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Assessing Species Richness with Camera Trap Surveys During Five Years of Large-Scale Mining Disruptions

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Simple Summary: Mining activities continue to disrupt and fragment natural habitats; therefore, it is vital to understand the effect of open-pit mining on surrounding wildlife species, and the pressure humans impose on local ecology. This study therefore aimed to determine the species richness and abundance of local wildlife within different vegetation types that surround the mining area in the Northern Cape Province of South Africa, by making use of camera traps. Data obtained from the camera traps identified a wide range of species (n = 44), varying from small mammals to large megaherbivores like giraffes. Some of the sites showed a high species richness while others observed alarmingly low numbers. Several red-listed species of conservation concern were documented, including animals such as the endangered mountain reedbuck (*Redunca fulvorufula*) and vulnerable black-footed cat (*Felis nigripes*). The results suggested that some species adapted to the change in habitat while others were deterred from the area. This research is therefore vital for the development of strategies to help understand and protect biodiversity and minimize the ecological impact of mining activities.

Abstract: In the Northern Cape Province of South Africa, an investigation was launched into the impact of large-scale open-pit mining on wildlife ecology and populations, more specifically on the animal species richness and detection rates across different vegetation types. Using camera traps, we monitored a 43,000-hectare area, which included active mining areas and adjacent lands, over a period of five years (2020–2024). Data on 44 animal species ranging from small mammals to large megaherbivores were collected, with a large variation in species richness across the study site being observed. The detection of species that are of conservation concern, such as the vulnerable Temminck's ground pangolin (*Smutsia temminckii*) and endangered mountain reedbuck (*Redunca fulvorufula*), highlighted additional potential risks that mining activities pose to biodiversity in the area, emphasizing the importance of monitoring biodiversity in areas that are impacted by large-scale anthropogenic and mining activities. Furthermore, the results suggest that some areas may require a more targeted approach to conservation in order to mitigate the disruptive effect of mining. Benchmarking the species present and proving the presence of endangered and vulnerable species prove the successful first steps into understanding habitat disruption caused by mining activities and will guide future conservation and management efforts.

Keywords: open-pit mining; conservation; biodiversity; IUCN; endangered species; red list

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1. Introduction

The Northern Cape Province of South Africa is challenged by multiple anthropogenic changes in land use, from natural habitats into cultivated, urban and mining areas [1]. Habitat loss impacts biodiversity, the magnitude of which can be exacerbated by the arrangement and fragmentation of the remaining habitats [2]. As the actions of humans continually impact natural habitats, the need to monitor population trends of vertebrate populations continually grows [3]. Although it is well known that the extraction of natural resources is a major disturbance that affects wildlife populations before, during and after exploitation for mineral resource activities, the environmental implications of broad-scale open-pit mining are still relatively unknown [4]. Understanding how organisms move throughout their environment is essential to ecological field research and critical to addressing environmental challenges such as land-use changes [5], especially when certain indicator and key species are negatively influenced by human activities.

The impact of mining activities not only poses a threat to the natural environment, but affects ecosystems and biodiversity as well [6]. The negative impact mining has on the environment and biodiversity can be both direct and indirect, through the clearing of vegetation and topsoil, the construction of additional infrastructure and increased human activity [7]. Open-pit and metal mining specifically pose a major concern for conservation, as they are both extensively and physically destructive to biodiversity, have the requirement of extensive infrastructure and have a lasting chronic and acute pollution footprint [8]. Sonter et al. (2018) [9] illustrated how mining has an impact on biodiversity across different special scales and through diverse pathways.

Most ungulates react dynamically to their environment, selecting the most suitable habitat and staying within defined home ranges [10,11]. The area animals use is determined by an interplay of their spatial movement and the environment, with factors such as habitat selection, biotic interactions and the movement of individuals playing a role [12,13]. Habitat selection is affected on both large and small scales by factors such as resource availability and distribution, geography, climatic conditions, reproduction strategies and predation pressure [14]. According to Van Moorter et al. (2016) [15], the primary links between habitat selection and home range are accessibility and movement. Furthermore, the addition of the anthropogenic pressure applied through habitat destruction caused by large-scale open-pit mining should not be underestimated as a possible influence on these animals and their environments. Mining-related activities and their pressure can be considered limiting factors in animal movements and survival.

With growing demands for resource extraction, scientists are challenged with developing environmental conservation strategies that not only achieve minimal disruption to wildlife but meet the expectations of resource supply [4]. According to Caldecott et al. (1996) [16], the uniqueness and complexity of natural ecosystems are reflected in two key attributes of biodiversity, i.e., species richness and endemism. Determining the type of animal species that are present, their estimated numbers and their regional distribution within the area of concern is essential in putting together an effective conservation plan [17]. Knowing how many animal species and individuals of each inhabit an area allows for insight into what controls their numbers and possibly why some locations are utilized more than others [18]. Different species react differently to change, especially that brought on by humans, from species that are very sensitive to human activity to species that actively seek out human-impacted areas [19]. Modern technology that is non-invasive has become more accessible in recent years, especially in remote areas and unforgiving environments [20].

Camera traps have become a significant tool in the monitoring and management of wildlife [21,22]. With the rapid improvement in camera trap technology, their efficiency as a tool to study elusive fauna has greatly improved [23]. An added benefit of camera traps is that they act as a complementary approach, allowing the identification of a wide range of animals (birds to medium-to-large mammals) at a single monitoring site [23]. The less expensive and less invasive nature of camera traps lends itself well to utilization by those who want to conduct large-scale studies monitoring multiple species over long periods [24].

Determining the proportional estimate of areas occupied by a particular species is important when it comes to long-term monitoring programs [25]. By drawing estimates of species diversity, occupancy and relative abundances, comparisons across time and space can be made to monitor population changes [26]. This investigation therefore focuses on (a) animal species richness, (b) their specific detection rates and (c) determination of the relative abundances of the wildlife populations surrounding an open-pit iron ore mine.

Accurately estimating abundance is important for both wildlife biology and management efforts [27] to determine anthropogenic impacts.

2. Materials and Methods

2.1. Study Area

This study was conducted on and around an open-pit iron ore mine in Postmasburg, located in the Northern Cape Province of South Africa. Postmasburg is situated in an area known as the Ghaap plateau [28]. The Ghaap plateau is an ecologically important part of the province, with numerous endemic species of flora and high faunal diversity [29]. Anthropogenic disruption, primarily in the form of agricultural and mining practices, threatens the biodiversity of the Ghaap plateau, especially in the Postmasburg region [30]. This study stretches over 17 farms that total over 43,000 hectares and include the area in which active mining takes place. The vegetation of the study area is made up of two main vegetation units, i.e., the Postmasburg Thornveld and Olifantshoek Plain Thornveld vegetation units [31]. In 2011, vegetation monitoring efforts started at the study site, and they have since been conducted up to 2024. The vegetation of the site was mapped to show the sub-vegetation units (Figure 1).

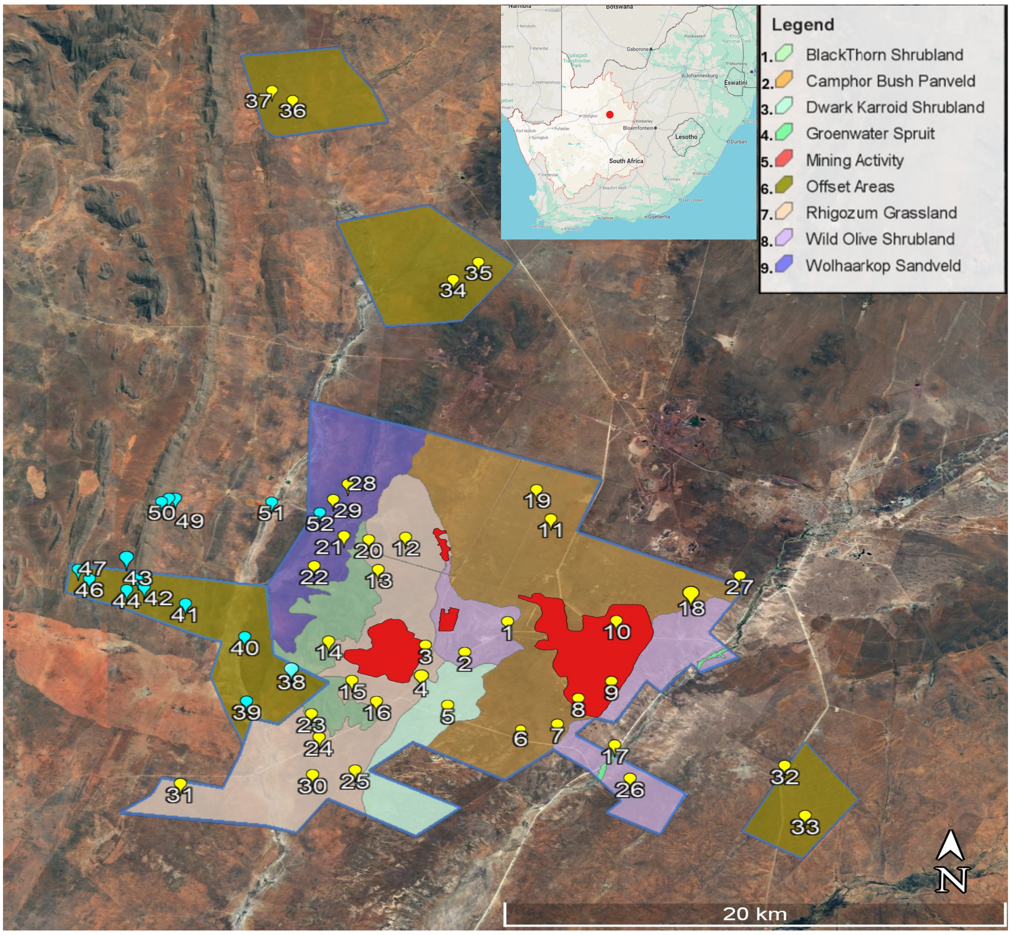

Figure 1. Aerial image of the vegetation type and camera trap layout over the study site. Yellow markers indicate camera set one, placed on the mining site and property owned by the mine. Blue markers indicate camera trap set two, which was added to the study in 2022. The smaller encompassed map illustrates the Northern Cape Province border within South Africa and the location of the study site within.

2.2. Equipment Deployed

During the duration of this study, two camera trap models were utilized and set out at two different times during the study. The initial positioning of the camera traps focused on species richness detections across the various vegetation units that marble the area radiating away from the area of the mining activities (Figure 1). These traps (n = 37) were placed in 2020 on fixed vegetation monitoring sites and randomly selected sites in between to identify the species that impact those specific sites. These camera traps included the Spartan GoCam 4G/LTE Models (Spartan Mfg, LLC, Lake Wales, FL, USA), with 8 MP resolution, 0.4 s trigger time, a 52° field of view and an 18.3 m detection range with a 20 m (930–950 nm wavelength) black light flash. Each unit deployed was equipped with a 32 GB SD card, a solar panel and an additional battery pack, all housed in standardized safety boxes, placed at 50 cm above ground level, facing a southern direction to minimize sun glare [32].

The second set of cameras was added to sites of special interest in 2022, and consisted of 15 Bushnell No Glow 24 MP cameras (Bushnell Corporation, Overland Park, KS, USA) mounted 80 cm above ground level, tilted downward and oriented south to optimize imaging and reduce false triggers from vegetation movement. These cameras boasted a 0.3 s trigger speed, 24 m detection range and infrared flash (940 nm wavelength), ideal for detecting nocturnal species. Every camera was fitted with a 32 GB SD card and a standardized safety box. Because of the elongated shape of the added study area, the positioning of the majority of the additional camera traps was linear and approximately two kilometers apart (Figure 1), deviating from the standard camera trap layout strategies. However, Cusack et al. (2015) [33] showed that placement strategies can be adjusted for by making use of adequate trap nights, without affecting inferences made at the community level.

Each camera was set to capture an image every ten seconds after motion was detected. Images captured by each camera were manually processed, and the logging date, time, temperature, moon phase, species identification and number of individuals per capture event were entered into an Excel spreadsheet. Continuous sequences were logged half-hourly to avoid duplication. In addition to the species richness, the vegetation type and whether water was present at the trap site were also accounted for as factors that influence species richness [34].

This study focuses on medium-to-large mammals; hence, mammal species with a weight greater than 500 g were considered a priority, meaning that the smallest species logged were species like the slender mongoose (*Galerella sanguinea*) and meerkat (*Suricata suricatta*). The spectrum of mammal species logged included the meerkat, kudu (*Tragelaphus strepsiceros*), eland (*Tragelaphus oryx*) and even giraffe (*Giraffa camelopardalis*).

The detection rate for each species was calculated for each camera trap location, treated as a singular unit within a spectrum of units. Ecological populations often naturally follow a log-normal distribution, with many species being rare and low in abundance while a few other species have high abundance, causing the data distribution to be right-skewed [35].

2.3. Statistical Analyses

Detection rates are determined by dividing the number of detections of the relevant species or individual by the number of active trap nights multiplied by 100 [26,36]. This provides a percentage value that indicates the likelihood of encountering said species at that place over a period of 100 days [37]. The detection rate for each species was calculated accordingly. Bootleg statistics was implemented with a 1000 replication factor to calculate the mean detection rates along with the 95% confidence intervals for each species.

The relative abundance incidences (RAIs) for each species were also calculated. As Tanwar et al. 2021 [36] explain, the RAI is calculated as the number of independent observations of each species, divided by the total sampling effort (from all the cameras collectively) and multiplied by 100. Fitting the RAI of each species to a general log-normal model [38] provided the relative abundance of each species across the study site. An important assumption the log-normal distribution model makes is one of multiplicative processes, where the assumption is that the variability in the data comes from several factors (like resource availability, predator pressure and climate and habitat suitability) interacting multiplicatively [39]. This is fitting, since the study site has high diversity in both vegetation and topography, with the added factor of high seasonal climate variability, as well as a significant anthropogenic impact. The Anderson–darling test for normality was used to test the log-normal distribution for fitness. As a modification of the Cramer–von Mises test, the Anderson–darling test gives more weight to the tails [40], and therefore is a more sensitive test to any discrepancy that might occur between the observed data and the distribution expected, especially at the extremes [41].

To test for correlations that may exist between the species richness observed, the vegetation units, whether water was present at the trap site and the distance from the mining activity, Pearson correlation coefficients were calculated for each interaction. The Pearson correlation coefficients were tested for significance at a 95% confidence level, using a standard *t*-test.

3. Results

3.1. Species Richness

For species richness, the number of species at each camera trap location was noted (Table 1). Over the set of 52 camera trap locations, a total of 44 species of interest were documented. Table 1 summarizes a wide range of animal species detected by the different cameras, with many of the camera traps documenting between 10 and 15 different species. On either end of the spectrum, some cameras detected a single species (cameras 1 and 51), while others went up to 22 and 29 species detected (cameras 22 and 36).

Table 1. The trap locations with the number of species detected and the strike rate of each, the vegetation type deployed and whether there was water present at the deployment site.

Trap Location	Number of Animal Species Detected	Strike Rate	Vegetation Type	Water Present
1	11	91.8	Wild Olive Shrubland	Yes
2	8	61.9	Wild Olive Woodland	No
3	13	146.1	Rhigozum Grassland	No
4	20	726.4	Dwarf Karroid Shrubland	Yes
5	13	39.8	Dwarf Karroid Shrubland	No
6	20	133.3	Camphor Bush Panveld	No
7	3	8.1	Camphor Bush Panveld	No
8	13	55.5	Camphor Bush Panveld	No
9	1	1.0	Camphor Bush Panveld	No
10	3	91	Camphor Bush Panveld	No
11	15	849.2	Camphor Bush Panveld	Yes
12	7	112.9	Rhigozum Grassland	No
13	17	173.8	Rhigozum Grassland	No
14	14	68.8	Black Thorn Shrubland	No
15	16	39.1	Rhigozum Grassland	No
16	12	185.1	Rhigozum Grassland	Yes
17	5	91.8	Groenwaterspruit	No
18	11	53.1	Wild Olive Shrubland	No
19	19	415.1	Camphor Bush Panveld	No
20	8	19.0	Rhigozum Grassland	No
21	7	37.3	Wolhaarkop Sandveld	No
22	22	488.4	Wolhaarkop Sandveld	No
23	11	138.7	Black Thorn Shrubland	Yes
24	14	87.8	Rhigozum Grassland	No
25	16	49.1	Dwarf Karroid Shrubland	No
26	10	116.0	Wild Olive Shrubland	No

Table 1. *Cont.*

Trap Location	Number of Animal Species Detected	Strike Rate	Vegetation Type	Water Present
27	5	11.1	Camphor Bush Panveld	No
28	15	52.3	Wolhaarkop Sandveld	No
29	20	139.2	Wolhaarkop Sandveld	Yes
30	18	60.7	Rhigozum Grassland	No
31	14	212.3	Rhigozum Grassland	Yes
32	7	132.8	Camphor Bush Panveld	No
33	10	153.8	Black Thorn Shrubland	Yes
34	12	25.6	Wolhaarkop Sandveld	No
35	16	353.3	Wolhaarkop Sandveld	No
36	29	71.7	Rhigozum Grassland	Yes
37	15	71.6	Rhigozum Grassland	No
38	13	706.6	Black Thorn Shrubland	Yes
39	17	317.9	Wolhaarkop Sandveld	Yes
40	16	462.3	Wolhaarkop Sandveld	Yes
41	8	134.6	Soutloop River	Yes
42	13	271.4	Black Thorn Shrubland	Yes
43	7	250.0	Black Thorn Shrubland	No
44	15	430.9	Black Thorn Shrubland	Yes
45	3	26.04	Banded Ironstone Ridge	No
46	4	418.7	Rhigozum Grassland	No
47	15	527.1	Black Thorn Shrubland	Yes
48	6	210.0	Black Thorn Shrubland	Yes
49	8	525.0	Black Thorn Shrubland	Yes
50	12	495.0	Black Thorn Shrubland	Yes
51	1	12.5	Wolhaarkop Sandveld	No
52	6	160.0	Wolhaarkop Sandveld	No

The Pearson correlation coefficient for the correlation between species richness and vegetation present was calculated at r = 0.127 (Table 2), indicating a weak positive correlation. The correlation is not significant enough to show that the vegetation was a determining factor in the species richness distribution observed (Table 1).

Table 2. The correlation values for species richness with vegetation, the presence of water at the trap site and the distance from the mining activity. A single * indicates significance at a 95% confidence level.

External Factor	Species Richness	*p*-Value
Vegetation	0.127	0.601
Water proximity	0.281	0.044 *
Distance from mining activity	0.218	0.121

The correlation coefficient for species richness and water being present at the trap site was calculated at r = 0.2811, indicative of a moderate positive correlation (Table 2). The positive correlation between water presence and species richness was deemed significant (*p*-value (0.044)).

3.2. Detection Rates

Across the 52 camera traps over the duration of this study (2020–2024) a total of 14 630 trap nights to date were attained, with 26 263 mammal detections. Table 3 presents the mean detection rate of each species documented across the study site. The species with the highest detection rates, i.e., the kudu (61.57%), springbok (47.31%), common warthog (24.86%) and common duiker (15.50%), are all free-roaming species with minimal fencing to hinder their movements, while the species with the lowest detection rates, like the brown hyena (0.02%) and Temminck's pangolin (0.01%), are extremely elusive and scarce species [42,43]. The low detection rate of giraffes is accounted for by them being brought in late during the study and with a low number of individuals.

Table 3. List of animal species detected across the study site, with their mean detection rate calculated over the entire area with 95% confidence level limits. * The information pertaining to the black rhinoceros is kept confidential, due to the high risk of poaching.

Species	Latin Name	Mean in %	95% Confidence Limits	IUCN Status
Kudu	*Tragelaphus strepsiceros*	61.57	±20,237	Least Concern
Springbok	*Antidorcas marsupialis*	47.31	±65,915	Least Concern
Common warthog	*Phacochoerus africanus*	24.86	±14,223	Least Concern
Common duiker	*Sylvicapra grimmia*	15.50	±6846	Least Concern
Gemsbok	*Oryx gazella*	11.01	±9950	Least Concern
Blue wildebeest	*Connochaetes taurinus*	8.19	±10,854	Least Concern
Steenbok	*Raphicerus campestris*	7.57	±3653	Least Concern
Cape porcupine	*Hystrix africaeaustralis*	6.81	±3523	Least Concern
Cape scrub hare	*Lepus saxatilis*	6.76	±3343	Least Concern
Black-backed jackal	*Canis mesomelas*	4.16	±1493	Least Concern
Rock hyrax	*Procedia capensis*	2.24	±3057	Least Concern
Slender mongoose	*Herpestes sanguineus*	2.17	±1230	Least Concern
Springhare	*Pedetes capensis*	1.99	±1539	Least Concern
Aardvark	*Orycteropus afer*	1.48	±0.791	Least Concern
Blesbok	*Damaliscus pygargus*	1.07	±1040	Least Concern
Yellow mongoose	*Cynictis penicillata*	0.94	±0.764	Least Concern
Meerkat	*Suricata suricatta*	0.89	±0.965	Least Concern
Chacma baboon	*Papio ursinus*	0.86	±0.661	Least Concern
Kori bustard	*Ardeotis kori*	0.83	±0.415	Near Threatened
Caracal	*Caracal caracal*	0.82	±0.408	Least Concern
Bat-eared fox	*Otocyon megalotis*	0.71	±0.855	Least Concern
Small-spotted genet	*Genetta genetta*	0.69	±0.581	Least Concern
Cape ground squirrel	*Xerus inauris*	0.27	±0.249	Least Concern
African wild cat	*Felis lybica*	0.26	±0.190	Least Concern
Mountain reedbuck	*Redunca fulvorufula*	0.25	±0.366	Least Concern
Aardwolf	*Proteles cristata*	0.23	±0.198	Least Concern
Cape fox	*Vulpes chama*	0.22	±0.280	Least Concern
Tsessebe	*Damaliscus lunatus* ssp. *lunatus*	0.20	±0.372	Least Concern
Impala	*Aepyceros melampus* ssp. *melampus*	0.19	±0.246	Least Concern
Red hartebeest	*Alcelaphus buselaphus* ssp. *caama*	0.18	±0.334	Least Concern
Common eland	*Tragelaphus oryx*	0.17	±0.230	Least Concern
Striped polecat	*Ictonyx striatus*	0.12	±0.123	Least Concern
Common waterbuck	*Kobus ellipsiprymnus* ssp. *ellipsiprymnus*	0.10	±0.150	Least Concern
Sable antelope	*Hippotragus niger*	0.09	±0.120	Least Concern
Vervet monkey	*Chloroneb's pyrethrums*	0.07	±0.076	Least Concern
Black-footed cat	*Felis nigripes*	0.07	±0.034	Vulnerable
Leopard	*Panthera pardus*	0.06	±0.031	Vulnerable
Roan antelope	*Hippotragus equinus*	0.05	±0.079	Least Concern
Plains zebra	*Equus zebra*	0.05	±0.095	Least Concern
Monitor lizard	*Varanus niloticus*	0.03	±0.049	Least Concern
Black wildebeest	*Connochaetes gnou*	0.03	±0.058	Least Concern
Nyala	*Tragelaphus angasii*	0.02	±0.039	Least Concern
Brown hyena	*Parahyaena brunnea*	0.02	±0.024	Near Threatened
Temminck's pangolin	*Smutsia temminckii*	0.01	±0.021	Vulnerable
Giraffe	*Giraffa camelopardalis*	0.01	±0.011	Vulnerable
Black rhinoceros *	*Diceros bicornis*	n/a	n/a	Critically Endangered

The average detection rate over the five-year period fluctuates significantly, with a decline in detection rates observed (Figure 2), while the number of species detected across the study site remained similar each year.

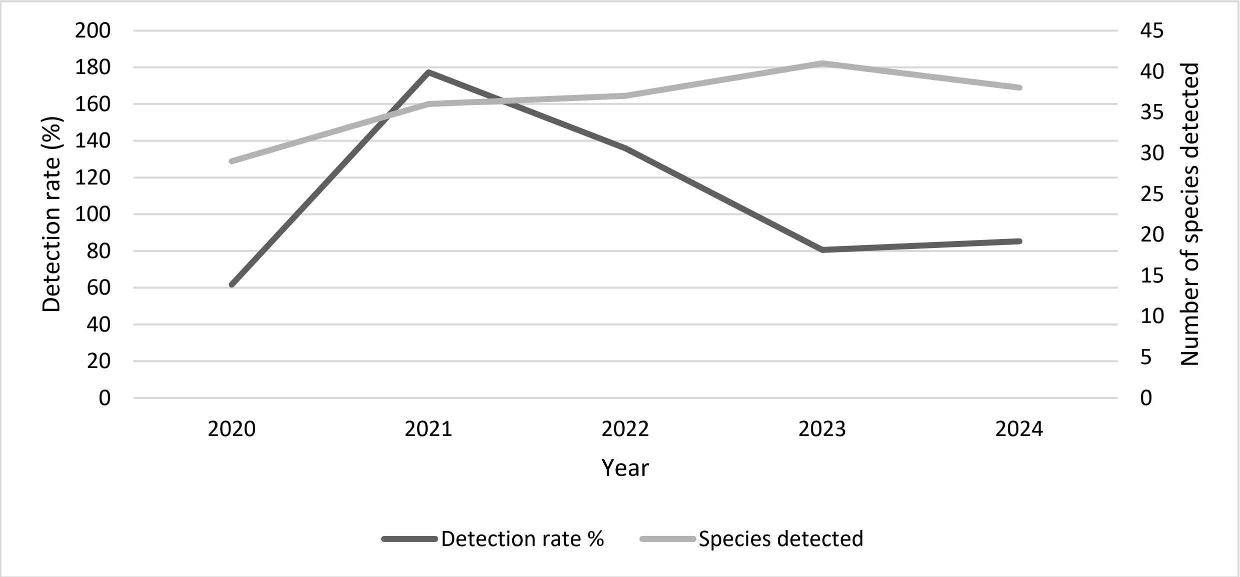

Figure 2. Illustration of the fluctuation in detection rates and the number of species detected each year for the duration of the study period.

3.3. Relative Abundance

The average relative abundance incidences (RAIs) for each species, fitted to a general log-normal model, provide an estimated abundance of each species relative to the rest [44]. Figure 3 shows that the kudu (1.79) had the greatest relative abundance, with the springbok (1.67) closely following. And the leopard (−1.22), ground pangolin (−1.85) and giraffe (−2.27) were on the lowest end of the spectrum. Low relative abundance numbers can be indicative of two situations: either there are a low number of individuals present across the study site, or the species experience highly restricted site occupancy [45]. The log-normal distribution (Figure 3) was tested for fitness with the Anderson–Darling test, and yielded a test statistic of 0.3404, *p*-value of 0.4971 and critical value of 0.7378 (Figure 3). This indicates that there is no significant deviation from the normal distribution.

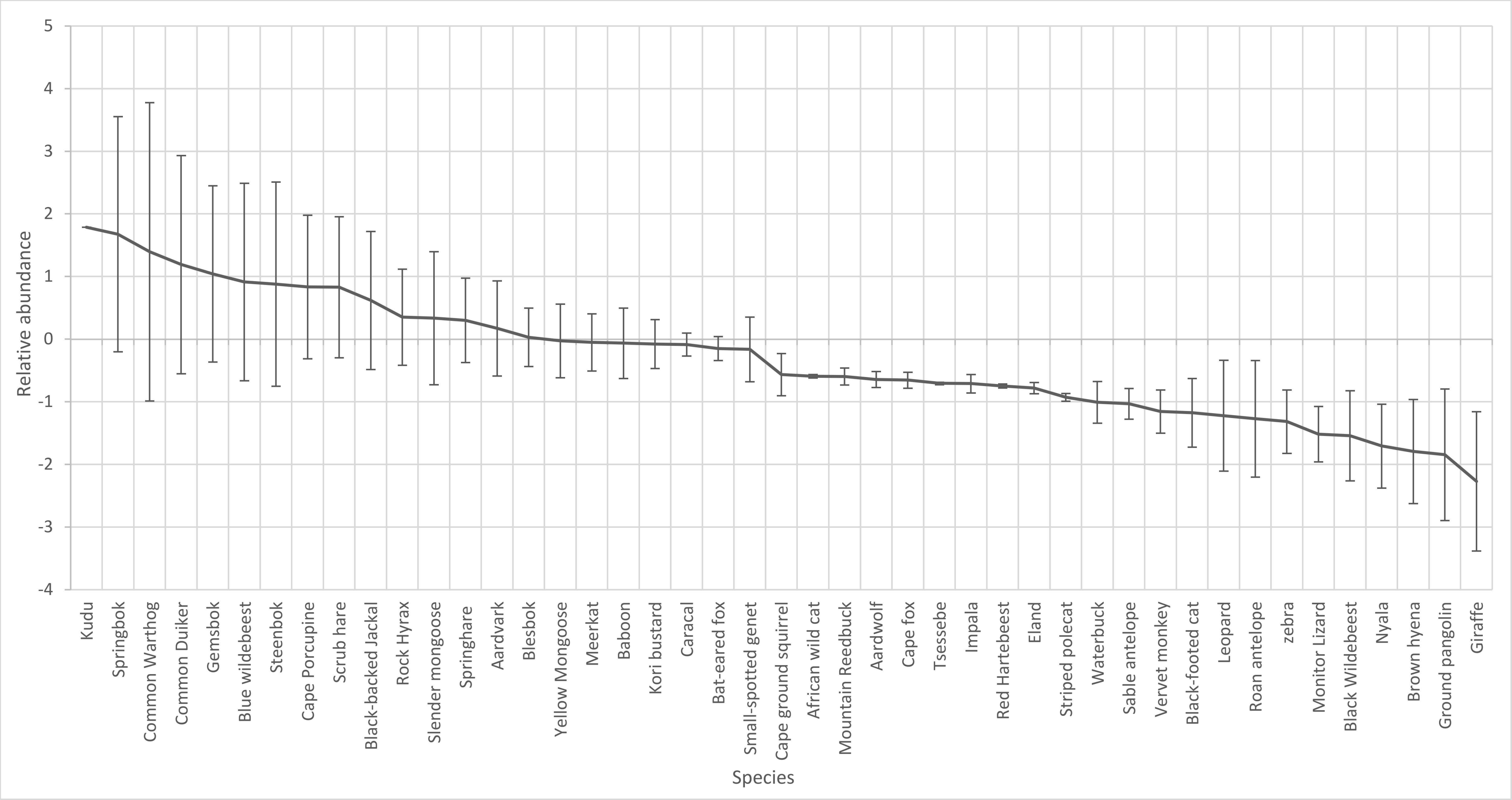

Figure 3. Illustration of the detection rates of each species fitted to a general log-normal model providing a comparison of the relative abundance estimates for each species detected.

4. Discussion

The species identified varied from species as small as the slender mongoose to the greater kudu and the largest, the giraffe. Odd species detected included the kori bustard (*Ardeotis kori*) and the Nile monitor lizard (*Varanus niloticus*). The kori bustard is a large ground-dwelling bird found throughout eastern and southern Africa but has been experiencing a decline in population across its entire distribution area [46]. The Nile monitor lizard both actively hunts prey and scavenges for food when available, can cover large areas to hunt and utilizes particular microhabitats as its preferred hunting grounds [47].

Only three camera locations detected just one animal species (9, 10 and 51), possibly because of their close proximity to mining reclamation areas, both in and near active mining zones. Despite this, the presence of both springbok and kudu at these cameras highlights the remarkable adaptability of these species to challenging environments, as well as their potential to become habituated to human activity. Interestingly, camera location 51 also recorded very low species detection, despite being placed near an animal graveyard where the carcasses of animals are left to decompose naturally. This site would typically attract scavengers such as black-backed jackals [33] and brown hyenas [48], yet only kudu sporadically passing through were observed.

The positive correlation between water presence and species richness, deemed significant (p-value (0.044), supports the findings of Edwards et al. (2016) [49], who suggested that placing traps near water sources in arid environments may be beneficial to studies determining species richness. However, the correlation with water was merely moderate; thus, another factor, possibly human impact, could be a stronger driver of the species richness distribution observed.

Figure 2 illustrates the fluctuation observed in the detection rates over the 2020–2024 period, with a significant decline in detection rates observed after 2021, despite an increase in survey efforts in 2022, through the addition of 15 camera traps. The number of species detected, on the other hand, remained somewhat constant, with a very slight increase in the number of species detected. The study site is considered an open system, as species and individuals can move into and exit the system without restriction [48]. Therefore, fluctuations in the number of species are expected. However, the disappearance of species like the Cape fox, which can hold home ranges as small as nine square kilometers [49], is concerning even in an open system.

Among the 45 species detected, 7 species of special conservation concern were detected. The black-footed cat, Temminck's pangolin and leopard are listed as vulnerable (Table 2). The brown hyena and kori bustard are near threatened, and the mountain reedbuck is listed as endangered (Table 2). Although detected, further information on the black rhinoceros (*Diceros bicornis*), listed as critically endangered, has been omitted for the safety of these animals. These species being low-density species within natural ecosystems [42,50,51] and having their numbers affected by habitat disruption, such as that brought on by mining activities, further exacerbates their already strained status. The mountain reedbuck being listed as endangered shines a special light on those documented in this study, as only two solitary females were observed at two separate sites (Sites 40 and 50). As mountain reedbuck home ranges vary in size from 8 to 21 hectares [52], it is highly unlikely that the two observations are of the same individual, as fenced camps and farms might limit free-roaming individuals. The presence of lone females is out of character even if they are considered a low-density species [53]. With its strained and rapidly declining population and an aversion to moving onto farmlands [54], further fragmentation of suitable habitats is detrimental to the mountain reedbuck. Therefore, further research into the home ranges of the resident mountain reedbuck population is essential to determining sites that need extra conservation measures to prevent the further decline of mountain reedbuck in the area.

The determination of absolute density, often utilizing capture–recapture models, has the restrictive requirement of using species with natural markings that vary enough to make individuals identifiable [55]. Most mammal species are, however, not individually recognizable, thus leaving biologists to utilize site occupancy or detection rate measurements from camera traps as indicators of abundance and density [26]. When effective detection rates are determined, they can be correlated to movement rates and home ranges [23].

The detection rates of kudu are high and out of proportion when compared to detection rates from a study carried out by Rogue (2023) [56] in several large nature reserves in the Limpopo Province of South Africa. Their data showed the detection rate of kudu go up to 10.31% in some areas of their study, owing to conducive vegetation and predation pressure. The detection rates of kudu in this study were thus 5.97 times higher than that observed in the Limpopo Province. This extremely high occurrence of kudu could be due to the favorable environment created by several factors. The area has large patches of blackthorn tree (*Senegalia mellifera*)-encroached areas, where the kudu can find space to browse and safely raise young. This, coupled with low predator presence, high freedom of movement due to largely low-fenced areas and large areas where humans rarely move, creates an optimal habitat for kudu.

Species of particular significance that showed up in the data are the small black-footed cat and Temminck's ground pangolin. The black-footed cat is the rarest African felid and is currently experiencing a population decline [57]. The black-footed cat is listed as vulnerable by the IUCN, specifically as C2a (i), defined as a species with a suspected population of less than 10,000 mature individuals [58]. Their highly patchy distribution makes it difficult to gather data on this extremely elusive species [57]. Temminck's ground pangolin is already scarce throughout its distribution and is becoming increasingly threatened due to anthropogenic pressure [59]. The ground pangolin is a highly elusive species, being considered as a solitary species in addition to having extremely low population densities [60]. This increases the significance of finding the ground pangolin, especially in an area under ecological disruption and over the five-year study period. The extremely low relative abundance incidences for both the black-footed cat (0.07) and Temminck's ground pangolin (0.01) further emphasize the rarity of these species. The Cape fox initially presented a higher detection rate of 0.22 (Table 2), but surprisingly disappeared entirely at the start of 2023. Although listed as of least concern on the IUCN red list, the vanishing of the Cape fox from the region is alarming.

For species like leopards, who routinely exhibit solitary behavior and hold large home ranges, it is expected that low detection rates with a singular individual will be observed [59]. However, being free-roaming in an area that is also under commercial stock farming, leopards do run the risk of falling victim to human–wildlife conflict [59]. Brown hyenas were documented at only two sites (Sites 18 and 13) and in close proximity to the mining activity. Brown hyena populations are estimated to range between a mere 5000 to 8000 individuals in the wild, with mining and human encroachment being the leading threats to their survival [51]. Large carnivore populations are in decline worldwide, especially as result of human activity [52]. Thus, finding leopards and brown hyenas still roaming free is significant, and it is crucial that they are monitored closely to ensure their continued survival in the area.

Often overlooked, the aardvark plays a key role in the ecosystem as it not only manages insect populations but creates shelter for numerous other species such as warthogs, monitor lizards and even ground pangolins [54]. Although Temminck's pangolins do burrow themselves, they prefer utilizing the abandoned burrows of aardvarks [42]. Aardvarks were detected at 29 of the 51 sites, with an average detection rate of 1.48, but most notably were not near the mining activity or access roads with high levels of movement. This will have to be taken into consideration as mining processes expand, particularly because they influence not only aardvark, but those species that utilize abandoned aardvark burrows as well.

5. Conclusions

The results highlight some important conservation concerns and ecological patterns. Some sites document up to 29 species, showing high wildlife diversity present in the region. However, sites presenting with merely a single species documented prompted further investigation into both possible ecological and anthropogenic reasons. Species richness showed a weak positive correlation with vegetation, but proximity to water presented a stronger but still moderate positive correlation with species richness, indicating that water may be a stronger driver of species distribution in this arid environment. Species richness did also show a slight positive correlation with distance from mining activities, indicating that disruption from mining activity does at some level influence the animal distribution in the region. The kudu and springbok did prove adaptable enough to still utilize areas in and directly adjacent to the mining activity, foraging on the mine reclamation sites.

The 45 animal species detected presented a standard log-normal abundance distribution, with a few species like the kudu, springbok and common warthog presenting high detection rates, while most of the species exhibited low detection rates. These included species of special conservation concern, ranging from the vulnerable black-footed cat to the critically endangered black rhinoceros. The documenting of free-roaming species like the endangered mountain reedbuck, vulnerable ground pangolin and near threatened brown hyena is encouraging and shows the importance of thorough species surveying. But the disappearance of species, in this case the Cape fox, and the aversion of aardvark to anthropogenically impacted areas prove that long-term biomonitoring is crucial to not only the flagship species but those often overlooked.

Limitations experienced throughout this study presented themselves in various ways. Available resources limited the number of camera traps that could be deployed and had an influence on the frequency at which the traps could be serviced. Vandalism and theft of traps led to the loss of several camera traps. Due to the prolonged exposure to the elements, equipment failures had to be frequently addressed. These failures were mainly in the form of SD cards and rechargeable batteries that stopped working after a year of use. Damage caused by animals in the area was a frequent sight, with cables chewed off or cameras knocked down.

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