and methods

### 2.1. Study area

The Pongolapoort Dam is located in the northern region of the KwaZulu-Natal province of South Africa (Fig. 1) between Pongola and Jozini towns. It was completed in 1972 and covers an area of approximately 13 279 ha with a capacity of 2445 million m$^3$. It is the largest dam in KwaZulu-Natal, the fifth largest in South Africa, and is an important source of water for both people and game (Ezemvelo KZN Wildlife 2009). Land use surrounding the dam is largely conservation and ecotourism; Pongola Nature Reserve and Pongola Game Reserve lie to the western and eastern sides of the dam, while the Royal Jozini Private Game Reserve borders the dam in the north in Eswatini (Fig. 1).

### 2.2. UAV survey

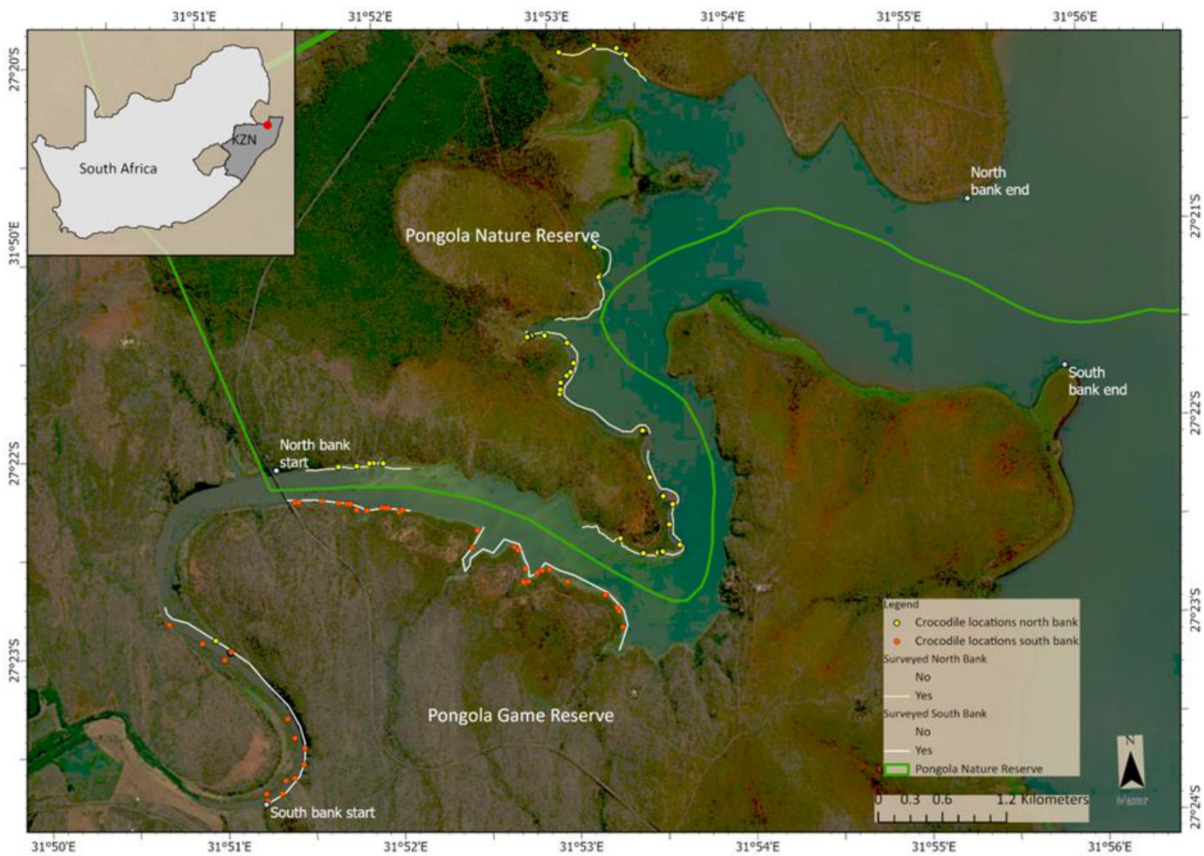
The survey took place along the Pongola River Inlet to the Pongolapoort Dam (Fig. 1) in winter, from 2 to 4 August 2022. Flights were restricted to the warmer parts of the day (between 10:00 and 15:30) when the crocodiles were more likely to be basking (Downs et al. 2015). Flying altitude was restricted to 50 m above the waterline to limit disturbance to the crocodiles (Mulero- Pázmány et al. 2017; Jewitt 2021). Flights on the northern bank took place from the Pongola Nature Reserve, whereas flights on the southern bank were flown from the Pongola Game Reserve (see Acknowledgements).

The aerial surveys were conducted using a DJI Phantom 4 Pro (20MP CMOS sensor), a DJI Mavic 2 (20MP CMOS sensor), and a DJI Matrice 210. A DJI Zenmuse Z30 camera (30x optical zoom on a CMOS sensor with 2.13 M effective pixels) was used on the Matrice. Multiple Aircrafts were used to ensure sufficient battery and flight time in the field. Three methods were tested in the field: orthomosaics, photographs, and videos. Pix4DCapture was used to plan the flights for the orthomosaic generation. Orthomosaic photographs had a 75% forward and side overlap. Pix4DMapper version 4.6.4 (by PIx4D) was used to stitch the images together. The average ground sampling distance was 1.42 cm. The photographic and video collection was obtained by flying along the shoreline. When a crocodile was observed, a photograph was taken. Similarly, video material was obtained by filming along the shoreline. In all instances, the material was manually searched and verified for the presence of crocodiles back in the office. The project and data analysis were conducted in ArcGIS Pro (version 3.1.3) (ESRI Inc.). The total lengths (from the tip of the snout to the tip of the tail) of all crocodiles captured in the orthomosaic images were measured and assigned to the appropriate length class. The length classes were ≤2.50, 2.51–3.00, 3.01–3.50, 3.51– 4.00, and 4.00 m.

Ground control points (GCPs) could not be used to georeference the orthomosaics due to half the survey area being in water and not being able to spread the GCP's evenly across the landscape due to the presence of dangerous game and no armed guard available at the time of the survey. Photographs were located based on the centroid coordinate obtained from the photograph metadata. Crocodiles observed in the video were geolocated by matching the time of the video with the flight path details. All flights were in accordance with local legislation. In South Africa, flight distances are restricted to 500 m from the pilot and visual line of sight (VLOS), unless the organisation holds a Unmanned Aerial System Operators Certificate from the South African Civil Aviation Authority (SACAA) and has beyond visual line of sight (BVLOS) ratings and authorisation from SACAA (Part 101 of the South African Civil Aviation Regulations, 2011, Civil Aviation Act 2009 (Act No. 13 of 2009). Our flights had to be conducted under VLOS.

The water level in the dam was high (79%) for the time of year (end of the dry winter season), reducing the number of sand banks available for the crocodiles to bask on. The water level also pushed up into the savanna causing crocodiles to be obscured by trees and making their detection difficult. Several roads needed to access the dam were underwater, lim-

**Fig. 1.** Nile crocodile *Crocodylus niloticus* survey area on the Pongola River Inlet to the Pongolapoort Dam, in KwaZulu-Natal (KZN) province, South Africa. Inset: Outline of South Africa indicating the position of the KZN province (grey shading) and of the study area (red dot). Data sources: Basemap: Esri, Maxar, Earthstar Geographics, and the GIS User Community. Plotted data: Provincial boundaries shape file (EKZNW 2019) and Protected Areas shape file (EKZNW 2021). Map projection: WGS 1984 UTM Zone 36S.




iting the areas that could be surveyed while complying with legislative requirements.

## 3. Results

Weather conditions were suitable for monitoring with temperatures ranging from 20.6 to 28.6 °C during the survey. Wind conditions were suitable ranging between 2.1 and 4.0 m/s except on the second day where gusts of up to 10 m/s were experienced and thus limited the ability of the aircraft to fly on that day. The speed of the aircraft ranged between 8 and 14 m/s, with the video survey being able to be flown the fastest. The flight of the aircraft would be halted to take a photograph.

A total of 16.5 km of shoreline was surveyed across 15 different flights (Table 1) with a total of 212 min of flight time. A total of 183 crocodiles were observed ($n = 129$ on the south bank and $n = 54$ on the north bank). Duplicate animals were not double counted where survey techniques or photographs overlapped for the total count. Juvenile crocodiles (total length of about 1 m; Pooley 1982; Downs et al. 2015) were not observed in this survey. The number of crocodiles observed per kilometre ranged between 2.5 and 40. The crocodiles had a few favourite basking locations where up to 24 individuals were observed in one location (Fig. 2). The remainder of the crocodiles were more sparsely distributed along the shoreline.

### 3.1. Orthomosaics

The location accuracy was highest for the orthomosaic imagery. Despite not being able to georeference the imagery using GCPs, there was only a shift of approximately 2 or 3 m in the final image compared to baseline satellite imagery. The orthomosaic imagery allowed for accurate measurement of the total length of each crocodile (Fig. 3). This was useful for determining the size class of the crocodile. Seven of the crocodiles observed in the orthomosaic imagery ($n = 30$) were less than 2.5 m in length and were considered sub-adults (Pooley 1982; Warner et al. 2016). The mean length of the crocodiles was 2.9 m, with the largest individual measuring 4.52 m. The length class ratio was 8:12:6:1:3 ($n = 30$; length classes: ≤2.50, 2.51–3.00, 3.01–3.50, 3.51–4.00, and >4.00 m). The disadvantage of this technique was the large number of photographs needed to be taken, resulting in smaller areas being surveyed. The processing time to stitch the images together was significant using the resources available to us. Another disadvantage of this technique is that animals that move between successive photographs are removed in the

**Table 1.** Details of the unmanned aerial system flights to survey Nile crocodiles *Crocodylus niloticus* at Pongola River inlet to the Pongolapoort Dam, KwaZulu-Natal province, South Africa in August 2022.

| Aircraft | Flight | Survey type | Date | Start time | Flight time | Number of crocodiles | Shoreline (km) | Number of crocodiles/km |
|---|---|---|---|---|---|---|---|---|
| DJI Matrice 210 | 1 | Video | 02 | 11:32 | 23 min 39 s | 6 | 1.00 | 6.0 |
| DJI Phantom 4 Pro | 2 | Mosaic | 02 | 12:58 | 18.57 s | 3 | 0.40 | 7.5 |
| DJI Matrice 210 | 3 | Video | 02 | 14:18 | 23 min 29 s | 9 | 1.17 | 7.7 |
| DJI Phantom 4 Pro | 4 | Mosaic | 02 | 14:55 | 18 min 30 s | 2 | 0.40 | 5.0 |
| DJI Phantom 4 Pro | 5 | Mosaic | 03 | 10:07 | 11 min 05 s | 16 | 0.40 | 40.0 |
| DJI Mavic 2 | 6 | Photos | 03 | 10:48 | 19 min 02 s | 28 | 2.60 | 10.8 |
| DJI Mavic 2 | 7 | Video | 03 | 12:57 | 3 min 46 s | 2 | 0.50 | 4.0 |
| DJI Mavic 2 | 8 | Photos | 03 | 12:30 | 05 min 12 s | 35 | 1.16 | 30.2 |
| DJI Mavic 2 | 9 | Photos | 03 | 12:55 | 06 min 33 s | 48 | 2.96 | 16.2 |
| DJI Matrice 210 | 10 | Video | 04 | 09:57 | 12 min 25 s | 6 | 1.07 | 5.6 |
| DJI Matrice 210 | 11 | Video | 04 | 10:44 | 08 min 02 s | 6 | 0.94 | 6.4 |
| DJI Matrice 210 | 12 | Video | 04 | 11:01 | 17 min 31 s | 16 | 1.06 | 15.1 |
| DJI Phantom 4 Pro | 13 | Mosaic | 04 | 12:30 | 15 min 23 s | 9 | 0.60 | 15.0 |
| DJI Phantom 4 Pro | 14 | Photos | 04 | 13:48 | 14 min 11 s | 3 | 1.22 | 2.5 |
| DJI Phantom 4 Pro | 15 | Photos | 04 | 14:35 | 14 min 37 s | 8 | 1.01 | 7.9 |

**Note:** The count of crocodiles in this table includes duplicate animals where survey locations overlapped.

**Fig. 2.** A photograph of a group of Nile crocodiles *Crocodylus niloticus* ($n = 24$) taken from a DJI Mavic 2 drone along one part of the shoreline of the Pongola River inlet to the Pongolapoort Dam, KwaZulu-Natal province, South Africa (photo credit: W. Landman).

stitching process, which could lead to an undercount of individuals.

## 3.2. Photographs

The technique of taking photographs of the crocodiles worked well for counts although it was essential to have a large screen that performed well in sunlight to spot the animals during the flight. It is possible that individuals could be missed using this technique, especially if the animals were obscured by trees or vegetation. A major advantage of photographing the crocodiles comes when using a zoom camera (Fig. 4). Being able to maintain a suitable height to not dis-

**Fig. 3.** Size class distribution of Nile crocodiles *Crocodylus niloticus* (total length (*m*)) measured on the orthomosaic imagery ($n = 30$) acquired using drones along parts of the shoreline of the Pongola River inlet to the Pongolapoort Dam, KwaZulu-Natal province, South Africa.

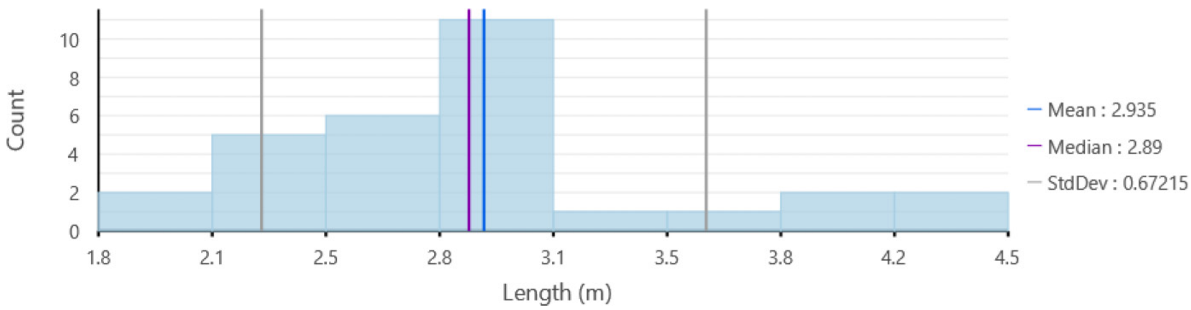



**Fig. 4.** A zoomed-in photograph of a Nile crocodile *Crocodylus niloticus* taken from the DJI Matrice 210 aircraft and the DJI Zenmuse Z30 camera at the Pongola River inlet to the Pongolapoort Dam, KwaZulu-Natal province, South Africa. Photo credit D. Jewitt.



turb the animal but still zoom in to get details provides for superior monitoring. The high-quality imagery will allow an assessment of the sex of larger animals as well as the health status of the animal. It was not possible to measure the length of the crocodiles using this technique.

### 3.3. Videos

Faster flights could be undertaken when videoing the shoreline, allowing the field monitoring to be completed more timeously. This technique allows for the most accurate detection and count of individuals as the video can be paused or played in slow motion to identify and count the crocodiles. However, locations of crocodiles could only be estimated, and the lengths of the crocodiles could not be accurately measured using this technique.

## 4. Discussion or conclusion

Since there have been declines in crocodile numbers in KwaZulu-Natal (Combrink et al. 2011; Calverly and Downs 2014; Ezemvelo KZN Wildlife, unpublished data), accurate population index estimates are required to understand the causes and magnitude of the declines and to stop them where possible and appropriate. Also, hunting of a small number of wild crocodiles is permitted annually at Pongolapoort Dam, and so annual monitoring of the population is required to assess the impact of the hunting on the population and to set scientifically defensible annual hunting quotas. Our study has provided baseline information, demonstrating that drones can be successfully used to monitor crocodiles in the inlet to the Pongolapoort Dam. Drones allow for better spatial and temporal data acquisition at lower cost. A UAV survey at a pan in Ndumo Game Reserve in northern KZN counted 26% more crocodiles than a traditional diurnal ground survey (287 vs. 211; Ezat et al. 2018). Drone surveys provide high-resolution images that can be carefully searched for crocodiles back in the office, although this may be time consuming. The use of machine learning and artificial intelligence will enhance the ability to detect, count, and measure crocodiles in future (Gonzalez et al. 2016). The imagery also can be used to map crocodile habitat and identify and monitor nests.

Owing to the constraints of the study (high dam water level, submerged access roads, insufficient number of drone batteries considering the requirement of VLOS, and the three methods employed), a complete census of the Nile crocodiles in the Pongolapoort Dam inlet area was not possible. However, all three survey methods (video, photographs, and photomosaics) were shown to be useful for monitoring crocodiles there. In future years, and with a sufficient number of batteries, we suggest that the shoreline be flown either annually or biennially and either video or photographs be taken, depending on the level of detail and information required from the imagery (e.g., visually determining the sex and health status of the larger crocodiles compared to a simple count of all crocodiles visible in the imagery). Where higher concentrations of crocodiles occur, a grid survey can be flown to create an orthomosaic image whereby the length of each crocodile in the concentration can be determined and a size-class ratio estimated.

Obtaining BVLOS ratings from the SACAA will allow for easier surveying of the full length of the inlet. Similarly, aircraft with improved flight times will facilitate surveying the full length of the inlet. While our flights were conducted at 50 m above the shoreline (Mulero- Pázmány et al. 2017; Jewitt 2021), the drone surveys for this particular population could potentially be conducted at lower height above the waterline (30–40 m) because test flights at different heights above the crocodiles did not result in any observable disturbance of the crocodiles above 30 m, and flying at lower altitude would result in improved ground resolution. The crocodiles at Pongolapoort Dam may be used to engine noise due to the motorised boating that takes place in the area. This demonstrates that a recommended flight height may not be uniform for every population of animal species, depending on the environment and the threats to which the animals are exposed. These lower flight altitudes may not be appropriate in other areas where crocodiles have not been subjected to engine noises, and hence it is recommended that a flight height of 50 m above the shoreline be maintained for future surveys.

A limiting factor of our technique was the length of time taken for the survey that was conducted over 3 days. This is long compared to the other survey techniques typically employed. Hence, it is possible that animals may move between the survey times, resulting in a possible double count of certain individuals if they move between the survey days. A BVLOS rating and adequate batteries will facilitate completing the survey in a shorter time period, thus reducing this error type. The drone surveys also require low wind and good weather conditions, although this would be applicable to other survey techniques as well to optimise the possibility of observing the crocodiles.

Juvenile crocodiles were not observed during this survey because they are known to hide in thick emergent vegetation such as reeds (Pooley 1982) and could not be detected in the imagery. However, of more importance to the issuing of hunting quotas is the ratio of the larger crocodile size classes. Breeding female crocodilians should not be hunted (Joanen et al. 2021), nor perhaps should the dominant Nile crocodile males (the larger bulls) as they achieve the most matings with the females (Pooley 1982; Kofron 1991; Champion and Downs 2017). However, whether hunting dominant bulls would disrupt the social order and affect population growth, particularly in a relatively small population like that at Pongolapoort Dam, is still an open question (Webb 2015). Repeated hunting of large male Nile crocodiles as trophies in a relatively small population has the potential to greatly decrease the ratios of the numbers in the larger size classes to the numbers in the smaller size classes, which may not be desirable from a population structure standpoint (Joanen et al. 2021). Annual quotas for the sustainable hunting of trophy Nile crocodiles outside the breeding season (August to February) at Pongolapoort Dam would be best set for the size classes up to 3.5 m, the maximum size of adult females (Warner et al. 2016; Champion and Downs 2017). A very low, occasional, quota for larger crocodiles based on the growth rate of males at large sizes could be considered as well. Monitoring the number of Nile crocodile nests each year in the inlet area would be useful to ensure that reproductive output does not decline over time (see, e.g., Joanen et al. 2021).

A disadvantage of other methods of monitoring Nile crocodiles at Pongolapoort Dam, e.g., spotlight counts using boats or vehicles, helicopter, or fixed-wing aircraft surveys, is the cost. The hire of a helicopter is approximately ZAR 11 000/h, depending on the type of helicopter used, and while fixed-wing aircraft are generally cheaper, they are still expensive at approximately ZAR 4000/h. Surveys by boat are more cost-effective, but at approximately 1 L of fuel per km, are not cheap either. Also, none of these methods can provide measured crocodile length data. The use of drones to survey crocodiles in the inlet area was cost-effective in that fuel costs were low (confined to driving to drone take-off sites) and high-resolution and accurate data were obtained despite the higher number of person hours required for the survey and for the data processing. Therefore, we recommend that UAVs are used in future monitoring of the Nile crocodile population in winter along the full length of the Pongolapoort Dam inlet.

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## Data availability
Data generated or analysed during this study are available from the corresponding author in compliance with the data policy of Ezemvelo KZN Wildlife.

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