ABSTRACT

OBRYCKI, PAWEL. Guidelines for UAV Surveying in the Arid Savanna.
Under the direction of Dr. Lawrence M. Silverberg.

Accurate information about animal populations is desirable for conservation and sustainability in long term resource mitigation in almost every ecological investigation. Estimating the population density is a complicated process, that requires proper planning and using correct tools. This thesis examines the applications of Unmanned Aerial Systems technology to animal counting, taking from the experience of numerous field experts and researchers. As a result, a set of guidelines was developed in order to aid with the preparation required before conducting an animal biodiversity survey in an arid savanna region using UAS. The set of guidelines consists of 11 factors, with their properties explained in detail.

To validate the guidelines in the field, the research team conducted a survey of a single block property located in Namibia. Some of the factors were optimized for the Semi-Arid environment and external environmental conditions of the region. The configuration of the UAV, the software and factors are discussed in the results section of the thesis.

The data collected during the survey process was analyzed by a team of students. The animals in the images were detected, divided into species and saved in database, which was later a subject of statistical analysis used to assess the precision and repeatability of aerial surveying method. After initial calculations, the CoV turned out to be higher than 0.2, but during further statistical analysis a bimodal distribution has been determined. The reason for the bimodal distribution was animal herding, effectively causing significant changes in animal density values depending on whether the herd was present. Missing a herd of animals during a single day of counting resulted in a data point that is inconsistent compared to days that the said herd was detected. The herding behavior of animals and detecting them turned out to be a crucial issue that needs to be identified to yield accurate and repeatable surveys and requires further investigation. The thesis concludes that UAV surveying is a viable methodology that is being successfully used in animal counting, and that will likely continue to grow in popularity. However, it requires proper preparation and knowledge.

Guidelines for UAV Surveying in the Arid Savanna

by
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DEDICATION

I dedicate this thesis to my sister, Zofia, who always supported me, in my brightest highs and darkest lows. I would not be able to do this without your belief in me.

BIOGRAPHY

Pawel Obrycki was born and raised in Poznań, Poland. He attended Poznań University of Technology receiving his B. S. in Aerospace Engineering in 2020. He will complete his master's in Aerospace Engineering at North Carolina State University in January 2023.

Before attending North Carolina State University he obtained the hands on experience fixing consumer grade UAVs at a small company in Poland, where he expanded his troubleshooting and mechanical skills, preparing for directing a biodiversity section of Namibia Wildlife Aerial Observatory project that was developed by Dr. Silverberg and directed by Dr. Manning. Throughout the program he helped with the design and manufacturing process, developing the methodology for wildlife applications and led a group of students through the savannah gathering data.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my entire family for their infinite support and belief in my success. My mother, Magdalena Obrycka, taught me perseverance. Thank you for showing me how to stay on the path and always move forward. My father, Antoni Obrycki, is the most hard-working person I know. I am grateful for teaching me the value of work and how to respect it. My sister, Zofia Obrycka, was always an emotional support and a person that I could rely on in every aspect, carrying me through my brightest highs and darkest lows. My aunt, Monika Lewandowska, was always ready to help me with logistics and bureaucracy, saving my skin numerous times in the middle of the night. Her husband, and my uncle, Piotr Lewandowski is a living definition of ambition, which I learned from him and his way of facing the future. My grandmother, Łucja Świderska deserves an honorable mention, for making sure that I am well fed and healthy, from my birthday till now. Finally, I would like to thank Anna Machowiak, for teaching me how to cherish the little moments, stop and take a breath, enjoying simple, everyday things, like a cup of coffee or a three-minute nap.

My adventure in North Carolina and Namibia would not take place without Dr. Hanka Gracz, who put me in touch with Dr. Silverberg and made it possible for me to come and study in the US, treating me like a part of her own family. She is the living proof that determination is more powerful than any obstacle.

I would also like to thank my advisor, Dr. Larry Silverberg, who saw my potential years ago and offered me the opportunity to work for him. That decision changed my life, opening new possibilities and areas of science that I did not even know existed. His ideas, way of explaining complicated concepts, and storytelling skills are the reason I believe he is the smartest person I have ever met. Without him this thesis would not even get started in the first place. I will be missing our hours long conversations in your office, exchanging the ideas and life experiences.

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CHAPTER 1: INTRODUCTION

Role of biodiversity in Namibian conservation

Africa contains the largest portion of the savanna biome. **Bush encroachment** due to incorrect resource partitioning, and overgrazing is quickly making this area vulnerable and reducing the productivity of semi-arid rangelands. The **ecosystem**'s carrying capacity is declining with increased species competition [1]. The failure to apply ecological knowledge to this issue can result in improper environment fire suppression where grazing ungulates are causing erosion, and thus browsers do not have proper resources to survive [1]. Large and small mammals coexist in different densities depending on population dynamics, size, and resource need. The loss of large mammals from African savannas can have a suite of unexpected consequences, leading to a less hospitable ecosystem for livestock, wildlife, and people [2].

Conservation in southern Africa introduces some new stakeholders to biodiversity conversation. These stakeholders include private ranchers and communities [3]. Unlike in most of the world, southern Africa wildlife is seen as belonging to the landowner [4]. Since the animals are seen as a personal resource, there are economic "incentives for landowners to conserve carnivores for **ecotourism** and **trophy hunting** in some instances" [3]. In particular, Namibia's conservation program puts land in the hands of communities in order to both protect the environment and alleviate poverty [5]. Any effective conservation programs in this part of the world must work closely with local landowners and communities, rather than established organizations that protect the environment.

Biodiversity is much more than just protecting endangered species. No two species are equal and thus, the extent to which biodiversity affects an ecosystem depends on how different the species are functionally. The protection of biological diversity as a resource involves integrating conservation into management practices to highlight different aspects of concern. Biodiversity surveys are a method of collecting data about species dynamics, diversity, and livelihood. Results are critical to measuring and protecting biodiversity [6]. Animal counts are one of the most important and frequently used surveys.

Accurately estimating wildlife **population density** is difficult and requires a considerable number of resources and time [7]. The primary researcher must address several questions before designing and undertaking a monitoring project including project timeline, specific scope, are the protocols in line with the expected outcome, and how the proposed project might affect the site [7]. Different species may require a different monitoring project, so it is important to design and undertake the project from multiple perspectives to ensure the most accurate and efficient methods and tools are utilized.

Accurate information about **animal populations** is desirable for conservation and sustainability in long term resource mitigation in almost every ecological investigation. Good information about the population density of a species, the total number of individuals, and the fluctuations in numbers from year to year are essential components of data needed for the evaluation of conservation and land management [8]. Observational studies are required to assess location and resource longevity with accuracy and precision. The failure to apply ecological knowledge can result in land and wildlife mismanagement. Management of large herbivores and mammals requires indicators which provide information on the response of both the animals and their habitat to changes in population abundance with a goal of preserving and protecting natural resources to sustain a balanced and naturally functioning ecosystem [9].

The savannas of southern Africa are renowned for their spectacular wildlife. Savannas are the most extensive biome in the tropics, and the most spatially extensive biome in the world. They are sub-climax ecosystems maintained due to edaphic, fire, and herbivore influence. Large mammals maintain the ecosystem, numerous ungulate grazing and browsing species coexist by dividing resources spatially and temporally, and well-armed species of shrubs and trees establish themselves in clearings, leading to thorny thickets [10]. Large diurnal mammals are good indicators of **habitat** value since they contribute to the conservation of other species. Large predators often shape the population size, distribution, and behavioral activities of prey populations. Herbivores act as ecological engineers by changing the structure and species composition of vegetation [11]. The distribution of large mammalian species is due to the presence of food, water, and stability of the area from human disturbances.

What is animal counting?

It is a process of estimating the number of animals (divided by species) in a given area. Among the simplest and most affordable methods of animal surveying is the water hole count. Surveyors conducting water hole counts watch an assigned water hole and record all animals that come to drink. These counts usually last for 24 hours so it is important that there is a full moon for the animals to be seen through the night. Other watering holes on the property are also monitored. Although water hole counts require few resources, this method can measure species density but not population [12]. Population sizes are not accurately depicted in watering hole counts alone [12]. Research from watering hole counts in Kruger National Park show that the data “did not reveal any definite correlations and it is concluded the strong and varying influence of environmental conditions on the drinking habits of game makes it virtually impossible to obtain an adequately representative picture of animal abundance and population trends from information based on waterhole counts” [13].

Camera trapping is a widely accepted method of conducting biodiversity surveys. First popularized by researchers studying large cats, camera traps allow for individual identification of animals, which can be used to measure species density and population [14]. In order to measure species density and population using camera traps alone, the species needs to be individually identifiable [14].

What is an aerial survey?

Effective monitoring is key for effective wildlife management. Aerial surveys are a proven method for monitoring large mammals [15]. Single engine aircraft are taken into the air at specific times in the year to monitor population growth and density. Though effective, they are considered highly expensive and dangerous for biologists. The entire process is done quickly and in real time. Experts are taken on the aircraft and count every animal they see while flying transects across the targeted property. They must be able to identify and count species immediately as soon as they see them, in order to achieve a full count. The accuracy of the count comes down to the people in the aircraft, whether that be a single engine passenger airplane or a helicopter. This is the most expensive method of counting and can only be done a few times a year due to the associated costs. Only large-scale wildlife management operations can afford it. Further, single engine aircraft are among the highest causes of death for wildlife and field biologists and ecologists, as aerial surveys routinely require low-level, low-speed flying. Air crashes accounted for 66% of the 122 job-related deaths of wildlife biologists documented by D. Blake Sasse, a biologist with the Arkansas Game and Fish Commission from 1937-2000 [16]. The most significant causes of accidents were aerodynamic stalls and power-line collisions. One researcher, who was involved in creating this article, is not with us anymore. Petri Viljoen [23], who was the first biodiversity expert helping with creating this study, died during an airplane crash while performing wildlife census in the Zambezi valley.

Unmanned aerial systems (UAS or drones) may offer a safe and efficient approach to wildlife population monitoring through routine animal counts [15]. Long range, fixed wing drones can survey properties from an altitude which does not disturb the wildlife and take pictures along property transects. The images can then be viewed slowly, and meticulously looked over after collection, allowing ample time for observation and correct species identification. Drones are cheap, easy to maintain, and adaptable to suit almost any environment's needs. UAS provides opportunities for business development in aerial surveillance for wildlife and biodiversity monitoring.

What are the best practices of animal counting using drones today and in the near future?

The first step of animal counting is **sampling.** It is the count of objects in a **block**, which is a part of the surveyed area. After collecting a dependable sample of the area, the next step is to extrapolate the sampled block to the whole area [17, 19]. In order to calculate the **abundance**, and to get reliable results of the whole area counts, a solid statistical analysis is necessary. Usually, field experts hired to manage the total count of the area are using the sampling and extrapolation method, while the academic researchers tend to extrapolate results collected in previous surveys [18].

Another important factor when considering the right tools with which to perform a biodiversity survey is the price attached. Helicopters and planes require substantial funds available to begin with, specialized personnel such as the pilot and ground crew, and at least two biodiversity specialists counting and identifying the animals in real time from the cockpit [17, 20]. This is not a small operation that can be performed by anyone in their backyard, limiting its viability to big players with substantial funding.

This raises the need for a smaller scale budget solution, possibly viable for a single individual or a small crew to conduct the whole survey by himself, without the high price tag attached to it.

For some years now the animal counting community has been experimenting with a relatively new technology - Unmanned Aerial Vehicles [21]. UAVs offer a handful of possibilities to the people who are conducting biodiversity surveys and animal counting. Unmanned technology provides features that were thought to be impossible 10 years ago, but that now are being integrated into counting procedures. The idea of the article is to talk about best practices used in the industry, but one must recognize that best practices differ between individuals. In particular, it is important to distinguish what ‘the best practices’ mean to field experts and to researchers, while trying to account for how the technology and practices will change in the future.

Drone technology has a lot of advantages compared to traditional surveying methods. First off, the UAVs are emitting way less noise than helicopters, which prevents animals from fleeing after hearing the object approaching [32]. Additionally, a researcher conducting the survey can stay safely on the ground, while the drone autonomously registers high quality images or video, instead of sitting in a small cabin, risking his or her life. Arguably, a factor of a great importance is the price [17, 21]. The cost of conducting a count using a drone is a fraction of the price of lending a helicopter with essential crew and fueling it.

Unfortunately, besides the advantages that UAV technology has, it is not always the best tool to conduct the counting with. Sometimes the incentive to use drones leads to designing the study in the wrong way, while there are other tools that would do better in such conditions. For example, on a small property in Africa, it would be easier and more cost-efficient to set up a camera trap surveying the water holes to get the number of the species on the property, instead of building and implementing the UAV system [17, 22].

Another aspect that makes implementing UAVs harder is the fact that field experts and researchers have different perspectives when it comes to surveying. The organizations who hire field experts, for example the wildlife preservation parks, want to get the final report with the population number of the animals within a species in their area, meaning that field experts are hired to conduct the routine government assessments [23]. On the other side, people who work in academia are more focused on writing journal articles and responding to the scientific community's needs, which can require more data than are possible to collect for the organizations that hire the field experts.

Surveyors tend to use off the shelf UAVs, usually customized for animal counting. Depending on conditions in which the counting will be conducted drones are equipped with different systems, for example: LiDaR sensors, thermal cameras, additional power supplies etc. [24].

UAV systems use autopilot software programmed to be able to register data over the target surface. There are different ways to create the flight patterns, the most common being parallel transects (with gaps between or overlaps) [19] but, depending on the conditions, some other patterns are used, for example the Rosette Pattern [25]. After the flight over the target surface the data is prepared and then analyzed.

Thanks to the high quality of the registered data, it is possible to deeply analyze captured images or any other data (depending on the sensor). It is extremely important to focus on avoiding the typical mistakes, which are very frequent while analyzing wildlife data. The most popular among them are availability error, perception error, misidentification, and **double counting** [21]. After making sure that the errors have been avoided one should start the process of actual data analysis. Using Hierarchical modeling leads to the model distribution, abundance (with associated demographic parameters) and detection ability.

While the possibility of recording gigabytes of data is convenient and tempting, it often leads to over analyzing it, as a result spending ‘too much eyes down time’, which is not efficient and is slowing down the counting process [24]. With the huge amount of data comes the problem with storing it. It may require deleting all the processed data, and it becomes difficult to share with the counting community. In the future other researchers might find a use for the old data that would have been deleted [24].

Another important aspect that is often problematic while conducting the counting is legislation. Most of the countries have introduced or updated their UAV restricting laws throughout the last 5 years, especially over national parks, and strategic facilities. Unfortunately, communication with government organs responsible for issuing the permits might be hard because of language and culture barriers. It is important to have it done before starting the counting [20]

The future status of UAV surveying could have to do with the technology or wildlife needs. From the hardware side, we are expecting to see a leap in battery cell technology [26], which will extend the range, flight time and payload mass. Along with the battery cells the sensors will be miniaturized and improved in terms of quality and reliability, leading to data of a higher quality and resolution. It is also possible that with technological progress, that companies release a consumer UAV system targeted to people who manage counts.

With the improvement of computing power, it will be possible to analyze the data in a more detailed way, registering and processing parameters that are still too complicated for current technology. People will start to believe the data the more accurate it is.

Everybody in the community does the same, but there are aspects about the steps that different researchers do differently. Current best practices reflect what the governments are currently expecting in terms of understanding the animal populations and what they want to learn about the animals, and that will change in the future. We expect the required accuracy to increase with time. The whole area of counting is going to demand more and more temporal and spatial resolution (toward abundance and frequency).

The material discussed in this Introduction section and compiled in the next section is based in part on conversations with scientists and field experts, which were approached based on the articles and studies they conducted. Every person mentioned in Table 1 provided us with their knowledge and experience, based on years of experience in the field or researching the theoretical side of animal surveys. This enabled us to gauge the best practices and have a better understanding of the technology opportunities, its limitations, and ecological factors, which were as important as the technical side of the study.

Table 1: Field experts and researchers who contributed to creating guidelines.

Name	Article	Company or University
Petri Viljoen	Citation [23]	University of Pretoria
Meyer Etienne De Kock	Citation [36]	Czech University of Life Sciences Prague
Ulrich Franke	Citation [17]	Aerosense
Katie Christie	Citation [18]	Alaska Department of Fish and Game
Peter Webley	Citation [24]	Center of Arctic Security and Resilience
Margarita Mulero Pazmany	Citation [20]	Website
Julie Linchant	Citation [25]	University of Liège, Belgium
Lance Brady	Citation [37]	USGS Unmanned Aircraft Systems

CHAPTER 2: BEST PRACTICES

Introduction

The following guidelines were developed in order to aid with the preparation required before conducting an animal biodiversity survey in an arid savanna region by an unmanned aircraft system (UAS). The methodology drew from a review of the literature and from interviews with experts in the wildlife and UAS engineering communities, as previously mentioned.

The UAS technology was divided into three categories – the unmanned aerial vehicle (UAV), camera payload, and operations. The wildlife parameters were divided into another three categories - the habitat, wildlife, and operations. The guidelines pertain to the collection of habitat and animal data, and to the analysis of that data.

With the UAS, aerial data (images or video recordings) is captured, stored automatically, and analyzed posteriori. The automated data collection and a posteriori analysis eliminate the limitations that result from the need to identify and record habitat/animal properties in real time. The flight speed and altitude are limited by required camera pixel density and shutter speed, to maintain a resolution needed to discern habitat and animal properties. The survey is capable of assessing the habitat and the animals, including but not limited to counting and differentiating between animal species.

As mentioned in the introduction section above, there are numerous reasons for conducting surveys, including but not limited to:

- The value of property is strictly connected to the number of animals on the property
- Carrying capacity / biomass calculations
- Monitoring – population trends, species distribution, security of the animals
- Game management - removal or introduction
- Conservation – in support of anti-poaching
- Specifically, to count rare or particularly numerous species
- Tourism (eco-tourism and trophy hunting) – in support of planning needs
- Property / concession contracts / legal issues with regards to game

- Support of research projects (i.e. predator / prey relationships)
- Securing endangered species - anti poaching
- Species protection surveillance

The selected blocks can be characterized by type of vegetation (like tree density, crone cover, species composition) and topography (like height above sea level, soil types, ground formations). Factors for consideration when selecting blocks include:

- Look for natural brakes (like a ridge)
- Density of the vegetation
- Define the time of the surveys and brakes (time for battery change or relocation)
- Total amount of time for aerial surveying
- Wind direction (in Namibia from east to west)
- Start hour after sunrise till 11am
- Account for the season, whether wet or dry
- Account for the weather

The guidelines below pertain to the biodiversity of a given block. They explain the reasoning behind the specific steps. One recognizes that every survey is different. The guidelines explain the factors involved and how they interact with the parameters of the problem. We will not further address the process of selecting the block.

Guidelines

Factor 1: Block sizes

The size of a block is often defined based on the time of day, and if the survey is taken in the morning or afternoon. Blocks range in size from three square-kilometers and larger. Available resources such as number of surveyors and number of vehicles dictate limitations in size. Topography and vegetation aspects are most important when choosing the block. The vegetation density should be homogenous.

Things to consider when planning the mission:

○ It is important to complete surveys (cover the blocks) within a morning and afternoon period. The best morning hours are just after the sunrise and before noon (6:30 - 10am local time), depending on the season.

○ One can accomplish this in a number of ways, such as by having more observers per aircraft, by widening the strip width, and by using multiple UAVs.

○ The internal temperature of the drone needs to be tracked. If it reaches 50 degrees Celsius the UAV may fail. If the temperature is too low, the components such as the flight controller can malfunction.

○ For safety reasons, ensuring that the UAV lands with the battery at 20% or more capacity reduces chances of a failed mission.

Factor 2: Block sampling

○ Ideally, the minimum % area to sample should be more than or equal to 30% of the block. The minimum % sampled decreases with increasing large ungulate animals' density and decreasing bush cover.

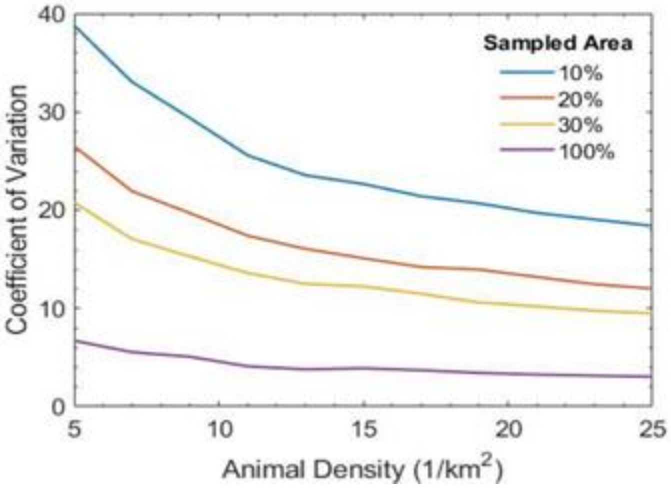


Figure 1: Change of CoV depending on Animal density and Sample Area covered [32].

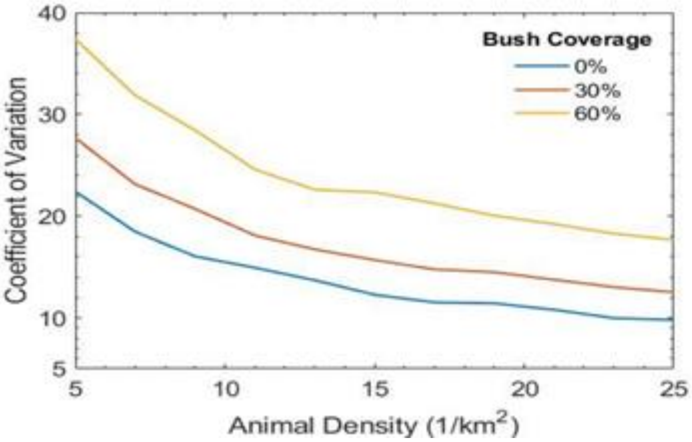


Figure 2: Change of CoV depending on Animal density and Bush Coverage [32].

○ How do you handle missing animals in the count due to bush cover?

When there is more bush cover and animals are difficult to spot, adjusting the parameters, for example reducing the UAV’s velocity, changing the camera angle etc, can assist in data collection. Missing the count depends on vegetation type, seasonality, time of day (which relate to shadows and animal habits) and movement to water during the dry season. In UAS surveys, an individual can be counted more than once by appearing in more than one image. **Double counts** may occur for at least two reasons: individuals present in overlapping parallel strips or overlapping successive images; or individuals might move between neighboring flight lines during a survey [21]. Double counts caused by animal movement may be more problematic when flight strips overlap or are adjacent, especially for highly mobile species. This also works the other way around: there is a possibility of **under counting**, which means that the animal that was supposed to be present in the image is not there, for example running out of the frame just before the image is captured.

According to the field experts, right now the industry standard is to get the counts within a block, but there is a push towards incorporating the abundance estimate to extrapolate the property count from multiple blocks.

Factor 3: Transect length

An excessively short transect causes an excessive waste in time and battery power in turning around. At the other extreme, an excessively long transect allows time for animals to move to adjacent transects, if they are not spaced far enough, which increases the likelihood of double counting or undercounting.

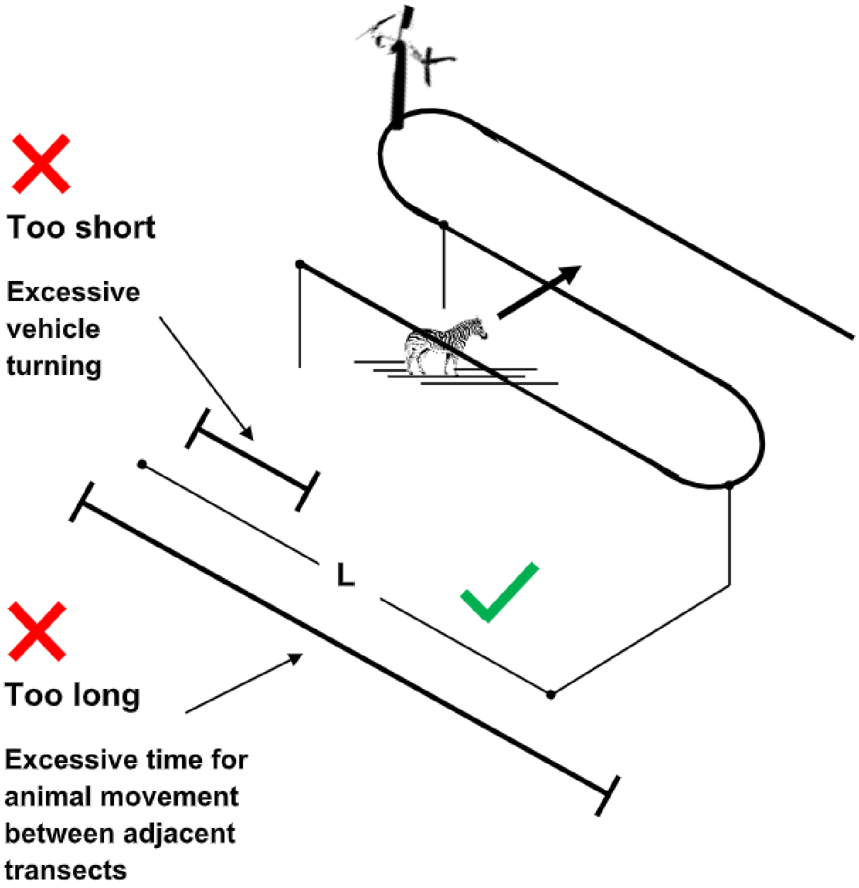


Figure 3: Transect length properties and consequences.

Factor 4: Transect overlap

Appropriate overlap is a crucial part of the design of a survey. Along the direction of the transect the recommended front overlap is 75%, to ensure the minimum overlap to build a valid and high quality orthomosaic. It helps with the detection of the movement, with distinguishing between animals and it prevents double counting. The minimum front overlap should be 50%, with higher overlap being useful but not at the detriment of mission success.

○ **50 - 75% Front overlap**

Front overlap (with imagery taken seconds apart) helps to address any image distortion, making it easier to identify and count animals further away (for 75% front overlap, every picture adds 25% in area). Note that **high front overlap** does not cost in vehicle time, although it will later add time in post processing (75% front overlap doubles the amount of images to process, compared to 50% overlap).

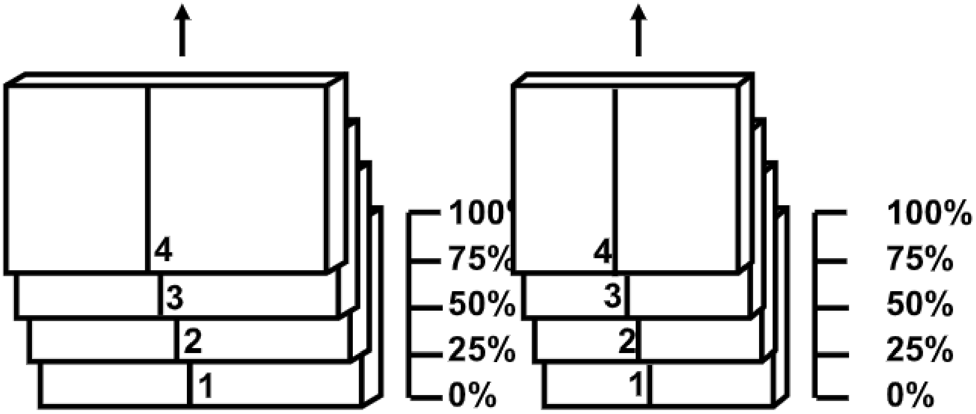


Figure 4: Overlap concept explained.

Overlap calculations

Terms: % of front overlap (X), ground speed of the UAV (S), longitudinal distance of the captured land (L), refresh time (R), new distance (ND).

Equations: $ND = (100\% - X) \cdot L$ $R = ND/S$

Examples:

$R = 35m/(20m/s) = 1.75$ s -> 1 picture every 1.75s

$ND = (100\% - 75\%) \cdot 140m = 35m$

○ **Optional: 10-15% side overlap (65% if you are planning to build and analyze orthomosaic)**

The purpose of **side overlap** (images taken minutes apart) is *not* to prevent double counting of moving animals. In animal counting, one assumes that their movement is slow and therefore does not compensate or accommodate for animal movement or not being completely in the image. The level of noise of UAS flying at altitudes of more than 50 m [32] above the ground level is lower than for manned aircraft and helicopters, which disturbs the animals less than a traditional aircraft. The purpose of the side overlap is just to prevent gaps in adjacent transects.

Some researchers state that side overlap is not necessary. Surveys without side overlap are said to be accurate enough but incorporating it slightly increases the quality. Side overlap is useful if the images are going to create an orthomosaic, but also very inefficient. Side overlap effectively increases the time required to cover the same area, because overlapping transects share some percentage of the covered area. Side overlap can be beneficial but comes with a flight time cost.

Factor 5: UAV altitude

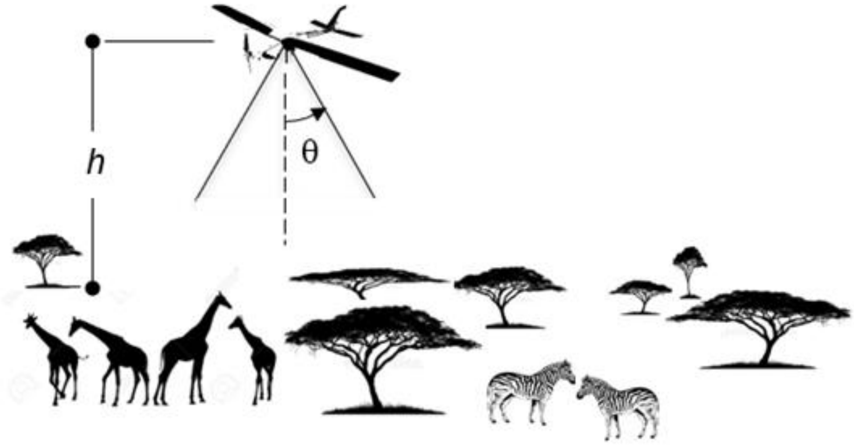


Figure 5: Altitude of the UAV visualized.

Fly at a minimum altitude, h, of 50 m. The higher the altitude, the fewer images that you will need to process but keep in mind the pix/cm aspect (Factor 7) and local regulations (altitude) of your flight locations and animals that you are wishing to count and analyze.

Studies [32] have shown at altitudes of more than 50 m above ground level will not disturb the animals so that most will not flee. Some inhabited animals will flee when they first experience the UAV, and these animals tend to habituate quickly.

Factor 6: Strip width and UAV velocity

Strip width

The strip width depends on these two factors (units):

- ○ Camera, whose properties are:
  - Weight (g)
  - Lens (Focal Length: mm)

  - Angle of view (degrees)
  - Pixel density (cm/pixel at m AGL)
  - Frame rate (/1s or Hz)
  - Memory (SD card, GB of storage)
- ○ Flight altitude (m)

Strip width calculations:

Terms: Strip width (W), altitude (H), horizontal resolution (R), pixel density cm/pix (PD)

Equations: $W = R \cdot PD$

Example:

Taking Sony Alpha 6000 resolution (6000x4000): $PD = 6000$ and $PD = 2\text{cm/pix}$

$W = 6000 \cdot 2 = 12\ 000\ \text{cm} = 120\ \text{m}$

120m is the maximum horizontal distance that Sony Alpha 6000 can cover at 65 m altitude while maintaining the pixel density.

AoV and FoV calculations:

Terms: Angle of View (AoV), frame dimension (h), focal length (f), Field of View (FoV), focus distance (s), sensor size (d), sensor width (sw), sensor height (sh)

Equations: $d = \sqrt{sw^2 + sh^2}$ $AoV = 2 \cdot \arctan(d/2f)$ $FoV = sw \cdot s/f$

Examples:

For Sony Alpha 6000 the sensor size is 23.5 x 15.6 mm, and focal length 16 mm.

$AoV = 2 \cdot arctan\left(\frac{\sqrt{(23.5\ mm)^2+(15.6\ mm)^2}}{2\cdot 16\ mm}\right) = 82.7895^\circ$ diagonal angle of view.

The altitude of the aircraft is equal to the focus distance s

$hFoV(sw) = \frac{23.5\ mm \cdot 65\ m}{16\ mm} = 95.47$ m horizontal distance

$vFoV(sh) = \frac{15.6\ mm \cdot 65\ m}{16\ mm} = 63.375$ m horizontal distance

Telephoto lenses allow the mission to be flown at a higher altitude and then to ‘zoom in’ the area under the aircraft. The wide-angle lenses increase the AoV that can be helpful when flying at lower altitudes. Keep in mind that when using telephoto lenses, the wind might make your aircraft unstable, which results in reduction in image quality and missing part of the transects area.

It is also recommended to add a GoPro angled as with the regular camera payload. This will assist in the post processing phase as one can watch the GoPro video clips recorded when uncertain images were taken. For example, if the person counting the animals is uncertain if the object in the imagery is an actual animal, he or she can analyze the video clip to look for potential movement or other indicators.

Velocity

The camera should aim backwards or forwards. If the animals are expected to be scared by the incoming UAV sound, the camera should be facing forward. This gives the advantage of being able to see animals when they try to hide under bushes and trees. This also makes the length L of the image larger than the width (disproportionate). There is a formula for L, depending on a, b, w, and the camera angle (The angle also affects the calculation of w).

Refresh time - one image taken every 1s, means 20 meters distance between each with 20 m/s ground speed. If it is too slow, there will be gaps on the ground between images. So, we typically set the capture rate to give us the “required image overlap”.

UAV velocity calculations:

Terms: UAV velocity (V), ground distance covered (D), time (t), capture frequency (f), new area covered (NA), front overlap % (FO), vertical field of view (vFoV)

Equation: $\mathrm{D} = \mathrm{V} \cdot \mathrm{t}$ $\mathrm{NA} = \mathrm{V} \cdot \mathrm{f}$ $\mathrm{FO} = 1 - (\mathrm{NA}/\mathrm{vFoV})$

Example:

For $\mathrm{D} = 20\ \mathrm{m/s}$, $\mathrm{f} = 1/\mathrm{s}$ and $\mathrm{vFoV} = 63.375\ \mathrm{m}$

$\mathrm{NA} = \frac{20\ m/s}{1\frac{1}{s}} = 20\ m$ $\mathrm{FO} = 1 - \frac{20\ m}{63.375} = 68.44\%$ front overlap

Using the quadrocopters or any other UAV systems is also a viable option. In different situations, they might be more suitable to fulfill operational requirements.

Factor 7: Image qualities

Camera resolution:

To be able to identify the animal and count it properly, the image must have sufficient pixel density. The pixel density should not be higher than 2.5cm/pixel and lower than 1cm/pixel.

> **Terms:** Vertical pixel density (vPD), horizontal pixel density (hPD), camera's horizontal resolution (HR), camera's vertical resolution (VR), horizontal Field of View (hFoV), vertical Field of View (vFoV)
>
> **Equations:** hPD = $\frac{hFoV}{HR}$ vPD = $\frac{vFoV}{VR}$
>
> **Example:**
>
> Taking values calculated as an example in Factor 6
>
> hPD = 63.375/6000 = 1.05 cm/pixel vPD = 95.47/4000 = 2.39 cm/pixel

Advice while setting up the camera:

- ○ White balance (WB) is very important if you perform any data extractions using color imagery. You can manually calibrate the WB by using a White Balance 18% Gray Reference Reflector Grey Card
- ○ Aperture f/11 or f/16 (keep constant overall surveys)
- ○ ISO 100
- ○ Shoot in RAW and JPG. You can adjust the exposure and adjust WB in RAW if needed, this is not possible in JPG.
- ○ Use the fastest SD card possible. A slow SD card creates a back-lock with continuous shooting and results in images not being saved.
- ○ The only 'automated' setting for the camera will be autofocus and shutter speed

Factor 8: Post processing image preparations

○ Acquiring the data (video or images):

Counting from video enables detection of animal movement and changes in the image. It requires a more advanced technology and way more memory available, compared to using still images. On the other hand, images will have a higher resolution (if using the same camera payload) and enable the individual performing the counts to focus on different parts of the image. In some scenarios, one can have both video and photos available for review and toggle between them when performing the search. We do not currently process video, only its frames, but it could be changed with the development of storage and video technology. Below, we will assume that we capture and process images (not video).

The major objective of these preparations is to standardize the process to achieve the highest image quality possible. Preparing the image quality supports different approaches of analyzing data from manual to automated processing (supervised or unsupervised).

○ Retrieve the data storage device (memory card) and plug it into the computer.

○ Extract the flight plan, geotag the images, and add in geo-information to each image (used while doing density)

○ Change image brightness: using 18% greyscale.

○ Prepare images for counting: sorting consecutively where you may need ability to zoom in and out or split the images to support reviewing of the captured images.

Factor 9: Animal identification and counting

○ Discuss together the methods of analysis, the amount of time it takes for identification of animals (looking at each image, skills needed, attention span issues), level of automation needed, and amount of real-time processing. Regardless of the approach, the counting is independently double checked; this is called a ‘double blind’ analysis. For example, in semi-automation, we can remove many of the images that we know do not include an animal or feature of interest, leaving fewer images to count. Manpower can then discern objects that the automation can't classify.

○ Manually identifying animals: two individuals independently perform the identification. This needs observers trained in identifying animals following a documented protocol. The first step is spotting the obvious animals. Second step of identifying areas in the image where there are potentially animals (near bush cover, or water surfaces) followed by zooming in to determine definitively of an animal for counting.

○ When a large cluster of animals is spotted, counting animals from still images a posteriori is easier than in real time. This counting allows enough time for the counts where real time counting is impractical and often inaccurate.

○ Recording identified animals: tag animals identified (animal type, location, number), make sure it is traceable back to the image, and place results in a spreadsheet for statistical analysis (next step).

○ There should be two observers independently counting (double blind), then comparing their results to validate them and find possible errors.

○ There should be an accuracy check assessment, which will consider the counting errors and species misidentification.

Factor 10: Statistical analysis

○ The first statistics of importance are the estimates of the counts of selected species in the given sampled areas. These statistics provide the primary information sought in conducting the animals.

○ The next statistics is the coefficient of variation (CV) of the estimates of the counts of the selected species in the sampled areas. As a rule of thumb, the CV should be less than 20% [34].

○ The final statistics are associated with sampling errors. These assess the errors that occur when projecting the counts from the sampled areas to the entire region. These statistics require additional effort to gather and are often omitted today from counts that are performed for government organizations, like parks.

Factor 11: Share your results

○ After concluding the research, it is important to make your data and derived products accessible to other researchers.

○ The best way to share data is by uploading it using Metadata Reporting Standards to make your research results consistent with other UAS campaigns and to make them easily accessible to anyone interested.

Definitions of terms used:

Animal abundance - the relative representation of a species in a particular ecosystem.

Animal population - the number of individuals of a particular species in an area.

Biodiversity - the variety of life on Earth at all its levels, from genes to ecosystems, and can encompass the evolutionary, ecological, and cultural processes that sustain life.

Block – Part of the surveyed area, used to sample the property, usually ranging in size from three square kilometers.

Bush encroachment - the expansion of native plants and not the spread of alien invasive species. It is thus defined by plant density, not species. Bush encroachment is often considered an ecological regime shift and can be a symptom of land degradation.

Double counting - In UAS surveys, an individual can be counted more than once by appearing in more than one image. Double counts may occur for at least two reasons: (1) individuals present in overlapping parallel strips or overlapping successive images; or (2) individuals might move between neighboring flight lines during a survey.

Ecosystem - a geographic area where plants, animals, and other organisms, as well as weather and landscape, work together to form a bubble of life. Ecosystems contain biotic or living, parts, as well as abiotic factors, or nonliving parts.

Ecotourism - a form of tourism involving responsible travel (using sustainable transport) to natural areas, conserving the environment, and improving the well-being of the local people.

Habitat - the natural home or environment of an animal, plant, or other organism.

Population density - the number of individuals living within that specific location.

Sampling - is the selection of a subset of a block from within a statistical population to estimate characteristics of the whole population.

Trophy hunting - is a form of hunting for sport in which parts of the hunted wild animals are kept and displayed as trophies. The animal being targeted, known as the "game", is typically a mature male specimen from a popular species of collectable interests, usually of large sizes, holding impressive horns/antlers or magnificent furs/manes.

UAS - Unmanned aircraft system, means an unmanned aircraft and the equipment to control it remotely.

CHAPTER 3: RESULTS

Surveyed area:

The chosen study area was located in the Khomas region of central Namibia. This region is characterized as a hot semi-arid savanna, with temperatures ranging from 12.7℃ to 30℃ and an average rainfall of 367.4 mm per year [27]. The average relative humidity during the months of study ranged from 18.58 percent to 23.33 percent. The Khomas region is located at an elevation of 1809 meters above sea level. Average wind speed ranged from 0 knots to 30 knots with frequent gusts above 30 knots. A property that the study has been conducted on was Naankuse Foundation Wildlife Sanctuary, in Namibia [29]. The wildlife sanctuary accommodates orphaned and injured animals that cannot be released safely back into the wild including leopards, lions, cheetah, wild dogs, and baboons all housed in purpose-built enclosures. The property is also wandered by free-roaming ungulates, like zebras, kudus, oryxes, elands, warthogs, giraffes, hartebeests, impalas, ostriches, springboks, and a donkey.

The size of the property was vast enough to classify it as a single block, while homogenous bush cover and animal density were optimal for the study. The land is used primarily for grazing and the vegetation is characterized by tall grasses and small woody plants [28]. The ground cover is composed of mica, quartzite, and carbonite which create a low-contrast environment [28]. The climate type of the region is subtropical arid, with a hot, rainy season from December to March and a dry season from May to October, within which there is a cool period from May to August. In the latter, at night the temperature can drop a few degrees below freezing. During the day, it can get very hot from September to March. It is also important to mention the natural elevation of the property is 1800m above sea level. The UAVs required customized propellers, because of the lower atmospheric density at this altitude.

Airframe:

Due to rapid changes in wind speed in the savanna, the airframe selected had to withstand variable wind with a fixed runway as well as crosswinds during flight. It was also able to handle crosswind in landings, takeoffs, and during transects. It also needed to be large enough to carry the necessary payload of aerial photography equipment, while being light enough to maximize flight time while maintaining flight speed. In addition, the airframe needed to be suitable for a high-altitude environment with thinner air, as mentioned.

The airframe chosen for aerial surveys was the Believer 1960mm airframe. This platform features a 1.96-meter wingspan with a v-tail configuration and twin brushless motors capable of differential thrust. As an off-the-shelf platform, the Believer is not only less labor-intensive and easier to maintain than a custom-built airframe, but it is also more representative of what remote African properties are likely to purchase, thus serving as a better indicator of the practical viability of aerial biodiversity surveys. The airframe can be purchased for less than $400 USD from most vendors. The airframe was fitted by the research team with high-altitude propellers for better performance in the thin air of Naankuse.

Internally, the Believer platform offers sufficient internal space for housing necessary aerial surveyal components with a maximum takeoff weight of 5.5 kilograms. This storage capacity, combined with a circular hole in the fuselage underside, allows the Believer to carry a lightweight downward-facing DSLR camera. The spacious hull of the Believer was a key factor in its selection by the research group as the survey platform as allowed for not only a camera but a larger battery as well, increasing the time aloft and granting fuller survey coverage for a single flight event. A rechargeable 6S 22.2-volt, 22000mAh Lithium Polymer (LiPo) battery was used for flights and provided 70-90 minutes of flight time.

The camera carried by the Believer was a Sony Alpha 6000 with a focal length of 16 millimeters. This camera was chosen due to its light weight of 344 grams, its high pixel density of 24 megapixels (6000 x 4000), and its low-cost relative to these specifications. The light weight is ideal for storing in the Believer airframe with minimal impedance to flight performance, and the high pixel density allows for greater clarity in animal identification. This camera was autonomously triggered by commands from the flight controller using a Seagull #REC multi camera controller. This camera controller was designed specifically for use with Sony cameras like the Alpha 6000, streamlining the processes of extending and retracting the lens and taking the pictures autonomously.

For other onboard equipment, the Believer used a Cube Orange Pixhawk flight controller. The Cube Orange operates at a frequency of 400 Mhz and features a triple-redundant set of Inertial Management Units (IMUs), 14 Pulse Width Modulation (PWM) servo outputs, and redundant 32-bit processors. A DragonLink V3 advanced telemetry system operating at 433 Mhz allowed for real-time first-person viewing of the flight from a ground station monitor within a range of up to 40 kilometers. See Figure 6 for a diagram of the airframe's components.

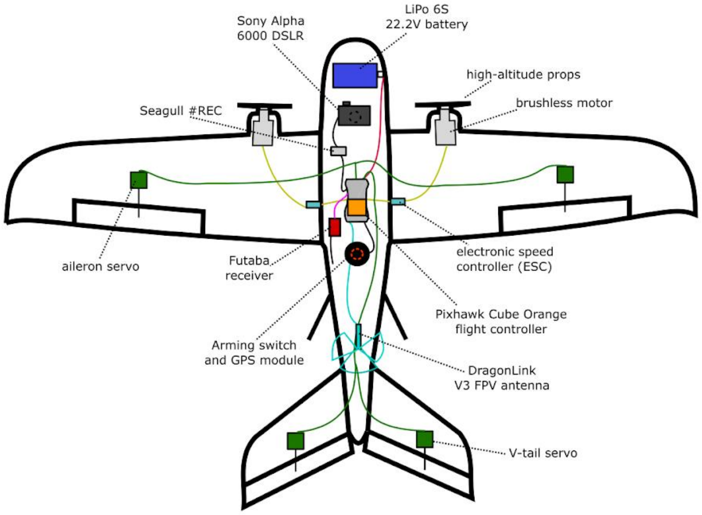


Figure 6: Diagram of the airframe components

ArduPilot's Mission Planner [30] was used to create the waypoints that navigated the Believer through the survey path, overseeing the parameters during flight. This software was chosen for its affordability, ease of use, and interoperability with the Pixhawk firmware. Mission Planner allowed the research group to import .KML files of the Naankuse property with borders and designated no-fly zones marked. The software also contains a 'survey grid' feature that allows users to select polygonal regions and automatically generate grid patterns of waypoints in the selected region for surveyance, with an option to trigger a camera at a set distance along the grid transects.

When designing the transect paths for surveys, the NC State researchers considered the performance limitations of the Believer, especially during turns. Designed for stable flight, the Believer lacks the tight turn radius of more maneuverable airframes, with a maximum experimental turn radius of 125 meters—a distance longer than the width between transects. To allow the aircraft to fly its transects, ‘bubble turns’ were incorporated, turning the plane outward after completing its transects to allow adequate turning distance (Fig. 7).

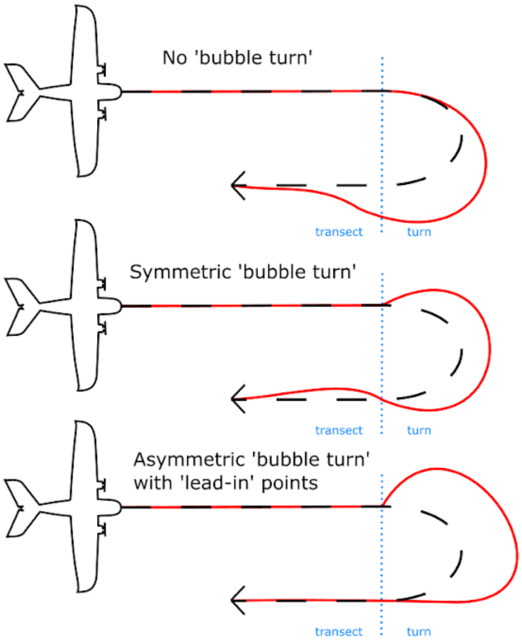


Figure 7. Turn design options.

As the Believer rotated about both its roll and yaw axes in these turns in a banking maneuver, additional ‘lead-in’ points were added to straighten its flight path and allow it to enter each transect straight and level (Fig. 8). A MATLAB script was written that automates the creation of these ‘bubble turns’ and ‘lead-in points’ after the initial Mission Planner survey grid was created.

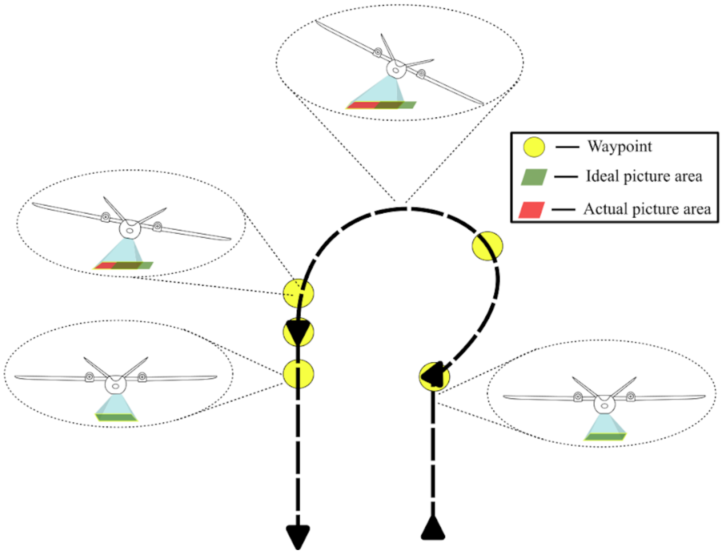


Figure 8. Effect of lead-in points on photograph area.

Flight:

A pre-flight checklist was created to lower the risk of crashes and component failures. Ensuring that the Believer's flight surfaces were responding to inputs correctly and the motors were adequately powered was paramount to preventing crashes, while checking that the Seagull successfully triggered the camera to extrude the lens and take a photograph prevented dataless flight events. The accelerometers and gyroscopes were calibrated, and temperature of the Cube Orange flight controller was regulated at 40 degrees Celsius. Another essential factor in the Believer flights was the weather, as excess wind or other inclement conditions could cause a crash event–for this reason, flights were scrapped when wind speed exceeded 12 knots.

The Believer was hand-launched, and flight events began approximately one hour after sunrise (7:30). Flights were conducted at this time for two reasons. First, this time yielded a shadow that was large enough to aid in identifying animals but not long enough to obscure the field of view. Secondly, the novel sun did not have time to significantly heat the earth yet, leading to less of a temperature differential between the ground and the air and therefore less wind to ground flights. The early flight time was also conducive to seeing a more representative population of the wildlife on Naankuse, as less heat-tolerant species migrate to shaded spaces as the temperature rises into the afternoon.

The NC State team collected data between 21 September and 15 October. Morning was chosen as the optimal flight and data collection time due to ideal shadow length of animals and low wind speeds. In that period, we managed to record 14 data points, varying between 15 – 34% of the property covered, as presented in Table 2. During these flights, we experimented with flight parameters, such as the altitude, aircraft ground speed and transect width to optimize flight efficiency and image quality.

Table 2: Captured data properties.

Date of flight:	Flight altitude [m]:	Area covered:	Number of images:	Comments:
September 21	65	30%	2002	Full mission, 30% of the property surveyed
September 23, 26, 27	65	15%	1007	Failed second launch after battery change
September 29	80	34%	1805	Full mission, 34% of the property surveyed
September 30	80	15%	700	Failed second launch after battery change
October 5	90	23%	645	Had to RTL because of strong wind
October 8	90	14.6%	426	Had to RTL because of strong wind
October 10, 11, 12, 13, 14, 15	90	25%	730	Full mission, one battery, 25% of the property surveyed

The operating altitude of the Believer was set up for optimal surveying parameters. Given that viewing area increases with the aircraft's altitude, a higher altitude yields fewer images recorded while maintaining the minimum pixel density, creating a more manageable workload for researchers after the flight event. However, a greater altitude also results in a smaller number of pixels per centimeter for the photographs, which places an upper limit on altitude. This occurs when the resolution of an animal decreases to the point at which it is indiscernible. It was experimentally determined that a minimum of 2 pixels per centimeter is necessary to identify the animals reasonably expected of the aerial survey–jackal-sized and greater. From this limit and the specifications of the Sony Alpha 6000, a maximum altitude of 90 meters above the terrain was determined and implemented in the flights.

Initially, we planned to cover 30% of the property daily, with two flights at 60 m altitude, including 50% front and 25% side overlap. The estimated flight time was 2.5 hours, with a battery change in the middle of the mission. While we usually had no problems launching it for the first time of the day, most of the second launches failed, resulting in a touchdown, shattered propellers, and damaged motors.

After some trial and error, taking into consideration the time constraints, battery life and bush cover, we decided to survey 25% (factor 2) with a single flight, using 50% front and no side overlap. The flight altitude (relative to the launch altitude) has been changed to 90m, to cover more area with a single transect, whose horizontal width arrived at 160m. We decided to space the transects (see figure below) away from each other, to minimize the possibility of double counting, and getting an accurate sample of the block. While planning the transects, we decided to split them into two groups: the northern and southern transects. This has been done to achieve a more reliable sample of the property, in case animals preferred one part of the area.

Our final configuration consistently captured 730 images per flight, covering 25% of the property with a single flight. This proved to work, resulting in consistent data recorded every day, avoiding the second launch issues.

For the flight path, waypoints were created in Mission Planner to navigate the Believer across the property without flying over the property border or into the no-fly zones as shown in Figure 9. At the location of the northern and southern ground transects, the Believer would pass over the exact points of the north and south transects, as well as two transects above and below for a total of five aerial transects around each ground transect. These two groups, five transects each, were closer together than the rest of the survey, with a distance of 65 meters between transects, to allow for better comparability to ground survey, granting a more accurate view of the efficacy of both methods against each other. The remaining transects were spaced 150 meters apart from each other with 50% front overlap and 0% sidelap to ensure minimal animals were double- or under-counted. The camera trigger distance was set by Mission Planner to 66 meters for 50% overlap, meaning the Seagull would trigger the camera to capture a photograph every 66 meters (per ground speed) covered by the Believer along the transect.

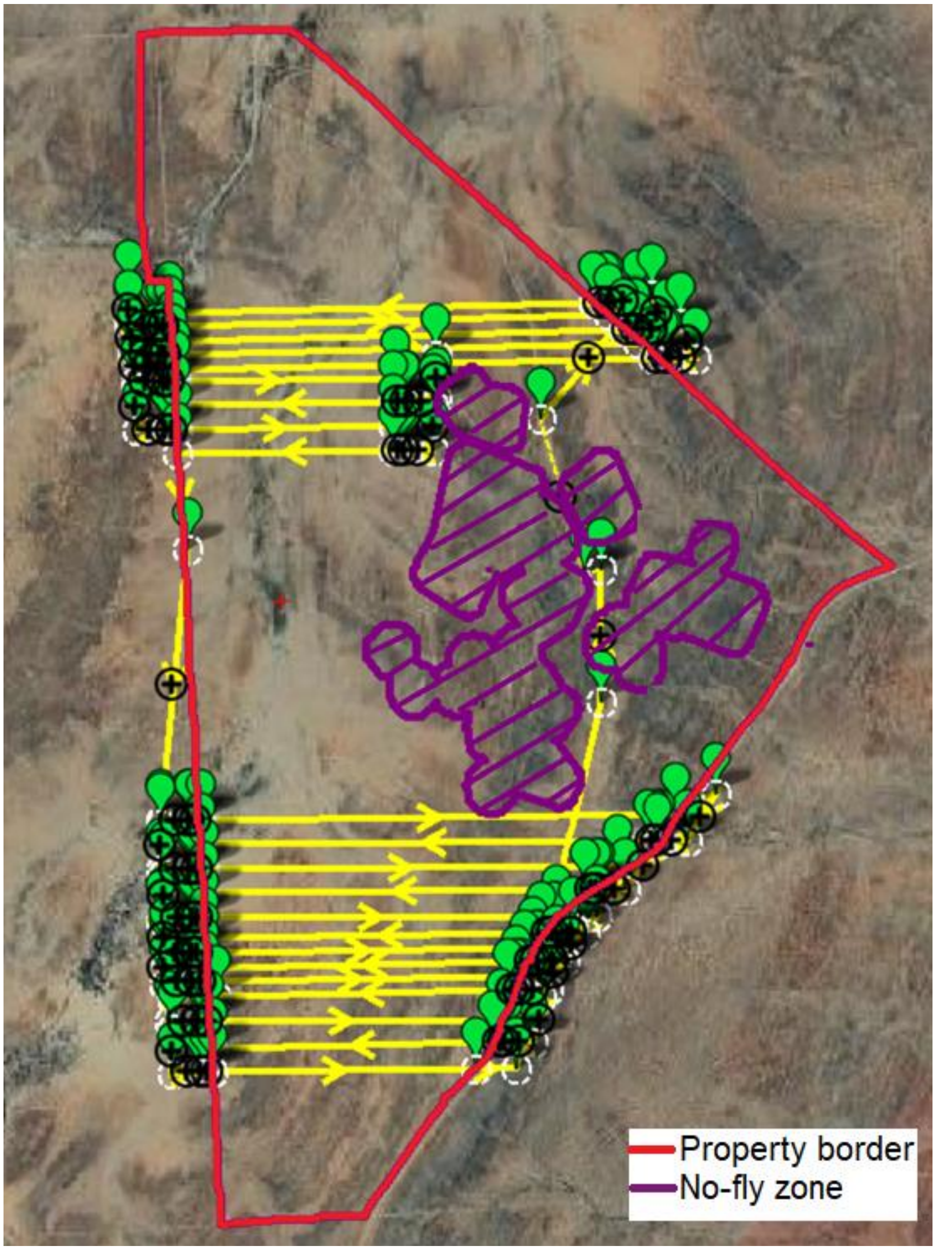


Figure 9: Layout of transects and waypoints, from Mission Planner.

The subsections of land chosen for the study area were matched for both the sky and ground transects on both the north and south ground transects. Data collection was done simultaneously for each matching transect, by air and on foot. By selecting matching transects, the researchers were able to compare and contrast the data from each. The north transect ran from east to west on the northern portion of the property, and began at coordinates -22.3702421°, 17.4053919° and ended at -22.3706338°, 17.3789021°. The south transect ran east to west on the southern portion, starting at -22.4045659°, 17.3995981° and ending at -22.4048058°, 17.3809315°. Teams of three researchers collected transect data from the north and teams of two collected data from the south transect. Researchers selected strips of land which produced the longest transects possible. For aerial counting, longer transects minimized time spent turning and maximized time spent on transect collecting data, allowing for greater data collection for each flight event on a finite battery life.

The strip transect method was employed to maximize the animal counts without double counting. The likelihood of spotting an animal from photographs taken during a flight was consistent throughout. With ground transects, a sighting probability curve was calculated through distance sampling, using data on animal location from the observer's sighting location (Fig. 10). The detectability of animal sightings becomes smaller as the distance from the observer increases.

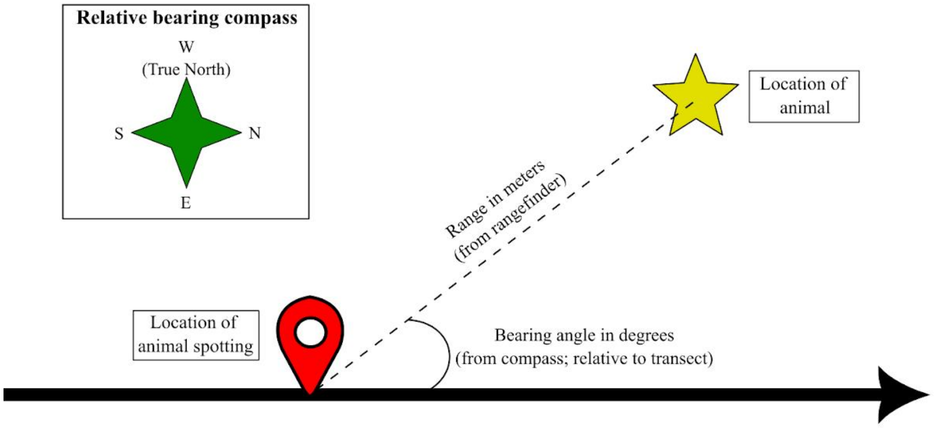


Figure 10. Plotting location of animal from data collected on ground transect.

The data used for calculations on ground transects were collected by the researchers during the transect walk using the EpiCollect application. EpiCollect allowed the researchers to enter data on animal species, number of animals sighted, location, time, bearing, and sighting distance. The GPS location of the researcher and time of the sighting were collected directly from the phone, while species type, number of animals sighted, bearing and distance of sighting were entered manually. Sighting distance was acquired using a rangefinder and bearing using a compass. Researchers then identified, counted and recorded the animal species and number of each species at the time of the sighting.

Image processing:

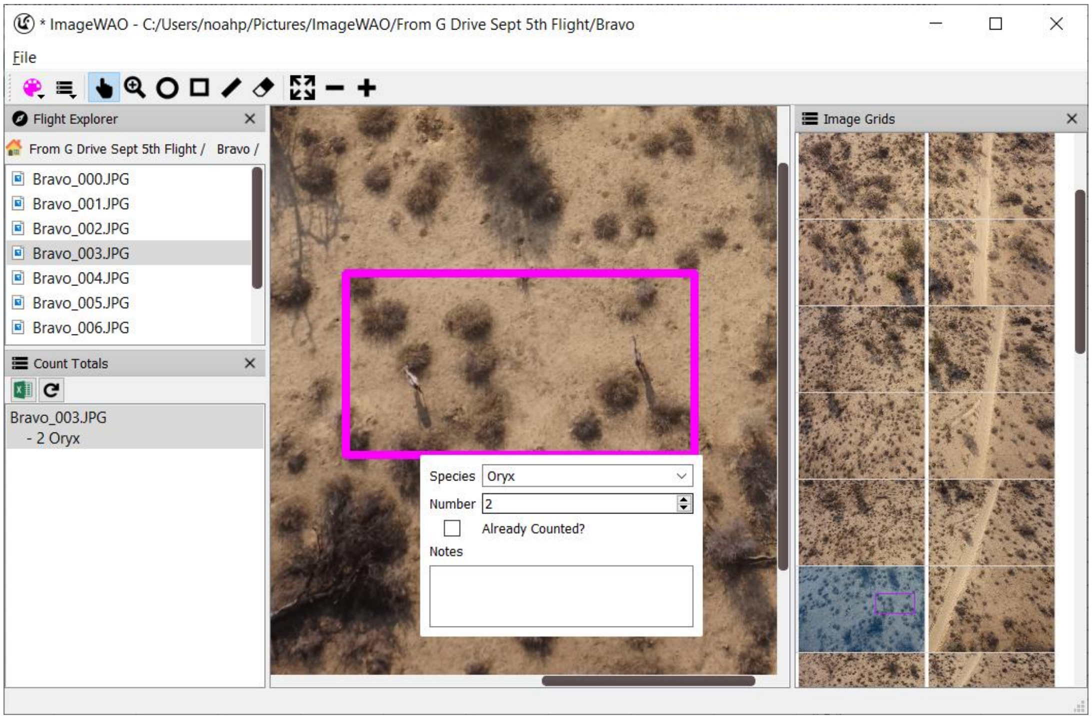
The team of researchers ended up recording 14 days of data and 14462 total images to process. Since the best practice in the industry is to 'double blind' review the data, we had to divide 28924 images between 12 researchers, each one ending up with about 2410.

The program we were using to increase the efficiency of image processing was ImageWAO [31], in house software, which was created by a student taking part in a previous edition of the program. The basic principles behind the program were to break down images into transects, split a single image into 4, to 'zoom in' on the quarters, and mark the detected animals with 'Paint-like' tools. The program had a feature of exporting all the records into an XLS file after the counting was done.

Identification of animal species was based on body size and shape, coat color, and horn shape and size. The shadow of the animal often provided a useful silhouette of the animal's profile for identification. Data were collected on mammals the size of a jackal, or larger and 18 main animal species were counted on the property as follows:

- Black-backed jackal, *Lupulella mesomelas*
- Chacma baboon, *Papio ursinus*
- Common duiker, *Sylvicapra grimmia*
- Common warthog, *Phacochoerus africanus*
- Donkey, *Equus africanus asinus*
- Eland, *Taurotragus oryx*
- Gemsbok, *Oryx gazella*
- Giraffe, *Giraffa camelopardalis*
- Greater kudu, *Tragelaphus strepsiceros*
- Hartebeest, *Alcelaphus buselaphus*
- Horse, *Equus ferus caballus*
- Impala, *Aepyceros melampus*
- Ostrich, *Struthio camelus*
- Plains zebra, *Equus quagga*

- Sable antelope, *Hippotragus niger*
- Springbok, *Antidorcas marsupialis*
- Steenbok, *Raphicerus campestris*
- Warthog, *Phacochoerus*



From G Drive Sept 5th Flight / Bravo /

Bravo_000.JPG
Bravo_001.JPG
Bravo_002.JPG
Bravo_003.JPG
Bravo_004.JPG
Bravo_005.JPG
Bravo_006.JPG

Bravo_003.JPG
- 2 Oryx

Species: Oryx
Number: 2
☐ Already Counted?
Notes

Figure 11: Screenshot from ImageWAO program used to process the data [31].

Animals were easier to detect in the images captured during a sunny day, compared to days with overcast because of their shadows and blending into the ground. It has been observed that the double-blind review is a bare minimum, since the numbers were different for every person counting, varying from slightly different (10% discrepancy) to extremely different (34% discrepancy). The difference was caused by skills and personal traits of the researchers. There was also a significant number of animals that were not possible to identify, which were labeled as ‘Unknown’ and disregarded in statistical analysis.

After coming up with the reconciled table of detected species for every transect for every day, we were able to proceed with the statistical analysis.

Statistical analysis:

From our initial 14 data points gathered during the NamibiaWAO 2022 Program we had to discard 5, with less than 20% area of the property covered. Discarded days are September 23, 26 and 27, and October 8. The data used in statistical analysis is presented in Table 3.

Table 3: Data used in statistical analysis.

Date of flight	Area covered [%]	Total animals counted	Animal density [animal/km^2]
September 21	30	157	29.752
September 29	34	159	26.586
October 5	23	156	38.559
October 10	25	172	39.113
October 11	25	102	23.195
October 12	25	120	27.288
October 13	25	201	45.708
October 14	25	215	48.891
October 15	25	121	27.516

Data from Table 3 has been used to calculate the standard deviation of the set, which was equal to 0.25563.

The value of the standard deviation is higher than 0.2, which means that the gathered data is unrepeatable by a small margin. The high value of standard deviation is caused by a discrepancy in animal density. This is a result of either encountering large herds of animals or missing them completely during the image capturing and counting process. Based on information in Table 3, it is clear October 5, 10, 13 and 15 have much higher animal density values than the rest of days. During these counts, we detected large herds of animals that elevated the values of animal density. This is an example of bimodal distribution [33]. Because of it, the data points will have two means, one created due to detecting the herding animals and one that did not. Knowing that, the data has been divided into two groups. The coefficient of variance has been calculated separately for both groups of data, as presented in Table 4.

Table 4: Coefficient of variation for two groups of data.

Animal density group	Date of flight	Animal density [animal/km2]	Mean value for the group	Coefficient of variation for the group
<30 animals/km ^{2}	September 21	29.752	26.87	0.0789
	September 29	26.586		
	October 11	23.195		
	October 12	27.288		
	October 15	27.516		
>38 animals/km ^{2}	October 5	38.559	43.06	0.1018
	October 10	39.113		
	October 13	45.708		
	October 14	48.891		

The mean values of two groups are clearly different by a large margin, which supports the bimodal distribution argument. Looking at the coefficient of variation for two groups of data, we can see that it is consistent within the groups. The values are very low, indicating that the counts are repeatable, depending on the large herds detection occurring or not.

Comparing the ground and aerial survey:

As discussed in chapter 3, during the image collection two ground teams were performing a ground survey on the northern and southern parts of the property. The teams were gathering the data from 5 transects at the same time as the drone was flying over their heads. Table 5 illustrates the comparison of the total number of animals counted by the aerial and ground surveys.

Table 5: Comparison of the total count of northern and southern part of the property between aerial and ground survey.

Day	Increase in total animal detection North [%]	Increase in total animal detection South [%]
5-Oct	52	2
10-Oct	14.8	730
11-Oct	500	-35
12-Oct	47.7	N/A
13-Oct	122.5	233
14-Oct	172.7	159.4
15-Oct	119.5	350

Table 5: (continued).

21-Sep	11	N/A
23-Sep	32.3	N/A
26-Sep	-266	-30
27-Sep	-46	-66
29-Sep	-45	540
30-Sep	145	0
Average	66.19230769	188.34

Because of technical difficulties on September 26 and 27 the ground count performed better than the aerial survey. On most of the other days the aerial survey was clearly advantageous, averaging 66.19% better detection for the northern part of the property and 188.34% better for the southern part.

CHAPTER 4: SUMMARY AND CONCLUSIONS

This thesis examined the applications of technology to animal counting. We already know that, in the right conditions and with proper implementation, it offers wonderful advantages over traditional methods, like walking a field, but we wanted to look at this closer - to assess the different aspects of these so-called advantages. We also wanted to offer guidelines to others getting into this. During the literature review we met with more than 10 researchers and field experts from around the world, who are pioneers in UAV animal counting, to discuss their best practices and instructions they were willing to share. We found that the experts follow similar practices from which general guidelines could be put together. We then gathered the methods and advice and created a set of guidelines for UAV implementation in animal counting.

To validate the guidelines in the field, the research team conducted a survey of a single block property located in Namibia, gathering 14 data points for statistical analysis, to compare the quality and viability of the UAV method with traditional solution. Some of the factors were optimized for the Semi-Arid environment and external environmental conditions of Namibia, where the survey took place, and some of them were completely changed. The configuration of the UAV and factors were discussed in the results section of the thesis.

After initial calculations, the standard deviation of animal density turned out to be higher than expected, rendering gathered data unrepeatable by a small margin, with mean animal density at 38 animals per square kilometer. After reviewing the data further, it was found that a bimodal distribution was occurring [33], so we divided the data points into two groups, with mean animal densities of 26.9 and 43. Calculating the coefficient of variation for them separately resulted in significant improvement in the CoV values. The reason for the bimodal distribution was animal herding, effectively causing significant changes in animal density values depending on whether the herd was present. Missing a herd of animals during a single day of counting resulted in a data point that is inconsistent compared to days that the said herd was detected. Per Ulrich Franke, this is an important problem that must be taken into account [35].

The herding behavior of animals and detecting them turned out to be a crucial issue that needs to be identified to yield accurate and repeatable surveys.

As discussed in Factor 2 in the Best Practices section, higher animal density would result in lowering the coefficient of variation significantly [32] but would not solve the herding issue. Choosing a block with a higher animal density, with animals spread more equally in the area, results in a more reliable count and lower CoV value. After identifying bimodal distribution and dividing the data into two groups, the very low coefficients of variation values indicate that aerial sampling technique is a viable method of sampling in right conditions, and the gathered data is consistent in groups. In instances where a large herd has been detected, one should expect a number of animals higher than in a case when the herd was missed.

A way of improving the data collection would be to cover more area on the property, which would result in detecting the animals more consistently. We were limited to one flight per day, due to technical difficulties, but doubling the area covered would result in more precise detection and better standard deviation value.

Finally, the hard environment and technical difficulties limited us to only 14 days of gathering data. If that period lasted longer, we would be able to successfully fly for more days and have more data points, which would result in a bigger sample, effectively increasing the quality and consistency of the data.

An unexpected bottleneck of the study was the image processing. After collecting gigabytes of data, we had to manually sort the images into transects, detect, and count the animals and analyze the data. The animal counting process was the most time-consuming, taking more than 30 hours on average for every researcher. It would be beneficial to automate or at least optimize the process in the future.

Despite the difficulties and disadvantages that have been already brought up, the comparison between ground and aerial count turned out to be more favorable for UAV surveys. It is more precise to use aerial drone count than ground surveying methods, even though both methods suffer from herding problems.

After completing the data analysis and discussing the gathered field experience, the conclusion has been formed. There is no universal guideline that could be defined while performing the animal counting procedure using UAVs in any environment or conditions, and additional studies should be conducted to investigate the herding issue. The external environment conditions could lead to contradictory factor properties for two blocks. During the data gathering process we experienced complications due to numerous conditions that we did not account for while preparing for the study. For example - high altitude of the surveyed area, which leads to complications during the second takeoff of the day. Because of the low air density, UAV’s motors, which got hot during the first flight of the day, performed worse during the second takeoff, leading to a touchdown just after launching. We had to give up on the second half of the data, fix the plane and try again the next day. Eventually we decided to increase the altitude and perform only one flight, as explained in Chapter 3.

Every single block will be different from the previous one. This requires tailoring the best practices to the area’s particular conditions and factors.

During the study the team has stumbled upon numerous issues that were not predicted before arriving in Namibia, but most of them have been eliminated incrementally, as mentioned in Chapter 3.

Although not perfect for every scenario, UAV surveying is a viable methodology that is being successfully used in animal counting, and that will likely continue to grow in popularity. However, it requires proper preparation and knowledge.

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