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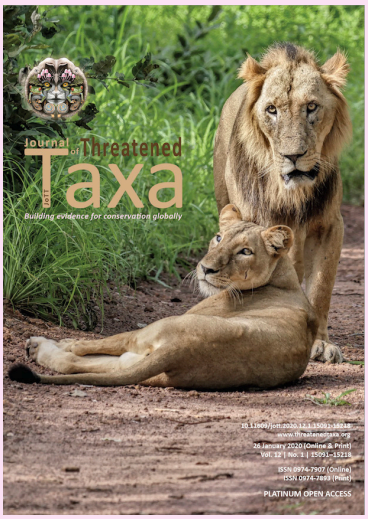

ARTICLE

A CITIZEN SCIENCE APPROACH TO MONITORING OF THE LION *PANTHERA LEO* (CARNIVORA: FELIDAE) POPULATION IN NIOKOLO-KOBA NATIONAL PARK, SENEGAL

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ARTICLE

A citizen science approach to monitoring of the Lion *Panthera leo* (Carnivora: Felidae) population in Niokolo-Koba National Park, Senegal

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Abstract: A voluntary citizen science approach was used in a pilot study of the relict population of the Critically Endangered western African Lion *Panthera leo* in Niokolo-Koba National Park (NKNP) in Senegal. In total, 93 observations involving 253 lion sightings were made by NKNP guides and their clients over a period of four and a half years in the central tourist area of the Park which represents about 3% of the total area of NKNP. Identification sheets were produced for 10 individual lions on the basis of whisker spot patterns measured from photographs contributed by the tourists. Although we were not able to identify a sufficient number of individual lions to estimate the lion population in the zone, extensive data on the geographic distribution, age-class and sex, and behaviour of the observed lions are presented. Data are also presented to tentatively support a relationship between the annual variations in lion observations and the total rainfall in the preceding year. The advantages of this citizen science approach in terms of complementing mainstream science, as well as in promoting tourism development and conservation sensitisation, are discussed, and recommendations are made for pursuing this cooperative effort at a higher level of effectiveness.

Keywords: Asiatic Lion, fur hue, genome, group size, nose colour, population, sex ratio, western African Lion, whisker spot.

Abbreviations: DPN—Direction des Parcs Nationaux | GIE NIOKOLO—Groupement d'Intérêt économique des guides du Parc National du Niokolo-Koba | NKNP—Niokolo-Koba National Park.

French abstract: Une approche science citoyenne bénévole a été appliquée pour une étude pilote de la population relicte du lion *Panthera leo* dans le Parc National du Niokolo-Koba (PNNK) au Sénégal, population appartenant à la sous-population des lions de l'Afrique de l'Ouest en Danger Critique d'Extinction. Au total, 93 observations conduisant au repérage de 253 lions ont été faites par les guides du PNNK et leurs clients pendant une période de quatre ans et demi dans la zone centrale touristique du Parc National qui représente environ 3% de la surface totale du PNNK. Dix fiches d'identification individuelles des lions ont été élaborées sur la base de motifs des racines de vibrisses identifiés à partir des photographies prises par des touristes. Bien que nous n'ayons pas pu identifier un nombre suffisant de lions individuels pour estimer la population de lions dans la zone, une quantité importante de données sur la distribution géographique, l'âge, le sexe, et le comportement de ces lions est présentée. D'autres données appuient de manière provisoire l'hypothèse d'une relation entre la variation annuelle du nombre d'observations des lions et la pluviométrie totale de l'année précédente. Les avantages de l'approche science citoyenne en tant que complément à la science traditionnelle ainsi que pour la promotion du développement du tourisme et de la sensibilisation en matière de conservation sont discutés, et des recommandations sont données pour la poursuite de cet effort coopératif à un niveau accru d'efficacité.

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INTRODUCTION

The African Lion *Panthera leo* has attracted particular attention as an example of the recognised critical decline in biodiversity worldwide, having declined to 35,000 individuals occupying 25% of its historic range (Henschel et al. 2014). Study of mitochondrial DNA (Bertola et al. 2011) showed that western and central African Lions form a distinct clade which is more closely related to Asiatic Lions than to the southern and eastern African Lions, which can be explained by a Pleistocene extinction and subsequent recolonization of western Africa from the Middle East; the relationships among the different African and Asiatic lion populations were recently further refined through whole genome studies (Bertola et al. 2019). The current status of the isolated western African population is especially worrisome, and it has now been listed as Critically Endangered by the IUCN (Henschel et al. 2015). This decision was based on the findings of Henschel et al. (2014) who had estimated the total number of West African Lions to be only 406, using survey data which confirmed the presence of lions in only four large protected areas in the region, including Niokolo-Koba National Park (NKNP) in southeastern Senegal (see Figure 1). NKNP is home to the westernmost and northernmost lions in Africa.

NKNP is one of the largest and most important nature sanctuaries in western Africa with an area of 913,000ha. The exceptional biodiversity of the Park was recognized in 1981 with its designation by UNESCO as a biosphere reserve (UNESCO 2007) and as a world heritage site (UNESCO 2019). Since 2007, however, NKNP has been listed as a world heritage site in danger. Poaching, incursion of livestock and illegal mining are among the factors that have contributed to this situation, which has resulted in dramatic decreases in the populations of megafauna in the Park (Renaud et al. 2006; Galat et al. 2015; UNESCO 2019). Henschel et al. (2014) estimated that in 2011 there were a maximum of 54 lions in the Park and stated that the population was small and appeared to be declining. A more recent report established by IUCN (Tiomoko & Van Merm 2015), however, states that the census conducted by the Park authorities in April 2015 noted positive signs of increased wildlife and in particular that the "lion, assumed absent from the property [sic] for several years, is now present." Regular surveys and scientific studies of the lions of NKNP (Bauer & Van Der Merwe 2004; Henschel et al. 2014; Kane et al. 2015) have not yet provided complete data on their number, distribution, physical, and behavioural characteristics, probably in part due to the difficulties in mobilising sufficient funding and human resources towards this goal.

The cooperative of local NKNP guides (Groupement d'Intérêt économique des guides du Parc National du Niokolo-Koba, hereafter referenced by its acronym GIE NIOKOLO), which has been at the forefront of efforts to improve and promote the Park and to foster sustainable development in the communities that surround it, began in 2015 to systematically document lion sightings in the course of their guiding work. The hypothesis of the present study is that the NKNP guides and the tourists they accompany could, through a voluntary citizen-science effort, contribute meaningful complementary scientific knowledge on the lions and at the same time help to advance lion conservation in the Park.

The main objectives of the present pilot study, conducted by GIE NIOKOLO with advice from an international scientific advisory team, have been: (i) to test the reliability and sustainability of such a citizen science lion monitoring effort and (ii) to collect and present data on the numbers, movements and behaviour of lions present in the main tourist zone of the Park (Figure 1). A secondary objective has been to gradually build expertise in identifying individual lions and, thereby, to contribute to the broader inventory of the lions of NKNP.

MATERIALS AND METHODS

Methods

There are about 30 NKNP guides; they have relatively little formal education but are very bush savvy, and most have over 20 years of experience in guiding tourists in the Park. The guides are certified by the Ministry of Tourism but, except for three who are employed by hotels, they are freelance professionals; they cooperate closely with, but do not have any direct administrative link to, the Direction des Parcs Nationaux (DPN) which is the government agency responsible for protecting the Park and managing its wildlife and the infrastructure.

We define a lion observation as viewing a group of lions and a lion sighting as spotting one lion within that group. Our pilot study aimed to document all lion observations made by tourist groups during four and a half calendar years of field study (from January 2015 to May 2019). While the study was uninterrupted during this period, the frequency of tourist safaris and accessibility of tracks in the Park varied considerably from month to month (see below). Fortuitous observations by personnel working in the Park were also included when

Image 1. Sub-adult Lion *Panthera leo* in Niokolo-Koba National Park.

these were brought to the attention of the guides. There are very few tourist groups visiting NKNP at any time but in the case that more than one tourist group observed the same lions in the same spot on the same half-day we grouped these observations into a single observation (in fact there were only two such occurrences among the 93 observations).

The study methodology was designed to benefit from the daily routine presence in the Park of NKNP guides able to spot lions in the bush, along with tourists who are fairly often equipped with good photographic equipment (every tourist group must be accompanied by a local guide while in the Park), in order to scientifically document visual lion observations. The guides are a closely-knit group, and the relatively rare lion sightings in the Park are of interest to all, so that the number of unreported observations was in principle very low.

At the end of each tourist visit, the accompanying guide provided details of lion observations to the local project coordinator for GIE NIOKOLO, who recorded data for each observation (number of lions, location, composition of the group in terms of age-class, sex and other physical characteristics, and behaviour) in a spreadsheet. A computer was available at the Park exit to deposit lion photographs contributed by the tourists, and, if this was not possible, the tourists were reminded by email to provide copies of their photographs. The tourists were encouraged on site by their guides to take the best possible photographs, especially trying to capture the whisker spot patterns as the most reliable method for the identification of individual lions (Mara Predator Project undated). A brochure developed to explain the project and to provide guidance on lion photography and identification was made available free of charge to visitors starting in autumn 2017, in order to enlist their cooperation and to enhance their understanding of the importance of lion conservation.

The collected observation data and photographs were regularly transmitted by the local project coordinator to the international advisory team of two experienced amateur naturalists (who either hold or are working on post-graduate scientific degrees) and one professional carnivore specialist (for details see the insert on Author Contribution and the Acknowledgements) who corrected and clarified the data together with the local project coordinator, and added the coordinates of the described observation sites. When there were doubts about the details of an observation, notably about classification by age and sex, the coordinator of the advisory team initiated a dialogue with the local project coordinator who in turn consulted the contributing guide if necessary. When photographs of sufficient quality were available, the advisory team analysed the physical characteristics of each lion, including scars, dentition and whisker spot patterns, and when possible created an individual lion identification sheet or added the observation to an existing lion identification sheet. The master database was maintained by the advisory team, with updates regularly transferred to the GIE NIOKOLO group.

The data collected, as well as the analysis (lion identity sheets and distribution maps), are available on an open access basis to all interested parties and have been regularly shared with the Park authorities. In addition to their scientific value, these citizen science data are used by the guides to help in their work and to encourage involvement in the lion conservation effort by the local community and by visitors to the Park.

The data were collected from vehicles in the Park and at fixed observation points next to wetlands and watercourses. In this pilot project we were unable to record information on the trajectories of the tourist safaris (other than those points at which lions were observed) or on the sampling effort in each area or site.

In order to ensure consistency in methodology, a protocol for collection, analysis and management of data and photographs was developed by the advisory team, employing the identification criteria on the website of Mara Predator Project (undated). A basic training workshop in lion photography and identification was organised for the guides in September 2017 based on the above protocol.

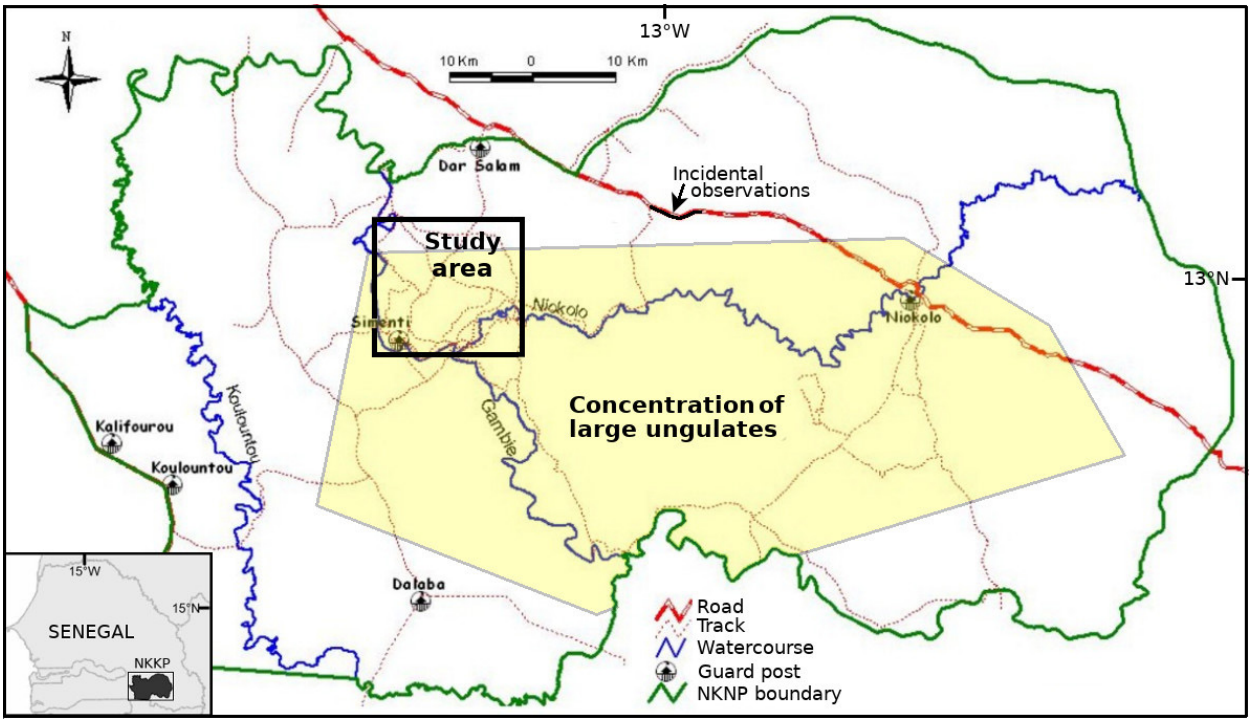

Figure 1. Niokolo-Koba National Park showing the 'study area' for observation of lions and the main area of concentration of large ungulates (main map and yellow polygon derived from Renaud et al. (2006)).

The study area

The study area was not pre-determined but can be defined as the zone within which the guides observed lions during their routine work of guiding tourists in NKNP. This area is shown in Figure 1, with corners at (13.159, -13.322), (13.159, -13.163), (13.014, -13.163) and (13.014, -13.322), and spanning 16.1km north-south by 17.2km east-west which represents an area of 28,300ha or about 3% of the Park. 97% of the lion observations (90 out of the 93) were within this area, while three additional incidental observations were made between 16 and 22 km to the east of the study area on the national highway traversing the Park.

Galat et al. (2015) and Tiomoko & Van Merm (2015) describe the main physical and biological characteristics of NKNP which are summarised below with particular reference to the study area.

Climate and hydrology

Annual precipitation in NKNP ranges from 900 to 1,200 mm of rainfall with a rainy season lasting from June to October. The hydrological system of the Park represents over 10% of the catchment of the Gambia River, which runs westward along the southern border of the study area then north along the western border. The Niokolo-Koba stream traverses the study area from east to west and joins the Gambia River. These two watercourses are quasi-permanent, although they may stop flowing continuously at the end of the dry season (with large permanent pools remaining in the Gambia River). More than 200 temporary or permanent pools have been identified in NKNP. Mare de Simenti at approximately 40 ha is the largest in the study area and is generally permanent because the level is managed by pumping water from the Gambia River. Ten smaller seasonal wetland areas in the study area are also accessible for observations by visitors.

Vegetation

The northern section of NKNP, including the study area, is Sudano-Sahelian in character and consists of a rich variety of habitats: wooded and scrub savannah, small zones of open grassland and closed gallery forests. The topography is relatively flat, with altitude ranging from 16m above sea level to about 70m (from measurements along the tracks with a Garmin Etrex 30 GPS unit). Seasonally flooded grasslands show a tendency towards encroachment and take-over by Giant Sensitive Tree *Mimosa pigra* (invasive) and False Abura *Mitragyna inermis* (native) and are actively managed by the Park authorities. Botanical studies conducted in NKNP have identified around 1,500 different plant

species, but no data are available on the number of species in the study area.

Wildlife

Eighty species of mammals, 360 species of birds, 36 species of reptiles, 20 species of amphibians and 60 species of fish have been identified within NKNP. The large- and medium-sized fauna that populates NKNP is very representative of the savannah biome. The common medium-sized mammals likely to provide prey for lions include: Guinea Baboon *Papio papio*, Bushbuck *Tragelaphus scriptus*, Bush Duiker *Sylvicarpa grimmia*, Red-flanked Duiker *Cephalophus rufilatus*, Oribi *Ourebia ourebi* and Common Warthog *Phacochoerus africanus*. Renaud et al. (2006) showed that these were widely distributed in the Park, including within the study area. The large ungulates present in the Park are Western Derby Eland *Taurotragus derbianus derbianus*, Roan Antelope *Hippotragus equinus*, Western Hartebeest *Alcelaphus buselaphus major*, Western Buffon's Kob *Kobus kobus kob*, Defassa Waterbuck *Kobus ellipsiprymnus defassa* and West African Buffalo *Syncerus caffer brachyceros*. Renaud et al. (2006) showed that, with the exception of the Roan Antelope which is widely distributed, the large ungulates were limited to a polygonal zone of about 325,000ha (shown in Figure 1) representing about 36% of the Park; all except the Western Derby Eland were present in the study area. The giant herbivores are only represented in the study area by the Hippopotamus *Hippopotamus amphibius*. Other than the lion, the large carnivores present in the study zone are Leopard *Panthera pardus*, Spotted Hyena *Crocuta crocuta* and African Wild Dog *Lycaon pictus*.

RESULTS

The details of 93 unique lion observations that were recorded during the study, involving 253 lion sightings, are analysed below. Thirteen of these 253 represented sightings or re-sightings of individual lions that could be identified and three others represented probable re-sightings. Therefore, 237 (94%) of the sightings were of lions that could not be individually identified. Given the relatively small number of individually identified lions, we have chosen to treat all 253 lion sightings equally in our analysis, recognising that these data substantially over-count the number of individual lions observed; the consequences of this are reviewed in the discussion section. The statistical calculations were performed with the "R" software package (https://www.r-project.org/), version 3.4.4.

Based on a total of approximately 2,000 visitors to NKNP in 2015 (Ndiaye 2015) and an estimate of about 4 tourists spending two days per visit (almost all during the dry season of eight months from November to June), 93 lion observations over 4.75 dry seasons (missing November and December of 2014) would equate to a roughly estimated likelihood of about 4% (probability = 93 × 4 / 2000 / 4.75) for a Park visitor to see a lion or of about 2% per day in the Park. On the other hand, the above approximations would imply about 4,750 days (2000 × 4.75 × 2 / 4) of observation by the guides.

Spatial distribution of lion observations

Figure 2 presents a map displaying the localisation of the observations and Table 1 summarises them by type of site, including the corresponding average group sizes observed.

The largest set (44 observations involving 108 lion sightings) consisted of observations made in close proximity (<100m) to water, such as those at the Mare de Simenti, small seasonal wetlands or the banks of the Gambia River (including during boat trips) and Niokolo-Koba stream.

The next largest number of observations (36 involving 121 lion sightings) were made away from water (≥100m) during the circuits by vehicle in the Park. It is interesting, referring to the map in Figure 2, that 27 of this second group of observations (75% of the total), which involved 100 lion sightings (83% of the total for the second group) were made in or very close to (<100m) wooded areas (as defined by submissions to the participatory cartographic website Open Streetmap (2019) based on the latter's publicly available satellite imagery). Relatively very few lions were observed in areas designated by Open Streetmap as open scrubland but it is difficult to draw a definitive conclusion since the relative observation efforts in scrubland and wooded areas are not known.

Ten fortuitous observations, involving 16 lion sightings, were made inside human occupied sites (lodging facilities or guard posts): two observations during the night within or in close proximity to the buildings and eight during the day. The location of the three additional sightings along the N7 national highway is surrounded by thick forest of African Lowland Bamboo *Oxytenanthera abyssinica*.

Combining the observations from around the Mare de Simenti with those from the adjacent Simenti Hotel (the zone of the Park most visited by tourists) yields 21 observations (23% of the total) involving 50 lion sightings (20% of the total) and lions were seen in this zone in

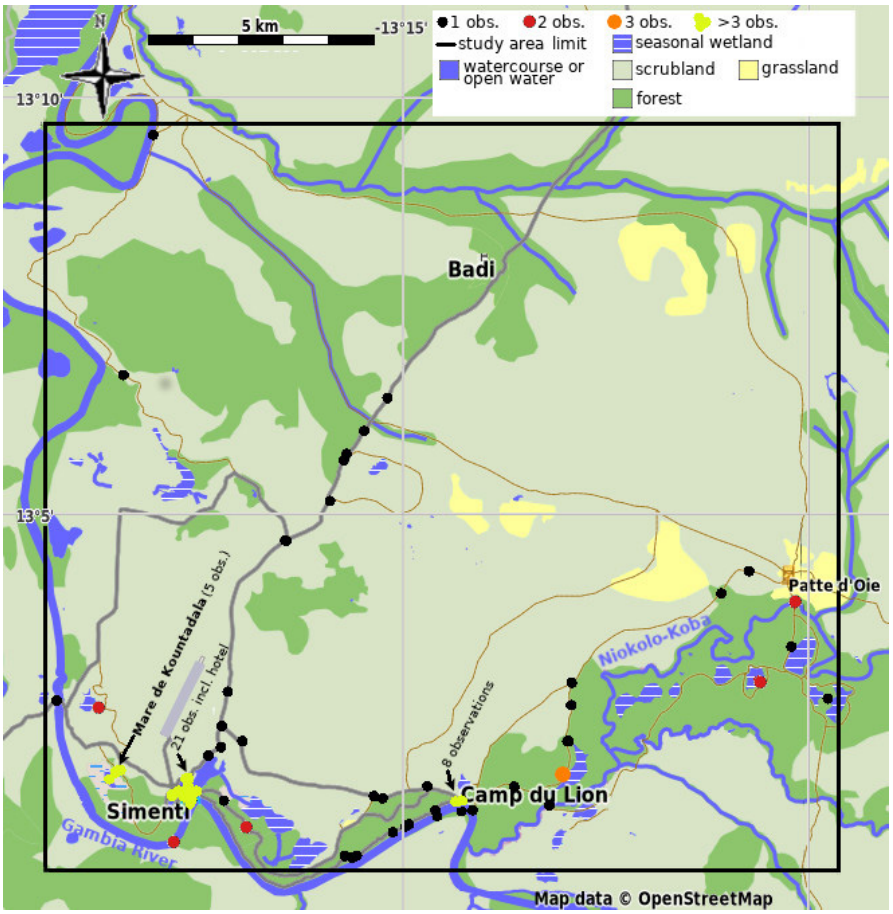

Figure 2. Localisation and frequency of the lion observations within the study area.

Table 1. Lion observations summarised by site category.

Site category	Number of observations	Number of lions observed	Average group size
Tracks away from water	36	121	3.4
Mare de Simenti	18	45	2.5
Seasonal wetlands	14	34	2.4
Banks of watercourses	12	29	2.4
Human occupation	10	16	1.6
National Highway #7	3	8	2.7
Total	93	253	2.72

all years of the study. The second largest cluster of observations was in and around the Camp du Lion on the Gambia River (the only major tourist accommodation in the Park other than Simenti Hotel during the study period); this cluster totalled eight observations (9%) involving sightings of 13 lions (5%). A third major cluster of 5 observations (5%) involving sightings of 11 lions (4%) was at the Mare de Kountadala, approximately 1.7km west of Simenti.

Variations in lion sightings by year and age-class

The annual number of observations and lion sightings, including the break-down of sightings by age-class, are given in Table 2:

The substantial variability in the number of lions observed annually cannot, in the recollections of the guides, be explained in terms of variations in effort on their part nor by variations in the number of tourist parties. One possible factor could be the quantity of annual rainfall since, when there is high precipitation during the rainy season from June to October, the vegetation grows more densely and also dries more slowly during the succeeding dry season between November and June of the following year, thus delaying the managed burning of the undergrowth by the Park authorities. Higher undergrowth during this dry season would generally make the lions more difficult to spot. In addition, delayed drying could mean that potential prey can wait longer before aggregating at water sources, which might lead to wider dispersal of, and thus lower visibility of, the lions.

To test the hypothesis that the number of lion

Table 2. Yearly total and average number of lions sighted by age-class (Percentages relative to the total sightings given in parantheses).

	2015	2016	2017	2018	2019 partial	Mean 2015–2018	Total
Adults	51 (91.1)	13 (86.7)	71 (77.2)	33 (100)	41 (71.9)	42.0	209 (82.6)
Sub-adults	2 (3.6)	0 (0)	7 (7.6)	0 (0)	0 (0)	2.25	9 (3.6)
Cubs	3 (5.4)	2 (13.3)	14 (15.2)	0 (0)	16 (28.1)	4.75	35 (13.8)
Total lions	56	15	92	33	57	49.0	253
Observations	21	6	27	15	24	17.25	93

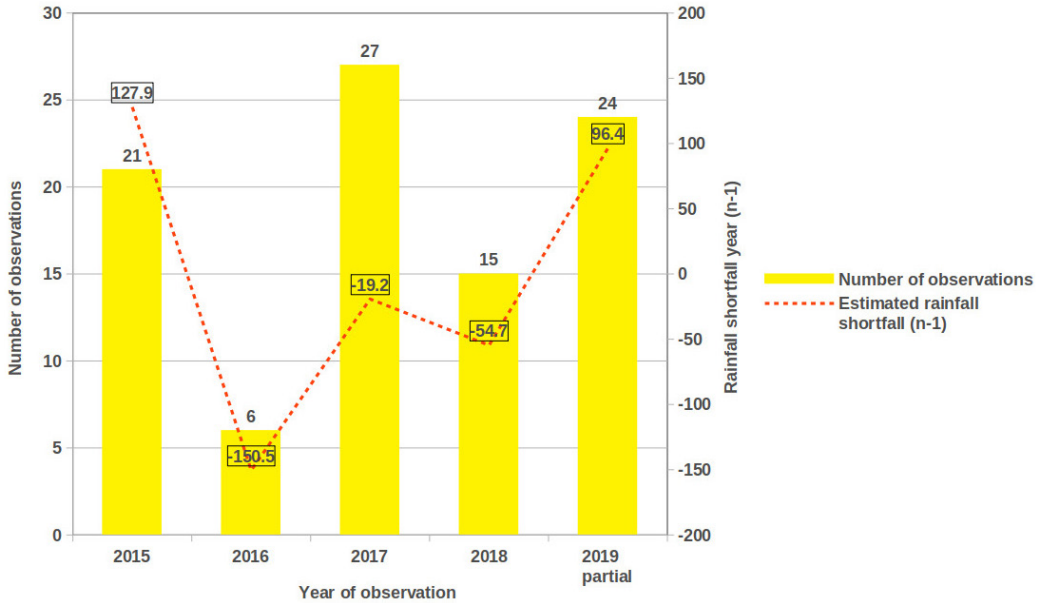

Figure 3. Comparison of the annual number of lion observations (year n) with the rainfall deficiency of the preceeding year (year n-1).

Table 3. Annual rainfall in Tambacounda and Kédougou along with their mean.

	2014	2015	2016	2017	2018	Mean
P_T	632.8	663.1	755.4	862.9	681.6	719.2
P_K	1061.0	1587.4	1232.6	1196.0	1075.2	1230.4
P_M	846.9	1125.3	994.0	1029.5	878.4	974.8

observations within the study zone is correlated with the annual rainfall of the previous year, we obtained rainfall data from the Senegalese weather bureau (Agence Nationale de l'Aviation Civile et de la Métorologie - ANACIM) at their two closest weather stations: Tambacounda (93km northwest of the centre of the study area) and Kédougou (123km east of the centre of the study area). We then approximated the annual rainfall in the study zone (P_M) by taking the mean of the values in Tambacounda (P_T) and Kédougou (P_K), as shown in Table 3.

The mean annual rainfall estimated for the study zone by this method (975 mm) falls in the range of 900–1,200 mm in NKNP given by Galat et al. (2015). When the rainfall data are offset for display purposes as the annual rainfall deficiency relative to the average rainfall in the period 2014–2018, the correlation between the number of lion observations each year and rainfall deficiency of the previous year seems evident (see Figure 3).

After confirming with the Shapiro-Wilk test that the number of observations and the estimated rainfall do not significantly vary from normality (p-values = 0.656 and 0.735, respectively), a Pearson's correlation test gives a rather strong correlation coefficient of -0.729, but with a 95% confidence interval of -0.981 to 0.429 due to small sample size. To rigorously test this hypothesis, further annual observation data would be needed and more accurate rainfall data for the study zone should be obtained, either through a more sophisticated

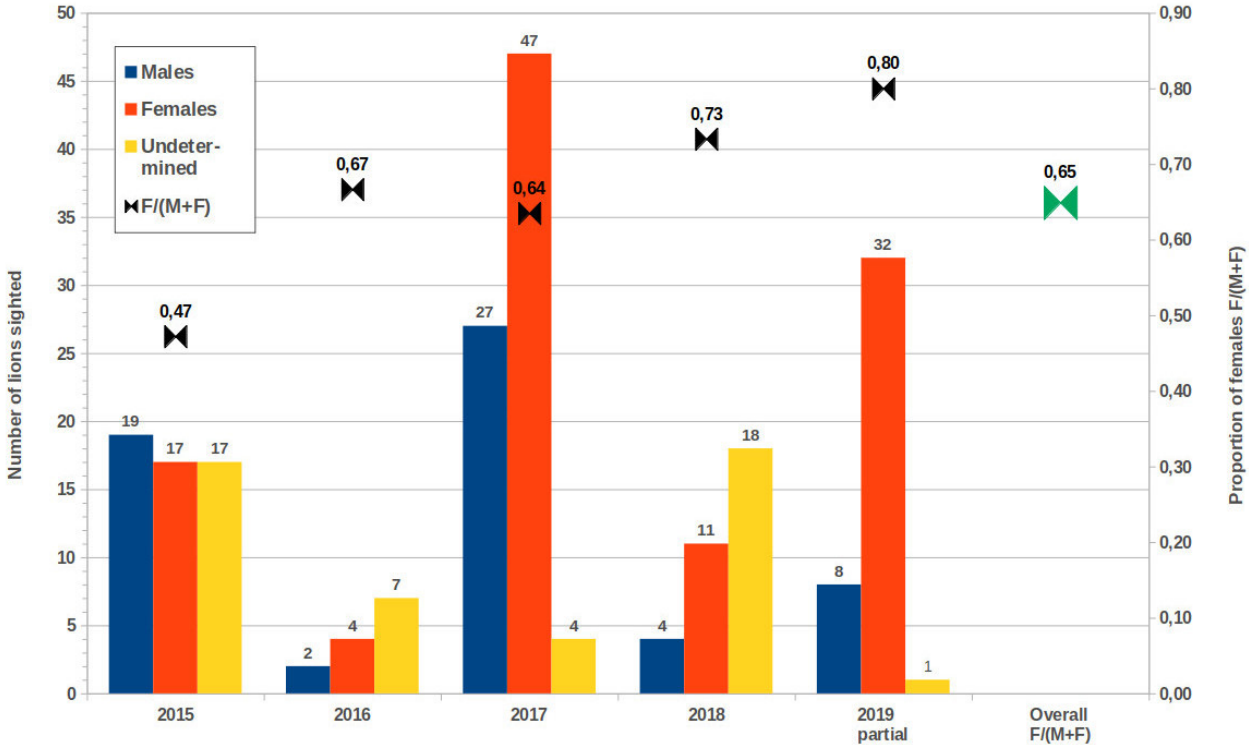

Figure 4. Number of adults and sub-adults by sex and proportion of females F(M+F).

meteorological model or by a locally-maintained rain gauge.

Another hypothesis implying the opposite effect of rainfall on lion observations is that low rainfall might reduce prey populations and thus lion numbers in the following dry season due to environmental stress on the prey, a factor that has been proposed to operate in NKNP over medium-term periods (Galat et al. 2015). There is, however, no evidence that such a mechanism could operate over periods as short as one year.

Sex ratio of lion observations

Figure 4 shows the number of male and female lions observed (excluding cubs, only one of which could be sexed from the data available), as well as the proportion of females to the total of both sexes observed.

The proportion (0.65) of females among the lions observed during the whole study is skewed towards females but with an outlying result for 2015 when more males than females were observed. We have included the partial data for January to May 2019 because for 2015–2018 these months represented a large proportion of the observations (74%).

We performed statistical analysis to test the significance of our sex ratio data, probing whether the skew towards females was a real effect. The values for the proportion of females over the five years were shown by the Shapiro-Wilk test not to significantly vary from normality (p-value = 0.796). We then applied a one-tailed t-test with the null hypothesis that the proportion of females is ≤0.54 and this hypothesis can be rejected at more than 95% certainty (p-value = 0.046).

Seasonal distribution of observations

Figure 5 shows the number of observations and the number of lions observed according to the month (excluding 2019 for which we have only partial data).

The number of observations should normally increase with the number of tourist parties (except if the increase in tourists differentially disturbed the lions, unlikely with the relatively small numbers of visitors to NKNP). These parties are most numerous in the period from December until March when the tracks have been cleared at the beginning of the dry season, decrease with the rise in temperatures from April to June and decrease further during the wet season from July until November when many of the tracks are impassable. The number of lion observations closely follows this pattern. There is also a factor of decreased visibility between July and November when thicker vegetation and undergrowth makes it more difficult to see lions although it is difficult to quantify this effect because the period of decreased

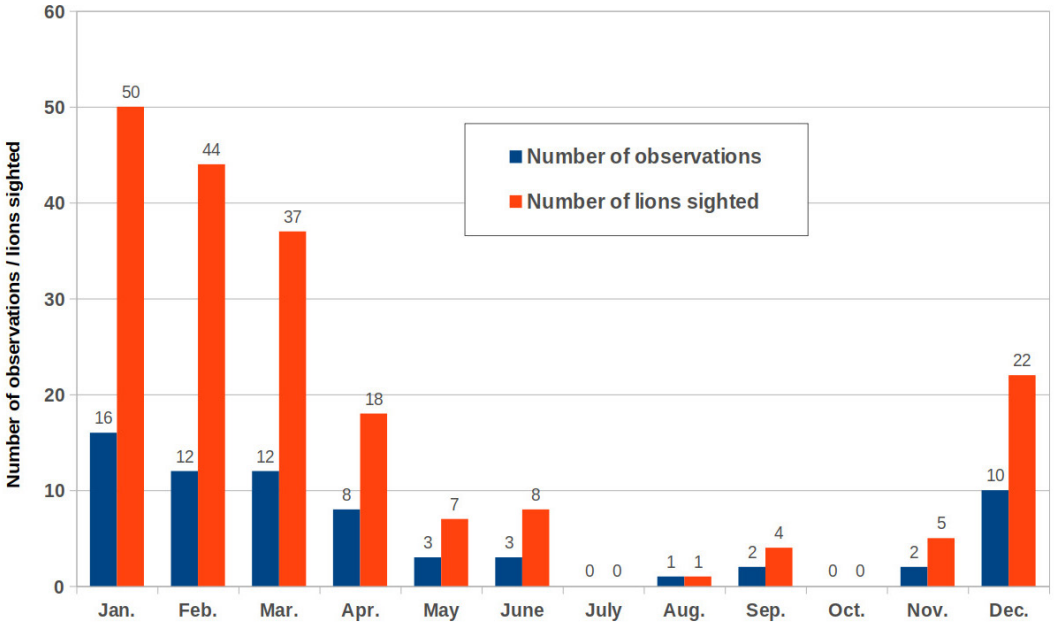

Figure 5. Number of observations and number of lions observed per month (2015–2018).

Table 4. Summary of individual lions identified from photographs (* = possible shared identity | ? = probable re-sighting).

File number	Name of lion	Sex	Estimated birth year	First observed	Characteristics	Relationships	Re-sightings
1	Alakay*	M	2014–2015	15.i.2017	Whisker spots left side	Possibly same as Kaly, seen with 3 brothers + mother	
2	Fidji	M	2009–2013	09.ix.2017	Whisker spots left and right, multiple scars	Seen with Gia	
3	Gia	F	<2010	09.ix.2017	Whisker spots left and right, multiple scars, vitrious right eye	Seen with Fidji	
4	Dinbadjinma	F	2015	15.xi.2017	Whisker spots left side, multiple scars, deformed right ear	Seen with Kekindo (probable sister), plus mother	24.xii.2017 21.i.2019?
5	Kekindo	F	2015	15.xi.2017	Whisker spots left and right, cut on right ear	Seen with Dinbadjinma (probable sister) plus mother	24.xii.2017 12.ii.2018?
6	Adama	F	2010–2011	08.ii.2018	Whisker spots left side, scar on left hind leg	Seen with Awa	03.iv.2018
7	Awa	F	2011–2013	08.ii.2018	Whisker spots left side, scar on right front leg	Seen with Adama	03.iv.2018?
8	Banna	F	2015	16.ii.2019	Whisker spots right side, scars on right front leg and at base of tail	Seen with Binta	
9	Binta	F	2015	16.ii.2019	Whisker spots right side, small ear marks	Seen with Banna	
10	Kaly*	M	2012–2015	30.iv.2019	Whisker spots right side, badly scarred muzzle, broken upper left canine	Possibly same as Alakay, seen with 2 other lions	

visibility corresponds closely to the period of fewest visits. It is also possible that internal migration within the Park could explain some of the seasonal variation even though zones of increased lion presence during the rainy season have not been reported.

Identification of individual lions

Tourist parties submitted photographs and videos of 22 lion observations, using equipment ranging from smartphones to professional level cameras. On the basis of the best of these images, identification sheets for 10 individual lions (described in Table 4) were established and have been made available at http://niokolo-safari.com/lions.htm

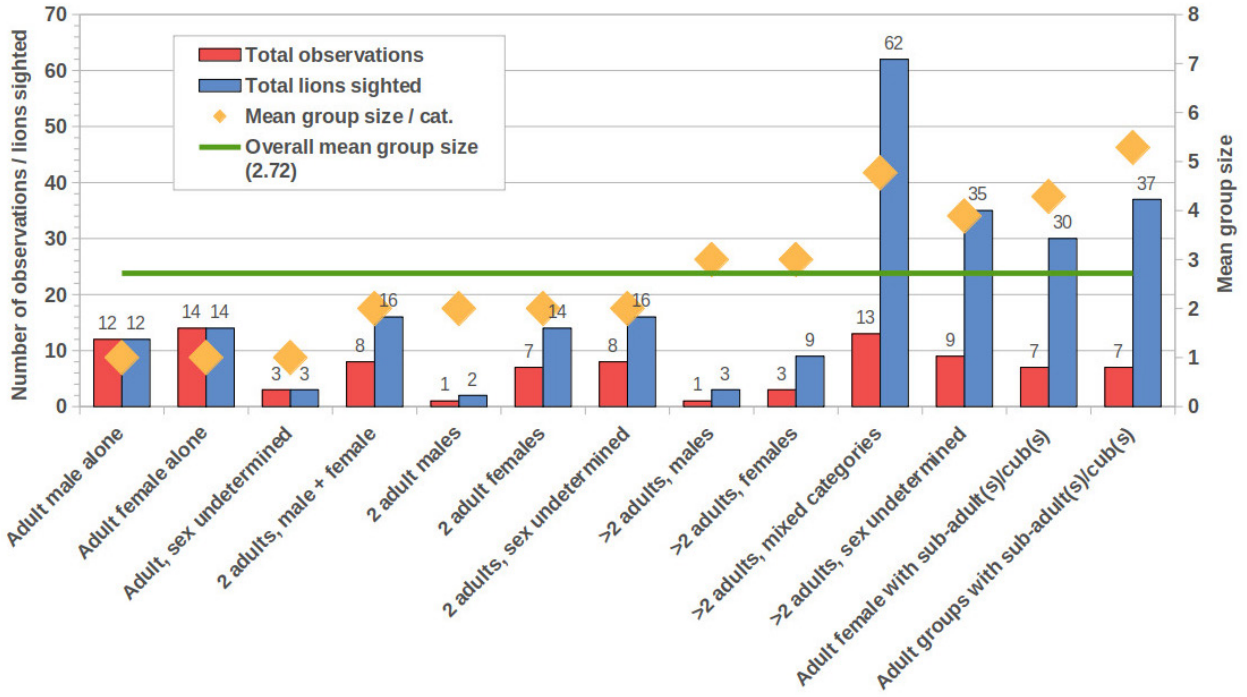

Figure 6. Composition of the groups of lions observed.

Table 5. Comparison of group sizes (adult and sub-adult lions, not including cubs) observed in the present and earlier studies.

Group size	1	2	3	4	5	6	7	8	9	10	Total number of observations	Total number of lions observed	Mean group size
Number of observations Bauer et al. (2003)	8	10	1	1	1	0	0	0	0	0	21	40	1.90
Number of observations present study	33	28	21	4	1	1	3	1	0	1	93	218	2.34

Distinguishing characteristics of the NKNP lions

According to the NKNP guides, some of the lions in the Park have greyish rather than tan fur and these lions are reputed to be generally more massive and with fuller manes. Indeed, in our photographs there appear to be large variations in fur hue among the lions observed, both for males and for females, ranging greyish to tan, although the apparent hue of a particular lion's fur varied substantially between photos of the same lion in different conditions. The three greyish males photographed did not have notably more ample manes than their browner counterparts. In the Mara Predator project (Kenya), greyish lions were rare (personal communication, Sara Blackburn) and a photograph of a greyish adult male lion named Marley, with a mane less full than average, can be seen on the website of the project (Mara Predator Project undated). It should be noted that Pocock (1939) indicates a high variability in fur colour in his description of the Asiatic lion.

Compared with the lions of eastern Africa (Serengeti/Ngorongoro in Tanzania as described by Whitman et al. (2004) and in the Masai Mara National Reserve in Kenya (Mara Predator Projet undated)) which are born with pink noses that darken by becoming increasingly freckled with age, all of the lions photographed with good resolution in NKNP, including the three sub-adults and one cub, had quite uniformly dark noses without freckling. In addition, in contrast with the lions of Masai Mara, many lions in NKNP retain substantial spotting on their underparts and legs into adulthood and the manes of the males in NKNP are smaller than those in the Masai Mara, with many adult males having only sparsely developed manes.

Observed lion behaviour

Lions were observed individually or in groups of 2 to 10 individuals. The most frequently observed category (31.2%) was of single lions, while 79.6% of the observations involved groups of 3 or fewer lions. The mean group size was 2.72 (including cubs). Figure 6

shows the number of observations and the number of lion sightings in such groups for different combinations of age-class and sex.

The majority of studies into the social behaviour of African lions have concentrated on populations in eastern and southern Africa and the results were summarised by Bauer et al. (2003): "[A] pride (10–20 lions) is composed of groups (3–6 lions) with varying composition that may regularly be observed together, so-called fission-fusion. A pride typically has a territory, defended by 1–3 males for 2–4 years against nomadic males." A more recent review of data from Serengeti National Park in Tanzania (Mosser & Packer 2009) defines a lion pride as composed of 1–21 adult females, their dependent offspring and a temporary coalition of 1–9 adult males.

Bauer et al. (2003) studied the social grouping of western African lions in three large protected areas, including NKNP, and found that group sizes were significantly smaller than those in eight studies in East and southern Africa, as reported by Van Orsdol et al. (1985). Bauer et al. (2003) describe three hypotheses for this difference (low prey density, low prey body size and greater reliance on livestock as prey) without providing conclusive proof for their relevance. They express scepticism that this difference in social behaviour could be an innate characteristic of the two populations but in the light of the recent study showing the genetic uniqueness of the western African population this possibility should be reassessed. This latter possibility may be strengthened by the observation of Jhala et al. (2009) of an average group size for adult female Asiatic lions in the Gir Protected Area of only 1.3 (although they cite earlier studies which observed adult female group sizes averaging 2.1 and 4.5).

The group sizes in NKNP documented by Bauer et al. (2003), tabulated without counting cubs (lions aged less than 2 years as per the Smuts et al. (1970)), are presented in Table 5 in comparison with similarly adjusted data from the present study. The mean group size per observation (total number of lions observed divided by the total number of observations) was 1.90 for Bauer et al. and 2.34 for the present study.

The differences in paired values were shown by the Shapiro-Wilk test not to significantly vary from normality (p-value = 0.624). Therefore, the paired samples t-test was applied to the differences adjusted by multiplication of each difference by the corresponding group size (in order to ensure that the mean of each series corresponded to the respective mean group sizes of 1.90 and 2.34) and by division by the number of observations in each study (n = 21 or n = 93). The significance of the test was determined to be α = 0.05. The null hypothesis that the mean group sizes of the two surveys was identical could not be rejected as statistically significant (p-value = 0.569). It should, however, be noted that Bauer et al. (2003) (n = 21) saw no groups of greater than 5 lions whereas the present study (n = 93) observed 6 such groups (6.45% of the groups observed), including one group of 10 adult or sub-adult lions. Therefore, the conclusion of Bauer et al. that "if there was a level of organisation higher than the small groups, their interaction was rare and hardly ever observed" does not seem to have been confirmed in our results.

In the large majority of observations (84 out of 93, corresponding to 90%), the lions showed banal behaviour, including resting, walking, observing the tourists and their guides, drinking (one observation) and fleeing the vehicle (one observation). In seven observations (7.5%) the lions were seen attentively watching or stalking potential prey (Western Buffon's Kob *Kobus kobus kob* in one observation (two adult female lions), Common Warthog *Phacochoerus africanus* in two observations (two adult male lions with an adult female, then a single adult female)). In one observation four adult lions (two males and two females) were feeding on the carcass of a Guinea Baboon *Papio papio*. No observations of actual predation attempts were observed. In another observation two adult lions (a male and a female) entered at dawn into the kitchen of a tourist camp to take some dried fish.

DISCUSSION

The study compiled a substantial amount of data on the lions observed by tourists and their guides, as a means of complementing the research by the Park authorities and the scientific community while helping the guides to improve their services and contribute to better protection of the lions of NKNP. A number of useful conclusions were drawn from the analysis of this data, some fully validated and others providing starting points for further study. In assessing the usefulness and effectiveness of the work, it should be noted that the study was organised on a strictly voluntary basis by the guides and the advisory team, without any external support (with the exception of an air ticket and some in-kind assistance with automated cartography).

The great experience of the guides in detecting and identifying wildlife, even in thick undergrowth, ensured efficiency in spotting lions. In general, the accuracy and precision of assignment of sex and age-

class steadily increased from 2015 to 2019, as the guides gradually became more competent and confident in lion identification. The difficulties originally encountered in obtaining photographs taken by tourists were gradually reduced through active sensitisation and mobilisation of visitors to the Park.

Beginning in 2017, we were able to receive photographs of sufficient resolution to identify individual lions although the percentage of lion sightings backed up with photographic evidence at adequate resolution remained low (13 sightings out of 182 (or 7%) for 2017–2019). This was too low to have confidence that our identified lions covered the entire local population.

Therefore, other than our observations of individually identified lions, we recognise that our data on the absolute numbers of lions observed, and the breakdown in terms of age-class and sex, cannot provide reliable estimates of the number of distinct lions observed due to the high probability of multiple counting individual lions. If we assume that, on average, the over-counting should tend to apply equally to the different lions, the calculated percentages of the age-classes and sexes (see Table 2 and Figure 4) are expected to be more reliable than the absolute numbers and may be seen as qualitatively useful.

The data provide interesting qualitative information on the spatial distribution of lions observed in the study area but without logs of the time spent observing and the field of view at each site and along each trajectory, the geographical abundance or the lions cannot be quantitatively deduced.

Henschel et al. (2014) state that 40–60% of a lion population typically consists of immature individuals although the underlying data for this statement come from populations in Tanzania and Namibia, while Banerjee & Jhala (2012) found a proportion of 37% of cubs and sub-adults in the Gir Protected Area in India. We recorded a proportion of cubs and sub-adults of only 17.4%, and although it is possible that this figure indicates low levels of reproduction, in NKNP the cubs are typically hidden in thick vegetation and some are thus likely to have been overlooked. It is also possible that some sub-adults were counted as adults, since during the first half of the study we did not distinguish between these age categories and had to attempt to subsequently clarify the dataset for this period on the basis of photographs and the recollection of the guides.

Pocock (1939) described several morphological differences between Asiatic and African lions (the African specimens apparently being from southern and eastern Africa), the former having different hair patterns including smaller manes as well as differences in cranial morphology, but we have not identified a scientific study of the morphological differences between western African Lions and either Asiatic Lions or those of southern and eastern Africa. Thus our observation of relatively less ample manes in our subjects relative to those of lions in southern and eastern Africa, although conforming to statements often seen in informal accounts, cannot at present be scientifically confirmed as a characteristic of the NKNP population.

Similarly, we have found no references in the scientific literature to study of the nose colour of immature Asiatic or western African lions. We have, however identified a photograph of an Asiatic lion cub (Chauhan (2015) with a mostly dark nose without freckling and of a sub-adult with a uniformly dark nose (Wakefield 2017), thus providing some corroboration for our observation that the immature NKNP lions have quite uniformly dark noses without freckling.

We are not in position to say to what extent the observed differences in fur hues are due to morphological variations among the lions or are possibly correlated with factors like season, stage of development, sex, or health, or whether they might at least partly depend on artefacts such as (i) different camera models and settings, (ii) lighting conditions, and (iii) external factors such as foreign material in the fur. We propose to continue to document the apparent fur hue which may well prove to be empirically useful in identification when combined with other data.

The guides were highly motivated to participate in this study and 22 of them contributed 90 of the 93 observation descriptions (two were from hotel employees and one from a government agent traversing the Park). Their contributions were unequally distributed, with three guides submitting 33 (37%) of the 90 descriptions (the amount of time spent within the study area by each guide is not known). The tourists were in general interested and cooperative once the lion monitoring project was explained to them. The major obstacles to obtaining more and better-quality photographs were that the tourists often had only smartphones or, if they had cameras with them, were generally not experienced wildlife photographers, while the guides generally had insufficient equipment and lacked photographic experience.

Lion population within the study area

Although lion vocalisations and fresh pugmarks are commonly encountered in NKNP, lion sightings are relatively rare and there is little published data

on the number of lions present. Although DPN, with the support of various scientific organisations, has conducted periodic inventories of megafauna in the Park, the survey methods (mainly transects by foot, by vehicle and by airplane) have not been specifically designed for the recording of lions (Renaud et al. 2006; Tiomoko & Van Merm 2015). A camera-trap study by Kane et al. (2015), covering 285.4km^2 (representing approximately the southern half of our study area plus an adjacent area to the east of the same size) during 78 days in February-April 2013, provided a density of 3.02 adult lions/100 km^2 (1.72–5.57/100 km^2). Applying this figure to the encompassing "state space area" of 1,687.20km^2 associated with their model yields a minimum population for the Park of 29–94 adult lions. Given that the "state space area" represents about 15% of NKNP, this estimate appears higher than the maximum of 54 lions (including immature subjects) estimated in 2011 by Henschel et al. (2014). Bauer & Van Der Merwe (2004) reported estimates of the NKNP lion population between 20 and 150 animals but the only published data they cited dated from 1976 (Dupuy & Verschuren 1977) and this publication did not present any details on the survey methodology employed.

Taking into account the number of males and females of different age groups observed, we can only state that a minimum of 10 adults (some of which could have been sub-adults) were present in the study area (five males and five females seen together in 2017). If we also count cubs, at least 21 individual lions must have been present in the study area (the above plus 4 unsexed cubs seen together in 2017 and 7 cubs seen together in 2019).

In the present pilot project, our data did not permit accurate calculation of the home ranges of the lions observed, nor of the lion density in the study zone, as was done in the Masai Mara area by Blackburn & Frank (2010) and Blackburn et al. (2016), principally because of our high level of unidentified lions. This is largely due to the difficulty in sighting, approaching and identifying lions in the thick vegetation of NKNP but also to insufficient expertise of the observers and their equipment in the field. It may, however, be noted that the presence of 10 adult lions in the study zone would equate to 3.5 lions per 100km^2 (or about 5 per 100km^2 if we consider only the polygon in which lions were observed), which is comparable to the results of Kane et al. (2015) and lower than the densities recorded in the Masai Mara area by Blackburn & Frank (2010).

We have every reason to expect that with improved organisation, local skills and equipment the quantity and quality of the lion monitoring data can be improved significantly. It would be very useful in this context to be able to compare our data on individual lions with those obtained in other studies in NKNP, notably by the use of camera traps. This would help in understanding the home range of the lions and in determining accurate estimates of the total population.

Sex ratio

A recent analysis of multiple studies in Tanzania and Zimbabwe (Barthold et al. 2016) showed that the average proportion of females varied from 0.51 at birth to 0.55 at less than one year old (in this study the term "sex ratio F:M" is used to refer to the proportion of females, F/(F+M)). This same study showed that male mortality was higher than female mortality in both populations for all age groups (although there were significant differences between the two populations) meaning that the average proportion of females in a population of adults and sub-adults would be greater than 0.55. Banerjee & Jhala (2012) found a proportion of females (excluding sub-adults and cubs) of 0.63 in a study of Asiatic lions in the Gir Protected Area, and said that "Demographic parameters of genetically less-diverse Asiatic Lions did not differ from those of African Lions."

Our results indicating a substantially higher proportion of females than males, are thus consistent with other studies although that does not exclude a systematic bias in our observations or explain the outlying value of 0.47 for 2015 when more males than females were observed.

Male and female lions differ in hunting methods, social behaviour and territory, resulting in many factors that could potentially bias our observations, which were limited to accessible areas of a small study zone and to daytime visits. Only two hypotheses will be discussed here as examples:

1. There might be a preference of male lions for areas of thicker vegetation in which they are less easy to observe. In South Africa, Loarie, Tambling and Asnera (2013) showed that male lions hunt in thicker vegetation than females and, therefore, they may be less frequent than females in the more open, intentionally burned zones where lions were mainly observed in NKNP (although the above study found only differences in hunting areas and not in resting areas).

2. Bauer et al. (2003) studied the home ranges of two male and three female radio-collared lions in Waza National Park in Cameroon. Their non-quantified spatial diagram showed home ranges of the females to be roughly the size of our NKNP study zone and those of the males to be substantially larger. Therefore, it is

possible that the males in our local population were more likely than the females to be outside the study zone. Likewise, if the male lions were moving in and out of the study zone more than the females, this could also be a factor in explaining the preponderance of males in our observations from 2015.

It is also possible that a small fraction of adult males seen at a distance with under-developed manes were under-counted, increasing the proportion of females recorded.

FUTURE DEVELOPMENT OF LION MONITORING IN NKNP

The citizen-science lion study presented here provides an important and informative methodology to support lion conservation in NKNP and complements the previous scientific or technological approaches that have been favoured for researching the lion populations in the Park, including studies undertaken by DPN and the international scientific community (Henschel et al. 2014; Kane et al. 2015). Although the citizen-science approach depends on the travel plans, itineraries and collaboration of visitors to the Park (thereby reducing programmability and consistency), its reliance on the engagement of the local community and guides make it more cost-effective in terms of external investment and, therefore, more likely to be sustainable over longer timeframes. The approach also facilitates responsible lion observation by tourists visiting Senegal, which in turn will contribute to the viability of the Park and, indirectly, to the better protection of lions in NKNP, as well as promoting public awareness of the precarious situation of lions in western Africa.

This citizen-science approach to lion monitoring can be made more effective by:

i) the acquisition of a greater number of high quality photographs enabling the identification of individual lions by providing suitable cameras and training to the guides

ii) building rigorous data collection and management capacity at the local level, with the medium-term aim of transferring administrative and scientific responsibility for the project to a Senegalese team

iii) collaboration with institutions and scientists studying the NKNP lions, and particularly with the DPN, in providing advice to the guides and in sharing and comparing data with them.

To address these ideas, the authors are seeking international and national support for continuation and reinforcement of the citizen-science lion monitoring project in NKNP over the next three years.

It may be noted that this consolidation effort has already been initiated with a 10-day training course in methodology of collection and management of observational data and in wildlife photography, organised by the authors for the guides in October 2019.

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Author contribution: The collection of data was carried out on a voluntary basis by GIE NIOKOLO through a project led by one of the authors (AK). JBR coordinated the international advisory team and the drafting of this article. DD was responsible for developing the data protocol and the identity sheets.

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