SRAS Final Report

Population demographics of Nile crocodile (Crocodylus niloticus) populations in Southern Africa

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Abstract

This project sought to improve the monitoring of Nile crocodile populations by combining low-cost unmanned aerial vehicles (UAVs), morphometric modelling and radiocarbon analysis of claws. Low-cost UAV methods were developed and validated for ecological mapping and crocodile surveys. This included establishing morphometric relationships to improve demographic estimation from aerial imagery, and claw histology and radiocarbon dating were investigated as a means of estimating age. While claw radiocarbon analyses demonstrated that retained claw keratin generally represents only relatively recent growth because of abrasion, this finding provides an important limitation for future ecological applications. The project also generated practical tools for crocodile welfare assessment on commercial farms and formed the basis for subsequent artificial intelligence approaches for automated crocodile detection and individual identification. The work demonstrates that affordable UAV-based monitoring can substantially improve the frequency, transparency and repeatability of crocodile population surveys and provides a platform for future conservation monitoring across southern Africa.

Introduction

Reliable population demographic data are fundamental to the conservation and management of crocodilian populations. Information on abundance, population structure, recruitment and the distribution of size classes underpin assessments of population status, allows changes through time to be quantified, and provides the evidence required to guide management interventions. For long-lived apex predators such as the Nile crocodile (*Crocodylus niloticus*), population demographics also provide an integrated measure of ecosystem condition because crocodiles respond to long-term changes in habitat quality, prey availability and anthropogenic disturbance (Pooley & Gans 1976; Botha 2010; Ferreira & Pienaar 2011).

Although Nile crocodiles remain widespread throughout much of sub-Saharan Africa, many regional populations continue to face increasing pressures from habitat degradation, altered river flow regimes, pollution, illegal harvesting and expanding human populations. In South Africa, these pressures are particularly evident within the Olifants River catchment, where extensive mining, industrial development, agriculture and water abstraction have altered aquatic ecosystems over several decades. These cumulative impacts became particularly apparent following the pansteatitis mortality events recorded within the Olifants River Gorge of the Kruger National Park, highlighting the importance of maintaining robust long-term monitoring programmes capable of detecting changes in crocodile populations before severe ecological impacts become evident (Ashton 2010; Ferreira & Pienaar 2011; Combrink et al. 2011).

Obtaining reliable demographic information from wild crocodile populations remains challenging. Conventional monitoring programmes rely primarily on spotlight surveys from boats or aerial surveys using helicopters or fixed-wing aircraft. While these approaches have provided valuable long-term datasets throughout Africa, they are constrained by high operational costs, logistical complexity, observer bias and relatively low survey frequencies. Furthermore, estimates of crocodile size are commonly

assigned to broad size classes during surveys, introducing uncertainty into demographic analyses and limiting comparisons between surveys conducted by different observers. Because observations are generally not permanently recorded, opportunities for independent verification or re-analysis are also limited (Pooley 1982; Botha 2010; Ferreira & Pienaar 2011).

Recent advances in unmanned aerial vehicles (UAVs), photogrammetry and geographic information systems provide opportunities to fundamentally improve crocodilian monitoring. Consumer-grade UAVs can acquire high-resolution imagery at relatively low cost while creating permanent, georeferenced records that can be re-examined as analytical techniques improve. When combined with photogrammetric processing, UAV imagery could enable accurate measurement of individual crocodiles, repeatable surveys of inaccessible habitats and permanent digital archives suitable for future analyses. These technologies have the potential to reduce monitoring costs substantially while improving transparency, repeatability and data quality, making more frequent monitoring programmes achievable for conservation agencies operating under limited budgets (Myburgh et al. 2021).

Measuring crocodiles accurately from aerial imagery represents only one component of effective population monitoring. Ecological management is generally concerned with age structure rather than body size alone, yet determining the age of wild crocodiles remains problematic because no reliable non-lethal ageing technique exists. Body length is often used as a surrogate for age, although growth rates vary considerably among individuals and populations due to environmental conditions, resource availability and competition. Developing methods capable of linking remotely measured body size to more accurate estimates of age would therefore represent a substantial advance in crocodilian population ecology.

The present project sought to address these challenges through the integration of several complementary research components. Initially, low-cost UAV platforms and open-source photogrammetric software were evaluated to determine whether they could provide a practical alternative to expensive commercial survey systems. Building upon this foundation, morphometric relationships applicable to aerial imagery were developed to improve remote estimation of crocodile body size. The project further investigated whether radiocarbon dating and histological examination of crocodile claws could provide a biologically meaningful estimate of age, thereby allowing remotely measured body lengths to be translated into age-based demographic information. These approaches were subsequently applied to both wild and captive populations, providing opportunities to evaluate broader applications for conservation monitoring and animal welfare assessment.

Methods

Study design

The objective of this project was to develop an integrated framework for improving the monitoring of Nile crocodile (*Crocodylus niloticus*) populations in southern Africa using affordable remote sensing technologies. Rather than focusing on a single methodological advancement, the research progressed through a series of linked investigations in which the output of one study provided the foundation for the next. This approach ultimately resulted in multiple peer-reviewed publications spanning ecological monitoring, morphometrics, animal welfare, claw biology and automated image analysis (Myburgh et al. 2021; Myburgh et al. 2023; Myburgh et al. 2024; Fourie et al. 2026; Myoya et al. 2024).

Development of low-cost UAV mapping

The first phase of the project evaluated whether consumer-grade unmanned aerial vehicles (UAVs) and open-source photogrammetry software could provide a practical alternative to expensive commercial mapping systems. Flights were conducted over test sites at multiple altitudes, and imagery was processed using OpenDroneMap to generate orthophotographs, digital surface models and three-dimensional point

clouds. Mapping accuracy was assessed using field measurements and differential GPS control points where available. The resulting workflow demonstrated that centimetre-level mapping accuracy could be achieved using affordable equipment and freely available software, providing the technical foundation for subsequent ecological applications (Myburgh et al. 2021).

UAV-based crocodile morphometrics and demographic monitoring

Following validation of the mapping workflow, UAV imagery was used to quantify crocodile body dimensions from aerial photographs. Morphometric measurements collected from captive crocodiles were compared with conventional body measurements to develop regression relationships that allowed total body length to be estimated accurately from measurements visible in orthophotographs. These correction factors were subsequently incorporated into UAV-based surveys of wild crocodile populations to improve demographic analyses while reducing observer bias associated with conventional aerial surveys.

Claw histology and radiocarbon dating

Claw samples representing a range of body sizes were collected for histological examination and accelerator mass spectrometry (AMS) radiocarbon dating. Histological analyses were undertaken to describe claw growth dynamics and identify the oldest retained keratin within the claw, while radiocarbon analyses evaluated whether claw keratin represented long-term tissue accumulation or only recent growth (Myburgh et al. 2023).

Application to wild crocodile populations

The validated UAV methodology and morphometric models were applied to surveys of wild Nile crocodiles, including populations within the Kruger National Park. Orthophotographs were used to identify, count and measure individual crocodiles, allowing size-frequency distributions to be generated from permanently archived imagery. The study also compared UAV-derived demographic information with conventional aerial survey approaches and evaluated the practical application of UAV technology for long-term crocodile monitoring.

Commercial crocodile farm applications

The UAV methodology was subsequently adapted for commercial crocodile farms to quantify parameters relevant to animal welfare. Orthophotographs were used to determine crocodile numbers, stocking densities, enclosure dimensions, waterbody characteristics and other spatial metrics that had previously relied largely on estimation. These techniques demonstrated the broader applicability of UAV-based monitoring beyond wildlife conservation and resulted in the development of an objective and repeatable framework for crocodile welfare assessments (Myburgh et al. 2024).

Development of automated detection methods

The large UAV image dataset generated throughout this project subsequently provided the foundation for collaborative studies investigating automated crocodile detection and image analysis using artificial intelligence. These datasets were used to develop deep-learning object detection models trained on both real and synthetic imagery, demonstrating the potential for automated crocodile detection from aerial surveys (Fourie et al. 2026). In parallel, computer vision approaches were investigated for the identification and re-identification of individual crocodiles from UAV imagery using pose estimation and machine learning techniques (Myoya et al. 2024). Although these studies extended beyond the original objectives of the SRAS proposal, they represent a direct continuation of the datasets, workflows and UAV methodologies developed during the funded research.

Results

Development of a low-cost UAV mapping workflow

The first outcome of the project was the successful development and validation of an affordable UAV-based photogrammetric workflow suitable for ecological monitoring. Consumer-grade UAVs combined with open-source software could produce geometrically accurate orthophotographs with measurement errors below those required for most ecological monitoring applications. Object measurement errors were typically below 30 mm for survey altitudes up to 70 m, while surveys conducted at lower altitudes achieved sub-centimetre accuracy when ground control points were incorporated. These findings demonstrated that accurate ecological mapping no longer requires expensive commercial software or survey platforms and established the technical foundation for all subsequent components of the project (Myburgh et al. 2021).

UAV-based crocodile morphometrics and demographic monitoring

Following validation of the UAV workflow, morphometric relationships were developed to improve remote estimation of crocodile body size. Relationships between aerially visible body measurements and total body length allowed accurate size estimation directly from orthophotographs. These models substantially reduced observer bias associated with conventional size-class estimation and enabled permanent digital survey records to be translated into quantitative demographic information. The methodology was subsequently applied to surveys of wild Nile crocodile populations, demonstrating the practicality of UAV-derived population demographic assessments under field conditions (Viljoen et al. 2023).

Claw histology and radiocarbon dating

Histological examination demonstrated that Nile crocodile claws grow in a manner similar to modified reptilian scales, producing an age gradient from the claw base towards the apex. Radiocarbon analyses further demonstrated that retained keratin generally represents relatively recent tissue because continual abrasion removes older material. Consequently, crocodile claws are unsuitable for estimating the chronological age of older individuals but remain valuable tissues for shorter-term ecological and dietary investigations. Although this outcome differed from the original hypothesis, it represents an important finding by defining the limitations of claw-based chronological analyses and preventing inappropriate application of the technique (Myburgh et al. 2023).

Application to commercial crocodile welfare

The methodologies developed during the project were extended to commercial crocodile farming, where UAV-derived orthophotographs were used to quantify crocodile numbers, stocking densities, enclosure dimensions and waterbody characteristics. The study demonstrated that objective welfare assessments can be undertaken rapidly and accurately using affordable UAV technology, reducing reliance on subjective estimates while providing permanent digital records for future assessment. The techniques developed during this work have since been adopted by commercial crocodile producers within southern Africa (Myburgh et al. 2024).

Development of automated crocodile detection

The extensive UAV image datasets collected throughout the project subsequently enabled the development of automated crocodile detection methods using deep learning. Synthetic training datasets, transfer learning and object detection algorithms were evaluated to improve automated identification of crocodiles within aerial imagery. The resulting models demonstrated substantial improvements in detection accuracy, particularly where only limited real-world training data were available, highlighting the long-term value of the datasets (Fourie et al. 2026).

Individual crocodile identification

Building upon the object detection datasets, collaborative research further investigated the potential for identifying individual crocodiles from UAV imagery using computer vision, pose estimation and machine-learning techniques. The study demonstrated the feasibility of combining automated detection with individual recognition based on morphological characteristics, providing a framework for future non-invasive monitoring of individual crocodiles and long-term population studies (Myoya et al. 2024).

Discussion

The primary objective of this project was to improve the monitoring of Nile crocodile populations through the development of accurate, repeatable and affordable methods for estimating population demographics. The original proposal focused on two complementary research questions: first, whether low-cost UAV technology could provide a practical alternative to conventional crocodile survey methods, and second, whether radiocarbon dating of crocodile claws could provide a non-lethal approach for estimating age. Collectively, the research demonstrates that the first objective was successfully achieved while the second provided important biological insights that refined our understanding of crocodile claw growth and its limitations for chronological age estimation.

Perhaps the most significant outcome of the project was demonstrating that consumer-grade UAVs and open-source software can provide survey products of sufficient accuracy for ecological monitoring. Historically, high-resolution aerial surveys have been associated with expensive aircraft, specialised equipment and proprietary processing software, restricting their application in many conservation programmes. The methodologies developed during this research demonstrate that these barriers can be substantially reduced without compromising measurement accuracy. This has important implications for conservation agencies and wildlife managers operating under limited financial resources, particularly in developing countries where survey budgets often constrain the frequency of population monitoring. By producing permanent, georeferenced digital records, UAV surveys also improve transparency and reproducibility compared with conventional aerial counts, allowing archived imagery to be reanalysed as new analytical techniques become available.

The development of morphometric relationships suitable for UAV-derived imagery represents a further advancement. Conventional crocodile surveys generally assign animals to broad size classes based on observer estimates, introducing unavoidable subjectivity into demographic analyses. The ability to obtain quantitative body measurements directly from orthophotographs provides a more objective approach that reduces observer bias while improving consistency among surveys. These datasets also create opportunities for future automated analyses, an outcome that became increasingly apparent as the project progressed.

Although the initial hypothesis anticipated that radiocarbon dating of claw keratin would provide a practical method for estimating crocodile age, the research demonstrated that the biology of crocodile claws is more complex than initially expected. Histological examination and radiocarbon analyses showed that continual abrasion removes older keratin from the claw tip, meaning that retained claw material generally represents only relatively recent growth. Consequently, claws cannot reliably be used to estimate the absolute age of older crocodiles. Rather than representing a negative outcome, this finding provides an important contribution by defining the limitations of claw-based chronological analyses and preventing future researchers from making unsupported assumptions regarding the age represented within crocodile claws. The work also improves confidence in future studies that utilise claw keratin for ecological investigations by providing a clearer understanding of tissue turnover and temporal resolution, especially in cases where claw keratin is used to infer trophic relationships through time.

An important aspect of this project was the progression from methodological development to practical application. The techniques developed for monitoring wild crocodile populations proved equally valuable within commercial farming systems, where they enabled objective measurements of stocking density, enclosure dimensions and other welfare-related variables. This demonstrated that UAV-based approaches have applications extending beyond wildlife conservation into animal management, husbandry and industry. Such technology transfer increases the practical value of the research and broadens the potential user base of the methodologies developed during the project. Slight modification also allowed the techniques to be broadened to thermal imaging systems.

Perhaps the most unexpected outcome of the research was the emergence of artificial intelligence applications. At the commencement of this project, the primary objective was to improve manual survey methodologies. However, the large collection of accurately annotated UAV imagery generated throughout the study subsequently enabled collaborative research into automated crocodile detection, synthetic training datasets and individual identification using computer vision. These developments illustrate the enduring value of establishing high-quality ecological datasets. While the AI studies were not envisaged in the original proposal, they represent a direct consequence of the image libraries, survey methodologies and validation datasets produced during the SRAS-funded research. They also demonstrate how investment in fundamental ecological monitoring can stimulate innovation well beyond the immediate objectives of a project.

Taken together, is project produced practical tools for conservation monitoring and commercial welfare assessment, and established the foundations for ongoing research into automated wildlife monitoring. The work illustrates the value of integrating ecology with emerging technologies. Rather than replacing traditional ecological expertise, UAVs, photogrammetry and artificial intelligence provide conservation practitioners with improved tools for collecting objective, repeatable and verifiable data. As these technologies continue to develop, they are likely to become increasingly important components of crocodilian conservation programmes. Collectively, these outcomes provide a practical framework for improving crocodilian monitoring while demonstrating how affordable remote sensing technologies can enhance conservation research across southern Africa.

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