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Assessment of selected methods for monitoring of large African ungulates

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled *Assessment of selected methods for monitoring of large African ungulates* 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 26/4/2019

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Zuzana Holubová

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Abstract

Population monitoring is one of the most common activities in wildlife management. There is a whole range of monitoring methods differing in their purposes, implementation but also cost and time demands. Thus, it is always necessary to focus on main aims, particular species and habitat specifics to select the most suitable method. We compared distance sampling (i. e. road and point transects) with plot sampling (i. e. circles, strips and squares) by estimating the abundance and/or density in African ungulates occurring in two private wildlife reserves, the Bandia Reserve and the Fathala Wildlife Reserve located in Senegal. We were two observers driving a ground vehicle and collecting data in 3 different daytime periods. By using DISTANCE software, lognormal distribution and Kilometric Abundance Index (KAI), we chose the most precise results which determined the most reliable method and daytime to conduct a survey. We reviewed all the factors that could influence the survey and suggested possible solutions to avoid bias and increase precision. Because of the inability to analyse data in the software DISTANCE due to an insufficient number of observations, we found the strip count to be the most suitable method in combination with the late afternoon time period for future regular monitoring in the study areas. However, it will be necessary to increase the number of sample repetitions to ensure greater precision and accuracy.

Key words: Wildlife management, ground-based monitoring, savannah large mammals, population size, distance sampling

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1. Introduction and Literature Review

1.1. Introduction

Most populations of large wild ungulates are subject to conservation plans or intensive management (Caughley & Sinclair 1994). In fenced areas, knowing sizes of animal populations occurring the area is crucial to face the limited space for a limited number of animals, inter-species relationships, carrying capacity and competition over resources (Ben-Shahar R. 1993; Boone & Hobbs 2004).

However, to conduct complete censuses to determine total population size is rarely feasible, expensive and inaccurate (Link & Sauer 1997; Cochran 1977; Lancia et al. 1994). Therefore, many types of monitoring methods have been developed to estimate population abundance or density (Lancia et al. 1994; Sutherland 2006; Goldsmith 2012), especially commonly used sample counts (Caughley & Sinclair 1994). Before selecting a method, the crucial point is to set all main goals of the monitoring and take into account limiting factors (Danielsen et al. 2005), such as time and financial demands (Danielsen et al. 2005), policy, experience of workers, target species characteristics, local climatic conditions, vegetation density (Singh & Milner-Gulland 2011) and other difficulties which could make survey intricate or even impossible to implement. No less important is also the compliance with the data processing, final analysis (Buckland et al. 1993, Thompson et al., 1998) of the results and the feasibility of the methods in terms of being transferred to the stakeholders and used by them.

In the African species of ungulates kept in the private Fathala and Bandia reserves, there was no monitoring program conducted in the past. We decided to run a pilot study to assess the most suitable monitoring method, from those which were applied and then compared (i.e. distance sampling and plot sampling) considering factors mentioned above.

1.2. Literature review

1.2.1. Basic terminology

In the very beginning of the thesis, we want to specify a few fundamental terms that usually occur in many studies focusing on measuring the population size of any animal species and could be somehow misinterpreted. These are mainly the words "monitoring", "inventory", "census" and "survey".

The word "monitoring" is usually defined as "*a repeated assessment of the status of some quantity, attribute, or task within a defined area over a specified time period*" (Thompson et al. 1998), while an "inventory"is conducted by gathering data for a single time period, so repeating the inventory at a particular time period (month, season, year) generally results in a monitoring study (Thompson et al. 1998). Census is considered as a total count of all animals in the defined area, while the survey is only some proportion of sampled objects in the area (Buckland et al. 2001).

Although these terms have their definitions, their meaning is often overlapped or interchanged by many authors. It is, therefore, necessary to distinguish from what point of view we look at the issue. In the title of this thesis, we used the term "monitoring", because it is our long-term objective. However, since we conducted single counting for the first time, we could also use the term "inventory". Thus, in order not to complicate the terminology, we will consistently use the word "survey" or "monitoring".

1.2.2. Method selection for long-term monitoring

As Legg and Nagy (2006) state: „*An underlying premise of successful monitoring programs is that the design is simple and the measures are straightforward, unambiguous and replicable*". Many wildlife counting methods exist, but they highly vary in their usage. One method may be ideal in one case, and in the other one totally useless (Thompson et al. 1998). Many monitoring programs suffer from being unsustainable because of both technical staff capacity and funding (Danielsen et al. 2005). When designing a survey, we should know the management objectives or the particular questions to ask (Sutherland 2006; Buckland 1993) for both justifying financial support for monitoring study and also for promoting local engagement (Yoccoz et al. 2001).

In wildlife management, very common is to monitor the population abundance (*N* = relative number of animals in the area), density (*D* = number of animals/ unit area), however to measure a complete population size (i. e. absolute abundance, resp. total number of animals in the area) is rarely feasible (Cochran 1977, Sutherland 2006; Stokes et al. 2010).

Main particular questions which should be asked already during preparations of the survey design are:

- What are the target animal species and its area of occurrence?
- Do we want to monitor only one species or multiple species?
- What variables need to be monitored and what measure should be used?
- How and for what purposes will the data be used?
- What level of accuracy/ precision is required for the purposes of making decisions?
- What are financial, time and personnel requirements?

(Alien et al. 1996; Sutherland 2006; Singh & Milner-Gulland 2011; Stokes et al. 2010)

1.2.2.1. Species specifics

The ecology of the selected species has a great influence on the choice (Stokes et al. 2010). Some mammal species can be difficult to observe due to their small size, camouflage colouration or timidity (Engeman & Witmer 2000). Many are nocturnal, some live under the ground, and may occur at low densities (Gese 2001)

The field work may be run in locations that pose many challenges to the field workers as for example rugged remote areas, areas in less developed countries, places with high vegetation density or zones in war conflicts (Singh & Milner-Gulland 2011).

1.2.2.2. Equipment and supplies

Sometimes, to get the equipment needed for the survey can be a big challenge. Especially if the working time is limited and without some tools, it is not possible to start the survey. If the equipment has to be shipped, plenty of delivery time has to be allowed for. Having back-up the equipment or repair materials should be considered a wise investment (Witmer 2005). Some special tools (e.g. traps, radio-telemetry frequencies, drones) can be under restrictions in use and need permission (Singh & Milner-Gulland 2011). Thus, the time of waiting for the permission needs to be count within survey planning as well. Last, but not least, personnel need to be well trained on how to safely use and repair of basic equipment.

1.2.2.3. Other complications

To avoid any conflict in the study area, careful coordination and frequent communication with resource managers and landowners are essential. Also, severe weather events can cause disturbance of survey plans, or even create misrepresented results (Singh & Milner-Gulland 2011). Finally, if there are rare or protected species of animals in the target area, the procedures and equipment should be used with care to do not negatively affect any of those species (Fryxell et al. 2014).

1.2.3. General types of monitoring methods

In various publications, different systems of counting methods can be found. (Sutherland 2006; Buckland et al. 1993; Lancia et al. 1994; Singh & Milner-Gulland 2011). Thus, there is no single classification system and the individual methods may fall into multiple categories. Different techniques can be, for example, classified based on the medium used for a survey: aerial, ground-vehicular, ground-walked and ground-other (Singh & Milner-Gulland 2011). Or if they are direct or indirect, i. e. when species presence in a site can be confirmed by direct observation of the animals or by the signs of their passage (i. e. indirect observation) that can be reliably detected by a field expert: tracks, footprints, feeding marks, droppings, dens, nests, hairs or feathers as well as body parts or carcasses (Sutherland 2006). Lancia et al. (1994) divide methods estimating animal populations into three general categories: 1) Complete counts, 2) Population index and 3) Sampling methods. In our study, we focused more on methods with population index and sampling counts.

1.2.3.1. Complete counts

The complete counts are based on recording all individuals in a given area and the results can be easily interpreted. Unfortunately, for use in wildlife, the technique is usually too expensive, rarely feasible and obtained results can be very inaccurate (Cochran 1977; Lancia et al. 1994).

1.2.3.2. Population index

This method based on the index of abundance and/or density which changes in a predictable way according to changes in population abundance and/or density in time. The method does not estimate the actual size of the population, but only if the index has increased or decreased in comparison with some previous survey studies (Fryxell et al. 2014; Marchandeau et al. 2006). One of the most common biological indicators used in wildlife studies is a **Kilometric Abundance Index (KAI)**, defined as a number of observed animals per total length of a transect (Buckland et al. 1993; Vincent et al., 1991). It is often used because of possible straightforward comparison of species abundance in different sites or at different times (Buckland et al. 1993; Vincent et al. 1991). It has been designed and is mainly used for vertebrate species (de Thoisy et al., 2008; Engeman 2005; Maillard et al. 2001) nevertheless it can be also adapted to other species depending on its behaviour and distribution in the study area. A simple method for KAI to implement are line transects surveys without the need for any special equipment (basically, a GPS receiver) and without a high number of operators compared to other survey techniques. Thus, the method is less expensive, practical, sensitive and robust (Engeman 2005). Since it is only a relative measurement, it cannot be used to deduce population density, if not combined with other field methods that can provide this estimate (Burnham et al. 1980). KAI is often used in preliminary studies to identify sites where it is worth applying other more demanding techniques such as live trapping, but it can be also used with slight modifications to apply Distance Sampling techniques (Buckland et al. 1993). For example, KAI was tested in the monitoring of roe deer by Vincent et al. (1991) and compared with population estimation by a capture-mark-recapture method. Also, Acevedo et al. (2008) correlated KAIs recording pellets with distance sampling in a red deer.

1.2.3.3. Sampling counts

Sampling counts are nowadays, the most preferred techniques for estimating species abundance and/or density. It is much cheaper approach, more precise and without such logistical constraints than the complete counts (Williams et al. 2002). One must first distinguish between the detected number of animals and the population abundance (or the detection probability) to estimate the true population abundance and/or density. Several sampling techniques estimating detection probability and population abundance have been developed. The mainly used are distance sampling (i.e. line and point transects) and mark-recapture (Sutherland 2006), but we will also mention conventional plot sampling.

The mark-recapture

The mark-recapture method is based on catching an animal, recording a marking (e.g. by tags, natural markings, DNA identification) and release it. The animal is then mixed into the rest of the population. The second sample is the same as that in the population at large (Sutherland 2006). Due to our focus on other methods, we will not describe this method in detail.

Plots sampling

The sampling plots can be of various sizes and various forms (Sutherland 2006). Under the assumption that all objects within the plots are counted, the population density is then estimated by dividing the total count by the total area surveyed (Thomas et al. 2002). As the animals are seen at a distance greater than the border of the plots, they are not included in the survey (Buckland et al. 2001; Thomas et al. 2002). Unlike the distance sampling, in these methods is no need of any model-based estimation (Thomas et al. 2010; Caughley & Sinclair 1994). For example, in the strip count, observer travels along a line and counts all objects within the line. The main advantages are that the observer does not need to record angles and distances of observed animals and can provide reasonable estimates (Eberhardt 1978).

The circle and square plots are useful in difficult terrain and for shy species, they are cost-effective, however, there is a high possibility that biases are generated because of detectability issues (Nichols et al. 2000). To avoid any missed animals/clusters, the size of plots should be determined by animal visibility and the vegetation density (Morrison 2014). For example, Ogutu et al. (2006) measured the efficiency of strip count in comparison with distance sampling line transect and he found that the strip count produced lower abundance estimates but higher precision than the line transect. Line transect is also prefered by Burnham et al. (1980) when the detectability decrease with increasing distance from the line.

1.2.4. Distance sampling

Distance sampling is a widely-used set of sampling methods, extended from quadrat-based sampling methods, estimating the density and/or abundance of biological populations, especially suitable for rare species of birds, carnivores and ungulates (Buckland et al. 2001). Although, they are less efficient for areas with large numbers of animals due to the need of time to record a distance of all animals (Fryxell et al. 2014).

The most used methods are a) line transects and b) point transects, which are widely used especially for surveying large and highly visible African ungulates (Ogutu et al. 2006). The main principle in both of the techniques is that an observer follows an unbounded line or a point and records distances of each individual or a cluster (means “a group”) to the line or point at first sight.

The theory accepts that some individuals remain undetected by the observer in the given area. There is a fundamental assumption that all objects occurring on the line or point are detected with 100% probability, but the objects with increasing distance from the line or point are less visible with the lower detection probability. Therefore, the probable population size can be estimated by specific analytic models. Most of the distance sampling surveys have been analysed by free software *DISTANCE* (Thomas et al. 2010; Buckland et al. 2001).

Three principal assumptions are essential to keep for reliable estimation of density from point or line transects sampling (ranked from most to least serious):

1) Objects on the line or point are detected with probability= 1.

In practice, the observer should detect all objects on or close to the line or point with certainty.

2) Objects are detected at their primary location, prior to any movements.

In practice, the non-responsive movement in line transect surveys is not so problematic when it is relatively slow to the speed of the observer. Non-responsive movement can be more problematic for point transect surveys, leading to population density overestimation.

3) Recorded distances are measured with precision.

This assumption may not be applied when untrained observers are responsible for the survey, but they have not enough experience in estimating distances by eye or ears (Alldredge et al. 2007). Sufficient training and technology (e.g. laser rangefinders) should be provided to ensure adequate results. In the case of line transects, where the observer should record both distance and sighting angle of the object to the line, it is also crucial to record an accurate angle. Then the perpendicular distance is calculated as $r \sin\theta$. Of course, the assumption that the species is well-identified has to be met. (Buckland et al. 2001)

1.2.4.1. Line transect sampling

In line transect sampling a set of straight lines (track lines) is crossed by an observer or a platform with more observers. This may be accomplished in various ways, mainly depending on the study species. In terrestrial studies, all-terrain vehicle, walking, horseback, aeroplane and helicopter can be used. For a comparison, transect surveys in water conditions can be managed by divers, from submarines, surface vessels, aircraft, etc. (Thomas et al. 2010).

Usually, it is not recommended to use roads or trails for line transect surveys. Roads tend to follow land contours and do not constitute a randomly representative habitat. Animals can avoid roads, for example, because of movements of vehicles with tourists or, on the contrary, animals use the roads to move more easily in their habitat (Anderson 2001). However, road counts have been used in many studies of mammals, especially of ungulates. One of the biggest advantages is that travelling through the study area is easy and fast (Zero et al. 2013).

Zero et al. (2013) does not avoid using roads for surveying Grevy´s zebra at Mpala Rach Conservancy, because the animals are generally habituated to vehicles and do not avoid the roads. Also, the area is covered by a dense web of trails, so the roads do not represent any special accessible place, where the animals would gather in a higher density.

Density estimation

During line transect surveys, distance r and angle are recorded (see Fig. 1) and then the perpendicular distances x is calculated as $x = r \sin\theta$. K lines of lengths $l1, \ldots lk$

(with $\sum lj = L$) are randomly positioned and then *n* animals are detected. The detection function *g(x)* assumes, that the animal occurring on the track line is visible with certainty *g(0)=1*. As it is not known the true number of animals in the plots, a detection model in *DISTANCE* software is then chosen (Thomas et al. 2010; Fewster & Buckland 2004). More details about using *DISTANCE* software and model-based density estimation we described more in detail in the next chapter.

Cluster Size Estimation

Animals are often grouped together, as flocks of birds, a herd of ungulates, etc. Then we use the term "clusters". If there is a cluster detected during a survey, the distance of an animal in the centre of the group is then recorded. The estimated density of individuals can be obtained by multiplying an estimate of mean cluster size in the population. Detection probability is usually influenced by cluster size, so there is a high possibility of bias (larger clusters are easier to detect, so it can over-represent the sample) (Buckland et al. 2001; Thomas et al. 2002).

Assumptions

To ensure ideal physical setting for line-transect sampling, these two assumptions need to be followed together with those three fundamental already mentioned:

- *N* objects are occurring in the area of size *A* according to some stochastic process with average rate parameter *D=N/A*.
- Lines located according to some randomly designed plan, are surveyed and *a* sample of *n* objects is detected.

The point and interval estimates of density D can become extremely robust to variation in *g(x)* due to other factors such as observer, habitat, etc. Large variations in density over the study area can be still acceptable, however, if it is possible to define areas of differing density in advance, then stratification of survey effort could increase precision (Buckland et al. 2001; Thomas et al. 2002).

1.2.4.2. Point transect sampling

In point-transect sampling, an observer visits a number of selected points, randomly localized in the area. The method is very often (but not exclusively) used for songbird populations, in which many species can be recorded and most detections are acoustic. The main point is that the observer can concentrate on detecting the objects of interest all around and does not have to move, navigate and follow a line through possibly less accessible terrain. The main drawbacks are:

- The detections made while travelling from one point to the next are not usable.
- Not very useful for rare species or those species that are generally detected by flushing them.
- Difficult to detect species that typically move their location markedly during the count (Thomas et al. 2002).

Density estimation

The distance of detection *r* is measured from the observer to each detected individual or cluster. As with the line transect, estimation of density from point distance sampling can be distinguished by using a special model in *DISTANCE* software (Buckland 1998, 2001; Thomas 2009) that we describe in an individual chapter.

1.2.4.3. *DISTANCE* software

DISTANCE software is a computer program capable of evaluating analyses of the type of distance data (Laake et al. 1993), which have been already previously described. It contains a graphical interface, where users can enter, import and view data, run analyses and get results. The program works with an algorithm for laying out samples (lines or points) in the study area and taking account perpendicular distances and sizes of clusters (Thomas 2009). It can provide much more than the estimates (e.g., confidence limits, goodness-of-fit tests, etc.) (Sutherland 2006). An important condition must be met to obtain reliable data by analysing it, with at least 40 observations of one species, but better 60-80 (Buckland et al. 1993). If there are not enough observations, Fryxell et al. (2014) recommend repeating the line survey until a sufficient amount of detected animals is recorded.

General assumptions

Sutherland (2006) describes that the first step in the analysis of distance-sampling data with exact measurements should be displayed in a histogram of the data and grouping the data into 10–20 distance classes as shown in Fig. 1. The reason is to check if the data have a “shoulder“ around zero rather than falling off sharply. In Fig. 2, there are a few examples of poor line transect data sets(Thomas et al. 2010).

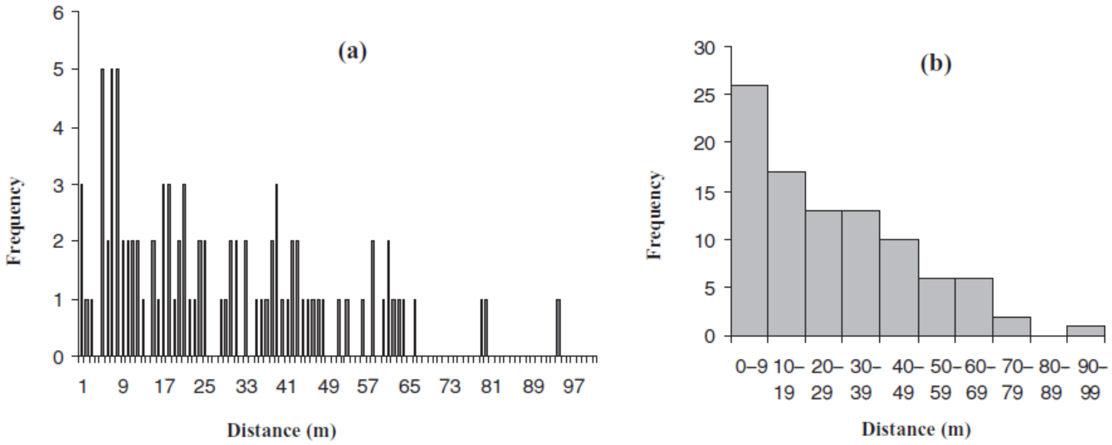

Fig. 1 Frequency distributions of simulated line-transect data: (a) detection distances as originally measured, to the nearest metre; (b) detection distances grouped into 10-m classes, to show the overall shape of the distribution more clearly. (Source: Sutherland 2006)

Also, the data should not be “heaped“ around values such as 0, 5, 10 etc. (as often happens if distances are not measured precisely, but only estimated). The histogram also enables observations of overly unique large distances to be identified and then excluded from the analysis, following the general principle of truncating the outlying 5 % - 10 % of observations (Sutherland 2006).

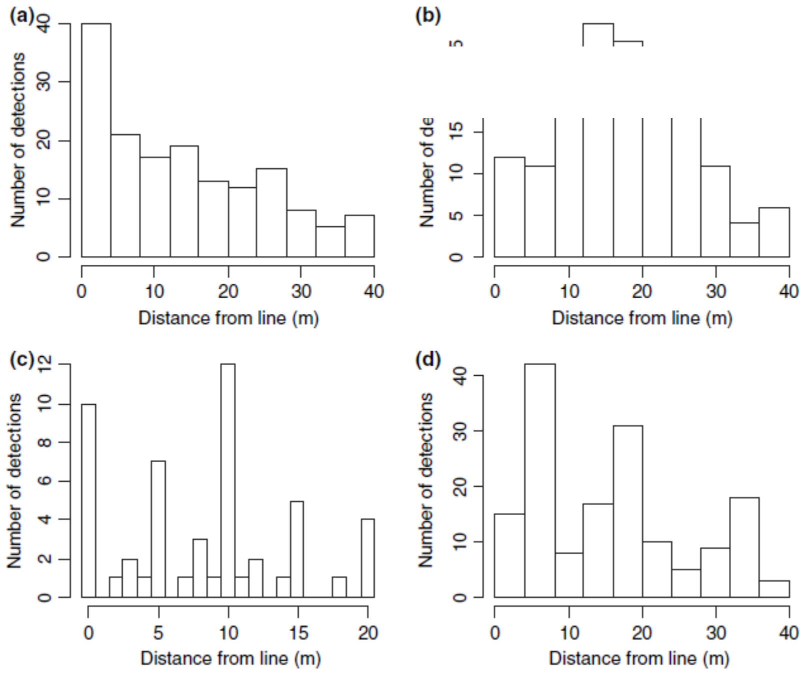

Fig. 2 Examples of poor line transect data sets: (a) spike at zero, (b) too few detections near zero, (c) rounding to favoured distances, (d) overdispersed data.

(Source: Thomas et al. 2010)

The Analysis Browser tools help users of the software to create and run analyses, set zone widths and truncation distances, select a model type, and specify the required outputs.

An analysis in *DISTANCE* combines three main components:

- A survey - specifying data layers and survey methods (e.g., point transects, line transects)
- A data filter - selecting data, truncation of distances, other processing
- A model definition - specifying by which engine, type of detection function model (e.g., half-normal with cosine adjustment) and by other specifications the data should be analysed. (Thomas et al. 2010; User's Guide Distance 7.3 Release 1)

Sometimes, two methods may be chosen to compare the results and decide for more adequate results with the lowest personnel commitment and resources. It can help to determine whether a population index well correlates with a more rigorous method of population estimation (Zero et al. 2013; Silveira et al. 2003)

1.2.5. Method reliability

1.2.5.1. Precision and accuracy

Each estimate is said to be accurate or unbiased if a large number of repeated estimates of density have a mean that does not significantly differ from the true density. Accuracy measures an error of bias, while the precision is a measure of sampling error.

Estimates are described as precise or repeatable if there is only a small scatter among the set of estimates. Both accuracy and precision should be maximized, but sometimes we have to select only one parameter according to the question which needs to be answered because it often happens that the set of estimation can provide quite precise estimates which are not accurate or vice versa. Most of the questions require precision than accuracy. Precision is usually reached by sampling efficiently when a rigid standardization of survey method is described and by working with a large sample (Fryxell et al., 2014).

1.2.5.2. Bias errors

Bias errors are usually caused by some systematic distortion in the counting method, observer´s skills or even behaviour of observed animals. Usually bias error occurs when the observer does not sample properly all habitats, respectively samples some areas more/less than others (e.g., waterholes, roads, etc.), the observer undercount or overcount animals in bigger groups, or does not detect animals hidden in vegetation, underwater, etc. (Fryxell et al., 2014).

According to Pollock and Kendall (1987), the best way how to measure bias error is to compare the census estimate with that from a known population. The experts review this method, along with the use of a subpopulation of marked animals, mapping with multiple observers, line transect sampling, and multiple sampling on the same area.

1.2.5.3. Stratification

Sampling intensity and variability of density among sampling units determine the precision of an estimate. Thus, if there are more distinct habitats in the area of survey differing significantly among each other (e.g., in vegetation density, altitude, water source, etc.), it is recommended to do the sampling in those habitats separately (= habitat strata). Also, a total abundance and/or density should be estimated separately for each habitat and combine it later, than to treat the area as one unit for the whole time (Thomas et al. 2010; Fryxell et al. 2014).

2. Aims of the Thesis

The aim of the thesis was to assess the suitability of selected ground-based animal counting methods for the long-term monitoring of large African ungulates in two fenced wildlife reserves located in Senegal, namely the Bandia Reserve and the Fathala Wildlife Reserve.

Distance sampling methods (i. e. line and point transect) and conventional methods with closed boundaries (i. e. strip, circle, square plot) were repeated in three different times of the day (morning, midday, late afternoon). The efficiency (mainly in terms of time, fuel, skills and manpower) of the method and accuracy and precision of the results were compared. The most suitable method and daytime were selected for each species and protocol for regular monitoring in following years has been created.

3. Methods

3.1. Study area

Both study areas, the Bandia Reserve and the Fathala Wildlife Reserve, are situated in western Senegal, in the Sahel zone (see Fig. 3). The local climate is influenced by InterTropical Convergence Zone (ITCZ) (Leroux 1970) which regulates two annual seasons, i. e. the dry season lasting from November to April/May and the rainy season lasting from May/June to October/November.

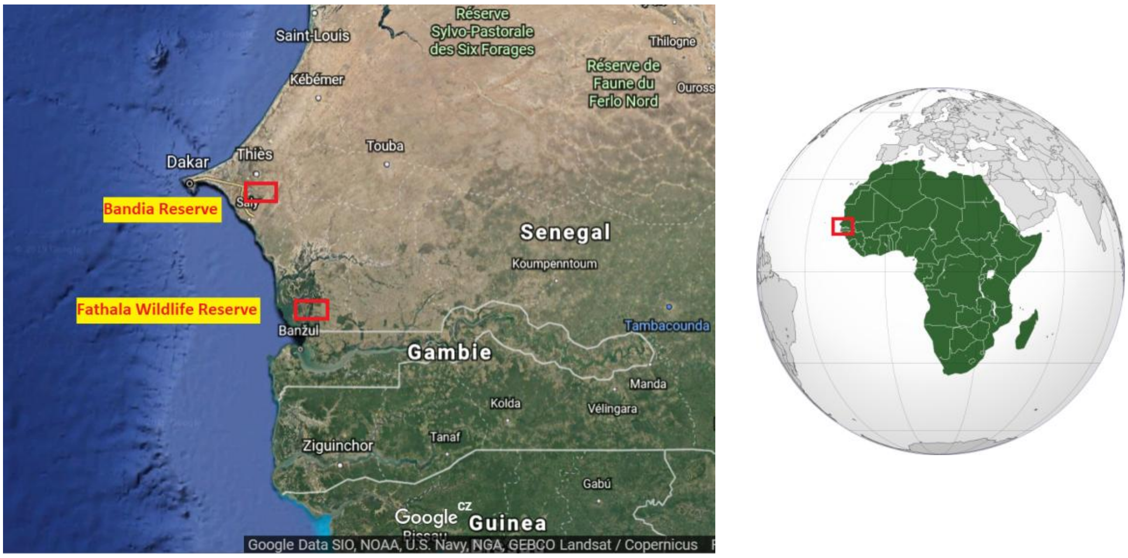

Fig. 3 Location of both study areas (a) in Senegal (b). (Source: a) Google Earth, b) Wikipedia)

3.1.1. Bandia Reserve

The Bandia Reserve is located approximately 60 km south-east of Dakar, the capital city of Senegal, and right between the towns of Sindia and Nguékhokh (GPS coordinates of the main entrance are: 17° 1' 5,438" W and 14° 33' 24,904" N).

The classification by Köppen and Geiger categorizes the study area as BSh (i. e. hot semi-arid climate). In the close city of Nguékhokh, the average annual temperature is 28.0 °C, January is the coldest month (around 23.2 °C), while the highest temperatures occur in June (around 29.7 °C). The month with the lowest level of average precipitation is February (0 mm), the highest in August (218 mm), and the average annual rainfall reaches around 549 mm (www.climate-data.org 1/3/2019).

In terms of vegetation types (see Fig. 4), it is predominantly *Senegalia ataxacantha-Vachelia seyal* bushland which covers the area (Lawesson, 1995). Namely, the dominant tree species are *Adansonia digitata, Azadirachta indica* and *Eucalyptus alba*, and the 5 main Acacia shrub species: *Vachellia seyal, Balanites aegyptiaca, Combretum micrantum, Feretia apodantera, Grewia bicolor, Tamarindus indica,* and *Ziziphus mauritiana* (Hejcmanová et al. 2010).

The relief is flat, and the temporary water flow called Somone, which passes through the reserve, is a very important water source for supplying the biggest of three artificial watering holes built to assure water for animals (Antonínová et al. 2004).

The whole area is fenced and covers in total 3,500 hectares, nevertheless, the part frequented by animals and used for touristic safari does not cover the whole area. A dense network of routes is created across the reserve and hundreds of visitors are driven by cars with a guide throughout the entire park area on a daily basis (33,000 visitors in 2001 according to Vincke et al. 2005).

Fig. 4 Various types of vegetation in the Bandia reserve.

3.1.2. Fathala Wildlife Reserve

The Fathala Wildlife Reserve that has been fenced since 2000 (Nežerková-Hejcmanová et al. 2005) is an area covering 2,330 hectares, and it is a part of the Fathala Forest in Delta du Saloum National Park on the western coast of Senegal and on the borders with Gambia (GPS coordinates of the main entrance are: 16°25'50.285"W and 13° 38' 27.732" N).

The climate classification according to Köppen and Geiger is the same as in the Bandia Reserve (BSh). The close city of Karang has an average temperature around 26.9 °C and annual rainfall of 774 mm. February is the driest month with 0 mm of precipitation, while the greatest rainfall comes in August (286 mm). The warmest weather is in October (28.3 °C) and the coldest in January with 24.4 °C. (www.climate-data.org 1/3/2019).

The local vegetation is principally represented by wooded grassland, woodland and Sudano-Guinean savannah with *Pennnisetum purpureum* and *Andropogon guayanus* in the undergrowth (Nežerková-Hejcmanová et al. 2005). Lawesson (1995) specified local trees and shrubs represented mainly by *Combretum nigricans-Prosopis africana* woodland, *Bombax costatum-Pterocarpus erinaceus* woodland, and *Piliostigma thonningii-Dichrostachys cinerea* thicket (see Fig. 5).

Fig. 5 Various types of vegetation in the Fathala Wildlife Reserve.

Although, the topography is largely flat, a wadi has been created in the northern part of the reserve by erosion from the superficial water crossing the area at the peak of the rainy season (July-September) (Jůnek et al. 2015). In the dry season, water is supplied artificially to two main waterholes.

3.2. Study animals

There are several species resident in the study areas, while some were translocated from the Niokolo Koba National Park (NKNP) and some were introduced from South Africa. A list of all species, their representation in the reserves and the origin is displayed in Tab. 1.

Tab. 1 List of monitored ungulates according to their place of occurrence and origin.

Species	**Reserve**	**Origin**
African Buffalo (*Syncerus cafer*)	Bandia Reserve, Fathala Wildlife Reserve	Niokolo Koba National Park
Southern Giraffe (*Giraffa giraffa*)	Bandia Reserve, Fathala Wildlife Reserve	South Africa
Derby eland (*Taurotragus derbianus*)	Bandia Reserve, Fathala Wildlife Reserve	Niokolo Koba National Park
Roan antelope (*Hippotragus equinus*)	Bandia Reserve, Fathala Wildlife Reserve	Niokolo Koba National Park
White rhinoceros (*Ceratotherium simum*)	Bandia Reserve, Fathala Wildlife Reserve	South Africa
Plain zebra (*Equus quagga*)	Bandia Reserve, Fathala Wildlife Reserve	South Africa
Warthog (*Phacochoerus africanus*)	Bandia Reserve, Fathala Wildlife Reserve	Resident
Common eland (*Taurotragus oryx*)	Bandia Reserve	South Africa
Greater kudu (*Tragelaphus strepsiceros*)	Bandia Reserve	South Africa
Impala (*Aepyceros melampus*)	Bandia Reserve	South Africa
Waterbuck (*Kobus ellipsiprymnus*)	Bandia Reserve Fathala Wildlife Reserve	Niokolo Koba National Park
Bushbuck (*Tragelaphus scriptus*)	Fathala Wildlife Reserve	Resident

Greater attention should be paid to the Western Derby eland *(Taurotragus derbianus derbianus*)(Fig. 6), whose wild population counting just 120-150 individuals currently occurs only in the area of the Niokolo Koba National Park and the subspecies is considered critically endangered by IUCN (2016). Two semi-captive populations are bred for conservation purposes right in the Bandia and Fathala Reserves. Thanks to the studbook and annual identifications of newborn Derby eland calves, a complete census of all individuals in both reserves is accomplished every year (Brandlová et al. 2013).

At the time of counting, there were 41 Derby elands included in the survey in the area of the Bandia Reserve and 18 individuals in the Fathala Wildlife Reserve. Besides the known numbers of the Derby elands, we also knew exact numbers of zebras (10), giraffes (7) and rhinos (1) in the Fathala Wildlife Reserve, and 2 known rhinos occurred in the Bandia Reserve.

Fig. 6 Female with a calf of the Western Derby eland.

3.3. Data collection

The survey took place from mid-January to mid-February, i. e. during the dry season. The sandy roads were easily accessible, and the vegetation was not so tall which is favourable for better visibility of animals. For our study, we applied ground-sampling monitoring methods in both reserves. The study was conducted by two less experienced, yet trained students, including the author of this thesis. During the sampling, one of us was driving a car and the other person was navigating, time tracking and recording all notes on a paper.

To apply the stratified sampling, both reserves were divided into 3 parts (i. e. zones) according to a different type of vegetation or a habitat structure. Their surface could vary and, also, we did not include fenced bomas and touristic basements in the survey area. We created a map in the Geo Tracker app by recording most of the roads in each reserve to allow for more efficient movement during the sampling. By using random point generator in ArcMap 10.5, we generated 6 random points mutual for point transects, circle transects and square plots, and 6 random points starting road transects or strips in each part of each reserve (i. e. 36 points per reserve). All the points were generated to be placed on roads in order to comply with the rules of the reserves forbidding to move away from the car, but also to enable an easier movement across the areas by the vehicle (see Fig. 7). The points for transects were at least 1 km apart to avoid overlapping.

The data were collected in 3 different daytime periods: morning (7:30 - 10:00), midday (12:00 - 14:30), evening (16:00 - 18:30). During the study period in the Bandia Reserve, sunrise came approximately at 7:37 a.m. and sunset at 7:07 p.m. Temperatures differed during the day. At 9:00 a.m. the temperature reached an average of 17.7 °C, at 12:00 p.m. the temperature was around 28 °C, and later, at 18:00 p.m. it was 27 °C on average (City of Mbour, WorldWeatherOnline 2019). Sun within our study period in the Fathala Wildlife Reserve rose around 7:22 a.m. and set at 6:55 p.m. The temperature at 9:00 a.m. was kept around 23.8 °C, in midday it was around 30.5 °C and later at 6:00 p.m. around 32.7 °C (City of Banjul, WorldWeatherOnline 2019).

Fig. 7 Observer with a vehicle used for the survey.

According to our study design, the aim was to visit each point/transect 3 times in all 3 daytime periods (i. e. 9 samplings per point per method), however, eventually we could manage only 2 repetitions (i. e. 2 repetitions of 3 daytime periods) of each method. In the Bandia Reserve, we did 3 repetitions of the road transects. For the list of coordinates of all points and transects see Appendix 1.

The total study area of the Bandia Reserve included in the counting covered around 1,434 hectares. The area was divided into the 3 following parts: **1) Northern Bushes** (343 ha) - a dense vegetation of *Vachellia seyal*, **2) Eastern Grasslands** (563 ha) - tree savannah and **3) Southern Old Part** (528 ha) -- trees and shrubs forming a light canopy. The map with the zone division and position of all transects and points are displayed in Fig. 8.

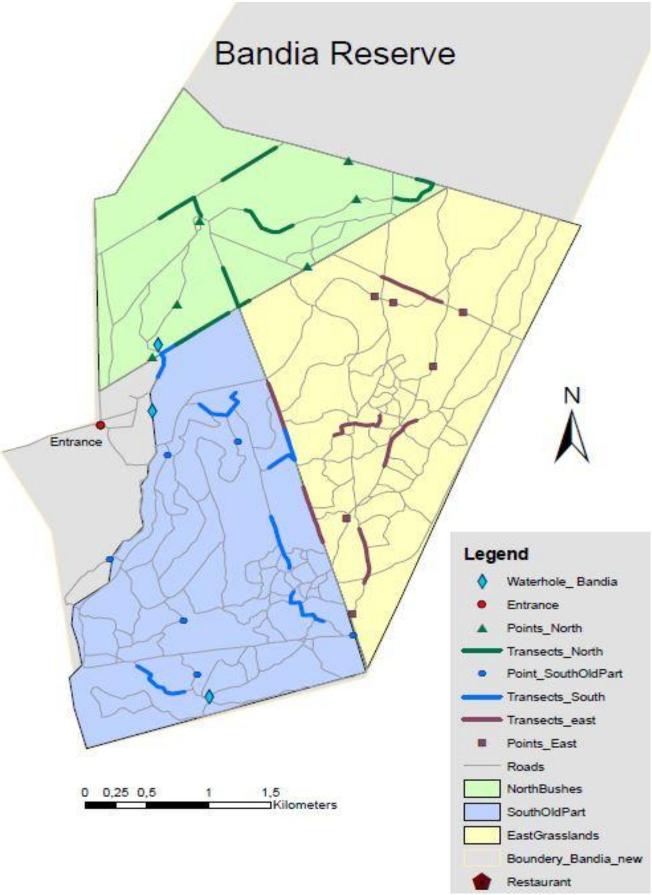

Fig. 8 Map of the study area stratified into 3 zones in the Bandia Reserve. (Created in ArcMap 10.6.1.)

The zones in the Fathala Wildlife Reserve covered in total 2,268 hectares. Their specifics are following: **1) Mare and Northern Plains** (540 ha)- wooded grassland/ woodland, **2) Southern Old Part** (572 ha)- Sudano-Guinean savannah, **3) Western New Part** (1,156 ha)- wooded grassland. Fig.9 shows a map of the study area.

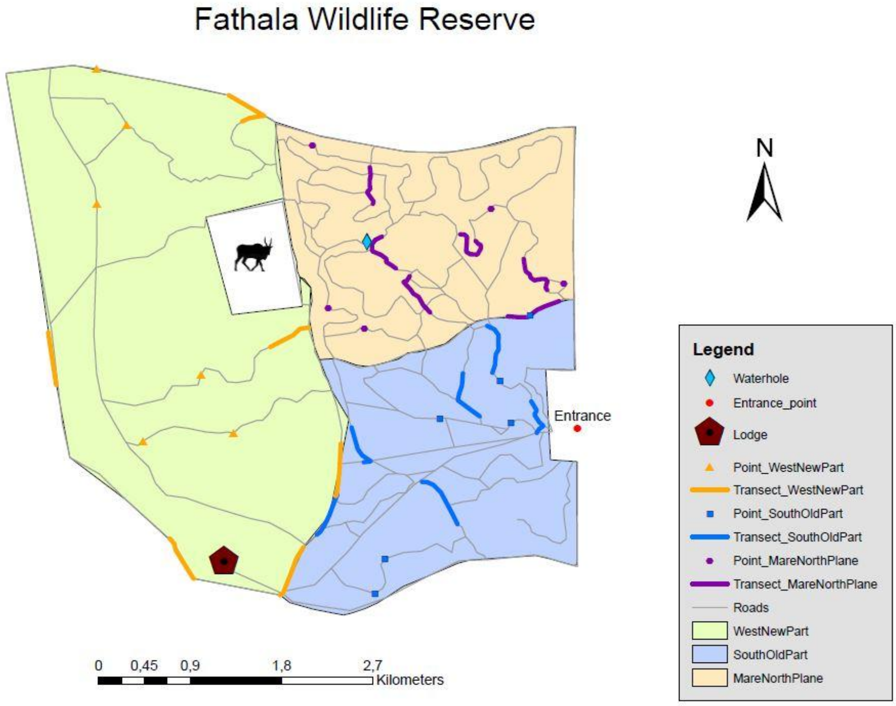

Fig. 9 Map of the study area divided into 3 zones in the Fathala Wildlife Reserve

(Created in ArcMap 10.6.1.).

3.3.1. Survey methods

Point transect

As already mentioned, point transects used for distance sampling were located at the same random points as the plots with closed boundaries- circle plots and square plots. One observer recorded all animals or clusters in 360˚ for 3 minutes and their distances from him (see Fig. 10). In case of detecting an animal group of the same species, we recorded the distance from the centre/ central animal of the cluster. As with all other methods, we used binoculars and a rangefinder.

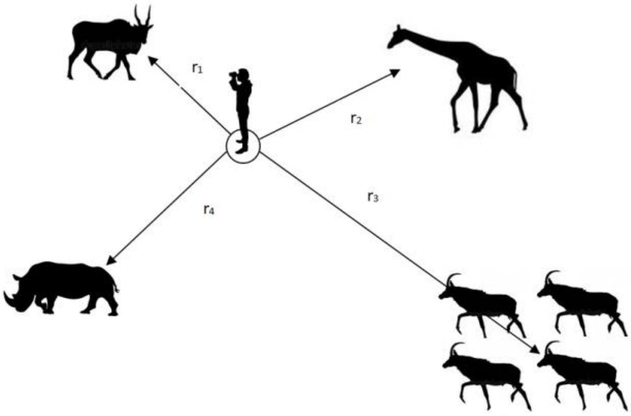

Fig. 10 An example of the point transect where the observer records all animals/clusters visible in 360°.

Circle plots

The data collected from the point transects were the same for the circle plots, but animals further than 100 meters were not included in data analyses (see Fig 11). Size of each circle reached 0.0314 km^2, so the total surface of the square plots in all 3 zones, 3 daytime periods with 2 repetitions covered 3.39 km^2.

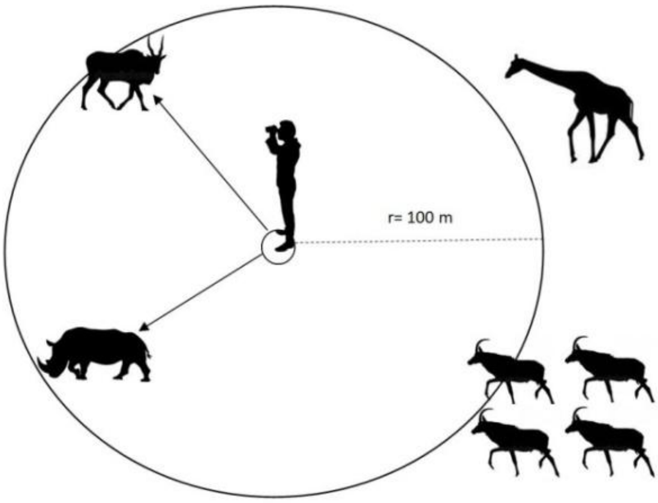

Fig. 11 An example of the circle plot with closed boundaries (r= 100 m).

Square count

Size of each square reached 0.01 km^2 (100 m × 100 m), which means that the total surface of the square plots in all 3 zones, 3 daytime periods with 2 repetitions covered 1.08 km^2. The orientation in space towards the starting point was always heading south-east (checked by compass). If this direction was not feasible to keep (e.g. due to borders with other zone or fence), we used other directions, preferably the south-west. For 3 minutes, one of the two observers recorded all individuals of each species occurring in the square (see Fig. 12).

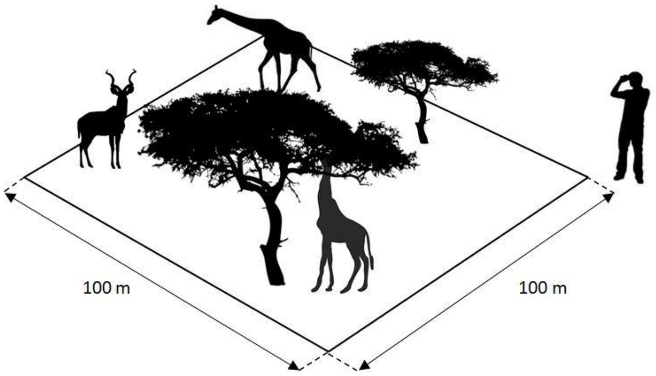

Fig. 12 An example of the square plot where the observation is done from one corner and only animals/clusters in the square (100 x 100 m).

Road transect

Transects were followed 500 metres along the roads in a car by speed of 7-10 km/h. Two observers (driver included) were detecting all animals or clusters, recording their distances (r_1, r_2, … r_i) and angles ($\theta_1, \theta_2, \ldots \theta_i$) to the vehicle to know perpendicular distances ($x=r \sin \theta$) (see Fig. 13). The distance and angle had to be recorded at the first sight when an animal was spotted. If the transect was between two zones, we counted only animals occurring on the side of the zone where the transect belonged to. Then only one observer searched for animals on that side.

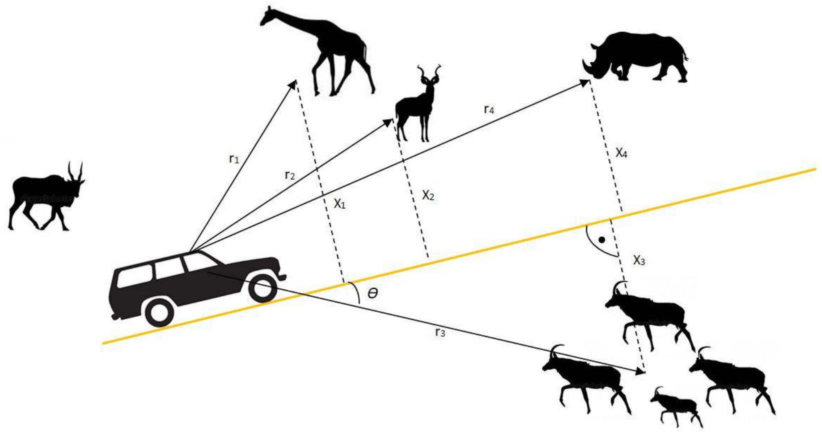

Fig. 13 An example of the road transect where distances and angles of animals/ clusters are recorded while observes are following the road for 500 m.

Strip count

For the strip transects, we used the collected data from road transect, but we excluded animals located further than 100 metres from the survey. All animals in the strip were supposed to be counted, and so we did not operate with distances and angles (see Fig.14).

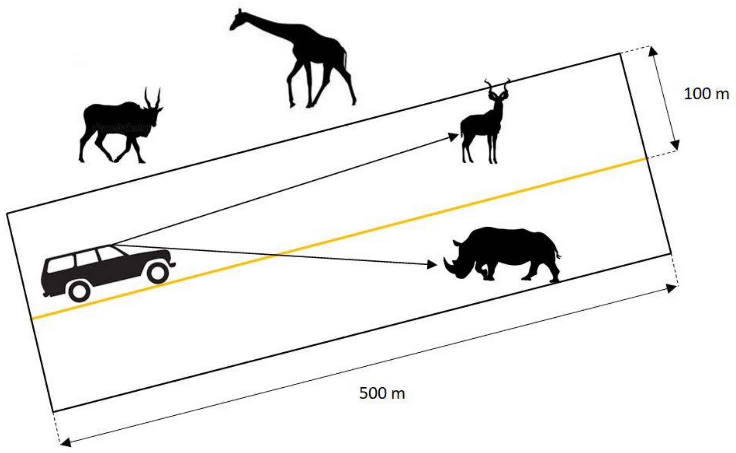

Fig. 14 An example of the strip transect where only animals in the strip of definite length and width are recorded.

3.4. Data analysis

3.4.1. Distance software

For the distance sampling analyses, we used the *Distance 7.3* software, specifically the *Conventional Distance Sampling (CDS) engine* (Buckland 2001). During our survey, in both reserves we did not obtain adequate sample sizes of most study species. Only the roan antelope (74 observations) and the cape eland (46 observations) surveyed by road transects in the Bandia Reserve could be evaluated by the Distance software.

To analyse the road transects, we divided the data according to different time slots, i. e. 3 long transects per reserve were created: 1) in the morning, 2) in the midday, 3) in the evening. However, initially some of the short transects were in between two zones, so we then reduced the length of those transect to half. In case of the Bandia Reserve, 4 transects were used for the survey only at one site, so the length of the long transect representing each daytime slot reached 24 km. In case of the Fathala Reserve, 6.5 transects were used only with half, so the one long transect representing one daytime slot reached 14.75 km of length.

According to Buckland et al. (1993), we selected these 4 models: 1) hazard-rate/cosine, 2) half-normal/hermite polynomial, 3) uniform/cosine, 4) uniform/simple polynomial. The formulas corresponding to these models are presented in the *User's Guide Distance* (Laake et al. 1992*).*

To run the analysis, it was necessary to know the total area, transect length, perpendicular distance, and the number of individuals observed. Following the advice of Buckland et al. (2001) we truncated 5% of the most remote observations to improve the fit.

3.4.2. Lognormal distribution

We used a Lognormal estimator which is suitable for estimating abundance in small samples (Milner-Gulland and Rowcliffe 2007) to analyse the data from the methods with closed boundaries (i. e. circle plot, square plot and strip count) divided into 3 daytime slots. For details of the analysis see Appendix 1.

3.4.3. Kilometric Abundance Index (KAI)

The analysis of the Kilometric Abundance Index evaluates numbers of animals observed in relation to the length of surveyed transects (in km). We used only the data obtained by strip count and applied following formula:

$$\mathrm{KAI} = \frac{\text{Number of presence sightings or signs}}{\text{Transect length covered (km)}}$$

(Buckland et al. 1993; Vincent et al. 1991)

4. Results

4.1. Bandia Reserve

4.1.1. DISTANCE software

From all ungulate species recorded during the distance sampling in the Bandia Reserve (by road transects: 233 observations, 589 animals; by point transects: 45 observations, 124 animals), only the cape eland (48 obs.) and the roan antelope (78 obs.) were counted in numbers as they had more than 40 observations (see Fig.15), which is the minimum possible number for processing the data in the Distance software (Buckland et al. 1993).

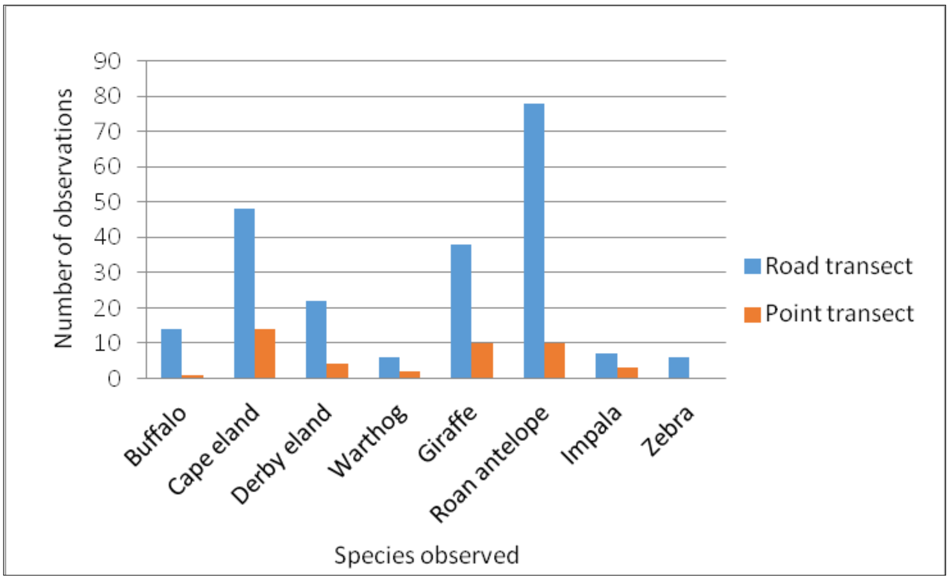

Fig. 15 Numbers of all species observations conducted by the distance sampling (i.e. point and road transects) in the Bandia Reserve.

The best models fitting the data were selected according to chi-square goodness of fit tests and by comparing the relative fit of the model functions using Akaike's Information Criterion-AIC (Buckland et al., 2001). For the data of the roan antelope, *uniform/cosine* model was used, while the model *uniform/polynomial* fitted to the data of the cape eland. Results about the mean herd sizes, estimate of abundance with the 95% confidence interval and density of both species are shown in Tab. 2.

Tab. 2 Estimation of mean herd size, the density and abundance with 95% confidence limit in species from the Bandia Reserve by Distance 7.3.

Species	Mean herd size (n)	Abundace estimate (n)	95% Confidence interval of abundance		Density (n/km^2)	Method
			Lower limit	Upper limit		
Roan antelope	1.64	48	32.00	73.00	3.38	Road transect
Cape eland	2.65	58	38.00	87.00	4.02	Road transect

4.1.2. Lognormal distribution

By the lognormal distribution, we were able to evaluate the mean herd size and abundance of 9 ungulate species which reached sufficient sample representation in at least one of all three methods of sampling (i.e. strip, circle or square plot). With the strip counts, we observed 227 clusters with 567 animals; in circle plots, there were 40 observations and 113 animals and in square plots, 38 observations with 104 animals included. The species observed were (sorted from the most abundant): Buffalo, Derby eland, impala, roan antelope, cape eland, giraffe, warthog, kudu and zebra. Neither rhino, nor waterbuck were observed for more than once, so we did not include any of their results to the final overview. Mean herd size was greatest in the buffalo and warthog, while the lowest (i.e. only 1 individual/cluster) was shown in kudu and roan antelope. According to the precision of the results, the best daytime slot and survey method were selected for each species (see Tab. 3...).

Tab. 3 Lognormal estimation of mean herd size, abundance with 95% confidence interval limit of species in the Bandia Reserve with the most suitable survey method and daytime slot selected.

Species	Mean herd size (n)	Abundance estimate (n)	95% Confidence interval of abundance (n)		Selected method (n)	Daytime period
			Lower limit	Upper limit		
Buffalo	6	134	38.56	468.72	Strip	Evening
Cape eland	2	54	13.15	219.96	Strip	Evening
Derby eland	3	81	20.82	312.45	Strip	Evening
Giraffe	2	42	11.02	158.85	Strip	Evening
Impala	3	72	12.94	397.28	Strip	Morning

Kudu	1	12	8.68	16.45	Strip	Midday
Rhino	-	-	-	-	-	-
Roan antelope	1	63	29.80	132.09	Strip	Midday
Warthog	6	39	2.88	524.28	Strip	Morning
Waterbuck	-	-	-	-	-	-
Zebra	2	12	0.50	285.32	Strip	Midday

4.1.3. Kilometric Abundace Index (KAI)

According to KAI, numbers of animals per kilometer were highest in the morning in 5 species (buffalo, cape eland, giraffe, impala and warthog), while the zebra and derby eland were counted more likely during the midday. Only the kudu is distinguished by the highest number of observations in the afternoon time slot. Simple overview is shown in Fig. 16 and more detailed overview is in Appendix 2.

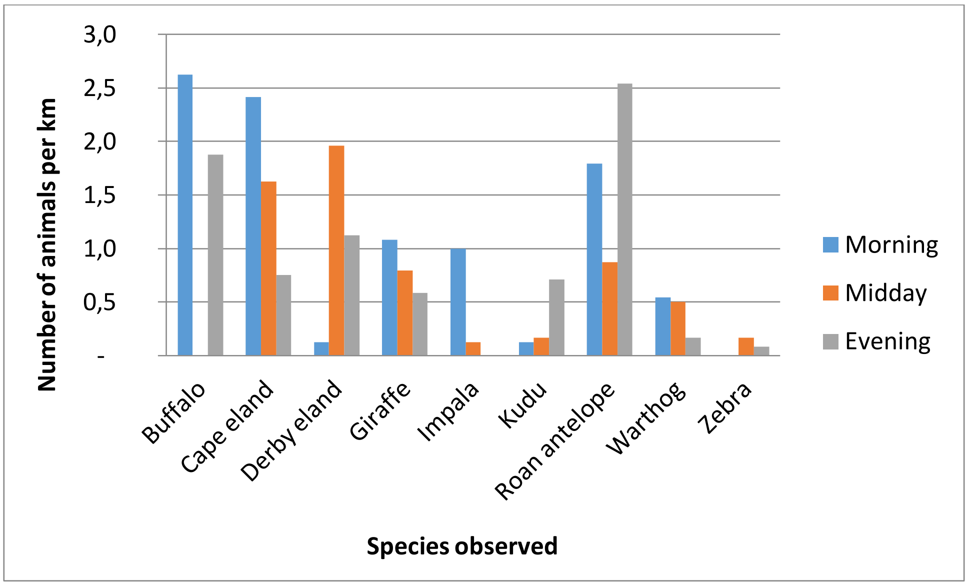

Fig. 16 Kilometric abundance index (n/km) of species observed in the Bandia Reserve in three different daytime slots.

4.1.4. Accuracy of results

To measure the accuracy of results, we used the known population size and compared it with the estimated abundance of this population. The only known population size in the Bandia Reserve which could be compared was the population of the Derby eland. However, the accuracy of the results from the lognormal distribution was about 51 % (See Tab. 4).

Tab. 4 Accuracy of strip transect method in estimating animal abundance in the Bandia Reserve.

Species	Reserve	Known abundance (n)	Abundance estimate by lognormal distribution (n)	Accuracy (%)
Derby eland	Bandia	41	81	50,62
Rhino	Bandia	1	not evaluated	-

4.2. Fathala Wildlife Reserve

4.2.1. DISTANCE software

When using the distance sampling in the Fathala Wildlife Reserve, we did not get enough observations in any species to evaluate the data in the *DISTANCE* software (by road transects: 43 observations, 140 animals; by point transects: 18 observations, 40 animals). A considerable amount of observations compared to other species was showed in the roan antelope with 23 observations in the case of road transects. The rest of observations did not exceed 7 per species. (see Fig. 17).

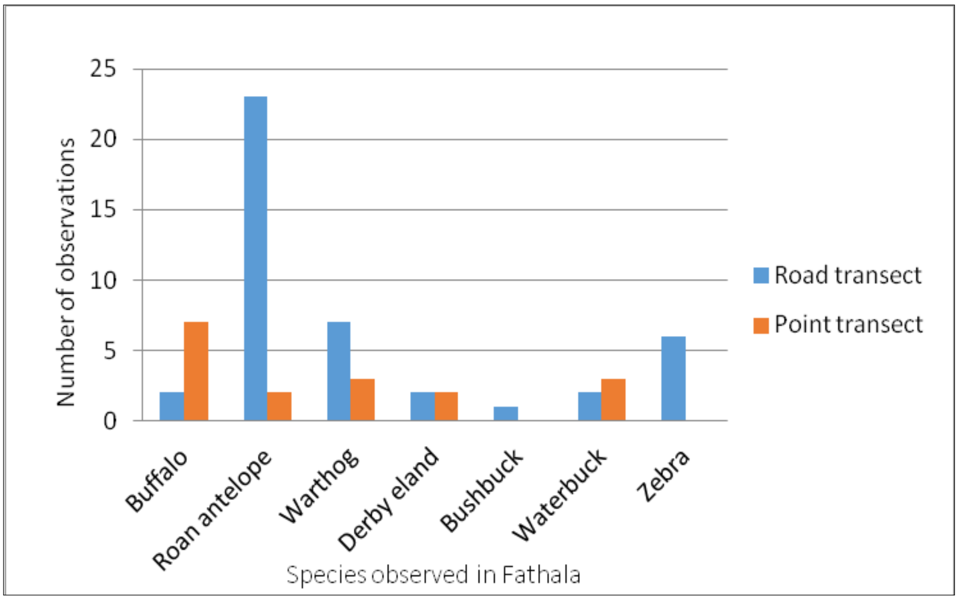

Fig. 17 Numbers of all species observations conducted by the distance sampling (i.e. point and road transects) in the Fathala Reserve.

4.2.2. Lognormal distribution

By the lognormal distribution, we could evaluate the mean herd size and abundance of 6 ungulate species which reached sufficient sample representation. With the strip transects, we observed 43 clusters with 140 animals; in circle plots, there were 14 observations and 31 animals and in square plots, 6 observations with 8 animals included. Those species are (sorted from the most abundant): Roan antelope, warthog, buffalo, zebra, Derby eland and waterbuck. Neither the bushbuck, nor rhino and the giraffe were observed for more than once, so we do not present any relevant results. Mean herd size was greatest in the warthog (3), the roan was estimated to be in a mean group of 2 individuals, while the rest of species were estimated to be solitary (i. e. only 1 individual). For all results see Tab. 5.

Tab. 5 Lognormal estimation of mean herd size, abundance with 95% confidence interval limit of species in the Fathala Wildlife Reserve with the most suitable survey method and daytime slot selected.

Species	Mean herd size (n)	Abundance estimate (n)	95% Confidence interval of abundance (n)		Selected method	Daytime period
			Lower limit	Upper limit		
Buffalo	1	40	32.20	49.86	Circle	Morning
Bushbuck	-	-	-	-	-	-
Derby eland	1	15	8.95	26.40	Strip	Evening
Giraffe	-	-	-	-	-	-
Rhino	-	-	-	-	-	-
Roan antelope	2	92	31.20	272.82	Strip	Evening
Warthog	3	69	15.47	309.58	Strip	Midday
Waterbuck	1	15	8.95	26.40	Strip	Morning
Zebra	1	23	18.80	28.29	Strip	Midday

4.2.3. Kilometric Abundance Index (KAI)

According to KAI, numbers of observations per kilometer in the buffalo, the roan antelope and the waterbuck were highest in the morning, the warthog was most commonly observed during the midday and the zebra and the Derby eland were counted more likely in the evening. Simple overview is shown Fig. 18 and more detailed overview is displayed in Appendix 3.

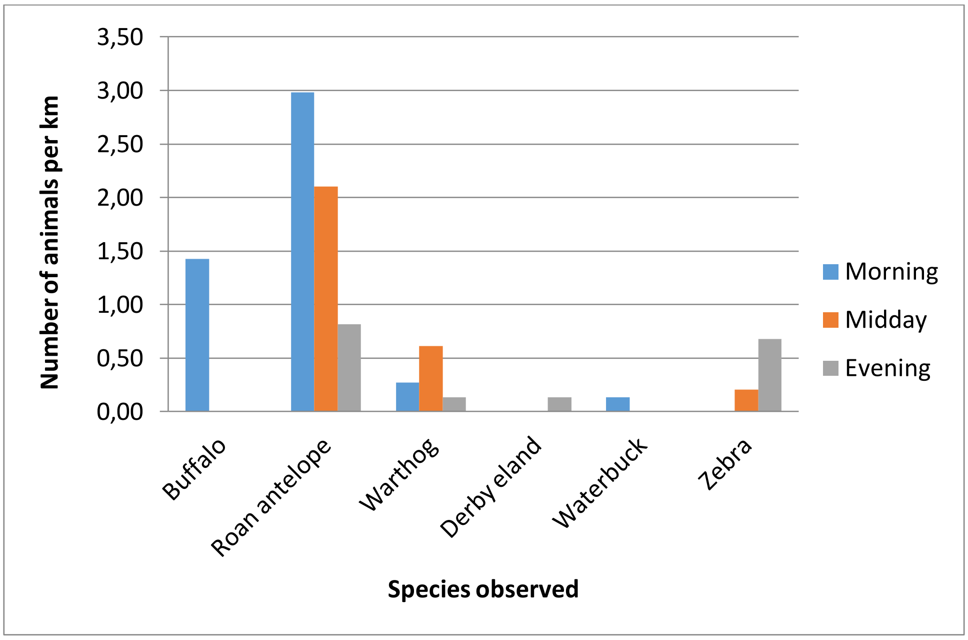

Fig. 18 Kilometric abundance index (n/km) of species observed in the Fathala Wildlife Reserve in three different daytime slots.

4.2.4. Accuracy of results

Accuracy of abundance estimates in the Fathala Reserve was possible to determined in the population of Derby eland and zebra. The abundance estimate by the lognormal distribution was quite accurate for the Derby eland, but less accurate for the zebra population (see Tab. 6).

Tab. 6 Accuracy of strip transect method in estimating animal abundance in the Fathala Reserve.

Species	Reserve	Known abundance (n)	Abundance estimate by Lognormal distribution (n)	Accuracy (%)
Derby eland	Fathala	18	15	83,33
Zebra	Fathala	10	23	43,48
Giraffe	Fathala	7	not evaluated	-
Rhino	Fathala	1	not evaluated	-

5. Discussion

5.1. Precision and accuracy of selected methods

As we wanted to determine precision of our results, the best way how to get this parameter, was to look at the 95% confidence limits of an estimate of abundance. This confidence interval basically says, that the chance that the true population size lies between the lower and upper limit is 95 % (Sutherland 2006). In the DISTANCE software, we could process only the data from road transect distance sampling of the roan antelope and cape eland for their sufficient number of observations.

Based on evaluating all the analyses results from the data sets obtained by the methods “strip count”, “circle plot” and “square plot”, the strip count can be consider ed as the most suitable method for counting all animals except for buffalo in Bandia (i. e. rather circle plot) and except species which were not observed more than once. We decided on the basis of 95% confidence interval, but we also looked at the numbers of observations and our own judgment according to reality. We have obtained the highest numbers of observations in both reserves using this method, and thus we have achieved the highest precision, as well as the ratio of time and area covered. At the same time, simplicity of the study design and analyses were the most favourable.

When comparing the results of the roan antelope and cape eland from both methods (distance sampling x strip counts), the confidence limit from the distance sampling showed more precise estimate of abundance than the confidence limit in the lognormal distribution of the data from strip. For example, in the roan antelope, the interval from the distance sampling estimated 32.00-73.00 of individuals, while in the by the strip an interval of 29.80-132.09 individuals. Also the estimation of the average herd size differs. In this case, the average herd size was larger from the distance sampling than from the strip count in both species. In the study of Ogutu et al. (2006) they came to almost opposite conclusion, that strip counts produced lower abundance estimates but higher precision than distance sampling.

Accuracy indicates how close the estimate is to its true value, on average (Sutherland 2006). Until we do not know the real population size, we can not evaluate the accuracy of our results. In our study, we knew real population sizes of several species, but we could estimate accuracy of results only in the population abundance of derby eland in the Fathala (88.33 %) and Bandia reserves (50.62 %) and the population of plain zebra in the Fathala (43.48 %). The results show that the estimates of abundance are still quite inaccurate even with the most precise method.

5.2. Financial costs

As far as financial demands are concerned, we could not really compare necessary costs for each method due to the need of the same equipment in all of them (i. e. ground vehicle, binoculars, laser range finder, compass, GPS navigation device). Also, the fuel cost for the car could not be evaluated. As we drove through the reserves, we did more methods in parallel and tried to save as much time and fuel as possible, thus it was not possible to divide those costs according to the different methods.

5.3. Study design and possible bias

Each method had its pros and cons. Whether sample size, poor feasibility, or low observation rates, all could lead to possible bias.

Road transect by distance sampling can cover as much surface as long as the animals are still visible, some individuals might even remain undetected by the observer, but to evaluate the data well, 3 fundamental assumptions need to be met (Buckland et al. 1993, 2001). The first assumption is that we should detect animals at 0 distance or very close to the platform (i. e. the vehicle) with 100% probability. When using the *DISTANCE* software, the frequency distribution displayed in histograms showed that most of our data did not have the “shoulder” as required. The two more assumptions are that the animals/clusters should be detected at their primary location and that the distances are recorded in precision. In our study, we were 2 observers only. One was driving and the other one was recording notes into a work sheet and navigating with help of a GPS device. As the speed of the vehicle was still around 7-10 km/h, at some moments when too many animals were observed at the same time, there was a great risk of some animals being overlooked or the distance estimates being poorly evaluated. Other authors always recommend using a laser range finder (Buckland et al. 1993; Sutherland 2006; Keeping et al. 2018), however we found this tool useless in most of the cases during the driving. When the car is moving, the range finder cannot focus on the exact point of an animal/cluster if it is hidden behind vegetation or if the animal is moving. Thus, before we started the survey, we trained to measure the distances well only by sight. Nevertheless, many distances may have been measured inaccurately, and thus create a possible bias. Also, it was quite difficult to use the binoculars for the driver when he had to watch curved roads. Even the other observer preferred not to use the binoculars in transects to have a wider view and not to miss animals in close proximity. Nevertheless, Keeping (2018) drove at the speed of 15-25 km/h during their study in Simanjiro plains of northern Tanzania, but they always stopped the car when target animals were seen to record all the distances and herd sizes. If animals fled before observers got to the perpendicular position, range measurements were made to a tree or shrub marking their previous location. Their car stopping technique would be appropriate for our case where we were only two people conducting the whole survey. On one hand, animals may escape before we reach them after many previous stops due to the high animal density, but on the other hand, most of the animals in both reserves are accustomed to cars, they are not responding to them if they are not too close. Thus, we would recommend trying both techniques for the future study design, i. e. with and without stopping the car during the transects and then decide for the better one.

With the **point transect**, the principal assumptions remain the same as for the road transects (Buckland et al. 1993, 2001), however in this method the observer stops and gets out of the car, has more time and wider view to look around, use the binoculars properly and record easily the distances with a laser range finder. Even animals which are not visible at the first sight, shy or well camouflaged can be found. However, a possible error can occur when the observer looks all around and overlooks the animals behind. Also, in comparison with the road transects, we did not get as many observations in the point transects as by following the roads for 500 metres, as the point transect can cover much smaller area.

The main point is that the distance sampling is a very useful survey technique which can enable a more accurate estimate of population abundance than other methods (Buckland et al. 2001), and is well applicable on African savannah mammals. On the other hand, it requires collecting a sufficient number of samples (i. e. recommended at least 40, but optimally 60-80) to get reliable results from the *DISTANCE* software

(Buckland et al. 1993, 2001, 2003). Many other studies had the same problem not only in heavily forested environments (e.g. Rovero and Marshall, 2004), but also in tropical deciduous woodlands (e.g. Jathanna et al., 2003) and even in open savannahs and grasslands (e.g. Ogutu et al., 2006). According to Caughlan and Oakley (2001), distance methods are more suitable for species occurring at moderate to low densities in areas where visibility varies considerably. For distance sampling in small areas, they recommend conduct several surveys to obtain adequate sample sizes or pool the data for example with those from previous monitorings (Sutherland 2006). However, in our case, no wildlife monitoring was conducted in any of the reserves before. For the Bandia Reserve, Al-Ogoumrabe (2002) reports a list of all ungulates imported from the Niokolo Koba National Park and South Africa, however he did not run any survey to compare with. Also, many of those ungulate species are not present in the reserve in these days. In the Fathala Wildlife Reserve, Jůnek et al. (2015) applied camera trapping for capture-recapture analyses and spatially explicit capture-recapture (SECR) to the closed population of the Western Derby eland only without using any survey method for other species.

For evaluating the **strip** and **circle plot** methods, we only sorted the data collected from the distance sampling (i. e. point and road transects) and did not include the animals observed further than 100 meters from the observers/platform to the data analyses. The surface covered by one strip count was 0.1 km^2 and the circle plot covered 0.0314 km^2. In general, these methods are easier to implement because it is not necessary to record the distances and angles of each individual animals/clusters, however it is assumed that all animals are observed in the given areas (Thomas et al. 2002). According to Caughlan and Oakley (2001), strip counts deserve serious consideration for surveying species living at high densities and forming large, open agglomerations. Thus, it may supplement the distance sampling to efficiently estimate densities of rare, abundant and highly clustered multi-species of African savannah mammals.

The last method, i. e. the **square plot** covering the smallest area (0.01 km^2) per point proved to be the least suitable for our study areas. With this method, we collected the least amount of samples in both reserves of all methods and from a feasibility point of view, it was hard to estimate the square boundaries always at the same location as the previous sample collection. However, the advantage of this technique was that the observer looked in the same direction and, therefore, there was a lower chance to miss many animals.

Thomson et al. (1998) have summarized the basic considerations and trade-offs in selecting a plot design. Long strips, for example, may allow for more precise estimates, but square plots have less edge effect. Sutherland (2006) also mentions an importance of choosing a right size of a sample plot. If the plots are too large, it requires huge effort, when plots are too small, it tends to include individuals standing on the boundaries. Plot size depends largely on the biology and distribution of the species being studied and its environment. Nevertheless, no single design is optimal for all situations, so it is recommended to try several designs in a pilot study (Thomson et al. 1998).

As we could see in our two study areas, in some parts the visibility was quite high and even plots with borders 200 m × 200 m would be applicable, however some parts were too densely vegetated to be able to see animals even 50 meters far. But after all, the precision of the overall estimate depends on the square root of the number of replicate samples. Thus, to halve the width of the confidence interval, the number of replicates needs to by quadrupled. It means that it is the number of samples that determines the precision of one’s estimate, not the sampling fraction (Sutherland 2006). In addition the importance of a right sample size, it is also recommended to think about variations in population density across the study area according to different types of habitat (Sutherland 2006; Morrison 2014;). For this case, we stratified each study area into 3 zones by some basic knowledge about the area, vegetation density and animal density. However, even in each strata, some variation in vegetation and thus animal density occured.

5.4. Selection of daytime slot

When comparing the KAI (Kilometric Abundance Index) with the lognormal distribution results, the daytimes where the KAI was highest showed an overestimation of animals in the lognormal (compared to the known population size of a few species). Thus, for our overall evaluation we principally use those results estimated by the lognormal distribution. However, the KAI can still be used in preliminary studies to determine sites with the highest animal density for other possible techniques (i. e. live trapping, distance sampling etc.) in the wildlife management (Buckland et al., 1993).

Generally, most of ungulate species are more active during the early morning hours and later in the afternoon, whereas resting during the hottest day period, but daily activities also highly depend on animal ecology, season, weather conditions, nature of habitat, etc (Estes 2012). However, there are always some species specifics which should be considered when planning a survey design (Bothman 2001).

For example, the **buffalo** is night-active, but it has a grazing period also in the morning, and it usually rests from midday till 4 p.m. (Mloszewski 1983). In our study, the best time for observing buffalo was in the evening (Bandia) and morning (Fathala). **Warthog** has its feeding peaks in early-morning and late-afternoon, but it grazes also between resting/sleeping time of about 1 hour (Clough and Hassam 1970). From our results, the morning slot in the Bandia and the midday slot in the Fathala were the most suitable to see this species. According to Estes (2012), the white **rhino** is more active in the morning and evening but during the hottest periods it lies out on the sun. During our sampling, we did not have any observation of the rhino in Bandia nor in Fathala, so we could not estimate any time period. **Giraffe** usually spends the first and last 3 hours of the daylight by feeding and the hottest periods in between these feeding hours are spent by resting and ruminating (Estes, 2012). We can confirm this statement from the sampling in Bandia, where the giraffes were active during the evening time slot. **Elands** activity varies through the day as they are one of the most mobile antelopes which move a lot to find a feeding spot (Estes 2012). We selected the evening time slot for both the cape elands and the Derby elands in both reserves. The **plain zebras** spend most of the day by active grazing, dustbathing, drinking, etc. and they rest irregularly (Klingel and Klingel 1966). The midday was, however, the time slot where we gained the most reliable results. In **bushbucks**, we could not estimate any suitable daytime period. Munthali and Banda (1992) also talk about the difficulties of estimating its population during daytime due to its semi-nocturnal feeding habits. According to Estes (2012), the **impala** is more active during the day by grazing, and when resting, it is standing in the shade. In the Bandia Reserve, we selected the morning time as the best one for the survey. Activity of **waterbucks** is variable during the day and night (Castelló 2016), however, we selected the morning time slot in both reserves. **Roan antelopes** and **greater kudu** are both more active during mornings and afternoons and they stay in the shade over the hottest time (Castelló 2016). In the Bandia Reserve, the kudu and roan antelopes were rather observed in the midday, while the roan antelope in the Fathala Wildlife Reserve is considered to be surveyed better in the evening.

As we can see from the results, we must take into account that we worked with a small sample and some animals were observed infrequently compared to others, thus it may not reflect the actual species activity in the reserves. Also, the animals are artificially fed every morning in the Fathala in usual places, and in the Bandia in random places.Threfore, this can cause some unnatural pooling of animals in one place at the same time. To determine a uniform time slot of day for all the animals in the reserves for future monitoring, we recommend conducting a survey during the late afternoons according to the highest rate of reliable results which we already discused, but also because the animal movements are not artificially influenced by feeders. In addition, the number of visitors is decreasing this daytime.

6. Conclusions

The strip count was selected as the most suitable monitoring method for African ungulates in the Bandia and Fathala reserves. We decided for this method according to the reliability of collected data and its precision, field feasibility, but also the simplicity to analyse the results. By the distance sampling methods, we did not reach a sufficient number of samples in any species, except the roan antelope and cape eland in the Bandia Reserve. However, after comparing the precision of both methods by using 95% confidence limit of abundance, the distance sampling was more precise. The Kilometric Abundance Index (IKA) simply indicated when animals were most observable, but the results did not coincide with the precision of the abundance estimates, therefore we chose the most suitable time for a survey - late afternoon according to the lognormal distribution. For future monitoring, we recommend setting a clear study aims and creating a well-prepared study design. Adjusting the ideal number of strips, as well as the number of repetitions that may ensure a sufficient number of observations and thus more precise/accurate results are crucial. Also, the size of the strip should reflect vegetation density and animal species specifics, because this technique assumes 100% detection probability. Equally important is precise work in the field, especially highly valued are observers skills and adequate working tools.

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Appendices

List of the Appendices:

Appendix 1: **Summary of parameters and derivations using lognormal estimator**

Appendix 2: **Kilometric abundance index in the Bandia Reserve**

Appendix 3: **Kilometric abundance index in the Fathala Wildlife Reserve**

Appendix 1: Summary of parameters and derivations for population size using lognormal estimator (Milner-Gulland and Rowcliffe 2007)

	Parameter	Derivation
Total study Area	A	GIS
Survey area	a	(Transect length * width)
Proportion of area surveyed	p	a/A
Number of groups detected for best estimate of Mean group size	gt	Raw data
Mean Group Size	s	Raw data
Number of groups seen on transect	g	Raw data
Total number of groups estimated in study area	G	g/p
Total Number of individuals estimated in study area	**N**	**sG**
Variance in number of groups	Var(G)	Gp(1-p)/p^2
Variance in number of individuals	Var(N)	N^2(var(G)/G^2+var(s)/s^2
95% CI For X(either G or N) , log-normal 95% confidence intervals(lcl/ucl) are given by d=exp{t√var(ln*X+) **(t = Student's t)**	d (Group d (Po estimate) var[ln(G)] var[ln(N)]	=exp(t√var[ln(G)]) =exp(t√var[ln(N)]) =ln(1+[var(G)/G2]) =[var(G)/G2]
Lower confidence limit Groups		G/d
Upper confidence limit Groups		G*d
Lower confidence limit Number		**N/d**
Upper confidence limit Number		**N*d**

Appendix 2: Annex Kilometric abundance index (n/km) of ungulate species observed in the Bandia Reserve in three different daytime slots (morning, midday, evening) in concrete numbers.

Species	Morning (n/km)	Midday (n/km)	Evening (n/km)
Buffalo	**2,63**	0,00	1,88
Cape eland	**2,42**	1,63	0,75
Derby eland	0,13	1,96	1,13
Giraffe	1,08	0,79	0,58
Impala	1,00	0,13	0,00
Kudu	0,13	0,17	0,71
Roan antelope	1,79	0,88	2,54
Warthog	0,54	0,50	0,17
Zebra	0,00	0,17	0,08

Appendix 3 Kilometric abundance index (n/km) of ungulate species observed in the Fathala Wildlife Reserve in three different daytime slots (morning, midday, evening) in concrete numbers.

Species	Morning (n/km)	Midday (n/km)	Evening (n/km)
Buffalo	**1,42**	0,00	0,00
Roan antelope	**2,98**	2,10	0,81
Warthog	0,27	**0,61**	0,14
Derby eland	0,00	0,00	**0,14**
Waterbuck	**0,14**	0,00	0,00
Zebra	0,00	0,20	**0,68**