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Detectability of Western Derby elands in West-African savanna by aerial imagery

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Detectability of Western Derby elands in West-African savanna by aerial imagery". Independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, 26/04/2019

Carlos Castillo Gómez

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Abstract

Western Derby (or Giant) eland (*Taurotragus derbianus* ssp. *derbianus*) is one of the two subspecies of Derby eland that exist on the planet and the most threatened of them. According to IUCN its status is Critically Endangered (CR) and has a single population of about 120-150 mature individuals in Niokolo Koba National Park, Senegal. Due to its critical conservation status, in 2000, one male and eight females were captured (of which only five females survived) and transferred to Bandia Reserve (to create a semi-captive population with conservation purposes), where this research has been conducted. Due to its small population and the vast extension of the only place where they live in the wild, the use of Unmmaned Aerial Systems (UASs) for census and monitoring has been valued, as it has been successfully developed with other ungulates. The objective of this pioneering study with this antelope is, first, to determine the parameters, such as flight height, sensor angle, pros and cons of photos and videos, flight speed and ethical considerations, that affect the detectability of individuals in aerial images (thanks to flight tests under different conditions to determine their impact on probabilities of detection) and, second, to evaluate two systems of detection of specimens, Manual (using untrained volunteer observers) and Automated Supervised (thanks to Ecognition machine learning software), to know the scope of each one. After this research it was determined that the most efficient flight height for the detection of specimens is 182.9 meters, the most appropriate angle of the camera: 34-35º, the use of photographs or videos will depend on the final use of them and our objectives, the most appropriate speed is 3-5 m/s and the height at which the UAS begins to cause discomfort, is 25 meters. On the other hand, the detection of specimens by untrained observers was affected by the speed of the video (the higher the speed, the greater the difficulty in detecting the individuals), by the possibility, or not, of stopping it (greater possibility of detection when it is possible to stop the video), by its level of studies and age (individuals 18-38 years old and with university studies were more skilled in detection) but by their sex. On the other hand, the Automated Supervised Classification showed partial results that should continue to be investigated due to its great potential, which has been demonstrated in numerous studies with other species. This study is a first step in the methodology of work with Western Derby eland and its detection through aerial images, opening a door to future studies that may shed light on the situation of this threatened and magnificent antelope.

Key words: Western Derby eland, WDE, UAV, Drone, Senegal, Detection, Woody savannah, Manual classification, Automated classification.

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List of the abbreviations used in the thesis

IUCN: International Union for Conservation of Nature

MTT: Maximum Time on Target

RGB: Red, Green and Blue.

UAV: Unmanned Aerial Vehicle

UAS: Unmanned Aerial Systems

WDE: Western Derby Eland

1. Introduction and Literature Review

1.1. Introduction

The Western Derby (or Giant) Eland (*Taurotragus derbianus* ssp. *derbianus*), is one of the two existing subspecies of the world's largest antelope. It is also the most endangered of them. According to IUCN (2017) it is currently Critically Endangered. This enormous African antelope is considered present in 3 countries: Guinea, Mali and Senegal (Darroze 2004), but only in the last one does there still exist a stable and viable population confined in the immense Niokolo Koba National Park (NKNP) (Koláčková et al. 2011), where a total of approximately 120-150 mature individuals survive (Renaud et al. 2006). This critical situation is due to past over-hunting, competition with domestic cattle, loss of habitat by human activities (IUCN 2017) or its special sensitivity to diseases such as rinderpest (Camara 1990). The serious situation in which this subspecies found itself, stimulated the actions of the Senegalese government for its conservation and, in 1999, one male and eight females from NKNP were captured (only 5 females survived) (Akakpo et al. 2004) to form semi-captive breeding groups that, today, 20 years after that operation, count with 115 specimens distributed between the Bandia and Fathala Reserves (Brandlová et al. 2018).

Figure 1: Western Derby eland, Male in Bandia Reserve (Photo credit Zuzana Holubová)

When working with species at serious risk of extinction, an essential aspect to know, is their population size (Cristescu et al. 2015). This information is very important to define the protocol of subsequent action and thus undertake the necessary actions to try to preserve the species. In order to obtain this information, ground surveys are usually carried out, which involve an enormous investment of time and effort (Wich et al. 2016) or aerial surveys, used with this magnificent antelope (Renaud et al. 2006) with a high economic cost and a risk for the occupants of the aircraft (Sasse, 2003). Other technologies, such as camera traps, could be used in Western Derby Eland´s censuses but the vegetation density of the last refuge of the 'African giant' and its enormous dimensions, 9,130 km^2, added to its elusive character or its low density, invites to look for a system as effective as possible, to be able to follow them, manage them and conserve them without giving them time to disappear completely.

That tool could be the Unmanned Aerial Vehicles (UAVs). UAVs are easy to handle, cheap, safe and provide excellent images (van Gemert et al. 2015) having proven useful in the conservation of threatened species such as the orangutan *Pongo* sp. (Wich et al. 2016), the Critically Endangered Tristan Albatross *Diomedea dabbenena* (McClelland et al. 2016) or ungulates such as rhinoceroses *Ceratotherium simum* and *Diceros bicornis* (Mulero-Pázmány et al. 2014) or yaks *Bos mutus* (Su et al. 2018), species larger than our protagonist. Never before has this technology been used to census WDE populations, but its large size, its striped patterns that allow individual identification, its gregarious behavior, its diurnal habits and its preference for areas of open savannah that can allow easier observation from above, suggest that UAVs can be useful allies in their conservation, to capture as much information as possible and thus be able to make the most efficient management decisions.

In the absence of published studies on the use of UAVs for the detection of WDE, it is necessary to know which parameters increase or favor their detectability, in order to apply them and carry out their search rigorously, not at random. Thanks to the research it is possible to elaborate a working protocol that allows to locate efficiently the WDE in natural conditions, that is to say, in its last wild refuge: NKNP, being able to know better its real population and its ecology, and applying this knowledge to its protection. Thanks to the ease of having specimens in captivity, as they are more accessible and easily observable, this research has been carried out with them, in one of the reserves that host individuals of WDE: Bandia. The results obtained can be transferred, after being optimised, to the conditions of Niokolo Koba in the future.

A Phantom DJI has been chosen to carry out this study because it has very interesting usability and pricing characteristics, which has made it a useful tool for studies with, for example, sea turtles (Bevan et al. 2015). It is necessary to pay attention to the temperature that, in this area, can easily reach the maximum tolerated by this device, 40ºC, so it may be interesting, for the future, to bet on devices such as Gatewing x100 UAS that seem more resistant to high temperatures (Vermeulen et al. 2013). As parameters, we evaluate the most efficient flight height that combines high covered surface and high image resolution (based on studies such as Jones et al. 2006; González et al. 2016), use of the camera with an angle of 0º or 45º and its effects on WDE detection, choice of photographs or videos as the most useful tools in the WDE detection process or to know the impact of the UAVs on the behaviour of the WDE, something that has been demonstrated necessary, from an ethical point of view, in numerous publications (Hogdson & Koh, 2016; Mulero-Pázmány et al. 2017).

In addition to determining these flight parameters in order to elaborate a WDE census protocol using aerial images obtained throught UAVs, we need to know how to analyze these images. We value the possibility of using a Manual Classification, through direct human observation (Rey et al. 2017) or Automated Supervised Classification, using specialized software based on machine learning (Seymour et al. 2017) to automatically detect our object of study.

Thanks to current studies on the ecosystems inhabited by these impressive antelopes, the knowledge about its morphological and behavioural features, the research developed on the use of UAVs in wildlife research seeks to delve into the keys to detection, through aerial images obtained by UAVs, of the latest Western Derby Elands to contribute to its better knowledge and the development of future tools that will help to keep them definitely out of the abyss of extinction.

1.2. Literature Review

1.2.1. Western Derby Eland *(Taurotragus derbianus* ssp. *derbianus)*

The Western Derby Eland (Gray 1847) (named in honour of Edward Smith-Stanley, the 13th Earl of Derby, who sponsored expeditions to Africa that would eventually unveil these impressive animals) is one of the largest antelopes in the Bovidae family and one of the most threatened, finding itself in a critical situation in its original range: Western Africa. According to International Union for Conservation of Nature (IUCN) Red List (IUCN 2017), this antelope is in the Critically Endangered (CR) category, which gives an idea of how sensitive its current situation is.

Figure 2: Current locations of WDE populations: ● Bandia Reserve ● Fathala Reserve ● Niokolo Koba NP

Currently, its presence is only confirmed in three countries out of those that formed its original distribution: Guinea, Mali (Darroze 2004) and Senegal. Of the first two, their existence is known but there are no reliable data on the status of their populations as well as their size. Only in Senegal, where specific lines of work have been developed on this animal, is there a more detailed knowledge of the current population in freedom, linked to the immense Niokolo-Koba National Park where the population is estimated to have 120-150 mature specimens only. In addition, a management and breeding programme under semi-captivity conditions has, in June 2018, a total of 117 specimens (Brandlová et al. 2018) distributed between the Bandia and Fathala Reserves. In other countries such as Togo (where its presence may have been confused with the Bongo, *Tragalephaus eurycerus*, according to Grubb (1998) or

Guinea-Bissau, its presence is uncertain. Unfortunately, Côte d'Ivoire, Gambia and Ghana, which in the past had populations of this magnificent animal, categorized as "Extinct" (IUCN, 2017).

This large animal, with males reaching 290 cm in length, 176 cm in height to the withers and up to 990 kg in weight. Females are significantly smaller, more graceful, reaching half the weight, a maximum height at the withers of 150 cm and length of up to 220 cm. Its coat is brown, with slight variations between individuals, and with 9-14 white stripes on the flanks that are unique to each specimen and can be used for individual identification. The black line that runs down the back of the adults and the enormous dewlap of the males are characteristics of these scarce animals. Both females and males have spiral horns, which are larger in size and with more developed spirals in males and finer and smoother in females (Kingdon 1982).

Although well known by the local population with whom it had shared space for millennia, the presence of this antelope was documented and presented in Europe in the 1840s, through the description of Dr. E.J. Gray (Gray 1847).

According to the IUCN, the Western Derby Eland (WDE) is one of two subspecies of the *Taurotragus derbianus*. The other subspecies, the Eastern Derby Eland *(Taurotragus derbianus* ssp. *gigas)* has a population of about 8,400-9,800 mature individuals (IUCN 2017) distributed between northern Cameroon, eastern Chad, Southern Sudan where they are still seen in places such as Southern National Park (Fay 2007) and, occasionally, NE of the Democratic Republic of Congo and NW of Uganda (East 1999; Planton & Michaux 2013), which categorizes this subspecie as Vulnerable (VU) according to the IUCN (2017). These numbers do not come from a single detailed study of the subspecies, but from an estimate developed by IUCN from different sub-population studies.

The Derby eland is a fundamentally browser animal of diurnal habits, which obtains most of its food from shrubs, with the least important herbs in its diet. Studies such as that of Hejcmanová et al. (2010) compare, thanks to the analysis of faecal samples, the diet of animals in the wild, in Niokolo Koba National Park, and in semi-captivity, in Bandia Reserve. In both environments, the consumption of herbs barely reached 5% and the leaves, fruits and shoots of woody plants were the most important part of the diet, which shows the importance of woody savannah for the survival of this enormous animal.

Even today, there is a great lack of information on movement ecology of the Western Derby eland in its natural habitat. This sentence by Ruggiero (1990) is a warning about that: *"Will the world´s largest antelope, a shy inhabitant of the densely wooded savannah, become extinct without ever having been studied in the wild?”*. Although knowledge is much greater today and conservation efforts are bearing fruit (see 1.2.2 Conflicts and Conservation) there are still gaps in their behaviour under natural conditions. In the case of the Eastern subspecies *T. d. gigas*, some articles (Angwafo 2006; Ruggiero 1991) have been published on this aspect that can help us shed light on its Western relative. It is known that a breeding group can have an estimated home range of up to 100,000 ha which is reduced to 30,000 ha during the dry season according to Bro-Jørgensen (1997). In the Central African Republic, a study conducted with Eastern subspecies by Graziani and D´Alesio (2004) estimated a size of 47,517 ha for males and 8,278 ha for females. They tend to be grouped in herds of females and juveniles of up to 25 individuals (but herds of more than 100 individuals used to be reported in the past according to Plantom and Michaux (2013)), while adult males tend to remain solitary or in small groups. Bro-Jørgensen (1997) observed that the larger grups split into smaller ones in the early dry season (December-January) and join together again in the early wet season (June-July). This gregarious behaviour, added to its unique pattern of stripes on the abdomen, can be characters that help in their detection and even their individual identification. Males can share from an hour to a week with females and, according to studies by Bro-Jørgensen (1997), the colour of their coat can be an indicator of their levels of androgen, a male hormone, which peaks during rutting. The specimens are usually very alert, being able to run at high speed (70 km/h) or jump easily (up to 1.5 meters) if the situation requires it, according to Burton (2002). Adult WDE, especially large males, are difficult prey to be hunted by lions or spotted hyenas, their potential predators. Only young or sick individuals can be hunted more easily. (Silvestre, 2000).

1.2.2. Conflicts and current conservation efforts

It is important to understand the reasons responsible for the population, to try to reverse them as much as possible and contribute to their conservation.

In 1990, a study of this magnificent ungulate in Niokolo Koba National Park, one of the last refuges of the “African giant”, estimated that about 1000 specimens were still living in this area (Sournia & Dupuy 1990). However, barely a decade later, their numbers plummeted to 100-170 individuals (Renaud et al. 2006), triggering alarms about their plight. The excessive hunting seems to be the cause of the decline of specimens in this National Park, which could be the only place in the world with a viable population of WDE according to the scarce data of presence in other areas of historical distribution (Darroze 2004). Habitat loss due to human expansion and cattle pressure have also affected this ungulate according to IUCN (2017). This, added to its greater sensitivity, compared to other antelopes, to diseases such as rinderpest (transmitted by domestic cattle) (Camara 1990) has taken it to a borderline situation. So much so that the "World Heritage Commission", in its evaluation mission to the NKNP in 2007, expressly recommended a long-term moratorium on WDE hunting due to its critical situation (UNESCO 2007). This conflicts with the attention this wonderful animal receives from hunters who are willing to pay huge sums of money for its eye-catching trophy (Batello et al. 2004).

The reduced population of this antelope urged the search for a plan for its conservation and avoid its extinction. Aware of the fragility of a single viable population of a species, as seems to be the case here, and even more so when the ecosystem in which it lives is under threat, human intervention through a captive breeding programme often becomes a necessary tool (Hanks 2001). For this type of actions to be successful, it is very important to take care of sufficient genetic diversity to avoid inbreeding and other associated problems (Trinkel et al. 2008) so that, if animals bred in captivity are reintroduced into the wild, they have the capacity to respond genetically to future environmental changes (Zachos 2009). In 1999, Senegalese authorities managed the capture of 9 WDE specimens in NKNP, 1 male and 8 females (three of the 8 females captured died during transport or shortly after, leaving a total of only 5 females.), which were transferred to Bandia Reserve (Akakpo et al. 2004). Today, 20 years later, that founder group have become 115 individuals (June, 2018) (Brandlová et al. 2018) distributed between Bandia Reserve, 77 individuals, and Fathala Reserve, 38, where a second group was formed with specimens from Bandia, descendants of wild ones (Antonínová et al. 2006). The need to start with an *in situ* conservation programme is known (East 1999) and there is a willingness to do so, although it has not been possible until now. Despite the genetic over-representation of the founder male, which recommends the future inclusion of new animals from the wild population, genetic analyses show that this captive WDE population can play a key role in the long-term conservation of this imposing antelope (Koláčková et al. 2011). Furthermore, the important efforts made at the educational and social involvement level (Grúňová et al. 2017; Grúňová et al. 2018) are key to ensuring that Senegalese society is receptive to the protection of this national emblem. In this way, social awareness, the correct management of populations in semi-captivity and the constant increase of knowledge about this subspecies (Antonínova et al. 2004; Zemanová et al. 2015; Galat-Luong et al. 2011) are basic pillars that make it possible to believe in a possible future for this fabulous animal that was on the verge of becoming only a memory.

1.2.3 Cultural importance of Western Derby Eland

It is easy to understand that an animal with the iconic aspect of the WDE is part of the culture of human groups that share (or have shared) space with it. According to Koláčková et al. (2011), these local communities consider the WDE to be part of their cultural and traditional ownership. However, there are no known rock paintings of this animal in its original home range, unlike the common eland painted in South African caves such as the "Eland Cave" in Drakensberg (Mazel 1983), which has been part of numerous tribal rituals linked to the passage from childhood to adulthood (Berghaus 2004). Traditionally, groups that have coexisted with this antelope, such as the Fulani tribe, have respected it by believing that it was a magical animal, capable of casting spells and transmitting diseases (Brandlová et al. 2013) but, currently, this ancestral respect has been lost in many cases. Some Fulani have become armed shepherds and hunt them regularly, as well as putting their existence at risk because of their cattle, which compete for space and transmit diseases to them (Ondua Ondua et al. 2017).

1.2.4 Senegal - Western Derby eland habitat description

Senegal, and especially the Niokolo Koba National Park, seems to have become the last viable refuge for the WDE. Located in southeastern Senegal, near the border with Guinea-Bissau (13º04´N 12º43´W), this park has an area of 9,130 km^2 making it one of the largest in West Africa. Created as a reserve in 1925 (Madsen et al. 1996), it was in 1954 when it reached the category of National Park, being the oldest in Senegal within the Sudan-Guinean Savannah (Mbow 2000). Its impressive ecological value led to its recognition as a Biosphere Reserve by UNESCO in 1981. However, in 2007, a committee of experts placed this NP on the list of "World Heritage in Danger" due to the great impact of poaching on native species of high importance such as the WDE, deforestation to use the land for cattle raising or dam projects for the Niokolo and Gambia rivers as well as highways proposed by the Senegalese authorities (UNESCO 2007).

The predominant ecosystem in the Niokolo Koba National Park is a Sudano-Guinean woodland-grassland mosaic and Sudano-Guinean savannah (Frederiksen & Lawesson 1992), being a transitional zone. The savannas, very important as refuge and food for a multitude of species, have suffered significant damage in recent years due to fires, human activities and climate change (Riggio et al. 2013). Among the animal groups affected by this degradation, ungulates are the most threatened (Baskaran et al. 2011) so it is especially necessary to know and protect areas such as this to preserve associated species of great value as the WDE. According to Camara et al. (2016), the WDE live in very rich areas at floristic level, being Combretaceae the dominant family, and, according to other studies, (Nežerková & Hájek 2000) the vegetation of the Park can provide sufficient space and nutritious food for the antelopes, although an update of these data would be of great interest to know the situation today.

Thanks to its privileged location, crossed by four rivers (Gambia, Sereko, Niokolo, Koulountou), it has all the ecosystems of the Sudanese bioclimatic zone: gallery forests, flood plains, herbaceous savannas, ponds, dry forests, dense forests or rocky hills, among others. To this is added a very rich fauna with more than 70 species of mammals (among which are the Koba, in local language, *Hippotragus equinus* that gives name to the NP), 329 species of birds or 36 different species of reptiles. Despite this, iconic species such as the giraffe *(Giraffa camelopardalis peralta)* have completely disappeared despite attempts at reintroduction (Dupuy & Verschuren 1977) and others such as the elephant *(Loxodonta africana)* seem to be in a not much better situation (Bouché et al. 2011).

Although NKNP is the last viable refuge for this antelope in the wild, areas such as the Falemé Hunting Area also appear to host WDE specimens at present (Brandlová et al. 2013). But it is important to describe the other two places in Senegal where this magnificent animal can currently be observed and which play an essential role in its conservation: Bandia and Fathala Reserves. Although they are populations in semi-captivity, constituted for the breeding and conservation of this ungulate, their differences at the landscape level and their permanent presence of specimens, make them very interesting spaces to evaluate the possibilities of the UAVs to detect individuals in different contexts.

Fathala Reserve (13°39'N and 16°27'W) is located within the Delta du Saloum National Park, an enormous protected area of 76,000 ha that includes islands, peninsulas, salt flats, mangroves and savannas of enormous ecological value. This explains its declaration as a World Heritage Site and Biosphere Reserve and as a RAMSAR wetland site. Fathala Reserve is part of Fathala Forest, and it is a fenced area of 2,000 ha (Nežerková-Hejcmanová et al. 2005) dedicated to luxury accommodation and ecotourism. The area belongs to the transition zone between phytochoria of the Sudanian regional centre of endemism and the Guinea-Congolian/Sudanian transition zone (White 1983) and the mean annual precipitation is 839 mm (Banjul meteorological station, Lykke 1996). Humid valleys, wooded grassland, dense woodlands, transitional woodlands on the pleateaus as well as gallery forests are the most frequent ecosystems in Fathala (Lawesson 1995). The abundance of rainfall allows tree species such as *Combretum nigricans*, *Bombax costatum* or *Piliostigma thonningii* to reach important densities. This, coupled with the presence of large areas of *Andropogon gayanus*, a grass that reaches a considerable height and grows at high densities, helps to reduce the visibility of the abundant fauna living in the Reserve, including the WDE.

Bandia Reserve (14º 35´ N, 17º 00´ W) is, on the other hand, a much dryer area. It has an annual rainfall of 484 mm, with a rainy season shorter than in NKNP or Fathala Reserve (Al-Ogoumrabe 2002). Bandia is further north than the other two WDE sites in Senegal, about 65 km from the capital, Dakar (Nezerková et al. 2004). According to Lawesson (1995) the most common type of vegetation is *Acacia ataxacantha-Acacia seyal*. The acacias and baobabs, distributed in a dispersed way, integrated in large extensions of grasslands, form the typical landscape of this reserve. It is, therefore, a much more open space, less leafy than Fathala, which favours the observation of animals in the wide spaces destined for the practice of photographic safari by tourists coming from all over the world (more detailed description of the space in 3.1 Study site).

1.2.5 Unmmaned Aerial Vehicles (UAVs) and its use in conservation

To properly manage any species, it is essential to know the size of its population as accurately as possible as well as to know in detail its habitat (Cristescu et al. 2015). Usually, species monitoring has been carried out by ground surveys or by small manned aircraft (Buckland et al. 2004). The disadvantage of ground surveys is that it is very expensive and requires an enormous effort when trying to cover large areas (Wich et al. 2016). For example, a 3-year cycle of ground surveys of orangutans *(Pongo* sp.*)* can cost about $250,000. This price makes it difficult to maintain a certain periodicity and, in addition, very remote areas are always left unchecked (van Gemert et al. 2015). On the other hand, aerial surveys can cover large areas but are very expensive and dangerous due to possible accidents (Sasse 2003). Even so, there are situations in which it is necessary to use manned aircrafts for their greater efficiency or other reasons, so it will always have a role in the world of conservation, not being possible to replace them completely.. Thus, other technologies came into the field of conservation to facilitate work. Camera traps have shown their effectiveness by rediscovering species in remote and inaccessible areas (Ahmed et al. 2016) or Google has proved to be a possible ally against illegal fishing (Craymer 2014), but even so, many of these techniques, such as remote photography, GPS collaring, scat detection dogs, tagging or DNA sampling require large investments of time and effort (Wittmer 2005) and, in many cases, have important limitations to determine accurately the size of a population. This becomes even more difficult when our "target species" have enormous home ranges (Gaston & Fuller 2009), low population densities (Wittmer 2005), hard-to-reach habitats, shy behaviour (Ditmer et al. 2015), and sensitivity to disturbance (Chabot & Bird 2015). All these features appear together, in an unlikely combination, in the protagonist of this study: the Western Derby eland.

Its more than reduced population, its elusiveness, the difficult access too many of the areas of this immense National Park that is Niokolo Koba, represent a challenge for its study. Therefore, novel techniques such as the use of unmmaned aerial systems (UAS) are presented as an interesting contribution to the future of work with this antelope.

If used correctly the UAVs are safe, small, easy to use and inexpensive devices that can take still images or high definition videos (van Gemert et al. 2015). In recent years they have shown their efficiency by detecting threatened animals such as sea turtles (Bevan et al. 2015), black bears (Ditmer et al. 2015) or birds (Chabot & Bird 2012), but also their tracks, such as orangutan nests (Wich et al. 2016) or even human threats like poachers (Mulero-Pázmány et al. 2014; Bondi et al. 2018). Although it still has limitations such as the short battery life of the device or social implications that must be taken into account for appropriate use, without long-term negative impacts (Sandbrock 2015), there is no doubt that the possibilities of this technique are enormous. And that its use in cases such as WDE looks promising.

Figure 3: Western Derby eland photographed with UAV during this research in Bandia Reserve. 45 m AGL. DJI Phantom 3 Pro.

1.2.6 UAVs as conservation tool in ungulates conservation

The group of ungulates, which has numerous endangered species, has been the protagonist of different studies with UAVs.. The UAVs have collaborated in the fight against rhinoceros poachers in Africa (Mulero-Pázmány et al. 2014), have made it possible to carry out precise hippopotamus (Lhoest et al. 2015) or red deer censuses thanks to the use of infrared cameras that have proved their effectiveness (Witczuk et al. 2018), as well as observing the movement patterns of the enormous yaks (Su et al. 2018). Therefore, its application with the Western Derby eland is presented as an opportunity that must be taken into account so that its future can be secured. Although this technique has not been used before with this species, its delicate situation invites us to seek all possible tools that can contribute to collaborate in their greater knowledge and protection.

2. Aims of the Thesis

This thesis overall aim is to become a starting point in WDE monitoring using a UAVs as a data acquisition tool to support the species conservation management plan in Senegal. As a pilot experience, we seek to know the basis for the study and monitoring of the WDE through images obtained by UAVs. Thus, the basic point of this study focuses on the detectability of these animals, through aerial images collected by a UAS.

The aims of this study was to determine the technical parameters for detectability of WDE through aerial imagery.

Within this general aim, the study focuses on two specific work objectives:

The 1st aim was to evaluate the technical parameters of the use of UAVs and their relationship with the probability of detecting the study animal. These technical parameters were:

1.1) Flight height; the research wanted to determine the most efficient flight height for the detection of Western Derby eland in a woody savannah.

1.2) Sensor Angle; the present study aimed to evaluate the angles 0º and 45º to know the efficiency (valued in covered surface per unit of time) of both.

1.3) Photography *vs.* Video; the objective was to test the pros and cons of both types of images (still or moving) to assess their use in each situation.

1.4) Flight speed: this Master Thesis aimed to describe how flight speed affects individual detection probabilities (in UAVs videos)

1.5) Ethical and environmental considerations using UAVs; It was an object of this research to determine how the use of UAVs affects or influences the behaviour of these antelopes and how to reduce this impact.

The 2nd aim in this scientific study was to assess the ability of two classification systems (Manual and Automated) to detect the presence of WDE specimens present in UAS images:

2.1) Automated Supervised Classification: The research was based on using Object Based-Image Analysis (OBIA) software; eCognition Developer 9®, to investigate the effectiveness of detecting WDE individuals in aerial photographs and to analyse its pros and cons.

2.2) Manual Classification: The study aimed to describe the detectability of WDE specimens through human observers, at a glance, without the use of computer tools and to analyse its pros and cons.

3. Methods

3.1 Study site

The data collection was carried out in the Bandia Reserve (14º 35´ N, 17º 00´ W), located close to Sindia village in Senegal, at a distance of approx. 65 km from Dakar, the capital of the country (Fig. 4).

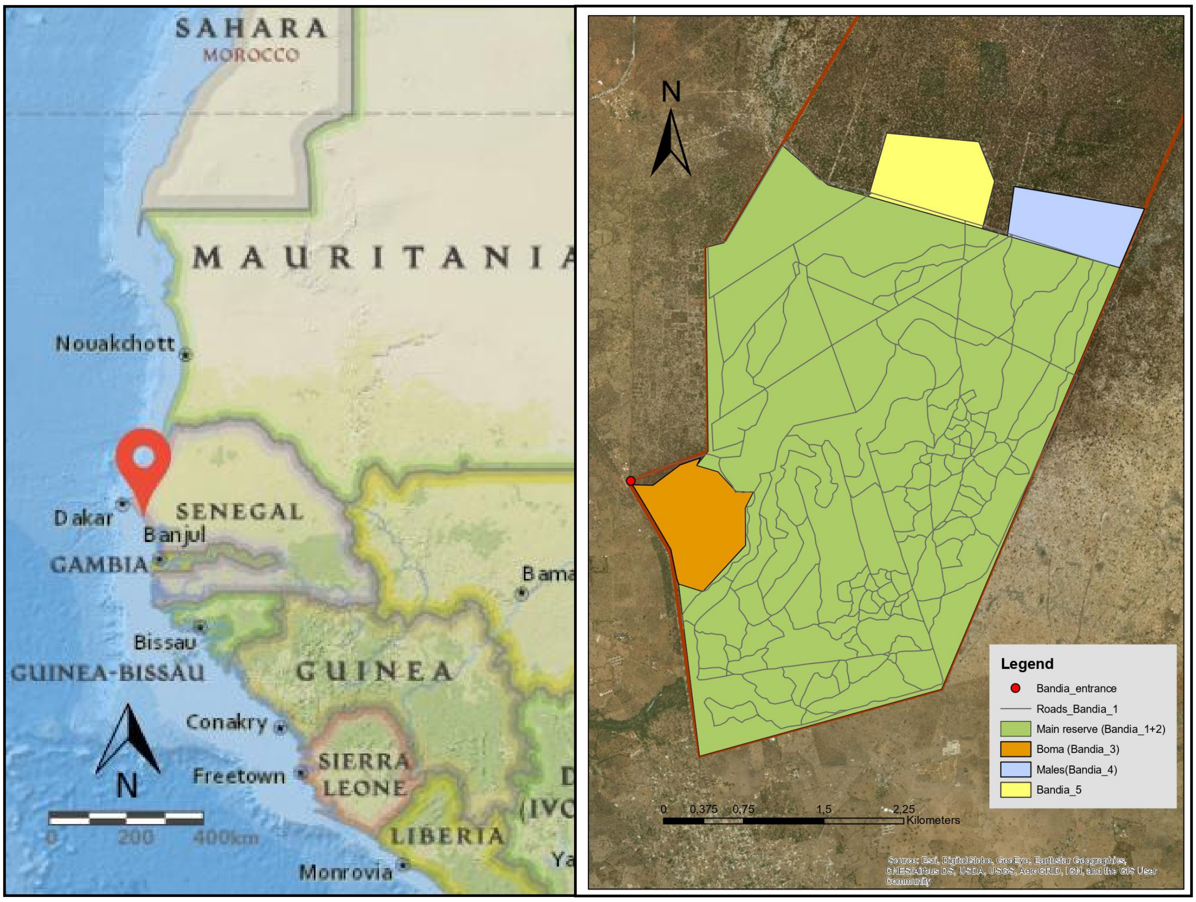

Figure 4: Location of Bandia Reserve (Senegal) and the enclosure distribution.

The data were collected in February 2018. This season was chosen because it is a dry season which provides favourable conditions for animal observations and when animal monitoring and surveys with aim to count individuals are usually practised. During the rainy season (June – October), the reserve becomes impracticable due to the dense vegetation, the constant mud and the water spots that make it difficult for vehicles to move, making fieldwork difficult.

The Bandia Reserve is an area of 3,500 ha, fenced, covered, according to Lawesson (1995) "by a dry deciduous woodland typical of Sudan-Sahelian savannah in which can be found more than 100 species of plants from 30 different families". When the reserve was established, the vegetation was degraded to different levels (Freeman & Resch 1985), mainly by the extraction of wood as fuel and the use of the land as a cultivation area for the surrounding population, although fortunately it was saved from more irreparable damage such as that suffered in 1979 in part of the original Bandia Forest. That year, 3,000 ha were deforested for the planting of exotic species: 80% of *Eucalyptus camaldulensis* and 20% of *Azadirachta indica*, a project that proved unfeasible and taught that the sustainable use of local vegetation could have been a profitable alternative (Freeman & Resch 1985). However, even today both exotic species are still present in the flora of the study area. After its past degradation, the current Bandia Reserve shows 3 different stages of ecological succession. The first stage is the open grassy savannah, with numerous annual species of genera such as *Brachiaria* sp. and *Digitaria* sp. A second stage, the bushy savannah, with shrubs and trees of the genus *Acacia* sp. (Fig. 5) and, finally, the most complex and developed stage, with the baobab *(Adansonia digitata)* as the dominant species, which forms the most recognizable and striking skyline of the reserve. Outside the reserve the vegetation is highly degraded, usually exploited by cattle and with isolated baobabs as the most remarkable elements.

Figure 5: Aerial view of Bandia Reserve, showing its typical landscape.

The current use of the Reserve is the ecotourism. For the visits, a series of facilities have been developed as a restaurant service, in addition to a fleet of vehicles with which to travel the roads and observe the animals. This touristic purpose explains that the Reserve of Bandia counts on a fauna not only Senegalese, looking for a mixture of species that the foreign tourist finds more attractive, more typical of a photo-safari. South African species such as the Cape giraffe *(Giraffa camelopardalis giraffa)*, Southern white rhinoceros *(Ceratotherium simum simum)*, Common eland (*Taurotragus oryx*), or Greater kudu *(Tragalephus strepsiceros)* are part of the inhabitants of this reserve. On the other hand, more than 120 native species of birds such as the Abyssinian roller *(Coracias abyssinicus)* or the red-billed hornbill *(Tockus erythorhynchus)* and numerous species of indigenous mammals from Senegal, as the roan antelope *(Hippotragus equinus)*, common warthog *(Phacochoerus africanus)*, patas monkey *(Erythrocebus patas)* or the protagonist of this study, the great Western Giant Eland, share space in Bandia Reserve.

In order to facilitate management and to be able to control relationships between different WDE individuals (and, for example, avoid inbreeding problems) the Bandia reserve was divided into 5 fenced areas. Two of them, Bandia 1 and 2, were connected and hosted the largest area of land in the Reserve, 3,500 ha. There were 3 breeding groups and one group composed exclusively of males. As shown in Table 1 there were mixed enclosures (the WDE lived together with other species in the Reserve) and others reserved only for this astonishing antelope. In total, 77 individuals (42 males and 35 females) were living in the Bandia Reserve (Brandlová et al. 2018).

Table 1: WDE´s groups in Bandia Reserve according to its number and distribution.

Enclosure designation	***Number of males***	***Number of females***	***Herd category***	***Enclosure size***	***Enclosure type***
Bandia 1+2	27	13	Reproductive	3,500 ha	Multiple sp.
Bandia 3	5	9	Reproductive	80 ha	Multiple sp.
Bandia 4	7	0	Bachelor	100 ha	Single sp.
Bandia 5	3	13	Reproductive	80 ha	Single sp.
Bandia total	**42**	**35**	**Totally 77**		

3.2 Data collection

3.2.1 Materials

We requested permission from the manager of the Reserve, to be able to take images of the space thanks to the UAV. After this, a map of Bandia Reserve was developed using information gathered in previous visits to the study area via mobile app GeoTracker (Fig. 4). This map made it easier to be located on the ground and to have a clearer idea of where we were at any moment. The car was a central element due to the need to travel long distances within the Reserve to locate and follow the WDE specimens. The notebook to note all the details observed was also necessary. As a central element of this study, we used a DJI Phantom 3 Pro drone (called UAV after here), which combined features of price, ease of use and image quality (12.4 M, 4K. Maximum image size: 3000 x 4000) that made it optimal for this type of studies. An essential complement was to have 6 batteries (4480 mAh and 15.2 V) to increase the possibilities of flight time in the field, due to the reduced autonomy (20-23 minutes, depending on different factors such as wind) of these devices. The maximum speed of this UAV is 16 m/s, in no wind conditions. It was necessary to use Secure Digital (SD) memory cards up to 64 gigabytes to increase the information storage capacity. We carried several SD memory cards, one for each flight, to avoid having to download the images to the computer in field conditions and make the work more efficient. Each card was numbered to control which flight (or group of animals) it belongs to. One thing to keep in mind before using this type of device in places that can be very hot a few hours a day, as is the case of Senegal, is that it works at temperatures between 0 and 40ºC, so it should avoid using it at higher temperatures. For the control of the UAV, the DJI GO© app was used through an Android mobile device.

3.2.2 Procedure

3.2.2.1 Location of individuals

The location of the individuals was carried out through direct observation from the vehicle. A low-speed route through the entire Reserve and the invaluable help of the guards or guides were decisive in locating the individuals. In the case of Bandia 4 and 5 (Fig. 4), located in smaller fenced enclosures and with artificial feeders close to the exterior road, their localization was much simpler.

3.2.2.2 Development of data collection

All the data obtained, and subsequently analysed, have been collected following the same working protocol. Two people were present at the data collection: an expert pilot, with hundreds of hours of UAV flight linked to wildlife conservation, Meyer de Kock, and supervisor of this thesis, as observer thanks to 10x40 binoculars, collecting the notes and learning the piloting skills of these devices through field practices, a working structure similar to that of other UAV research (McClelland et al. 2016). Once the specimens have been detected by direct observation (with or without the use of binoculars), a series of steps common to all flights are developed, regardless of the Aim studied.

- Turn off the car as gently as possible to avoid frightening the specimens. Due to the impossibility of predicting where the animals would be, since many encounters could be fortuitous, we tried to maintain a minimum distance of 45-50 meters when possible, observing that at that distance the animals could show interest, but did not show flight behaviour.

- Silently, both technicians left the car. To make the process more efficient and quicker, the pilot started the remote control to establish connection with the UAV, while the second person, arranged the device in a flat area, without vegetation around and any obstacle (branches, etc) above. Finally, this second person ensured that the propellers are correctly arranged and switches on the UAV. After this, he went close to the pilot to take the appropriate data and to avoid, with his movement, altering the animals.

- Once established contact and checking that the device is ready to fly, the pilot took the flight vertically, up to a height of 150 meters. The pilot always flew in manual mode in order to keep the WDE individuals within the field of vision.

1.1) Flight height; Determine the most efficient flight height for the detection of Western Derby eland in a woody savannah.

To determine the most efficient flight height, the UAV is placed on the vertical of the individuals at 150 meters of height and a photograph was taken thanks to the remote control. This operation was repeated after reducing the height, progressively, by 25 meters until reaching 50 meters above the ground (150, 125, 100, 75, 50 meters) with the camera angle equal to 0º. The image of the same area at different heights was useful to us to evaluate at what height the ratio of area covered and number of pixels per square meter is more efficient. The “Aerial Camera Ground Footprint calculator”, a website used to determine the footprint taken by UAVs, allowed us to know the surface covered at each height, and thanks to it, knowing that the picture size of the camera has 3,000 x 4,000 píxels, it was possible to determine the relation píxel/square meter. For the correct use of the web application "Footprint calculator" it is necessary to adjust the technical parameters to the UAV used, a DJI Phantom 3 Pro. In this case, the lens focal length is 3.61mm, the sensor is 6.16mm wide and 4.62mm height. Since it was impossible to enter decimal values in the application, these numbers were rounded off: lens focal length, 4 mm; sensor wide, 6 mm; sensor height, 5 mm.

The higher the height, the images obtained to cover a greater surface but (by keeping the camera the same number of pixels) the images taken at a higher height, have lower definition, fewer pixels per square meter. And, therefore, the lower the definition, the more difficult it is to successfully detect our target species. On the other hand, too low flight increases the definition of the image but covers too little surface so it would not be efficient because takes too much flight time to cover a large area.

1.2)Sensor Angle; Evaluate the angles 0º and 45º to know the efficiency (valued in covered surface per unit of time) of both.

To evaluate which camera angle was the most efficient for detecting WDE in a woody savanna environment, the pilot placed the UAV on the vertical of the control zone, at 100 meters high, and activated the video mode. From this point, a horizontal path of approximately 200 meters was traced in the direction of the observed specimens, with constant speed (approx. 4 m/s) and the camera at an angle of 0º. After this first taking of images, the process is repeated changing the angle of the camera to 45º. To determine the covered surface in each situation, was used the “Aerial Camera Ground Footprint calculator”, through its web app that allows us to know this surface knowing parameters like the drone altitude or camera angle.

1.3) Photography Vs. Video; Test the pros and cons of both types of images (still or moving) to assess their use in each situation.

To assess the advantages and disadvantages of photography and video in the detection of WDE specimens in a woody savannah, the original habitat of this ungulate, we took a photo and video images of the same area where WDE individuals have been detected. Both at 50 meters of height, from the position of the pilot and in the direction of the antelopes, with the angle of the camera at 0º, during a transect of about 200 meters on the animals (trying to follow them if they started to move). First, images were taken during the transect at a constant rate. Then, from the same starting point and the same length, a video shot at a constant speed of about 4 m/s.

1.4)Flight speed: Describe how flight speed affects individual detection probabilities (in UAVs videos)

To know how flight speed affects the detectability of WDE individuals, we evaluated the Maximum Time on Target (MTT) of a specimen, i.e. the maximum time that a specimen can appear in the image. For this experiment, the observed animal is expected to meet two requirements: 1) It is not moving 2) It is just at the front limit concerning to the direction of movement of the UAV, as shown in Figure 6. Depending on the height, the footprint (obtained through the Footprint calculator, with the same technical parameters of the UAV exposed above) varies. The higher the height, the greater the footprint and, therefore, the longer it takes for the UAV to change frames from its origin. It evaluated the time it takes the UAV to travel that space depending on each speed.

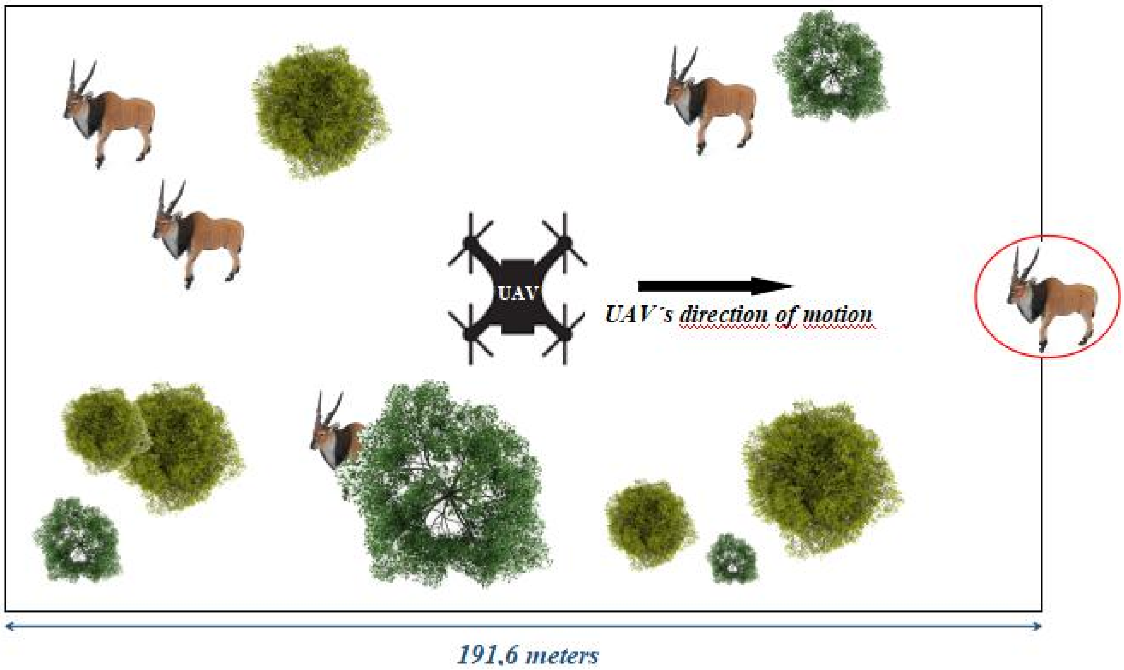

Figure 6: Example of Footprint area (AGL 100 meters). In red circle, WDE observed.

As a test, 22 voluntary observers observed the same video clip at three different speeds: 2.5x, 1.5x and original speed (2.5x and 2.5x were obtained thanks to Sony

Vegas Pro, video edition software). In 4 from 5 selected clips, we had made sure that at least one individual of WDE appeared. In one of the WDE were absent. Five different video clips were used (a total of 15 videos, each one of the 5 ones, at 3 speeds) and were displayed following this order: First, all the high speed videos, after the medium speed videos and, in the end, the original speed videos, to avoid make easier the detection in the high and medium speed videos after watching the original ones. Observers noted how many individuals they saw in each video, to assess whether flight speed affects detectability. Previously, to know the real number of individuals in each video (and to be able to relate them to the number observed by the volunteers), a detailed and low-speed review was carried out by the research team.

1.5)Ethical and environmental considerations using UAVs

To define an ethical protocol for monitoring WDE using UAVs, we determined at what height these devices caused a nuisance or alteration in the behaviour of antelopes. To evaluate the reaction of individuals was used a table (Table 2) (Blank 2018) with 3 different behaviors related to the WDE response to the UAV: 0 = No response; 1 = Observation: Animal shows nervousness, moves ears, and/or directly looks at the UAV; 2 = Flight: The animal begins its flight away from the UAV

Table 2: Types of response of WDE specimens against UAV

WDE-UAV Behavioural Responses	
Type 0	No response
Type 1	Observation: Animal shows nervousness, and/or directly looks at the UAV
Type 2	Flight: The animal begins its flight away from the UAV.

The pilot placed the UAV on the vertical of the individuals, at the height of 100 meters and began to descend at a constant and moderate speed. The second person of the team observed the WDE with binoculars to detect any of the behaviours 1 or 2. Once detected, note was taken of the height at which they occurred. Behaviour 1 was recorded when at least one of the individuals raised his head and looked towards the area of the sky where the unmanned aerial vehicle is. Behaviour 2 is recorded when at least one of the individuals began to trot away from the noise source that is the UAV.

The height was obtained according the data that appears in the remote control device that the pilot used during flights.

Evaluate two systems of detection of the specimens:

1.6) Automated Supervised Classification: Through a software of detection of objects in images (Ecognition), assess whether it is capable of detecting WDE individuals in aerial photographs. Analyzing its pros and cons.

For the Automated Supervised Classification the software based on machine learning Ecognition has been used, which allows detecting, according to coulometric characters, objects (individuals of WDE in this case). To test the validity of the software by detecting specimens, we obtained an image of Bandia Reserve, in RGB format, using DroneDeploy. It was opened that image in Trimble - Ecognition developer 64 and, using only 3 of the 4 layers, it was made a classification (Nearest neighbour) with 2 Output, one positive (Eland) and another negative (No Eland), where are selected as “positive” those ones that look like contain part of the body of a WDE (Fig. 7), and as “negative” 1-2% from total polygons of other surfaces, rocks, floor, vegetation... Once the categories are defined, and the software “knows” how a WDE looks, we tested the software observing its capacity, or not, to detect specimens in photographs through different set-up, and discern which one was more efficient to get this goal. It was chosen eight different set up (Table 3) to analyze the same image, obtained in Bandia Reserve and in which appeared five different WDE. Two of them were chosen as “Positive Input”. In the selected subset,a total of 94,488 polygons were present after segmentation.

Table 3: Set-ups applied to analyse the aerial image using Ecognition software.

	SEGMENTATION						CLASSIFICATION		
	Input L.	*Output L*	*Classific*	*Scale*	*Color*	*% Negat polygons*	*Posit. Output*	*Negative Output*	*Feature Space*
1	**L1**	L1	Unclas.	**5**	**0.1**	**2%**	Eland	No_El	**Colour**
2	**L1**	L1	Unclas.	**5**	**0.1**	**2%**	Eland	No_El	**C +T**
3	**L1**	L1	Unclas.	**5**	**0.1**	**3%**	Eland	No_El	**Colour**
4	**L1**	L1	Unclas.	**5**	**0.1**	**3%**	Eland	No_El	**C+T**

5	**Pixel**	L1	Unclas.	**125**	**0.45**	**2%**	Eland	No_El	**Colour**
6	**Pixel**	L1	Unclas.	**125**	**0.45**	**2%**	Eland	No_El	**C+T**
7	**Pixel**	L1	Unclas.	**125**	**0,45**	**3%**	Eland	No_El	**Colour**
8	**Pixel**	L1	Unclas.	**125**	**0,45**	**3%**	Eland	No_El	**C+T**

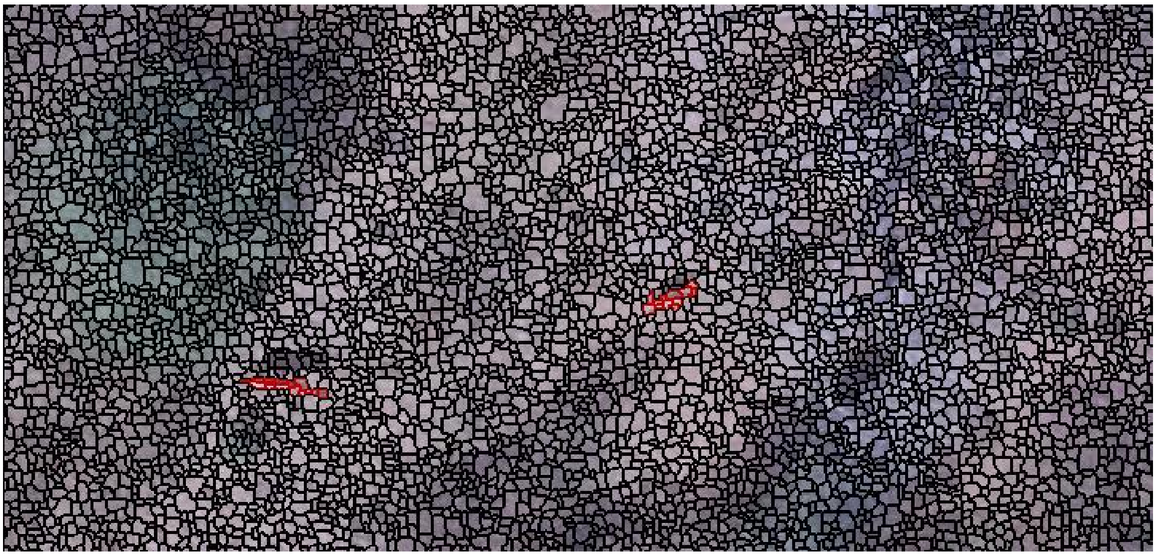

Figure 7: After segmentation, two of WDE individuals selected as positive input.

1.7) Manual Classification: Describe the detectability of WDE specimens through human observers, at a glance, without the use of computer tools. Analyzing its pros and cons.

For "Manual classification", 15 images have been selected that contain at least one individual of WDE at a height of, at least, 50 meters. Previously, each selected image was thoroughly checked for the exact number of individuals present. Another 15 images are selected that do not have any WDE individuals. After this, individually, the 30 images, mixed at random, have been shown to 20 observers (choosen also at random), aged between 18-70 years, divided acording 3 age sectors: 18-38 (young), 39-59 (mature) and 60-80 (old). Also, they were asked about their sex, education (Primary/ Secondary / Universitary) and proffesional relationship with nature or wildlife conservation (yes or no) to take in acount these factors related with the ability to detect WDE individuals in the aerial images. Of the 22 participants, 50% were men (n=11) and the other 50% were women. The participants were 14 persons aged between 18 and 38 (63.6%), 5 subjects aged between 39 and 59 (22.7%) and 3 respondents aged 60-80 (13.6%). 16 of the participants had a university level of studies (72.7%), 4 had a secondary level of studies (18.2%) and 2 had a primary level of studies (9.1%).Viewing takes place on a 17-inch screen. None of the volunteers involved in image monitoring has had previous contact with the species. In order to give them an idea of what to look for, they have been shown an aerial image at low height of a WDE to give them an idea of its shape and colours. The observers can visualize each image for 30 seconds and control the zoom values as much as they need to facilitate their search. After the viewing time of each image, in a table designed for it they write down the number of specimens observed to determine what percentage of the total they can see under such conditions. We will observe how the detectability of WDE by observers changes, or not, depending on their level of education, sex or age, to select appropriate people for the detection of specimens according to their profile.

For the observation of videos, the same volunteer observers are present. Each of them, and in the same environmental conditions (same screen, same room, etc.) watch 3 aerial videos in this order (each):

1)Video low difficulty level (called ELAND1): in which it can easily observes WDE specimens, no animals covered by trees or so far away. Without the possibility of stopping the video.

2)Video high difficulty level, without stops (called ELAND2): There are more difficult specimens to observe, hidden by shadows, partially hidden under trees, etc.. Without the possibility of stopping the video.

3)Video high difficulty level, with stops (called ELAND3): The same video as 2) but giving observers the possibility, for 5 minutes, to stop, advance or restart the video as many times as they want, within that time.

3.2.2.3 Data Analysis

The maps of the study area have been obtained thanks to the GIS ArcMap software. To determine the most efficient flight height, through Microsoft Excel 97-2003, was created to determine the height (independent variable) at which the optimum resolution (dependent variable) of 8cm/pixel occurs. In order to determine which camera angle, 0º or 45º, was more appropriate, a graph has been elaborated thanks to Microsoft Excel 97-2003 that related the camera angle (independent variable) with the covered surface (dependent variable) and to be able to evaluate how this factor affected detectability. In order to evaluate the preference of videos or photographs in the work of detecting WDE specimens, pros and cons have been evaluated after observing all the material obtained during the investigation, both still and moving images. To determine how speed changes affect the detectability of WDE, based on the time that a specific area remains on screen during the movement of the UAV, a table has been created that shows parameters like the distance, speed and time to cover it, thanks to Microsoft Excel 97-2003. With the data of "number of observed specimens" at each speed, for each observer, the IBM SPSS Statistics v.23 was used to make the necessary statistical analyses. First, a test of normality was applied which showed the non-normality of the data. Therefore, a Kruskal Wallis H test was used to evaluate if there are significant differences between the difference "real antelopes-observed antelopes" at different speeds: original (low), medium and high. To evaluate the minimum height without disturbance to the specimens, Microsoft Excel 97-2003 was used to know the average height at which type 0, 1 and 2 reactions occur. In the case of Automated Supervised Classification, DroneDeploy software was used to obtain an aerial image of Bandia Reserve in RGB format and Ecognition software, based on machine learning, was the response for making a classification with 2 output, one positive (WDE) and one negative (No eland). To analyse the data tested for Manual Classification was used Microsoft Excel 97-2003 for the development of graphs and tables, and IBM SPSS Statistics v.23 for the necessary statistical tests. First, a Kolmogorov-Smirnov test was applied to determine the normality of the data. Normality exists if $p > 0.05$, something that didn´t occur in any of the variables. For this reason, non-parametric tests were applied. To check if there were differences in the variables "Number of observed antelopes" and "Difference between number of real and observed antelopes" in terms of sexes, the Mann-Whitney U test was performed. The Kruskal-Wallis H test was used to determine whether there were differences in the variables described above, according to the age group in which the subject was enrolled. The same test was used to confirm or disprove the hypothesis regarding the level of studies and to evaluate the differences between the 3 ELAND videos.

4. Results

After the days in the field searching and monitoring the WDE specimens thanks to the use of UAV, it has been possible to collect a large amount of data from different groups of WDE in Bandia reserve: About 350 photographs (some obtained only as proof or test) and 45 videos (of the different characteristics exposed above in terms of height, camera angle, etc.).

4.1 Optimum flight height

We observed how the surface covered by the UAV, increased as the height at which the device flies increased (Fig 8). Therefore, the higher the height, the greater the area collected in the image. But, as the resolution of the camera remained constant, increasing the height reduced the number of pixels per square meter, so, the resolution of the image decreased.

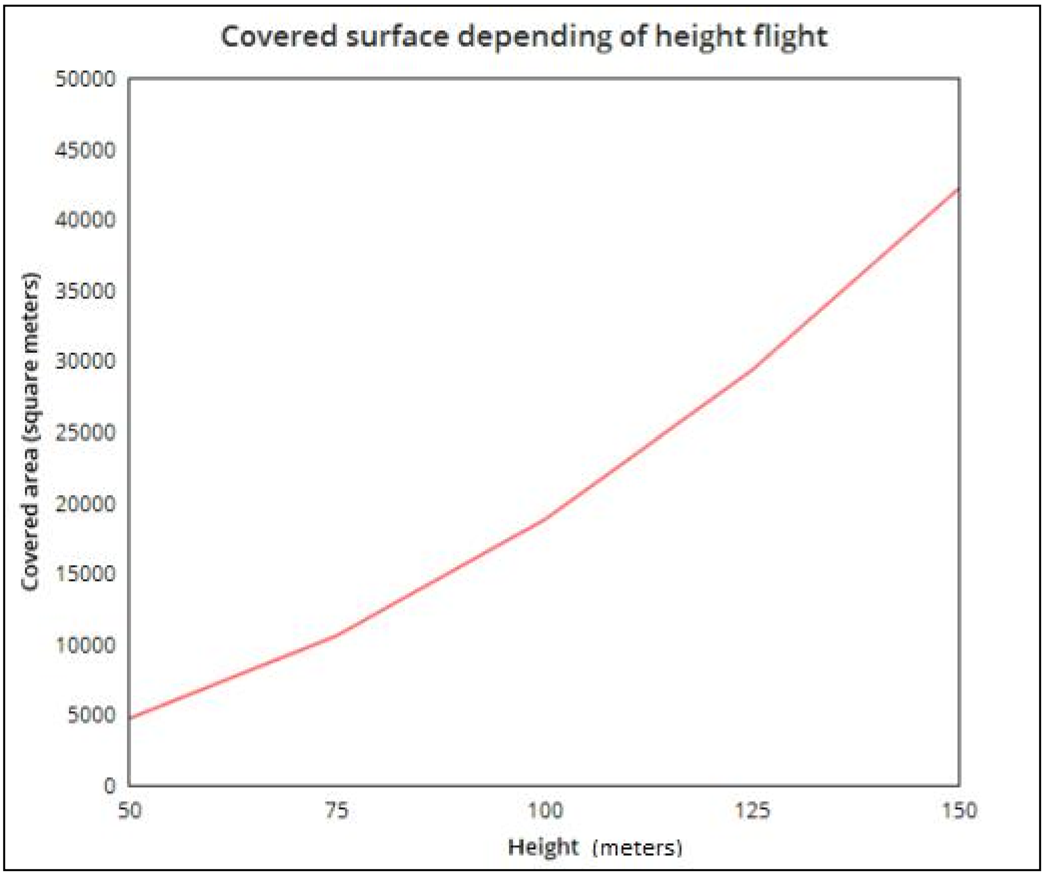

Figure 8: Relationship between flight height and area covered by the UAV.

4.2 Camera angle

The technical parameters of the camera were, as usually for the used device, lens focal lenght, 4 mm; sensor wide, 6 mm; sensor height, 5 mm. In "Footprint calculator" application (y-axis = 30°), the x-axis values were increased in 5° increments from 0°. It was observed how, with 45º, the covered surface was almost 5 times greater than that of 0º. Also that, from 45º the curve becomes markedly exponential, increasing the values of covered area in a marked way, being, for example, the covered surface with 55º, 20 times superior to the area captured with 0º.

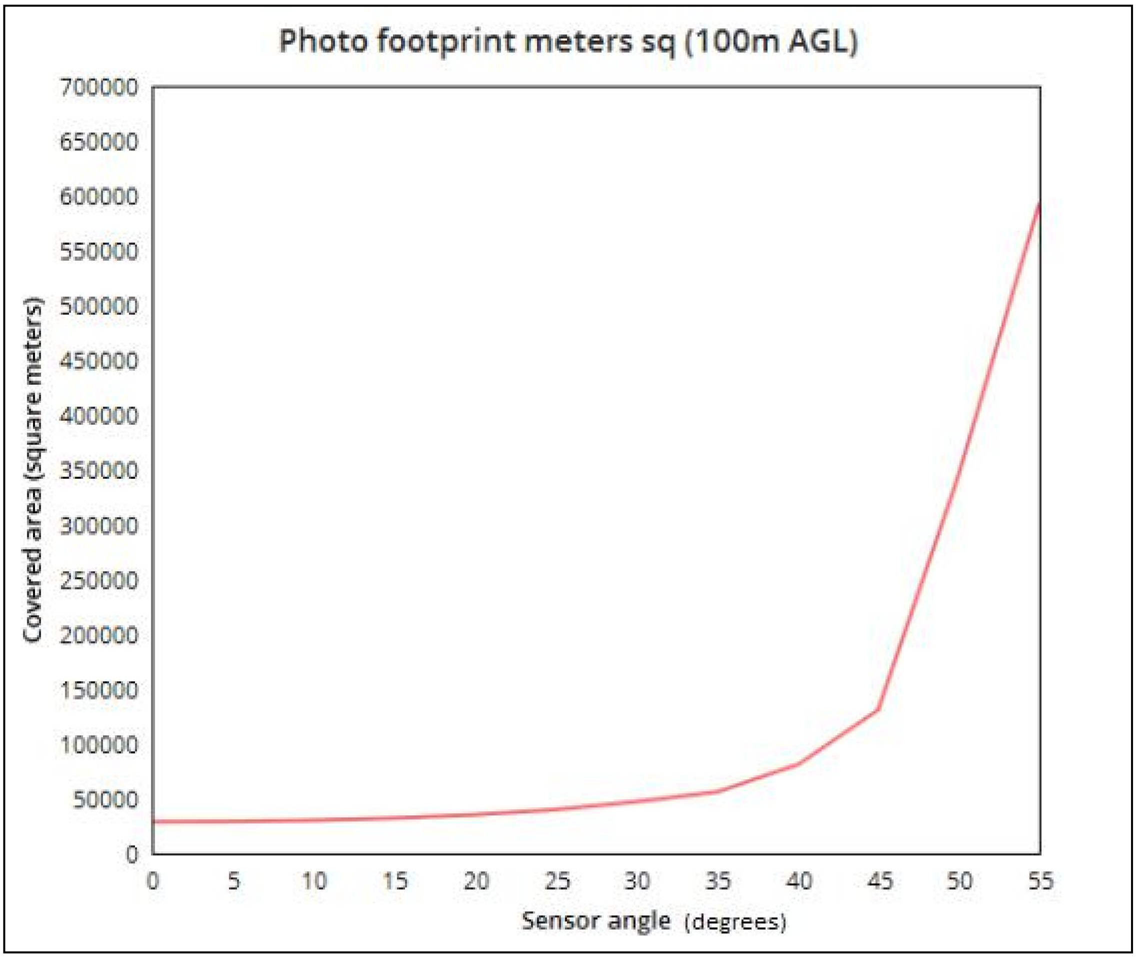

Figure 9: Relationship between camera angle and surface covered by the UAV.

4.3 Photography Vs Video

After observing numerous still images (photographs) and moving images (video) we could determine that both showed pros and cons that must be evaluated and weighed to determine which one we want to use according to the circumstances. The photos were less heavy (between 4,69 MB and 23,2 MB for 1 picture) and could be analyzed more easily with object detection software, such Ecognition, to locate specimens of our main species. Videos were heavier files (470 MB for a 1:05 min video, for example) and were more difficult to analyze in a computerized way due to the higher complexity in the use of specific software, but they had an important point in favour: they allowed detecting light movements of the animals, such as tail movement, which made detection much easier. Moreover, being a continuous image, it was very easy to observe (on a screen), giving (as the UAV go ahead through the transect) different points of view of the same place, favouring that, sooner or later, if there was a specimen in the area, it can be detected.

4.4 Filming speed

As it seen in table 3, at higher flight speed, the observation time of a particular area of ground was reduced. This reduction of observation time was progressively reduced as the speed increases, although the rest of parameters like height were changed. The reduction of the time of observation of a concrete place, reduced the probability of observing a specimen, especially when the environment, of similar colors and cover with vegetation, favors its concealment. With the UAV flying at 100 meters high (and the lens focal lenght parameters, 4 mm; sensor wide, 6 mm; sensor height, 5 mm), the camera straight down (0º sensor angle), the surface covered by the UAV image was: 191.6 (hight) x 150 (width) meters (28740 m^2). When the drone moves forward, in a linear fashion, it traveled those 191.6 meters to completely change the observed frame in the origin of transect. The maximum time the animal remained on the screen, i.e., the Maximum Time on Target, MTT, (therefore, with the possibility of being observed) depends on the distance to travel, 191.6 meters and the speed of the device.

Depending on the height, the footprint will be different and, therefore, the Maximum Time on Target, also, as shown in Table 4. It has been seen that, at higher speed, the MTT is also lower, reducing the time the animal is on the screen and, thus, the possibility of being detected.

Table 4: Maximum time on target according UAV´s speed and height

		Maximum time on target according UAV´s speed		
Height UAV	**Footprint (m^2)**	**5 m/s**	**10 m/s**	**15 m/s**
50 meters	**95.81** x 75.0 m	*19.16 sec*	*9.58 sec*	*6.38 sec*
75 meters	**143.7** x 112.5 m	*28.74 sec*	*14.37 sec*	*9,84 sec*
100 meters	**191.62** x 150.0 m	*38.32 sec*	*19.16 sec*	*12.77 sec*
125 meters	**239.52** x 187.5 m	*47390 sec*	*23.95 sec*	*15.96 sec*
150 meters	**287.43** x 225.0 m	*57.48 sec*	*28.74 sec*	*19.16 sec*

It was also observed, by showing 22 untrained individuals, five videos (where specimens of WDE are confirmed by the author, but the observers do not know whether or not there are individuals) at three different speeds (normal, 1.5x and 2.5x) in an order defined in the Methods section. After discarding the normal distribution of the data, a Kruskal-Wallis H test was applied which showed $p<0.001$ ($X^2=18.690$) that there are significant differences between the real antelopes present in the images and those observed by the volunteers, depending on the speed. That is to say, at higher speed, fewer individuals are observed concerning to the specimens present (Fig 10)

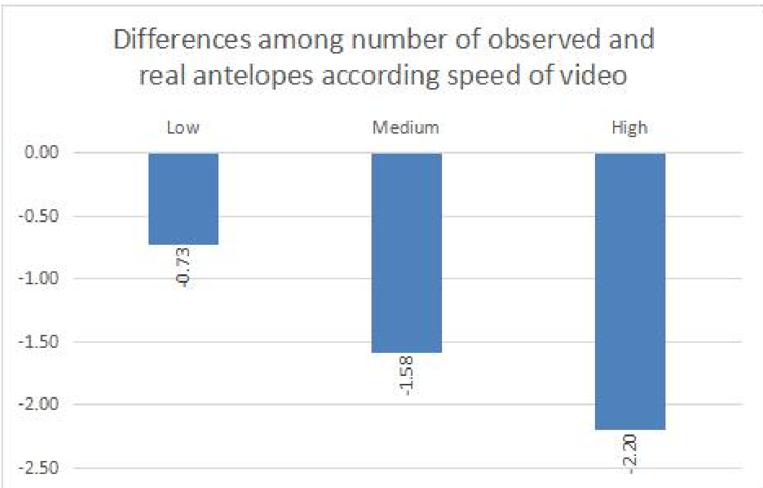

Figure 10: Differences among the number of observed and real antelopes according speed of video.

4.5 Minimum height without disturbances

During the observation of the behavioural response to the presence of the UAV it was observed that there was no reaction (Type 0) during the first meters of descent of the apparatus. At an average height of 25 meters, the animals began to show a type 1 reaction, looking at the apparatus carefully and showing signs of nervousness. At an average height of 20.5 meters, the WDE began an escape reaction (type 2) in the presence of the UAV.

4.6 Automatical Supervised Classification

After carrying out the tests according to the set-up described above, the results obtained (depending on the 3 possible WDE that could be detected. Two of the five total specimens present in the image had been selected as Positive Input) were these:

Table 5: Results of WDE detected from aerial image using Ecognition Developer 64

Number of proof	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
WDE detected	0/3	0/3	0/3	0/3	0/3	0/3	0/3	**2/3**

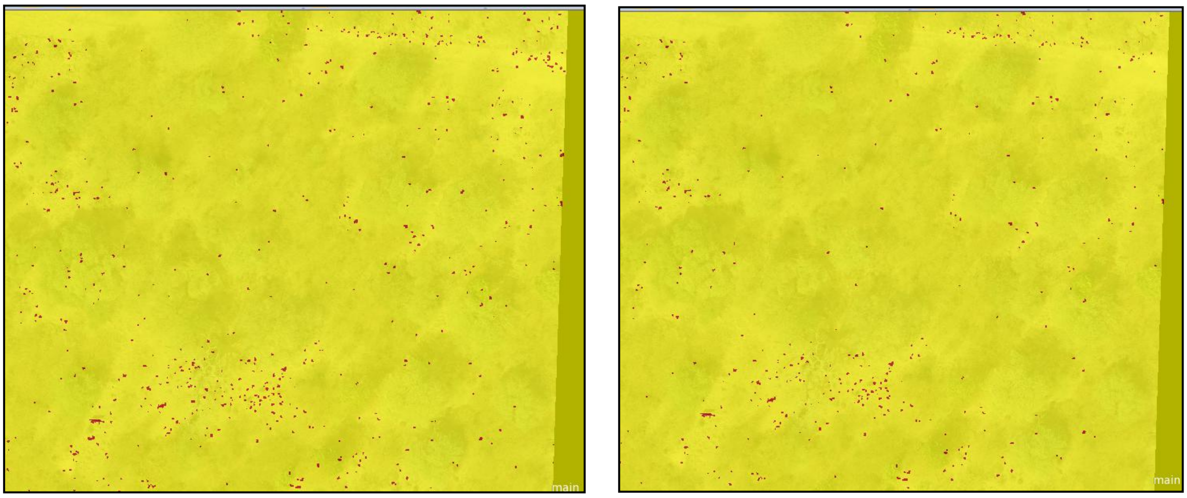

Figure 11: Output from 1 and 2, with 2% of total polygons selected as Negative output.

The outputs that were obtained from 1 and 2 showed that the treatment "Color Texture" (C+T) made it possible to refine the search for "positives" according to the inputs introduced, greatly reducing the number of "false positives" although without detecting any of the 3 WDE searched (Fig. 11) In 3 and 4, the output is quite similar, with the difference of having less positive output thanks to a wider percentage of negative input that allowed the software discern in a better way among positive and negative, but still it wasn´t possible to detect any WDE present. As is observed in Fig. 12, the WDE was not detected.

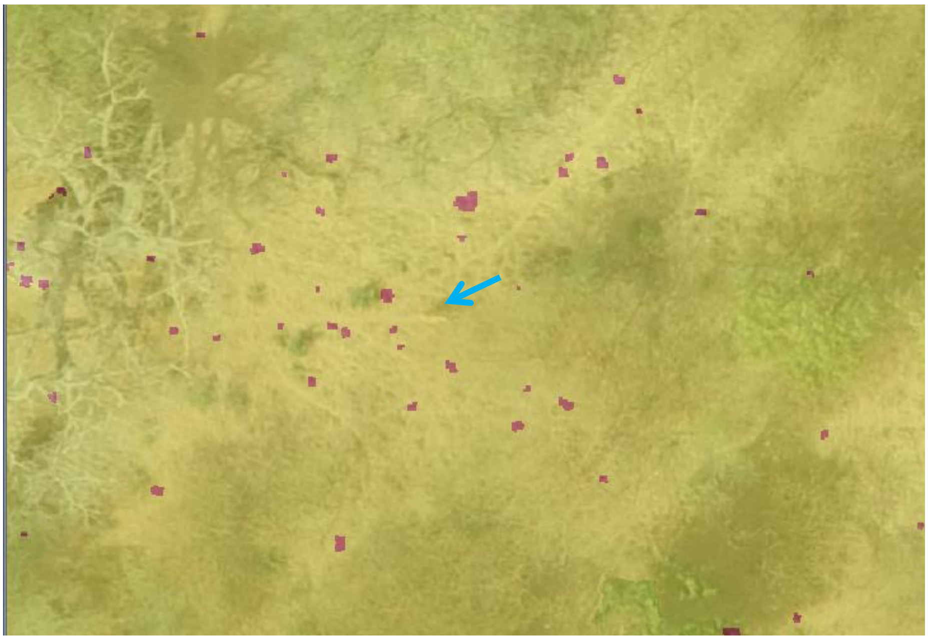

Figure 12: Output of Ecognition treatment. Yellow, negative output. Red, positive. Blue arrow showing a non-selected WDE individual

In treatment 8, the changes in the set-ups did allow 2 of the 3 individuals present in the image to be finally detected. However, on the other hand, the high number of "positives" makes it difficult to detect the specimens promptly and effectively (Fig. 12)

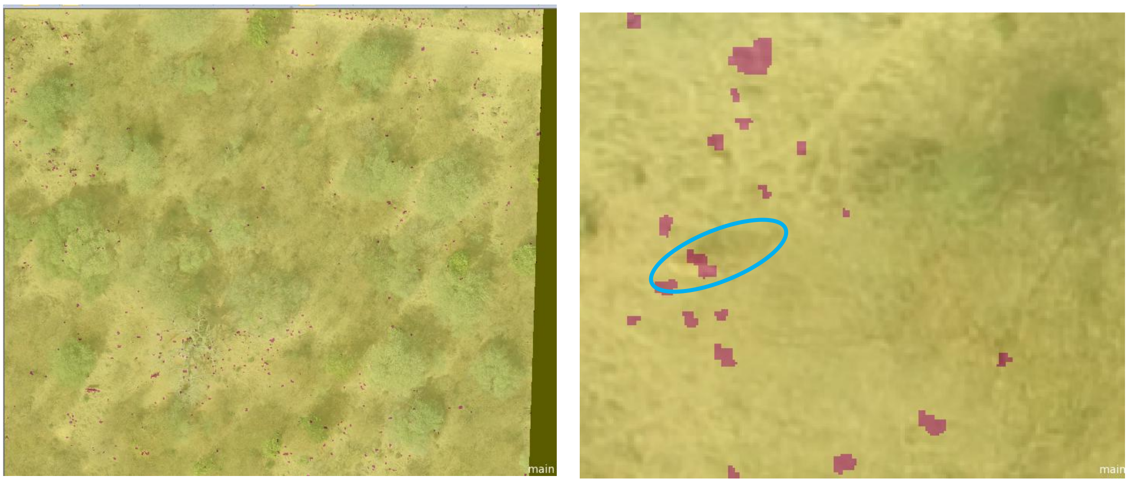

Figure 13: Output of 8 treatment (left) and one of two detected WDE (in blue oval) surrounded by several "false positives" (right)

4.7 Manual Supervised Classification

The results of the Manual Supervised Classification of antelopes observed in photographs or videos are as follows:

The Mann-Whitney U test was performed, obtaining that there were no significant differences (p=0.641 for the first variable and p=0.787 for the second) in terms of gender

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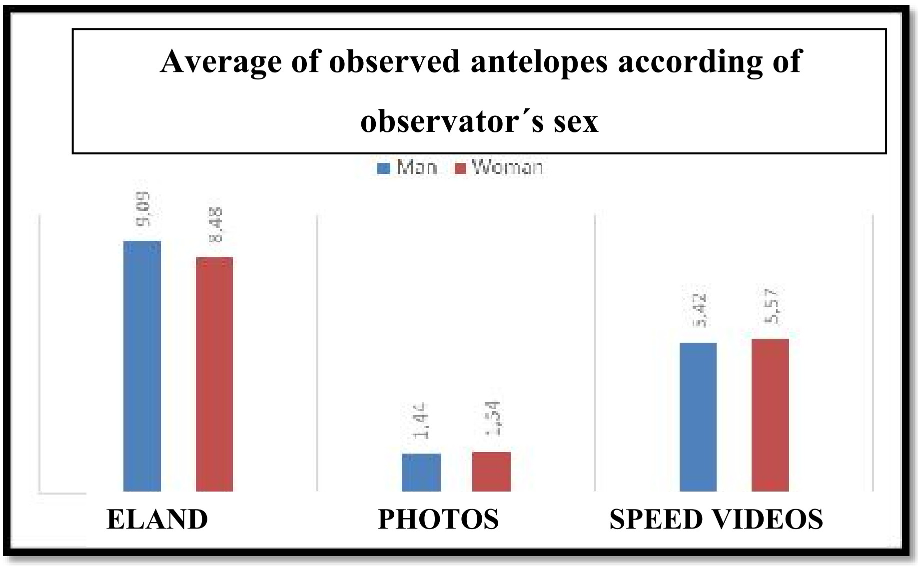

Figure 14: Average of observed antelopes according to observator´s sex.

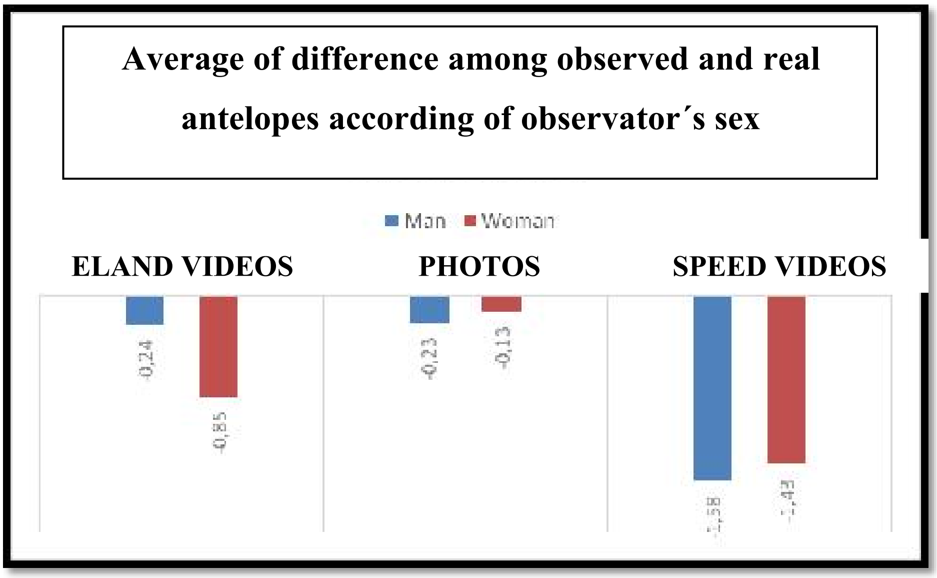

Figure 15: Average of difference among observed and real antelopes according to observator´s sex

The Kruskal-Wallis H test was used to determine whether there were differences in the variables described above, according to the age group in which the subject was enrolled. The results show a partially significant difference between groups (p=0.080) for the variable "No. of observed antelopes", and a very significant difference for the variable "Difference between no. of observed antelopes and actual" (p<0.001)

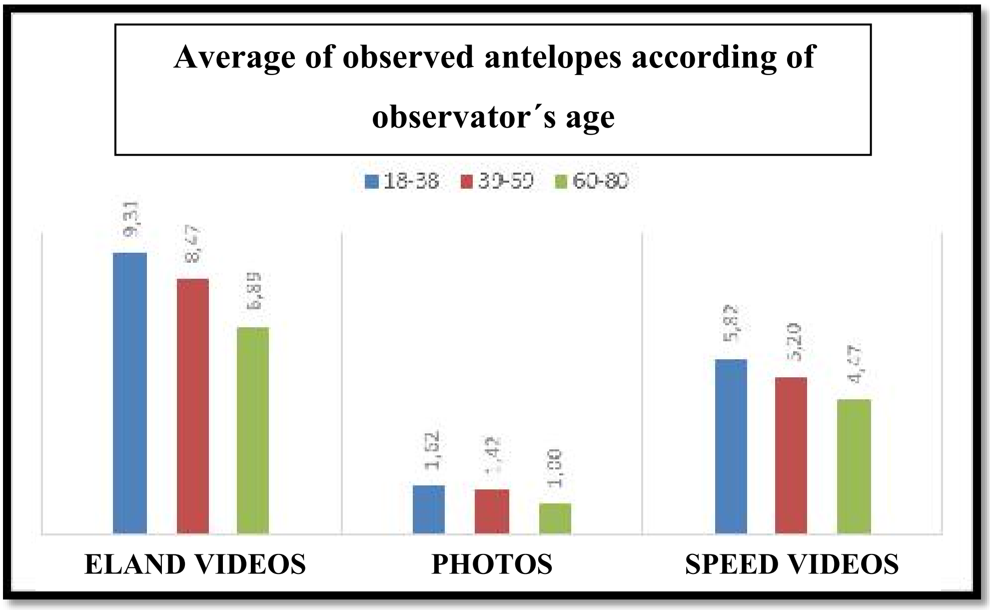

Figure 16: Average of observed antelopes according to observer´s age

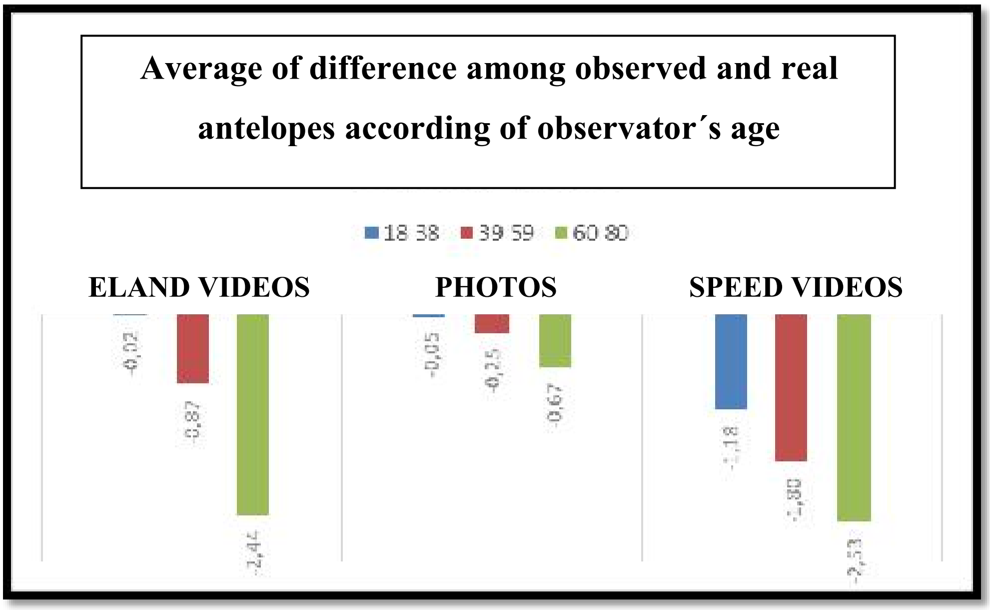

Figure 17: Average of difference among observed and real antelopes.

The same test was used to confirm or disprove the “study level hypothesis”. The calculations confirmed that there are no differences between groups in the variable "No. of observed antelopes" ($p=0.287$) but in the variable "Difference between no. of observed and real antelopes" ($p<0.001$).

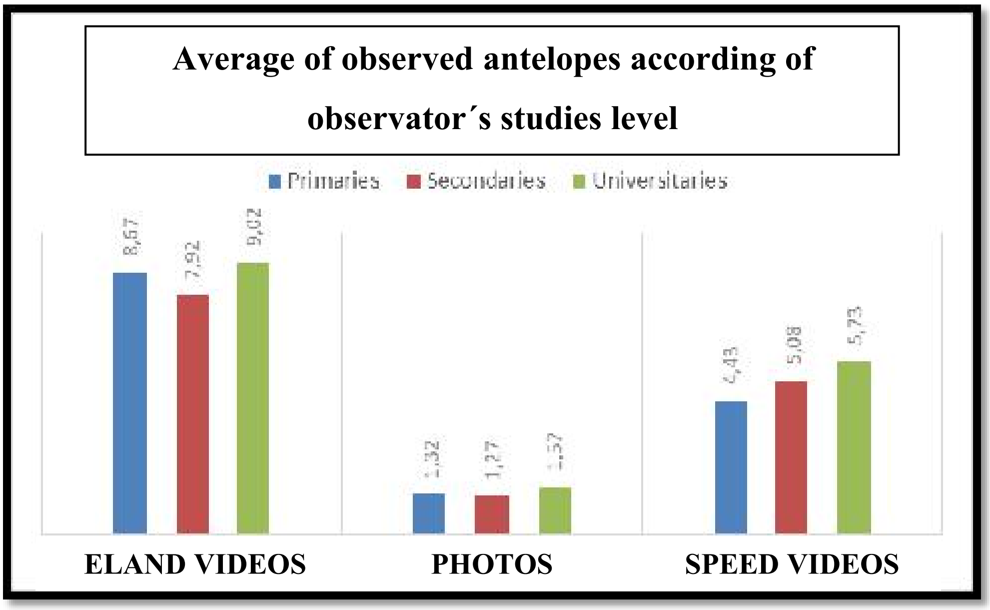

Figure 18: Average of observed antelopes according to observer´s studies level

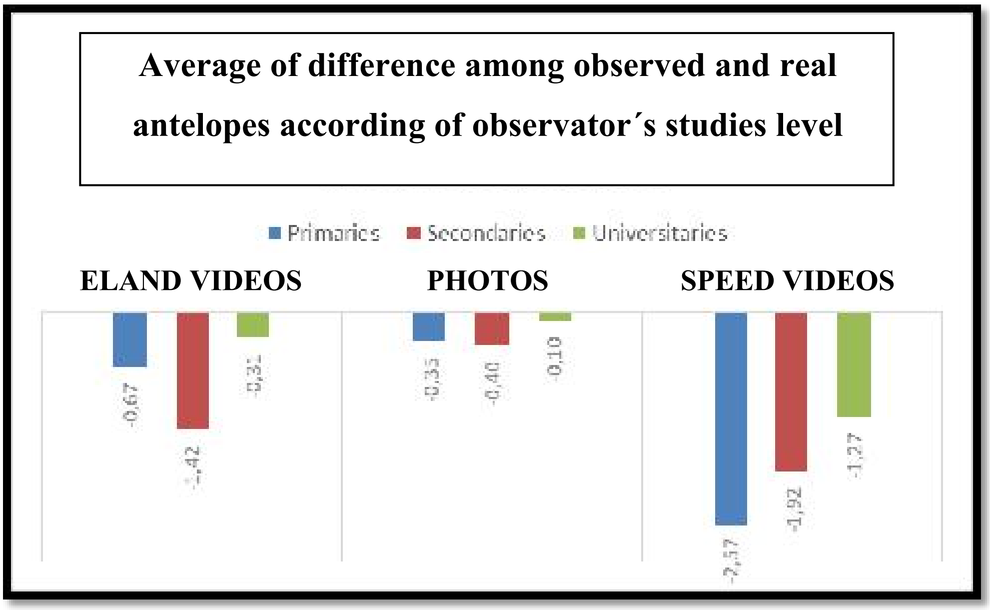

Figure 19: Average of difference among observed and real antelopes according to observer´s studies level

Finally, with regard to the Eland videos, it has been found that there are significant differences ($p<0.001$) between the ELAND videos, having the ELAND 3 video, the one in which it was possible to stop and go back on the video, a smaller difference than in ELAND 2 (same video but without the possibility to stop)

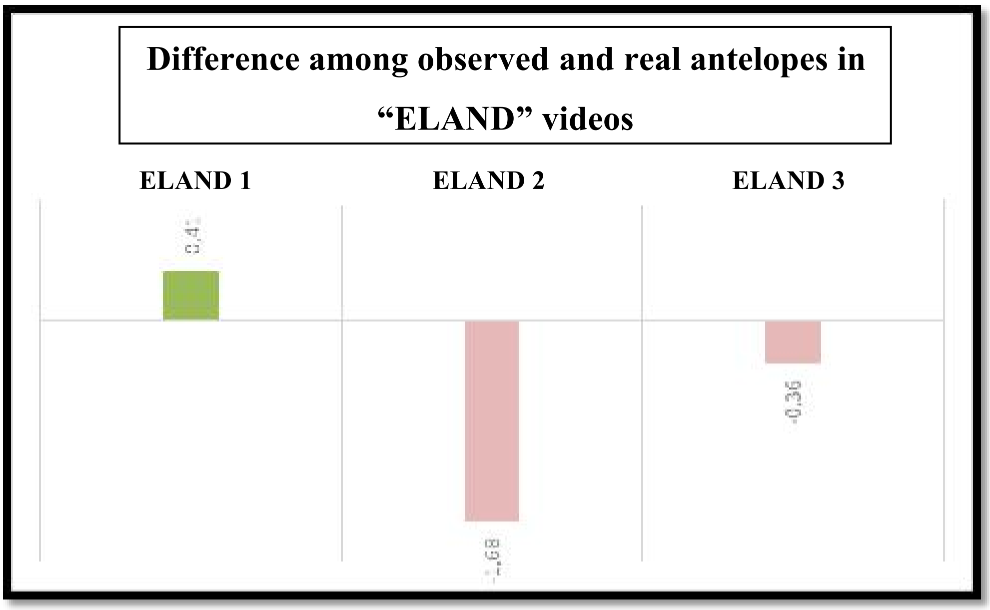

Figure 20: Difference among observed and real antelopes in ELAND videos

5. Discussion

After evaluating the results obtained, steps have been taken to determine the most appropriate parameters to use a UAV in the detection of Western Derby eland, as well as to know which lines can be followed to obtain the most accurate information of the images obtained through these unmanned vehicles.

When determining the most efficient flight height, it is necessary to combine the search for: maximum possible height (to cover as large an area as possible) and minimum loss of resolution. This point of equilibrium between both factors is found in the height at which the resolution reaches approximately 8 cm/pixel according to different studies (Chabot and Francis, 2016. Cherétien et al. 2016. Chabot and Bird, 2015. Patterson et al. 2015. Getzin et al. 2012). Knowing the resolution of the camera used, 4000 x 3000 pixels, it can be determined that the height at which the required conditions are found is 182.9 meters. This height exceeds the flight heights that were carried out during our investigation, which maximum was 150 meters. Thus, the most efficient flight height would be approximately 183 meters above the surface. However, we must also pay attention to the legislation in force in the country where the research is being carried out, Senegal. According to the Agence Nationale de l´Aviation civile et de la Meteorologie (2018), which regulates the use of UAVs in the African country, it is forbidden to fly with these devices above 300 feet of height, so 91.4 meters, approximately half the height of the one considered most efficient. It is also true that it specifies that this prohibition is maintained "*unless authorized by the competent authority*," so it would be necessary to apply for the necessary permits to develop more efficient flights that could, for example, help cover the vast expanse of places such as Niokolo Koba National Park.

The use of straight down UAV´s camera is common in many wildlife studies (Chabot and Bird, 2015. Ferguson et al, 2018). This arrangement of the camera allows simpler analyses, while changes in the angle of the sensor can be interesting to avoid effects of vegetation (Burke et al, 2018) thanks to the 3D effect achieved (which makes it possible to detect, for example, specimens hidden under trees). Furthermore, as can be seen from the results, the surface area covered by the UAV increases as the angle of the sensor increases. However, as with height, the greater the area covered, the lower the resolution of the image and the greater the difficulty in locating the specimens. It is valued to find a balance between angle and covered surface, to increase the observed surface, but without it being so big that it makes difficult the detection of specimens. Thus, this intermediate point, after observing the graph, would be approximately 34-35º, which is the previous point to the exponential beginning of the graph. These data are similar to those obtained by other researchers in dugong studies, in which they determined 37º as the most efficient, for the camera (and for the Sun), in what is called Brewster´s angle (Hodgson et al, 2013). Other studies, also in aquatic areas, used 45º to reduce the impact of water glare on the image obtained (Biserkov & Lukanov, 2017).

When determining the validity of photos against videos to detect specimens it is necessary to examine different factors. The photos have been more widely used since the beginning of work on ecology from aerial imagery (Van Andel et al, 2015). This early availability, coupled with the simplicity of a still rather than moving image, allowed the development of more research and detection systems (such as specific software) that make it easier to work with photographs. Moreover, at a technical level, it is more efficient to work with them because of their smaller size (almost 20 times smaller compared to a 1-minute video), which allows more information to be stored without the need for new external memory systems. On the other hand, the use of videos for wildlife detection is increasingly developed (Fang et al, 2016) thanks to the application of methods such as background modelling methods (Stauffer and Grimson, 1999) and State Estimation methods (Bhat et al, 2000). In addition, the possibility of directly observing small movements of the animals, such as tail movement, can help to detect them easily, giving an advantage over photographs. The bet for photographs or video will depend on our objectives and the type of treatment we want to carry out with this material.

For the flight speed of the UAV, it has been observed how, at higher speed, the Maximum time on target, decreases. The shorter the time that the animal remains visible, the lower the probability of capturing it. For this reason, there are publications that do not recommend the use of the maximum speed (Ivošević et al, 2015) to facilitate the control of the device, to allow an appropriate detection and to favour the taking of images with the correct resolution, without alterations or movements. Therefore, as has been done in our case, many researchers value a speed between 3 and 5m/s as the most appropriate (González et al, 2016. Hodgson et al, 2016. Tremblay et al, 2017) for wildlife studies with this type of UAV. On the other hand, the speed could be higher (and, therefore, the covered surface) if a fixed wing drone were used, which can develop this type of image capture at higher speeds such as 13 m/s (Hogdson et al, 2016) or even 25 m/s (Muchiri and Kimathi, 2016), but these devices are sensibly more expensive and more difficult to handle. In addition to this, the data obtained in the test with voluntary observers confirm this. It has been observed that by increasing the speed (starting from the speed used in this study, about 4 m/s) the number of specimens detected is lower. This reinforces the idea of choosing this speed as the most suitable for the detection of specimens of this subspecies of antelope since it increases the possibilities of detecting them.

After detecting at what flight height the specimens show reactions of attention or escape, it is observed that it is much lower than the "ideal flight height" previously determined for this subspecies, so there is no conflict between efficiency and ethics. It is also true that, being animals bred in semi-captivity, they may be less reactive to external stimuli, being accustomed to the presence of tourists' cars or guards' motorcycles. It would be interesting to study, in wild conditions, if they show reaction at higher altitudes. Even so, predictably, there is a sufficient margin between the most efficient flight height and the one at which the animals, in the wild, could show adverse reactions. These results are connected with those obtained in some articles (Mulero-Pázmány et al. 2017) where it is shown that terrestrial mammals are the least sensitive to the nuisance caused by UAV (only surpassed by animals living under water, due to the acoustic isolation involved in the change from air to aquatic environment). According to the same authors, electric UAVs (and smaller ones) produce less discomfort than UAVs with fuel engines, which can be taken into account for future studies with this antelope. Although, thinking about the possible need to cover immense areas in Niokolo Koba National Park, and the resistance to the nuisance that these animals seem to be, the use of UAVs with fuel engine, which can cover much larger areas, could be considered. It has also been observed that the animals take longer to flee when they are pregnant, due to the difficulties of movement on the part of the females, or when they are raising their little ones, due to their refusal to abandon them, which may be of interest when scheduling flights at an appropriate time of year, assuring us that their reactivity will be less and, therefore, the chances of detecting them, greater. But we must be cautious when it comes to causing any impact on animals in the process of reproduction, because it is their most sensitive moment and, when talking about one of the most threatened antelopes in the world, any alteration could have unfortunate consequences. Unfortunately for our "target species", animals living in large groups flee before those living in small or solitary groups, but it is necessary to evaluate this with the Western Derby eland to determine if it is a handicap for study and/or detection. In the same publication it is pointed out that lawn-mower flights, more regular and at higher altitudes, cause less impact than those that go directly to a pre-established target. But, in any case, according to other studies (Efroymson & Suter 2001) the degree of discomfort of UAVs with respect to manned aircraft (below 500 m Vs. 105 m- 15 km, respectively) is much lower, which makes it a less invasive method. However, these methods should not be used indiscriminately. To be conservative in the working protocol, to fly as high as possible, preferably with small electric UAVs, taking care of the moment of the biological cycle in which the antelopes are, is necessary to avoid discomfort. Even more so when it is a technology not used before with these magnificent animals, and there is no deep knowledge of the possible impact of their use.

The use of Manual Supervised Classification has demonstrated its usefulness and efficiency in different studies, demonstrating that the human eye can be a reliable element to detect ungulates, such as roe deer, among vegetation (Israel 2011). However, it is also known that the use of such systems employing humans is 3 to 8 times slower than the use of Automated Classification, which makes it less efficient (Lyons et al 2019). This means that its use becomes very costly, prohibitively time-consuming by observers being only applicable to small areas (Díaz-Delgado et al. 2017). Even so, the presence of human controllers is always necessary (Ofli et al. 2016) and researches such as that of Kellenberger et al. (2018) seek to reduce this need to its maximum expression in order to make the processes more effective, making humans the last filter to discern specimens after automatic analysis. Even so, we cannot and should not underestimate the importance of human observers. Today it is known that manual observation is the one that best discriminates between animals and non-animals, it is the one that has fewer overcounting errors and has a relatively low probability of undercounting an animal which is a very interesting value according to Terletzky and Ramsey (2016). Also in certain adverse field conditions, Manual Classification may be the only viable way to do a quick first count, in the absence of other methods, so it should be taken into account (even more so in cases like this with species with very small populations). In this study, the number of observers, 22, is relatively low compared to other studies in which more than 230 participated (Rey et al. 2017). However, we can observe interesting information that may be applicable to future field work with drones and Western Derby eland. According to our analysis of the real antelopes and those observed by the volunteers in the ELAND 1, 2 and 3 videos, among which there are significant differences, we can see how in video 3, where it is possible to stop and go back as many times as necessary, the difference between real and observed antelopes is much smaller than in video 2, which is the same video but without the possibility of stopping or going back in the video. This gives us information about the need to allow observers to monitor the flow of the video to make estimates of individuals as accurate as possible. In the future we could assess whether that difference is reduced if we work with professional or previously trained observers, as it might be more efficient in terms of time to capture more copies without having to stop the video. As for the impact of factors such as the incidence of sex, level of education or age, the results are very interesting. Sex does not seem to have any impact on the results obtained by observers. Men and women show equal "visual acuity" detecting individuals, which shows the present gender equality and opening a window to possible future work in which local women from areas with WDE presence could take part in the supervision of aerial images for the search of this antelope. Age does seem to influence the results, with younger observers (18-38 years old) showing a greater capacity to detect specimens, which may be related to their better visual conditions from a physiological point of view added to their greater mental acuity. University studies seem to be an advantage in detecting WDE, although it is likely to be an "indirect" advantage, not developed directly by the knowledge acquired during the studies but by the habit of locating phrases in scientific articles or information in images or diagrams, which could stimulate that acuity. Even so, it would be interesting to evaluate professional profiles closely linked to the observation of the natural environment, such as rangers or shepherds, whose habit of daily observation can turn them into excellent scouts of these animals in aerial images, being able to suppose a possible future line of work with the local population in projects of manual detection of WDE in images obtained by UAV.

In recent years, Automatical Supervised Classification systems have become excellent allies for the census or control of animal groups (Kellenberger et al. 2017; van Gemert et al. 2014; Shahbazi et al. 2014; Rey et al. 2017). In many cases, these animals are difficult to study without these novel methods. In our study we have detected, in all the set-ups tested, both type 1 and type 2 errors. Type II errors occur when a pixel corresponding to a positive class (in our case, Eland) appears as negative. On the other hand, Type I errors occur when a negative pixel is classified by error as positive (Richards 1993). The use of machine-learning-based software, in particular Ecognition, has proven its validity in studies on large African mammals according to research by Yang et al. (2014). In the mentioned study they used very-high resolution GeoEye-1 satellite imagery obtaining an accuracy similar to the one obtained with aerial photos what gives a sample of the potential of this method (and that open a door in front of possible future investigations in this line with WDE) and, in addition, showing that the detection of animals through this method is not affected by the density of the same ones nor by a background with colors that could make think about affecting the objective of the project. It is true, on the other hand, that this article points out that it is necessary to bear in mind that the software is incapable of differentiating between different species of antelopes, and this can be a problem when evaluating the population of a specific antelope, the Western Derby eland in our case. In addition, the processing time is a small handicap that we have also experienced in this process, in addition to the time of the selection of the "negative" polygons that can sometimes extend for hours. The different set-ups proposed in our research provide light and interesting ideas for future research, even if they have not yet allowed us to determine a complete working protocol for the application of Ecognition in the search of WDE on aerial photographs. One factor that could have had a decisive influence was the low resolution of the starting image, which makes it difficult to make very precise analyses. On the other hand, however, it has been observed that the software discriminates better between positives and negatives when the percentage of selected negative inputs (soil, rock, trees...) increases, allowing it to more easily discern between the different surfaces. Also, that when using the treatment Colour + Texture, the degree of detail is greater, as it happens when increasing the color and scale before the Classification, favoring this way a more precise sieve. Thus, in treatment 8 it was found that 2 of the 3 specimens searched were found although accompanied by a very high number of false positives that make it difficult to find antelopes, so it is not very helpful. In the future, trying to work with this set-up line and trying to do it on a higher resolution image may help us to shed light on the most efficient way to locate WDE specimens in images taken with UAV and, thus, be able to use this fantastic technology that has already demonstrated its results in numerous animal groups in many places on planet Earth.

5. Conclusions

The pioneering nature of this study has provided valuable information to continue research into possible applications of UAS for the detection and census of Western Derby eland. But, above all, it has opened new questions that invite us to continue along this path that has provided excellent results and valuable information on other species. In this research we have been able to determine the most efficient flight height for the detection of this antelope (182.9 meters), the most suitable camera angle (34-35º), the speed that best suits our interests (3-5 m/s) or the height at which individuals begin to be disturbed by the presence of the UAV (25 meters). In addition, an interest profile has been developed for observers of specimens of this animal in aerial images: Youth (18-38 years) and educational level (university) are significantly related to greater ability to detect individuals, while the sex of observers does not seem to be a factor of interest. On the other hand, testing with the Ecognition software has given some indication of its usefulness but further research is needed to achieve its full potential, using images at different resolution, infrared images, diverse set-up or seasons of the year due to changes in the environment that could affect to software´s ability to detect antelopes. The knowledge of basic flight parameters useful in the detection of this antelope makes it possible to begin prospecting in Niokolo Koba National Park to know the real scope of this technique in wild conditions. On the other hand, the Manual Classification data can help to integrate the local population in the revision of aerial images, including them in the project, giving them a relevant role and involving them in the conservation of their national jewel. It is recommended to continue research with specialized software such as Ecognition for its tuning and the determination of specific parameters that allow the automatic and efficient detection of these antelopes in their natural environment, reducing costs and time and giving a real vision of its population, a key point for shaping the next steps in management and conservation.

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