

1 Abundance of larger mammals in Dinder National Park, Sudan

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15

16 Abstract

17 Wildlife is in decline across Africa, particularly in the Sudan-Sahel savanna. An important but little
18 studied area on the eastern reaches of this biome is Dinder National Park in Sudan. In March 2021,
19 we conducted a distance sampling survey in its ~3,000km² core area around the main Gelego
20 camp, walking a total of 56 line transects over a cumulative 273km. We calculated densities of
21 those species with over 20 independent detections using the best performing model. The most
22 abundant wild species recorded were olive baboon (25.0 ind/km²) and common warthog (7.3
23 ind/km²), while bohor reedbuck (2.1 ind/km²) and oribi (1.9 ind/km²) were the most abundant
24 ungulates. Our survey confirmed the illegal presence of large cattle herds inside Dinder (10.7
25 ind/km²). The substantial ungulate densities in the core area support regionally important
26 populations of large carnivores, making this one of the best functioning ecosystems in the region.
27 When compared to historical unpublished data from waterhole and road counts we detected a
28 declining trend in wildlife numbers over the past five decades. We call for improved wildlife
29 monitoring and conservation actions to protect this important ecosystem and for increased
30 efforts to extend effective protection beyond the core area of Dinder.

31

32 Keywords

33 Bohor reedbuck, distance sampling, herbivore community, livestock

34

35 Statements and declarations

36 The authors have no conflicts of interest to declare that are relevant to the content of this article.

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38 Author contributions

39 AAM HB and PC designed the experiment, analysed the results and wrote the manuscript. AAM
40 HB OM IE RA EY NB GEI AMM and MAI did the fieldwork and curated the data. CSZ coordinated
41 the project and contributed to the manuscript.

42 Introduction

43 Over the last two decades, Sudan was hit by international sanctions, resulting in limited
44 international exchange in non-humanitarian sectors. Biodiversity conservation is one such sector
45 that has developed in relative isolation, with few recent international publications. Protected
46 areas are the backbone of biodiversity conservation, and Sudan historically has had an elaborate
47 protected area network, but little is known about its effectiveness in terms of current species
48 diversity and abundance (Siddiget al., 2018).

49 Sudan is politically grouped with North or East Africa, but its climate belts also run across West
50 and Central Africa; the Sahara in the North, the Sahel in the centre and the Sudanian savanna in
51 the South. The southern belt falls in the East Sudanian Savanna Ecoregion, the easternmost part
52 of the Sudanian savanna belt, starting in the Atlantic coast of Senegal to the West and running
53 to the Ethiopian plateau escarpment in the East. It is characterised by a biogeography and
54 species composition more similar to that of West and Central Africa. This ecoregion faces a
55 biodiversity crisis (Mallon et al., 2015; Scholte et al., 2022). Widespread wildlife population
56 declines across the wider Sahel/Sudanian savanna are typically anthropogenic in origin and
57 often associated with political instability; with natural resource exploitation, hunting, and
58 habitat destruction being common threats to large mammals (Brito et al., 2018; Scholte et al.,
59 2022). Low levels of funding compound wildlife conservation issues and hinder population
60 recoveries (Waldron et al. 2013; Scholte et al., 2022) as well as inefficient and inadequate
61 coverage of protected areas (Brito et al., 2016; Scholte et al., 2022). An effective protected area
62 in Sudan could therefore make a contribution of continental importance (Bauer et al., 2021).

63 Within Sudan, Dinder National Park (DNP) is considered to be among the most effective
64 protected areas, with a long tradition of field conservation. However, little has been published
65 internationally and no recent (last 10 years) wildlife census data are available, except for lions
66 (*Panthera leo*) and spotted hyaenas (*Crocuta crocuta*) (Mohammed et al., 2019). As a
67 contribution to knowledge on mammal diversity and abundance in the area, we report on a line
68 transect survey using distance sampling techniques. This type of survey has not been done here
69 before, so direct comparisons are not possible. Instead, we discuss our results in the context of
70 unpublished historical waterhole and roadside counts to make inferences about long-term
71 ecosystem changes.

72

73 Material and methods

74 The 10,291km² DNP is contiguous with the 2,666km² Alitash National Park (formerly spelled as
75 Alatash) in Ethiopia. Although Dinder-Alitash is an ecological unit, there is no transboundary
76 management or indeed any access to or across the international boundary; the work described
77 here was limited to the DNP component in Sudan only. DNP was established in 1935 following
78 the London convention (1933) for the conservation of African fauna and flora (Dasman, 1972),
79 and declared as a Biosphere Reserve since 1979. DNP has three seasonal rivers; the Dinder and
80 Gelego rivers that have their confluence at Gelego Camp (DNP's main security station), and the
81 Rahad river which is the northern boundary (Fig 1). These rivers are small in Ethiopia, but they
82 gather more water from their basins and further downstream, especially in the West of the
83 park, they have very large and wide permanent water ponds and floodplains, locally called
84 'maya', where wildlife concentrates.

85 The habitat is dominated by *Combretum-Acacia-Balanites* woodland, with patches of Doum
86 palm (*Hyphaene thebaica*) and grasslands. DNP contains an important mammalian species
87 assemblage, with robust populations of subspecies that have become rare across West and
88 Central Africa (i.e., northern lion *Panthera leo leo*, northern ostrich *Struthio camelus camelus*). A
89 few charismatic species have apparently been locally extirpated (Tora hartebeest *Alcelaphus*
90 *buselaphus tora*, savanna elephant *Loxodonta africana* and giraffe *Giraffa camelopardalis*) but
91 an important mammalian community remains present, with 29 medium and large mammal
92 species recorded recently (Bauer et al., 2018).

93 Large parts of DNP are inaccessible and our work was limited to a core zone of 3,000km². Even
94 in this core zone, the road network is inadequate for roadside wildlife counts and therefore we
95 used transects traversed on foot (Fig 1). In March 2021, we walked 56 transects with a
96 cumulative length of 273km., working in four independent teams composed of three people
97 each; one observer, one navigator and one scout. We used CyberTracker® software
98 (www.cybertracker.org) to log all direct wildlife observations; including species, time, location,
99 distance, bearing, number of individuals and, where possible, their sex and age. Data were
100 analysed using Distance 7.3 (Thomas et al., 2010). We present density estimates for those
101 species with at least 20 independent detections in total. The best performing model for

102 estimating density of each species was selected based on comparison of Akaike Information
103 Criterion (AIC) values between the candidate models: Half-normal key with Simple polynomial
104 adjustments; Half-normal key with Cosine adjustments; and Hazard Rate key with Hermite
105 polynomial adjustments. Goodness-of-fit of the best performing model was calculated using the
106 Kolmogorov-Smirnov test (Table 1).

107 A combination of roadside and waterhole counts were conducted in DNP over the last five
108 decades; in 1972, for several years in the 1980s and 1990s, and last in 2010. Almost all
109 waterholes are located in the DNP core zone, the area that we surveyed. We cannot be sure of
110 the exact areas for which species abundances presented relate, but they relate to similar (but
111 not necessarily exactly the same) land areas. Results of these surveys were never published in
112 peer-reviewed literature; thus we curated and collated the data (Supplementary Material, Table
113 S1). Due to the variation in methods and the absence of measures of uncertainty we cannot test
114 whether differences over time are significant, but we nevertheless performed a linear
115 regression on these imperfect data to indicate plausible trends over time for several species.

116

117 Results and Discussion

118 The most abundant wild species recorded were olive baboon *Papio anubis* and common
119 warthog *Phacochoerus africanus*, while oribi *Ourebia ourebi* and bohor reedbuck *Redunca*
120 *redunca* were the most abundant ungulates found; densities were 24.1 ind/km² (olive baboon),
121 6.7 ind/km² (common warthog), 2.6 ind/km² (oribi) and 1.9 ind/km² (bohor reedbuck),
122 respectively (Table 1). Domestic cattle *Bos spp.* was also abundant with a density of 10.7
123 ind/km², even though these are rarely seen from the road. Herders lead them away from roads
124 to avoid detection by park management, leading to underestimation of livestock encroachment
125 as a threat in public perception. For wild species we would caution against extrapolating our
126 results beyond the 3,000km² core area of DNP, but for livestock there is no reason to assume
127 that densities would be higher in the core zone than elsewhere, which would suggest an
128 estimate of just over 100,000 head of cattle for the whole of DNP.

129 Fig 2 shows historical estimates of key wildlife species collated from unpublished reports
130 (Supplementary Material, Table S1), with the caveat that these estimates are based on differing
131 methodologies used by different observers, have no measure of precision (no SE or CI) and have

132 gaps spanning over a decade. Several species are still abundant, but they all appear to have
133 declined over the last five decades; Fig 2 shows linear regression lines to visualise these
134 declining trends, but these regressions cannot be used to test the significance of declines
135 because of the aforementioned caveats. Without measures of uncertainty it is impossible to test
136 the significance of past declines, but going forward our results will provide a useful baseline.
137 Particularly noteworthy, however, is the decimation of the bohor reedbuck population, from an
138 estimated 118,677 individuals in 1972 to 5,700 in 2021. Partly, these trends could be caused by
139 grazing competition with livestock. Indeed, patterns of avoidance and decline in wild grazer
140 numbers has been noted in other livestock-grazed Sudanian savanna ecosystems (e.g. Hibert et
141 al., 2010) and the presence of nomadic herders (Felata and Umbararu) has been raised as a
142 conservation concern by park wardens in DNP and adjoining Alitash NP, Ethiopia (Mohammed et
143 al., 2019). An alternative hypothesis is rainfall variability; we have no data to investigate this
144 here but note that this hypothesis was raised in other Central African savannas (Scholte et al.,
145 2022). Poaching could be another factor, but we have no specific observations to support this
146 suggestion. Nevertheless, poaching and lack of law enforcement has been recorded as
147 contributing to large mammal declines across other Sahelian/Sudanian savanna ecosystems (e.g.
148 Bouché et al. 2012; Brito et al. 2018; Hema et al. 2019; Scholte et al. 2022). However, we note
149 that the core area of DNP appears relatively well protected by comparison with many regions of
150 the Sahel/Sudanian savanna (see Biro et al., 2018; and Scholte et al., 2022): with over 250 scouts
151 providing a permanent presence at all major wetland outposts (Bauer et al., 2018). We are wary
152 of assigning definite reasons to the declines outlined in this study in the absence of more
153 detailed investigation. More and better data are needed to draw conclusions, alongside more
154 detailed consideration of the geopolitical nuances and conservation governance of the Dinder-
155 Alitash landscape. We note issues in methodological compatibility in accurately establishing
156 wildlife population trends in Dinder NP, and are therefore cautious in our interpretations not to
157 misrepresent the system by over-interpretation. Notwithstanding the negative trends, we still
158 found substantial numbers of wildlife, and DNP remains an important stronghold for wildlife in
159 the East Sudanian savanna ecoregion that merits improved wildlife monitoring and targeted
160 conservation actions.

161 No buffaloes *Syncerus caffer* were detected on the line transects, but two large herds of ~250
162 individuals each were opportunistically observed off transect, leading to a conservative
163 minimum estimate of 500 buffalo for DNP. These herds were observed several times, so we had

164 enough time to estimate herd size; on some days we observed both herds in different areas so
165 we are certain they were distinct herds rather than counted twice. Our ungulate estimates
166 constitute a substantial prey base, consistent with our population estimates of 47 lions and 54
167 spotted hyaenas in the same core zone (Mohammed et al., 2019). From an East African
168 perspective these wildlife populations may appear small, but from a Central African perspective
169 we understand their crucial importance (Bauer et al. 2015; Bauer et al. 2021; Scholte et al.
170 2022). Sudan has long been relatively isolated from the international research community and is
171 thus comparatively poorly known internationally in terms of wildlife conservation. We therefore
172 caution against wide-reaching comparison of our results between countries and wider
173 geographical regions (i.e. Eastern and Southern Africa) in the absence of more detailed
174 understanding of Sudanese biodiversity management and natural resource governance. These
175 surveys break the long silence in international literature on biodiversity and underscore the
176 importance of the Dinder-Alitash transboundary ecosystem for regional conservation efforts.

177 Our survey had several shortcomings. Our efforts were based on expected densities from an
178 imperfect baseline of old population estimates; a higher sampling effort would have increased
179 precision and given adequate detections to derive estimates also for less abundant species. The
180 low number of detections even for the more common species also precluded further analysis;
181 our transects covered dry forest, floodplain, and riverine habitat, but the data were pooled
182 whereas realistically densities will probably vary between habitats. Furthermore, the southern
183 half of the park remains inaccessible, and political challenges remain an obstacle to line transect
184 surveys across the ecosystem, into the adjacent Alitash NP in Ethiopia. In the context of the
185 acknowledged limitations, our study should be treated going forward as a baseline, a proof of
186 concept and an effort to strengthen local capacity to use this methodology more intensively in
187 routine wildlife monitoring in the future.

188

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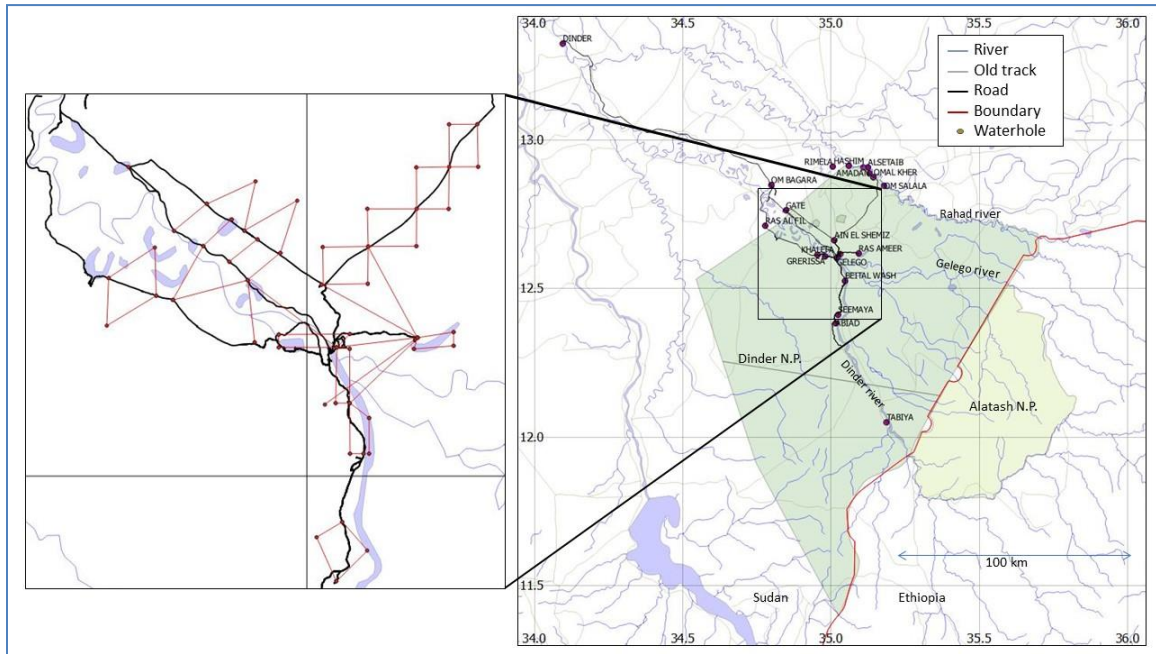
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242 Table 1: results of foot line transects in Dinder National Park; densities calculated using Distance
 243 Sampling and extrapolated to the 3,000km² DNP core area.

Species	Detections	Density (ind/km ²)	Density CI 95%	Abundance in core area	Distance model	Goodness-of-Fit (Kolmogorov- Smirnov test)
Common warthog	136	6.7	3.9-11.4	20,100	Hazard Rate key, $k(y) = 1 - \text{Exp}(-\text{y}/\text{A}(1))^{**}\text{-A}(2))$	0.0331 p = 0.9984
Bohor reedbuck	95	1.9	1.3-2.7	5,700	Half-normal key, $k(y) = \text{Exp}(-\text{y}^{**2}/(2*\text{A}(1)**2))$	0.0811 p = 0.5602
Oribi	66	2.1	1.3-3.3	6,180	Half-normal key, $k(y) = \text{Exp}(-\text{y}^{**2}/(2*\text{A}(1)**2))$ Cosine adjustments of order(s) : 2	0.0608 p = 0.9678
Olive baboon	66	24.7	12.6-48.3	74,100	Hazard Rate key, $k(y) = 1 - \text{Exp}(-\text{y}/\text{A}(1))^{**}\text{-A}(2))$	0.0651 p = 0.9426
Moustached monkey	30	2.1	0.8-5.3	6,360	Half-normal key, $k(y) = \text{Exp}(-\text{y}^{**2}/(2*\text{A}(1)**2))$	0.1903 p = 0.2273
Cattle	20	10.7	2.0-55.6	32,040	Half-normal key, $k(y) = \text{Exp}(-\text{y}^{**2}/(2*\text{A}(1)**2))$	0.1568 p = 0.7088
Waterbuck	20	1.0	0.4-2.6	3,120	Half-normal key, $k(y) = \text{Exp}(-\text{y}^{**2}/(2*\text{A}(1)**2))$	0.1556 p = 0.7181
Grivet	17	n/a				
Ostrich	6	n/a				
Heuglin's gazelle	4	n/a				
Monitor lizard	4	n/a				
Bushbuck	2	n/a				
Lion	2	n/a				
Wild cat	2	n/a				
Goat	2	n/a				

244

245 Figure 1: Dinder ecosystem, smaller panel showing the core zone with the location of our line
246 transects.

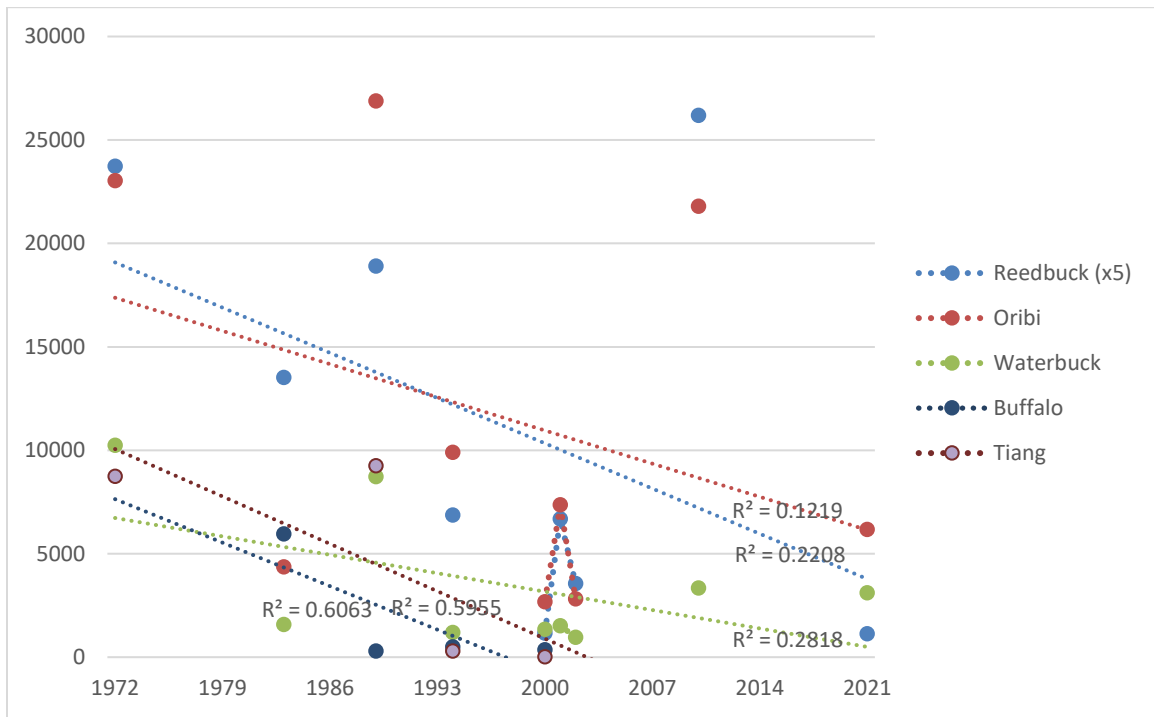


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249 Figure 2: Linear regression of wildlife population estimates since 1972 of most abundant
250 ungulates (reedbuck estimates divided by 5 to fit on scale); note caveats on different
251 methodologies in text.

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254 Supplementary Material

255 Table S1: Mammal population estimates from historical surveys of the waterholes in Dinder National Park, collated from various unpublished
 256 reports, presented along with our 2021 distance-sampling results in the last column. Estimated densities (ind/km²) for the 3,000km² DNP core
 257 area are presented alongside historical abundances (Ab.) but see text for important caveats.

258

Common name	Scientific name	1972		1983		1989		1994		2000		2001		2002		2010		2021	
		Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.	Density	Ab.
Oribi	<i>Ourebia ourebi</i>	7.7	23,037	1.5	4374	9.0	26,880	3.3	9900	0.9	2683	2.5	7366	0.9	2822	7.3	21,796	2.1	6180
Waterbuck	<i>Kobus ellipsiprymnus</i>	3.4	10,239	0.5	1590	2.9	8736	0.4	1200	0.4	1344	0.5	1524	0.3	964	1.1	3353	1.0	3120
Buffalo	<i>Syncerus caffer</i>			2.0	5965	0.1	300	0.2	500	0.1	358								
Tiang	<i>Damaliscus lunatus</i>	2.9	8742			3.1	9248	0.1	300	0.0	21								
Bohor reedbuck	<i>Redunca redunca</i>	39.6	118,677	22.5	67,604	31.5	94,528	11.5	34,400	1.9	5824	11.1	33,401	5.9	17,812	43.6	130,946	1.9	5700
Roan antelope	<i>Hippotragus equinus</i>	0.2	465	0.1	397	0.1	224	1.2	3600	0.0	85	0.3	762	0.1	333	0.1	335		
Bushbuck	<i>Tragelaphus scriptus</i>	0.1	233	0.3	795	0.7	2016					0.7	2038	0.3	952	10.9	32,694		
Common warthog	<i>Phacochoerus africanus</i>											4.3	12,945			43.5	130,443	6.7	20,100
Heuglin's gazelle	<i>Eudorca tilonura</i>			0.1	396			6.0	17,912	0.2	635								
Olive baboon	<i>Papio anubis</i>											18.0	54,064			229.4	688,095		
Moustached monkey	<i>Erythrocebus poliophaeus</i>											1.4	4081			3.2	9724	2.1	6360
Northern ostrich	<i>Struthio camelus</i>											2.2	6477			3.5	10395		

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