Evaluation of low-cost consumer-grade UAVs for conducting comprehensive high-frequency population censuses of hippopotamus populations

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Evaluation of low-cost consumer-grade UAVs for conducting comprehensive high-frequency population censuses of hippopotamus populations

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Abstract

The hippopotamus *Hippopotamus amphibious* (hereafter referred to as hippo) is classified as vulnerable according to the IUCN Red data list. They play a significant role in aquatic systems as allochthonous nutrient providers, and as facilitators and competitors in grasslands. Traditional census methodologies for hippo are difficult and costly to repeat. Previous research has been conducted on the use of unmanned aerial systems (UASs) to conduct hippo population estimates; however, findings either needed justification through additional field testing or used high-cost UASs that may be unaffordable for management authorities in developing countries in Africa. Therefore, using a low-cost, consumer-grade, DJI Phantom 3 Advanced multi-rotor unmanned aerial vehicle (UAV), 47 surveys were conducted of the hippo population at Ndumo Game Reserve (NGR), South Africa, between August 2016 and July 2017. In addition, comparisons were drawn between the results of and the logistical requirements and costs of the respective helicopter and UAV surveys conducted on the same day of the same hippo population. The use of a consumer-grade UAV permitted frequent, accurate, and comparatively low-cost surveys to identify temporal changes in the number of hippos present in NGR and at different locations within NGR. Hippos are a data deficient species, particularly in remote developing countries. UAVs surveys of hippo will allow accurate, highly repeatable, and comparatively low-cost data collection for management of hippos and the ecosystems within which they occur.

KEYWORDS

aerial census, drone, hippos, Ndumo game reserve, population estimate, South Africa, UAS

1 | INTRODUCTION

Applications for unmanned aerial systems (UASs) in wildlife research are increasing, particularly considering their benefit for effective monitoring and managing of species of conservation importance in areas and countries with budgetary limitations (Bevan et al., 2018; Ezat, Fritsch, & Downs, 2018; Hahn et al., 2017; Linchant, Lisein, Semeki, Lejeune, & Vermeulen, 2015; Roberts et al., 2020). Population censuses are utilized by conservation area managers as an overarching indication of species and ecosystem health (Dice, 1938; Lancia, Kendall, Pollock, & Nichols, 2005). Traditional census methods include foot and ground counts as well as manned aerial methods. These methods have been implemented in the monitoring of a variety of species including large African herbivores like the African elephant (*Loxondonta africana*), white rhinoceros (*Ceratotherium simum*), black rhinoceros (*Diceros bicornis*), and the common hippopotamus (*Hippopotamus amphibius*) (hereafter referred to as hippo) (Brockett, 2002; Owen-Smith, 1981; Whitehouse, Hall-Martin, & Knight, 2001). The high costs and high effort associated with surveys conducted using traditional methods have provided opportunities for new methods with broader application. UASs have made strides in superseding traditional methods and have been implemented in studies monitoring a variety of species including Nile crocodiles (*Crocodylus niloticus*), bowhead whales (*Balaena mysticetus*), Sumatran orangutan (*Pongo abelii*), and several surface nesting bird species (Afán, Máñez, & Díaz-Delgado, 2018; Chabot & Bird, 2012; Ezat et al., 2018; McClelland, Bond, Sardana, & Glass, 2016; Schweder, Sadykova, Rugh, & Koski, 2010; Wich, Dellatore, Houghton, Ardi, & Koh, 2016). However, few studies have assessed the capabilities of UASs for conducting comprehensive population censuses of large African mammal species of conservation importance or if surveys can be repeated at high frequencies to divulge high-resolution management related data (Vermeulen, Lejeune, Lisein, Sawadogo, & Bouché, 2013).

Hippos are a target for conservation management and their predictable diurnal wading behavior make them detectable and a good pilot species for managers to evaluate and ameliorate UAS survey methodologies that can later be adapted and applied to other species. The hippo is one of Africa's most iconic species, yet the historical fragmentation of their habitats and continued recent global declines of up to 20% in the last 10 years have focused more attention on their conservation (Lewison & Pluhacek, 2017). The aforementioned, along with unreliable population estimations and a paucity of research on hippo ecology and behavior, have contributed to the hippo being classified as vulnerable according to the IUCN (Lewison & Pluhacek, 2017). Furthermore, because of the impacts associated with an exponentially expanding human population in sub-Saharan Africa, a growing proportion of the global hippo populations are being displaced and/or restricted to protected areas (Lewison, 2007; Lewison & Pluhacek, 2017; Ramesh, Kalle, Rosenlund, & Downs, 2016; Tilman et al., 2017).

Outside of the conservation importance, the role of hippos as ecosystem engineers in African aquatic and grassland environments make them an important species to consider in managed systems (Bakker, Pagès, Arthur, & Alcoverro, 2016; Field, 1970; Lock, 1972; McCarthy, Ellery, & Bloem, 1998; McCauley et al., 2018; Moore, 2006; Subalusky, Dutton, Rosi-Marshall, & Post, 2014). Hippos graze on land and defecate when wading, facilitating the transport of allochthonous carbon, silicates, and nutrients into aquatic systems (Dutton, Subalusky, Hamilton, Rosi, & Post, 2018; Schoelynck et al., 2019; Subalusky et al., 2014). Allochthonous nutrient contributions by hippos play a fundamental role in supporting aquatic communities (McCauley et al., 2015). However, excessive inputs by dense congregations can have varying effects such as eutrophication in systems with highly variable habitat characteristics like flow, discharge, and water quality (Bengis et al., 2016; Stears et al., 2018). Additionally, although periodic grazing by hippos promotes the diversification of grazing areas, unmanaged hippo populations contribute significantly to inter- and intra-species grazing competition and cause overall deterioration of grazing areas through overgrazing (Bengis et al., 2016; Field, 1970). Hippos have few natural predators, and population numbers are instead controlled naturally by disease and drought, or controlled directly with management strategies like culling (Bengis et al., 2016; Harrison, Kalindekafe, & Banda, 2008; Lewison, 2007; Marshall & Sayer, 1976). Consequently, the effects of unmanaged hippo populations are endured exponentially in closed systems or in open systems that experience periodic or seasonal influxes of hippos (Bengis et al., 2016; Chansa, Milanzi, & Sichone, 2011; Lock, 1972).

Hippos are nocturnally active and wade or lie-up diurnally in or near water bodies, rivers, or lakes (Chansa, Senzota, Chabwela, & Nyirenda, 2011; Taylor., 2013). Where traditional methods would have been limited by varying exposure and submergence of individuals and the remoteness of wading locations, the predictability of hippos diurnal wading activity facilitates surveys that employ the use of a UASs birds-eye-view (Delvingt, 1978; Lhoest, Linchant, Quevauvillers, Vermeulen, & Lejeune, 2015; Stuart, 2001). Previous studies on the application of UASs for surveying hippo populations have formed the building blocks of the methodology. Studies conducted in the Democratic Republic of Congo outlined census parameters like optimum flight altitude, the impact of environmental conditions, and the importance of observer bias in calculating hippo population estimates from UAV surveys, in addition to the utilization of algorithms for automatic detection and counting of hippos from infrared UAV imagery (Lhoest et al., 2015; Linchant et al., 2018). Further research in Botswana evaluated the capabilities of a low-cost UAV for collecting census data, including population demographics, under an experimental setting (Inman, Kingsford, Chase, & Leggett, 2019). However, the abovementioned studies have all been conducted under experimental conditions in closed lake or pond systems, without taking into account changing environmental conditions and habitat types, the variability of pod size and number, and have therefore not tested the capabilities of a UAV census conducted in a real-world scenario. Additional research to ameliorate current UAS census methodologies will help normalize a universally accessible methodology to aid in future management and conservation of hippos, especially in parks and areas with budgetary limitations and data deficiencies.

Therefore our aims were: (a) to contribute to the evaluation of a low-cost, consumer-grade, multi-rotor UAVs for conducting comprehensive population surveys, and particularly if these systems permit surveys at increased frequencies to divulge data at a finer temporal scales; (b) to compare the logistical requirements and the results of a UAV survey to a helicopter survey conducted on the same day of the same hippo population to justify the relevance of UASs amongst current population census methodologies for hippos; and (c) based on our results and previous research on the use of UAS for census of hippos, provide a protocol to be followed when using a low-cost multi-rotor UAV for such censuses of minimum population number.

2 | METHODS

2.1 | Study area

NGR (26°S, 32°N) is a relatively small 10,117 ha reserve managed by the provincial authority Ezemvelo KwaZulu-Natal Wildlife (EKZNW) in northern South Africa (Figure 1). NGR is situated along South Africa's northern border with Mozambique within the Mozambique Coastal Plain (Whittington, Malan, & Panagos, 2013). NGR's northern boundary with Mozambique is formed by the Usuthu River, which runs from west to east. The Phongolo River, the other predominant river within the system, runs from south to north through the eastern side of the park. During periods of high rainfall (November–February) these rivers swell, then flood, inundating the

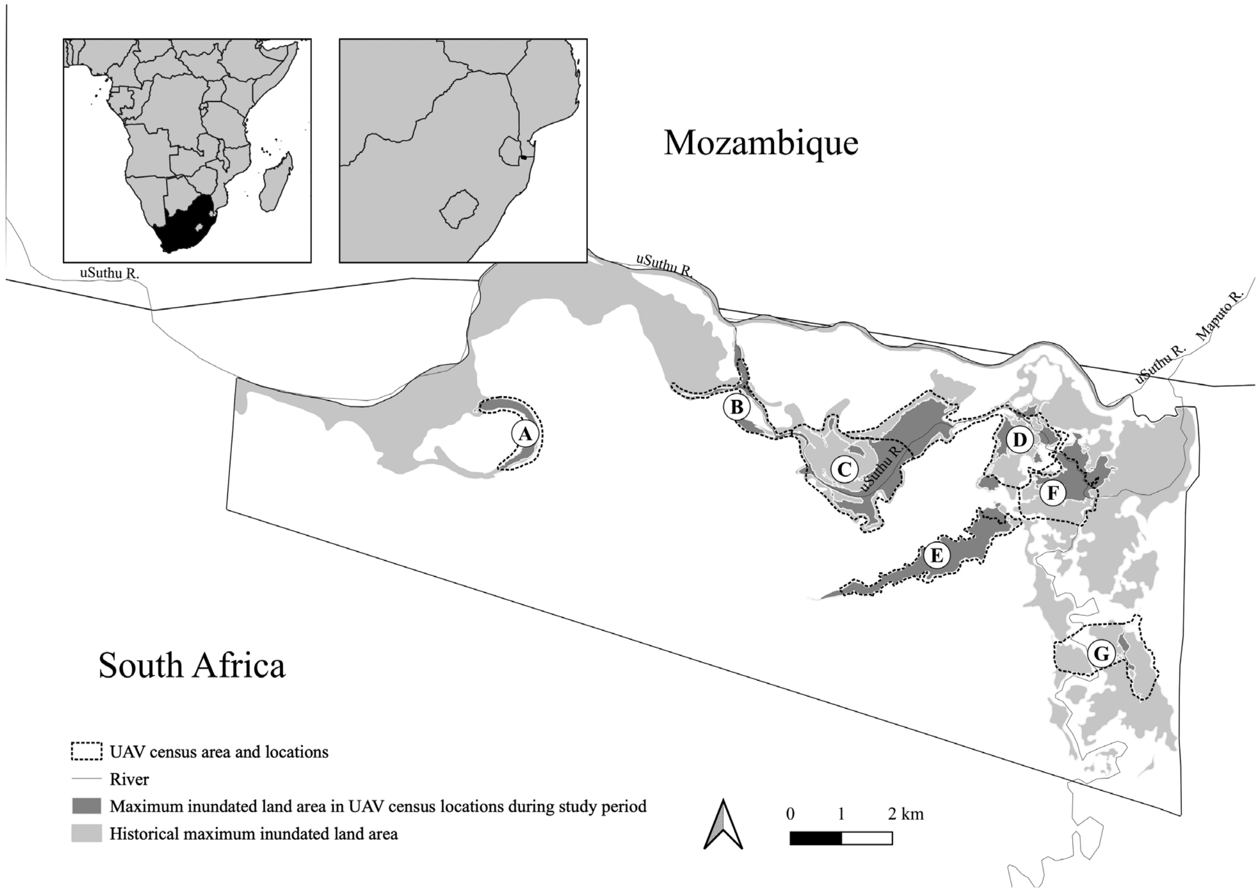

FIGURE 1 Location of Ndumo Game Reserve, South Africa, situated along South Africa's northern border with Mozambique and the UAV census area and locations

Usuthu and Phongolo floodplains accounting for over 4,000 ha of inundated land stretching over 40% of NGR (Calverley & Downs, 2014a, 2014b). These two main river courses along with 12 pans, of which Nyamithi Pan is the largest (157 ha), form the predominant water bodies in NGR (Calverley & Downs, 2017).

2.2 | UAV survey locations

We conducted four monthly UAV surveys of the important wading areas in NGR (Figure 1) from August 2016 to July 2017. Surveys were conducted at seven different locations along the Usuthu and Phongolo Rivers and associated floodplains, pans, and lakes (Figure 1). The UAV survey area was first designed to account for dry season wading localities as determined from previous year's aerial census data as well as by known localities of hippos reported by EKZNW field rangers and management staff. The large survey area was then strategically broken down into seven survey locations (Figure 1) based on the accessibility of the pilot, bandwidth of the UAV, and UAV battery life. Travel between survey locations was also considered. Survey localities were then adjusted or expanded when new wading locations were identified either visually, from spore, by vocalization, or with the UAV. Surveys were mostly comprehensive of the available wading areas in low-flow season and accounted for most of the expanded inundated area in the wet season. Each of these localities was surveyed once each survey day for four respective surveys per month. Surveys were not conducted outside of the major floodplain system as these areas are dominated by Makatini Clay thicket and Western Maputaland Clay bushveld and do not provide conducive wading environments for hippos (pers. obs.). To account for potential changes in hippo numbers through different times of the day, we surveyed localities according to four different patterns interspersed across the four survey days each month. In order to decrease the amount of time spent travelling between survey locations, these patterns also considered the distance between locations, where locations that were closer together were surveyed together.

2.3 | Unmanned aerial vehicle used

We employed the use of a DJI Phantom 3 Advanced UAV to collect the images necessary for our surveys (DJI has since discontinued this product but the description is available at https://www.dji.com/phantom-3-adv/info). Excluding the propellers, the Phantom 3 Advanced UAV had a diagonal breadth of 350 mm and weighed 1,280 g. An additional two batteries were purchased to increase the total possible survey time. The maximum flight time was estimated to be ~23 min with a top speed of 16 m/s and a maximum flight distance of 6,000 m. The UAV is manufactured with a 2.7 K Camera and 3-Axis Gimbal with the capacity for shooting 12 megapixel JPEG files, a 1/2.3″ sensor, fast f/2.8 prime lens, and a preset focus optimized for aerial images. All image global positioning system (GPS) locations were automatically embedded as part of every image.

2.4 | UAV survey protocol

The UAV was controlled by a pilot on the ground via the DJI GO app on an Apple iPhone 6 and operated through the DJI Phantom 3 Advanced remote controller. An example flight path is pictured in Figure 2. The operator used a live video feed from the UAV to manoeuvre the UAV to, from, and around the survey locations. Only aquatic habitat was surveyed, and surveys were completed once all possible wading locations in the survey area were surveyed. The breadth of the survey areas was first determined by the distribution of dry season wading habitat; accounting for potential increases in the survey area in the wet season, and second by connectivity with the UAV, where if bandwidth was limited, then survey areas were split so that all available habitat could be surveyed. An effort was made to conduct all flights at a consistent altitude of 30 m and a constant speed of between 8 and 10 m/s; however, some increases in altitude of up to 60 m were required to compensate for low bandwidth during surveys. The flight height was determined based on the lowest flight altitude possible above the highest tree canopy to increase detection and achieve the highest count precision and accuracy. Although the floodplain was generally uniform in topography, the flight altitude of the UAV was gauged based on the height of the UAV above the take-off location and not the actual altitude during flight, and therefore images taken during flight were taken from unknown altitudes. Although the pilot made an effort to search for hippos with the camera facing forward to identify targets on the horizon, the pilot was sometimes forced to adapt to environmental conditions and changes in survey area characteristics. Single individuals, as well as large pods, were distinguishable during surveys. Once a target was located, the piloted hovered the drone above with the camera facing directly below and took at least three sequential photographs of each hippo or group of hippos. These photographs were taken from different angles to avoid glare and to ensure the best photograph quality. The number of photographs taken of each group of hippos depended on the number,

FIGURE 2 A selection of imagery representing the UAV census process (a) a sample flight path of a UAV census of Nyamiti Pan in August 2016 (b) a screenshot of a UAV image taken at Dephini showing the interface used to count hippos (c-f) a selection of photographs from the UAV census conducted in August 2016 exemplifying differences in ease of detection of hippos at four different survey locations (c) a single hippo at Bhakabhaka (d) a large congregation of hippo's in muddy water at Banzi (e) a small pod well-hidden at Shabathan (f) a set of hippos basking in shallow water on the periphery of Nyamiti Pan

the level of submergence, and level of disturbance of hippos. Increased numbers of images were taken of large congregations, pods that were either entirely or partially submerged, and groups that were disturbed by the presence of the UAV. An effort was made to capture as many hippos in each photograph as possible. If congregations of pods did not allow for all hippos to be captured in a single photograph, sets of photographs were taken of different portions of hippo congregations so that all individuals could be accounted for. It was necessary that UAV batteries be fully charged before each survey. Therefore, batteries were charged in a research vehicle between survey locations using a car-charging adapter.

2.5 | UAV image processing and hippo counts

We processed images using Apple Preview (https://support.apple.com/en-za/guide/preview/welcome/mac) (Figure 1). Each image taken during the survey was captured, assuming that it contained at least one hippo. However, some images contained only objects that resembled hippos and no actual hippos and were therefore removed from the data set. We grouped images containing hippos based on date and survey area. We then sorted images of the same pod containing different numbers of visible individuals, and we kept the photographs that contained the highest minimum number of individuals for the data set. Each hippo was counted and marked using the "sketch" tool in the "markup toolbar" to prevent multiple counts of single individuals. Each photograph was counted and marked twice, and if there were discrepancies between counts, the image was counted a third time or until a consistent total was determined. Once we had counted all hippos, we calculated a total for each location as well as a total for the survey. All recordings and calculations were done in Microsoft Excel.

2.6 | EKZNW helicopter survey

EKZNW conducted their annual survey of the hippo population at NGR on August 22, 2016, using a Bell Jetranger

III helicopter. These surveys are typically conducted during the dry season between July and August when water levels are lowest and were designed to cover the entire wading habitat in the reserve targeting previously known wading habitat. Four observers were aboard the aircraft; two in the front and two in the rear. One observer in the front of the aircraft was equipped with a Canon 30D camera with an 18–135 zoom lens used to capture photographs of the hippo. The hippo count was carried out from 10 hr:00 to 11 hr:30 min. Flight height was ~30–90 m at a speed of 30 knots. When a congregation of hippos was spotted, the helicopter hovered until a satisfactory number of quality images could be taken. The images were processed by EKZNW staff and the results recorded in Microsoft Excel.

3 | RESULTS

A total of 47 of the 48 planned UAV surveys were conducted from August 2016 to July 2017. Mean total census area was 2.26 ± 1.79 km^2 with a maximum of 6 km^2. The mean flight distance covered by the UAV in a single census survey 5.28 ± 3.15 km with a maximum of 22.08 km. Mean UAV survey time at single survey location was 13:57 ± 6:56 min with a maximum of 49:17 min. The ground sampling distance (GSD) realized while flying the UAV at 30 m altitude was 1.3 cm/px. The maximum distance attained between the UAV and remote during flight was 3.6 km flying over open water at Nyamiti Pan. The maximum number of flights required to cover the census area in a single survey was 13 flights. Battery life and connectivity from the UAV to the remote were the greatest limitations and determined UAV census area. Increases in forest density decreased connectivity between the UAV and remote. UAV surveys enabled us to identify temporal changes in density, distribution, and minimum hippo population. This manuscript aims to highlight the capabilities and methodologies resulting from implementing UAS based censuses of a hippo population, and therefore the behavioral and ecological findings that resulted from these censuses are reported in a separate manuscript (Fritsch et al. in prep.). We were able to use the UAV to survey areas where hippo localities were known, as well as at discovering new localities through changing distribution of wading locations. A total of 7,435 images of hippos were processed (Figure 2). The mean number of hippos detected in a census was 145.6 ± 54.5 with a maximum number of 246 hippos and a minimum of 26 hippos.

On August 22, 2019, the total census areas for the UAV and helicopter censuses were 0.77 and 50.54 km^2, respectively (Table 1). The maximum attained UAV survey area in the study period was 5.99 km^2 (Table 1). The costs for the UAV census included the fuel costs for vehicle travel between survey take-off locations and excluded initial costs: UAV purchase (~$1,500) and, although it was not relevant to this study, UAV pilot hire (~$150/hr) or UAV pilot licensing (~$1,500–$8,000) (South African Civil Aviation Authority, 2019). The cost of the helicopter census was determined based on an hourly rate of $756/hr that included the fuel, pilot hours, and cost of utilization of helicopter but excluded initial purchase of a helicopter, its maintenance, and the cost of travel to and from the census take-off location. In August 2016, the UAV census accounted for ~43% of the cost/km^2 of the helicopter census (Table 1). The maximum flight area UAV census in the study period (November 2016) was 4% of the cost/km^2 of the helicopter survey in August 2016. The person-hours required are also documented in Table 1, where the August 2016 UAV census required 7.25 hr from one person, while the helicopter census required 1.5 hr from 4 people (6 total man-hour) (Table 1). The total minimum population estimate derived from the August UAV survey was 227 hippos, and the total derived from the helicopter survey was 255 hippos (Table 1). The UAV census accounted for all the same localities as the helicopter within the UAV flight area (Table 2). The UAV census detected a higher number of hippos at 2/7 survey locations (Banzi and

TABLE 1 Cost and effort comparisons between UAV and helicopter survey methodologies for counting hippos in Ndumo Game Reserve, South Africa

Parameter	UAV (Aug. 2016)	UAV (Nov. 2016)	Helicopter (Aug. 2016)
Elapsed survey time (hours)	7.25	7.5	1.5
Person hours required (hours)	7.25	7.5	6
Approximate total survey area (km^2)	0.77	6.00	50.54
Cost per survey (US dollars)	4.07	4.07	756
Census cost per km^2 surveyed (US dollars)	6.49	0.68	14.96

Note: Fuel costs were calculated using March 2019 exchange rates between South African Rands and US dollars and March 2019 fuel prices.

TABLE 2 The total number of hippos counted by location during the UAV and helicopter censuses conducted in August 2016 in Ndumo Game Reserve, South Africa

	UAV	Helicopter
Shokwe	0	0
Dephini	37	31
Shabathan	0	0
Banzi	49	47
Nyamiti	8	8
Bhakabhaka	38	67
Pholwe	95	99
Outside UAV census area	–	3
Total	**227**	**255**

Note: Helicopter disturbed hippo leading to underestimate by UAV.

Dephini), an equal amount was detected at 3/7 survey locations (Shokwe, Shabathan, and Nyamiti), and less were detected at 2/7 locations (Bhakabhaka and Pholwe) (Table 2).

4 | DISCUSSION

Large government-run conservation authorities in South Africa, namely South African National Parks (SANParks) and EKZNW, generally conduct hippo population surveys using helicopters. At a fraction of the cost and skill-level required, low-cost multi-rotor UAV surveys provided accurate population estimations that could be easily repeated over diel and annual timescales to identify temporal changes in number and distribution of hippos. Although some discrepancies in counts were realized between the helicopter and the UAV, the UAV resulted in comparable data (Table 2). The underestimate of the minimum population at least 1/7 locations (Bhakabhaka) was attributed to the disturbance caused by the helicopter, which instigated the retreat of the hippos to deeper water where they submerged, and later in the day, went undetected during the UAV survey (Table 2). Normal shifts in the distribution of hippos through wading localities may have also contributed to the discrepancies between counts, even though both surveys occurred on the same day. In August 2016, the helicopter census was more than two times more expensive per km^2 surveyed than the UAV census, and although the helicopter covered far more area, most of the area covered can be attributed to taxiing between census locations and did not account for areas with viable hippo habitat (Table 1). On the contrary, the UAV census was designed to focus on known aquatic wading sites and surrounds, and the only costs incurred were related to commuting by car between survey locations. An even larger discrepancy in cost per km^2 surveyed was realized when the maximum attained UAV flight area in the study period was compared with the helicopter census in August 2016 (Table 1).

Hippos are the last remaining large herbivore (>1,000 kg) that occur outside of protected areas in South Africa (Eksteen, Goodman, Whyte, Downs, & Taylor, 2016; Lewison & Pluhacek, 2017). South Africa has the third-largest population in the world accounting for 5–6% of global numbers, of which roughly 90% occur in managed protected areas (Eksteen et al., 2016; Lewison & Pluhacek, 2017). NGR's estimated 250–300 hippo in 2017 accounted for the second-largest population managed by EKZNW, after iSimangaliso Wetland Park (iSWP), and the third-largest remaining natural population in South Africa (the largest being in Kruger National Park). In the 2016–2017 fiscal year, across more than 120 parks (> 6,750km^2), EKZNW spent ~1% (~$50,200) of their annual budget on logistics related to game counts utilizing methods including walked transects, fixed-wing aircraft, and helicopter censuses (pers. comm.). Even so, a number of the planned annual censuses could not be completed because of monetary constraints and over-booked aircraft. To add to the problem, in 2017–2018 EKZNW experienced dramatic budget cuts, and funding towards censuses and logistics were reduced a further 40% (pers. comm.). Assuming the hippo censuses in NGR and iSWP covered 50 and 750 km^2 respectively, our cost estimates indicate that EKZNW could save between ~$6,776 and 11,424 annually by replacing helicopters with UAS based survey methodologies at these two locations. These cost-saving opportunities are not only relevant in South Africa as according to the IUCN, nine African countries have unknown or data-deficient populations, the majority of which are budget-related (Eksteen et al., 2016; Lewison & Pluhacek, 2017).

Other challenges remain ahead before UAS survey methods are adapted in conservation management and scientific research in South Africa. The South African Civil Aviation Authority (SACAA) has established some of the most stringent laws in the world for remotely piloted aerial systems (RPAS) and licensing comes at a relatively high financial cost (≤ ~ $15,000), even for research and conservation management entities (South African Civil Aviation Authority, 2019). These entities, which, at first glance, neither fall under “personal or private use” nor “commercial outcome, interest, or gain,” are blanketed under the “commercial” category, and are required to jump through a number of costly hoops before implementing UAS methodologies (South African Civil Aviation Authority, 2019). In a different setting, these stringent laws and licensing requirements lead to better overall public safety; however, many of these precautions are less relevant in remote, expansive, protected areas, away from tourists and people. Across EKZNW protected areas, there is a growing concern about the potential application of UAS's as part of illegal poaching activities, particularly rhino poaching. Although there are additional security and logistical concerns that arise when piloting UASs in protected areas with elevated security protocols, conservation management, and scientific research should be afforded a different level of scrutiny than outside entities and members of the public.

In addition, although the data are not presented here, this study is the first to collect high-resolution population-level behavioral and demographic data for hippos and demonstrates the management as well as the scientific opportunities that arise from high-frequency population censuses (Fritsch et al. in prep.). The pilot had no experience flying a UAV prior to the study, yet the surveys were easy to conduct and yielded important results. The multi-rotor UAV offered advantages in manoeuvrability and permitted active detection and approximation of hippo numbers during the course of survey flights. The manoeuvrability and ease of piloting of the UAV enabled sustained relevance of the methodology through changing ecosystem-level characteristics like increases in inundated land surface area. In addition, when hovering, multiple images could be captured of targets. The most significant hurdle we encountered with the implementation of the multi-rotor UAV was restricted flight range because of limited bandwidth.

Some ameliorations to the UAV census protocol used in this study can be made to increase its quality and efficiency. The UAV offered relatively low levels of disturbance compared with the helicopter; however, we did encounter some disturbance of hippos dependent on pod size and water level through our surveys (pers. obs.). A hippo's eyesight is generally less sensitive than it's hearing. In addition, the UAV was of diminutive size, and therefore any disturbance during surveys was more likely to be caused by noise disturbance rather than visual disturbance (pers. obs.). Hippos were more difficult to count where deeper water allowed them to submerge once disturbed by the sound of the UAV. We did not quantify the impact of a potential change in altitude on the quality of a census, but did at some points increase our flight altitude to compensate for low bandwidth, and believe an increase in survey altitude to 40–50 m (GSD: 1.73–2.16) will still result in effective and informative surveys as individual hippo and large pods were still distinguishable. We acknowledge that the implementation of UAS-based census methods will be dependent on several variables including (a) the population size where populations with <1,000 hippo will be easier to survey, (b) the behavior and particularly the level of disturbance or persecution of the population where a previously undisturbed population will be more favorable, (c) the system type where rivers, dams, and lakes will be much easier to survey than floodplain systems and systems with open grasslands will be easier to survey than forested, (d) the road access and remoteness of target survey areas where localities that are less remote will allow enough bandwidth between the UAV and pilot and decrease the time needed for surveys, (e) the level of cover and water depth at survey locations where hidden or submerged hippos will be more difficult to account for, (f) the presence and flexibility of drone regulations, (g) the available budget. Our recommendations are that low-cost multirotor UASs are effective for intensive surveying of known wading areas and surrounds. If wading areas are unknown, then we rather recommend the use of a more powerful multi-rotor UAS or the use of a multirotor UAS system in unison with fixed-wing UAS, or a helicopter, to first locate hippo wading locations as they are more adept to surveys covering large areas, for example, 10–30 km^2 (Guo et al., 2018). Some unforeseen advantages of using a multi-rotor UAV was that it permitted the identification and investigation of targets, and increased adaptability during flight and provided immediate feedback without needing to download or process imagery. In terms of management, the multi-rotor UAV also allowed the collection of finite data on groups of animals, like the identification of individuals, group-level social structures, and the identification of snared or injured animals. This is a useful tool in protected areas in Africa where management scenarios on the ground require constant and adaptable surveillance techniques.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Camille J. Fritsch and Colleen T. Downs conceptualized this research and found funding. Camille J. Fritsch collected the data, conducted the analyses and wrote the manuscript. Colleen T. Downs edited and reviewed subsequent drafts.

DATA AVAILABILITY STATEMENT

All data used in this manuscript are available on request and are stored at the University of KwaZulu-Natal.

ETHICS STATEMENT

No ethics approval was required for this research.

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