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Brief Report

Are Afrotropical Protected Areas Effective in Increasing Waterbird Richness and Diversity? A Case Study from South Sudan (East Africa)

Gift Simon Demaya [1], Shazali Abdallah Gordon [1], Thomas Francis Lado [1], Luca Luiselli [2,3] and Corrado Battisti [4,*]

[1] Department of Wildlife Science, University of Juba, Juba P.O. Box 80, Sudan; gftsimon@gmail.com (G.S.D.); shazaligordon@gmail.com (S.A.G.); jsuliman.lado@gmail.com (T.F.L.)
[2] IDECC—Institute for Development, Ecology, Conservation and Cooperation, 00144 Rome, Italy; lucamlu@tin.it
[3] Department of Applied and Environmental Biology, Rivers State University of Science and Technology, Port Harcourt 5080, Nigeria
[4] "Torre Flavia" LTER (Long Term Ecological Research) Station, Città Metropolitana di Roma Capitale, Servizio Aree Protette, Via G. Ribotta, 41, 00144 Roma, Italy
* Correspondence: c.battisti@cittametropolitanaroma.it

Abstract: In many tropical areas of high conservation concern there is still no evidence on the effectiveness of protected areas in protecting specific components of biodiversity. Here, to assess the management effectiveness of protected areas, we carried out a field sampling design for collecting data on waterbird communities within the Nibule National Park (South Sudan), a poorly-known hot-spot of biodiversity, and in the surrounding buffer zone. All the metrics of richness (absolute species richness, Margalef index, Chao-1) and diversity were significantly higher for bird communities inhabiting the national park, when compared to the buffer zone. Evenness was predictably lower in the national park when compared to the buffer zone, probably due to the large numbers of rare species that were observed in the park's richer communities, thus increasing the differences in relative frequencies between species. The diversity profiles highlighted this pattern, with more sloping curves in the park sites, evidencing a role of protected area management in positively affecting the bird community structure. Our data provide the first evidence for a poorly-known area of high conservation concern on the effective role played by a National Park in maintaining high values of richness and diversity, at least for wetland-related birds.

Keywords: protected areas; richness; diversity; evenness; rarefaction; diversity profiles; monitoring

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1. Introduction

The role of natural parks and reserves for the conservation of species and ecosystems is largely known, but data for tropical areas are still scanty [1]. In particular, their effectiveness in conserving threatened targets of biodiversity can be measured by starting specific monitoring actions and using many different indices and indicators (e.g., [2]): these last may be focused both on management results (outputs) and on biological responses (outcomes) [3].

Among the biological indices, those at the community level (univariate metrics; [4]) have been largely used to verify changes in the status of environmental systems before and after the implementation of management and conservation actions [1].

Although monitoring research is already available worldwide [5,6], in many tropical contexts of high conservation concern there is still no evidence on the effectiveness of protected areas in conserving specific components of biodiversity [7]. Assessing management effectiveness of protected areas is particularly urgent in these contexts where conservation actions are urgent [6].

One of the lesser studied areas of the African continent is South Sudan, for which ecological research on birds at the community level has been carried out only in recent times [8]. In this geographical area, the system of nature reserves includes some areas that are located along the Nile River, with a landscape matrix dominated by wet environments. Here, field studies aimed to compare bird diversity in protected vs. neighbouring non protected areas are not yet available [9,10].

Wetlands are strategic to waterbirds since they provide them suitable habitats for breeding and foraging needs [11,12]. Moreover, due to their ecological sensitivity, waterbird species are considered as good indicators of wetland health [13]. In tropical areas, waterbird species are at risk due to the large-scale loss of wetland habitats due to human-induced disturbances. For example, it was estimated that over 50% of total wetland sur- face was lost during the last century [14]. In this regard, the role of protected areas (e.g., parks and reserves) may be strategic.

This study aims to compare a set of uni-variate metrics of diversity of water-related birds in a national park versus its nearby non- protected territories of South Sudan, a poorly known hot spot of biodiversity [15]. To explore this, we performed a field sampling design for collecting data within the national park and in its comparable neighbouring area, using a set of univariate metrics of diversity.

2. Methods

2.1. Study Area

The study was conducted at Nimule National Park and in a comparable surrounding buffer area located in Eastern Equatorial State of South Sudan (Magwi County), near the border with Uganda (Figure 1). Nimule National Park (latitude of 3-599912; longitude of 32.055294) was established in 1954 mainly for the protection of large iconic mammals and for its rich biodiversity and scenic beauty.

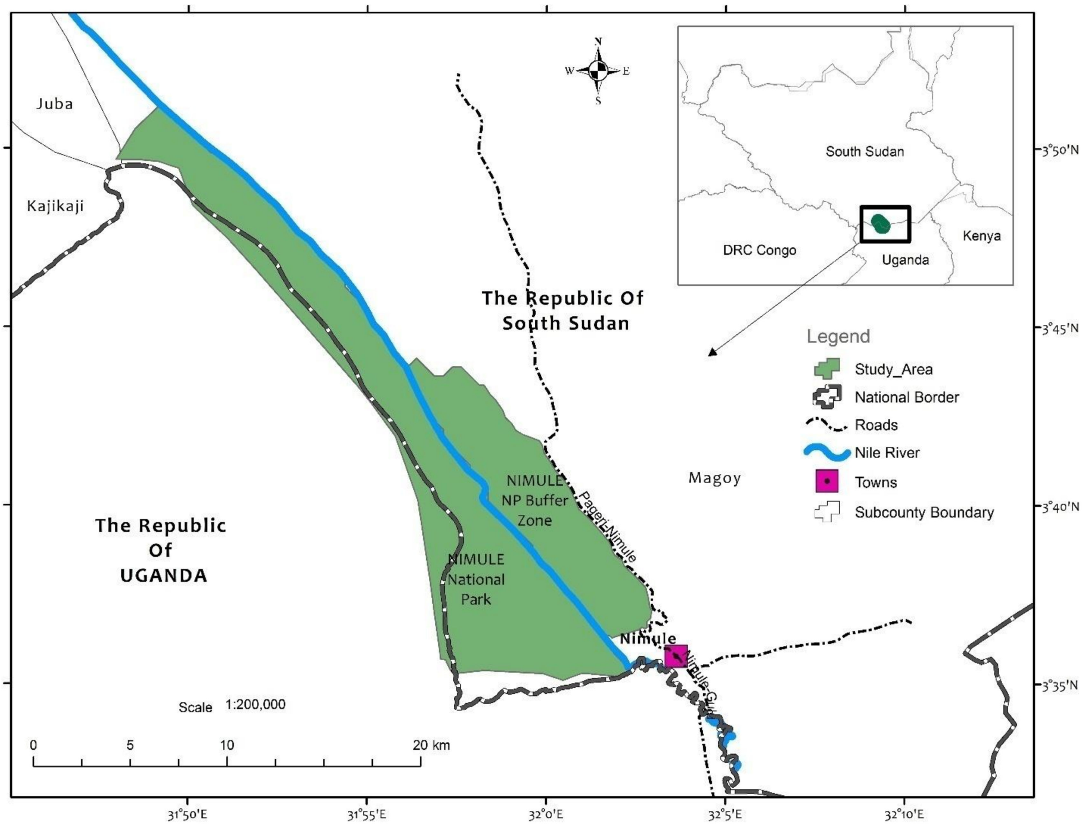

Figure 1. Map showing the location of Nimule National Park (South Sudan).

Nimule National Park is characterized by deciduous tree species typical of the savannah and bush environments as *Kigelia africana*, *Acacia seyal*, *A. abysinica, A. sieberiana* and *A. brevispice*, *Schelerocharya birrea*, *Afteli aquanzensi*, *Ziziphus mouritiana*, *Euphorbia candelabrum, Combretum molle*, *Tamarindus indica, Borasus aethiopium, Anona senagalensis,* and *Caesesalpinia decapetala.* A riverine woodland vegetation is present, occurring along seasonal and permanent rivers and streams. The Kayu River that flows through the park from the Uganda border to the hills and the Illunga mountains are some of physical features of Nimule National Park [16]. This park hosts a variety of fauna of high conservation concern (e.g., among mammals: *Loxodonta africana, Hippopotamus amphibious, Kobus defassa, Tragelophus scriptus, Cercopithecus acthios, Procavia cupensis*; among reptiles: *Cyclanorbis elegans, Crocodylus niloticus* and others). Biodiversity in Nimule National Park and the surrounding buffer had suffered intensive threats (e.g., poaching, human encroachment, cattle keeping, deforestation and other anthropogenic activities) that were carried out by people living nearby during the South Sudan 2013–2019 civil war. More particularly, these threats are now actively controlled by the park rangers (with a priority toward illegal hunting and bushmeat trading).

To carry out a comparison, we selected a study area extended over 410 km^2 and bordering the White Nile River in the eastern part of the park (we selected the eastern sector to avoid crossing the international border with Uganda). The selected portion of the buffer zone was situated in the eastern bank, and was bounded by the Assua River to the North, and the Juba-Nimule road to the East. Vegetation, fauna and landscape mosaics are highly comparable with the national park.

The climate is tropical with warm/hot temperatures (average temperature of 37 °C in February, and 29 °C in July) with scarce rainfall. The monthly rainfall varies between 2 (January) and 127 mm (October).

2.2. Protocol

The field study was conducted between 18 and 26 March 2020, in the dry seasons. We carried out a sampling design comparing sites located in the National Park vs. sites located in the surrounding buffer zone and selecting ecologically similar sites (wet habitats along primary and secondary rivers).

Locations were:

(i) in the buffer zone: Commando, Fula, Rai, and Landing; and
(ii) in the Nimule National Park: Lobubu–Apanzala, Simo2, Simo1, Iria, and Apalla.

In each site, any aquatic and semi-aquatic bird species (hereafter, 'waterspecies') were identified and recorded along an unlimited distance line transects (threshold detectability: 500 m) for a total length of 3400 m (3.4 km), randomly located [17].

The identification of the recorded birds was performed visually and by photographic record using field guides for identification. Waterbirds not classified at a species level were not considered. All individuals were identified to the species level with binocular 8 × 30 Leica [18].

2.3. Data Analysis

To compare the diversity of the bird assemblages among habitats, we calculated the following univariate metrics at community level, for each line transect/site [4,19]: (i) abundance index: number of recorded individuals (for each species and totally); (ii) species richness, that is the total number of species; (iii) normalized species richness (Margalef index) calculated as (S-1)/ln(n); (iv) Chao-1, as an estimate of total species richness. Chao1 = $S + F1(F1 - 1)/(2\,(F2 + 1)$, where $F1$ is the number of singleton species and $F2$ the number of doubleton species [4]; (v) Shannon–Wiener index: $H' = -\Sigma \mathrm{fr} \times (\ln \mathrm{fr})$, where $\mathrm{fr} = n/\mathrm{N}$, where n is the number of individuals of each species in each study site (national park vs. buffer) and N is the total number of birds that were recorded; and (vi) Pielou's Evenness index, calculated as: $e = H'/H'\max$, where $H\max = \ln S$, with H' representing Shannon's index, and S the total number of bird species recorded (for details of metrics: [4,19]). Hmax corresponds to the maximum value of diversity (i.e., when all species are equally represented [4]).

Data were pooled in sites belonging to Nimule National Park versus sites belonging to the surrounding buffer zone, using single transects as replicates. We compared the averaged values in univariate indices between the buffer zone and park sites using a non-parametric Mann-Whitney U test, using box plots to illustrate medians values and variance. We used a *t*-test to compare the differences in diversity indices between the buffer zone and National Park sites [4,19,20] after having verified the normality and homoscedasticity of the raw data.

We performed individual rarefaction curves to compare diversity in samples of different sizes. This module estimates how many taxa you would expect to find in samples with a smaller total number of individuals. With this method, it is possible to compare the number of taxa in samples of different size. Using rarefaction analysis on a large sample, it is possible to read out the number of expected taxa for any smaller sample size [21]. We performed rarefaction curves both for species richness and Shannon-Wiener H′ diversity index both for singles sites and cumulating data buffer vs. National Park.

To graphically compare diversities in several samples, we used the diversity profile models [22]. Diversity profiles have been used because the validity of comparing diversities across samples can be criticized because of the arbitrary choice of a diversity index. In this regard, a number of diversity indices may be compared to make sure that the diversity ordering is robust. A formal way of doing this is to define a family of diversity indices, dependent upon a single continuous parameter [22]. We used the exponential of the so-called Renyi index, which depends upon a parameter α on the x-axis. For $\alpha = 0$, this function gives the total species number, $\alpha = 1$ gives an index proportional to the Shannon index, while $\alpha = 2$ gives an index which behaves like the Simpson index [22,23]. The bootstrapping option (giving a 95% confidence interval) was based on 2000 replicates.

Analyses were performed with PAST version 4.1 computer software [23]. Alpha was set at 5%.

3. Results

A total of 1755 bird individuals, belonging to 73 different species, were observed in nine sites (buffer zone: n = 548; Nimule National Park: n = 1207).

All the metrics of richness (species richness, Margalef index, Chao-1) were significantly higher for communities inhabiting the Nimule Park, when compared to the buffer zone. The diversity index showed higher values in the park, however without a significant difference in terms of averaged values. Nevertheless, comparing the total value of diversity of park versus buffer zone, we obtained a significant difference ($t = -2.14$, $p = 0.032$). Pielou's evenness showed a lower value in the park communities when compared to the buffer zone (Figure 2; Table 1; Appendix A).

Table 1. Univariate metrics of diversity for the studied wetland-related bird communities (Ab, total abundance index; S, species richness; Dm, normalized species richness (Margalef index); Chao-1, Chao-1 richness estimator; H′, Shannon-Wiener diversity index; e, evenness. Buffer area: C, Comando; F, Fula; R, Rai; Ls, Landing site; Nimule National park: L, Lobubu; Si2, Simo 2; Si1, Simo 1; Apalla, Apalla; Iria, Iria. *: $p < 0.05$.

Buffer	Ab	S	Dm	Chao-1	H′	e
C	75	17	3.706	18	2.314	0.595
F	66	6	1.193	6	1.64	0.860
R	209	20	3.556	22.5	2.314	0.506
Ls	198	20	3.593	20.25	2.421	0.563
mean (sd)	137 (77.01)	15.75 (6.65)	3.012 (1.21)	16.688 (7.36)	2.172 (0.36)	0.631 (0.16)

Table 1. *Cont.*

Park	Ab	S	Dm	Chao-1	H′	e
L	300	31	5.26	31.91	2.353	0.339
Si2	293	32	5.458	34.55	2.069	0.248
Si1	193	36	6.651	36.77	2.856	0.483
Apalla	196	42	7.768	49.09	3.11	0.534
Iria	225	38	6.831	42.09	2.985	0.5206
mean (sd)	241.4 (51.89)	35.8 (4.49)	6.394 (1.04)	38.882 (6.83)	2.675 (0.44)	0.425 (0.13)
Z	1.347	2.337	2.327	2.327	1.353	1.837
P	0.178	0.019 *	0.02 *	0.02 *	0.176	0.066

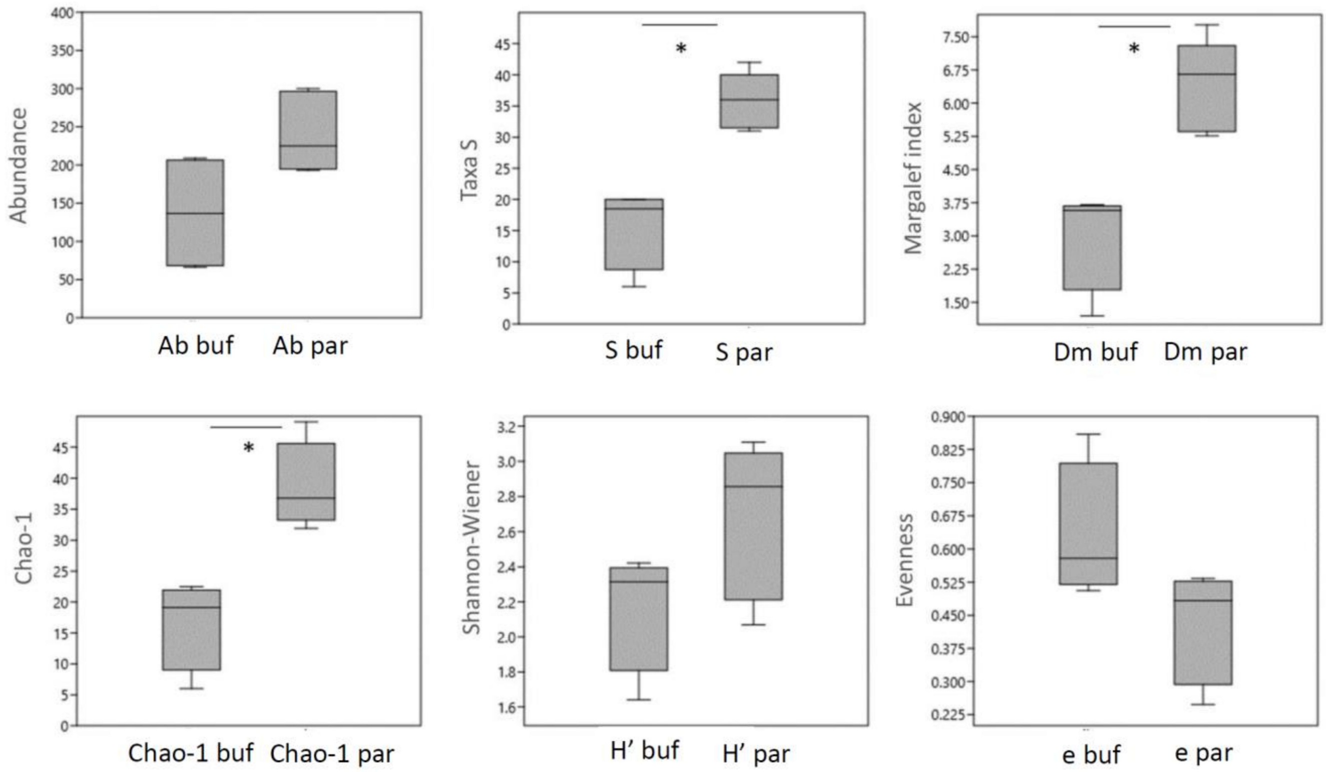

Figure 2. Boxplots with mean values (and standard deviation) for the uni-variate metrics of diversity. Ab, abundance index; S, species richness; Dm: Margalef index (normalized species richness); Chao-1, Chao-1 richness estimator; H′, Shannon-Wiener diversity index; e, evenness; buf, buffer; par, park. See Methods for details. *: $p < 0.05$.

An individual rarefaction curve revealed that community diversity was sampled adequately both in buffer zones and inside the park, given that the plateau between the number of individuals and the number of detected taxa was clearly reached in all cases. However, higher values in the plateau were observed in the park, with the buffer community showing lower values, apparently without reaching a plateau (Figure 3).

Diversity profiles confirmed the pattern obtained by the univariate metrics, with a different shape (higher slope) in the curve evidencing the higher richness and diversity of the park's sites (Figure 4).

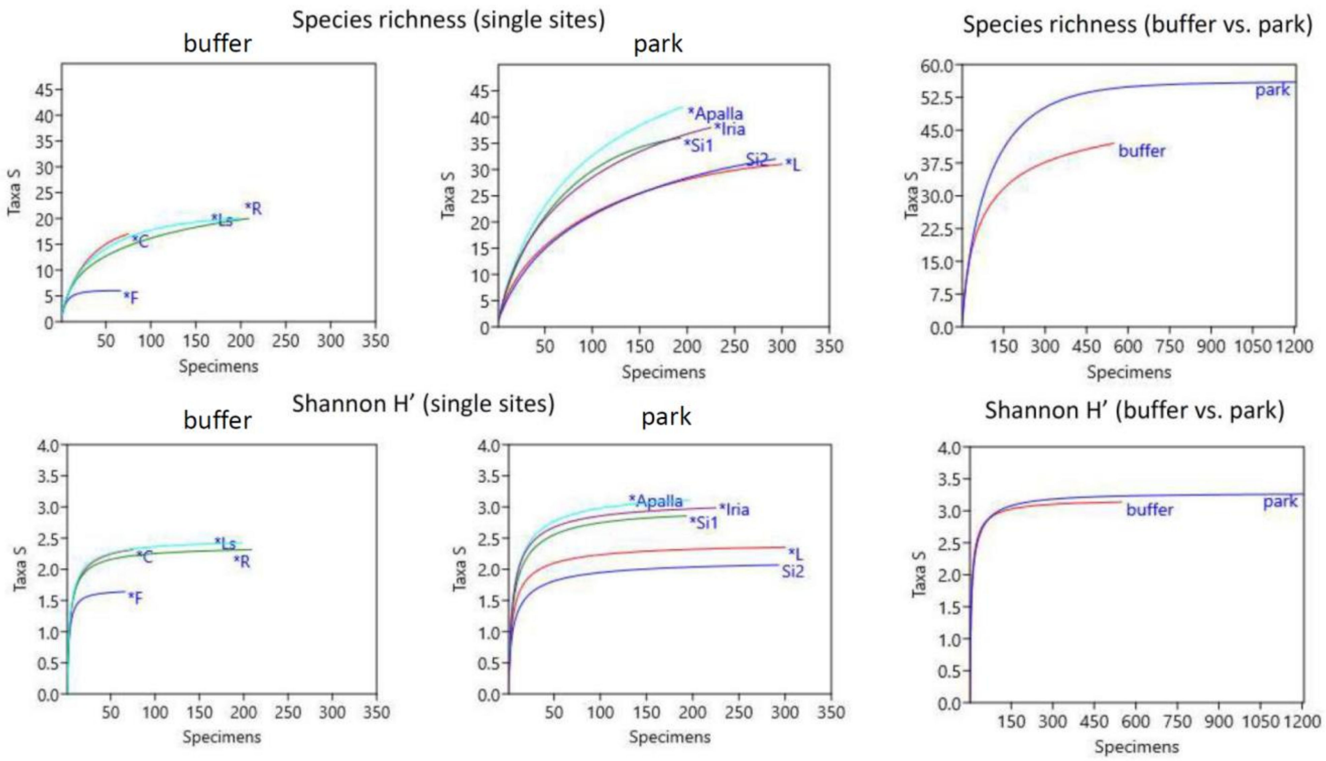

Figure 3. Rarefaction curves for species richness and Shannon-Wiener diversity H′ index. On the (**left**): comparison among single sites in buffer zone (**left**) and national Park (**middle**); On the (**right**): comparisons between total communities (buffer zone vs. national park).

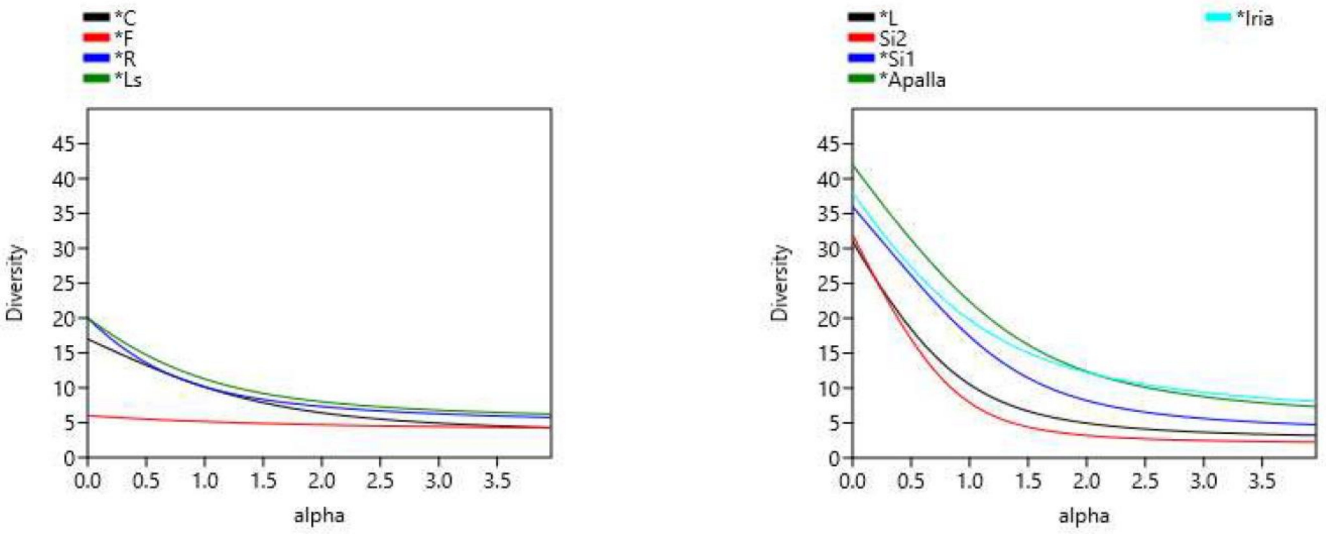

Figure 4. Diversity profiles for the community diversity of birds in buffer zone's sites (**left**) vs. Nimule National Park (**right**), South Sudan. X-axis indicate the q-order of alpha-diversity (see Methods for details).

4. Discussion

Our study highlights a difference between the diversity patterns inside and outside Nimule National Park (South Sudan). The data showed, for all sites, a consistently significant drop in the variables related to the number of species (absolute and normalized richness and Chao-1 richness estimator) and a significant decrease in diversity considering the cumulated values. The only parameter that showed a decrease is the evenness, that was predictably lower in the National Park when compared to the buffer zone. This may be due to the large numbers of rare species that were observed in the richer communities inside the park (i.e, we observed a large number of species with low abundance indices: a known pattern in community ecology: [24]), thus increasing the differences in relative frequencies between species. The diversity profiles highlighted this pattern, with more sloping curves in the sites inside the park when compared with the surrounding buffer. However, our patterns reported only abundance indices since we have not carried out a correction of detectability (obtaining true abundance values). Although further studies could be focused in this regard, we think that data are enough exhaustive enough for first consideration about the role of the park in improving bird diversity. Waterbird species in South Sudan are under stress due to a set of human-induced threats (cattle keeping or grazing, fishing, habitat loss and fragmentation, poaching for bushmeat, war-related stresses etc.; [25]. In our study area, these threats are less controlled outside the park where, in buffer areas, they can heavily affect the structure of bird communities, thereby changing the observed patterns and inducing a marked reduction in diversity metrics.

Apart from the purely ecological aspects, however interesting given that these areas are little studied [8], these data provide initial information on the effective role played by a National Park (i) in maintaining high values of richness and diversity of critical areas of exceptional environmental value and (ii) improving the role of these areas as driving forces positively affecting the local social and economic system (e.g., through a biodiversity-focused sustainable tourism).

Finally, we suggest the park could adopt a monitoring protocol aimed to assess its effectiveness in management success in nature conservation [26].

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Check-list of the sampled species (in systematic order) with the regional phenology, realm of distribution (chorology), trophic level, classes of local abundance (+: rare; 1: uncommon; 2: frequent; 3: abundant), and level of conservation concern (IUCN threat category; source: iucnredlist.org: LC: Least Concern; EN: endangered; CR: Critically endangered). *: Introduced species.

Taxonomic Family and *Species*	Phenology	Realm	Trophic Level	Abundance	Iucn	Taxonomic Family and *Species*	Phenology	Range	Trophic Level	Abundance	Iucn
Phalacrocoracidae						*Cuculus gularis*	Partially migratory	Afro-tropic	Carnivore	2	LC
Phalacrocorax lucidus	Sedentary	Afro-tropic	Carnivore	2	LC	*Centropus senegalensis*	Sedentary	Afro-tropic	Carnivore	1	LC
Microcarbo niger	Partially migratory	Indo-Malay	Carnivore	2	LC	*Chrysococcyx caprius*	Sedentary	Afro-tropic	Carnivore	1	LC
Microcarbo africanus	Sedentary	Afro-tropic	Carnivore	1	LC	Strigidae					
Anhingidae						*Bubo africanus*	Sedentary	Afro-tropic	Carnivore	1	LC
Anhinga rufa	Sedentary	Afro-tropic	Carnivore	1	LC	Apodidae					
Ardeidae						*Cypsiurus parvus*	Migratory	Afro-tropic	Carnivore	2	LC
Ixobrychus minutus	Migratory	Afro-tropic	Carnivore	2	LC	Coliidae					
Ardeola ralloides	Migratory	Afro-tropic	Carnivore	2	LC	*Colius striatus*	Sedentary	Afro-tropic	Herbivore	1	LC
Bubulcus ibis	Partially migratory	Palaearctic/Afro-tropic	Carnivore	3	LC	Alcedinidae					
Butorides striata	Partially migratory	Afro-tropic	Carnivore	1	LC	*Halcyon leucocephala*	Partially migratory	Afro-tropic	Carnivore	1	LC
Egretta garzetta	Partially migratory	Palearctic	Carnivore	3	LC	*Halcyon senegalensis*	Partially migratory	Afro-tropic	Carnivore	1	LC
Ardea melanocephala	Sedentary	Afro-tropic	Carnivore	2	LC	*Ceryle rudis*	Sedentary	Afro-tropic	Carnivore	2	LC
Ardea cinerea	Sedentary	Palearctic	Carnivore	3	LC	*Ispidina picta*	Sedentary	Afro-tropic	Carnivore	1	LC
Ardea goliath	Sedentary	Afro-tropic	Carnivore	1	LC	Bucerotidae					
Scopidae						*Tockus nasutus*	Sedentary	Afro-tropic	Herbivore	2	LC
Scopus umbretta	Partially migratory	Afro-tropic	Carnivore	2	LC	Capitonidae					
Ciconiidae						*Lybius guifsobalito*	Sedentary	Afro-tropic	Herbivore	2	LC
Anastomus oscitans	Partially migratory	Indo-Malay	Carnivore	2	LC	*Trachyphonus darnaudii*	Sedentary	Afro-tropic	Herbivore	1	LC
Ciconia episcopus	Sedentary	Afro-tropic	Carnivore	1	LC	Alaudidae					
Threskiornithidae						*Pinarocorys erythropygia*	Sedentary	Indo-Malay	Carnivore	2	LC
Pseudibis papillosa	Sedentary	Indo-Malay	Carnivore	1	LC	Hirundinidae					
Anatidae						*Hirundo rustica*	Migratory	Palearctic	Carnivore	3	LC
Dendrocygna viduata	Partially migratory	Afro-tropic	Herbivore	2	LC	Motacillidae					
Anser cygnoides *	Migratory	Palearctic	Herbivore	2	LC	*Motacilla alba*	Partially migratory	Palearctic	Carnivore	3	LC
Accipitridae						Pycnonotidae					
Milvus aegyptius	Migratory	Afro-tropic	Carnivore/Omnivore	2	LC	*Pycnonotus jocosus*	Sedentary	Indo-Malay	Herbivore	1	LC
Milvus migrans	Migratory	Palearctic/Afro-tropic	Carnivore/Omnivore	2	LC	Sylviidae					

Table A1. *Cont.*

Taxonomic Family and *Species*	Phenology	Realm	Trophic Level	Abundance	Iucn	Taxonomic Family and *Species*	Phenology	Range	Trophic Level	Abundance	Iucn
Haliaeetus vocifer	Sedentary	Afro-tropic	Carnivore	+	LC	*Sylvia atricapilla*	Partially migratory	Palearctic	Omnivore	3	LC
Gyps rueppellii	Sedentary	Afro-tropic	Scavenger	+	CR	*Sylvia borin*	Migratory	Palearctic	Omnivore	2	LC
Hieraaetus pennatus	Migratory	Palearctic	Carnivore	+	LC	*Sylvia communis*	Migratory	Palearctic	Omnivore	2	LC
Sagittariidae						Cisticolidae					
Sagittarius serpentarius	Partially migratory	Afro-tropic	Carnivore	+	EN	*Cisticola chiniana*	Sedentary	Afro-tropic	Carnivore	2	LC
Falconidae						Muscicapidae					
Falco biarmicus	Partially migratory	Afro-tropic	Carnivore	+	LC	*Melaenornis edolioides*	Sedentary	Afro-tropic	Carnivore	1	LC
Numididae						*Muscicapa striata*	Migratory	Palearctic	Carnivore	3	LC
Numida meleagris	Sedentary	Afro-tropic	Herbivore	2	LC	*Terpsiphone viridis*	Sedentary	Afro-tropic	Generalist	1	LC
Rallidae						*Myopornis boehmi*	Sedentary	Afro-tropic	Carnivore	+	LC
Amaurornis flavirostra	Sedentary	Afro-tropic	Carnivore	2	LC	Nectariniidae					
Jacanidae						*Cinnyris pulchellus*	Sedentary	Afro-tropic	Herbivore	1	LC
Actophilornis africanus	Partially migratory	Afrotropic	Carnivore	2	LC	Malaconotidae					
Microparra capensis	Migratory	Palearctic	Carnivore	2	LC	*Laniarius erythrogaster*	Sedentary	Afro-tropic	Herbivore	2	LC
Charadriidae						Corvidae					
Charadrius dubius	Migratory	Palearctic	Carnivore	2	LC	*Corvus albus*	Partially migratory	Afro-tropic	Carnivore	2	LC
Vanellus spinosus	Sedentary	Afro-tropic	Carnivore	2	LC	Sturnidae					
Sternidae						*Lamprotornis purpureus*	Partially migratory	Afro-tropic	Herbivore	2	LC
Sterna nilotica	Migratory	Cosmopolitan (excl. Australasia)	Carnivore	1	LC	Ploceidae					
Columbidae						*Bubalornis albirostris*	Sedentary	Afro-tropic	Omnivore	1	LC
Treron calvus	Partially migratory	Afro-tropic	Herbivore	1	LC	*Ploceus cucullatus*	Sedentary	Indo-Malay	Carnivore	2	LC
Oena capensis	Partially migratory	Afro-tropic	Herbivore	2	LC	*Ploceus jacksoni*	Sedentary	Indo-Malay	Carnivore	2	LC
Streptopelia capicola	Sedentary	Afro-tropic	Granivore	3	LC	*Euplectes hordeaceus*	Sedentary	Afro-tropic	Herbivore	2	LC
Cuculidae						Estrildidae					
Clamator jacobinus	Migratory	Afro-tropic	Carnivore	1	LC	*Uraeginthus bengalus*	Sedentary	Afro-tropic	Granivore	+	LC

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