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Population structure of critically endangered Western Derby eland (*Tragelaphus derbianus derbianus*) in Niokolo Koba National Park, Senegal

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "*Population structure of Western Derby eland in Niokolo Koba National Park, Senegal*" 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 21/04/2021

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Bc. Kristýna Stehlíková

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Abstract

Western Derby eland is a critically endangered subspecies whose last refuge appears to be the Niokolo Koba National Park in Senegal. Despite its critical status and very limited area of distribution, there have not been many studies done considering their population and demographic parameters. This study brings the assessment of Western Derby eland's current population status by analysing the structure and size of the population and its demographic parameters from images collected by camera traps during the dry season in 2021.

The population size was analysed using the secr package in R Studio, resulting in an estimated density of 0.1 females/km^2 (± 0.05) and 0.04 males/km^2 (± 0.01). From that, the abundance was estimated at 126 females (CI95 from 76 to 466) and 50 males (CI 95 from 20 and 151). Together with the estimated number of calves this then resulted in the total population size of approximately 255 individuals. More detailed analysis of the population showed adult males and two years old individuals as the most vulnerable, possibly affected by combination of several factors between which potentially belongs poaching, higher predation pressure or livestock encroachment and other agricultural activities in the park. The population also seemed to be centralised only into one, relatively small area in the park, which may indicate either limited possibilities for dispersion or lack of data about its distribution.

It is not clear from the results weather there is an increasing population trend or not and what specific factors have the biggest influence on the population size. In the future, it will be necessary to continue with a monitoring specifically targeted on the elands, to address those factors and bring solutions to the park managers, which would help them to better understand this subspecies and streamline its protection.

Key words: Western Derby eland, Niokolo Koba National Park, population size, population structure, demographic parameters, spatially explicit capture-recapture model

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List of the abbreviations used in the thesis

IUCN - International Union for the Conservation of Nature

WDE - Western Derby eland

DE - Derby eland

NKNP - Niokolo Koba National Park

NP - National Park

SPEFS - Society for the Protection of Environment and Fauna of Senegal

CZU - Czech University of Life Sciences

DNP - Directorate of National Parks in Senegal

SD - Secure Digital

SECR - Spatially Explicit Capture Recapture

1. Introduction and Literature Review

1.1. Introduction

Knowledge of species population size, population structure, and demography is an essential part of effective conservation management. Especially for endemic species with a small population size, this information can be crucial. It affects management decisions and helps to positively affect the key vital rates of the population. Long-term, continuous monitoring allows to follow population trends and helps to assess and target threats which are specific for the population in given area. This can potentially help improve species status and population growth (Mills 2012; Brandlová et al. 2013).

Although listed as critically endangered subspecies with only around 120 – 150 adult individuals remaining in the wild (IUCN 2017), there have not been many studies focussing on the population size and structure of the Western Derby eland (WDE) in Niokolo Koba National Park (NKNP) in Senegal. The main reason seems to be the lack of a sufficient amount of data from the area. Several aerial and ground surveys mapping local flora and fauna were conducted in NKNP since 2000 (Hájek & Verner 2000; Mauvais 2002; Mauvais & Ndiaye 2004; Renaud et al. 2006; Hejcmanová et al. 2018), yet all of them report only low number of encounters with WDE or none at all. Renaud et al. (2006) estimated the population size to total 170 individuals, observing only one herd of 69 individuals, during their aerial survey. This only supported the critical status of the wild population at that time and showed serious decline during the past 20 years, as Sournia and Dupuy (1990) estimated the population size at 1,000 individuals.

In 2021, Gueye et al. published first more detailed study with analysis of population structure, size, and dynamics of WDE by using camera trap data from ecological monitoring project conducted during 2017 and 2018. They estimated the population size to be 195 WDE (CI95 from 54 to 708 individuals). This research showed the potential growth dynamics of the population in NKNP, but also pointed out the localisation of WDE in the core area of the park (<5 %) which results in an underutilised capacity for population density (Gueye et al. 2021).

This work relates to the one of Gueye et al. (2021) and continues with analysis of population size, population structure and demographic parameters of the wild population of WDE in NKNP. For that we were using camera trap data collected during 2021 as a part of Ecological monitoring programme run by Panthera, designed specifically for Niokolo Koba (Rabeil 2017). The results will then serve as a report for Panthera, Directorate of National Parks of Senegal and managers of the park to help them implement better management and protection measures for conservation of the WDE population to further improve its status.

1.2. Western Derby eland

Derby eland (*Tragelaphus derbianus*) is considered to be the largest of all antelopes, with the Eastern Derby eland (*Tragelaphus d. gigas*) being slightly bigger than the western subspecies. It belongs to family Bovidae, the tribe Tragelaphini, which is also referred to as spiral-horned antelopes (Kingdon & Hoffmann 2013). The two subspecies of Derby eland are geographically separated, with eastern one occupying areas of Cameroon, Central African Republic, Chad, and South Sudan and WDE being present only in limited area of Niokolo Koba National Park in Senegal. Although Eastern Derby eland is listed as vulnerable with population size estimated between 8,400 and 9,800 mature individuals, western subspecies is critically endangered, and the estimated number of mature individuals is not exceeding 200 (IUCN 2017). No exact study, considering social organization, home range or behaviour of WDE in wild, was ever published therefore here we refer to the knowledge acquired for eastern subspecies and the population of semi captive WDE from Bandia and Fathala reserves in Senegal.

1.2.1. Morphology

The most prominent and striking feature of WDE are their horns. They are very long and massive, present in both sexes, with males having more prominent ridges, especially at the horn base. In females the horns are thinner, and the twists are not so distinct (Kingdon & Hoffmann 2013). The size and shape of horns can be a good indicator for assessing age and sex of an individual, especially in the first three years of age (Antonínová 2008).

Their coat is short with a bright rufous ground colour, dominated by 10 – 18 white vertical stripes that differ on the left and right flanks and are unique for each individual. There is a stripe of grey to blackish hair on the neck, bordered by a paler or even white collar in males and females respectively. The neck skin flap can be present, especially in adult males, it is very prominent, particularly during the breeding season. There are black and white markings on the face (except for old adult males) and dark marks behind the knees on the forelegs. Pasterns and fetlocks are black, with a white spot on the front of all four pasterns. Additionally, females are generally smaller and more lightly built (Bro-Jørgensen 1997; Kingdon & Hoffmann 2013).

All these variations in body size and colouring, together with the unique striping allow for good individual identification (Antonínová 2008; Kingdon & Hoffmann 2013).

Figure 1. Adult male WDE in NKNP (Panthera/DPN, 2021).

1.2.2. Ecology and social organisation

WDE is a generalist, browsing on a large variety of plant species, mostly tree and shrub leaves, shoots, and some types of fruits. To a lesser extent, it forages also on forbs, but very rarely on grasses (Bro-Jørgensen 1997; Graziani and d'Alesio 2004; Hejcmanová et al. 2010; Brandlová et al. 2013). Kingdon & Hoffmann (2013) state that they browse mostly during the night, but they were observed to forage without preference of daytime, even during the hot midday, especially when forage is scarce (Brandlová & Hejcmanová, personal observations). If possible, they visit water sources on a daily basis, but can move without drinking for longer time when disturbed (Bro-Jørgensen 1997; Kingdon & Hoffmann 2013).

WDE have a fission-fusion social system, meaning that the composition and size of herd changes during the year. Generally, the herd consists of adult females, their calves, and sub-adults of both sexes, sometimes accompanied also with a breeding bull. Young males, leaving the herd, can aggregate into bachelor herds. Old big bulls often remain solitary. The number of individuals in group can vary significantly during the wet and dry season. From the beginning of the dry season, WDE tend to aggregate into larger herds, which can reach up to 100 individuals as the dry season progresses. Before the start and during the wet season, big herds split into groups of even less than 10 individuals, usually females, their offspring, and one bull (Bro-Jørgensen 1997; Reanud et al. 2006; Brandlová et al. 2013; Kingdon & Hoffmann 2013; Brandlová et al. 2018; personal observations of rangers in NKNP).

1.2.3. Distribution and conservation status

In the past WDE were probably distributed across Senegal, Mali, Sierra Leone, Gambia, Guinea-Bissau, Togo, and Ghana. However, they may have never been highly widespread in Western Africa due to the limited area of suitable habitat, which is connected to precipitation level (Spinage 1986). In 1990 Sournia and Dupuy estimated the population to about 1,000 individuals, with its majority (700-800 individuals) residing in NKNP and the rest occupying areas around Falémé River.

Nowadays the wild population seems to be restricted only to a small core area of the NKNP and its size was estimated not to reach over 200 mature individuals (Brandlová et al. 2013; Gueye et al. 2021). The rapid and severe decline during past few decades is mainly result of uncontrolled over-hunting and habitat destruction caused by human and livestock expansion into the areas critical for WDE (IUNC 2017). Furthermore, the former population in Gambia suffered devastating effect of rinderpest, to which they seem to be more susceptible than any other antelope (Camara 1990).

The survival of WDE firstly depends on continued, intensive and long-term monitoring of the wild population and the natural ecological processes and relationships in NKNP. As well as on monitoring and minimalization of the effects and impacts of human encroachment and pressure from grazing livestock on the area, since NKNP represents a key area for the conservation of WDE and many other species. And secondly, it is dependent on the continuous management and monitoring of semi-captive population of WDE which was established in 2000 in Bandia reserve in Senegal by cooperating partners SPEFS, CZU and DPN as a breeding programme aiming for the subspecies conservation. The semi-captive population was based on six wild founders (1 male and 5 females) captured in the NKNP, and since 2002 it has been successfully reproducing. Currently, this population is residing in two reserves: Bandia and Fathala. Its size is reaching over 100 individuals and is registering an increasing population trend. This semi-captive population represents crucial element for the wild population as a source of genetic diversity and stock of animal, but also as an important tool for fundraising and public awareness activities which help with preservation of the unique ecosystem of NKNP (Antonínová 2008; Brandlová et la. 2013; IUCN 2017).

1.2.4. Threats

Since the population in NKNP represents the largest and likely even the only wild population of WDE in the world, any threat affecting the National Park is also affecting elands. The area was declared as Senegalese national park in 1954, later on it was also inscribed as a World Heritage Site, as a UNESCO-MAB Biosphere Reserve and added to the UNESCO List of Endangered World Heritage sites (UNESCO 2022). In addition, there has been an extensive ecological monitoring programme run by Panthera since 2017 and regular ranger patrols secured by DPN to control the area. Despite all those actions the population of WDE still seems to be balancing on the edge of its threshold of 250 mature individuals or even slightly below it (IUNC 2017; Gueye et al. 2021).

First and probably also the most serious direct threat, which led to the massive reduction of all large mammals in the area in the last thirty years, is poaching (Howard et al. 2007; UNESCO 2011). In the past, poaching activities were confirmed many times (Mauvais and Ndiaye 2004; Nežerková et al. 2004; Renaud et al. 2006). Thanks to the regular patrols and protection measures implemented during last few years, the level of poaching in the area has decreased. Yet, it still remains a major threat for many species, especially those with small population size that were already significantly affected by illegal activities during the last decades.

The second serious problem present in Niokolo Koba is livestock grazing (Howard et al. 2007). Herds of thousands of sheep, goats and cattle were estimated to graze inside the area (Renaud et al. 2006). As a consequence, there is a direct risk of disease transmission between domestic animals and wildlife (Pedersen et al. 2007). Besides rinderpest, which has been declared as eradicated from the region (OIE 2011) and is one of the most dangerous diseases for elands as they are highly susceptible to it, there are other infectious diseases of livestock which can severely jeopardize the wild populations (Pence & Ueckerman 2002). Additionally, there is also an indirect effect on the wild populations in NKNP caused by the presence of high numbers of livestock in the park. Source competition between the wild and domestic animals leads to overgrazing and soil erosion. This then may lead to the complete change of vegetation composition and unsuitability of the habitat for resident species (Ba Diao 2006).

Habitat loss and degradation is yet another problem vexing the park and it is caused by multiple factors. Probably the most severe one of them are uncontrolled bushfires. Set by pastoralists in the early dry season, fires promote growth of new herbaceous vegetation and leaves on trees and bushes. They can also be used as a protective measure against more severe and uncontrolled fires around settlements. But in the context of national park, uncontrolled fires set by pastoralists to promote growth of new vegetation for livestock grazing or by poachers to drive game out of bushes represent serious problems causing degradation or complete loss of suitable habitat (Mbow et al. 2000). Among other causes belong also crop cultivation, cutting of Borassus palm (*Borassus sp.*) or illegal logging (Renaud et al. 2006). Another cause of the loss of suitable forage and water sources in the area is the encroachment of invasive plant species into marshes and wet grasslands. Additionally, the area is suffering by encroachment of savanna and bush into open grasslands, likely caused by steep decline of elephants (*Loxodonta cyclotis*) during last few decades (Brandlová et al. 2013).

Finally, the expansion of farmland and other development is increasing the fragmentation and isolation of the park. Major road is cutting NKNP into two parts which results in easier access to the area for poachers, limits the movement of animals between the separated parts of the park and threatens them with direct mortality by car collisions. Furthermore, the population of WDE is constantly, indirectly threatened by economic and political decisions on the NKNP, which may significantly affect the natural habitat of the eland (Brandlová et al. 2013).

1.2.5. Importance

Being one on the biggest antelopes in the world, with its majestic appearance WDE can be considered as a flagship species for the West African savannah. Since the local human population relies on livestock or other large species of wildlife as its main resource, the consumptive value of WDE is insignificant. On the other hand, they have huge potential non-consumptive value (Brandlová et al. 2013).

Critical conservation status and very limited distribution range, the possibility of observing them in their natural habitat only in Senegal, the huge horn and body size, and the unique coat pattern. All this gives WDE the potential to become a key species for ecotourism and consequently for economic development in the region. Scientific research is another field where WDE has a very important potential. Regarding their shyness and small population size, there is very limited knowledge and basically no scientific research on the behaviour, dynamics, or ecological role of WDE in its natural habitat. Elimination of any such large herbivore, together with decline of other large herbivore species, such as elephants, buffaloes (*Syncerus caffer*) or roan antelopes (*Hippotragus equinus*), can lead to unpredictable changes of habitat. For example: bush encroachment, change of vegetation composition, or even a total loss of the habitat. The importance of WDE for the ecosystem functioning is therefore undeniable.

Apart from those already mentioned, WDE has also some potential future value. If strict and enforced protection leads to a significant increase in the current population size, WDE could be considered for trophy hunting tourism in the future. Assuming that it would be done under strict control and supported by scientific research. Trophy hunting could then potentially support another economic development of the region and help with further support of conservation activities for NKNP (Brandlová et al. 2013).

1.3. Use of camera traps as a conservation tool

To some extent, camera traps have been used in wildlife photography for more than 100 years now. Thanks to the rapid development of technologies in this field during the last two decades they came a long journey. From being used just as an experimental technology, to popular commercialised tool used not just by researchers, but also by professional photographers, hobbyists, or hunters (Wearn & Glover-Kapfer 2017). Nowadays, camera traps have become an indispensable tool in ecological and conservation studies. They are very often used as a main tool for collection of wide variation of information about wildlife, such as occupancy, abundance, conservation assessment or population dynamics, interactions with human population and more (Rowcliffe & Carbone 2008; Wearn & Glover-Kapfer 2017).

1.3.1. Pros and cons of camera traps

In 2019, Wearn & Glover-Kapfer presented a global assessment of camera trap effectiveness. They brought forward the virtue of use of camera traps in wildlife conservation, especially for detection of wide range of species and during broad-spectrum biodiversity surveys. Camera traps were confirmed to have significantly better performance than live traps and comparable performance as other widely used survey methods like hair traps, scat samples, or detector dogs. Furthermore, it can be suspected that the effectiveness of camera traps will only advance with the further development of technologies in the future (Wearn & Glover-Kapfer 2019).

One of the biggest advantages of camera traps are undoubtedly their technical properties. First, the ability to collect large amounts of data for a very long period of time and without the need for human assistance in the field. Hundreds or even thousands of detections are made before the camera needs servicing, in contrast with for example live traps which can usually capture just one or at most few individuals at once and require checks and resetting on a daily basis. Second, camera traps are classified as a 'non-invasive' method, which means that they do not physically capture the animal or cause it any harm by sampling. There still can be some impacts of camera traps as they may alter animal behaviour (curiosity about camera, avoidance etc.) but the impacts are much smaller when compared to other sampling methods, especially live traps or tissue and blood collection. Since camera traps are deployed 24/7 in the field, they are also very effective method for detection of nocturnal or cryptic species which are especially difficult to capture by other methods. This, together with all the properties mentioned above, allows for recording even very rare events such as reproductive behaviour, activity patterns, use of the habitat or presence of very rare species (Wearn & Glover-Kapfer 2017).

Additionally, there are several methodological benefits that make camera traps ideal conservation tools. Camera traps use an electronic sensor for detection, which makes them more easily repeatable and replicable sampling methods than, for example, human detectors. Thanks to this, one trapping model can be used in several different studies and in different parts of the world. This is especially important for global biodiversity research. Even though the methodology of research very often targets on one specific species, camera traps capture any animal crossing the camera, which is big or close enough to trigger the sensor. This makes camera traps a broad-spectrum sampling method extending their potential from one specific research to a wider number of studies, if the collected data about non-target species are shared with other researchers. One example for all can be the Ecological Monitoring Programme run by Panthera and DPN in Niokolo Koba National Park (Rabeil 2017), where they mainly target on capturing carnivores for their research and data on other species are shared with other partner institutions (such as data on antelopes shared with Derbianus Conservation) to run the analyses. Images or eventually videos from camera traps can also be powerful tools for spreading public awareness about the species and helping raise funds for its further protection. They can help to attract tourists to visit the protected area and thus support the local economy. And lastly, camera trapping can also help with engagement and education of local communities that may be an essential element for wildlife conservation in the area (Wearn & Glover-Kapfer 2017).

As everything else, even camera traps have their disadvantages. Probably the most prominent one is the initial cost of the equipment, which is significantly higher than for other research methods. Depending on the objectives and robustness of the research, the number of cameras needed can vary from units to higher tens. That is especially true if there is a need to deploy two cameras, facing each other at one camera trap station to capture animal from both sides for better identification. That is often the case for big felids, giraffes (*Giraffa sp.*) or some antelope species. When finally deployed in the field, camera traps frequently became a target of curious animals, which can cause fatal damage to them, or they catch the eye of a human and are without difficulty stolen or compromised. This causes significant losses in not only money and equipment, but also valuable data that has already been collected. The same losses can be caused as well by extreme environmental conditions, such as high humidity and precipitation, or by fires. On the other hand, triggering the sensor by vegetation can cause a rapid overload of the SD card by useless data and the batteries to drain faster. Another issue connected with the batteries is their content. Containing a combination of alkali metals and other elements makes their disposal complicated and expensive, not mentioning possible leakage of those elements into the natural environment which can potentially cause serious problems with pollution. Finally, there are still many animal species which are quite challenging to capture by camera traps. Small-bodied, ectothermic, and aquatic species are particularly problematic (Wearn & Glover-Kapfer 2017).

Despite all these problems, the advantages of using camera traps as a survey method still prevail. And there is huge potential for their use in the future when current technology advances even further.

1.3.2. Population size estimation with use of camera trap images

Spatially Explicit Capture Recapture analysis (SECR) is used for estimation of the population density of free-ranging animals, where animals are considered to be independently distributed and to occupy home ranges (Efford 2004). The two main assumptions for this method are that the location of detectors needs to be known and animas have to be identified on individual level at each detector on each occasion (Borchers 2010).

This approach consists in fitting a model which includes population parameters (animal ID and eventually sex or age) and parameters for the detection process (date of capture, occasion at which it was captured, CTS ID, and coordinates). The basic population parameter estimated is then density D. Detection of an animal is represented by a function saying that the probability of detecting the animal decreases as its home range centre /distance from detector increases.

Different shapes of detection functions can be fitted in the model depending on the type of data. The most commonly used ones for maximum likelihood model fitting of camera trap data are half-normal (HN), negative exponential (EX) and hazard rate (HR) functions. The main difference is in their probability to assign to very distant detections, from highly improbable (HN) to potentially very probable (HR) (Efford 2022). All three functions follow a *Poisson distribution* with mean λ_{ij} which is describe as the number of times an animal *i* is detected by trap *j* during a sampling occasion y_{ij} (Gardner et al. 2010).

Outputs of fitting the model are estimates of D, intercept g_0 and spatial scale σ. Where g_0 represents the probability of capturing the animal by the camera station during an occasion *j* and σ is a scaling parameter of the function related to the size of the home range, showing the skewedness of a curve with increasing distance from the centre of the home range. Population size can be then calculated as derived parameter multiplying D by mask area. Where mask area is automatically calculated by the secr package during the model fitting in R Studio (Efford 2004; Borchers & Efford 2008; Efford, Borchers & Byrom 2009).

2. Aims of the Thesis

The aim of this study was to assess the current population status of the Western Derby eland in Niokolo Koba National Park in Senegal to get a general overview of the population's condition and demographic parameters. This was done firstly to support local authorities in better understanding the status and needs of WDE regarding their conservation and protection. And secondly, to present first draft for further, more extensive research of this subspecies.

The main objective was to estimate the population size and structure of WDE. This was done by processing and comparison of camera trap images collected in 2021, identification of individuals and subsequent analysis of obtained data.

The first goal was to estimate the current population structure based on data obtained from the processing of the collected images. The second goal was to estimate population size using the spatial explicit capture recapture model in R from the dataset of individually identified animals, which was based on different sex. The third goal was to calculate demographic parameters of WDE, using individually identified animals and results from the population size analysis. Fourth and last goal was to compare the results to the study conducted by Gueye et al. (2021), and to raw data from the same study which were provided by Assoc. prof. Ing. Karolína Brandlová, Ph.D. and analysed again but by the same method as data from 2021.

3. Methods

3.1. Study area

Extending over the area of 913,000 ha, Niokolo Koba National Park is the second largest protected area in West Africa. It is located in southern Senegal (Fig. 2), and it was established as the last refuge for large West African wildlife in 1954, making it also the oldest national park in the region (Madsen et al. 1996). During its history, it was listed first as a World Heritage Site, then as a UNESCO-MAB Biosphere Reserve and later it was also added to the UNESCO List of Endangered World Heritage sites (UNESCO 2022).

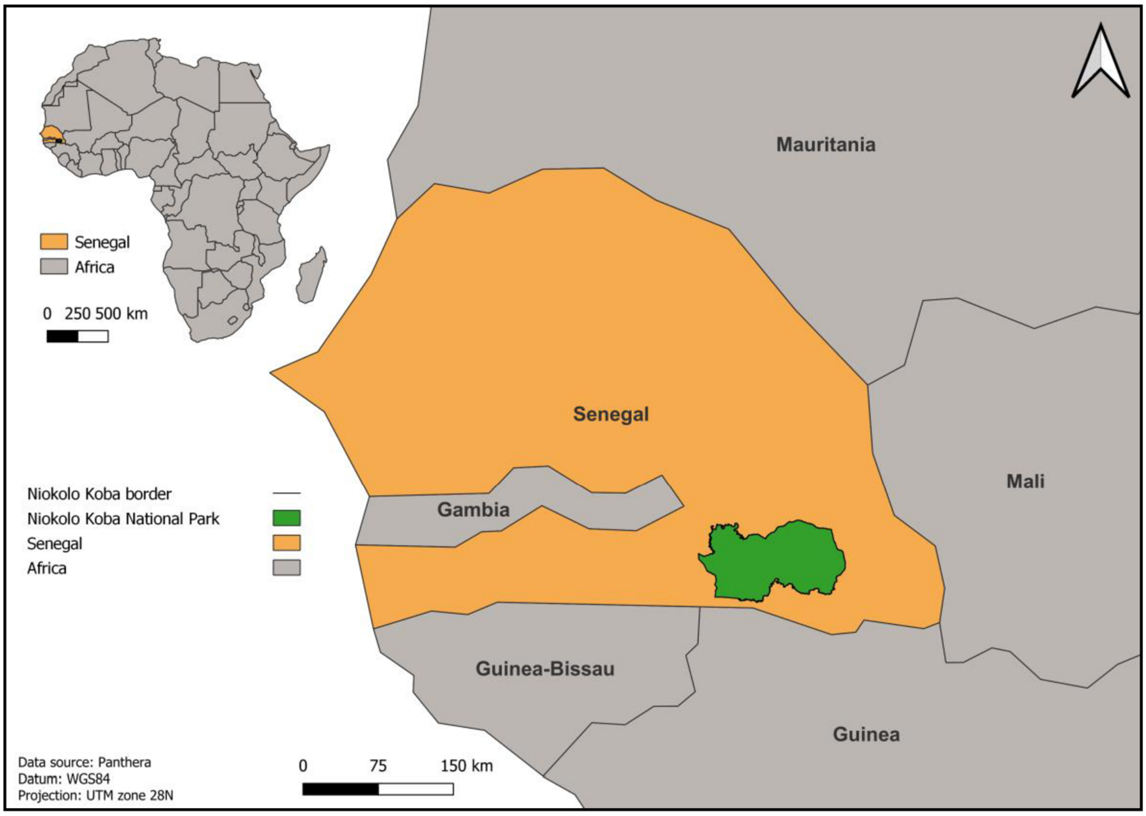

Figure 2. Location of Niokolo Koba National Park

NKNP is located on the transition of Sudanese and Guinean bioclimatic zone which is reflected in ecosystem composition very typical for this area. It is watered by 4 main rivers: Gambia, Sereko, Niokolo and Koulountou which are surrounded by gallery forests and grassy floodplains. Another characteristic habitat is herbaceous and woody savanna with around 1,500 important plant species and at least 80 recognized tree species typical for this bioclimatic region (Madsen et al. 1996). There can be found more than 70 mammalian species, 329 species of birds, 36 reptile species, 20 species of amphibians and vast number of invertebrates. Between the most charismatic ones, there are lions, Derby elands, elephants, leopards (*Panthera pardus*), African wild dogs (*Lycaon pictus*) or chimpanzees (*Pan troglodytes verus*) (UNESCO 2022).

Three distinct seasons are alternating there: dry-cold season lasting from November till late February, dry-hot season from March to May, and rainy season from June to October. The average annual precipitation spans from 600 to 1,200 mm. The landscape is generally flat with an average elevation of 100 to 150 m above the sea, with the highest point being the Assirik mountain in height of 311 m (Vieillefon 1971; Leroux 1983; Mbow 1995).

Both natural and human-induced fires play important role in the ecology of the region. For centuries, they burn up to 80% of the savannas every year. Except for fires, there are also other human-induced activities that affect the park. Agriculture, livestock grazing, logging, and poaching has been reported to have even higher abundance than some key wildlife species. Although the first four activities are restricted to specific zones of the park, poaching is generally more spread across the area, especially in parts with greater presence of wildlife (Antonínová 2008).

3.2. Data collection

Panthera Senegal collected data for this study as part of the Ecological Monitoring Project of leopards and other species to evaluate environmental values of NKNP. In total 72 camera stations with 139 cameras were deployed at an average distance of 3 km. Since the survey was targeting primarily on leopards and other smaller carnivores the cameras were placed in the height of 30-40 cm above the ground in areas with the highest possibility of capturing those species (based on previous research), like natural pathways or waterholes. From the 72 CTS (Fig. 3) 63 consisted of two cameras opposing each other to capture both flanks of the animal passing by. Those cameras were not directly opposite to each other to prevent disturbance by flash, but there was around one-metre shift between them. Three types of cameras were used. 94 cameras were PantheraCams model V7 with led flash and 1 Browning model BTC-6HDX with LED infrared flash both of which were sourced by NiMH rechargeable batteries with theoretical endurance around 40 days. The last 44 cameras were also PantheraCams, but model V6 with infrared flash sourced by lithium batteries with duration around 90 days. Those cameras were installed in less accessible and complicated terrain, considering their bigger autonomy (Drouilly et al. 2021).

Together 513 images of elands were collected during the period from March to July 2021. From the 72 CTS deployed only 12 (Fig. 3) captured WDE (CTS number 33, 37, 39, 43, 50, 51, 60, 61, 62, 63, 71 and 72), all of them installed in the core area of the park. Only stations 39, 43, 50, 51, 61, 63 and 72 consisted of two camera traps. At all CTS, at least one camera was operating constantly for the whole study period, from 25/03/2021 till 07/06/2021 except for CTS 71 and 72. These two stations were deployed later to further support the research and obtain more WDE captures as they were placed in locations where was confirmed higher eland activity. Those stations were operating from 19/04/2021. The whole study period lasted 75 days and the trapping effort was 1271 days.

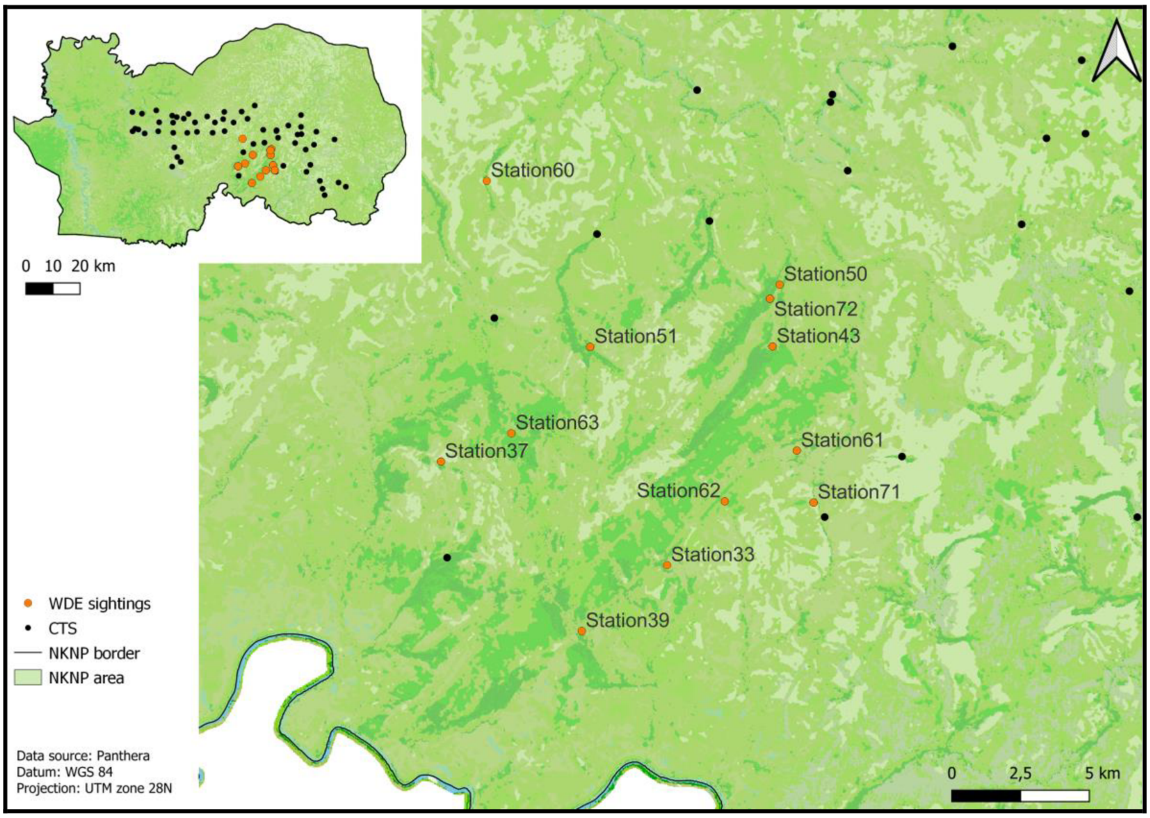

Figure 3. CTS positions with stations capturing WDE highlighted.

3.3. Data analysis

3.3.1. Data processing

The data set was obtained as images and Excel spreadsheet with metadata containing date, time, coordinates, number of camera station, number of cameras, and camera ID. From this, images were further sorted, categorised, and analysed as follows.

3.3.1.1. Events and age-sex categories definition

Images were sorted into events using a criterium of 30-minute interval between consequent images to ensure their independence and therefore prevent recounting the same individual as different one. All images within each event were then visually inspected by two independent observers, elands on each image were counted and sorted into one of 13 categories based on body size, horn shape (Figure 4) and external characteristics (Figure 5, Table 1). All individuals captured within one event were considered as members of one herd. The herd was then characterised according to the number of individuals and their sex (Table 2).

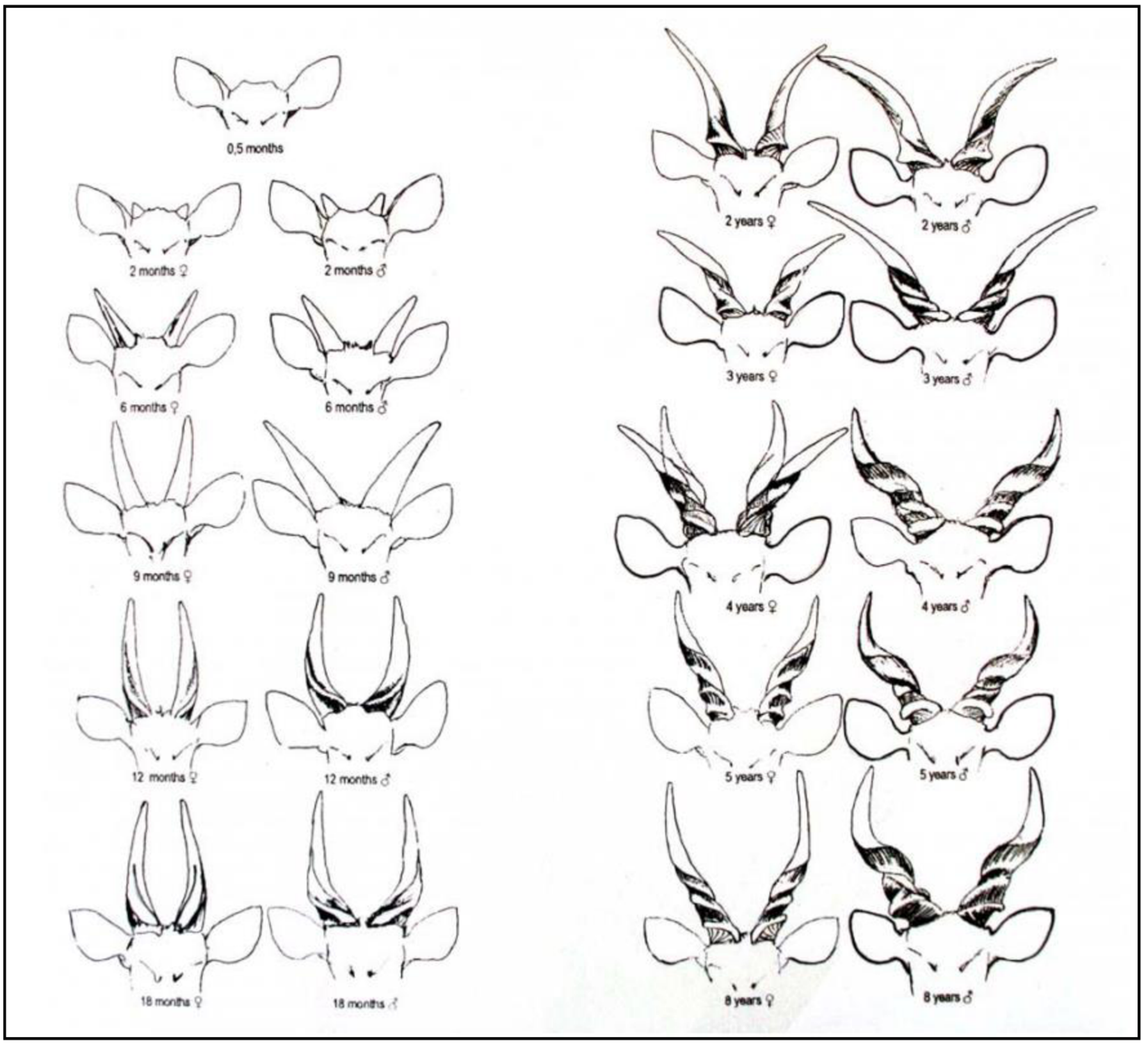

Figure 4. Age determination of the Derby eland based on horn shape and size.

On the Figure 4, the age categories are depicted in this order: from left upper corner – 0.5 months, 2 months, 6 months, 9 months, 12 months, 18 months. Right column – 2 years, 3 years, 4 years, 5 years, 8 years. Females on the left, males on the right (Antonínová 2008).

Figure 5. Examples of WDE sex-age categories. From top to bottom – AD, 2YO, 1YO, JUV. Left column – males, right column – females (Panthera/DPN 2021).

Table 1. Name and code for identified age-sex categories of WDE.

Age-sex category	Code
Adult male	ADM
Adult female	ADF
Adult unidentified	ADU
2 years old male	2YM
2 years old female	2YF
2 years old unidentified	2YU
1 year old male	1YM
1 year old female	1YF
1 year old unidentified	1YU
Juvenile	JUV
Unknown	UNK

Table 2. Name and code for identified herd types.

Herd	Code
One individual	SINGLE
Unisex – Male	UNIM
Unisex – Female	UNIF
Mixed	MIX

3.3.1.2. Individual identification

Where possible (identified sex and age, good resolution of image), animals were individually identified based on the number and shape of stripes on their flanks or eventually on another external features (Figure 6). Stripes in Derby elands are stable long-lasting feature enabling identification of individual throughout its whole life. Yet the number and shape of stripes differ on the left and right side, therefore for a full identification it is essential to have photos of both flanks. This can be reached by either when individual passes between two cameras which are facing each other, and it is clear it was the same individual or when it visibly turns in front of one camera. The data set with individually identified animals was then examined again by two independent observers and the recaptured animals were assigned together (Figure 7). Juveniles under one year of age were excluded from individual identification as their fur coat is still too long and wrinkled, making identification hardly possible.

Figure 6. Example of individual identification of ADF based on different striping, horn shape, and other external features. From upper left – C6, C10, C14 and C20 (Panthera/DPN 2021).

Figure 7. Example of recapture of the same ADF at different CTS (Panthera/DPN 2021).

3.3.2. Population structure

Population structure was determined from the composition of each herd which was obtained by detailed inspection of every image within all events. The total number of individuals in each category and the number of individuals who were successfully identified from the right side in that category were counted. Then the mean number of every age-sex category per event and their range were calculated. This was done with using the data just from image counts therefore those data can serve only as index of population size. More precise estimations were done in chapter 3.3.4. Demographic parameters. Comparison to data from 2017 and 2018 (Gueye et al. 2021) was also provided however, different approach in data collection between the years had to be considered.

3.3.3. Population size

The secr package in R Studio version 2022.07.2+576 was used to estimate the population size. Only records of animals that were individually identified from the right or from both sides were used as input data. This was because the right side had higher percentage representation than the left side (55 % and 45 %, respectively). Detector type was first set as "proximity" however with this setting the secr package did not properly count the number of occasions in the outputs, therefore it was changed to 'multi' considering Efford's troubleshooting vignette for secr (2022). There he is suggesting that setting can be changed from proximity detector to multi if it is in practice almost impossible to observe one individual at multiple sites during one occasion, because in that case there is basically no evident difference between the two detection processes (Efford 2022). Difference in density for males and females separately were modelled by separating data as different sessions in the first column of the capture file by coding 'M' and 'F' for males and females respectively. The term 'session' was then included in the relevant model formulation as follows: D~session, g0~session, sigma~session (Efford 2022). The half-normal, negative exponential and hazard rate functions were fitted in 3 different models, compared by the AICc criterion and the best fitting one was selected. The same process was used also on data from 2018 (provided by Assoc. prof. Ing. Karolína Brandlová, Ph.D.) which were not previously analysed separately for males and females.

3.3.4. Demographic parameters

The density estimated by the secr package in R was used as a basis for further operations. Abundance for males and females separately was calculated with the use of mask area, which was automatically generated during the population size analysis. From this, the abundance was recalculated for all the age-sex categories using the percentual representation of each category in the input dataset (Table 3, for males and females separately). The sex ratio for all males and females and then just for ADM and ADF was calculated from the results of the population size analysis as well.

The number of JUV was estimated based on the assumption that the number of calves is directly dependent on the number of adult females. The number of ADF counted on the images and their estimated abundance were taken, and the percentage difference of those two was calculated. This difference was then subtracted from the total number of JUV counted on the images to obtain the estimate of JUV abundance within the population. After that, breeding rate was calculated from the estimated number of ADF and JUV. Lastly, the survival rate of 1YO and 2YO individuals was calculated as the percentage difference between the number of JUV and 1YO and between 1YO and 2YO, respectively.

Table 3. Number of individuals identified from right side (ID) in 2021 and their percentage representation.

Age-sex category	ID	%
ADF	33	80.5
2YF	3	7.3
1YF	5	12.2
Total	41	100.0
Age-sex category	**ID**	**%**
ADM	7	33.3
2YM	2	9.5
1YM	12	57.1
Total	21	100.0

4. Results

4.1. Events and age-sex structure

The organised images resulted in 44 independent events. The first event was from 25/03/2021 captured at station 63 and the last one was captured on 07/06/2021 at station 71. From the 44 events, 15 captured only a single individual (6 ADM, 4 ADF, 1 2YM, 2 2YF and 2 UNK) and one UNIF herd with 2 females was also recorded. The rest of 28 events recorded MIX herds. The mean group size for all the groups was 11.6 (ranging from 1 to 37) and the mean group size considering only MIX herds was 13.32 individuals. A total of 390 animals were assigned to one of the age-sex categories. From those the most represented category was ADF with 102 detections and the least present one was 2YU with only 4 detections. The overall sex ratio was estimated to 0.47:1 (69 M:147 F) and adult sex ratio to 0.14:1 (14 ADM:102 ADF). The total and mean number of individuals counted in each age-sex category is presented in Table 4, together with the number of individuals identified from the right side and complemented with results from 2017 and 2018 (Gueye et al. 2021). The population structure in % and total numbers is presented in Table 5, together with comparison with results from 2017 and 2018 from Niokolo Koba (Gueye et al. 2021), 2017 from Chinko (Brandlová et al. 2018) and with Studbooks from Bandia and Fathala reserves from 2008 and 2019 (Antonínová et al. 2008; Brandlová et al. 2019). When comparing the results from the different studies, the difference in methodology and trapping effort must be considered; therefore, those results compared to 2021 and between each other are only indicative. Additionally, all those are results only from image count data that have not yet been further analysed. For results based on estimated population size, see Chapter 4.4. Demographic parameters.

Table 4. Total and mean numbers of WDE assigned to predetermined age-sex categories during the camera trap surveys in the Niokolo Koba National Park, Senegal

		2017		2018		2021	
Age – sex category	**Code**	**Total number (number ID R)**	**Mean number per event (range)**	**Total number (number ID R)**	**Mean number per event (range)**	**Total number (number ID R)**	**Mean number per event (range)**
Adult males	**ADM**	12 (1)	0.75 (0-2)	30 (11)	0.94 (0-5)	14 (7)	0.32 (0-2)
Adult females	**ADF**	17 (2)	1.06 (0-3)	32 (17)	1.00 (0-5)	102 (33)	2.32 (0-12)
Adults unidentified	**ADU**	23 (0)	1.44 (0-7)	12 (0)	0.38 (0-4)	10 (0)	0.23 (0-2)
2-year old males	**2YM**	7 (1)	0.44 (0-2)	15 (4)	0.47 (0-4)	14 (2)	0.32 (0-3)
2-year old females	**2YF**	5 (0)	0.31 (0-3)	2 (2)	0.06 (0-1)	12 (3)	0.27 (0-2)
2-year olds unident.	**2YU**	13 (0)	0.81 (0-4)	8 (0)	0.25 (0-3)	4 (0)	0.09 (0-1)
1-year old males	**1YM**	4 (0)	0.25 (0-2)	8 (0)	0.25 (0-2)	24 (12)	0.55 (0-4)
1-year old females	**1YF**	1 (1)	0.06 (0-1)	6 (2)	0.19 (0-3)	18 (5)	0.41 (0-3)
1-year old unident.	**1YU**	5 (0)	0.31 (0-2)	8 (1)	0.25 (0-4)	14 (0)	0.32 (0-4)
Juveniles	**JUV**	32 (1)	2.00 (0-9)	48 (2)	1.50 (0-9)	80 (0)	1.50 (0-10)
Unknown at all	**UNK**	40 (0)	2.50 (0-13)	36 (1)	1.13 (0-6)	98 (0)	2.23 (0-23)
Total		**159 (6)**	**9.94 (1-32)**	**205 (40)**	**6.41 (1-32)**	**390 (62)**	**8.86 (1-37)**

Table 5. Comparison of Derby eland population structure.

Age category	**Code**	**Studbook 2008**	**Studbook 2019**	**Chinko 2017***	**Niokolo 2017***	**Niokolo 2018***	**Niokolo 2021***
Juveniles	**% (N) JUV**	16 (8)	8 (9)	15 (16)	27 (32)	29 (48)	28 (80)
1-year old	**% (N) 1YO**	21 (10)	10 (12)		8 (10)	13 (22)	19 (56)
2-years old	**% (N) 2YO**	16 (8)	13 (15)	25 (26)**	21 (25)	15 (25)	10 (30)
Adults	**% (N) AD**	47 (23)	63 (89)	59 (61)	44 (52)	43 (72)	43 (126)
Total population		100 (49)	100 (118)	100 (103)	100 (119)	100 (168)	100 (292)
Growth rate λ		1,38	1,12				

*Numbers of animals detected using the camera traps serve only as indexes of population size.

**The number contains the sum of 1Y and 2Y individuals.

The table shows the ratio of juvenile (JUV), 1- year (1Y) and 2-year (2Y) olds, and adult (AD, > 2 years old) individuals in the fenced reserves in Senegal, as calculated from Studbook 2008 (Antonínová et al. 2008) and Studbook 2019 (Brandlová et al. 2019). The number of recorded detections in the Chinko Protected Area, Central African Republic (Brandlová et al. 2018), datasets referred to as 'Niokolo 2017' and 'Niokolo 2018' from Gueye et al. 2021 and the current dataset referred as 'Niokolo 2021'. The growth rates were calculated for the population in the fenced reserves and show high values, even if a much lower number of JUV and SUB individuals are reported than for that of the wild populations.

4.2. Individual identification

Total of 98 animals were individually identified from either left, right or both sides. ADM were identified on 11 images from 10 different events and assigned to 7 different IDs (B1-B7). B1 was captured during two events, both times in a MIX herd. B4 was captured in 3 events, once in a MIX herd and twice alone. All the rest of the bulls were captured only once (B3, B5, and B7 as a SINGLE and B2 and B6 in a MIX herd). Based on the striping code, horn size, or other external characteristics it was possible to determine that all the 7 ADM are different individuals even though not all of them were captured from both sides.

ADF were identified on 86 images from 25 different events and finally assigned to 55 different IDs (C1-C55). C1-C23 (except for C11, C19, and C21) were captured on at least two or more occasions. The rest (C24-C55 + C11. C19 and C21) were captured only once. The highest number of captures within different events had C1 and C23, which were both captured during 4 events. C1 was captured once alone from both sides and 3 times in MIX herd, C23 was captured only in MIX herd and only from left side. Two ADF (C2 and C27) were captured in a UNIF herd, C9 was captured SINGLE (as well as C1), and the rest were captured only in the MIX herd. 22 of the identified ADF were captured only from left side, 28 only from right side and 5 from both sides.

2YM were identified on 6 images from 6 different events and assigned to 4 final IDs (2B1-2B4). Only 2B1 was captured during 3 events, the rest of 2YM were captured just once. 2B2 was detected SINGLE whereas the rest in MIX herd. Additionally, 2B1 + 2B2 were captured only from the left side and 2B3 + 2B4 only from the right.

2YF were identified on 5 images from 4 different events and without recapture (2C1-2C5). 2C1 and 2C4 were detected SINGLE and the rest in MIX herds. 2C1-2C3 were captured from the right and 2C4 + 2C5 from the left side.

1YM were identified on 24 images from 11 different events and assigned to the final 17 IDs (1B1-1B17). 1B1-1B5 were captured during at least two different events and the rest was captured only once. All 1YM were captured only in MIX herds.

5 individuals were captured from left side, 10 of them from right and 2 (1B5 and 1B6) from both sides.

1YF were identified on 11 images during 8 different events and assigned to 10 IDs (1C1-1C10). Only 1C1 was captured in two occasions. All the 1YF were detected within MIX herds. Half of the individuals were captured from the left and half from the right side.

In the dataset from 2018, in total 28 animals were individually identified from the right side and used for further analysis in this study. From those were 19 females and 9 males (details in Table 6, for males and females separately).

Table 6. Number of individuals identified from right side (ID) in 2018 and their percentage representation.

Age-sex category	ID	%
ADF	15	78.9
2YF	2	10.5
1YF	2	10.5
Total	19	100.0
Age-sex category	**ID**	**%**
ADM	6	66.7
2YM	3	33.3
1YM	0	0.0
Total	9	100.0

4.3. Population size

62 individually identified animals within 92 detections were used for the analysis. Based on the best-fitting model (half normal, AICc= 931.435), the density estimate (± SE) was 0.1 females/km^2 (± 0.05) and 0.04 males/km^2 (± 0.01). Considering that the mask area generated was 1,258.5 km^2, the population size of WDE can be estimated as 126 females with a confidence interval (95 %) ranging from 76 to 466, and 50 males with a confidence interval between 20 and 151 individuals.

Same analysis was repeated also with the data from 2018 where there was 28 individually identified animals within 37 detections used in the input database. The best-fitting model was also HN (AICc= 552.007), and the density (± SE) was estimated to 0.14 females/ km^2 (± 0.1) and 0.08 males/km^2 (± 0.04). The mask area calculated was 1,014.4 km^2 which then resulted in population size estimate of 142 females with confidence interval from 101 to 649, and 81 males with confidence interval ranging from 41 to 284 individuals.

4.4. Demographic parameters

The estimated population size of 126 females and 50 males was used for further analysis of demographic parameters. The number of identified animals from each sex-age category was recalculated from the population size estimate to obtain estimate of individuals in each of the categories. The highest percentage representation had ADF with 39.6 % (101 individuals) and the lowest 2YM with 2 % (5 estimated individuals). For results of all the sex age categories, including estimation of number of JUV see Table 7. The sex ratio was strongly female biased, estimated to 0.39:1 (50 males: 126 females). This bias towards females was even more pronounced in the adult sex ratio which was estimated to 0.17:1 (17 ADM:101 ADF).

The number of JUV was estimated to 79 individuals. This was based on the number of ADFs counted in the pictures (102) and their estimated number from the population size (101). The percentage difference between these two numbers was 1 %, since 101 is 1 % smaller than 102. This percentage difference was then subtracted from the counted number of JUV (80), resulting in an estimate of 79 JUV. With the estimated number of JUV the total population size of WDE in NKNP during the study period can be estimated to 255 individuals (Table 7).

Table 7. Estimated number of individuals in each category and their percentage representation.

Age category	Estimate from D	%
AD	118	46.3
2YO	14	5.5
1YO	44	17.3
JUV	79	31.0
Total	255	100.0
Age-sex category	**Estimate from D**	**%**
ADF	101	39.6
2YF	9	3.5
1YF	15	5.9
ADM	17	6.7
2YM	5	2.0
1YM	29	11.4
JUV	79	31.0
Total	255	100.0

The table is based first on age (AD – adult, 2YO – 2 years old, 1YO – 1 year old, JUV – juvenile), and second on age and sex.

The breeding rate was estimated at 78 %, based on the estimated number of ADF and JUV. The annual survival rate was calculated at 55.7 % for JUV (79 JUV and 44 1YO) and 31.8 % for 1YO (44 1YO and 14 2YO individuals). The percentage of surviving individuals from JUV till 2YO was then estimated to 17.7 %.

Analysis for representation of each age-sex category for 2018 dataset was also performed, where the population size was estimated to 142 and 81 individuals for females and males, respectively (except for the estimation of number of JUV). The highest percentage had ADF with 50 % (112 individuals) followed by ADM with 24 % (54 individuals) and the lowest representation had 1YM which were not identified from the right side at all, resulting in 0 % (for complete results, see Table 8). The sex ratio was then estimated to 0.57:1 for all males and females together (81 M:142 F) and 0.48:1 for adults only (54 ADM:112 ADF).

Table 8. Estimated number of individuals in each category and their percentage representation for 2018 dataset.

Age category	Estimate from D	%
AD	166	74.4
2YO	42	18.8
1YO	15	6.7
Total	223	100.0
Age-sex category	**Estimate from D**	**%**
ADF	112	50
2YF	15	7
1YF	15	7
ADM	54	24
2YM	27	12
1YM	0	0
JUV	0	0
Total	223	100

The table is based first on age (AD – adult, 2YO – 2 years old, 1YO – 1 year old, JUV – juvenile), and second on age and sex.

5. Discussion

All recorded images of WDE were strongly localised in area around the Assirik mountain and partly extending also south-east to area of Banghare. Considering that the mask area was calculated to 1,258.5 km^2 and the total area of the park is around 9,130 km^2, the space used by WDE is either very limited (even less than 15 % of the park) or they are also using the space which was not yet monitored by camera traps and therefore there is a lack of data about their distribution. During the study published in 2021 (Gueye et al.) was on the images counted significantly lower number of WDE (159 WDE in 2017 and 205 WDE in 2018, compared to 390 WDE in 2021, Table 4). This seems to be a result of a different CTS positioning (Figure 8) and trapping effort between the study periods. If we look at the map with the positions of CTS in 2017/2018 and in 2021 (Figure 9) we can see that the area where WDE were captured is bigger for dataset from 2021 as there were new cameras placed in a part of the park that was not sampled before. It is therefore possible that detections from 2017/2018 were made by cameras which were placed on the eastern edge of WDE home range, but their distribution actually spans more west to the centre of the park and eventually also more south to the border of the parc. Whether this is true and the central, not yet monitored part of NKNP, represents an important area for WDE or it is a potential area for expansion of their home range (if the population grows in the future), requires further studies based on a long-term monitoring.

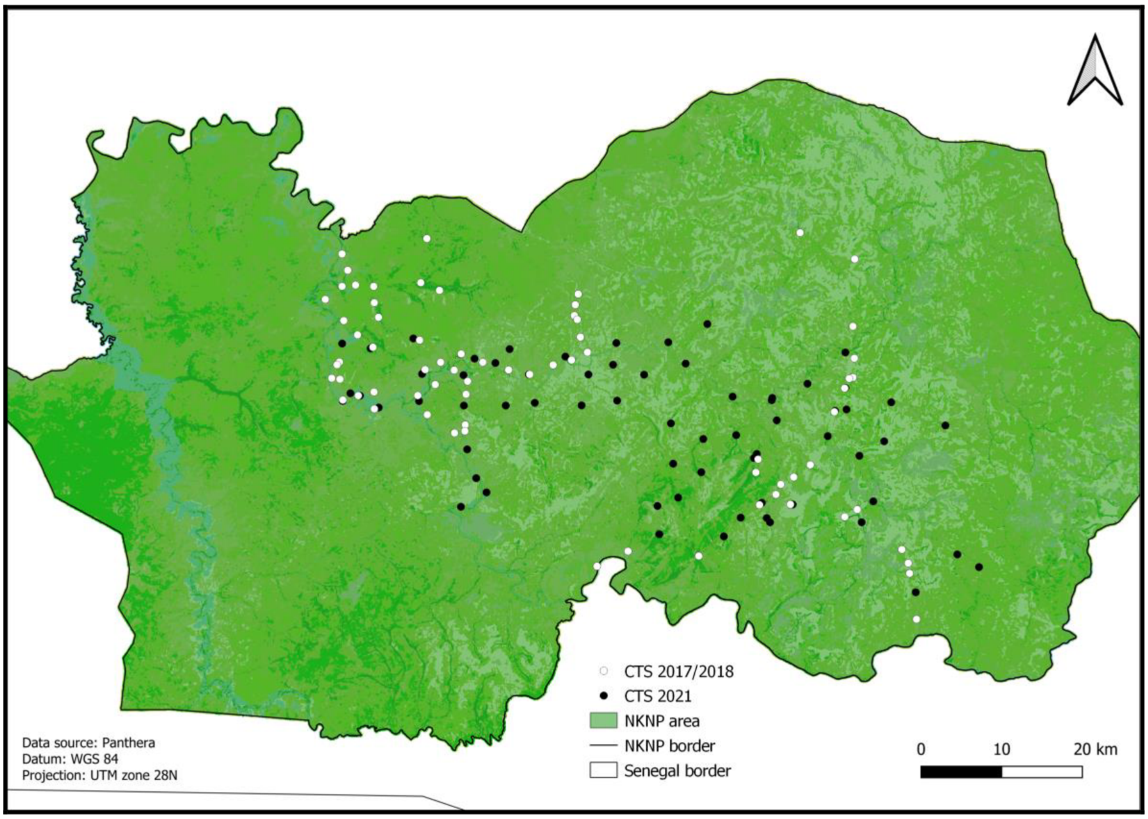

Figure 8. Comparison of CTS positions in 2017/18 and 2021.

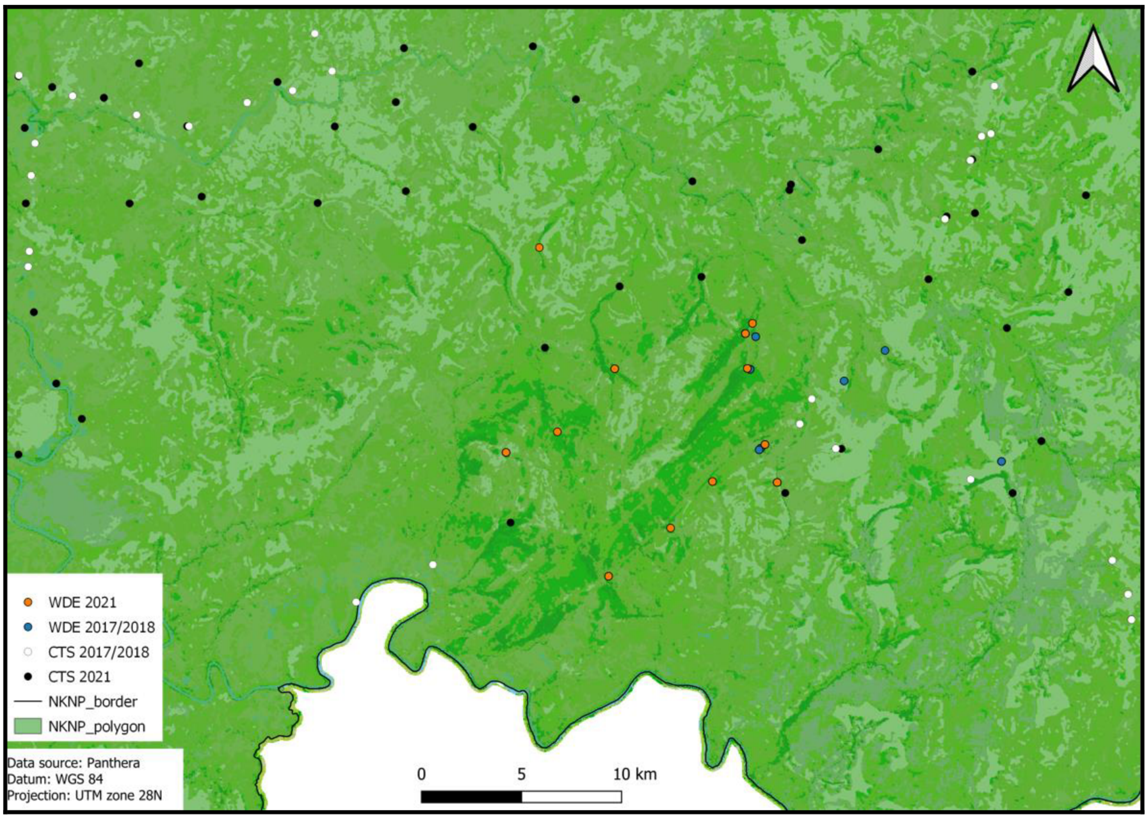

Figure 9. CTS which captured WDE in 2017/18 and 2021, and area of NKNP that was not yet monitored.

5.1. Events and age-sex structure

If we do not consider individuals whose age-sex category was impossible to determine (UNK), the most represented groups of WDE on the images were ADF with 102 sightings, followed by JUV (80 sightings). This is significantly higher than any other category, where there were not more than 20 animals in each of them (except for 1YM with 24 sightings) (Table 4). This could potentially point out a relatively high calf mortality during the first year after birth, which can be mainly caused by natural processes like source competition or predation. But it also shows significantly higher mortality of ADM compared to ADF; this can be a result of not just natural factors, but also several artificial factors related to the conservation of the subspecies. Both will be further discussed in following chapters.

When we look at the number of individuals counted on the images in different years (Table 4) it might seem that the population of WDE grew between 2017/2018 and 2021. But as was already mentioned it is possibly just a result of different methodologies and trapping effort. In the previous study, only 8 cameras in total captured WDE, half in 2017 and half in 2018 (from those, 2 were placed in the same area as one CTS) and they were operating for 936 days (249 days in 2017 and 687 days in 2018) (Table 9). Whereas in 2021 19 cameras at 12 stations detected WDE (Table 10) and they were operating in total for 1,271 days. It is therefore highly probable that the population of WDE did not grow significantly in numbers, but it was rather much better sampled during 2021. Especially when we also consider that the CTS 71 and 72 were deployed in areas specifically targeting on capturing WDE.

Table 9. Camera traps which recorded WDE in NKNP, and their operation days during 2017 and 2018 (Gueye et al. 2021).

Year	Camera ID	Data collection period	Days deployed	Operational days
2017	Mont 6	14/03–24/05	71	39
2017	Mont 7	14/03–24/05	71	70
2017	Mont 11	14/03–24/05	71	70
2017	Mont 12	14/03–24/05	71	70
2018	Mont 1	11/01–28/06	168	107
2018	Mont 3	10/01–28/06	169	169
2018	Mont 4	10/01–28/06	169	106
2018	Mont 4'	21/03–28/06	99	56

Table 10. Camera traps which recorded WDE in NKNP, and their operation days during 2021.

Year	CTS	Camera	Data collection period	Days deployed	Operational days
2021	Station33	Camera1	25/03–07/06	75	75
2021	Station37	Camera1	25/03–07/06	75	74
2021	Station39	Camera1	25/03–07/06	75	75
2021	Station39	Camera2	25/03–07/06	75	75
2021	Station43	Camera1	25/03–07/06	75	75
2021	Station43	Camera2	25/03–07/06	75	75
2021	Station50	Camera1	25/03–07/06	59	59
2021	Station50	Camera2	25/03–07/06	75	75
2021	Station51	Camera1	25/03–07/06	75	75
2021	Station51	Camera2	25/03–07/06	75	75
2021	Station60	Camera1	25/03–07/06	75	75
2021	Station61	Camera1	25/03–07/06	75	75
2021	Station61	Camera2	25/03–07/06	75	61
2021	Station62	Camera1	25/03–07/06	75	75
2021	Station63	Camera1	25/03–07/06	75	75
2021	Station63	Camera2	25/03–07/06	75	39
2021	Station71	Camera1	19/04–07/06	50	50
2021	Station72	Camera1	19/04–07/06	50	50
2021	Station72	Camera2	19/04–07/06	50	38

5.2. Individual identification

Considering that Gueye et al. (2021) estimated the population size to 195 WDE in 2018 (CI95 from 54 to 708 individuals), we can regard the individual identification of 98 animals as relatively successful. These 98 elands were captured on 143 images, of which 66 captured individuals only once and 77 were recaptured. 49 of the identified animal detections were made at CTS 72, which was more than twice as much as at any other station. CTS 61 detected identified animals 22 times, and the rest of the CTS captured even less, ranging from 1 to 18 (Table 11, Fig. 10). This was possibly because CTS 72 was placed facing a water source that was often visited by elands for a longer period than just passing by, which was the case for most of the other stations.

Table 11. Number of identified animals detected at each CTS for every sex-age category separately and in total.

CTS	ID total	ID ADM	ID ADF	ID 2YM	ID 2YF	ID 1YM	ID 1YF
Station33	1	0	1	0	0	0	0
Station37	12	1	6	1	0	2	2
Station39	6	2	3	0	0	1	0
Station43	17	0	12	2	0	2	1
Station50	2	0	2	0	0	0	0
Station51	9	1	6	0	0	2	0
Station60	1	1	0	0	0	0	0
Station61	22	1	14	1	3	2	1
Station62	5	0	4	0	1	0	0
Station63	1	1	0	0	0	0	0
Station71	18	0	10	1	1	4	2
Station72	49	4	28	1	0	11	5

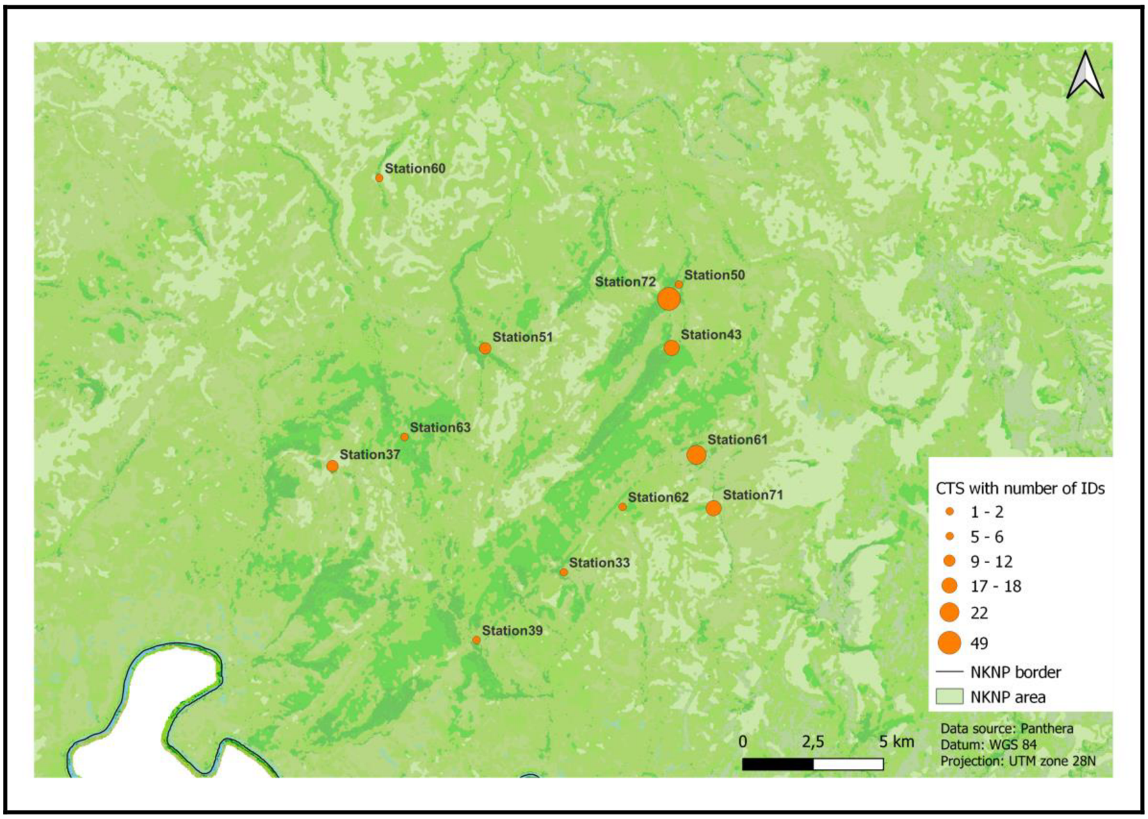

Figure 10. Number of identified animals detected at each CTS.

Individual identification within different herd types also confirmed the social organisation of WDE described by Bro-Jørgensen 1997, Reanud et al. 2006, Brandlová et al. 2013, Kingdon & Hoffmann 2013 and others. Whereas 1YO individuals were always captured only in MIX herd associated with at least one ADF, 2YO animals were already detected SINGLE in some cases, possibly showing higher independence of this age category. This can be also supported by the fact that the 2YO age category had the lowest representation during the image counts and subsequently also the individual identification. Individuals at this age, and especially males, start leaving their maternal group in search of new areas to occupy (Bro-Jørgensen 1997; Kingdon & Hoffmann 2013). This can then result in lower abundance within the MIX herds, and since it is more difficult to detect a single individual rather than a whole group (in connection with the trigger sensitivity of the camera and detectability on images), it can reflect on the number of detections of this age category, especially if it is also connected with dispersion to areas which were not monitored. The detections of ADM reflect what is stated in the literature as well; they were captured either alone (especially during night) or associated within a big group of MIX herd. One of the males was even captured in both cases, showing that they do not just stay with the group or roam alone but shift between those two (Fig. 11).

Figure 11. B4 captured SINGLE and in MIX herd (Panthera/DPN 2021).

5.3. Population size

Since it was possible to identify individuals from all the age-sex categories (except for JUV) the estimated number of males and females represents the whole population of WDE that were one or more years old in 2021. That makes all together 176 WDE (CI95 from 96 to 617 individuals), which would be approximately the same as 195 animals (CI95 from 54 to 708 individuals) estimated by Gueye et al. (2021), yet they used only records of adult individuals for this estimation, therefore it is not comparable with our results as it does not include the 1YO and 2YO categories. That is the reason why we took also records of all elands identified from right or both sides in 2018 and analysed them in the same way as data from 2021, to obtain more comparable results. It should be noted here that even though the data from 2018 and 2021 were analysed by the same method, the methodology in collecting them still differs. That is reflected for example in different mask areas which can potentially have effect on the estimated density. Additionally, the results for 2018 seem to be slightly overestimated (especially for males) which might be result of relatively small dataset that was strongly biased towards adult individuals. They created 75 % of all the IDs whereas the identification of individuals in other sex-age categories ranged only from 0 to 3 animals.

The density estimated from 2021 data was 0.14 individuals/km^2 (0.1 and 0.04 for females and males respectively) which in general corresponds not only with the density estimated by Gueye et al. (2021), where it was estimated to 0.138 individuals/km^2 but also with densities reported for Eastern Derby elands from Central African Republic (ranging between 0.002 and 0.1 individuals/km^2) and the Chinko/Mbari drainage basin (densities reported from 0.04 and 0.16 individuals/km^2) (Bouché et al. 2010; Brandlová et al. 2018). In literature, the densities of DE were recorded ranging from 0.15 to 0.30 individuals/km^2 (Planton & Michaux 2013) therefore the population of WDE in NKNP still has a potential to grow in the future. It should be also noted that the density of WDE can vary during the year (Planton & Michaux 2013) and since the data were collected during the dry period, when the elands aggregate into bigger herds, the density was potentially estimated higher than it would be in the rest of the year.

5.4. Demographic parameters

As was already mentioned, the estimate of 195 WDE from 2021 by Gueye et al. was only for adult individuals and considering that adults are likely to form around 44 % of the whole population, they assumed that the total population size could reach up to 300 individuals. The estimated number of AD in our data set was 118 which was 46.3 % of all the estimated individuals; therefore, it corresponds with the assumed number of adult individuals within the whole population. Despite that, it is significantly less than the estimates from the previous study, although the CI from 2017/18 and 2021 datasets overlap. But if we consider the other age-sex categories and the estimated number of JUV in this study, we get the total estimated population of around 255 individuals. That is corresponding more with the estimates made by Gueye et al. (2021) and it is also over the line of 200 individuals which were estimated in other studies from previous years (Renaud et al. 2006; Brandlová et al. 2013). On the other hand, data from IUCN (2017) present the population to have around 120 - 150 of only mature individuals, therefore it is not clear from the results whether the population of WDE has an increasing trend and grew significantly in last few years. However, we can say that the population trend appears to be minimally stable when we compare the 2017/18 and 2021 results. One of the reasons why the population does not seem to be decreasing anymore could be antipoaching activities such as patrols, which have been implemented more intensively since 2017. If this and other conservation activities implemented in the NKNP do have a positive effect on the WDE population and whether the population is slowly growing, or it has been just stagnating at current level for the last several years should be one of the main subjects of further research.

Although the number of calves in the population was estimated based just on raw counts of the detected animals and estimated number of adult females, the calculated breeding rate (78 %) is corresponding with those reported for Eastern Derby elands (74 %) and with 83 % reported for wild Eland population (Bro-Jørgensen 1997). Even though it did not seem like it at the beginning from the raw image counts, the estimated survival rate of JUV was relatively high, and more than half of the calves could survive until the first year of age. This would potentially result in significant growth of the population every year. Yet if we look at the survival rate between JUV and 2YO it drops to less than 20 %. We can also see that the detected and subsequently estimated number of 2YO individuals is much lower than for other categories. Whether this is just a coincidence, result of some stochastic effects, dispersion of this category to non-monitored areas, predation, poaching or some other unknown events is unclear, and it should be explored in the future.

Even though the density estimated for 2018 and 2021 was somehow comparable if we take in consideration the differences between those two datasets, the same cannot be said about the numbers of individuals in each age-sex category when we recalculated them from the density. With those results, in 2018 ADF would create half of the whole population and all AD would create more than 74 %, which is far from the previous assumption that AD should form around 44 % of the population. Notwithstanding that there were no records of 1YM and the number of records of other categories were extremely low, ranging from 2 to 15. Because of such a small dataset which also seems to be biased towards AD individuals, those more detailed results of the age-sex population structure cannot be compared with the results from 2021 data as was originally planned.

5.5. Factors influencing WDE population

Even though there have been several protection measures implemented in the NKNP for more than 4 years (2017-2021) they do not seem to have significant impact on the population of WDE so far. If the population had an increasing population trend, we would see more striking change in the population size during the past 4 years even if it would grow just for 10 % every year. However, it seems that there are several factors that keep the population of WDE at approximately the same level.

The first factor that is still potentially affecting the population is poaching. Even though it is more strictly controlled now than it was before 2017, this risk is still prevailing, and it could be affecting the population in several ways. If the poachers are targeting on the biggest catch possible, it would be affecting mainly adults, and especially males. Considering that adult males are in general less represented in the population of polygenic species and since the population of WDE in NKNP is already very small, removing adult males from the population could be lowering its reproduction potential. And in general, targeting on adult individuals could cause considerable loss of genetic diversity and loss of knowledge about the area and possible sources which might then affect population survivor during harsh conditions. On the other hand, adult males can weigh up to 900 kg (Kingdon, & Hoffmann 2013; Planton, personal observation) which makes, in connection with lower accessibility into the area of the park where WDE are present, unobtrusive transport of a carcass out of the park rather complicated. It is therefore possible that poachers are targeting more on younger individuals around 2 years of age which are lighter but already big enough to worth the energy invested in their hunting and transporting out of the protected area. This would also partly explain the low number of 2YO individuals detected during this study.

Another issue that could potentially affect the WDE population in the future is related to the ecological monitoring programme run by Panthera Senegal. In cooperation with DPN they were able to successfully strengthen the management and security in the park. This resulted in the growth of the lion population which is now double the size it was in 2017 (Panthera Senegal 2023). This is an amazing conservation achievement and thanks to all the protection and management measures implemented in the area, this increase in population trend will probably continue in the future. Although the number of lions in the park is still small, around 30 individuals, we must also consider other predators in the area such as wild dogs or leopards, whose population in NKNP is probably the largest remaining in West Africa (Panthera Senegal 2023). And although other large prey has been reported to also have positive population trends, for such a small population as the elands this might be yet another factor limiting the population growth, especially if they remain on the same population size as they seem to be for past several years. The predation would affect mainly the survival of calves and younger individuals but since lions are able to hunt down even adult African buffaloes, which have around the same weight as the elands, it could have some effect on the adults as well.

Lastly, one of the reasons which could explain why the population is so strongly centralised in the area around the Assirik mountain could be a lack of suitable areas for dispersion. This could be caused by the lack of suitable habitat and food sources in the rest of the area, by the presence of some other species that are avoided by the elands or by human activities and the presence of artificial factors such as livestock grazing and agriculture, infrastructure, or mining. All these could be potential stressors and disturbances that restrict the WDE population from spreading further into other parts of the park.

It is important to say that all those are just hypothesis about factors which may or may not be potentially affecting the population, and they need to be further tested.

5.6. Recommendations for future research

Probably the most serious issue related to the conservation and protection of WDE is the lack of data about this subspecies in its natural environment. As was already mentioned, the first more detailed study about the elands' spatiotemporal behaviour, population size, and demographic parameters was published in 2021 by Gueye et al. But the dataset they analysed comes from years 2017 and 2018 and since our dataset is from 2021 there is a two-year gap with none or extremely low amount of data which were not possible to analyse without strong bias. In the future, it will be therefore essential to collect and analyse data about the elands regularly each year and preferably also during both, the dry and wet season. This could then help, firstly, to better identify and address the factors which have the biggest influence on limiting the population dynamics and size. And secondly, it will help to determine whether and how applied conservation actions influence the population growth.

It is also not clear whether the area sampled by camera traps is spanning over the whole home range of WDE and their distribution is therefore very limited or whether the whole area of their distribution has not been mapped yet. Therefore, it is advisable to place additional CTS in the unmonitored area to test this and gain a better understanding of the space used by the elands. Moreover, it would be more effective to use methodology specifically designed for collection of data about large ungulates rather than collect the data as a bycatch product of a different study. This would result in larger datasets and more possibilities for individual identification which would then help with more precise estimations of the population size and structure.

It would be recommended to consider also radio collaring of several individuals, preferably from different age-sex categories, to further support the camera trap survey. This could help to even better map the movement and space used by the elands, it could also show differences in space use and interactions between the animals during the different seasons, daily activity patterns and potentially also some more detailed behavioural patterns.

Another essential part for the continued protection of WDE will be active cooperation with other research teams operating in the NKNP to better understand the ecological links and how different animal populations influence each other. This could be done for example by scat analysis of large predators for the presence of eland hair or by comparing the space use and activity patterns of WDE to other big ungulates in the area.

6. Conclusions

This study provided a second more detailed analysis of the population structure and demographic parameters of the Western Derby elands in what appears to be their last refuge, the Niokolo Koba National Park in Senegal. Our findings showed that there is good potential for the population to growth. Yet compared to the results from previous study (Gueye et al. 2021) the population did not seem to have a significantly increasing population trend over the years. This could be a result of several factors which combined together have restricting effect on the population growth, especially on the numbers of adult males and two-year-old individuals. We were able to identify some of those issues, but it is still unclear how and on what level they can influence such a small population. Further and more detailed monitoring of the population is needed to better understand its dynamics, space use, habitat selection and ecological links to other species present in the area. This should then help with better implementation of conservation measures by the managers of the protected area, which will be based on the current needs of the population.

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