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1 Running head: Waterbuck ecology in Burkina Faso

2

3 **Long-term changes in population size and the age-structure and sex-**  
4 **ratio of Waterbuck in a Sudanian savannah of Burkina Faso**

5

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31

32 **Abstract** The waterbuck (*Kobus ellipsiprymnus*), though widespread throughout Africa, is suspected to be  
33 declining overall. Data on population numbers and structure are lacking for many parts of its range,  
34 especially in West Africa, where the subspecies *defassa* is found. The aim of the present study was to  
35 evaluate the abundance, distribution and attributes of waterbuck populations in the Nazinga Forest Reserve,  
36 southern Burkina Faso. We investigated waterbuck population trends in the park using transect data collected  
37 in 1985-2019. For the more detailed analyses of population structure and distribution of the animals we used  
38 census data gathered during 2019. Most animals were adults (46.6%), and the sex ratio was heavily skewed  
39 towards females (5:1). Most animals were concentrated along the larger rivers. There was no influence of  
40 poacher activity on waterbuck distribution. In the long term (1985-2019), the population dynamics of  
41 waterbuck can be roughly divided into two main periods: a phase of population increase from 1985 to 2005,  
42 and one of ongoing population collapse from 2007-2019. Although the declining population trend was  
43 obvious, coefficients of determination were low indicating that the years explained poorly the number of  
44 individuals and the number of sightings obtained. Waterbuck numbers in the Nazinga Forest Reserve are  
45 declining, but we found no single reason to explain this trend. It is likely that a combination of factors,  
46 including global warming (increased aridity) and illegal activities such as poaching, are responsible. Because  
47 there are probably multiple reasons for the observed waterbuck population decline in our study area, we  
48 suggest that a multifaceted approach should be adopted in order to enhance the conservation status of the  
49 local waterbuck populations.

50

51 **Keywords** *Kobus ellipsiprymnus defassa*; Bovidae; abundance; density; group size; sex ratio; age structure;  
52 ecology; West Africa

53

## 54 **Introduction**

55 The waterbuck (*Kobus ellipsiprymnus*) remains widespread across western, central, eastern and southern  
56 Africa, and occupies a range of habitats such as grassy savannah plains, and open woodland near permanent  
57 waterbodies (Nowak 1991). Waterbuck are also an important game species (e.g., Berry 1975; Cloete *et al.*  
58 2007) but they are often poached. According to the IUCN Red List (IUCN 2020), the abundance of the  
59 species is suspected to be declining, but there is no evidence to confirm that the rate of decline meets the  
60 requirements for Near Threatened or Vulnerable status.

61 Although a number of studies on the ecology of the species has been published (e.g., Spinage 1968,  
62 1969; Melton 1978, 1983; Tomlinson 1978; Kassa *et al.* 2008), reliable population estimates are scarce. This  
63 is especially true for waterbuck populations in the Sudanian savannahs of West Africa (subspecies *defassa*;  
64 Lorenzen *et al.* 2006), where the species is perceived to be declining (Chardonnet and Chardonnet 2004).  
65 Although some preliminary surveys have been undertaken on the population status of the species in  
66 Zakouma, Chad (Mackie 2004), Pendjari, Benin (Rouamba and Hi 2004), Gashaka Gumti, Nigeria (Nicholas  
67 2004), and in Gambia (Jallow *et al.* 2004), few quantitative studies are currently available (i.e. in Benin:  
68 Kassa *et al.* 2008; Djagoun *et al.* 2013), and little is known of the population dynamics of any West African  
69 waterbuck population.

70 In Burkina Faso, where the waterbuck is found primarily in protected areas in the South of the  
71 country, some estimates data for the species (alongside other ungulates) are available for the gallery forests  
72 of the Comoé-Léraba region (Hema *et al.* 2017a) and the Nazinga region (Hema *et al.* 2018). In this study,  
73 we report abundance, density, group size, sex and age structure of waterbuck populations in the Nazinga  
74 Forest Reserve (FC/RGN). More specifically, we answer to the following key questions:

75 (1) Is the population structure of Burkina Faso waterbuck consistent with that studied elsewhere in  
76 Africa in terms of sex-ratio and age structure?

77 (2) Are the yearly density estimates of Burkina Faso waterbuck comparable with those observed in  
78 East Africa or, as expected on the basis of the widespread threatened status of West African ungulates, are  
79 they lower than in other regions of the continent?

80 (3) Is there any long-term consistent yearly trend (increasing, decreasing, stable) of waterbuck  
81 population in Burkina Faso?

82 Our results will serve to highlight the conservation needs of the species in West Africa, in the light of  
83 the extreme challenges that ungulates are currently facing in the West African savannahs due to extensive  
84 habitat loss and poaching (e.g. see Bouché *et al.* 2016).

85

## 86 **Methods**

### 87 *Study area*

88 The field study was carried out in the FC/RGN, a protected area, 97436 ha surface, in south-central  
89 Burkina Faso (West Africa) (Figure 1). The vegetation of the study area is Sudanian-type woody savannah  
90 vegetation dominated by *Detarium microcarpum*, *Burkea africana*, *Azelia africana*, *Isoberlinia doka*,  
91 *Pteleopsis suberosa*, *Acacia dudgeoni*, *Gardenia* spp., *Vitellaria paradoxa*, *Terminalia* spp. and *Combretum*  
92 spp. The dominant perennial herbaceous plants are *Andropogon ascinodis* and *Schizachyrium sanguineum*.  
93 The woody species of the alluvial valleys are *Anogeissus leiocarpus*, *Daniellia oliveri* and *Mitragyna*  
94 *inermis*, associated with *Andropogon gayanus* and *Vetiveria nigriflora* as perennial herbaceous dominant of  
95 this type of environment (Dekker 1985; Yameogo 1999). Along the water bodies, relatively closed, "wet"  
96 habitats made up of gallery forests can be seen; this formation is dominated by large woody species such as  
97 *Anogeissus leiocarpus*, *Khaya senegalensis*, *Diospiros mespiliformis* and *Piliostigma thonningii*, and for the  
98 herbaceous layer by grasses such as *Andropogon gayanus* and *Pennisetum angustum*. Annual rainfall in the  
99 region of FC/RGN is about 1,500 mm.

100 In the study area there still exist large populations of ungulates (*Tragelaphus scriptus*, *Sylvicapra*  
101 *grymmia*, *Alcelaphus buselaphus*, *Hippotragus equines*, *Phacochoerus africanus*; cf. Hema et al., 2018) and  
102 *Loxodonta africana* (Hema et al., 2016), with *Crocuta crocuta* being the largest predator (Hema et al., 2019).  
103 Illegal poaching is present, especially in the boundary strips of the park (Hema et al., 2017c).

104

### 105 *Data collection*

106 Large mammal censuses in FC/RGN have been undertaken in the park since 1981 along 30  
107 equidistant 1.4 km transects (Figure 1), during the months of February to early April. In 2019, we performed

108 all transects during 19-25 March. Data collection protocols were first set up in 1981 (as occasional and  
109 somewhat unstandardized surveys) and revised by O'Donoghue (1985) after which standardized line  
110 transects were to be walked each year to obtain comparable estimates of the local abundance of animals.  
111 Sexes of adults were distinguished based on the presence/absence of horns (present in males). We defined  
112 juveniles those individuals that were less than 8 months old, subadults those between 8 months and 1.5 years  
113 old for females and between 8 months and 2 years old for males. We used relative size and the appearance of  
114 the horns in males to determine the relative age of the observed animals.

115 All transects were oriented in a South-North direction throughout the entire park. The entrance and  
116 exit to each transect was signposted using a numbered metal disc fixed on a tree at eye level. During each  
117 annual census, the same 79 transects (691.811 km) in the seven FC/RGN zones were covered during the dry  
118 season. The methodology employed was always identical: after a training session, transects were walked by  
119 12 teams of three people each; each team consisting of a team leader and two observers (i.e. a villager and a  
120 tracker). We applied unlimited bandwidth linear transects (Burnham et al., 1980, Buckland et al., 1993,  
121 2001).

122 During each annual census, teams walked along the centre of a transect, equipped with binoculars,  
123 GPS, compasses, rangefinders, maps, and cards on which to note the species, number of individual animals  
124 observed, their sex and age, as well as radial distance, viewing angle, activity and signs of illegal human  
125 activities (bullets, tree cutting, human tracks, motor-bike tracks, tree-branch thinning and pastoralism tracks).  
126 Animal observations were georeferenced using a Garmin 64S GPS, and compasses were used to measure  
127 angle with range finders to determine radial distances. All surveys started at 6am, immediately after which  
128 visibility conditions allowed the surveyors to clearly see the animals, even at a distance.

129

### 130 *Data analysis*

131 In this study, we investigated waterbuck population trends in FC/RGN using transect data for the period  
132 1985-2019. Data for 1985-2007 has already been published (Hema *et al.* 2018) and previous census results  
133 (1981-1985) were not used because a different field method was employed during this period (O'Donoghue,  
134 1985). For the more detailed analyses of population structure (age and sex-ratio) and distribution of the

135 animals in the park we used census data gathered in 2019 as the same type of data was not collected in the  
136 previous years.

137 QGIS 2.18.10 was used to map sighting records and for determining waterbuck concentration zones.  
138 QGIS was also employed to measure distances between the different waterbuck groups, and distances of  
139 waterbuck groups from the nearest waterbody, from paths/tracks and from signs of illegal human activity.  
140 We used the standardized Morisita dispersion index ( $I_p$ ) (Zar 1999) to measure spatial dispersion.  $I_p$  ranges  
141 from -1.0 to +1.0. The random dispersion modes (Poisson distribution) give an  $I_p$  equal to zero, while  
142 uniform distribution modes have an  $I_p$  less than zero. Grouped distribution modes have an  $I_p$  greater than  
143 zero.

144 On the basis of the number of contacts and the number of waterbuck individuals, we calculated the  
145 proportion of sex and age classes in the population for 2019, as well as the density (measured as the  
146 Kilometric Index of Abundance, KIA, and as the Kilometric Index of Contacts, KIC) (Maillard *et al.* 2001).  
147 In KIC, we considered all independent sighting events; so, for instance, if we observed 5 individuals in a  
148 group and one solitary individual apart, the count was 6 for KIA but just 2 for KIC.

149 
$$\text{KIA} = (\text{number of individuals} / \text{numbers of kilometers covered}).$$

150 
$$\text{KIC} = (\text{number of observations} / \text{numbers of kilometers covered}).$$

151 In these formulas, the number of kilometers covered represents the sum of the total distance of the transects.

152 We calculated the total number of encountered individuals among transects from 1985-2019, but  
153 with some years in which these numbers were not available due to the lack of field surveys. We estimated  
154 waterbuck density with the Distance Sampling method (Buckland *et al.* 1993, Thomas *et al.* 2002), using the  
155 DISTANCE software, version 7.2. This method makes it possible to estimate the population density by  
156 calculating the probabilities of detection of animals as a function of their distance to the transect. The general  
157 formula for estimating the density of waterbuck groups is as follows (Burnham *et al.* 1980):

158 
$$\hat{D} = \frac{n\hat{f}(0)}{2L}$$



159 where  $\hat{D}$  is the density estimator;  $n$  is the sample size (number of observations) of observations;  $L$  the total  
160 length of the transects;  $\hat{f}(0)$  the estimator of the effective half-width of the band is the detection probability  
161 function estimated by the software through robust mathematical models related to the probability density  
162 function.

163 The following estimators, that are considered as the most robust (Buckland *et al.* 1993), were  
164 analysed: the cosine and polynomial-tuned uniform function, the cosine and Hermite polynomial-adjusted  
165 semi normal function, and the cosine and simple polynomial-adjusted chance rate function. The choice of the  
166 model was made according to the following criteria:

- 167 (i) the value of the effective strip width was close to the calculated mean perpendicular distance and the  
168 value obtained with the threshold method;
- 169 (ii) the expected group size (calculated by DISTANCE software) was closest to the mean group size  
170 (calculated on Excel);
- 171 (iii) the Akaike's Information Criterion (AIC) value was the lowest one, and the visual observation of the  
172 curve of the detection function was good;
- 173 (iv)  $\chi^2$  value was not significant.

174 Two types of densities were estimated: the density of groups (DS) estimates the number of contacts  
175 with animal groups per unit area (in our case per km<sup>2</sup>); the density of individuals (D) estimates the number of  
176 single animals per unit area (also per km<sup>2</sup>).

177 To evaluate age structure of the waterbuck population we distinguished three age classes: adults,  
178 sub-adults, and juveniles.

179 We used observed-versus-expected  $\chi^2$  test to check whether adult sex-ratio was even or not, and  
180 Pearson's  $\chi^2$  to test for differences in the frequency of waterbuck sightings among zones of the protected  
181 area. Correlations between (Box-Cox transformed) number of observed individuals and (i) (Box-Cox  
182 transformed) distances to illegal activities, (ii) (Box-Cox transformed) distances to the nearest path/track  
183 used by people, and (iii) (Box-Cox transformed) distances to the nearest water point, were carried out by

184 Pearson's correlation coefficient. Correlation between estimated yearly KIA and the (arcsine) percentage of  
185 females in the sample size was performed using a Pearson's product moment correlation coefficient.

186 Box-Cox transformation (Box and Cox 1964) was used to normalize variables whose data were not  
187 Gaussian (i.e. number of waterbuck individuals, distance separating the waterbuck groups to the illegal  
188 activities and to the nearest water points). The statistical software SPSS Statistics 21 and Past 3.0 were used  
189 to perform all analyses.

190

## 191 **Results**

### 192 *Population structure by sex and by age (year 2019)*

193 A total of 25 visual contacts of waterbucks were recorded during our 2019 census, with a total number of  
194 103 observed individuals. Of the 25 visual contacts, in 13 cases the animals were fleeing or on alert, while in  
195 the rest of cases they were either resting or walking or grazing. Adults represented 46.6% of the observed  
196 population (n = 103), sub-adults were 6.8%, juveniles were 17.5% and undetermined individuals were  
197 29.1%. Sex ratio was heavily skewed towards females (5:1; observed-versus-expected  $\chi^2= 24$ , df = 1, P <  
198 0.0001). The size of the great majority of the groups ranged 2-6 (Figure S1).

199

### 200 *DISTANCE-generated estimates of population parameters (year 2019)*

201 The probability of detecting waterbucks according to the Hazard rate/Cosine model (Figure S2) showed that  
202 there was a small number of observations between 0m and 30m compared to observations made between  
203 31m and 49m. The summarized results on the estimates of parameters of the waterbuck population by the  
204 Hazard rate/Cosine model are given in Table 1. The population estimate showed wide confidence limits  
205 (Table 1) and there was large variation in the sizes of the various groups observed (up to 18 individuals;  
206 Figure S1). The fit between the observations and the visibility curve was also not good (Figure S2).The  
207 calculated population size in FC/RGN for 2019 was 502 animals (see Table 1 for the confidence intervals of  
208 the estimate).

209

210

211

212 *Density and spatial patterns of occurrence (year 2019)*

213 Waterbuck sightings in FC/RGN were concentrated along the principal rivers: 96% of the species' sightings  
 214 were within 1.8km of the water, mainly around the artificial perennial waterbodies built along some streams  
 215 for elephants (Figure 2). Most observations occurred in the core conservation area (density of individuals  
 216 was 0.39 per km<sup>2</sup>), but very few were in the hunting area (density = 0.05 individuals per km<sup>2</sup>). These two  
 217 sectors differed significantly in terms of waterbuck density: Pearson's  $\chi^2=31$ , df = 1, P < 0.001. We obtained  
 218 a KIC = 0.036 and a KIA = 0.149. The dispersion analysis also revealed that waterbuck groups were  
 219 spatially aggregated (Morisita Ip = 0.568;  $\chi^2 = 902.3$ , df = 78, P < 0.0001).

220         Regarding illegal activities, a total of 146 signs could be counted along the transects during our 2019  
 221 surveys (Table S1). These activities were observed throughout FC/RGN but were statistically concentrated  
 222 (dispersion index of Morisita: Ip = 0.521) in its eastern side where waterbucks were not observed (Figure  
 223 S3). The distance from the nearest sign of poacher activity did not influence the number of observed  
 224 individuals (r = 0.04, n = 25, P = 0.842), and the same was true for the distance from the nearest water-body  
 225 (r = - 0.21, n = 25, P = 0.324) as well as for the distance from the nearest path/track (r = 0.191, n = 25, P =  
 226 0.360).

227

228 *Yearly population trends: 1985-2019*

229 During the period 1985-2019, the population dynamics of the studied waterbuck population can be roughly  
 230 divided into two main periods (Figure 3): 1) a population increase between 1985 and 2005 (Spearman's rank  
 231 correlation coefficient:  $r_s = 0.692$ , P < 0.05), and 2) an ongoing population collapse from 2007-2019 ( $r_s = -$   
 232 0.715, P < 0.01). There was also an annual slightly, non-significant, negative trend ( $r_s = - 0.520$ , P = 0.123)  
 233 in the number of individual waterbucks observed during the period 2008 to 2019 (Figure 3). However, in this  
 234 latter phase, the coefficients of determination (R<sup>2</sup>) were low (respectively, 0.1366 (number of individuals)  
 235 and 0.1803 (contact numbers)), thus indicating that the years explained poorly the number of individuals and  
 236 the number of contacts obtained. In general, both the number of contacts and the number of individuals  
 237 showed a sharp decline from 2010 to 2014 followed by a slight increase from 2014 to 2016.

238           The interannual observed sex-ratio was not affected by the density estimates: indeed, there was no  
239 correlation between estimated yearly KIA and the (arcsine) percentage of females in the sample size ( $r =$   
240  $0.086$ ,  $P = 0.893$ ).

241

## 242 **Discussion**

### 243 *Population structure by sex and by age*

244 In FC/RGN, waterbuck groups are typically mixed families of adult females and juveniles, with females  
245 being largely dominant over males (5 to 1). Such a skewed sex-ratio was very different from that reported in  
246 the literature: for instance, in Uganda the male: female sex-ratio was 1: 1.6 (Spinage 1970), and in Ethiopia  
247 1: 1.72 (Tsegaye *et al.* 2015). However, within a national park in Tanzania the sex ratio was 3: 1 in favour  
248 of females and 2: 1 outside the same national park in favour of females (Caro 1999). Thus, it seems that the  
249 adult sex-ratio is very variable in the species, with poor predictability on the basis of habitat characteristics,  
250 exposure to exploitation or resources available, but almost invariably with a higher number of adult females  
251 compared to the adult males. In ungulates, males are killed disproportionately to their abundance compared  
252 to adult females with local predation directly affecting patterns of sex ratio variation among adults (Berger  
253 and Gomper 1999). Since differences in survival of sexes may arise as a direct consequence of greater age-  
254 specific mortality among males, with selection operating differently on males and females (Berger and  
255 Gomper 1999), we suggest that the same should be possibly the case at our study area with predation-risks  
256 (especially by hyaenas and crocodiles) being much higher in males than in females. There are no available  
257 data on whether waterbuck males are indeed more preyed upon compared to females in FC/RGN. It is also  
258 possible, however, that the strong sex ratio deviation could be due to a higher incidence of illegal hunting on  
259 males or to behavioural differences between females and adult males causing less detectability in the latter.  
260 Although there are insufficient data to test any of these hypotheses, it is clear that the long-term changes in  
261 age structure and sex-ratio of the studied waterbuck populations played a minor role in the decline of  
262 numbers. Given this, the effects of hunting and changes in the animals' behavior should be more adequately  
263 assessed with ad-hoc studies.

264           Data on age structure of waterbuck populations in different parts of Africa are still limited. However,  
265 our data were comparable to other populations: in Ethiopia, for instance, adults accounted for 55.65%,

266 subadults for 23.5% and juveniles for 21.06% (Tsegaye *et al.* 2015). However, if we exclude indeterminates  
 267 (29%) from our study, the proportions of age classes are: adults 65%, sub-adults 10%, juveniles 25%,  
 268 scarcely comparable to that of Ethiopia (Tsegaye *et al.* 2015). The ratio of adults/ juveniles averaged 2.66 in  
 269 FC/RGN, which was very similar to that observed in (= 2.52) South Africa's Kruger National Park (Owen-  
 270 Smith and Mason 2005). Thus, neither the sex ratio nor the age structure is comparable to that from other  
 271 studies, and, in general, transect surveys can be suboptimal in determining the actual sex-ratios and age  
 272 structure of savannah ungulates (Hema *et al.*, 2020). In ungulate populations, age structure is an important  
 273 determinant of adult survival as the mean survival is associated with age of adults (Festa-Bianchet *et al.*  
 274 2003). More studies are needed to understand annual variations in age structure and their implications for  
 275 survival.

276

#### 277 *Density and associated parameters*

278 Our study revealed that (i) waterbuck density varied significantly among the different FC/RGN zones  
 279 (ranging from 0.05 individuals per km<sup>2</sup> up to = 0.39 individuals per km<sup>2</sup>), and that (ii) the various groups  
 280 showed clumped spatial pattern of distribution. The various groups observed tended to be non-randomly  
 281 distributed within the FC/RGN area but showed “spatial contagion” effect between each other. When we  
 282 tried to identify the main factor explaining this “aggregated pattern”, we rejected any linear relationship with  
 283 both anthropic negative factors (distance from paths/tracks and distance from sites with sign of illegal  
 284 activities) as well as environmental positive factors (distance from waterbodies). However, our survey was  
 285 undertaken during the dry season when water is clearly a limited resource, and since these ungulates are  
 286 highly water-dependent species (e.g. Melton 1978), there was obviously a greater chance that they are  
 287 grouped around the permanent water points (Hien *et al.* 2007). This would explain the strong aggregative  
 288 distributions of their groups around permanent water points without any linear relationship with the distance  
 289 from the waterbody itself.

290 We estimated an average density of 0.25 individuals × km<sup>2</sup> and a mean group density of 0.21 × km<sup>2</sup>.  
 291 Although the individual density observed at FC/RGN was much lower than the highest observed so far in  
 292 Africa (at Lake Nakuru in Kenya, with over 10 individuals × km<sup>2</sup>; Kutilek 1974), it was still higher than in  
 293 most areas: indeed, the mean density is 0.05-0.15 × km<sup>2</sup> in areas where the species is reasonably common

294 and  $0.2-0.9 \times \text{km}^2$ , more frequently  $0.4-1.5 \times \text{km}^2$  in remote areas that are presumably in good habitat status  
295 (Furstenburg 2005). Thus, our data suggest that waterbuck population abundance is still high in FC/RGN  
296 despite the observed declining population trend. Waterbuck density at Lake Nakuru, as a comparison, was  
297 likely to have been artificially high to be stable, and we suggest that this extraordinary concentration of  
298 animals was perhaps unusual due to abnormally favourable ecological conditions (high food resource  
299 availability in an exceptional year, migrations, or something equivalent) that do not occur in the other above-  
300 mentioned areas. In fact, high densities of *K. ellipsiprymnus* populations have been observed during very  
301 favourable years. For example, in FC/RGN, in 2010 there was a density four-fold higher than in 2014 (Fig.  
302 3), so annual variability should be mentioned as an important factor when making comparisons between  
303 populations, and an important factor to be considered in further studies of the demography of this species.  
304 Since the data were not analysed with the same statistical methodology in the various areas of Africa studied  
305 so far, the density estimates reported in the various studies may not be totally comparable. DISTANCE  
306 methodology also requires about 60 contacts to obtain unbiased density estimates (Buckland *et al.* 1993,  
307 2001) whereas our study achieved an insufficient number of contacts ( $n = 25$ ) for obtaining a robust estimate.  
308 Thus, the density values reported in this paper should be considered merely as preliminary. Similarly,  
309 previous estimates of waterbuck densities using DISTANCE methodology in West Africa were also biased  
310 by too small sample sizes: for instance, Brugière *et al.* (2005) in Guinea and also Cornelis (2002) in our same  
311 study area. Group density at FC/RGN was consistent with published studies (range  $0.27-0.96 \times \text{km}^2$ ; see  
312 Brugière *et al.* 2005).

313 On the basis of the KIA estimates (that is least prone to statistical biases than DISTANCE but  
314 obviously more empirical), our data ( $\text{KIA} = 0.149$ ) suggest a much higher abundance in the FC/RGN  
315 savannah than in the gallery forests of south-west Burkina Faso (Comoè-Léraba National Park:  $\text{KIA} = 0.022$ ;  
316 Hema *et al.*, 2017a). In the latter, available habitat is differently shaped as it basically exists along the banks  
317 of the river Comoé (Hema *et al.* 2017a).

318

319 *Yearly population trends: 1985-2019*

320 Our study revealed that in FC/RGN, Waterbucks had a phase of population growth between 1985 and 2005  
321 and then a significant decrease between 2007-2019. However, for the declining phase, the determination

322 coefficient and sample size (10 years) are low and the strength of the negative tendency cannot be totally  
323 reliable. We consider that the low value of the coefficient of determination is due to the low slope in the  
324 straight line after 2008, so that a relatively small population decline cannot be explained as having such large  
325 variations between years. In other words, a leap up from a new year can make the negative trend disappear.  
326 Hema et al. (2018) analysed the fluctuations in population size of waterbucks in FC/RGN during 1985-2008  
327 and found that these fluctuations were stronger than for other sympatric ungulates. It should be taken into  
328 account that, concerning the period 2009-2019, the population estimates showed wide confidence limits  
329 because the number of contacts was relatively low and there was large variation in the sizes of the various  
330 groups observed, thus reducing the estimate performances of the DISTANCE method. The low number of  
331 contacts also produced the suboptimal fit between the observations and the visibility curve as estimated by  
332 DISTANCE.

333 Why then did the population trend become constantly negative after 2005 and with a clear collapse after  
334 2007? Previous studies uncovered a significantly positive correlation between rainfall and population size of  
335 *Kobus ellipsiprymnus* (Ogutu et al. 2008; Bouché et al. 2016), and at FC/RGN it was demonstrated that the  
336 probability of high population sizes of this species increased with an increase of precipitation in August  
337 (Hema et al. 2018). Therefore, it can be hypothesized that the increasing aridity due to global warming that is  
338 affecting the Sahel region may be an important cause of the decreasing trend of the waterbuck population at  
339 the study area. Other reasons, for instance the changes in the management schemes adopted by the  
340 authorities (responsible for considerable population fluctuations in the warthog *Phacochoerus africanus*; see  
341 Hema et al. 2017b), are least likely to be involved in this declining trend. These management strategies  
342 implemented by the FC/RGN managers involved the strengthening of the FC/RGN surveillance teams, the  
343 development of reservoirs and salt water basins, and the permanent monitoring of the fire system. Indeed,  
344 waterbuck population fluctuations did not mirror the changes in management type observed in warthogs  
345 (Hema et al. 2017b). Illegal exploitation by poachers may also be an additional reason for the declining trend  
346 of the local waterbuck population (Hema et al. 2017c). Indeed, other two ungulate species are declining at  
347 FC/RGN (*Ourebia ourebi* and *Sylvicapra grimmia*), and their decline has been attributed to overhunting  
348 because these species were highly valued in the illegal bushmeat trade (Hema et al. 2017c). In addition, in  
349 another protected area of southern Burkina Faso (Comoé-Léraba), Hema et al. (2017a) uncovered a negative

350 correlation between hunting intensity and KIA estimates for waterbucks as well as for *Kobus kob*, *Ourebia*  
351 *ourebi* and *Cephalophus rufilatus*. Nonetheless, there was no direct evidence that poaching was a main  
352 reason for the continued decline of the species in our study area. Overall, it is likely that a combination of  
353 factors may explain the negative population trends of waterbucks in FC/RGN. Factors, including global  
354 warming (by increasing aridity) in combination with illegal activities such as poaching, may be responsible.  
355 We suggest that a multifaceted approach should be adopted in order to enhance the conservation status of the  
356 local waterbuck populations.

357

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361

362 **Data availability statement.** The authors declare that their data will be provided in case of request by  
363 interested readers

364

365 **Conflict of interest.** The authors declare no conflicts of interest

366

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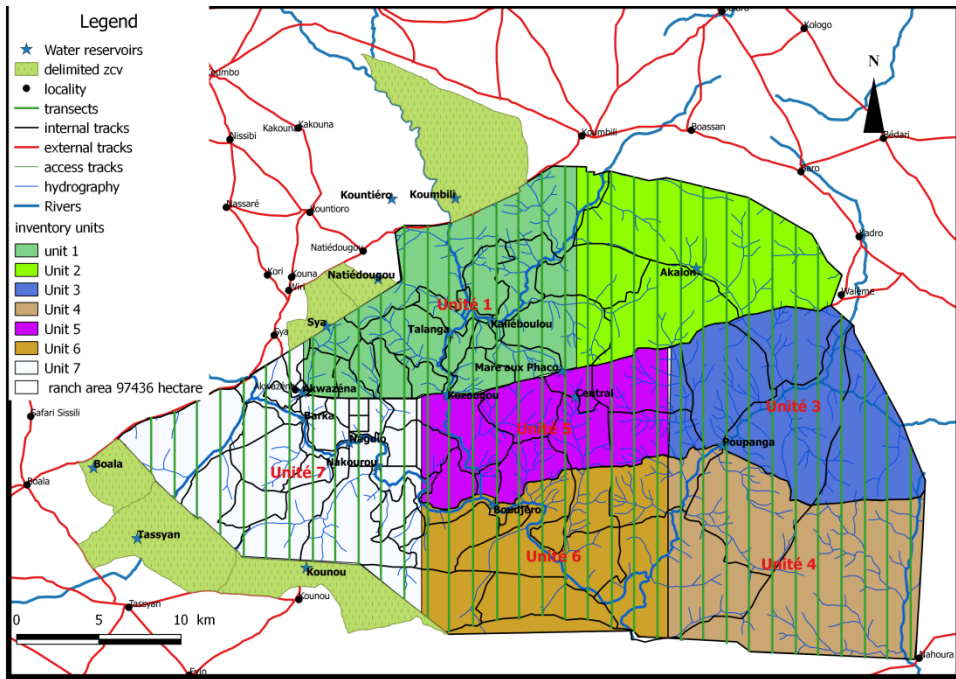
478 Table 1. Synthesis of the density and population size estimates obtained by DISTANCE methodology on the  
 479 bushbucks at the study area in southern Burkina Faso.

480

Parameter	Estimate
DISTANCE model	Hazard rate/Cosine
f(0)	0.0118
Var [f(0)]	0.02
Width of the W band (m)	85.011
density (D) of waterbucks per km <sup>2</sup>	0.515
Variance of (D)	1.164
95% upper confidence limit	1.359
95% lower confidence limit	0.195
% Coefficient of Variation	51.60
Estimate of waterbuck population size	502
95% upper confidence limit	1325
95% lower confidence limit	190
$\chi^2$	5.184
P	0.269
df	4
Number of individuals per group (range)	1-18
Density of groups per km <sup>2</sup>	0.212
Mean number of individuals per group	4.12

481

482 Figure 1. Map of the study area, showing the seven zones in which, the protected area was divided.

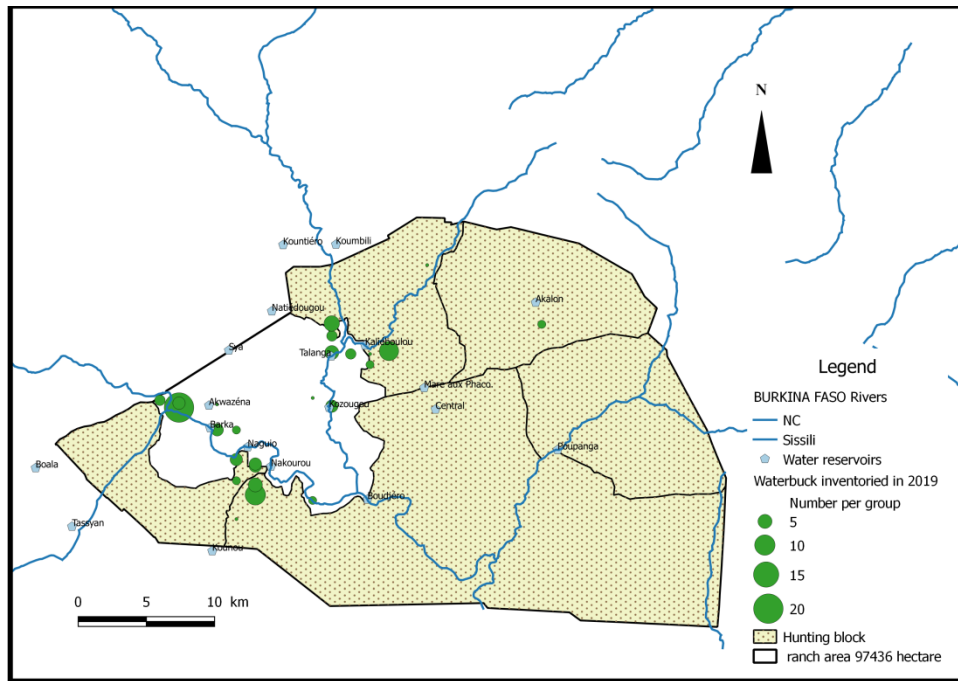


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486 Figure 2. Distribution of the waterbuck sightings in the study area, during the year 2019.

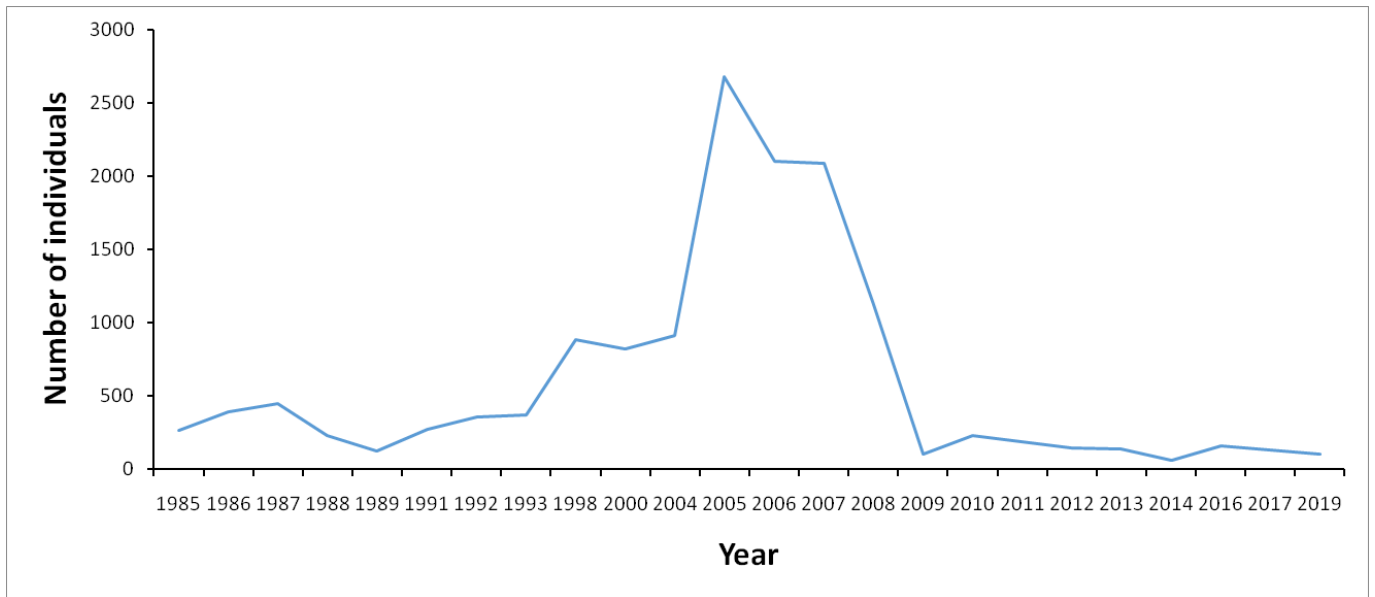


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489 Figure 3. Yearly trend (period 1085-2018) in the number of individuals of waterbucks at the study area in  
490 southern Burkina



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492

493 **ONLINE SUPPLEMENTAL MATERIALS**

494 Table S1. Synthesis of the dataset collected on the tracks of illegal activities within the study area during 2019.

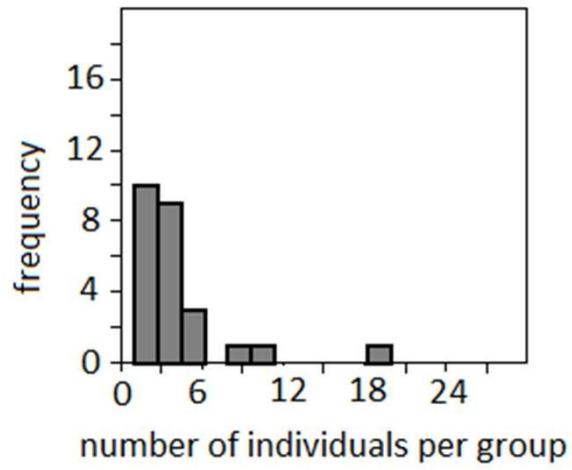
	number of cases
Poaching	42
Pastoralism	34
charcoal	18
tree cutting	22
human tracks	14
motor bike tracks	11
tree-branch thinning	5
Total	146

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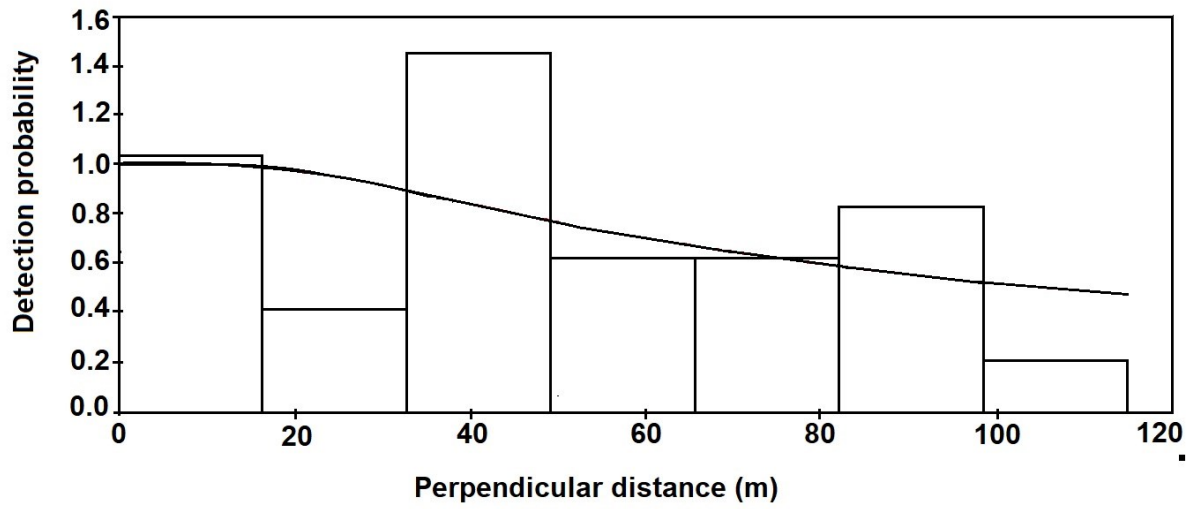
498 Figure S1. Frequency distribution of the various waterbuck groups in relation to the number of individuals in  
499 each group.



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501

502 Figure S2. Profile of the visibility curve for the waterbuck observations at the study area, during the year 2019

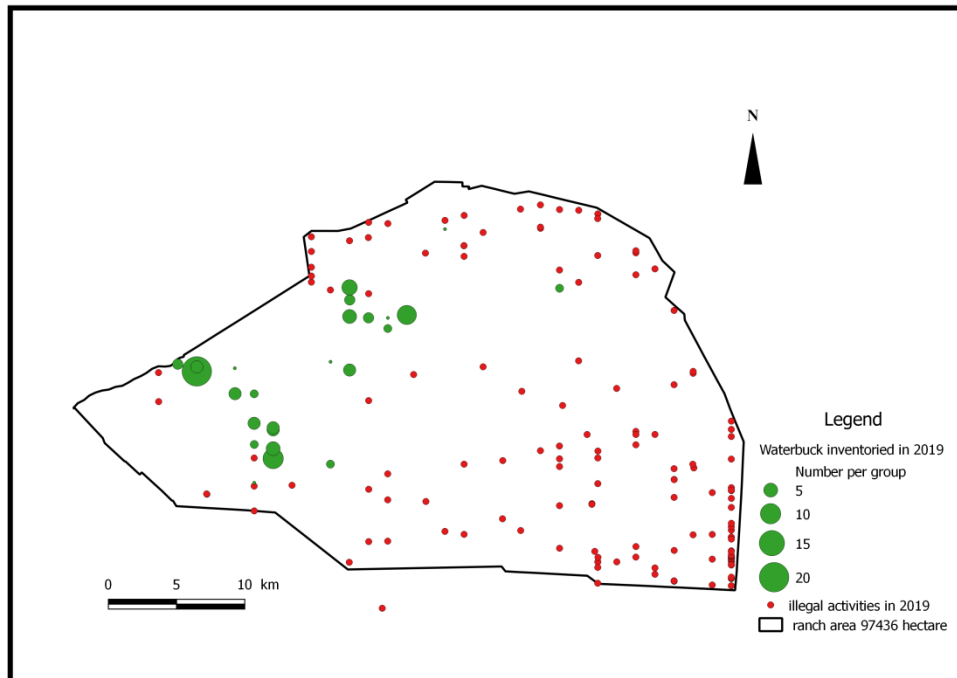


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505 Figure S3. Spatial distribution of the tracks of illegal activity within the study area in the year 2019, in relation  
506 to the group size of waterbucks.

507



508