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Influence of mining on herbivore occurrence in Mufurudzi Safari Area, Zimbabwe

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SUMMARY

Understanding how mining activity influences habitat suitability as observed through selection and occupancy dynamics is important for wildlife conservation in rich mineral-resourced protected areas. The study aimed to establish whether the mining of gold, black granite stone, and tantalite have an impact on kudu (*Tragelaphus strepsiceros*), sable (*Hippotragus niger*), and zebra (*Equus quagga*) distribution. We used data from an aerial survey conducted in Mufurudzi Safari Area (MSA) in 2016. Maximum Entropy (MaxEnt) modeling was used to determine the habitat suitability of the three species based on presence-only data with distance from mines, elevation, NDVI, distance from roads, and distance from artificial water points and natural rivers as environmental predictor variables. MaxEnt modeling of selected herbivores using environmental variables was successful for kudu (AUC = 0.756), sable (AUC = 0.737), and zebra (AUC = 0.867). The probability of occurrence of kudu was explained more by elevation, NDVI, and distance from artificial water points which accounted for a combined 76.9% contribution. The distance from artificial water points and the distance from roads explained 98.2% of the sable distribution. The distance from mines (31%) and distance from roads (24%) were more predictive of zebra with relative influence also of elevation and distance from artificial water points. The distance from rivers had the least percentage contribution for all three species. The zebra and sable showed high sensitivity to mining disturbance. This study highlights that the potential negative influence of mining activities on habitat selection differs among species and this influence differs according to species sensitivity to disturbance. These findings are important insights that aid conservation planning and wildlife restoration programs in protected areas where mining takes place. The study underscores the essence of zoning park areas where conflicting land use activities occur. In situations where zoning to establish special protection zones is not readily feasible translocation to protected areas with no mining disturbance may be a sustainable option to conserve the genetic diversity inherent in affected populations.

Keywords: Mining disturbance, habitat suitability, habitat selection, MaxEnt modelling.

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INTRODUCTION

The geology and diversity of geomorphological processes influence the observed flora and fauna distribution in landscapes (Cottle, 2004). Geology on the other hand explains the occurrence and concentration of mineral resources that are exploited for economic benefits. Protected areas (PAs) being biodiversity hotspots also at the same time provide direct and indirect ecosystem services and resources that support human livelihood around them (Campbell, 1996). It is in this background that PAs have been viewed as social-ecological systems. The sustainability science theory asserts that there is a dynamic interaction between nature and society (Clark and Dickson, 2003). Among these resources are minerals including precious minerals that are sought for economic transformations. The existence of rich mineral deposits in some protected areas in some cases coincides with highly productive habitats (Durán et al., 2013; Murguía et al., 2016; Venter et al., 2016).

The sustainability of mining activities in protected areas, however, is highly contested (Fitzgerald, 2015). The contention arises from the evidence that mining operations pose a threat to habitat integrity and the viability of wildlife populations (Garcia et al., 2017; Mascia and Pailler, 2011). Sustainable development as a principle emphasizes that development should balance economic, social, and environmental objectives. Nevertheless, mining has often been associated with negative impacts on natural ecosystems. Such impacts of mining include changes in land cover; habitat fragmentation and degradation; changes in microhabitat characteristics; hydrogeological disturbance (Edwards et al., 2014; Owusu et al., 2018; Tendaupenyu et al., 2017). These conservation threats related to mining have in some instances led to the protected area downgrading, downsizing, and degazettement (PADDD) (Edwards et al., 2014) including several attempts to downgrade key biodiversity areas such as Hwange National Park Zimbabwe and Sahara Sumbu National Park in Zambia (Mascia and Pailler, 2011). In light of this mining activity has remained a source of conservation funding in PAs where mining takes place. From an anthropocentric point of view mining is recognized as having community benefits and social costs (Phillips, 2001). The mismatch between natural resource endowment and poor economic social as well as environmental conditions hastherefore often been labeled a resource curse (Siegle, 2008).

The distribution of herbivores is a reflection of associated patch selection and use in protected areas. This selection is influenced by a myriad of biotic and abiotic factors (Bhola et al., 2012) including the availability of water, elevation, ecological interactions, illegal hunting, habitat quality, and human-induced disturbance (Anderson et al., 2016; Muposhi et al., 2016). Habitat selection theories highlight that species actively and adaptively choose a habitat based on cues that reliably inform individuals of the fitness cost and the benefits associated with a habitat (Pulliam and Danielson, 1991). Human disturbances such as mining activities are perceived to provide a landscape of fear in protected areas (Laundré et al., 2010).

In protected areas that are focusing on habitat and species restoration is important to understand how mining activity influences habitat suitability, selection, and occupation by wildlife. There remains a knowledge gap in our understanding ofthe fundamental biophysical and economic ramifications of mining activities in protected areas (Limpitlaw et al., 2017). Studies that investigate the direct and indirect impacts of mining on large and mid-sized mammals across all ecosystems are few and need to be intensified (Martins-Oliveira et al., 2021). We sought to explore whether mining activity influences herbivore habitat suitability to contribute knowledge to conservation management in protected areas where mining occurs.

MATERIALS AND METHODS

STUDY AREA

Mufurudzi Safari Area (MSA) is located 17°15´ and 16°50´ South and 31°40´ and 32°00´ North, 150km north of Harare Metropolitan City of Zimbabwe (Figure 1). It is 760 km² in extent with altitude ranging from 740 to 1020 m. The average rainfall received per annum is 650 mm whereas the temperatures range from 8°C in winter to 41°C in summer (Muposhi et al., 2014). The geological formation of the study area is made up of Makaha greenstone, Mukaradzi schist and Shamva greenstone and granite rock type which give rise to moderately shallow to deep, coarse-grained kaolinitic sands and sandy loam moderately deep to deep (Ashton et al., 2001). The area is a wooded Miombo ecosystem (Muposhi et al., 2014). Species common in MSA include *Hippotragus equinus* (Sable antelope), *Tragelaphus strepsiceros* (Greater kudu), *Connochaetes taurinus* (Wildebeest), *Equus burchelli* (Zebra), *Aepyceros melampus* (Impala), *Oreotragus oreotragus* (Klipspringer), *Tragelaphus scriptus* (bushbuck), *Phacochoerus aethiopicus* (Warthog) and *Sylvicapra grimmia* (Common duiker). Large carnivore species comprise *Panthera pardus* (leopard) and *Crocuta crocuta* (Spotted hyena).

DATA AVAILABILITY

This study made use of September 2016 Helicopter survey species presence data for common herbivores derived from MSA station records. The following environmental variables were used for modeling the herbivore occupancy: normalized vegetation index (NDVI), elevation (derived from Digital Elevation Model-DEM), distance from artificial water points, distance from rivers, distance from roads, and distances from mines. NDVI which is a proxy of habitat quality (Ndaimani et al., 2016) was computed from Landsat images for September 2016 coinciding with the month when the animal count was done.

ANALYSIS

Distance from artificial water points, rivers, roads, and mines wascalculated using Euclidian distance algorithm in the remote sensing environment using ArcGIS 10.7.1. The raster files for the environmental variables were further converted into ASCII which is the acceptable format in MaxEnt software. Maximum entropy (MaxEnt) modeling was used to model the spatial occurrence of three selected herbivores taking into account the multiple associated with this model (Muposhi et al., 2016; Ndaimani et al., 2016). In executing occupancy modeling the default variable settings in MaxEnt wereused to execute the model and the bias file function to adjust for sampling bias which is usually associated with the presence-only data. The model prediction was evaluated using the Area under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve technique which is the most important index of model quality as it provides a single measure of accuracy that is not dependentupon a selected threshold (Mpakairi et al., 2017). The MaxEnt model's response curves were then used to examine the three herbivores' responses to NDVI, elevation, and distance to artificial water spots, rivers, highways, and mines. A binary map depicting the spatial extent of suitable and unsuitable habitats for the three species was created using the logistic threshold of equal training and test sensitivity. The binary map was then loaded into ArcGIS 10.7.1 to be represented and the true extent of the expected occupancy determined.

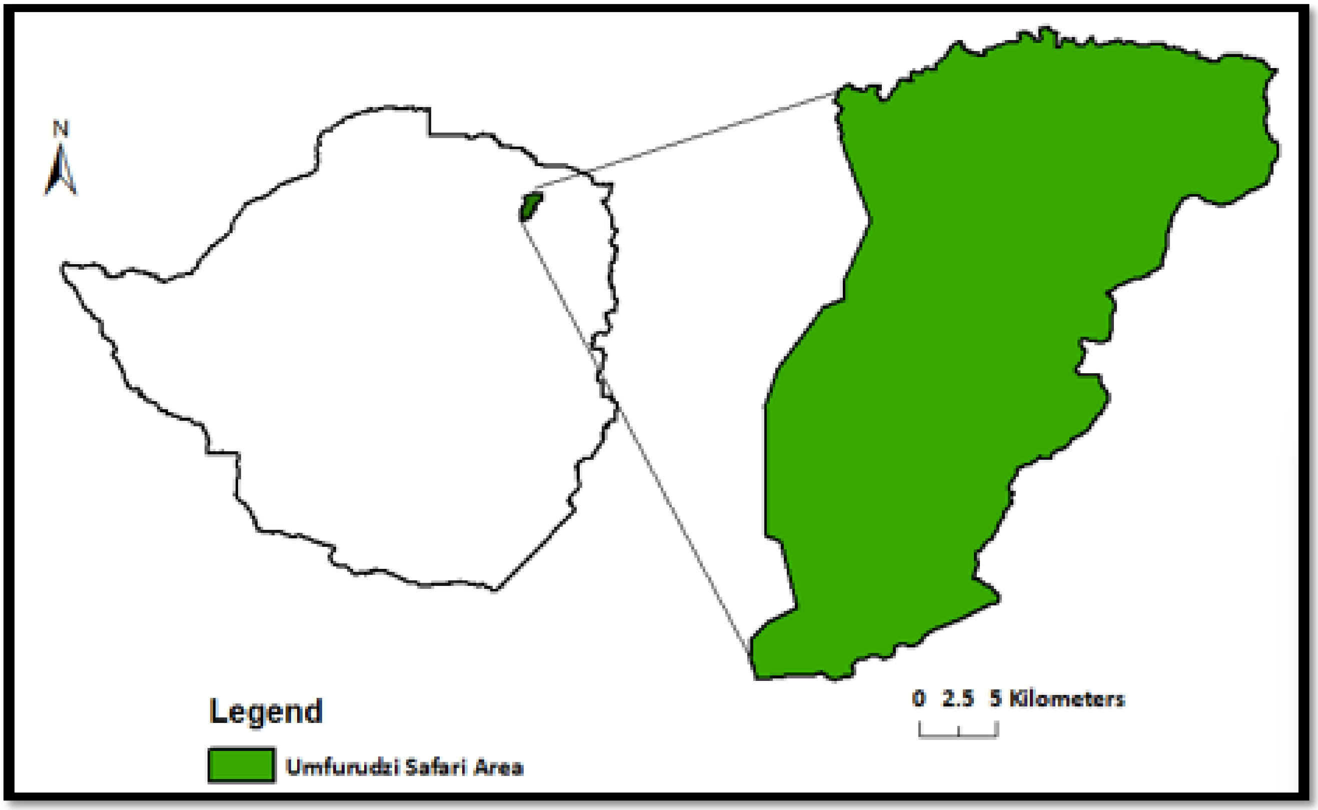

Figure 1: Map of the study area.

RESULTS

ACCURACY OF ASSESSMENT

The habitat prediction maps were assessed based on area under curve (AUC) from a Receiver Operating Curve (ROC) plot. MaxEnt model successfully predicted the species occurrence of Greater kudu (AUC Training data= 0.756; test data=0.661), sable (AUC Training= 0.737; Test data=0.700) and zebra (AUC Training data= 0.867; Test data=0.782) (Figure 2).

PROBABILITY OF OCCURRENCE

Elevation, NDVI, and distance from artificial water spots successfully predicted the frequency of presence of kudu, accounting for a combined 76.9% contribution (Table 1 and Figure 3). The distance from artificial water points and the distance from roads explained 98.2% of the sable distribution. The distance from mines (31%) and distance from roads (24%) were more predictive of zebra occurrence. The distance from rivers had a low predictive contribution for all the species. Overall, the distance from mines significantly explained the distribution of zebra more than sable and kudu.

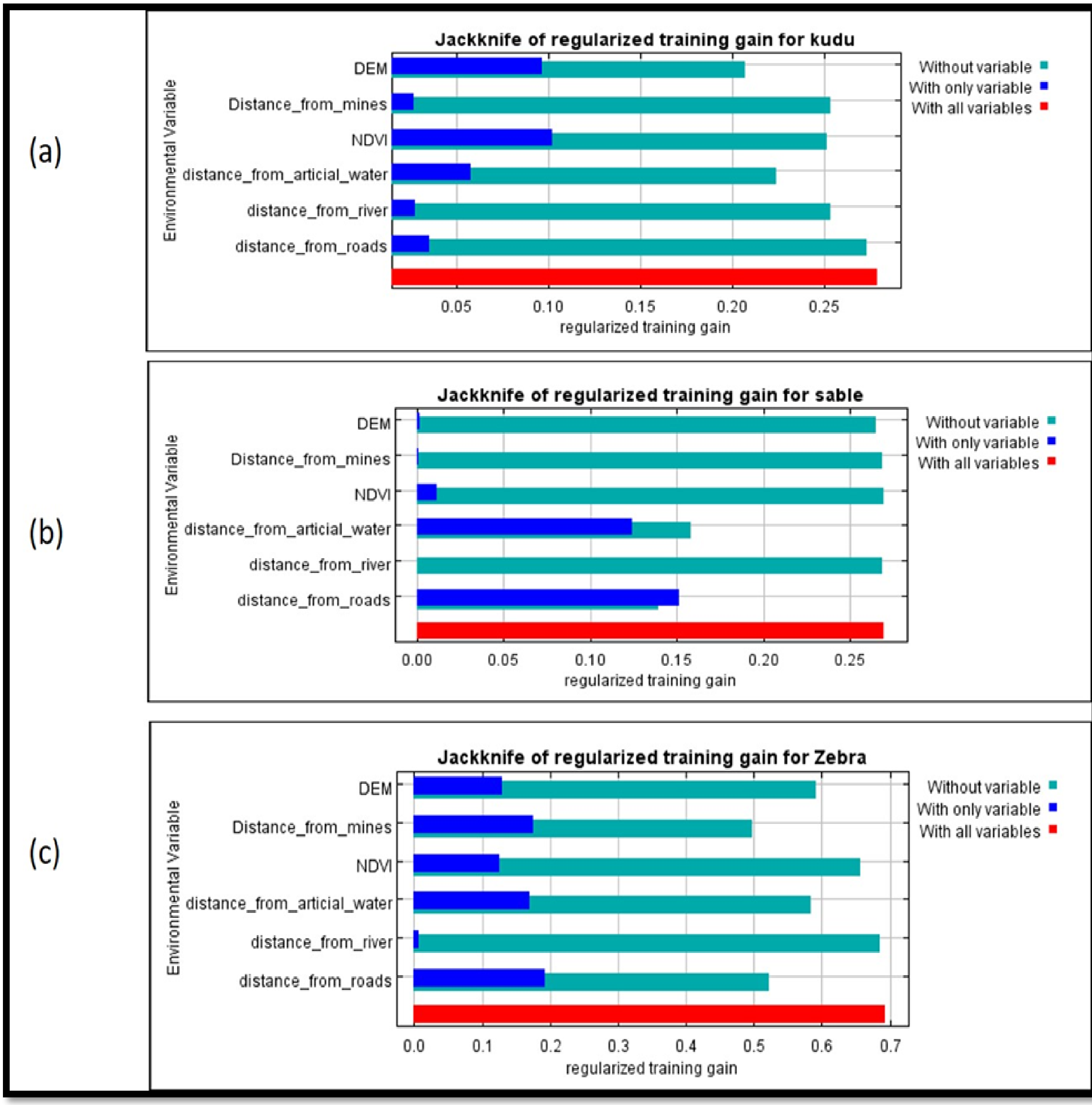

Figure 2: MaxEnt model showing the Jacknife test of the importance of variables used in training the distribution model of kudu, sable and zebra for the year 2016. Notes: DEM =Digital Elevation Model (elevation/terrain); Dist_ from mines=Distance from mines, NDVI=Normalized Difference Vegetation Index; Dist_waterpoints=distance from water points (artificial waterholes); Dist_rivers=distance from rivers and Dist_roads=distance from roads.

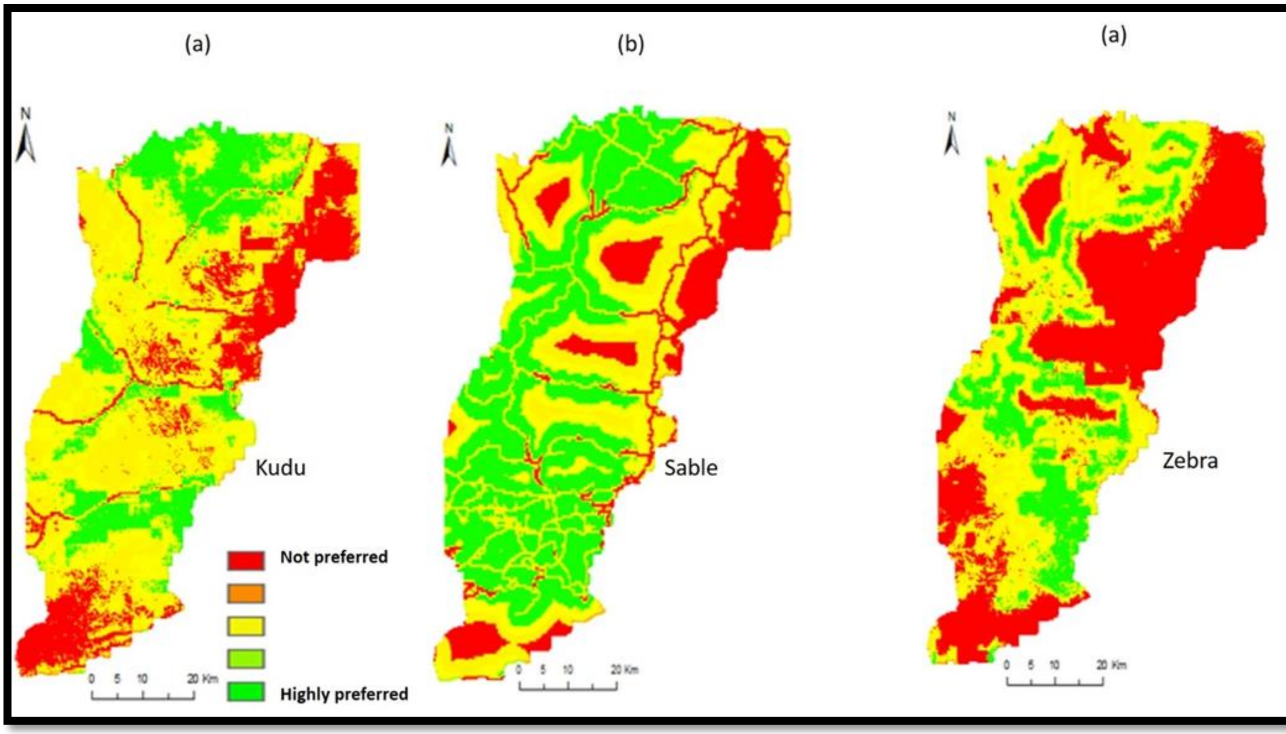

Figure 3: Habitat suitability models of kudu, sable and zebra. The greener the color the more suitable areas (areas with better-predicted conditions) based on the presence data used for training, and model test locations. Unlike other species, kudu wasmore tolerant of mining areas in the far north-west and southeast of the park. The sable distribution is more on the flat areas. The zebra avoided the park periphery and mining areas.

DISCUSSION

MANAGEMENT OF MSA

MSA falls within the Safari area category of protected areas set aside to preserve and protect the natural habitat and the wildlife therein so that facilities and opportunities may be afforded to the public for camping, hunting, fishing, photography, viewing of animals, birdwatching or such other pursuits that may be permitted therein (Government of Zimbabwe, 1996). At a global scale, this category is equivalent to the IUCN classification VI of Protected Areas with Sustainable Use of Natural Resources. While MSA is under the jurisdiction of the Zimbabwe Parks and Wildlife Management Authority (ZPWMA), it is being co-managed under a public-private partnership (PPP) between ZPWMA and a profit-oriented private company, Pioneer Travel, and Tours Private Limited.

Under the partnership, wildlife reintroduction and introduction reintroductions were done between 2011 and 2018 to restore animal populations, breeding, genetics and biodiversity after many years of conservation threats such as poaching and disturbance from mining. The introduced wildlife included islisted in the table below (MSA station records).

MINING IN MSA

There was an average of 46 mining permits per year issued by the Ministry of Mines and Mining Development and supported by ZPWMA from 2008 to 2021. The main mineral mined in the park is gold. Gold mining dates back to the early 1890s before the park was designated as a protected area. The other minerals that are mined include tantalite and black granite. Both open-cast and underground mining is used. The geological and distribution of mines in MSA in 2016 is given (SM 1 and 2). A total of 4 900 illegal miners (average 350 annually; range 22-1 501; n = 14 years) were arrested in MSA between 2008 and 2021. The number of illegal miners arrested decreased since 2008 with the start of the partnership but started to increase from 2018 including in COVID-19 years of 2020 and 2021 (MSA Unpublished Reports). Most of the illegal miners came from neighboring communities.

HABITAT SELECTION AND HERBIVORE OCCUPANCY

The habitat prediction maps were assessed based on the AUC from ROC plot. The ROC curve, which is a graphical technique for describing and comparing the accuracy of diagnostic tests, is obtained by plotting the sensitivity of a test on the y axis against 1-specificity on the x axis (Akobeng, 2007). The AUC values of kudu (0.756), sable (0.737) and zebra (0.867) are reasonable in explaining distribution predictors based on an acceptance threshold of AUC > 0.75 (Mwangi, Waithaka and Boitt, 2018) even though only one survey data set was used.

We predicted that distance to mining areas with a lot of human activity and distance from roads used by miners and other park users will have much influence on the distribution of sable and zebra. Our findings suggest that the most sensitive species to mining areas and roads was zebra.

The kudu distribution was mostly explained by elevation (terrain), distance from artificial water points and NDVI. This may be explained by the ecology and the adaptation of kudu to rugged terrain which makes it the dominant species (Number counted=352) in MSA. Granite kopjes are associated microhabitats with mosaic woody vegetation whose phenology changes at different times of the year unlike grassland. In such terrain management practice such as early burning (Mpakairi et al., 2017) further creates regrowth o woody species favored by browsers. The distance from the road did not explain much distribution of kudu. This is contrary to predictions and findings elsewhere (Muposhi et al., 2016) where distance from roads negatively influenced kudu distribution due to trophy hunting.

The sable antelope distribution was mostly explained by distance from artificial water points and distance from roads. This is consistent with the findings by (Muposhi et al., 2016). While we focus on mining as a main source of disturbance (Muposhi et al., 2016) did their study in a hunting area, however, the argument that human presence and activity influence the distribution of sable remain fundamental from a management and conservation point of view.

The selection and occupancy of habitat by herbivores is explained by interlinked driving factors based on the cost and benefit that a particular species accrue (Rosenzweig, 1981; Bjørneraas et al., 2012). In contrast where human presence is associated with safety to species (non-hunting areas), species such as zebra were found close to roads (Mpakairi et al., 2017). In gold rich areas, the absence of herbivores near rivers is largely explained by artisanal mining activity. Other habitat characteristics such as homogenous dense woodland may not favor occupancy by kudu due to lower species diversity and grazers due to lower grass biomass (Gandiwa et al., 2013; Muposhi et al., 2014). The occurrence of zebra and sable antelope far away from natural water sources and less influence of NDVI has, however, been observed in Malilangwe (Traill and Bigalke, 2007). The observed distribution of the sable and zebra in MSA due in this study is largely a water provisioning and season factor. The location data was obtained during the dry season and the wildlife species utilize artificial water points more during the dry season. The zebra preferred areas with less NDVI. This has been observed in Zambezi national park where zebra avoided areas with high NDVI and preferred vegetation types with intermediate grass biomass and grass height (Mandinyenya et al., 2020). Further, it has been observed that the provisioning of artificial surface water source in habitats far away from rivers make these types of habitats suitable for these species (Smit et al., 2007).

Mineral exploitation threatens large and mid-sized by the pollution of soil and water sources, vegetation disturbance, and due to changes in landscape configurations (Martins-Oliveira et al., 2021). While human disturbance may negatively influence herbivore distribution, it has been highlighted that the response to disturbance by mammals depends on body size, home range size and level of disturbances (Maitima et al., 2009). Other studies have suggested that animals may develop behavioural alterations in response to external disturbance and survive in human-modified landscape (Averbeck et al., 2009; Mata et al., 2016). This possible behavioral plasticity to the disturbance in areas with high mining activity may be difficult. Mining is more often related with destruction of habitat and direct as well as indirect illegal wildlife utilization.

The study area at one point was facing potential degazettement after wildlife populations had plummeted. The co-management arrangement that took effect in 2011 is trying to reverse this through increased law enforcement, resource protection, community engagements and restocking of wildlife. One long term vehicle that is anticipated to drive conservation is tourism. However, the presence of mining in the park also presence a huge threat to photographic tourism. Vegetation removal, fires, noise, human presence and infrastructure associated with mining are a source of disturbance to wildlife and affect natural landscape aesthetics (Roopsind et al., 2017). The success of tourism in a protected area where mining occurs may be minimized.

IMPLICATIONS FOR CONSERVATION

This study highlights the negative influence of mining activities on habitat selection and suitability for herbivores. This influence differs according to the species sensitivity to disturbance. The study also highlights the influence of elevation (terrain), habitat quality and artificial water provisioning as among the major predictors of species distribution. There is therefore a great need to consider both species' ecological needs and mining imperatives in protected areas where there are rich mineral deposits.

CONCLUSION

The study highlights the high potential negative impacts of mining on habitat selection and occupation by sensitive herbivore species where mining takes place. Very sensitive herbivores in this study avoided areas associated with mining such as mining zones and main roads where trucks move. Management of protected areas with rich mineral reserves needs to recognize this and use it in parkland use planning. The positive influence of surface water both natural and artificial provisioning is evident. The role of habitat quality and elevation also has a great influence on habitat suitability, therefore, influences herbivore habitat selection and occupancy. This research did not look at the seasonal influence on herbivore habitat selection and occupancy due to seasonal wildlife survey data limitations. Research findings indicate that habitat selection by species may be influenced by seasonal variations (Bhola et al., 2012).

RECOMMENDATIONS

This study recommends that:

i. There urgent need for a general area management plan zoning the protected area into special species conservations, tourism zones and mining zones. A general management plan puts limits and controls that may affect the conservation of biodiversity as well as facilitate law enforcement.
ii. Park management should focus on increasing wildlife species that thrive well in the park with high human disturbance and not focus on species sensitive to mining disturbance.
iii. In situations where no adequate protection measures are in place for sensitive species, translocation to safer more suitable protected areas is vital to conserve the genetic diversity inherent in affected populations.
iv. There is a need to continuously have a systematic database of wildlife surveys to evaluate long-term impacts of mining and other drivers on the performance of wildlife in the park.

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Table 1: The relative contribution of the environmental variables used in MaxEnt modeling of habitat selection by three herbivores for the year 2016 in MSA, Zimbabwe.

Kudu	Percent contribution	Permutation
Elevation	30.10	37.00
Distance from artificial water points	24.00	14.80

NDVI	22.90	15.90
Distance from rivers	9.10	21.50
Distance from mines	9.00	9.80
Distance from roads	5.00	1.10
Sable	**Percent contribution**	**Permutation**
Elevation	1.00	0.10
Distance from artificial water points	44.30	50.10
NDVI	0.00	0.00
Distance from rivers	0.30	0.50
Distance from mines	0.20	0.00
Distance from roads	54.20	49.30
Zebra	**Percent contribution**	**Permutation**
Elevation	14.00	21.50
Distance from artificial water points	19.20	22.90
NDVI	9.70	9.40
Distance from rivers	1.10	0.00
Distance from mines	31.00	20.30
Distance from roads	24.90	25.90

Table 2: Schedule of reintroduced (restocked) wildlife and not restocked.

Species	**Wildlife introductions**				**Total Introduction**	**2016 Count Park aerial survey**
	2011	**2012**	**2013**	**2014**		
Eland	52	276	0	0	328	67
Elephant	0	0	13	0	13	13
Impala	206	193	243	0	642	209
Giraffe	0	25	18	0	43	16
Buffalo	25	134	0	0	159	138
Tsessebe	33	0	0	0	33	3
Sable	1	0	0	0	1	144
Wildebeest	56	162	0	0	218	94
Waterbuck	16	26	8	0	50	43
Warthog	0	0	110	0	110	59
Zebra	70	131	0	0	201	234
Bush buck	0	0	0	10	10	18
Wildlife Species not restocked						
Kudu						352
Baboons						945
Bushpig						21
Roan antelope						2
Common duiker						173