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Abundance and spatio-temporary distribution of the buffalo (*Syncerus caffer*, sperman, 1779) in Garamba National Park (Haut Uele, DRC)

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ABSTRACT
Objective: The aim of this study is to analyse the composition, abundance, and distribution of buffalo in Garamba National Park. To achieve this, a wildlife inventory was conducted, encompassing both terrestrial and aerial surveys.
Methodology and Results: The results indicate a total of 4 675 buffalo detected during 150 ground encounters, compared to 2 457 from 38 aerial observations. The terrestrial survey reveals a sighting rate of 63% in the grassy savannah and 31% in the shrubby savanna. Blocks 4,5,7,8 and 9 recorded the highest numbers, with 741 buffalo, while Muki reported only 23. In aerial observations, sector GB3 accounts for 47,36% of sightings, with 18 encounters, whereas blocks 10 to 14 host 690 buffalo, representing 28,08% of the total. The density is established at 0,911 buffalo per km² for terrestrial surveys and 0,478 for aerial surveys, with significant abundance indices in marshy areas and grassy savannas. The distribution of buffalo is primarily concentrated in the southern part of the park, near the Gangala hunting area.
Conclusion and Application of results: This study highlights a notable buffalo population, underscoring the urgent need for adaptive habitat management to protect this key species and guide future conservation strategies.
Keywords: Abundance, spatio-temporary distribution, buffalo.

INTRODUCTION

In the Democratic Republic of Congo, buffalo populations are returning to the forests, a phenomenon that follows five years of monitoring and evaluation carried out by the European Union in collaboration with CIFOR-ICRAF (Joel Masimo Kabuanga, 2024). These animals, once abundant in the late 1990s, had declined significantly due to intensive hunting, particularly during the civil wars that ravaged the country until 2003 (Bland *et al.,* 2016;

IUCN, 2010). The Garamba National Park, located in HautUele province and covering 5,130 km², is notable for its varied fauna, including 11 species of primate, 15 species of carnivore, 20 species of artiodactyl, as well as the aardvark (Flora &Ngoi, 2004; Smith, 2018;). Unfortunately, this biodiversity has been severely impacted by poaching, exacerbated by the region's political instability. For example, the buffaloes, which numbered around 60,000 in the 1970s, now stands at just 4,000 (Bland *et al.,* 2016; ICCN, 2010; IUCN, 2019). The park is also home to a large number of small mammals (rodents, bats, insectivores), with a total estimated at 130 species. Notable species include the Congo giraffe and the elephant, while the northern white rhino (*Ceratotherium simum cottoni*) is now extinct, its population having fallen to four individuals in 2007 (Smith, 2018). There is also a rich diversity of birds, with 285 species. The park is located on the boundary between forest and savannah, offering contrasting landscapes and a variety of species unique to these two ecosystems (IUCN, 2010; Vergnes, 2012). This partly explains the presence of the Garamba dwarf buffalo. However, scientific studies on this species are still scarce, leaving a fragmentary bibliography of biological and ecological research on the park's buffalo (Greyling, 2007; Liesel Laubscher, 2012; Winterbach, 1998). Nevertheless, buffalo play a crucial ecological role, particularly in the regeneration of vegetation (Timothy Rondwel, Roy G. Bengis, 2001). This species is of considerable importance to tourism, as it is part of the Big Five Game (Caro &Riggio, 2014). In addition, it is essential to have up-to-date data on animal species and populations (Caron, 2023; Corne *et al.,* 2013). To achieve this, it is crucial to have precise knowledge of the composition of the communities still present. Proper management of fragments of animal populations also requires the identification of taxonomic groups with a view to their conservation (Rabeil & Rabeil, 2004). However, as a result of habitat loss, the majority of large wild animals are now confined to protected areas, such as national parks and nature reserves (Kadjo *et al.,* 2014). Hunting pressure and the loss of natural habitats remain unbearable for many confined species, many of which are threatened with extinction (E. Anderson Bitty; Sery Gonedele Bi; Jean-Claude Koffi Bene, 2015). Among animal communities, mammals, and in particular large mammals, are the most affected by human activities (Ouattara et al., 2009). The African buffalo, *Syncerus caffer*, stands out as one of the large herbivores capable of tolerating a variety of climatic conditions and habitats, as long as it has a sufficient water supply (Cyrille-joseph et al., 2020). This mammal displays greater morphological variability than most other African mammals, in terms of body size, weight, coat colouration and horn dimensions (Venter, 2006). Unlike buffalo in other regions, such as Ethiopia (Megaze & Balakrishnan, 2017), South Africa (Ryan, 2010; Ryan & Getz, 2018; Venter, 2006), Benin (AZANLIN, 2015; Mouzoun, 2019) Nigeria (Edem Eniang, 2018; Owolabi *et al.,* 2020) and Côte d'Ivoire (Cyrille-joseph et al., 2020; Kadjo et al., 2006; Koffi et al., 2019), information on buffalo in the Democratic Republic of Congo is scarce. This led to the initiative of carrying out a study on the behaviour and ecology of savannah buffalo in Garamba National Park, with the aim of responding to the conservation challenges facing this species in this habitat. This study focuses on the composition of buffalo herds, as well as their abundance and spatio-temporal distribution within Garamba National Park. This issue constitutes the main question of our study. The general objective of this study is to determine the composition, abundance and spatio-temporal distribution of buffalo in Garamba National Park. This will enable us to generate recent qualitative and quantitative data on these animals.

MATERIALS AND METHODS

This study was carried out in the Garamba National Park, located in the HautUele province, at an altitude of between 600 and 1,240 metres, at latitude 4.2000° N and longitude 29.1833° E. The Garamba National Park, located in the Haut-Uélé region in the north-east of the Democratic Republic of Congo, covers an area of 5,130 square kilometers. It is bounded by the Garamba and Dungu rivers, and shares its borders with the Lantoto National Park to the south. Its geographical coordinates lie between 4°30' and 5°30' north latitude, and between 29°30' and 30°30' east longitude. The park encompasses a variety of ecosystems including savannahs, forests, rivers and hills, and is surrounded by three hunting areas: Mondo missa, Gangalanabodio and Azande. Renowned for its exceptional biodiversity, it is home to a wide variety of animal and plant species, including elephants, giraffes and buffalo.

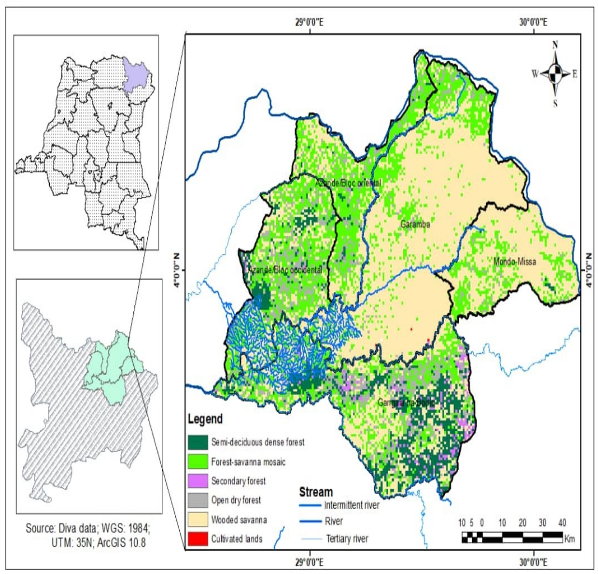


Figure 1: The map of Garamba National Park

Materiel: The biological material consists of different populations of buffalo in the Garamba National Park.

Technical equipment: The observation equipment consisted of a reflex camera used for taking images and a pair of binoculars for the precise identification of individual buffalo from a distance. The geolocation equipment consisted of a GPS device used to record the geographical coordinates of the sampled sites and observation points. In addition, we used other equipment such as:The TOYOTA Land cruiser vehicle fitted with an odometer: for transport and land tracking; GPS(Garmin ETREX 32X and Garmin GPSMAP 65s): for taking coordinates for field observations;And Husky Savannah (CESNA) for aerial tracking

Methods

Study sites:

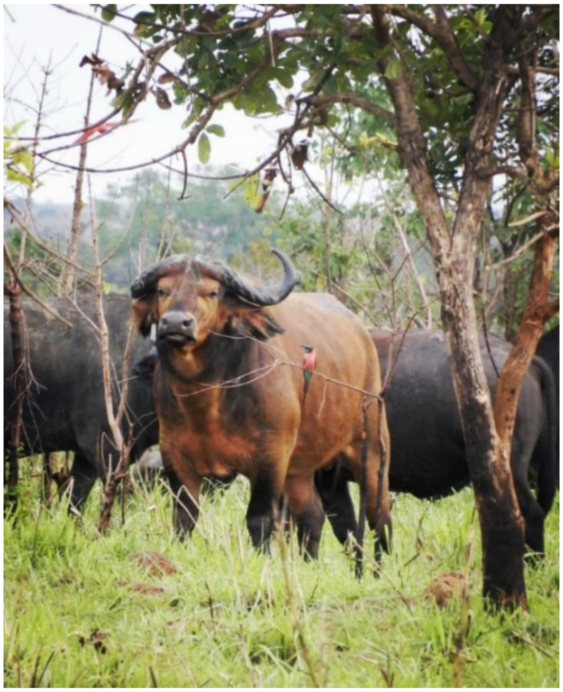


Figure 2: Buffalo (*Syncerus caffer*). Photo taken in Garamba National Park. Source:Kakule Kambere Prosper in September 2024

Data collection was carried out throughout Garamba National Park, following tracks subdividing the patrol sectors using a Land Cruiser L037 vehicle, in order to ensure ground surveillance of buffalo. In total, twelve sectors, comprising ten blocks and two patrol sectors, were defined over the entire area of the park, representing a total sampling effort of 2,857.05km. It should be noted that, given the topographical and hydrological irregularities of the areas studied, the length of the routes per sector varies. Garamba National Park is predominantly savannah.

Figure 3: Ground monitoring track for buffaloes in Garamba National Park.

Progress of buffalo surveys in the park: The inventories were carried out in two stages: Ground surveillance and aerial surveillance. The first, carried out by a team of at least five people, including two park rangers and three researchers from the monitoring team, involved following the tracks by vehicle. The members of this team were tasked with observing the buffalo directly, collecting data on these observations, estimating distances and recording geographical coordinates, while describing the environment. A network of tracks was established to facilitate the surveys in the patrol areas. During the raids, only direct observations of buffalo were taken into account, with signs of presence such as droppings and footprints being discarded to ensure a more accurate interpretation of the results. For each encounter with a buffalo or a herd of buffalo, the geographical coordinates were recorded, as well as the distance between the herd and the track, the time of the encounter, the direction and the activity of the group, making it possible to produce maps of the distribution of buffalo in Garamba National Park. The frequency of encounters and the count of individuals per group provided information on the kilometre indices of abundance and the density of buffalo populations in the park. To do this, the entire park was divided into twelve sectors, with track lengths varying according to topographical and hydrographic conditions. Using an odometer, the total distances covered on each run were recorded, measuring the difference between the point of arrival and the point of departure. As a result, at the end of 31 land surveillance runs, carried out between 17 January and 25 September 2024, a total of 3,266.1 km was covered, i.e. an average of 105.35 km per run at an average speed of 20 km/h. The surveys totalled 164 hours and 08 minutes of effort over the nine months of the study, with an average duration of 5 hours, 17 minutes and 44 seconds per run. The tracks were used to monitor the patrol sectors, running from the Nagero station to the end of each patrol sector, forming a closed-loop network during each land-based monitoring operation. The second part of the study inventory was carried out by aerial surveillance aboard a helicopter. This aerial team, made up of a pilot and park scientists, was dedicated to recording direct observations of buffalo, while respecting the procedures established for ground monitoring. The park was divided into four areas: Nagero- Gangala, Nagero-GB3, Nagero-Blocs 10 to 14 and Nagero-Parc. The positions of the buffalo were recorded and geo-referenced using a GPS, making it possible to estimate the number of buffalo per herd at each encounter, which was done by aerial counting.

Figure 4: Aerial view of Garamba National Park during aerial surveillance [Photo A(on the left) taken during our investigations in September 2024. Source: Kakule Kambere Prosper. Photo B (on the right) taken by the park's Biominitoring team. Source: J. Kasogho].

Information on the type of habitat in which each herd was seen was also recorded.

The results of this inventory method were largely influenced by weather conditions, particularly visibility, and by the type of habitat in which the buffalo were found at the time of the observations. In the course of nine overflights carried out between 17 January and 25 September 2024, a total distance of 2,448 km was covered, i.e. an average of 272 km per overflight at an average speed of 138 km/h.

Data Analysis: Estimation of buffalo densities in Garamba National Park:

Buffalo densities were estimated on the basis of data on total numbers, which were plotted against the surface area of Garamba National Park.

Density $=\frac{N}{S}$with N:Total number of buffaloes inventoried= park surface area.

Spatial distribution of buffalo in Garamba National Park: The geographical coordinates of encounters with buffalo herds were used to produce maps of the spatial distribution of this species within Garamba National Park. Encounter rates were determined based on the monitoring tracks, followed by a summation to establish the average number of encounters per track. These coordinates were used to produce thematic maps illustrating the distribution of buffalo by superimposing layers of shape files.

Estimation of the kilometric Index of Abundance in the Garamba National Park: The Kilometric Abundance Index (KAA) is an indirect measure of the size or status of an animal population, based on the number of animal signs observed per unit of time or distance in a defined area. The choice of tracks to explore is particularly important, as the spatial distribution of animals and watering holes can influence the results obtained. In this study, once the existing tracks had been explored and the distance covered estimated, the kilometer index was calculated using a specific formula:

$$IKA = \mathbf{n/l}$$

Where **n: the** total number of observations and **l:** the total distance travelled (in kilometers).

Principal component analysis of buffalo preferred habitats: Several species are sensitive to changes in habitat, even on a very small spatial scale. Based on the KAIs calculated for the different vegetation types, the buffalo's preferred habitat was determined using principal component analysis (PCA). PCA is a descriptive factorial statistical method whose objective is to present, in graphic form, the maximum amount of information contained in a large data table. In the present study, PCA was used to group the different zones according to buffalo encounter rates in the different habitat types. The aim is to find out which habitat is preferred by buffalo in Garamba National Park.

Statistical tests and analysis: The chi² test was used to compare the abundance of buffalo by age class during the dry and rainy seasons, and the non-parametric Kolmogorov-Smirnov test was used to compare the distribution of buffalo according to the different sectors patrolled. The various tests were carried out using Excel 2016 and SPSS software. Frequency calculations and elementary analysis were carried out using R software. The R software also enabled us to perform principal component analysis.

RESULTS AND DISCUSSION

Presentation and interpretation of results : In Garamba National Park, the buffalo studied belongs to the subspecies *Syncerus caffer brachyceros*. They were observed in grassy savannahs, shrublands and, occasionally, in swamps. Figures 3 illustrate the frequency of encounters with these buffalo in the different environments where we carried out ground and aerial surveys.

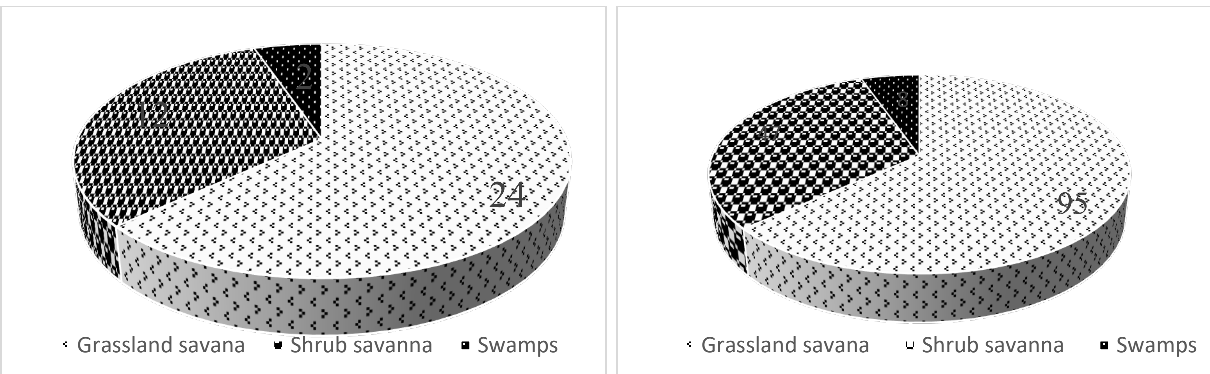


Figure 5: Places where buffalo were encountered during ST (left) and SA (right).

The results for buffalo encounter sites show a similar general trend for both ground and aerial surveillance. During the ground surveillance, the encounter rate was 63%, corresponding to 95 encounters out of 150 in the grassy savannah, 31% (47 encounters) in the shrub savannah, and only 5% (8 encounters) in the swamps (standard deviation= ±43.57752). Aerial surveillance also recorded 63% of encounters with buffalo in the grassy savannah, i.e. 24 out of 38, and 32% (12 out of 38) in the swamps (standard deviation = ±10). The environments in which the buffalo were encountered were therefore similar according to the surveillance methods used. In all, the study recorded a total of 2,457 buffalo during the 38 aerial surveillance encounters, compared with 4,674 buffalo during 150 ground surveillance encounters.

The composition of buffalo herds in Garamba National Park: Buffalo groups made up of two or more individuals are referred to as family units. During aerial observations, these units were detected 36 times, representing 94.7% of the 38 total detections. Considering the total number of buffalo observed using this method, i.e. 2,457, it appears that 99.9% of individuals live within family units, while 0.081% are found alone. In terms of land observations, family units were seen 111 times, corresponding to 74% of the 150 detections recorded. Here, the total number of buffalo was 4,674, indicating that 99.16% of them lived in families, while 0.84% were solitary. Figures 4 illustrates the situation of families according to the two inventory methods.

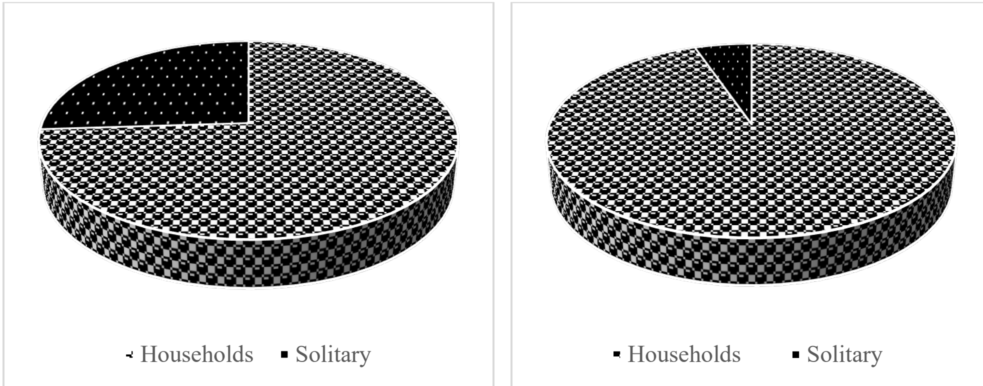


Figure 6: Family organization of buffalo herds during ST (left) and SA (right).

The family units observed had a modal size of two individuals, with five detections during aerial surveillance, representing 13.15% of total detections (N= 38), and twenty-one detections during ground surveillance, or 14% (N=150). The average size of the family units was estimated at 65.85 individuals (standard deviation = ± 68.126242; N= 36), with a maximum of 415 individuals per herd during aerial surveillance. On the other hand, for ground surveillance, the average size was 37.92 individuals, with a maximum of 350 individuals per herd.

Abundance and density of buffalo in Garamba National Park: In this study, we sought to determine the abundance of buffalo in Garamba National Park and to estimate the density of buffalo populations in this protected area. For terrestrial monitoring, the park was divided into twelve patrol sectors. Table 1. Shows the different patrol sectors during ground surveillance and the frequency of encounters with at least 1 buffalo in these patrol sectors.

Table 1: Sectors patrolled during ground surveillance.

Sector patrolled	Number	Frequency
Baroko	5	0,033
Bloc 1à9	4	0,026
Bloc 4_5_7_8	19	0,126
Bloc 5_6_7_8_9	28	0,186
Bloc5_6_7_8_9_10	10	0,066
Bloc5_6_8_9	3	0,020
Muki	4	0,026
Parc	40	0,266
Triangle	8	0,053
Triangle-Bawes.	13	0,086
Triangle-Bloc4	9	0,060
Triangle-Wil.	7	0,046
Total	***150***	***1***

Source: Kakule Kambere Prosper in September 2024.

Table 1.Ci. -It shows that 40 of the 150 buffalo encounters were in the heart of Garamba National Park and that the lowest frequency of buffalo encounters was during the monitoring of block 5_6_8_9 with only 3 encounters of at least 1 buffalo. The abundance of buffalo in Garamba National Park therefore varies from sector to sector. A total of 4674 buffalo were counted throughout the national park, with the highest number of buffalo being 741, or 15.84% of the total number counted during the surveys of blocks 4_5_7_8_9. The lowest number was recorded during patrols in Muki, with 23 buffalo. The average number of buffalo counted per patrol sector was 389.5 (standard deviation= ± 290.5557). In addition, aerial surveillance made it possible to divide the park and its hunting grounds into 4 aerial surveillance sectors, which made it possible to achieve the frequency of encounters with buffalo herds shown in Table 2.

Table 2. Sectors overflown during aerial surveillance.

Sector	Number	Frequency
Block 10 à 14	5	0,131
Block 1_2_3_4	7	0,184
Gangala_na_bodio	8	0,210
GB3	18	0,473
Total	***38***	***1***

Source: Our investigations in September 2024.

According to the data in Table 2. Above, the sector where encounters with buffalo were most frequent was GB3 with 18 encounters, i.e. 47.36% of encounters recorded during aerial surveillance (N= 38). On the other hand, the sector with the highest number of buffalo recorded was blocks 10 to 14, with 690 buffalo, i.e. 28.08% of the total number of buffalo recorded during aerial surveillance (N= 2,457). The lowest number of buffalo was 500 recorded in the Gangala_na_bodio sector, which accounted for 20.35%. The average number of individuals per patrolled sector was 614.25 buffalo (standard deviation = ± 85.46491). The density of buffalo was estimated by taking the total number of buffalo on the ground (4674) divided by the total surface area of the park (5130km²), excluding the hunting grounds. Thus, for ground surveillance, the density was 0.911 buffalo per km² and for aerial surveillance, with a total of 2457 individuals, the estimated density was 0.478 buffalo per km². Taking the average value of these two monitoring methods, the average number of buffalo inventoried in Garamba National Park is 3,565.5 individuals. The density in relation to this average number gives us 0.695 buffalo per km² (standard deviation = ± 0.1238568).

Spatial and temporal distribution of buffalo in Garamba National Park: In order to understand the spatial dynamics of buffalo herds within Garamba National Park, we recorded the geographical coordinates of the points of encounter with at least one buffalo. These coordinates were used to produce maps of the spatial distribution of buffalo in Garamba National Park during the study period. The maps were adapted to the two monitoring methods. The same study parameters were observed during aerial and ground surveillance. The maps below show how buffalo were spatially distributed during our investigations using aerial surveillance (left) and ground surveillance (right).

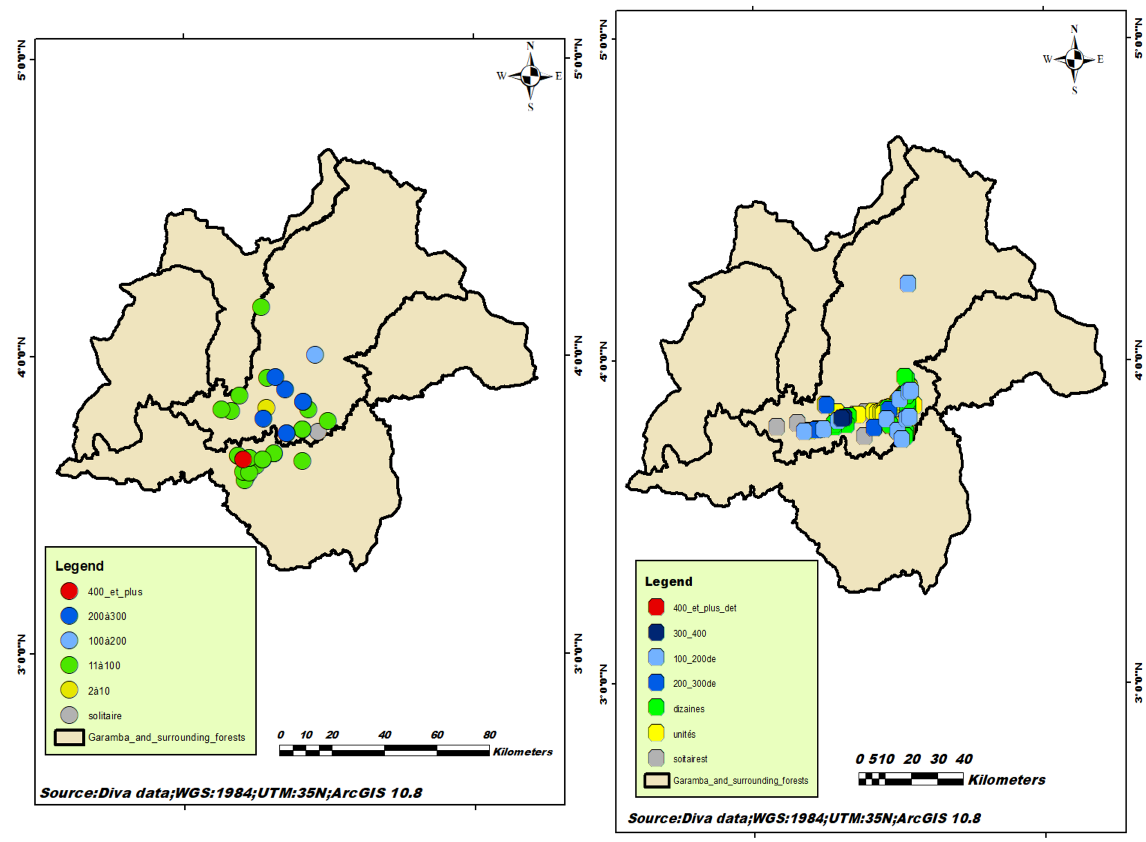


Figure 7: Maps of the spatial distribution of buffalo in Garamba National Park.

The data on these maps show the spatial distribution of buffalo during the study period according to the different monitoring methods used during the study. All of the buffalo populations that were seen in the park during ground and aerial surveillance made it possible to detect other herds in the most remote parts of the park, hunting grounds close to the park. During aerial surveillance, buffalo were abundant in the southern part of the park and near the northern part of the Gangala_na_bodio hunting area. This method did not allow us to distinguish males from females and solitary buffalo were very rare during this stage of our study. However, during ground surveillance, all the herds seen were in the heart of the park, but the buffalo were spread out on either side of the surveillance tracks. Temporal distribution refers to the way in which the buffalo herds were distributed within the park at different times of the year, and it was possible to visualise this aspect of the study using cartography. The maps below show the evolution of the buffalo herds within the park during the first, second and third quarters of the current year.

The First quarter :

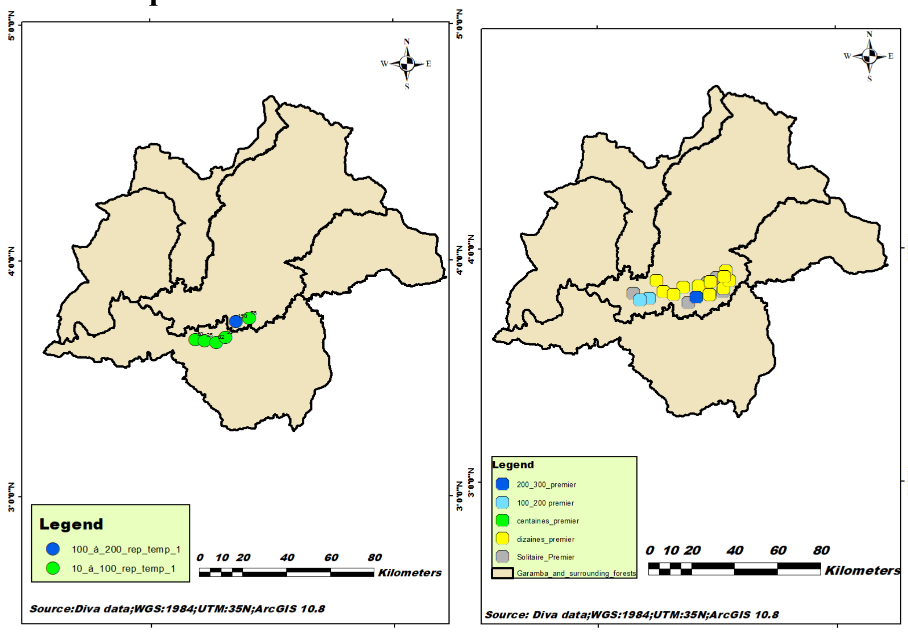


Figure 8*:* Buffalo dynamics in the first trimester during SA (left) and ST (right*)*.

In the first quarter, aerial surveillance enabled herds of 10 to 100 buffalo to be spotted in the Gangala-na-bodio hunting area, and two herds were spotted in the extreme southern part of the park, one with a herd size of 100 to 200 buffalo and the other with a herd size of 10 to 100 buffalo. As for ground surveillance, all of the herds were sighted in the park, with numbers of 10 to 100 individuals per herd being encountered more frequently, and solitary individuals were scattered here and there throughout the southern part of the park. Numbers of more than 100 individuals per herd were very rare at this time of year.

The second quarter:

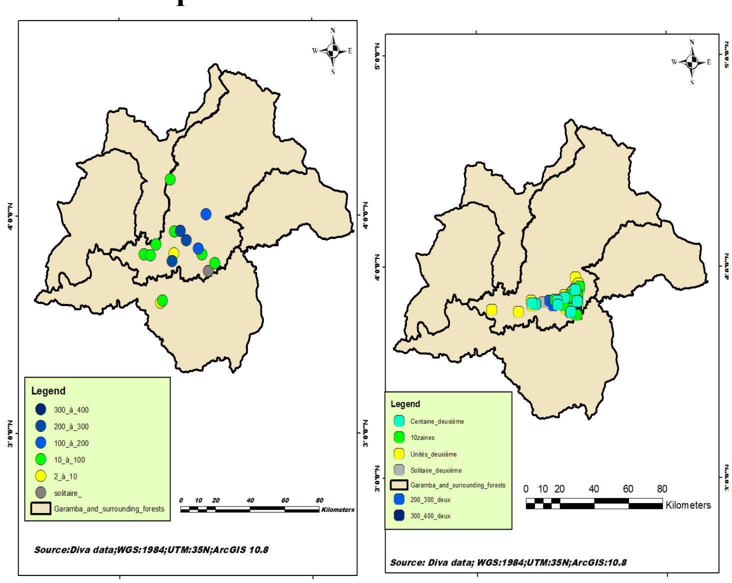


Figure 9: Buffalo dynamics in the second quarter during SA (left) and ST (right).

In the second quarter, the herds spread from the south of the park towards the central part and the north. Buffalo numbers fell considerably in the Gangala_na_bodio hunting area, where two herds were sighted, one with between 2 and 10 individuals and the other with between 10 and 100 individuals. The trend in buffalo movements is that they move from south to north during the second quarter of the year. During ground surveillance, we observed massive movements of buffalo herds from the south towards the centre of the park and south-east towards the Mondo misa hunting area. Only a few solitary individuals are seen in the southern part of the park, but the large herd formations are moving from the south either towards the western part of Mondo misa or towards the northern part of the park.

The third quarter:

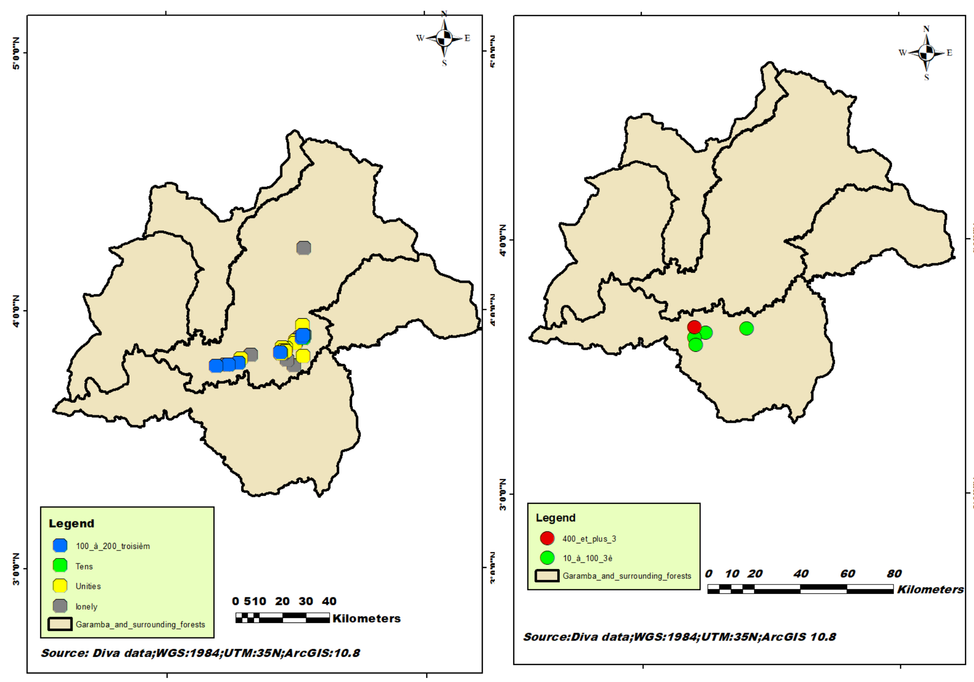


Figure 10: Buffalo dynamics in the third quarter during SA (left) and ST (right).

In the third quarter, the buffalo once again covered the entire park. The south of the park, which is the area where buffalo were most frequently encountered, began to receive herds from the centre and north. Large herds of over 400 individuals were seen in the Gangala_na_bodio area and other small herds of between 10 and 100 individuals were visible in the area thanks to aerial surveillance. During the ground surveys, a few buffalo were seen in the north, but large mixed herds were seen from the south-east to the south-west.

Ecological factors influencing buffalo dynamics in Garamba National Park: One of the specific objectives of this study was to understand the ecological factors that influence the distribution and range of buffalo in Garamba National Park. Habitats, i.e. the types of vegetation and/or environments in which we had direct encounters with buffalo, were therefore considered to be essential elements in this study. Buffalo were mainly found in grassy savannahs (SH), shrub savannahs (SA) and a few herds in swamps (MA). The KAIs were calculated on the basis of observations made in these different types of habitat and according to the type of method used, including terrestrial surveillance (ST) and aerial surveillance (SA). Results relating to kilometre indices of abundance. In each of the following habitats, the data collection methods used are summarised in the table below.

Table 3: Kilometer indices of abundance by habitat type

Méthode	Habitat	Buffle	Km parcourus	IKA
ST	MA	200	73	2,73
	SA	738	935,5	0,78
	SH	3735	2257,6	1,65
SA	MA	102	332	0,30
	SA	468	226	2,07
	SH	1887	1890	0,99

As the IKA is the chance of encountering a buffalo per kilometer travelled, it can vary depending on the environment and, above all, the distance travelled. Thus, in sectors where long distances were travelled, the quotient of abundance per distance travelled would appear to be minimal compared with sectors where little distance was travelled. For terrestrial monitoring, with 73 km covered in a marshy environment, the IKA was 2.73 and in the shrubby savannah we recorded an IKA of 0.78. The grassy savannah, where descents were more frequent, had an IKA of 1.6. The kilometer indices of abundance also varied according to the method of monitoring; through aerial monitoring, the IKA of the marshy areas fell to 0.3, in the shrubby savannah IKA=2.07 and in the grassy savannah 0.99. The IKAs observed using our two inventory methods were not significantly different in the different habitats (p-value = 0.4575) and as the two methods covered the same area, we calculated the average IKA values by habitat type. In swampy areas, the average IKA was 1.515 buffalo/km (standard deviation = ±1.718269). In the shrub savannah, the average IKA was 1,425 buffalo/km (standard deviation = ± 0.9121677) and finally in the grassy savannah there was an average IKA of 1,275 buffalo/km (standard deviation = ± 0.5303301). To determine the buffalo's preferred habitat within the set of different habitats, we performed a PCA. The aim of this principal component analysis is to study the variability of buffalo individuals in the different habitats, but also to study the link between buffalo abundance, the distance travelled during the surveys and the kilometer indices of abundance. The first two axes of this PCA explain 99.3% of the total variability for aerial surveillance and 99% for ground surveillance.

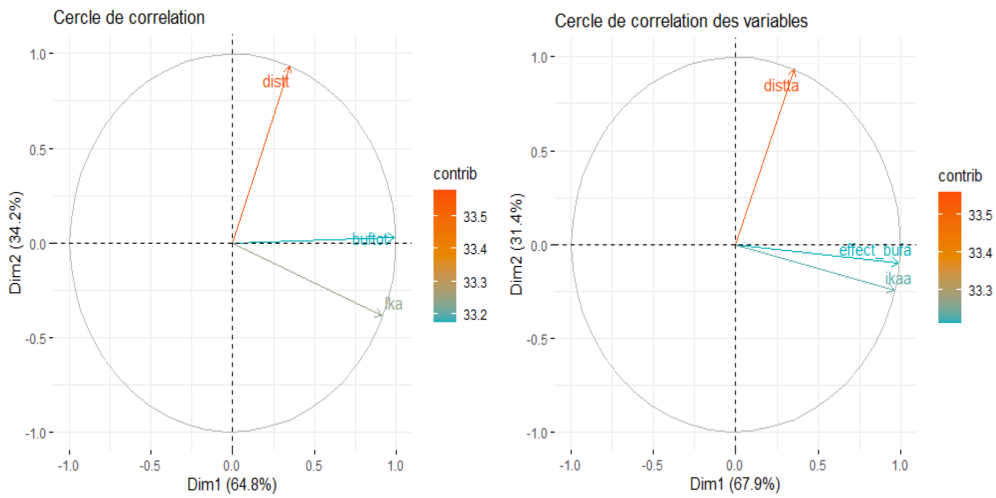
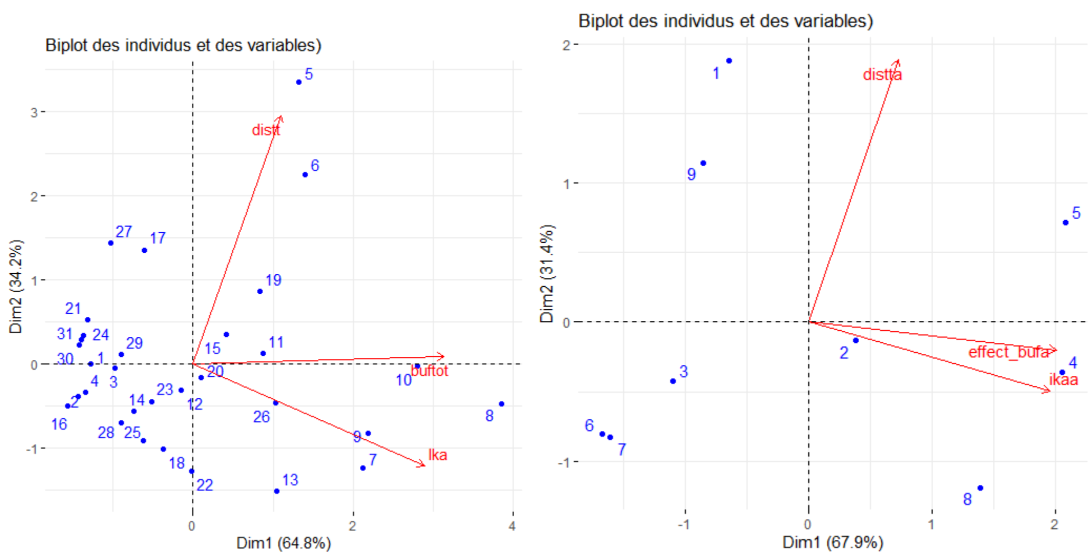


Figure 11: The relationship between the variables abundance, distance travelled and IKA during ST (left) and SA (right).

The spatial traces of the components show that the IKA and distance travelled variables are highly correlated on the first axis, while buffalo abundance is highly correlated on the second axis. Buffalo numbers therefore vary according to the distances travelled, and these two variables determine the kilometer index of abundance (graph left). However, the results of the aerial surveillance showed a degree of independence between the IKA variables and distance. But everything is related to the number of buffalo in the area. Travelling long distances allowed the most buffalo to be seen, and the greater the abundance of buffalo, the higher the kilometer indices of abundance (graph right).



Figures 12: The cloud of points indicating the buffalo's preferred habitat superimposed on the variables observed during ST (left) and SA (right).

Grassy savannah (HS) is by far the preferred habitat of buffalo, followed by shrub savannah, which are the two habitat types that had good orthogonal projections on the two principal components of the PCA. In fact, the AMs are much more centred around the area where the two principal axes meet, and are therefore the habitat type least represented in the PCA.

DISCUSSION

This study was carried out in Garamba National Park, focusing on the inventory of the savannah buffalo species. Two methods of data collection were used: ground surveillance and aerial surveillance. During aerial surveillance, 2,457 buffalo were observed in 38 encounters, while ground surveillance recorded 4,674 buffalo in 150 encounters. The buffalo encounter rate was 95 out of 150 in the grassy savannah (63%), 47 out of 150 in the shrub savannah (31%), and only 8 out of 150 in the swamps (5%). Aerial surveillance revealed that 24 of the 38 encounters (63%) had taken place in the grassy savannah, 12 in the shrub savannah (32%), and 2 in the swamps (5%).The study area was characterised by grassy and shrubby savannah vegetation, interspersed with a few swamps. The ground survey revealed a maximum of 741 buffalo (15.84%) in blocks 4, 5, 7, 8 and 9, while the lowest number was recorded in Muki with only 23 buffalo. The average number of buffalo per patrol sector was 389.5 (standard deviation = 290.56). In terms of aerial surveillance, sector GB3 had the highest number of encounters (18 out of 38), while blocks 10 to 14 had a total of 690 buffalo, representing 28.08% of the total observed. The minimum number of buffalo was 500 in the Gangalana Bodio sector. A previous study carried out in Odzala National Park by C. Chamberlan and colleagues estimated the population of forest buffalo, revealing a significant density but highlighting threats linked to hunting and habitat degradation (Chamberlan & Maurois, 1998). Similarly, research carried out by Kadjo *et al.* in 2020 in the Comoé National Park indicated a total population of 2,306 buffalo, showing that density is influenced by factors such as habitat and hunting pressure. The data obtained in our study in Garamba National Park exceed those in Comoé Park, partly thanks to improved collection methods and sustainable management of the Garamba ecosystem, which benefits from a reduction in anthropogenic activities. Finally, the density of buffalo was estimated at 0.911 buffalo per km² for ground surveillance, and 0.478 buffalo per km² for aerial surveillance. Taking into account the total number of buffalo and the surface area of the park (5,130 km²), including hunting grounds. This information is crucial for the conservation of the species and the management of the park's ecosystems. Taking into account the average value of these two monitoring methods, the average number of buffalo inventoried in Garamba National Park is 3,565.5 individuals. The density in relation to this average number gives us 0.695 buffalo per km² (standard deviation = ± 0.1238568). The high density of a species is not necessarily due to its abundance, it can also be due to a high activity of a species within the protected area. A high species density does not necessarily mean an increase in the number of individuals, but rather a high level of activity (Assemien, 2022). For example, Virginie's 2012 estimate of buffalo density in Comoé Park was 0.08 individuals per km² (Vergnes, 2012). In 2014, the same analysis was repeated by Kouakou and the density was 0.07 buffalo per Km² (Koffi et al., 2019). In 2016, Bouché found an increase in density in the same protected area with 0.16 buffalo per Km². The density of buffalo in the Garamba Park explains the positive trend, which is conditioned by several factors combined. All of the buffalo populations were seen in the park during ground surveillance, and aerial surveillance. During aerial surveillance, buffalo were abundant in the southern part of the park and near the northern part of the Gangala_na_bodio hunting area. However, during ground surveillance, all the herds seen were in the heart of the park, but the buffalo were spread out on either side of the surveillance tracks and the meeting points took the direction and shape of the routes. As for the temporal distribution, in the first quarter, aerial surveillance enabled herds of 10 to 100 buffalo to be spotted in the Gangala-na-bodio hunting area, and two herds were spotted in the extreme southern part of the park, one with between 100 and 200 buffalo and the other with between 10 and 100 buffalo. But during ground surveillance, all the herds were seen in the park, with numbers of 10 to 100 individuals per herd being more frequently encountered, and solitary individuals were scattered throughout the southern part of the park. Numbers of more than 100 individuals per herd were very rare at this time of year.In the second quarter, the herds spread from the south of the park towards the central part and the north. Buffalo numbers fell considerably in the Gangala_na_bodio hunting area, where two herds were sighted, one with between 2 and 10 individuals and the other with between 10 and 100 individuals. The trend in buffalo movements was from south to north during the second quarter of the year. During ground surveillance, we observed massive movements of buffalo herds from the south towards the centre of the park and south-east towards the Mondo misa hunting area. Only a few solitary individuals are seen in the southern part of the park, but the large herd formations are moving from the south either towards the western part of Mondo misa or towards the northern part of the park. In the third quarter, the buffalo once again covered the entire park. The south of the park, which is the area where buffalo were most frequently seen, is beginning to welcome herds from the centre and north. Large herds of over 400 individuals were seen in the Gangala_na_bodio area and other small herds of between 10 and 100 individuals were visible in the area thanks to aerial surveillance. A few buffalo were seen in the north during the ground surveys, but large mixed herds were seen from the south-east to the south-west. These observations over time and space correlate with the analyses carried out by Abraham Megaze in 2017 at Chebera Churchura National Park, who pointed out that the buffalo population in this region has a complex dynamic, influenced by various ecological and anthropogenic factors. The results indicate a population that is unevenly distributed across the park, due to variations in habitat and the availability of food resources (Megaze & Balakrishnan, 2017). We considered the kilometre indices of abundance as a function of habitat type. Thus, for terrestrial monitoring with 73 km covered in a marshy environment, the IKA was 2.73 and the shrubby savannah recorded an IKA of 0.78. In the grassy savannah where descents were more frequent, the IKA was 1.6. In the grassy savannah, where descents were more frequent, the IKA was 1.6. The kilometre indices of abundance also varied according to the monitoring method, since during aerial surveillance the IKA of the marshy areas fell to 0.3, the shrub savannah IKA=2.07 and the grassy savannah 0.99. The IKAs observed using our two inventory methods were not significantly different in the different habitats (p-value= 0.4575) and as the two methods covered the same area, we calculated the average IKA values by habitat type. In swampy areas, the average IKA was 1,515 buffalo/km (standard deviation = ±1.718269). In the shrub savannah, the average IKA was 1.425 buffalo/km (standard deviation= ± 0.9121677) and finally the grassy savannah with 1.275 buffalo/km of average IKA (standard deviation= ± 0.5303301). To determine the buffalo's preferred habitat within the set of different habitats, we performed a PCA. The aim of this principal component analysis was to study the variability of buffalo individuals in the different habitats, but also to study the link between buffalo abundance, distance travelled during surveys and kilometre indices of abundance. The first two axes of this PCA explain 71.43% of the total variability. The study by Melletti et al, carried out in 2007, shed light on the habitat preferences of the forest buffalo. Using a rigorous methodology combining direct observation and ecological analysis, Vincenzo Penteriani identified the specific characteristics of suitable habitats to this species. The results indicate that woodland buffalo prefer areas with a high density of vegetation and areas close to waterholes (Melletti et al., 2007).In Garamba National Park, grassy savannah (HS) is by far the preferred habitat of buffalo, followed by shrub savannah. These are the two habitat types that had good orthogonal projections on the two principal components of the PCA. In fact, AMs are much more centred around the area where two principal axes meet and therefore this is the habitat least represented in the PCA, which was not the case at Chebera Churchura National Park in Ethiopia where Megaze et al., instead found that areas of high buffalo density were identified, mainly in grasslands and riparian areas (Megaze & Balakrishnan, 2017).

CONCLUSION AND APPLICATION OF THE RESULTS

The present study aimed to analyse the abundance, composition, and spatio-temporal distribution of savanna buffaloes. The main objective was to determine the composition, abundance, and distribution of buffaloes over time and space.The methodology consisted of an inventory. The park was monitored by flying over it in a tourist aircraft (Husky) and by land cruiser vehicles. The results were as follows: the buffalo density was estimated at 0.911 buffalo per km² for ground surveillance and 0.478 buffalo per km² for aerial surveillance. As for the dynamics of the buffalo in Garamba National Park, herd movements moved from the south in the first quarter of the year to the centre and south-east in the second quarter. In the third quarter, the buffalo tended to return to the southern part of the park. The average IKA values by habitat type were 1,515 buffalo/km in the marshy areas (standard deviation = ±1.718269). In the shrub savannah, 1,425 buffalo/km (standard deviation= ± 0.9121677) and finally the grassy savannah with 1,275 buffalo/km of average IKA (standard deviation= ± 0.5303301),The results of this study can guide conservation efforts by improving habitat management strategies for buffaloes, areas for enhanced protection. Furthermore, these findings will enable the establishment of monitoring protocols to observe changes in buffalo populations and their distribution, contributing to the conservation of mammals in Africa and the implementation of sustainable management policies.

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