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An Evaluation of the Land Cover Classification Product *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* for Namibia

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ABSTRACT

Global information on land cover is a primary output of remote sensing applications due to its importance to global change sciences, but also to governments and international initiatives. Consequently, a variety of land cover datasets have been developed in the past. Today users can choose among different products with various spatial resolutions for applications on global as well as on regional scales. A new classification covering the African continent was released by the European Space Agency only recently. Thanks to its mapping approach of 20 m, the *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* constitutes a novelty among the freely available products. However, being only a prototype, it is still missing final validation. This study aimed at evaluating the classification for the extent of Namibia by quantitatively and qualitatively comparing it to a selection of four low- to medium-resolution land cover products. Within the framework of an accuracy assessment for four test sites, statistical parameters were calculated which served as indicators for assessing the classification quality. According to the analysis, the overall accuracy of the prototype land cover product is on a medium level attaining approximately 54%. The per class accuracy varies from 2% to 100% suggesting that some classes require considerable reworking whereas others need less improvement. However, compared to the reference datasets, the prototype classification already constitutes a major development in land cover mapping.

Keywords: Accuracy assessment; classification; European Space Agency; land cover; Namibia; Sentinel 2; spatial resolution; validation

INTRODUCTION

Global information on land cover (GLC) is of importance for environmental change studies but also for international initiatives engaging in e.g. land resource management. Since the development of the first land cover dataset in the 1980s, the number of products has constantly risen (DeFries *et al.* 1995, Matthews 1983, Olson *et al.* 1985, Wilson & Henderson-Sellers 1985). However, not only the quantity but also the quality has changed thanks to the availability of higher resolution sensors. The initially low spatial resolution of 1° has been gradually increased to 1 km (e.g. *DISCover*) (Loveland *et al.* 2000), 500 m (e.g. *MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid, MCD12Q1*) (Friedl & Sulla-Menashe 2018) and 300 m (e.g. *GlobCover*) (Arino *et al.* 2011). These spatial resolutions are still too low for most regional and local scale applications. The publication of the classification *GlobeLand30* with a 30 m mapping approach has therefore been of great importance to the mapping society (Chen *et al.* 2015). A further improvement is the 20 m medium-resolution land cover map *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* (*S2 LC Africa*) of the European Space Agency (ESA), which was released in September 2017 (Ramoino *et al.* 2018). Due to its exceptional spatial resolution, it currently takes a special position among the freely available land cover products for Africa. However, it is still a prototype that has not yet been validated on a regional scale. Up to the time of this research there was only one detailed study of the authors Lesiv *et al.* (2017) who had examined the product accuracy using two independent land cover datasets at 10 m resolutions developed within the Copernicus Global Land Services (CGLS). According to their estimates, overall accuracy of the prototype LC Africa map at 20 m was approximately 65%. Regions were highlighted where the spatial distribution of specific land cover classes such as shrubs, crops and trees should be improved before the map can be used as input for research questions, e.g. conservation of biodiversity, crop monitoring and climate modelling. These regions also include the central and north western areas of Namibia which are characterised by a more inhomogeneous land cover and higher overestimations of shrub, grass and croplands. The main aim of the study was to comply with the request of the ESA to evaluate the quality of the *S2 LC Africa* product and provide further user feedback. Four freely available low- to medium-resolution land cover datasets served as reference.

METHODS

Study Area

Namibia is characterised through clearly definable landscape units with a multitude of different forms and shapes (Hüser *et al*. 2001). Along with the gradually changing climatic conditions, they result in a varying plant density and diversity (Mendelsohn *et al*. 2009). This makes the country interesting for land cover analysis. Furthermore, its rainfall gradient from the northeast to the coast in the west allowed the choice of four highly heterogeneous test sites with a size of 50 km x 50 km (Figure 1). These not only capture hydric differences, but also topographic variability. Whereas the Zambezi is part of the plain highland, the other three test sites are located in terrain with higher relief energy.

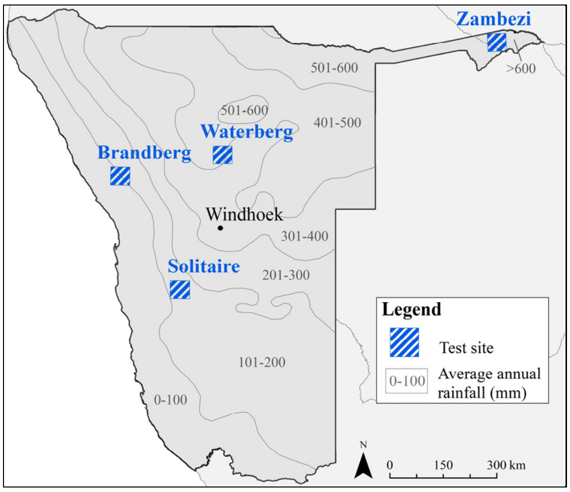

Figure 1*: Average annual rainfall and locations of the four test sites.*

The first test site is located in the Zambezi region. The high annual precipitation allows for savanna woodland as well as grassland (Hüser *et al*. 2001). Cropland can be found especially along the major roads and in proximity to settlements (Mendelsohn *et al*. 2009). The second test site contains the southwestern part of the Waterberg. Here a mosaic of vegetation and rocks form the plateau (Hüser *et al*. 2001). The surroundings are partially used for farming (Mendelsohn *et al*. 2009). The third test site lies on the foothills of the Great Escarpment. Its land cover is substantially affected by the arid climate (Jacobson *et al*. 1995). Vegetation can almost only be found along the banks of the ephemeral and endorheic river Tsondab and its inflows (Jacobson *et al*. 1995). The Brandberg Mountain area forms the last test site. Even though the climate is arid (Nordenstam 1974), plants can grow thanks to the rainfall-increasing impact of the relief (Hüser *et al*. 2001). The ephemeral river Ugab (Eckardt *et al*. 2001) runs through the north of the tile suggesting the presence of denser riverine vegetation.

Land Cover Products

The comparison included five freely available low to medium resolution products (Table 1). The global dataset *DISCover* classified according to the IGBP (International Geosphere Biosphere Programme) scheme is based on monthly maximum Normalised Difference Vegetation Index (NDVI) composites of the months April 1992 to March 1993 derived from the NOAA-AVHRR (National Oceanic and Atmospheric Administration – Advanced Very High-Resolution Radiometer) satellite sensor scheme (Hansen & Reed 2000). These served as input into an unsupervised cluster classification. The *MODIS* (Moderate Resolution Imaging Spectroradiometer) *MCD12Q1* Version 6 product of the year 2016 was

Table 1: *The land cover products and their spatial resolution. Sources: Friedl & Sulla-Menashe (2018), Hansen & Reed (2000), Ramoino et al. (2018), Santoro et al. (2017), Servir Global (2015).*

Product	**Sensor**	**Spatial Resolution**	**Period of Data Acquisition**	**Classification Scheme**	**Spatial Coverage**	**Overall Accuracy ***	**Group**
DISCover	NOAA AVHRR	1000 m	April 1992 - March 1993	IGBP	Global	59.4%	Low resolution
MCD12Q1 V006	MODIS	500 m	2016	IGBP	Global	-	
CCI-LC 2015	MERIS FR & RR, SPOT-VGT, AVHRR & PROBA-V	300 m	2015	FAO LCCS	Global	71.5%	
Namibian Land Cover 2010 Scheme II	Landsat 5 TM	30 m	2009 - 2011	Modified LC categories of the IPCC	Namibia	76.9%	Medium resolution
S2 Prototype LC 20 m Map of Africa 2016	Sentinel 2	20 m	December 2015 - December 2016	Own classification scheme	Africa	65.0%	

**Overall accuracy computed by the product developers* chosen as a second product, also containing classes of the IGBP scheme. The product was developed using a supervised classification algorithm of MODIS reflectance data (Friedl & Sulla-Menashe 2018). As a third global medium-resolution product the ESA *CCI-LC* (*Climate Change Initiative Land Cover*) of the year 2015 was used. The product is based on the time series of MERIS (Medium Resolution Imaging Spectrometer) Full Resolution (FR) and Reduced Resolution (RR), but it is supplemented by images of SPOT-VGT (Satellite Pour l'Observation de la Terre - VEGETATION), AVHRR and PROBA-V (Project for On-Board Autonomy - Vegetation) allowing for mapping and incorporation of land cover changes (Santoro *et al*. 2017). The legend was developed applying the Land Cover Classification Scheme (LCCS) of the United Nations (UN) Food and Agriculture Organization (FAO). This was supposed to facilitate comparisons with other global land cover products.

The medium-resolution and national dataset *Namibia Land Cover 2010 Scheme II* (NLC 2010) served for a more detailed comparison. It was generated using images derived from the sensor Landsat 5 TM (Thematic Mapper) of the years 2006, 2010 and 2011 as inputs for a supervised classification. A country-specific legend with 13 classes was created, which is based on the LC categories of the Intergovernmental Panel on Climate Change (IPCC) (Servir Global 2015). The *S2 LC Africa* product was developed applying the classification algorithms Machine Learning and Random Forest to data of the sensor Sentinel-2A for the period December 2015 until December 2016. The two resulting maps were then combined allowing the selection of best land cover representations. The initial 22 classes of the global *CCI-LC* map were reduced to the ten most relevant land cover classes for the African continent (Ramoino *et al*. 2018).

Legend Harmonisation

A quantitative and qualitative comparison was used to show differences between the land cover products. A key challenge before product comparison was the harmonisation of the different legends, as the number of classes as well as their definitions varied substantially. By assigning a common legend to all datasets the classifications became comparable. The developed legend (Table 2) is based on the *S2 LC Africa* product due to the lower number of classes, the absence of mixed classes and the broader formulation of classes.

Comparison of Land Cover Products

The reference products were compared to the *S2 LC Africa* classification in respect to common features and classification differences using the geographical information system ArcMap 10.4 of the company ESRI. So-called agreement maps (Figure 4) were produced to visualise areas of uncertainty or mismatch as well as areas of thematic consistency in the map outputs, allowing conclusions on product accuracy. Prior to the comparison, the spatial

Table 2: *The classes of the common legend and the assignment of the respective classes per product.*

Value	Class	Description	DISCover & MCD12Q1	CCI-LC 2015	NLC 2010
0	Unclassified		100	0	0
1	Woodland	Opened to closed woodlands with a minimum surface coverage of 10%	1, 2, 3, 4, 5, 8, 9	60, 62	1, 2
2	Shrubland	Opened to closed shrubs and bushes; proportion of trees must not exceed the proportion of the shrubs	6, 7, 14	11, 12, 40, 100, 110, 120, 122	4
3	Grassland	Dominance of grasses; the proportion of woody plants must be negligible	10	130	3, 5
4	Cropland	Comprising cultivated as well as uncultivated, irrigated as well as unwatered fields	12	10, 20, 30	6
5	Wetland	Regularly flooded areas which can be covered by grasses, shrubs and trees	11	180	7
6	Sparse vegetation, lichens, mosses	Sparsely vegetated areas, lichens or mosses	*	150, 153	*
7	Bare areas	Areas without vegetation or almost no vegetation such as rocks, barren soil, dunes, desert, salt pans and streets	16	200, 201, 202	10, 11, 12, 13
8	Built up areas	Artificial surfaces, settlements and industrial areas; excluding streets	13	190	9
9	Permanent snow and/or ice	Areas that are covered with snow and/or ice all-season	15	*	*
10	Water bodies	Areas that are covered with water all-season	17	210	8

**Class does not exist in the classification*

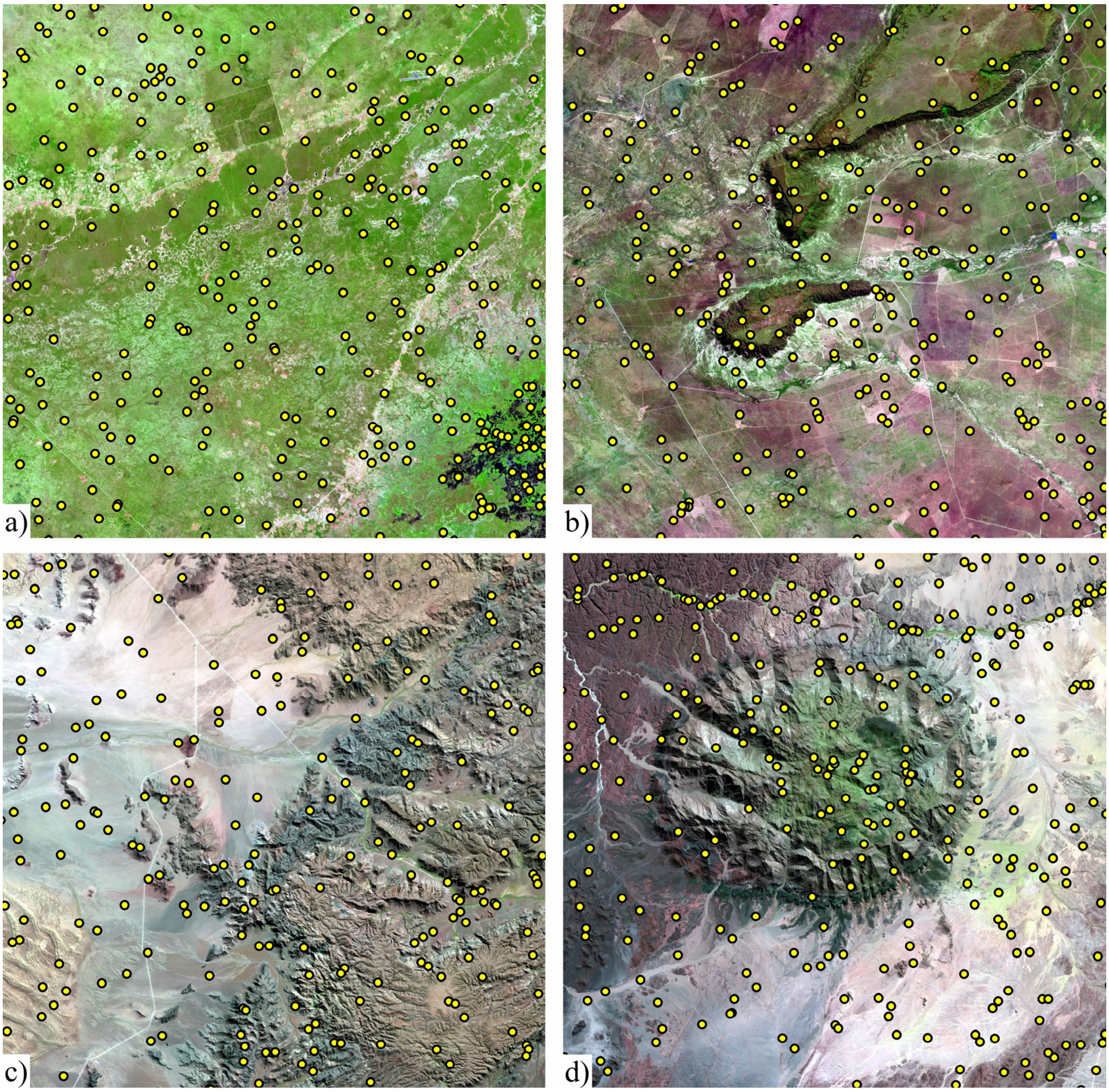

***Figure 2**: False-colour images (SWIR1 – NIR – Red) of the test sites (a) Zambezi, (b) Waterberg, (c) Solitaire and (d) Brandberg showing the location of the reference data.*

resolution of the reference maps was resampled to the higher resolution prototype dataset.

Accuracy Assessment

The majority of the datasets analysed in this paper include their own accuracy assessment (Table 1). However, comparability is limited as products were derived using different methodologies and reference data. For that reason, a common accuracy assessment was performed to evaluate the land cover datasets. The accuracy assessment was carried out by means of an error or confusion matrix which is a cross tabulation of classification results against reference data. An error matrix allows for statistical conclusions on the proportion of correctly classified pixels and the dependency of misclassifications on other classes (Lange 2002). The derived classification accuracy parameters included the overall accuracy (OA) as the percentage of pixels classified correctly, the producer's accuracy (PA) as the percentage of correctly classified reference data and the user's accuracy (UA) as the percentage of correctly classified map pixels (Lange 2002). Moreover, the kappa coefficient was calculated which indicates how good the classification results compare to reference data. Kappa coefficient values range between 0 (no agreement between the classification results and the reference data) and 1 (total agreement between the classification results and the reference data) (Congalton & Green 2009).

The reference data were generated applying a stratified sampling methodology (ground truthing).

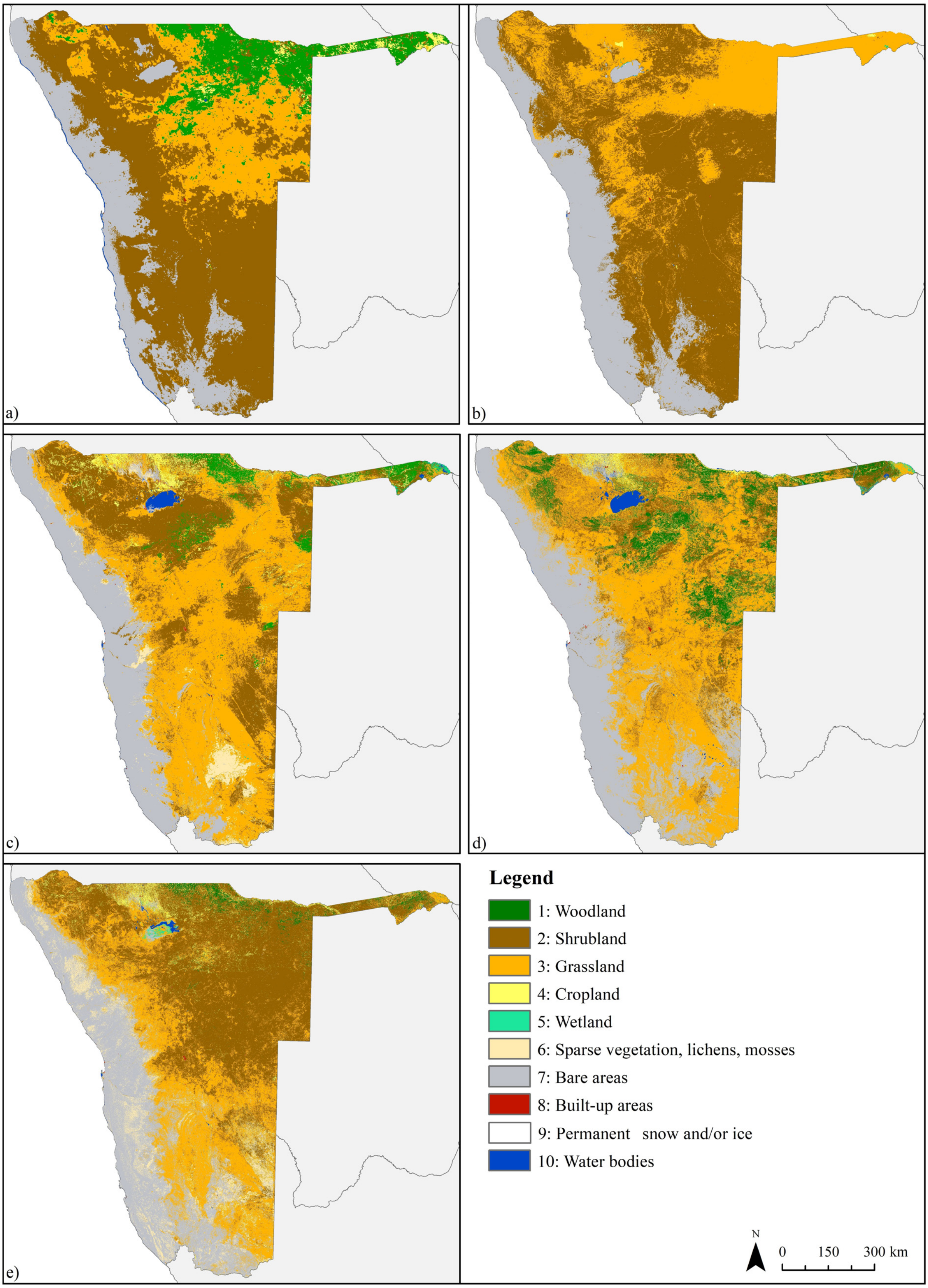

***Figure 3**: Reclassified land cover products DISCover, 1993 (a), MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid (MCD12Q1 2016) (b), Climate Change Initiative Land Cover (CCI-LC 2015) (c), Namibia Land Cover 2010 Scheme II (NLC 2010) (d), Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa) (e) with legends harmonized to the Sentinel 2 product.*

According to Congalton (1991) the minimum number of reference points for each land cover class should be 50. Classes of greater extent require between 75 and 100 samples. In this study the maximum number of samples was limited to 338 for Zambezi, 296 for Waterberg, 228 for Solitaire and 334 for Brandberg (Figure 2). The number depended on the test site's diversity and land cover heterogeneity. The sampling points were classified based on visual image interpretation of recent high-resolution World Imagery Basemap of ArcGIS, SPOT imagery with a spatial resolution of 5 m acquired in 2010 as well as Aerial Orthophotos acquired in 2009 with a 1 m spatial resolution covering the northern communal areas. The multi-temporal approach was necessary as different time stamps of the investigated land cover products have effect on land cover and land cover changes over time.

RESULTS

Comparison of freely available Land Cover Products

Significant differences in the distribution of land cover classes can be seen countrywide, but vary depending on the product. Areas in the northeast with small-scale mosaics of land cover, where woodlands are mixed with shrubs, grass and cropland (Hüser *et al.* 2001), represented a major challenge for

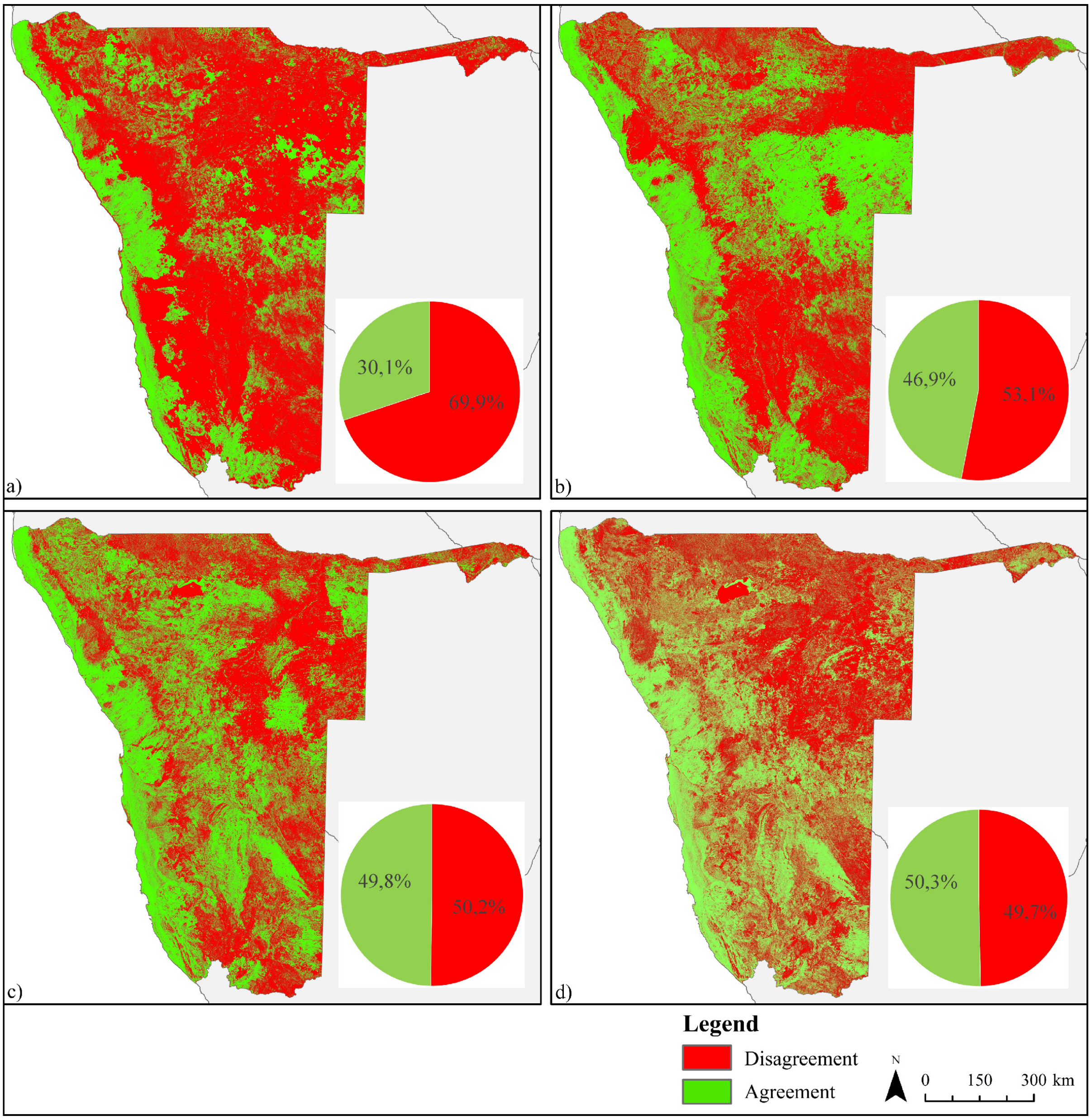

***Figure 4**: Spatial agreement and disagreement among the datasets Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa) and (a) DISCover; (b) MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid (MCD12Q1); (c) Climate Change Initiative Land Cover (CCI-LC); (d) Namibia Land Cover 2010 Scheme II (NLC 2010).*

consistent mapping. However, also large areas with predominantly homogenous land cover types show patterns of disagreement. In the southern area, where shrubland is interspersed with grassland (Mendelsohn *et al*. 2009), the disagreement is largely due to the under-representation of grassland in the *DISCover* and *MCD12Q1* products (Figure 3).

Figure 4 shows the spatial agreement and disagreement between the *S2 LC Africa* product and the four chosen reference products. All four maps show large areas of agreement along the coastline of Namibia due to the extensive dune belt and the large-scale gravel plains of the Namib desert (Leser 1982). Irregular patterns of disagreement increase further inland (i.e. in the transition zone between the Great

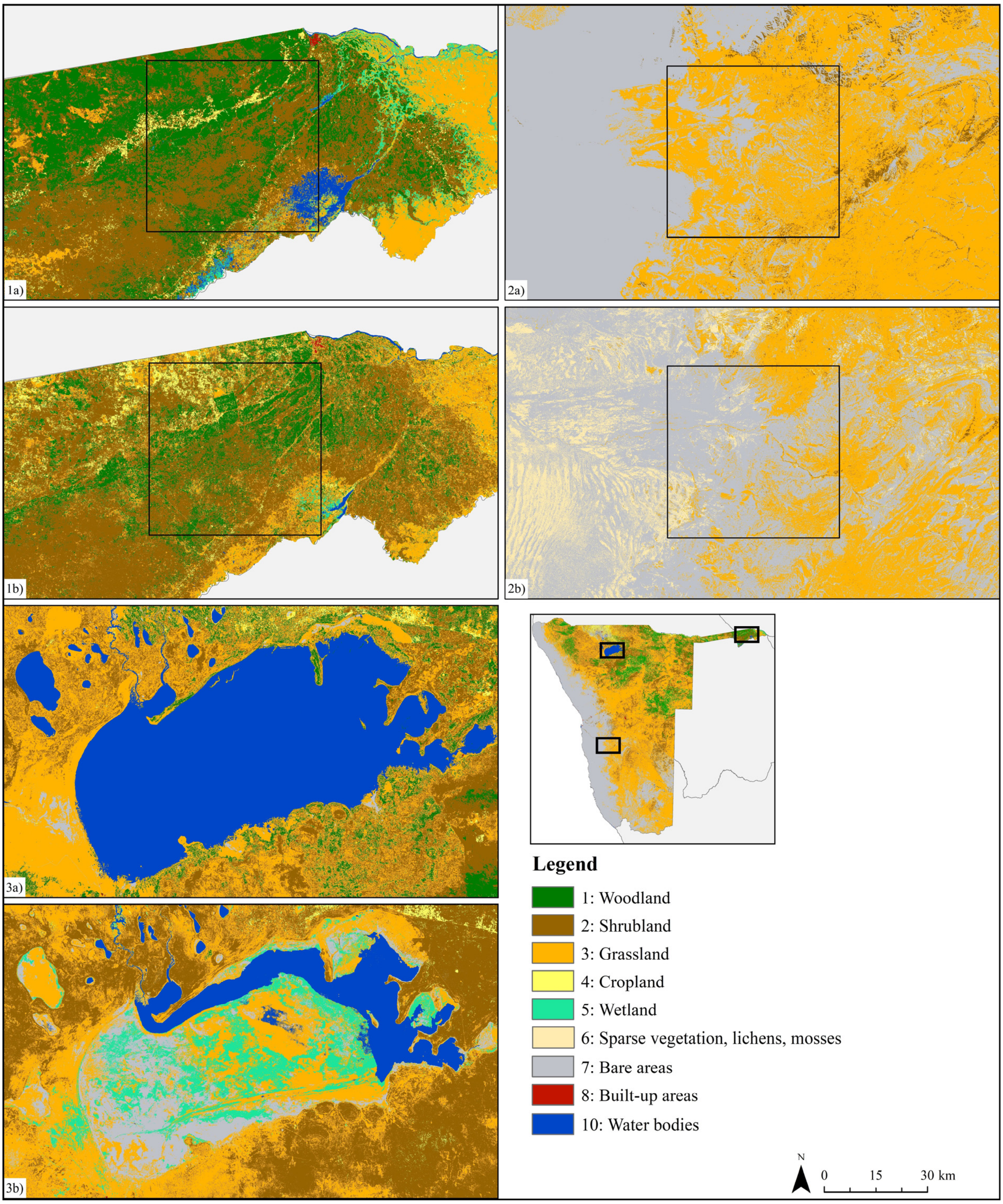

Figure 5: *(1) The Zambezi region, (2) the Solitaire region and (3) the Etosha Pan classified by (a) the Namibia Land Cover 2010 Scheme II (NLC 2010) and (b) the Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa. Locations are visible in the overview map.*

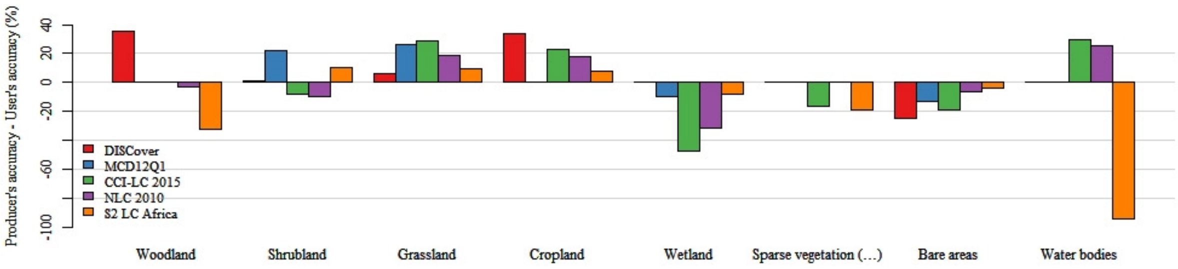

***Figure 6**: Difference between the producer's and the user's accuracy.*

Escarpment and the coast or towards the central-eastern regions, Kalahari).

The highest level of agreement is visible when comparing the *NLC 2010* and the *S2 LC Africa* product. The comparison with the *DISCover* map shows the highest disagreement. The increase of agreement thus correlates with the increase of sensor resolution (Table 1), suggesting higher thematic accuracies of these products. The disagreement amounting to 49.7% of the total area in the agreement map of *S2 LC Africa* and *NLC 2010* (Figure 4c) tends to slightly negatively correlate with the rainfall gradient. Therefore, it is opposed to vegetation density and height. As already mentioned, the largest connected agreement area covers the coast where land cover varies slightly. This leads to a relatively high percentage of qualitative correlation (35%) of bare areas. The grassland class shows the second highest qualitative agreement of 27%.

The map extracts (Figure 5) compare the *NLC 2010* product with the *S2 LC Africa* product for selected sites. The Etosha Pan is a salt pan which is irregularly flooded in the rainy season but dry during the winter (Namibia National Commission for UNESCO 2016). Due to seasonally changing land cover patterns, correct mapping of the salt pan is definitely a challenge. The *NLC 2010* product classified it as a permanent water body. The *S2 LC Africa* product shows a mosaic of barren, vegetated and flooded areas. The test sites Zambezi and Solitaire also show significant differences such as an under-representation of sparse vegetation in the *NLC 2010* product extract for 'Solitaire' and a seemingly more detailed representation of the classes woodland, shrubland and cropland in the *S2 LC Africa* product extract in the Zambezi region.

Accuracy Assessment

The accuracy varies depending on land cover class and spatial resolution (Table 3). Bare areas were classified most precisely. The class sparse vegetation, lichens, mosses shows complete disagreement due to the absence of corresponding classes in the original legends. The error matrix reveals a clear trend to higher accuracy values as the spatial resolution increases. Therefore, the *S2 LC Africa* product has the highest OA and the highest kappa coefficient of all freely available products. None of the analysed classifications is satisfactory according to Anderson *et al.* (1976) or Fitzgerald & Lees (1994) who defined a minimum accuracy of 85% and 70%, respectively. Considering the kappa coefficient values, only the prototype classification reaches a medium agreement (kappa coefficient ≥0.4) according to Congalton & Green (2009).

To evaluate the balance between the producer's and the user's accuracy, the differences between these two measurements were calculated (Figure 6). The

***Table 3:** Accuracy assessment showing the overall accuracy (OA, %), user's accuracy (UA, %) and producer's accuracy (PA, %) and the kappa coefficient of the freely available land cover products for the four test sites (summed up).*

	DISCover		**MCD12Q1**		**CCI-LC 2015**		**NLC 2010**		**S2 LC Africa**	
	UA	**PA**	**UA**	**PA**	**UA**	**PA**	**UA**	**PA**	**UA**	**PA**
1: Woodland	35.7	71.1	0	0	40.3	40.6	59.1	56.1	76.0	43.9
2: Shrubland	17.6	19.1	36.2	58.6	37.2	29.2	51.9	42.6	57.4	67.7
3: Grassland	12.4	18.7	12.3	38.3	11.4	40.2	7.7	26.2	10.7	20.6
4: Cropland	5.9	40.0	0	0	16.7	40.0	22.2	40.0	2.4	10.0
5: Wetland	0	0	23.1	13.0	60.0	13.0	40.0	8.7	21.4	13.0
6: Sparse vegetation, lichens, mosses	0	0	0	0	22.0	5.8	0	0	41.7	22.7
7: Bare areas	76.3	51.7	72.8	59.4	75.9	56.8	68.2	61.5	79.5	76.0
10: Water bodies	0	0	0	0	39.3	68.8	31.0	56.3	100.0	6.3
OA	34.5		38.5		38.1		43.3		54.4	
Kappa	0.18		0.21		0.24		0.29		0.41	

Table 4: *Accuracy assessment showing the overall accuracy (OA, %) and the kappa coefficient of the freely available land cover products for the four test sites.*

		DISCover	**MCD12Q1**	**CCI-LC 2015**	**NLC 2010**	**S2 LC Africa**
Zambezi	OA	33.4	13.9	59.6	44.7	45.3
	Kappa	-	-0.9	23.6	23.1	24.7
Waterberg	OA	18.9	53.0	31.4	39.2	53.0
	Kappa	7.6	2.2	8.1	23.8	21.2
Solitaire	OA	22.8	27.2	20.6	21.5	51.3
	Kappa	6.5	9.3	7.0	5.8	15.4
Brandberg	OA	53.9	59.9	59.6	59.9	67.7
	Kappa	17.5	19.4	23.6	11.4	41.5

balance varies strongly among the different classes and products. *S2 LC Africa* shows the highest imbalance due to the strong bias towards the user's accuracy in class Water bodies. The product *CCI-LC 2015* shows the second highest imbalance. The results of *DISCover* and *MCD12Q1* are more concerted but difficult to compare due to the presence of zero values. The classes shrubland, sparse vegetation, lichens, mosses and bare areas are the least biased in all land cover products.

The achieved accuracies vary considerably. Not only for the land cover products but also for the four chosen test sites (Table 4). All products achieve the highest accuracy for the test site Brandberg. One reason might be the more homogeneous land cover which is predominately unvegetated and bare and can therefore be mapped with little confusion. In contrast, the test site Solitaire was classified with almost exclusively low values mostly due to confusions in the classes shrubland, grassland, sparse vegetation, lichens, mosses and bare areas. Terrain variability, which is more homogeneous within the Zambezi test site compared to the mixed terrain of the other three test sites, does not seem to influence classification accuracy.

DISCUSSION

The applied methodology is one possible way to compare and validate land cover classifications. However, it should be considered that inherent dataset characteristics and personal assumptions might have induced some bias in the results. The re-classification of the reference products could have modified the classification results to some extent. Even though it was conducted with care, a perfect re-coding of some classes was challenging because of missing or insufficient class descriptions. The biggest challenge was the re-classification of mosaic classes. These contain several land cover types, which are subject to regional differences in vegetation composition. Furthermore, it should be noted that, although assumed to be correct, the ground truth data is easily subject to misinterpretation. According to Congalton & Green (2009) up to 30% of the differences between the reference data and the classification results are likely to be the result of subjective interpretation.

Apart from procedural issues, natural processes are likely to have caused some disagreement. Landscape units or land cover itself can easily be influenced through seasonal and inter-annual changes. The transition from dry to rainy season leads to changes in phenology every year (Hassler *et al.* 2010). Due to the significant time difference in the data collection of up to 26 years, it is highly probable that real land cover changes such as desertification (Klimm *et al.* 1994, Seely & Klintenberg 2011), bush encroachment (Mendelsohn & Obeid 2005) or urbanisation (Röder *et al.* 2015) took place and led to disagreements when comparing the reference datasets with the prototype classification. Timely differences and the lack of high-resolution reference imagery definitely had an effect on the evaluation of the older *DISCover* land cover product based on imagery of the years 1992 and 1993. For time reasons the study did not include historical imagery which can be accessed in Google Earth Pro. The other products were derived from imagery of almost the same period in time (see section on land cover products).

Consequently, most of the differences can be assumed to be the result of misclassification. This is the case in the north due to the overestimation of grassland in the *CCI-LC 2015* and *NLC 2010* products. Apart from a few exceptions, extensive grassland can be located in the transition area from the central highland to the Namib desert (Hüser *et al.* 2001), whereas in the north, grassland only covers small areas near rivers or is mixed with other types of land cover (Mendelsohn *et al.* 2009). Most of the country, however, is dominated by shrubland of different densities (Hüser *et al.* 2001). The S2 prototype classification displays the distribution of grassland more accurately, yet slightly

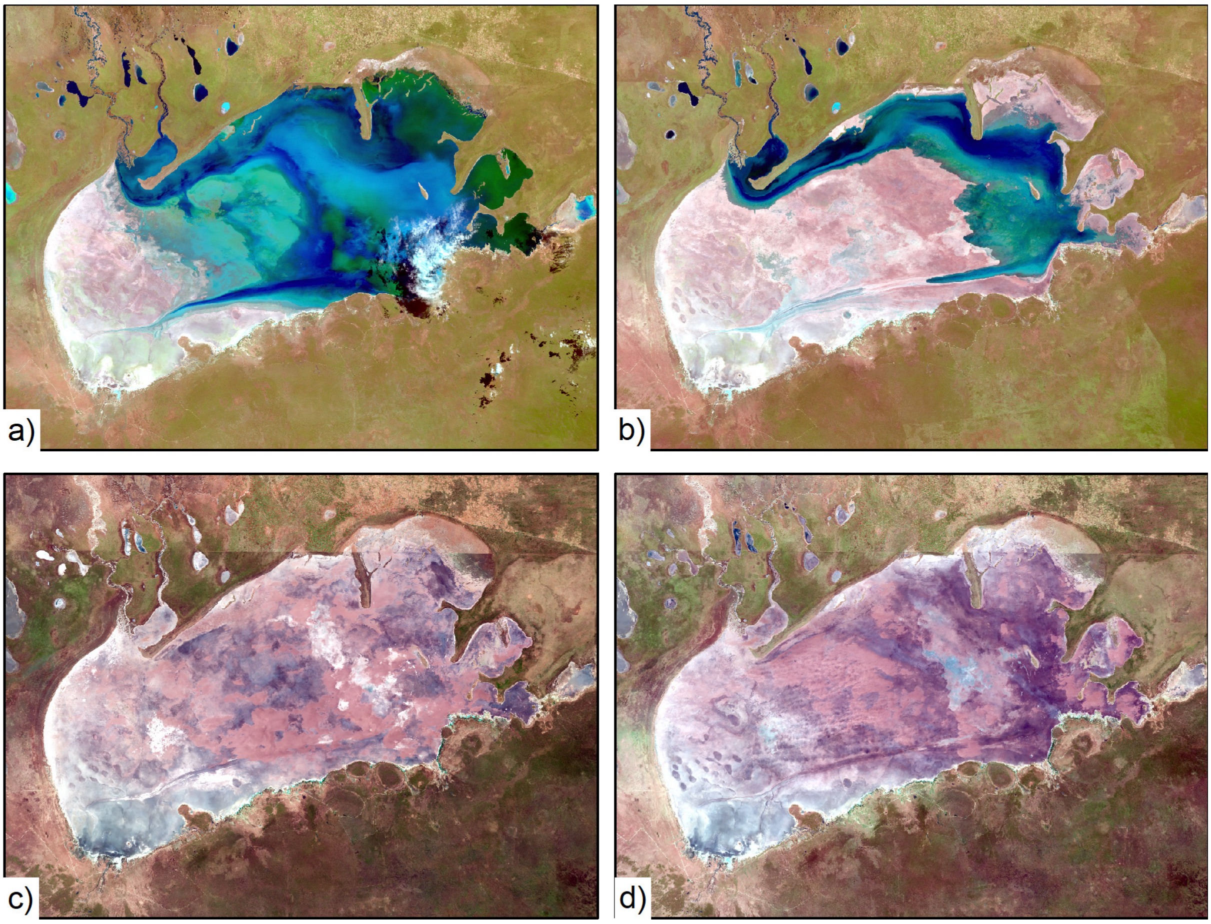

Figure 7: *Images of Landsat-5 and Landsat-8 as false natural colour composites showing the desiccation of the Etosha pan in (a) May 2009; (b) May 2010; (c) June 2015; (d) May 2016. Source: USGS (2018).*

overestimating it in parts of the country. Varying results can rather be attributed to the presence of different land cover types, particularly in areas of land cover mosaics which can be challenging for consistent mapping, especially when the heterogeneity leads to the generation of mixed pixels. In general, this issue is independent from the spatial resolution of the satellite sensor. However, low-resolution sensors produce higher amounts of mixed pixels (Fisher & Pathirana 1990).

The map extract of the Etosha pan (Figure 5) suggests that small-scale mosaics were classified more accurately in the *S2 LC Africa* product dataset. Although the years of the data collection (2009-2011) for the *NLC 2010* map were extraordinarily high in precipitation (Earth Observatory 2018), displaying the whole area as a permanent water body is considered critically. Firstly, satellite images prove that the salt pan dried out in the dry season of the years considered (Figure 7). Secondly, images of the dry season were preferred according to the product description. Consequently, a classification as a mosaic of barren, vegetated and flooded areas, as described by the Namibia National Commission for UNESCO (2016), is believed to be more realistic. This finding implies that the higher resolution prototype map provides more precise information on the actual land cover than the lower resolution reference datasets. This assumption is confirmed by the accuracy assessment, however, some of its per class accuracies are still on a low level. This finding implies that other factors such as spatial coverage, tools and classification procedures influence the accuracy of land cover products.

CONCLUSION

The results of the study suggest that the *S2 LC Africa* product constitutes a major improvement for land cover mapping of Namibia. It is more detailed and precise in terms of quantitative and qualitative representation of land cover than the low and medium-resolution reference datasets. However, the accuracies per class are still too low to meet the user requirements of a good qualitative and reliable land cover map which can be used as a basis for environmental analysis. Consequently, further improvements should be made to satisfy all user needs. Finally, it should be noted that the results do not represent a complete accuracy assessment of the analysed products since these are limited to the test sites. The objective was rather to provide information on the possible strengths and weaknesses of the datasets, and to contribute to the validation of the *S2 LC Africa* product. Hence further examination and validation is recommended. These should include reference data for the whole country to ensure meaningful results.

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Rehabilitated cheetahs exhibit similar prey selection behaviour to their wild counterparts: A case study of prey selection by rehabilitated cheetah released into an enclosed reserve in north-central Namibia

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ABSTRACT

A major challenge for cheetah (*Acinonyx jubatus*) conservation is locating suitable areas to release captive-raised cheetahs that meet their need for large home ranges, whilst protecting them from human-wildlife conflict. The AfriCat Foundation has been rehabilitating and releasing cheetahs onto Okonjima Nature Reserve (ONR) near Otjiwarongo, Namibia, from 2000-2018. We analysed kill data for rehabilitated cheetahs on ONR to determine if captive-raised cheetahs exhibit similar prey selection to their wild counterparts. Between August 2017 and November 2018, a total of 65 kills made by seven cheetahs, comprising two sibling coalitions and three solitary individuals were recorded and analysed. Results suggest captive-raised cheetahs can hunt successfully, although all cheetahs in ONR required supplemental feeding for variable periods immediately after release. Once they were successfully hunting, rehabilitated cheetahs demonstrated similar prey selection behaviours to wild cheetahs. The ONR cheetahs selected prey based on size and local species abundance, and showed little difference in prey diversity across cheetah groupings. This study builds on previous studies into cheetah prey-selection behaviour, and can provide insight into choosing release sites for cheetahs, creating cheetah coalitions in captivity before release, as well as managing released cheetahs living with humans and other predators in smaller, fenced reserves.

Keywords: *Acinonyx jubatus*; cheetah; Namibia; prey selection; rehabilitated.

INTRODUCTION

Cheetahs (*Acinonyx jubatus*) were historically found across most of the African continent. However, due to human population growth, habitat loss, illegal wildlife trade, and human-wildlife conflict, they have been reduced to 9% of their former range in the last 40 years (Marker *et al.* 2018b). Cheetahs are classified as ‘Vulnerable’ and ‘Decreasing’ by the International Union for Conservation of Nature’s (IUCN) Red List of Threatened Species (Version 2019-3), with an estimated population size of 7,100 in 2015 (Durant *et al.* 2015). However, a more recent and comprehensive estimate by Weise *et al.* (2017) indicates the number is likely closer to 6,800. These estimates, paired with population growth modelling, have prompted Durant *et al.* (2017) and Weise *et al.* (2017) to recommend cheetahs should be uplisted to ‘Endangered’ status. Namibia is home to approximately 1,500 cheetahs, the largest number of wild (free-ranging) cheetahs left in any country in the world (Marker *et al.* 2018b).

Two key reasons for the declining cheetah population are human-wildlife conflict outside of protected areas, and their position as subordinate predators to lion (*Panthera leo*), spotted hyaena (*Crocuta crocuta*), and leopard (*Panthera pardus*) when living inside protected areas. Cheetahs require larger home ranges compared to other predators; male home ranges in Namibia have been recorded as large as 1,595 km^2 (±1,151 km^2) (Melzheimer *et al.* 2018). Weise *et al.* (2015) found during long-term monitoring of translocated cheetahs that less than 5% of public or private protected areas in Namibia were large enough to keep cheetahs from leaving the protected boundaries. Because of this, more than 80% of cheetahs in Namibia live outside of protected areas on farmlands and communal conservancies where they can roam freely over vast areas with fewer people and fewer predators to compete with for resources (Durant *et al.* 2017, Marker *et al.* 2018a).

Free-roaming cheetahs can cause human-wildlife conflict among both game and livestock farmers. Domestic livestock and game farming support 70% of the Namibian population (Powell *et al.* 2017). Human-caused cheetah mortality from retaliatory and preventative killing due to real and perceived livestock and game losses is responsible for the most deaths (Lindsey *et al.* 2013). Although they are protected, the Namibian government allows cheetahs to be killed or captured if people or livestock are in immediate danger (Marker *et al.* 2018b). The responsibility of reporting carnivore killings is on the farmer, but many do not report fatalities. Therefore, the true number of cheetah losses per year is unknown (Marker *et al.* 2018b).

Translocation and lethal removal of adult 'problem' cheetahs to mitigate human-cheetah conflict are common practices on farmland in Namibia (Weise *et al.* 2015). However, a recent study in Botswana estimated only 18% of translocated cheetahs survived one year after translocation (Boast *et al.* 2016). Furthermore, 63.6% of farmers who moved cheetahs off their land did not perceive a decrease in predation (Boast *et al.* 2016). In spite of poor long-term results, either translocation or bringing cheetahs into permanent captivity are often the only options to avoid lethal control (Revised National Policy on Human Wildlife Conflict Management 2018). However, the goal of cheetah conservation is to keep their populations viable in the wild, not captivity. Hauser *et al.* (2011) conducted extended post-release monitoring of captive-raised cheetahs in a fenced reserve in Botswana, and found cheetahs developed the skills to sustain themselves in the wild, but all of the cheetahs in the study were killed by humans within days of leaving the fenced reserve (Hauser *et al.* 2011). Less than 5% of the wild cheetah population lives in protected areas, further supporting the theory that the best chance for long-term cheetah survival is enabling them to range freely on farmlands (Durant *et al.* 2017).

Finding safe areas where conflict-translocated cheetahs can be released is increasingly difficult. Furthermore, when dependent juveniles accompany their captured mothers into box traps or stay within the vicinity of a trapped mother, they are often surrendered alive to non-government organisations (NGOs). These juvenile animals, unable to survive independently in the wild, are usually captive-raised, which poses the dilemma of where to place these animals once they become adults. The AfriCat Foundation, based on the Okonjima Nature Reserve (ONR), north-central Namibia, chose to release captive-raised cheetahs into the ONR where constant post-release monitoring could be conducted to monitor the success of such individuals. The ONR is equipped with a predator-proof electric fence perimeter, which prevents the cheetahs from moving into surrounding farmlands and potentially causing further human-wildlife conflict. Whilst adult captive-raised cheetahs demonstrated the ability to hunt independently, the high density of leopards within the ONR was found to be a major source of cheetah mortality, with interspecific encounters accounting for 71% of all known causes of death. In a 2015-2016 density survey, Noack *et al.* (2019) estimated 14.51 adult leopards per 100 km^2 in ONR, compared to 3.60 per 100 km^2 in the commercial farmlands bordering the Waterberg Plateau Park, which is approximately a 100 km straight line distance from the study site (Stein *et al.* 2011). In 2019, the decision was made to bring the cheetahs back into captivity and stop future releases into the ONR.

There is a substantial body of literature exploring several aspects of prey selection among wild cheetahs, including wild-caught and translocated cheetahs, but minimal research about different demographics of rehabilitated, captive-raised and released cheetahs (Hauser *et al.* 2011). The few released-cheetah studies looked at the species as a whole, and suggest they exhibit similar hunting, killing, and feeding behaviour to wild cheetahs (Hauser *et al.* 2011). However, studies have shown captive-raised cheetahs have a lower survival rate than wild-caught cheetahs once released into the wild (Jule *et al.* 2008). Released cheetahs are often housed with other cheetahs and form different coalitions in captivity than those found in the wild. Coalitions with both males and females, and unrelated individuals are common, compared to the wild where most coalitions are all male, and females are solitary unless they are raising cubs (Hilborn *et al.* 2018).

We analysed existing data from an aerial population density and census survey of ONR, as well as sightings of cheetah kills on ONR. We aimed to discern if the prey selection of released cheetah groups reflected the findings for free-ranging cheetahs, and the role cheetah groupings, sexual dimorphism, prey diversity, size, and abundance play in prey choices. Our findings could guide future research into increasing the success rate of released cheetahs on both farmlands and in fenced reserves.

METHODS

Study Site

This study was conducted in the Okonjima Nature Reserve (ONR), a 200 km^2, privately-owned, fully fenced reserve which lies approximately 50 km south of Otjiwarongo, north-central Namibia. The ONR perimeter fence traces a central plateau, at an average altitude of 1,600 metres, surrounded by the Omboroko Mountains. The electrified perimeter was erected in 2010 and is largely impenetrable to wildlife. Two tourism lodges, staff housing and offices are situated in the south-east section of the reserve, and the 20 km^2 surrounding these buildings is also enclosed with an electric wildlife proof fence, resulting in a total of 180 km^2 of the ONR in which a variety of wildlife, including leopards, spotted and brown hyaenas (*Parahyaena brunnea*), and cheetahs reside. The reserve receives an average annual rainfall of 450 mm, which falls during the hot, wet season from October to March. The vegetation is predominantly tree and scrub savannah, interspersed with silver Terminalia (*Terminalia sericea*) and several Acacia species. Perennial water is provided from 18 artificial waterholes across the reserve.

ONR is home of the AfriCat Foundation. Founded in 1991, the core mission of AfriCat is to conserve Namibia's large carnivores in their natural habitat (AfriCat 2018). It has been rehabilitating and releasing captive-raised cheetahs into its 200 km² private wildlife reserve for 18 years, and since 2000, a total of 53 cheetahs have been released into the ONR (AfriCat 2018). Released individuals were fitted with very high frequency (VHF) collars to enable post-release monitoring to be conducted, with individuals being located on a daily basis. When an individual was located and visually sighted, its location, behaviour and any kills were recorded.

Data collection

Cheetah kill data used for this study were collected from August 2017 to November 2018, and were recorded by the AfriCat research team and guides during early morning and late afternoon tourist game drives. There were less data recorded during the rainy season (October-March) due to the low season for tourism and fewer game drives. An aerial survey was conducted in August 2018 to estimate game counts and densities of larger herbivores. There are no population estimates for smaller potential prey species such as duiker (*Sylvicapra grimmia*), Damara dik dik (*Madoqua kirkii*), scrub hare (*Lepus saxatilis*), warthog (*Phacochoerus africanus*), bat-eared fox (*Otocyon megalotis*), and aardwolf (*Proteles cristata*), all of which require a ground survey for accurate counts.

Table 1: *A key of the cheetah social groupings observed in Okonjima during the study period, Aug 2017-Dec 2018.*

Name	Sex	Notes
Coalition A		Two male siblings
1M	M	
2M	M	
Coalition B		Two males & one female sibling
3.0F*	F	*In coalition Sept-Nov 2017
4M	M	
5M	M	
Solitary Cheetah		
3.1F**	F	** Alone May-Sept 2017; Nov 2017-Sept 2018
6M	M	
7F	F	

Data were collected from seven released cheetahs, including two sibling coalitions and three solo cheetahs (Table 1). Coalition A was comprised of two brothers (1M and 2M). Coalition B consisted of two brothers (4M and 5M) and one sister (3.0F), who were brought to AfriCat when they were less than three months old. They had difficulty hunting after their first release in 2012, and were brought back into captivity to serve as ambassador cheetahs. Five years later, they were released again, and lived in the reserve until each of them died of old age. The female (3.0F), became solitary (3.1F) after the death of her brothers, and was a successful hunter until she died in September 2018. Two of the solo cheetahs are female (3.1F and 7F), and one is male (6M). All rehabilitated cheetah required supplemental feeding immediately after release until they began hunting. Supplemental feeding periods ranged between one week and seven months. Data considered here reflect the times when cheetah were successfully hunting on a regular basis.

Due to the low sample size (65 total kills) and to enable comparisons of results with published literature, we grouped the prey species into small (<15 kg), medium (15-46 kg), and large (>47 kg) categories (Table 2). Juveniles and adults of the same species were treated separately because of the

Table 2: *Size classifications of observed prey species. Weight categories devised from Hayward et al. (2006b). Juvenile weight calculated as 70% of adult weight.*

Small (<14 kg)	**Medium (15-46 kg)**	**Large (>47 kg)**
Aardwolf *Proteles cristata*	Duiker *Sylvicapra grimmia*	Eland (J) *Taurotragus oryx*
Bat-eared fox *Otocyon megalotis*	Impala (J) *Aepyceros melampus*	Gemsbok (J) *Oryx gazella*
Dik dik *Madoqua kirkii*	Impala	Kudu (J) *Tragelaphus strepsiceros*
Scrub hare *Lepus saxatilis*	Springbok (J) *Antidorcas marsupialis*	Red hartebeest *Alcelaphus buselaphus caama*
Steenbok *Raphicerus campestris*	Warthog (J) *Phacochoerus africanus*	Mountain zebra* (J) *Equus zebra*
	Warthog	Plains zebra* (J) *Equus quagga*

J = juvenile
** Both zebra species are present in the study area and have been combined for analysis*

Table 3: *Observed kill data for Okonjima cheetah, Aug. 2017-Dec. 2018.*

		Coalitions		**Solo Cheetah**		
Observed Prey Species	**Total Kills**	**A (MM)**	**B (MMF)**	**3.1F**	**6M**	**7F**
Aardwolf	1		1			
Bat-eared fox	3		1		1	1
Duiker	8	1	2	3		2
Dik dik	4			3	1	
Eland (juvenile)	1	1				
Gemsbok (juvenile)	2		2			
Impala (juvenile)	4	2	1	1		
Impala	6	3				3
Kudu (juvenile)	6	2	2	1	1	
Red hartebeest	1	1				
Scrub hare	5			1		4
Springbok (juvenile)	3	2				1
Steenbok	9	2	1	3	1	2
Warthog (juvenile)	5	2	1		2	
Warthog	1				1	
Zebra (juvenile)	6				6	
Unidentified	5*	2*	1*	1*	1*	
Total Observed Kills	**70*/65**	**16**	**11**	**12**	**13**	**13**

**Unidentified kills were not included in analysis.*

significant weight differences between the developmental stages.

We compared the prey species taken by each cheetah grouping. However, due to the small samples, statistics were not used on the data.

RESULTS AND DISCUSSION

During the data collection period, a total of 70 kills comprised of 14 different species were recorded. The species could not be identified for five of the kills, and those were removed from data analysis. The raw data (Table 3) shows, when combining all cheetah kills, steenbok was preyed upon the most (14%), followed by duiker (12%), and impala, juvenile kudu, and juvenile zebra, all at 9%. The solitary male (6M) showed a selection for juvenile zebra, comprising 46% of his kills. Solitary female 7F selected scrub hare 31% of the time.

Medium-sized prey made up the largest percentage of all cheetah kills (42%), and 63% of the male coalition kills (Figure 1). The solitary male took the highest proportion of large prey (54%), and the solitary females took the highest percentage of small prey (56%).

ONR's solitary male cheetah's 54% proportion of large kills is a result of his selection for juvenile zebra. This data is unusual because previously, male coalitions have been documented killing the largest prey of all cheetah groupings (Clements *et al*. 2014, Tambling *et al*. 2014, Rostro-Garcia *et al*. 2015, Mills & Mills 2017). In their comprehensive study of cheetahs in the southern Kalahari Desert of Botswana, Mills and Mills (2017) suggest that solo males have a similar diet to solo females, favouring small and medium sized prey. They also hypothesise that individual cheetahs can have long-term prey species preferences that are not significantly correlated to other widely accepted factors such as size and abundance. The rank of cheetah groupings choosing large prey (Figure 1) is most likely skewed by the number of juvenile zebra taken by the solo male. Since we were only tracking one solo male, it is difficult to conclude if this male truly favours larger prey.

Solo female cheetahs (n=2) consumed 77% of the small prey recorded. Similar to the solo male who frequently hunted juvenile zebra, solitary female 3.1F most frequently hunted scrub hare. But considering small prey comprised 56% of the solo females' diet, the species selection does not contradict previous findings. Radloff and Du Toit (2004) noted that smaller prey is often underestimated because it is eaten quickly and there are no remains. Furthermore, Mills and Mills (2017) note that scrub hares are nocturnal, and are most often hunted at night, making remains and direct observations less likely. This could indicate the percentage of small prey eaten is not accurately represented across all cheetah groupings. Mills and Mills (2017) utilised scat in addition to observations to develop a more accurate record of cheetah diet, and determined solo male cheetahs relied on small prey for 50% of their nutritional needs. Without population estimates for scrub hares, it is not possible to know if the potential preference is due to abundance or size preference.

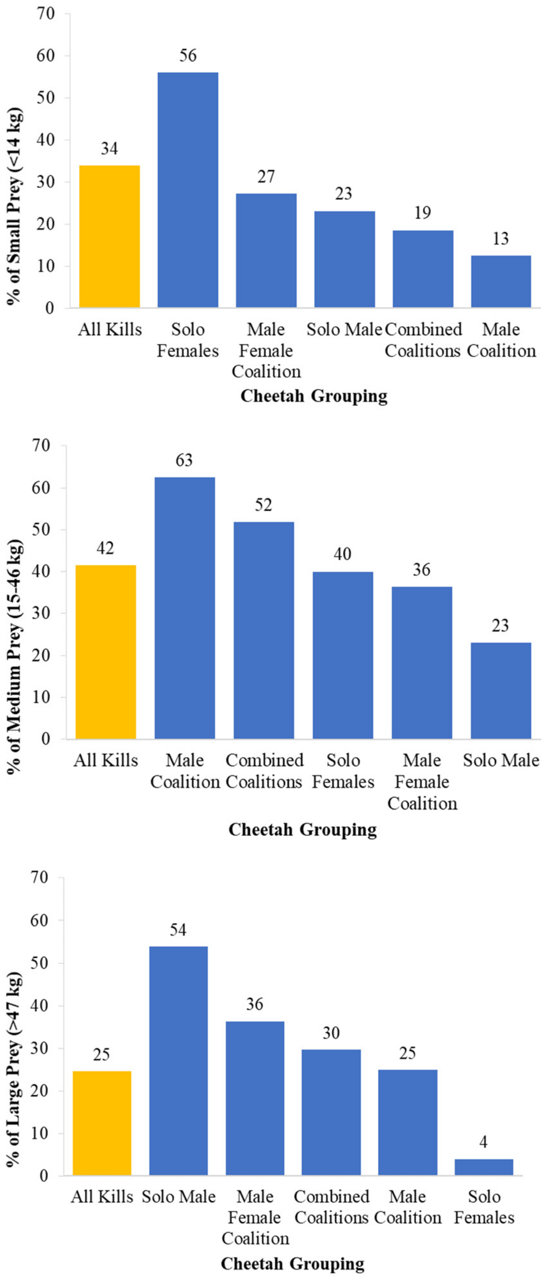

***Figure 1:** Percentage of all observed cheetah kills in each prey size classification compared to each cheetah grouping*

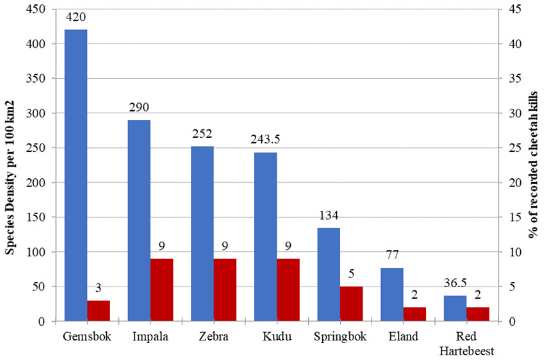

***Figure 2:** Percentage of recorded cheetah kills per species (red) compared to species density on Okonjima Nature Reserve (blue).*

The lower energy expenditure and risk level of hunting small prey may also be a factor.

Bissett and Bernard (2006) studied the habitat and feeding ecology of different released cheetah groups in the Eastern Cape Province, South Africa, and their data showed the male coalition consumed larger prey (specifically kudu) 55% of the time, compared to medium-sized prey (7%). They hypothesise it was not only because kudu was the most abundant species, but because of cooperative hunting and the increased nutritional needs to sustain a male coalition. Rostro-Garcia *et al* (2015) recorded similar results in their reintroduced cheetah study in Phinda Reserve, South Africa. The male coalition in ONR clearly selected medium-sized prey (Figure 1), and did not support either Bissett and Bernard's (2006) or Rostro-Garcia *et al*'s (2015) results. However, data was based on one male coalition in each study, and requires further study with a larger sample size of cheetah social groups to draw firm conclusions.

Our data show prey abundance and size influenced prey choices of released cheetahs more than species, as has been recorded in free ranging cheetahs, which most often choose medium-sized prey weighing between 15-46 kilograms (Marker *et al*. 2003, Hayward *et al*. 2006b, Clements *et al*. 2014, Clements *et al*. 2016, Broekhuis *et al*. 2017). Medium-sized prey is easier to catch with lower risk of injury, and it can be eaten quickly, enabling cheetahs to maximise their nutritional intake before other predators can steal it (Radloff & Du Toit 2004).

We compared species proportions of all cheetah kills to the available species densities in ONR to determine if prey selection mirrored species abundance as is suggested by Hayward *et al*. (2006b). With the exception of gemsbok, which has the highest density of any species recorded in ONR, species density and observed cheetah kills exhibited a similar pattern (Figure 2). Mills and Mills (2017) hypothesise gemsbok pose too much of an injury risk for cheetahs to hunt frequently because the adults have large horns, and the juveniles are closely protected by the adults. They found that coalition males were the only group that hunted gemsbok, and only smaller juveniles.

Okonjima has a high density of kudu (243.5/100 km²), zebra (252/100 km²), and gemsbok (420/100 km²), which are often too large for solo cheetah prey, and could explain the 22% of juvenile kudu, juvenile zebra, and juvenile gemsbok kills reported in the ONR data (Figure 2). The literature indicates cheetahs most often hunt juveniles and subadults of large prey species rather than adults (Rostro-Garcia *et al*. 2015, Mills & Mills 2017). Mills and Mills (2017) disagree with Hayward *et al*.'s (2006b) assessment that abundance is the primary factor in

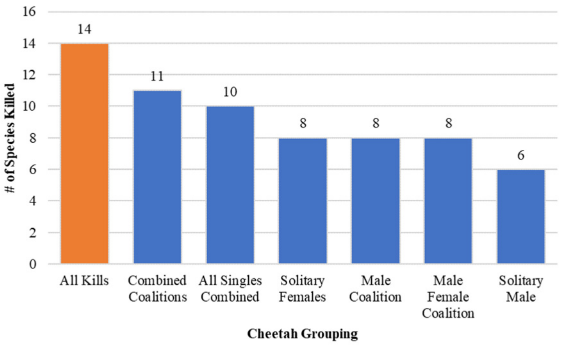

Figure 3: *Number of different species killed by each cheetah grouping compared to all species kills.*

cheetah prey selection. Their findings conclude that habitat selection, individual specialisation, opportunity, and demographic group are also important factors in prey choice.

Comparing the number of prey species used by each cheetah grouping, the results indicated virtually no difference in prey diversity between coalitions, solo cheetahs, or gender (Figure 3). The overall number of species for each grouping is very similar, and the higher diversity numbers occur when combining groupings. This validates the earlier indications that abundance and size are important factors in prey selection. However, the difference in which species were selected in each cheetah grouping suggests cheetahs could develop individual species preferences. For example, the solo male had the lowest diversity (n=6), but made the same number of overall kills as other groupings (n=13), because 46% of his kills were juvenile zebras. This corresponds with other studies that argue prey species diversity is based on the largest species a predator can kill (Clements *et al*. 2014, Radloff & Du Toit 2004). They theorise just because a predator can kill larger prey does not mean it stops hunting smaller prey as well. The coalitions have a species breadth advantage because they are able to kill a larger variety of species due to cooperative hunting (Clements *et al*. 2014). Leopards have a similar broad range, giving them the highest prey overlap with cheetahs (Hayward *et al*. 2006a). This potential competition for resources could be a contributing factor in the high number of cheetah mortalities caused by leopards in ONR.

Male cheetahs are generally 25% heavier than females, raising the question if weight difference between the sexes is a significant factor in prey selection, as is widely recorded (Marker *et al*. 2003, Radloff & Du Toit 2004, Bissett & Bernard 2006, Tambling *et al*. 2014, Clements *et al*. 2016). We compared the body weights of the males (n=5) to the body weights of the females (n=2) used in the study by performing an unpaired t-test to assess the significance of sexual dimorphism, and found no significance (t=2.09, df=5.43, p=0.08). It would be interesting to explore if this is a difference between captive-raised and wild cheetahs, but due to our small sample size, further testing is necessary.

Whilst we could not conclude that sexual dimorphism significantly impacted prey selection on ONR, demographic grouping and sex did play a role. Even though male coalitions have been well documented as the cheetah grouping taking the largest prey, it does not hold true for solo males (Clements *et al*. 2014, Tambling *et al*. 2014, Rostro-Garcia *et al*. 2015, Mills & Mills 2017). This suggests the larger body size of males does not provide a hunting advantage over females, and cooperative hunting is a bigger factor in large prey selection. Mills and Mills (2017) noted that male coalitions displayed a different diet profile than solo males, solo females, and sibling coalitions, which were all similar. In fact, the solo males in Mills and Mills (2017) consumed the highest percentage of small prey across cheetah groupings.

CONCLUSION

Whilst cheetahs continue to be trapped and shot on farmlands, the challenge of finding suitable locations to place the offspring of lethally removed individuals will persist. A key factor in determining suitable release sites will be identifying the prey base required by captive-raised individuals to survive. Here, we show captive-raised cheetahs are able to hunt successfully, and that their prey selection mirrors that of wild counterparts. Furthermore, the data suggested whilst there are species selection differences among the individual groupings, when combining all cheetah groupings, the overall prey diversity is very similar. This indicates cheetahs may be more flexible in their diet, allowing them to be successful across a range of habitats, regardless of grouping. Although the high leopard density on ONR ultimately caused the deaths of the majority of captive-raised cheetahs, our results show the ability of captive-raised cheetahs to adapt and hunt a diversity of prey species independently, suggesting such individuals may do well in areas with reduced competitor pressure.

ACKNOWLEDGEMENTS

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Anatomical comparison between skulls and mandibles of Hartmann's zebra *Equus zebra hartmannae* and Burchell's zebra *E. burchellii antiquorum* in Namibia

HH Berry†

† Deceased: 25 July 2011

ABSTRACT

External anatomical features of skulls and mandibles of ten Hartmann's zebras and ten Burchell's zebras in Namibia are described. Out of 44 structural features examined, 13 differ significantly (p=0.001) to the extent that they can be used to unambiguously identify the two species from intact skulls and mandibles. These differences are found in the *foramen magnum*, *processus zygomaticus*, *crista pterygoidea*, *meatus acusticus externus*, *processus mastoideus*, *crista facialis*, *sutura frontonasalis*, *os frontale*, *foramina supraorbitale*, *crista sagittalis externa*, *processus palatini*, *processus retroarticularis* and interalveolar border of the mandible. Using a combination of some or all of these differences enables an observer to identify the skulls of these two species of zebra with relative ease.

Keywords: anatomy; *Equus burchellii antiquorum; Equus zebra hartmannae*; mandible; Namibia; skull; zebra

INTRODUCTION

In Namibia, Hartmann's or mountain zebra *Equus zebra hartmannae* Matschie, 1898 (hereafter ***Ez***) and Burchell's or plains zebra *E. burchellii antiquorum* H. Smith, 1841 (hereafter ***Eb***) intermingle in western Etosha National Park and increasingly so on freehold game farms where introduction of especially ***Eb*** takes place. Following mortalities, carcases are often rapidly reduced to skeletons by scavengers, making identification of which zebra species is involved difficult. Moreover, poaching of these zebra species has legal consequences in which defence lawyers for the accused argue that the State cannot prove whether the skull or mandible of a court exhibit is ***Ez*** or ***Eb***. Consequently, the purpose of my investigation was to examine and quantify differences that may occur in the skulls and mandibles of these species. I based my work on a similar study involving Cape mountain zebra *E. zebra zebra* Linnaeus, 1758 and *E. burchellii antiquorum* by Smuts & Penzhorn (1988).

METHODS AND METHODS

Taxonomy of the two zebra sub-species follows Meester *et al*. (1986). Ten skulls and mandibles (five males, five females) of ***Ez*** were obtained from the Namib-Naukluft Park where zebra were culled as part of management action. Similarly, ten skulls and mandibles of ***Eb*** were obtained from the Etosha Ecological Institute where specimens from natural mortalities in the Etosha National Park are stored. I estimated the age of the specimens, based on tooth development and attrition of ***Ez*** by Joubert (1972) and of ***Eb*** by Smuts (1974). I identified the skull and mandible structures according to an accepted international veterinary anatomical nomenclature (Anonymous 1983), following the procedure and illustrations used by Smuts & Penzhorn (1988). Using a vernier calliper, I measured to the nearest millimetre, the skulls of ***Ez*** from the caudal, lateral, dorsal and basal aspects, to serve as a basis for comparison. Its mandibles are described as a whole. I then compared measurements and morphological aspects of the skulls and mandibles of ***Eb*** to those of ***Ez***. All measurements were analysed, using a statistical package, to establish means, standard deviation (SD), and standard errors of the mean (SE). Using the t-test's paired two sample for means, I tested for significant differences at a probability level of 0.001. Furthermore, if an overlap in the range of any comparative measurements occurred where the means were significantly different, I discarded them as a distinguishing feature between the species. I use the illustrations published by Smuts & Penzhorn (1988) to illustrate the comparison between ***Ez*** and ***Eb***, annotating them with the differences observed in this study. The figures are therefore based on the South African and not the Namibian specimens.

RESULTS

The only marked sexual dimorphism in the skulls and mandibles of ***Ez*** and ***Eb*** are the well-developed canines in males, whilst the females exhibit vestigial canines. Small wolf teeth (*dens premolaris* 1) occurred uni- or bilaterally in three female ***Ez*** and none were observed in ***Eb***. The age classes of the specimens examined were: ***Ez*** 3 years (1 female), 5-6 years (3 males), 7-9 years (1 male), 9-11 years (1 male, 3 females), 11-13 years (1 female) and ***Eb*** 5-6 years (2 males, 3 females), 7-9 years (1 male, 1 female), 9-11 years (2 males, 1 female). The 3 year old specimen of ***Ez*** was sub-adult (permanent molar

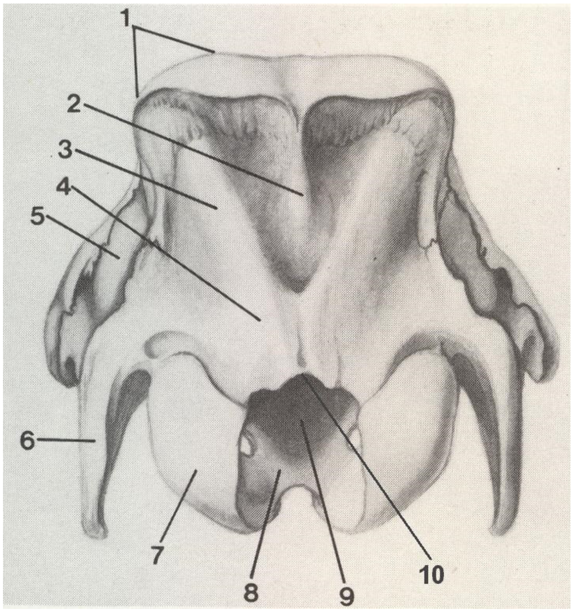

***Figure 1:** Skull of* Equus zebra*, caudal aspect, giving the structural components. 1.* Crista nuchae*; 2.* Protuberantia occipitalis externa*; 3. 'Column' in* squama occipitalis*; 4.* Pars lateralis *of occipital bone; 5.* Processus mastoideus *of temporal bone; 6.* Processus paracondylaris*; 7.* Condylus occipitalis*; 8.* Pars basalis *of occipital bone; 9.* Foramen magnum *has median notch (10) in dorsal border. (Source: Smuts & Penzhorn 1988).*

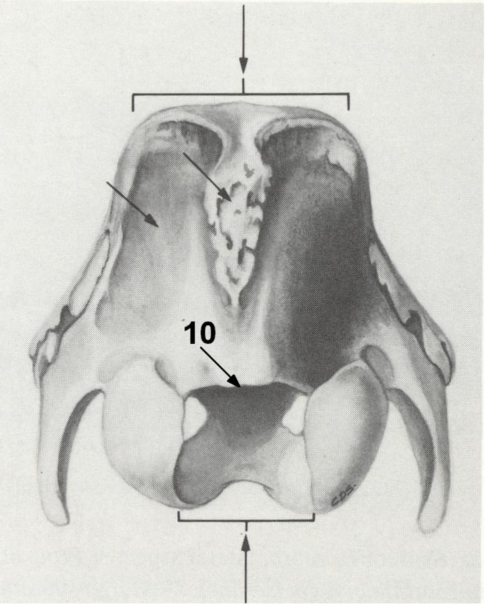

***Figure 2:** Skull of* Equus burchellii*, caudal aspect. Unnumbered arrows are differences identified by Smuts & Penzhorn (1988). Numbered arrows are significant differences between **Eb** and **Ez** found in the present study: 10. Dorsal border of* foramen magnum *unnotched in **Eb**.*

3 erupting); the remaining specimens were all adult with permanent dentition.

When presenting the figures, I use the skull of ***Ez*** as a basis for naming the complete anatomical structure of the caudal, lateral, dorsal and ventral aspects, as provided by Smuts & Penzhorn (1988). I then compare these aspects with the skull of ***Eb***, indicating with arrowed numerals the significant differences that correspond with the structures in ***Ez***. Numbers preceding each anatomical feature in the lists below relate to the number that indicates this feature in the figure.

Caudal (nuchal) aspect (Figures 1 and 2)

10. *Foramen magnum*: The only visible difference is the morphology of the *foramen magnum*. It has a square shape in ***Ez***, with an orifice mean of 29 mm in the vertical and horizontal planes (range 26-31 mm). In ***Eb*** it is rectangular, with a mean of 30 mm (range 28-33 mm) in the vertical and 32 mm (range 30-34 mm) in the horizontal planes. There is overlap in the range of both the vertical and horizontal planes of 15 out of 20 specimens however, and consequently these measurements are not reliable parameters with which to distinguish the two species. The most consistent difference observed is the dorsal border of the *foramen magnum*, which has a distinct median notch in ***Ez***. In ***Eb*** this border forms a more or less straight line.

Lateral aspect (Figures 3 and 4)

7. *Aditus orbitae*: The osseous rims of the orbits in ***Ez*** are significantly less rostrocaudally (mean 54 mm, range 51-58 mm) than in ***Eb*** (mean 61 mm, range 57-70 mm). There is an overlap in three of the 40 orbital measurements however, meaning that there is the possibility of ambiguity in this parameter. It is therefore discarded as a distinguishing characteristic. The dorsoventral orbital measurements in ***Ez*** and ***Eb*** are 54 mm (range 48-57 mm) and 56 mm (range 52-69 mm) respectively. This is statistically not significant, with 24 out of 40 range overlaps, and therefore not a distinguishing feature.

8. *Processus zygomaticus*: The zygomatic processes of both frontal bones are significantly broader in ***Ez*** (mean 29 mm, range 26-33 mm) than in ***Eb*** (mean 20 mm, range 14-24 mm). This is a distinguishing feature. Moreover, in ***Ez*** the dorsal edge of the zygomatic arch is directed horizontally at a point caudal to the orbit. In ***Eb*** its direction is dorsocaudal.

9. *Crista pterygoidea*: In ***Ez*** the pterygoid crest has a pronounced triangular shape, whereas in ***Eb*** it is neither triangular nor prominent. This is considered a feature that distinguishes the species.

14. *Processus mastoideus*: The elongated mastoid process of the left and right temporal bones exhibit significant differences, with means of 53 mm (range

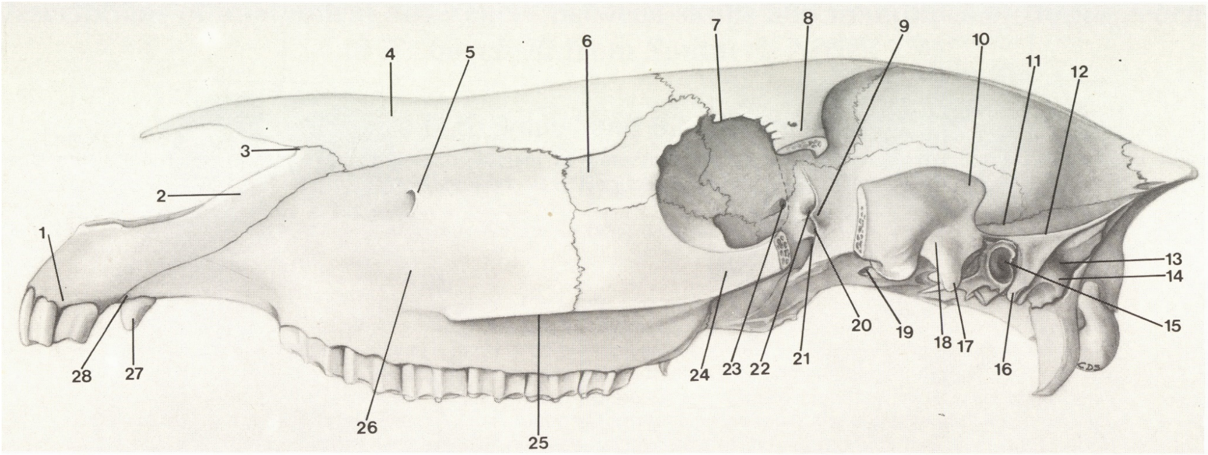

Figure 3 (top): *Skull of* Equus zebra*, lateral aspect, giving the structural components. 1.* Processus alveolaris *of* Os incisivum*; 2.* Processus nasalis*; 3.* Incisura nasoincisiva*; 4.* Os nasale*; 5.* Foramen infraorbitale*; 6.* Os lacrimale*; 7.* Margo supraorbitalis*; 8.* Processus zygomaticus *of frontal bone; 9.* Crista pterygoidea*; 10. Caudal end of* arcus zygomaticus*; 11.* Fossa temporalis*; 12.* Crista temporalis*; 13. Groove for caudal meningeal artery; 14.* Processus mastoideus*; 15.* Meatus acusticus externus*; 16.* Processus retrotympanicus*; 17.* Processus retroarticularis*; 18.* Fossa mandibularis*; 19.* Foramen alare caudale*; 20.* Fissura orbitalis*; 21.* Foramen rotundum*; 22.* Canalis opticus*; 23.* Foramen ethmoidale*; 24.* Processus temporalis *of zygomatic bone; 25.* Crista facialis*; 26.* Maxilla*; 27. Canine tooth; 28. Sutura maxilloincisiva. (Source: Smuts & Penzhorn 1988).*

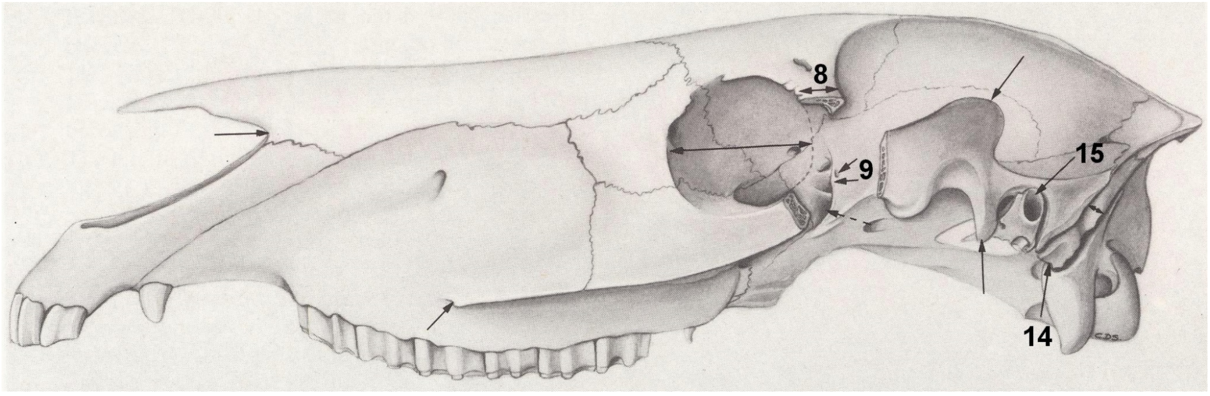

Figure 4 (bottom): *Skull of* Equus burchellii*, lateral aspect. Unnumbered arrows are differences identified by Smuts & Penzhorn (1988). Numbered arrows are significant differences between* **Eb** *and* **Ez** *found in the present study. In* **Eb***: 8.* Processus zygomaticus *is narrower; 9.* Crista pterygoidea *is not triangulated or prominent; 14.* Processus mastoideus *is shorter; 15.* Meatus acusticus externus *points dorsolaterally at 45°.*

47-59 mm) in ***Ez*** and 19 mm (range 15-22 mm) in ***Eb***. No overlap in the ranges occurs; consequently, this is a distinguishing parameter in the species' skulls.

15. *Meatus acusticus externus*: In all specimens of ***Ez*** the external acoustic meatus is placed horizontally and faces laterally. In ***Eb*** it points dorsolaterally at an angle of about 45° in all specimens. This is a distinguishing feature.

17. *Processus retroarticularis*: Although the retroarticular process is, on average, significantly longer in ***Ez*** (mean 26 mm, range 21-30 mm) than in ***Eb*** (mean 19 mm, range 17-27 mm), 19 of the 40 measurements overlapped in their range. It is therefore not a reliably distinguishable feature.

19. *Foramen alare caudale*: Although the lengths of both left and right alar canals were significantly different for ***Ez*** (mean 24 mm, range 20-28 mm) and ***Eb*** (mean 20 mm, range 17-25 mm), 19 out of 40 measurements overlapped in their range. It is thus not a distinguishing feature.

Dorsal aspect (Figures 5 and 6)

2. *Crista nuchae*: The width of the nuchal crest in ***Ez*** is significantly greater (mean 71 mm, range 64-77 mm) than in ***Eb*** (mean 63 mm, range 57-70 mm). The overlap in eight of the 20 measurements makes it necessary to disregard this feature for identification purposes.

4. *Crista sagittalis externa*: The length of the external sagittal crest is significantly shorter (mean 81 mm, range 72-88 mm) in ***Ez*** than in ***Eb*** (mean 102 mm,

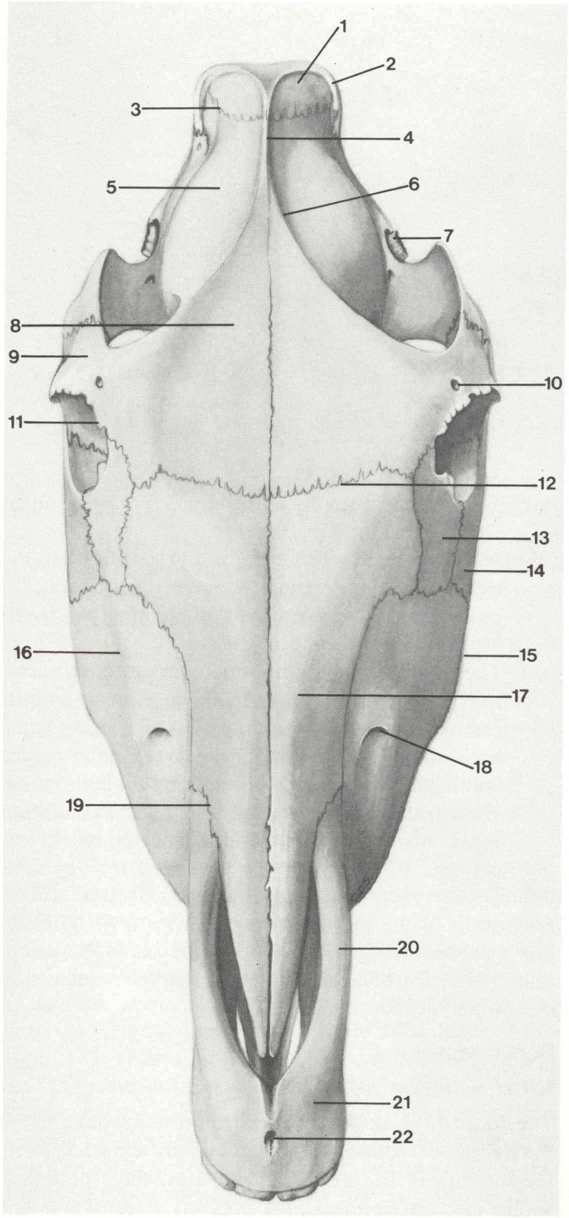

Figure 5: *Skull of* Equus zebra*, dorsal aspect, giving the structural components. 1.* Squama occipitalis*; 2.* Crista nuchae*; 3.* Sutura squamosoparietales*; 4.* Crista sagittalis externa*; 5.* Os parietale*; 6.* Linea temporalis*; 7.* Meatus acusticus externus*; 8.* Os frontale*; 9.* Processus zygomaticus *of frontal bone; 10.* Foramen supraorbitale*; 11.* Margo supraorbitalis*; 12.* Sutura frontonasalis*; 13.* Os Iacrimale*; 14.* Os zygomaticum*; 15.* Crista facialis*; 16.* Maxilla*; 17.* Os nasale*; 18.* Foramen infraorbitale*; 19.* Sutura nasoincisiva*; 20.* Processus nasalis ossis incisivi*; 21.* Corpus ossis incisivi*; 22.* Canalis interincisivus*. (Source: Smuts & Penzhorn 1988).*

range 92-112 mm), with no overlap. This feature distinguishes the two species.

8. *Os frontale*: In ***Ez*** the mean width of the frontal bones is 152 mm (range 142-165 mm). In ***Eb*** it is 130 mm (range 125-136 mm). This difference is significant, with no overlap between the ranges. It is a feature that distinguishes the species.

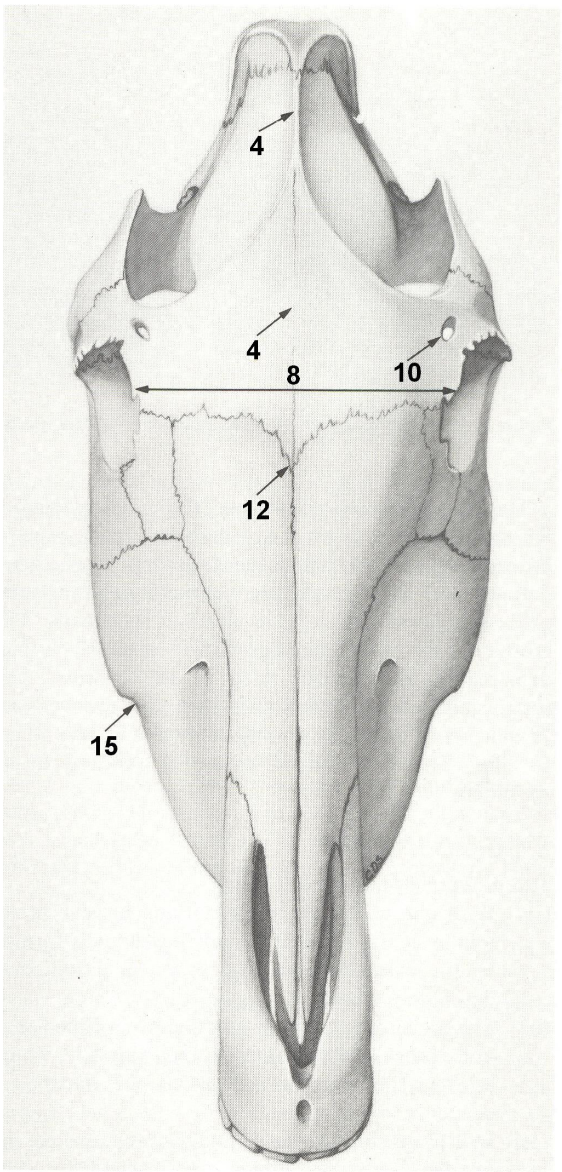

Figure 6: *Skull of* Equus burchellii*, dorsal aspect. Numbered arrows are differences between* **Eb** *and* **Ez** *identified by Smuts & Penzhorn (1988) and found to be significantly different in the present study. In* **Eb***: 4.* Crista sagittalis externa *is longer; 8.* Os frontale *is narrower; 10. The major* foramen supraorbitale *diameters are twice as large; 12.* Sutura frontonasalis *has a rostrally directed median angle; 15.* Crista facialis *is notched rostrally.*

9. *Processus zygomaticus*: In ***Ez*** the outside width of the paired zygomatic processes of the lateral frontal bones, measured across the skull, is significantly greater (mean 188 mm, range 180-192 mm) than in ***Eb*** (mean 172 mm, range 166-180 mm). There is an overlap in one out of 20 measurements, thereby invalidating this as a distinguishing parameter.

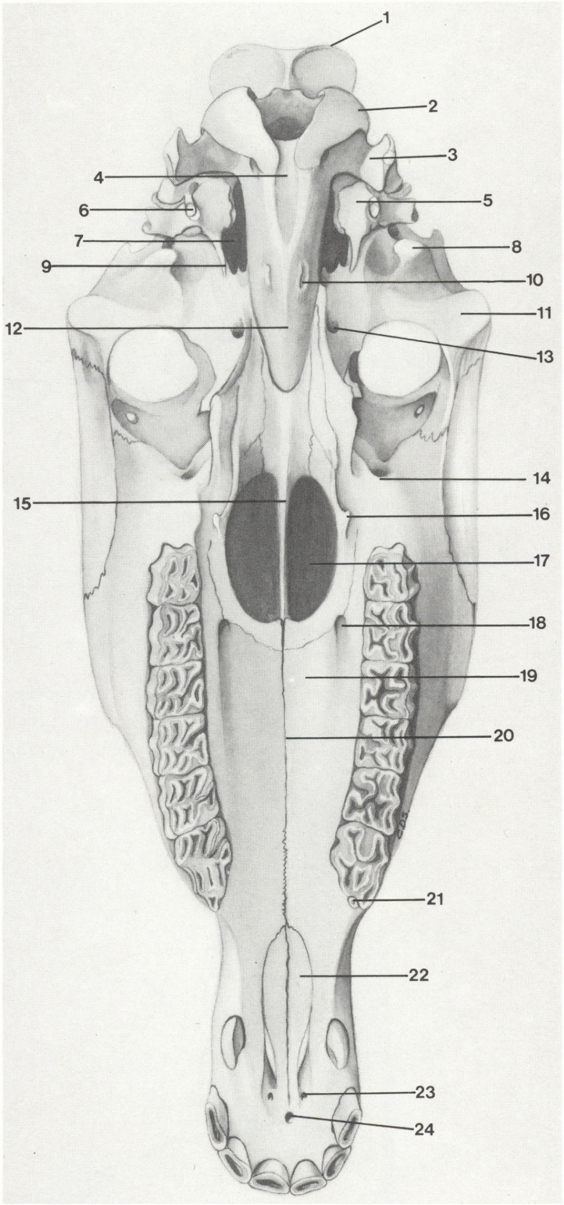

Figure 7: *Skull of* Equus zebra*, basal (ventral) aspect, giving the structural components. 1.* Crista nuchae*; 2.* Condylus occipitalis*; 3.* Fossa condylaris ventralis*; 4.* Pars basilaris *of occipital bone; 5.* Bulla tympanica*; 6.* Processus styloideus*; 7.* Foramen lacerum*; 8.* Processus retroarticularis*; 9.* Processus muscularis*; 10.* Tuberculum musculare*; 11. Articular surface of* fossa mandibularis*; 12.* Os basisphenoidale*; 13.* Foramen alare caudale*; 14.* Tuber maxillae*; 15.* Vomer*; 16.* Hamulus *of pterygoid bone; 17.* Choana*; 18.* Sulcus palatinus*; 19.* Processus palatinus *of maxilla; 20.* Sutura palatina mediana*; 21. Wolf tooth (PM 1); 22.* Processus palatinus *of incisive bone; 23. Opening of incisive canal; 24.* Canalis interincisivus*. (Source: Smuts & Penzhorn 1988)*

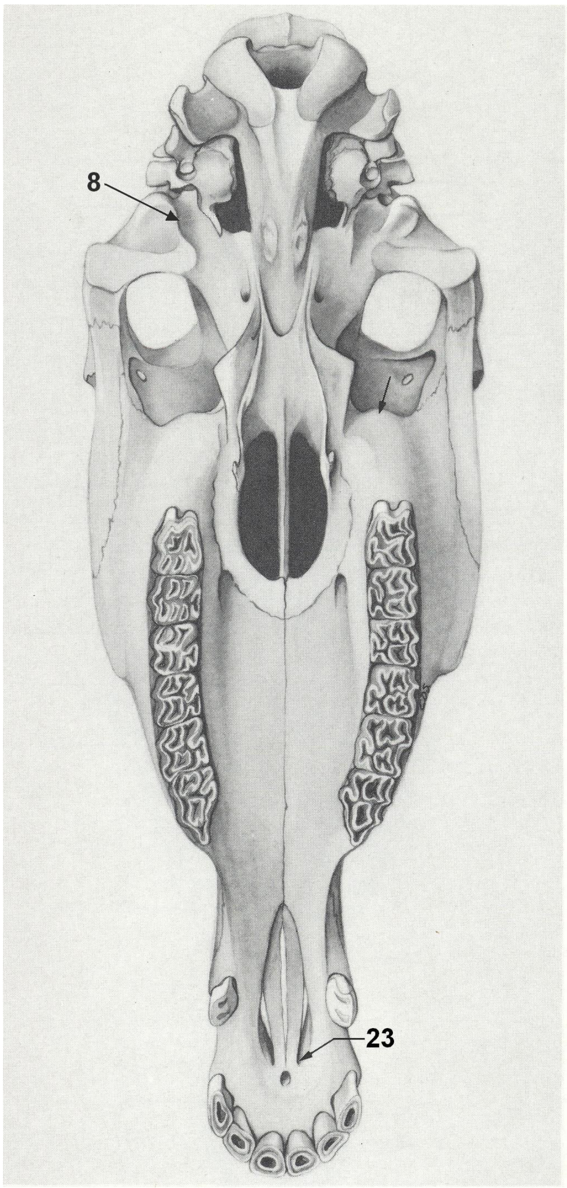

Figure 8: *Skull of* Equus burchellii*, basal (ventral) aspect. Numbered arrows are significant differences between* **Eb** *and* **Ez** *found in the present study. In* **Eb***: 8.* Processus retroarticularis *medial border is not notched; 22.* Processus palatinus foramina *are absent.*

10. *Foramina supraorbitale*: The supraorbital foramina in each frontal bone vary in number from 1-3 in ***Ez***. In ***Eb*** they are 1-2 in number, the minor foramen always being minute, and the diameter in the major foramen is twice that (5 mm) of ***Ez***. With experience, an observer will be able to distinguish the species using this parameter.

12. *Sutura frontonasalis*: The frontonasal suture is a more or less straight line in ***Ez***, while in ***Eb*** it forms

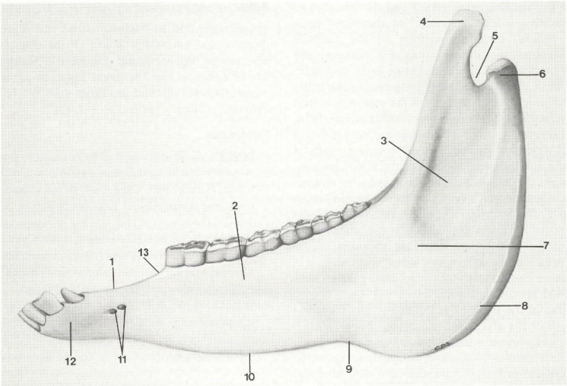

***Figure 9:** Mandible of* Equus zebra, *left lateral aspect, giving the structural components. 1.* Margo interalveolaris*; 2.* Pars molaris *of* Corpus mandibulae*; 3.* Fossa masseterica*; 4.* Processus coronoideus*; 5.* Incisura mandibulae*; 6.* Processus condylaris*; 7.* Ramus mandibulae*: 8.* Angulus mandibulae; *9.* Incisura vasorum facialium*; 10.* Margo ventralis*; 11.* Foramen mantale *(paired); 12.* Pars incisiva *of* corpus mandibulae*; 13. Interalveolar border. (Source: Smuts & Penzhorn 1988).*

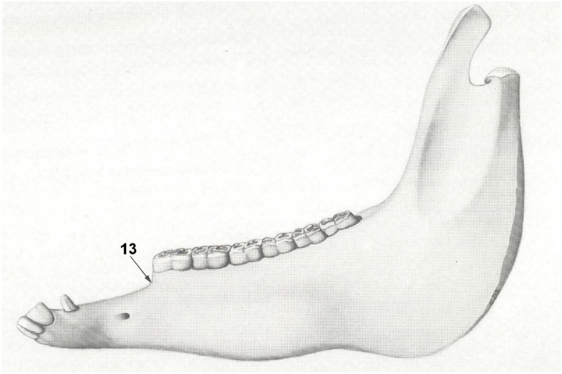

***Figure 10:** Mandible of* Equus burchellii*, left lateral aspect. Arrow 13 is the significant difference between* **Eb** *and* **Ez** *identified by Smuts & Penzhorn (1988) and the present study, i.e. the interalveolar border has an angle of almost 90° in* **Eb**.

an angle, meeting rostrally in the median plane. This feature is diagnostic.

15. *Crista facialis*: In ***Ez*** there is no notch at the rostral end of the facial crest where it joins the alveolar process of the maxilla. In ***Eb*** there is a pronounced notch at this junction, when viewed from the dorsal aspect. An experienced observer will be able to use this to distinguish between the species.

Ventral (basal) aspect (Figures 7 and 8)

8. *Processus retroarticularis*: The medial border of the retroarticular process is notched in ***Ez***, whereas it is straight in ***Eb***. This difference is distinctive.

23. *Processus palatini*: There are paired foramina at the rostral end of the palatine fissure in all ten specimens of ***Ez***, forming a triangle with the *canalis interincisivus* at its apex rostrally. In ***Eb*** the paired foramina are absent in all ten specimens, with only the intercisive canal present at the rostral end of the median palatine suture. This is a distinguishing feature.

Mandible (lateral aspect) (Figures 9 and 10)

12. *Pars incisiva*: In ***Ez*** the width of the incisive plate between the base of incisors 3, measured at their lateral edge, is significantly less (mean 54 mm, range 48-57 mm) than in ***Eb*** (mean 58 mm, range 57-63 mm). There are three out of 20 measurements that overlap in their range, making this parameter unreliable.

13. Interalveolar border: In ***Ez*** there is no acute angle at the junction of this border with the border of the first premolar. In ***Eb*** they join in such a way that the junction forms an angle of almost 90°. This distinguishes the two species.

DISCUSSION AND CONCLUSIONS

Smuts & Penzhorn (1988) describe at least 17 anatomical differences between the skulls and mandibles of ten *E. z. zebra*, taken from South Africa's Mountain Zebra National Park, and ten *E. b. antiquorum* from various localities in South Africa's Transvaal Province and neighbouring Botswana. They found ambiguity in some of the parameters because of exceptions and overlap in measurements. Their data give means, providing ranges of measurements only where a degree of variation occurred, and no statistical analyses were presented. My investigation, based also on a small sample size, shows similar ambiguity in several parameters and I decided to discard the parameters with overlapping measurements, notwithstanding the fact that the means were statistically significantly different. Thereby the number of apparent differences in the specimens I examined is reduced from 18 to 13, which are mutually exclusive. Considerable variation exists in the range of measurements done on the 20 specimens I examined, and it is possible that with a larger sample, overlap of some parameters will occur, which were not recorded in this study.

The five parameters whose means are significantly different, but where overlap in their ranges occurs are: length of the alar canal, rostrocaudal diameter of the orbit, length of the retroarticular process, width of the nuchal crest, and width of the mandible's incisive plate.

Thirteen parameters are identified where the measurements or the morphology are mutually exclusive to either ***Ez*** or ***Eb***. These are:

Caudal

10. *Foramen magnum*: Presence of a median notch in the dorsal border in ***Ez***. Absence of this notch in ***Eb***.

Lateral

8. *Processus zygomaticus*: The zygomatic process of the frontal bone is broader in ***Ez***.

9. *Crista pterygoidea*: The pterygoid crest has a pronounced triangular shape and is prominent in ***Ez***. It has neither of these attributes in ***Eb***.

14. *Processus mastoideus*: The mastoid process of the temporal bones is longer in ***Ez***.

15. *Meatus acusticus externus*: The external acoustic meatus is placed horizontally and faces laterally in ***Ez***. It is directed dorsolaterally in ***Eb***.

Dorsal

4. *Crista sagittalis externa*: The length of the external sagittal crest is shorter in ***Ez*** than in ***Eb***.

8. *Os frontale*: The frontal bones are broader in ***Ez*** than in ***Eb***.

10. *Foramina supraorbitale*: The diameter of the major supraorbital foramen in each frontal bone is twice as large in ***Eb*** than it is in ***Ez***.

12. *Sutura frontonasalis*: The frontonasal suture forms a more or less straight line in ***Ez***. It has a rostrally directed angle in the median plane in ***Eb***.

15. *Crista facialis*: There is no notch at the rostral end of the facial crest in ***Ez***, whereas a pronounced notch occurs in ***Eb***.

Ventral

8. *Processus retroarticularis*: The medial border of the retroarticular process is notched in ***Ez***, whereas it is straight in ***Eb***.

23. *Processus palatini*: There are paired foramina at the rostral end of the palatine fissure in ***Ez***, which are absent in ***Eb***.

Mandible

13. Interalveolar border: There is no acute angle at the junction with the border of the first premolar in ***Ez***, compared to the angle of almost 90° in ***Eb***.

ACKNOWLEDGEMENTS

Profs. Malie Smuts and Banie Penzhorn (Faculty of Veterinary Science, Onderstepoort, South Africa) permitted me to use their illustrations of zebra skulls as a basis for reference. Prof. Alan Hodgson, Scientific Editor of the South African Journal of Zoology (now African Zoology), which holds the copyright, gave permission to reproduce these illustrations. I appreciate their helpfulness. I thank Chief Warden Wilferd Versfeld for access to skulls housed at the Etosha Ecological Institute. Likewise, Senior Warden Peter Bridgeford provided skulls from the Namib–Naukluft Park. My wife Conny checked all measurements and my son Paul modified the original figures of zebra skulls by computer.

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Postscript by editor:

Dr. Hu Berry was a renowned and respected Namibian scientist, serving in the Ministry of Environment and Tourism. At one time he was called upon to testify in a court case where poachers claimed that the evidence, zebra skulls, were from plains zebras and not from mountain zebras, which carried different penalties. After researching the differences between zebra skulls, he was able to convince the court that the skulls indeed belonged to mountain zebras (P. Bridgeford, pers. comm.).

The current paper deals with that work on zebra skulls. It was first submitted to Cimbebasia, the former journal of the National Museum of Namibia, in September 2003. At the time A. Kirk-Spriggs (pers. comm.) was editing Cimbebasia as a mostly unpaid volunteer. Dr. Berry's manuscript was peer-reviewed and accepted for publication in what would have been Cimbebasia volume 20. That volume, as well as Cimbebasia Memoir 10 (Advances in Afrotropical Arachnology, co-editor T. Bird) and Cimbebasia Memoir 11 (Lepidoptera of the Brandberg, co-editor W. Mey) were all in various stages of completion with manuscripts ranging from still under review to print-ready when Dr. Kirk-Spriggs left the museum in July 2004. None of these volumes were ever published (A. Kirk-Spriggs, T. Bird, and W. Mey, respectively, pers. comm.), nor did any other issues of Cimbebasia ever appear.

During recent clean-up operations at the National Museum all the comprising manuscripts of these volumes were found. They lack any indication of editorial activity subsequent to July 2004 although, somewhat bizarrely, literature (Suhling & Martens 2007; Kipping 2010) indicates that other papers were later accepted for a different 'Cimbebasia Memoir 10' that was also never published.

Most of the authors involved in all the abandoned volumes eventually published elsewhere, sometimes with great difficulty due to having to recreate original illustrations they could no longer access (K. Vohland, pers. comm.). Dr. Berry had not yet followed suit when he passed away in 2011, and his is today the only remaining unpublished manuscript from that time. The conservation law-enforcement aspects of the paper remain as relevant now as they were then, and NJE is honoured to publish it. The text has been left mostly unchanged, minor anachronisms and all.

Paul Berry is gratefully acknowledged for assistance and permission to publish his father's paper posthumously. Dr. Conrad Brain kindly agreed to check the content for currency. Former Naukluft warden Peter Bridgeford, Walfish Bay; former Cimbebasia editor Dr. Ashley Kirk-Spriggs, London; arachnologist Dr. Tharina Bird, Pretoria; lepidopterist Dr. Wolfram Mey, Berlin; and myriapodist Dr. Katrin Vohland, Berlin, are all thanked for providing contextual information.

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Criteria for biodiversity special value zones in the Sperrgebiet – plant endemism and species richness measures in practice

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ABSTRACT

Zoning protected areas for management purposes usually requires a base layer representing biodiversity and ecological criteria. This study illustrates a systematic process of assigning special value zones within the Tsau||Khaeb (Sperrgebiet) National Park. Clearly defined criteria resulted in fourteen areas of very high biodiversity importance. These are the Kowis mountains, Lüderitz peninsula, Tsaukhaib-Haalenberg inselbergs, Grillental-Pomona corridor, Boegoeberg, Klinghardt mountains, Tsaus mountain, Heioab-Aurus mountain range, Chamnaub inselbergs, Rooiberg-Nudavib mountains, Skorpion inselbergs, Obib mountains, Schakalsberge and the Orange River valley.

Keywords: Aurus mountains; conservation planning; Namibia; protected area; range-size; southern Namib; Sperrgebiet; Succulent Karoo Biome

INTRODUCTION

Zoning protected areas uses criteria related to biodiversity and ecological functioning as the base layer. In this context plants are often used as indicators (Pearman & Weber 2007; Mandelik *et al.* 2010; Ferreira *et al.* 2013). As primary producers they form the basis for most terrestrial ecosystems. Relatively evenly spread spatial data are more readily available for them than for most other groups of taxa. This is certainly the case in the Tsau||Khaeb (Sperrgebiet) National Park, where the park was recently zoned for management purposes. This article focuses on the biodiversity component of this zoning exercise. In addition to data availability, plants have an even greater importance in this park, as this is the northern tip of the Succulent Karoo Biome, a world-renowned biodiversity hotspot. This hotspot was assigned on the basis of plant species richness and endemism as well as threats to the biome (Mittermaier *et al.* 2004). Plant species richness, endemism and protection status were therefore used as the prime criteria for identifying biodiversity special value zones (Ministry of Environment & Tourism 2019) within the park. The objective of this article is to document the reasoning for assigning biodiversity special value zones based on clearly defined criteria.

Study area

The park is situated in the south-western most corner of Namibia and the northern-most tip of the Succulent Karoo Biome. Historically created as a buffer zone for the diamond mining industry, the area has been virtually inaccessible since 1908 to anybody except for staff and services related to the mining industry. Less than 1 % (approximately 0.7 %) of this vast area (some 2.1 million hectares) has been directly disturbed by mining, but exploration and service infrastructure, largely inside the mining licence areas along the Orange River and the coast, tell a story of over hundred years of man’s quests for diamonds. Large areas away from these diamond deposits are nearly pristine. Today they present the only large, continuous section of Succulent Karoo Biome which has not been altered by livestock grazing; except for areas along the eastern boundary of the park, which were used for emergency grazing until the early 1980s.

The park harbours over 1,000 plant species which is nearly one quarter of the entire flora of Namibia (Burke & Mannheimer 2004). A healthy population of brown hyena is present in the park which shows behavioural patterns different from other brown hyenas in southern Africa, due to the cool, coastal environment and reliance on seals as the main food source (Wiesel 2010). Although large mammal diversity is lower than in most other parks, large populations of gemsbok and springbok occur, as well as a largely unstudied and expected to be varied reptile, small mammal and invertebrate fauna. The Orange River Mouth is a declared Ramsar site supporting wetland bird populations which also extend to and move along the coastal section of the park.

The climate of the study area is arid with a largely moderate temperature regime. Average annual rainfall ranges between zero and approximately 80 mm. The annual mean rainfall at Lüderitz is 17 mm, at Oranjemund and Rosh Pinah around 50 mm, and at Aus, just to the east of the Sperrgebiet, 85 mm. Higher mountain areas in the Sperrgebiet receive more rain than surrounding lowlands, and annual averages at high altitudes may well exceed 100 mm (Burke *et al.* 2004). The Sperrgebiet falls within a transitional zone between winter and summer rain. Hence rains may fall at any time of the year. A rainfall gradient of decreasing rain from southwest to northeast, related to winter rains originating in the Cape, is indicated within the Sperrgebiet (Burke *et al.* 2004). Summer rains become increasingly more important towards the northeast, winter rains towards the southwest.

Another important source of moisture is fog. It is an almost daily occurrence along the coast. Its frequency decreases eastwards (Olivier 1995). The Orange River provides an important conduit for fog, as it often moves eastwards along the valley and reaches as far as Rosh Pinah, well over 60 km inland from the coast. Although no data on fog precipitation exist for the Sperrgebiet, the fog belt in the central Namib extends approximately 30 km inland and on average brings about 64 mm of moisture per annum at the coast, decreasing to about 35 mm at the eastern edge of the fog belt (Hachfeld & Jürgens 2000). At the coast, fog precipitation therefore exceeds rainfall.

Temperature regimes in the study area are comparatively moderate. Although daily means are expected to only range between 14 and 18 °C at the coast (e.g. Lüderitz) and from 10 to 24 °C further inland (e.g. Aus) (Pallett *et al.* 1995), maximum temperatures of 40 °C have been reported in both areas. Frosts are frequent in winter in the Aus area, but the remaining area at lower altitudes only rarely experiences frost.

Apart from aridity, wind is the most critical climatic factor affecting biodiversity and habitats in this area. Strong, southerly coastal winds prevail throughout the year, abating slightly as one moves eastwards. Constant daily winds at Pomona, for example, range between 30 and 50 km/hr in summer (Pallett *et al.* 1995), but often reach 100 km/hr. In winter, easterly 'berg' winds related to high pressure cells over the southern African interior can occasionally generate equally high wind speeds and impose hot, desiccating conditions on biota.

METHODS

Data sources

Landform-based mapping during 2003-2006 which delineated broad habitat units and associated vegetation types in the park (Burke 2006) was revisited and cross-checked with additional data from the National Botanical Research Institute in Windhoek and the author's own observations. More available data resulted in minor adjustments to some vegetation types (e.g. on the Lüderitz peninsula and the Klinghardt mountains). This was verified during workshops with key stakeholders such as the National Botanical Research Institute, the Ministry of Environment & Tourism, the Namparks project and environmental staff of mining licence holders.

Defining criteria

To enable a transparent assignment according to biodiversity importance, measurable criteria were developed which were backed by available data and reflected conservation importance and management-related objectives. Plant endemism, protection status and species richness are measurable criteria and were used directly to develop a 4-scale assignment. Plant endemism and protection status are species-based and occurrence in a particular mapping unit was used as indicator. Species richness was applied directly by counting the number of plant species occurring in a mapping unit.

Red list criteria were initially considered, but not incorporated. The reasons are: (1) To be applicable systematically across the entire park, the information would need to be reasonably complete. This means all plant species occurring in the park would need to have been evaluated against red list criteria. This is unfortunately not the case, as only a portion of the species has so far been evaluated with the focus on endemic plants and plant collector's items. Using this criterion would therefore be skewed towards the areas where plants occur that have been assessed. (2) The majority of species listed in a threatened category in the Sperrgebiet are either endemic or protected (e.g. all *Aloe* and *Crassula* species) and thus already included as a criterion. This would therefore be a duplication of information used as criteria.

Other biodiversity components such as landscape and fauna were not directly used in the assessment of biodiversity importance. These were assigned the category 'special management' (Ministry of Environment & Tourism 2019), based on existing features (e.g. natural monuments) and expert-driven identification during workshops. The main natural springs and wetlands in the park which attract a multitude of wildlife, and breeding and/or feeding areas of flagship animals were assigned as 'special habitats' in this study. Brown hyena (*Parahyaena brunnea*) and Damara Tern (*Sterna balaenarum*) were identified by the wildlife experts as flagship species and their breeding and/or feeding areas were therefore delineated as 'special habitats'.

Plant endemism, range size and protection status

As abundance data and detailed information on the status of plant populations are not available in the park, range sizes provide an approximation of a plant's risk to extinction. The more restricted a plant's range, the higher is the extinction risk, as even small disturbances could result in the elimination of a species (Smith *et al.* 1991; Burgess *et al.* 2006; Collins *et al.* 2009; Cadotte & Davies 2010; Davies *et al.* 2011). In the context of this study three range sizes were considered appropriate as key criteria: (1) species restricted to a mapping unit (broad habitat or vegetation type), (2) species endemic (i.e. restricted) to the park and (3) species endemic to the Namib Desert. Plants legally protected in Namibia (Nature Conservation Ordinance 4 of 1975 and Government Notice 247 of 1977, Forest Act 12 of 2001 and Government Notice 170 of 2015) also served as indicators, if they were not already included as endemic.

Plant species richness

Thresholds for plant species richness were assigned purely on numerical principles: 150, 100 and 50 were used as cut-off points. These proved appropriate when applied to the distribution of the park's plant species richness. Although plant distribution data are considered the most complete spatial information on biodiversity for the park, there are still some inaccessible areas which have been poorly surveyed. Expert opinion, without field data to back this, was only applied in the latter case. Expectation of occupancy by protected species or Namib endemics was then used as a criterion to rate this mapping unit of 'medium' conservation importance.

Once these criteria were defined, rules were developed for assigning biodiversity importance (Table 1). Where more than one criterion applied to a species (e.g. *Conophytum taylorianum* is a park endemic and protected), the species was only counted in one category. Also all mapping unit endemics are automatically park endemics, but were not counted as park endemics. This means each plant species was assigned only one categorical criterion.

RESULTS AND DISCUSSION

Of the over 1,000 plant species occurring in the park (Burke & Mannheimer 2004), some 30 plant species are strictly endemic to the park, another approximately 30 almost restricted to the park. These and, in addition, protected species combined with species richness served as indicators to define areas of particular biodiversity importance. This includes all mountains and most inselbergs, but also rocky areas and sand plains along the coast and the Orange River (Figure 1). The scale of mapping around mountains and inselbergs includes foothills and plains near these mountains. These habitats are therefore also included in 'special value zones'

The park is richest in one of the most difficult groups of plants to identify, the family Aizoaceae or Mesembryanthemaceae. The confusion already starts at higher taxonomic order, as some taxonomists consider this the family Aizoaceae, others Mesembryanthemaceae (Herre 1971; Bittrich & Hartmann 1988; Germishuizen & Meyer 2003; Snijman 2013). The fact that this group is evolutionary relatively young is one of the reasons for this confusion. It is one of the fastest evolving groups of plant species on earth (Klak *et al.* 2004).

Table 1: *Criteria for assigning biodiversity importance based on plant indicators in the Tsau||Khaeb (Sperrgebiet) National Park.*

Biodiversity importance	Criteria	Rules
Very high	≥ 1 plant species endemic to mapping unit ≥ 150 plant species ≥ 5 park endemics ≥ 10 protected species	At least two criteria apply
High	≥ 100 plant species ≥ 5 park endemics ≥ 5 protected species	At least two criteria apply
Medium	≥ 50 plant species ≥ 1 Namib endemic ≥ 1 protected species poor data, but protected or Namib endemics expected	One criterion applies
Low		None of the criteria apply
Special habitat	Important habitats for flagship species, e.g. feeding or breeding sites, special habitat for wildlife or providing essential ecosystem function (e.g. wetland)	Recognised of national importance
Natural monument	Natural feature of outstanding importance	Recognised of national importance

This, together with improved techniques (e.g. molecular studies), and more field data has resulted in continuous revisions in this group. New genera are created, new species described, others are combined to one species, genera are sunk and then re-created again when yet another study provides new information (e.g. Hartmann & Dehn 1989; Klak & Linder 1998; Klak *et al*. 2007; Snijman 2013). It makes it difficult even for experienced botanists to keep up-to-date with the latest developments.

More field surveys will change the information on distribution of species and add more species to some mapping units. It may also change the status of endemics. All this will then affect the statistics such as number of endemics and protected species and

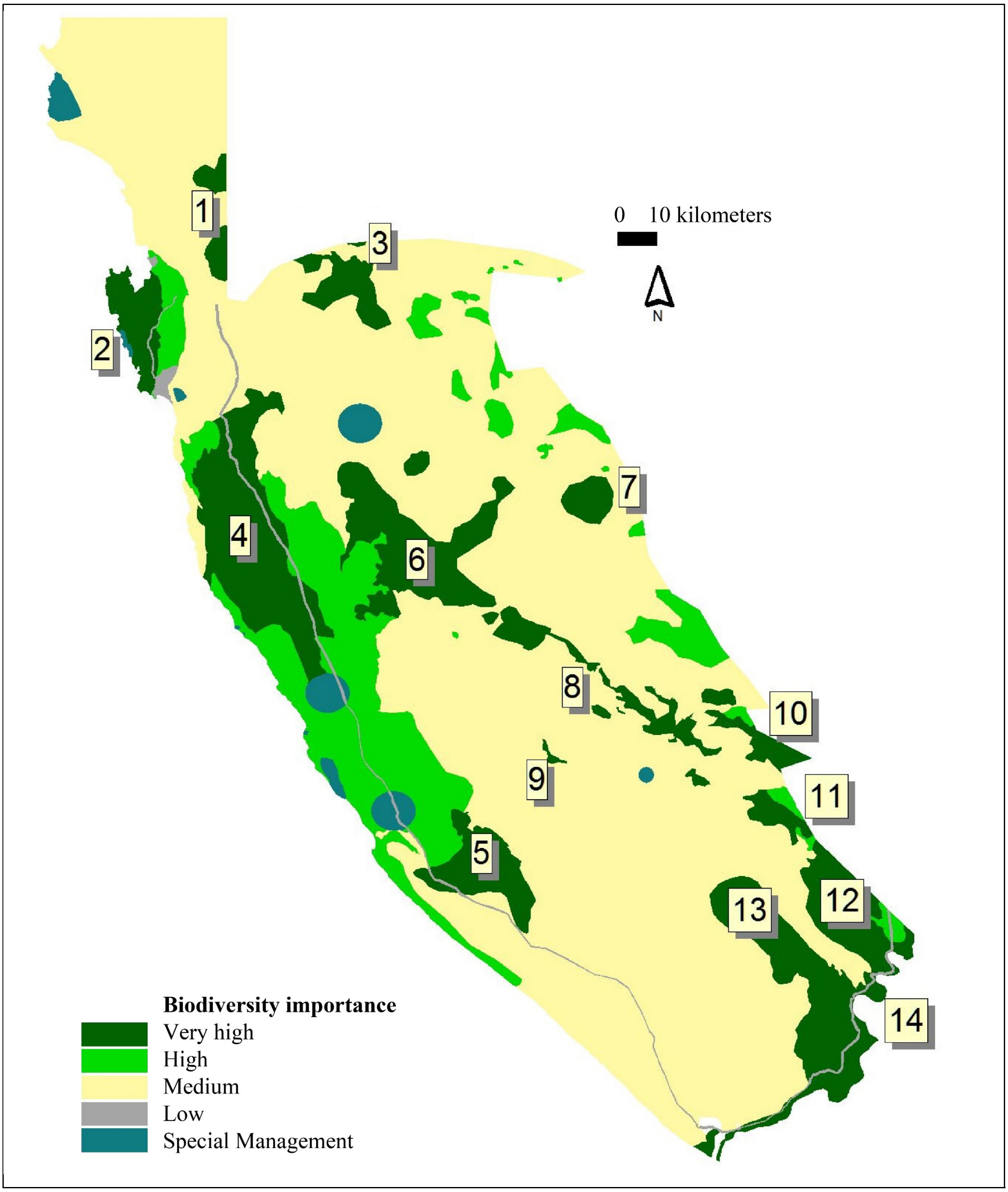

Figure 1: *Biodiversity importance of mapping units in the Tsau||Khaeb (Sperrgebiet) National Park. The labels correspond to the heading numbering in the text (1 Kowis mountains, 2 Lüderitz peninsula, 3 Tsaukhaib-Haalenberg inselbergs, 4 Grillental-Pomona corridor, 5 Boegoeberg, 6 Klinghardt mountains, 7 Tsaus, 8 Heioab-Aurus mountain range, 9 Chamnaub inselbergs, 10 Rooiberg-Nudavib mountains, 11 Skorpion inselbergs, 12 Obib, 13 Schakalsberge, 14 Orange River valley).*

overall species richness. The figures provided in this paper have to be seen in this context and provide the best approximation available at the time.

Areas of very high biodiversity importance

Fourteen mapping units of 'very high' biodiversity importance based on the criteria above were assigned in the Tsau||Khaeb (Sperrgebiet) National Park. The reason for this is explained in the following section, describing the mapping units from north to south. The heading numbering corresponds to the map (Figure 1).

1. Kowis mountains

Some 20 km east of Lüderitz, ridges of metamorphic rocks (metasediments, schist and gneiss) of the Namaqua Metamorphic Complex (Miller 2008c) rise to some 250 m above the surrounding plains (highest point at 656 m above mean sea level (amsl)). They are positioned in a sand corridor and most plants are continuously exposed to sand-blasting (Figure 2). Just over 100 plant species have been recorded, including one possible endemic to this inselberg (*Juttadinteria kovisimontana*), at least four park endemics (e.g. *Amphiglossa thuja*, *Drimia secunda*, *Juttadinteria simpsonii* and *Namibia ponderosa*), and over ten protected species (e.g. *Acanthosicyos horridus*, *Aloidendron dichotomum*, *Commiphora capensis*, *Conophytum saxetanum*, *Crassula ausensis*, *C. elegans*, *Eberlanzia clausa*, *E. sedoides*, *Lithops karasmontana* and *Psammophora modesta*).

The status of the potential endemic *Juttadinteria kovisimontana* is not entirely clear as it could be a hybrid between *Namibia ponderosa* and *Juttadinteria simpsonii* (Mannheimer 2006). Whatever the outcome of more detailed studies may reveal, it is still a very rare plant. *Namibia ponderosa* and *Juttadinteria simpsonii* are only known from the Kowis mountains and Haalenberg, some 14 km to the east of the Kowis mountains.

2. Lüderitz peninsula

The peninsula is largely rocky terrain dissected by a network of sandy washes and pans. Rocks are largely gneiss and metasediments such as schist of the Namaqua Metamorphic Complex, with a few isolated granite outcrops and an amphibolite ridge in the northern part of the peninsula (Miller 2008c). The lichen fields near Grosse Bucht are also included in this mapping unit. Proximity to the coast guarantees a regular, though meagre moisture supply.

Over 100 plant species have been recorded. Park endemics are represented by at least five species, including *Eremothamnus marlothianus*, *Fenestraria rhopalophylla*, *Lithops optica*, *Pelargonium cortusifolium* and *Pteronia spinulosa*; protected species are at least ten (e.g. *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, *Crassula elegans*, *Crassula muscosa*, *Juttadinteria deserticola*, *Lavrania marlothii*, *Ruschia deminuta* and *Tylecodon schaeferianus*). Higher plant diversity was reported in previous studies for the quarter degree square into which this mapping unit falls (Burke 2006). However, this proved to be a data error. Historic records in the National Botanical Research Institute's specimens database for "Lüderitz District", which covers the entire Sperrgebiet, were lodged in this quarter degree square (2615CA).

A rare red mutant of *Lithops optica* which used to be more abundant in the past, occurs on the peninsula, called 'rubra' and is considered a different form by some succulent specialists (Tischer 1925). It is highly sought after by collectors (Krainz 1948; Heine 2004). *Lithops optica* is in the process of being merged with *Lithops herrei* based on molecular studies and may therefore no longer be considered a park endemic (Loots *et al.* in prep.). However the 'rubra' form was not included in this revision, because of lack of material (Loots, pers. comm. August 2019).

Figure 2: *The dunes along the southern end of the Kowis mountains (left) are a testimony of the sand-blasting the gneiss outcrop receives regularly, resulting in relatively low plant cover (right).*

3. Tsaukhaib-Haalenberg inselbergs

Outcroppings of granodiorite gneiss of the Namaqua Metamorphic Complex form the Tsaukaib-Haalenberg inselbergs at the northern border of the park (Miller 2008c). The Haalenberg section extends north into the Namib-Naukluft Park. The highest peak is 1068 m amsl and rises some 250 m above the plains.

One dwarf succulent (*Conophytum halenbergense*) and a bulb (*Eriospermum halenbergense*) are endemic to these inselbergs, possibly also *Lithops francisci* and *Juttadinteria simpsonii*, depending on the outcome of further taxonomic studies. Over 150 plant species are recorded here and these include more than ten protected species (e.g. *Adromischus* species, *Aloidendron dichotomum*, *Amphibolia saginata*, *Boscia albitrunca*, *Commiphora capensis*, *Crassula ausensis*, *Crassula muscosa*, *Dracophilus delaetianus*, *Eberlanzia clausa* and *E. sedoides*) and three park endemics (*Juttadinteria simpsonii*, *Lithops francisci* and *Namibia ponderosa*).

4. Grillental-Pomona corridor

This encompasses the largest, contiguous mapping unit of ‘very high’ conservation importance. It consists of a variety of rock types and outcrops from dolomites near Grillental, syenite at Drachenberg and Dreizackberg to the volcanic cone at Schwarzer Berg, dolomite outcrops around Pomona, outcrops near Bogenfels to the sedimentary rocks of Buntfeldschuh in the south of this mapping unit (Miller 2008a). Various inselbergs and rocky outcrops dot the landscape in between. Not all these have been studied. Those that have either harbour plant species only occurring in this mapping unit, such as *Namibia cinerea*, and/or more than five park endemics (e.g. *Antimima dolomitica*, *Eremothamnus marlothianus*, *Fenestraria rhopalophylla*, *Frankenia pomonensis*, *Marlothiella gummifera*) (Figure 3) and/or at least ten protected species (e.g. *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, *Crassula deceptor*, *C. mesembrianthemopsis*, *C. muscosa*, *Eberlanzia clausa*, *E. sedoides*, *Juttadinteria deserticola*, *Larryleachia* species, *Lithops optica*, *L. karasmontana* and *Psammophora modesta*). Well over 150 plant species are recorded in this mapping unit.

Although this study focused on describing quantifiable biodiversity indicators, the Grillental-Pomona corridor gains additional significance by containing important fossil sites (e.g. at Elizabethfelde, Grillental, Bogenfels corridor and Buntfeldschuh) (Pickford & Senut 1999). The well-known natural monument Bogenfels also falls into this mapping unit.

5. Boegoeberg

This is the closest inselberg to the coast in the park and rises some 200 m above its surrounding. The highest peak is at 540 m amsl. Metavolcanics, quartzite and phyllite of the Gariep Complex are the main rock types (Miller 2008b). Apart from the inselberg and associated outcrops this mapping unit also includes a lichen field to the west of the inselberg and the plains in between. The inselberg is frequently shrouded in fog and the lichen field is on a slight rise, thus also receiving more moisture.

Just over 150 plant species have been recorded. These include at a minimum five park endemics such as *Antimima buchubergensis*, *Antimima dolomitica*, *Fenestraria rhopalophylla*, *Frankenia pomonensis* and *Pteronia spinulosa*. Protected species in this mapping unit are well over ten and include *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, at least seven *Crassula* species, *Eberlanzia sedoides*, *Stoeberia beetzii* and *Tylecodon schaeferianus*. The elusive geophyte *Eriospermum buchubergense* is believed to occur only on this inselberg; elusive because it has only been recorded once and was never found again (Dinter 1932; Perry 1994).

Figure 3: *Two Sperrgebiet endemics:* Namibia cinerea *at Grillental (left) and* Marlothiella gummifera *at Bogenfels (right).*

6. Klinghardt mountains

This mountain complex consists of a range of inselbergs of medium height, rising up to 300 m above the plains. The highest peak is Höchster which reaches 1114 m amsl. Complex geology, with outcroppings of quartzite, phyllite, dolomite and limestone of the Gariep complex, interspersed with phonolite intrusions of more recent origin (Miller 2008b), and the mosaic of inselbergs, dunes, gravel and sand plains provide a great diversity in habitats (Figure 4). This mapping unit also includes Münzenberg to the north-east of the Klinghardt mountains.

Over 300 plant species have been recorded to date, more than five of these endemic to the Sperrgebiet and two only occurring in the Klinghardt mountains. *Conophytum taylorianum* subsp. *taylorianum* has so far only been recorded from one locality in these mountains (Hammer 2002) and *Blepharis meyeri* has only been recorded here (Vollesen 2000). Park endemics include *Amphiglossa thuja*, *Antimima dolomitica*, *A. buchubergensis*, *Conophytum klinghardtense*, *Drimia secunda*, *Eriocephalus klinghardtensis* and *Hoodia officinalis*. The flora also contains an additional over 30 protected plant species, including *Adromischus montium-klinghardtii*, *Aloe erinacea*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia saginata*, *Astridia velutina*, *Cephalophyllum ebracteatum*, *Cheiridopsis robusta*, *Conophytum pageae*, *Dracophilus dealbatus*, *Eberlanzia sedoides*, *Ficus cordata*, *Larryleachia* species, *Psammophora modesta*, *P. nissenii*, *Quaqua mammillaris*, *Ruschia muelleri*, *Stapelia similis*, *Tylecodon paniculatus* and well over ten *Crassula* species. Also found on these inselbergs are the Gariep centre endemics *Delosperma klinghardtianum*, *Pelargonium klinghardtense* and *Lachenalia klinghardtiana*. The fact that so many plant species are named after these mountains indicates their importance as a locality where these were first collected, even if they were subsequently found elsewhere.

7. Tsaus mountain

This mountain is positioned in the central eastern section of the park. It is comprised of black limestone, sandstone, conglomerate and shale of the Nama Group, underlain by gneiss of the Namaqua Metamorphic Complex (Miller 2008c). The gneiss outcrops are at the north-eastern section of the mountain. These rocks form a flat-topped mountain with a plateau of about 9 km in length and 8 km wide, which gently slopes from 1226 m amsl at the highest point in the north to about 879 m in the south. The mountain rises on average about 400 m above the surrounding plains.

The more uniform landscape and rock types and greater aridity support less plant species than many other inselbergs in the park. However nearly 150 species have been recorded to date. Although no strict park endemics are recorded, a number of Gariep endemics occur such as *Euphorbia namibensis*, *Jamesbrittenia bicolor*, *Lessertia acanthorachis*, *Pteronia pomonae* and *Stipagrostis lanipes*. More than five protected species also occur (e.g. *Acacia erioloba*, *Aloidendron dichotomum*, *Boscia albitrunca*, *Crassula muscosa*, *Dracophilus dealbatus*, *Hoodia gordonii*, *Juttadinteria attenuata* and *Larryleachia* species). The main reason for its assignment of 'very high' biodiversity importance is the occurrence of *Lithops hermetica* which only grows on the Tsaus mountain (Cole 2000). The rare shrub *Euclea asperrima* which is only recorded from limestone in the Huns mountains, central escarpment and one other inselberg in the Sperrgebiet, also grows on the Tsaus mountain.

Figure 4: *A great variety of habitats supports a diverse flora in the Klinghardt mountains.*

8. Heioab-Aurus mountain range

This very large mapping unit in the central east has the highest habitat diversity in the park. It includes high and low mountain ridges, inselbergs and low outcrops of various geology (metasediments and metavolcanics such as gneiss, granite, quartzite, phyllite, conglomerate and dolomite) of the Namaqua Metamorphic and Gariep Complexes, but also quartz gravel and sandy plains, semi-vegetated dunes as well as a section of the dry Uguchab river. Heioab, at 1121 m amsl, is the highest peak, followed by the Aurus peak at 1084 m amsl. The Aurus mountains form a horseshoe towards the east and slope gently to the eastern plains and Uguchab river, but rise steeply for some 480 m above the plains to the west. The southern ridges of the Aurus mountains form a protective barrier against the constant southerly winds. Therefore the densest permanent plant cover and the highest plant diversity in the park are found here (Figure 5). This mapping unit also includes the inselbergs to the west of the Aurus range and Buschmannberg with a peak of 984 m, rising some 290 m above the surrounding (it is marked as Wasserkuppe on some maps).

Some 400 plant species have been recorded in this mapping unit, and this includes at least five park endemics (*Antimima aurasensis*, *Conophytum klinghardtense* ssp. *klinghardtense*, *Crassula aurusbergensis*, *Eriocephalus klinghardtensis* and *Pteronia spinulosa*) and, in addition, another over 50 protected plants. The two dwarf succulents *Tylecodon aurusbergensis* and *T. aridimontanus* are endemic to this mapping unit (Williamson 1995). *Tylecodon aurusbergensis* has only been recorded on south- to west-facing slopes of the Aurus range, while *T. aridimontanus* is recorded from the Heioab mountain. Both are restricted to the mountains in this mapping unit. Another species worth mentioning is the recently described elusive geophyte *Moraea thermarum*, which has only been recorded from two localities so far: on a mountain near the Orange River in the Ai-Ais Richtersveld Transfrontier Park and in the Aurus mountains (Goldblatt & Manning 2013).

Protected species include some 20 species of *Crassula*, *Adromischus marianiae*, *Adromischus montium-klinghardtii*, *Aloe erinacea*, *A. microstigma*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia saginata*, *Cephalophyllum confusum*, *Cheiridopsis robusta*, *Conophytum pagae*, *Holothrix filicornis*, *Eberlanzia sedoides*, *Hoodia gordonii*, *Juttadinteria deserticola*, *Psammophora modesta*, *Quaqua incarnata*, *Ruschia muelleri*, *R. odontocalyx*, *Stoeberia gigas*, *Tylecodon paniculatus* and many more.

9. Chamnaub inselbergs

Positioned more or less half way between Boegoeberg and the Aurus mountains, this group of inselbergs is largely composed of quartzite, shale and schist of the Gariep Group (Miller 2008b). The inselbergs rise some 110 m to 160 m above the surrounding vegetated dunes. The highest peak is 690 m amsl.

Close to 100 plant species have been recorded on these isolated inselbergs and this includes at least five park endemics and well over ten protected species. Park endemics include *Amphiglossa thuja*, *Antimima buchubergensis*, *Crassula aurusbergensis*, *Eriocephalus klinghardtensis* and *Pelargonium cortusifolium*. In addition, protected species include *Aloidendron ramosissimum*, *Amphibolia saginata*,

Figure 5: Aloe microstigma *at Heioab (left) and remarkably dense perennial vegetation in the eastern section of the Aurus mountains (right).*

Aridaria noctiflora, *Cephalophyllum ebracteatum*, *Conophytum* sp., at least another five *Crassula* species, *Eberlanzia sedoides*, *Larryleachia* species and *Stoeberia beetzii*.

10. Rooiberg – Nudavib mountains

The Rooiberg and associated inselbergs which stretch towards the Nudavib mountains extend south-east from the southern end of the Aurus mountain chain. They are comprised of diverse rock types from gneiss to mixtite and metasedimentary rocks. This also includes the low conglomerate (diamictite) inselberg to the north of Rooiberg, called Kegelberg on some maps, Schwarzkuppe on others. Rooiberg is by far the highest of these and rises some 325 m above the plains reaching 1125 m amsl. Kegelberg (Schwarzkuppe) is 847 m amsl.

Over 170 plant species were recorded on Rooiberg alone and this includes well over ten protected species. Most remarkable is the occurrence of at least one endemic to this mapping unit, *Conophytum klinghardtense* subsp. *baradii* which is found on Rooiberg and mixtite outcrops in the vicinity of Rooiberg (Young *et al.* 2019). Although the rich flora does not include any other strict park endemics, there are many Gariep endemics such *Aloe erinacea*, *Amphibolia saginata*, *Antimima quarzitica*, *Eriocephalus giessii*, *Lachenalia pearsonii* and *Pteronia pomonae*. Protected species include, amongst other, *Adromischus montium-klinghardtii*, *Astridia velutina*, *Boscia albitrunca*, *Cephalophyllum confusum*, *Conophytum saxetanum*, eight *Crassula* species, *Ruschia muelleri*, *Stoeberia frutescens*, *S. gigas* and *Tylecodon paniculatus*.

11. Skorpion inselbergs

Complex geology in the south-eastern part of the park created a range of inselbergs and exposed different rock types. These include dolomite, mixtite, phyllite, quartzite, rhyolite, shale and schist outcrops of the Gariep Complex and Orange River Group, many formations interspersed with quartz veins. The higher inselbergs rise approximately 100 m above the surrounding.

Although no high altitudes are reached, these inselbergs are very diverse in plants and over 200 species have been recorded in this mapping unit (Burke 2009). At least one park endemic occurs, *Eriocephalus klinghardtensis*. There are also many Gariep endemics; amongst others *Bulbine rhopalophylla*, *B. namaensis*, *Justicia cuneata* and *Manulea namibensis*. The number of protected species reaches well beyond the threshold of ten, which is made up by over ten *Crassula* species alone. In addition to these, other protected species in this mapping unit are, for example, *Adromischus montium-klinghardtii*, *Aloe garipensis*, *Aridaria noctiflora*, *Boscia albitrunca*, *Cheiridopsis robusta*, *Conophytum taylorianum* subsp. *ernianum*, *C. saxetanum*, *Eberlanzia schneideriana*, *Ebracteola derenbergiana*, *Hoodia gordonii*, *Psammophora nissenii*, *Ruschia muelleri*, *R. tumidula* and *Tylecodon paniculatus*.

12. Obib mountains

This mapping unit in the south-eastern corner of the park contains the Obib mountains and Gomtsawibberge and comprises the most formidable mountain range in the park. The highest point, Obib peak, is 908 m amsl. Peaks rise on average approximately 300 m above the surrounding. The highest peak of the Gomtsawibberge, Gumchavib, is only 668 m amsl, but rises almost 500 m above the valley of the Orange River. Metasediments and sedimentary rocks such as dolomite, limestone, schist, quartzite and conglomerate of the Gariep formation provide most of the substrate (Miller 2008b).

Plant diversity is extraordinary in these mountains and over 400 species have been recorded to date, so it is not surprising that this contains well over 30 protected species, and one plant endemic to the Obib mountains. The elusive herb *Heliophila obibensis* (Schreiber 1979) has so far only been recorded in these mountains. Although only two other strict park endemics, *Eriocephalus klinghardtensis* and *Psammophora saxicola* (Hartmann 2002) have been recorded, many Gariep endemics occur. *Amphibolia saginata*, *Senecio giessii*, *Sarcocaulon inerme*, *Trachyandra lanata* and *Stipagrostis garubensis* are some of these. At least 15 different *Crassula* species grow in these mountains, which are all protected, as well as the protected *Adromischus filicaulis*, *A. alstonii*, *A. marianiae*, *Aloe gariepensis*, *A. pachygaster*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia obscura*, *Anacampseros filamentosa*, *Boscia albitrunca*, *Cephalophyllum compressum*, *C. ebracteatum*, *Cheiridopsis robusta*, *Eberlanzia ebracteata*, *E. schneideriana*, *Haworthia venenata*, *Hoodia gordonii*, *Larryleachia* species, *Ruschia muelleri*, *Psammophora modesta*, *Stoeberia gigas*, *Tylecodon paniculatus* and more.

13. Schakalsberge

Stretching over some 30 km, these north-northwest to south-southeast trending ridges of greenschist, phyllite, dolomite, marble, breccia and greywacke of the Gariep formation (Miller 2008b) extend up to the Orange River. The highest peak, at 625 m amsl, rises some 220 m above the surrounding. These mountains also include the Rooilepel outcrop and Skilpadberg in their southern reaches.

Plant diversity is high, with over 150 plant species. This includes the local park endemic bulb *Bulbine francescae* and at least three broader park endemics

(*Astridia hallii*, *Euphorbia angrae* and *Fenestraria rhopalophylla*) and in addition more than 20 protected species (e.g. *Aloe ramosissima*, *Astridia velutina*, *Cephalophyllum ebracteatum*, *Conophytum pageae*, *C. taylorianum* subsp. *ernianum*, at least ten *Crassula* species, *Dracophilus dealbatus*, *Eberlanzia clausa*, *E. sedoides*, *Juttadinteria deserticola*, *Larryleachia* species, *Psammophora modesta*, *Ruschia odontocalyx*, *Stapelia similis*, *Stoeberia gigas* and *Tylecodon paniculatus*. Skilpadberg near the Orange River is a particularly diverse and exceptional area, as a number of additional species of conservation importance occur here, such as the range-restricted *Aloe pearsonii* (only known from Namuskluft, some outcrops along the Orange River and a few localities in the Richtersveld), *Amphibolia obscura*, *Euphorbia herrei*, *Portulacaria pygmaea* and *Sarcocaulon multifidum*.

14. Orange River valley

The Orange River valley from Sendelingsdrif to Hohenfels comprises a diverse landscape with the permanently-flowing river, river banks, islands, and dry rivers, plains, dunes and mountains flanking both sides of the Orange River. A variety of rock types of the Gariep formation such as schist, mixtite, breccia and dolomite are exposed (Miller 2008b). Where north-south-trending mountain chains such as the Gomtsawibberge and Schakalsberge meet the Orange River, steep slopes and gullies provide a great variety of habitats. Terraces of former courses of the Orange River are exposed at various places. Some of these not only harbour diamonds but also provide a unique habitat. The habitat changes from Hohenfels to the Orange River mouth in that there are no longer mountains, but dunes and sand plains on the north-bank. Fog regularly moves upriver and precipitates on slopes and outcrops facing the river. Such sites are particularly rich in plant species and harbour a number of Orange River endemics (Figure 6).

The perennial river supports woodlands, in many places with dense undergrowth, grassy flood plains, reed beds and a variety of aquatic plant communities. These support diverse fish, amphibian and aquatic invertebrate communities. They are feeding and breeding grounds for a variety of water and other birds as well as mammal and reptile fauna.

Rocky slopes, gullies and ancient gravel terraces are particularly rich in plant species and over 170 plant species have been recorded along this stretch of river. This includes at least two park endemics (*Astridia hallii* and *Fenestraria rhopalophylla*) and over 20 protected plant species (e.g. *Aloe pearsonii*, *Aloidendron dichotomum*, *A. ramosissimum*, *Astridia velutina*, *Amphibolia obscura*, *Cephalophyllum herrei*, *Crassula muscosa*, *Crassula subaphylla*, *Conophytum saxetanum*, *Larryleachia* species, *Lithops herrei*, *Portulacaria pygmaea* and *Tromotriche pedunculata*). The significance of the outcrop Skilpadberg, which can be considered the southern-most extension of the Schakalsberge is described above.

Due to the proximity to the Richtersveld, one of South Africa's biodiversity hotspots (Cowling & Pierce 2000), there are also a number of Orange River plant endemics which only occur along this stretch of river, but on both sides in Namibia and South Africa. These include *Hartmanthus pergamentaceus*, *Juttadinteria albata*, *Sarcocaulon inerme*, *S. multifidum* and *Tylecodon buchholzianus*.

Downriver of Hohenfels species richness and occurrence of plants of conservation importance decreases, except at Swartkop. However, the Orange River valley here becomes part of a Ramsar site, an area of international importance for wetland birds. Although the Ramsar site does not include Pink Pan, the pan is also included as an area of very high

Figure 6: *Outcrops along the Orange River support range-restricted species such as* Aloe pearsonii *on Skilpadberg (left) and* Cheiridopsis verrucosa *on Swartkop near Oranjemund (right).*

conservation importance in this mapping unit. The valley west of Hohenfels could either be categorised as of ‘very high biodiversity importance’ (based on rare and protected plants at Swartkop) or mapped as a special habitat during zoning of the park.

Areas of high biodiversity importance

Areas of ‘high’ biodiversity importance are the remaining, more significant inselbergs in the park as well as the areas adjoining the Lüderitz peninsula and Grillental-Pomona corridor to the east. There are no plant species endemic to these mapping units, but they are nevertheless species rich and harbour at least five park endemics and/or protected species each. This also includes the northern section of mined areas in Namdeb’s high security area. Here a number of protected and endemic species have either recolonised the disturbed landscape or remain in small pockets of undisturbed ground in between (Burke 2007).

It is important to note that not all range-restricted park endemics, such as *Polemanniopsis namibensis* which is only known from a few localities (van Wyk *et al.* 2010), occur in areas assigned ‘very high’ or ‘high’ biodiversity status. This is due to their disjointed distribution. There are possibly more plant species which do not automatically receive adequate protection based on the overall biodiversity assignments, for the same reason.

Implications for conservation planning and management

This study forms the basis for management zones in the park. It needs to be supplemented by information of important historic sites and sites of special scientific interest such as fossil sites and sites of geological importance. Fauna-based indicators could be considered in future once adequate spatial information is available for certain groups of taxa and the habitats they occupy. Information on plant distribution changes and new discoveries could lead to up- or downgrading biodiversity importance of certain species which may also affect the overall biodiversity importance of a mapping unit. This study should therefore be reviewed and updated when an adequate body of new information becomes available (e.g. linked to comprehensive biodiversity surveys).

Although the area was divided into 56 vegetation types based on prevailing landform, in many instances this is still not sufficiently detailed mapping for management purposes. Large mapping units for example contain pockets of critical areas of exceptionally high diversity, or populations of species with an extremely limited range. These are very vulnerable to disturbance. Mountain peaks and the Aurus saddle are some examples. But there are also populations of vulnerable species on south- to west-facing slopes (e.g. *Crassula aurusbergensis*, *Tylecodon aridimontanus*, *T. aurusbergensis*), particular substrates (e.g. *Namibia cinerea* on dolomite) and isolated for some other reason (*Conophytum klinghardtense* subsp. *baradii*, *Polemanniopsis namibensis*). These need to be identified, mapped and zoned as exceptional sites within their respective zones of biodiversity importance.

The scale of mapping invariably influences the level of biodiversity importance. A larger mapping unit such as the Grillental-Pomona corridor harbours more plant species and with this also a greater chance of species of particular conservation importance because of the mapping units large extent. More detailed mapping to subdivide this large unit would help to better guide management, but requires intensive surveys during a good vegetation season.

CONCLUSION

With some 30 plant species strictly endemic to the park, the Tsau||Khaeb (Sperrgebiet) National Park by far exceeds the level of endemism encountered in any other protected area in Namibia. However, this level of endemism does reflect the high level of endemism of the Succulent Karoo Biome overall which, with 26 % plants endemic to this biome (Driver *et al.* 2003), supports one of the most unique arid floras in the world.

Although this study is a descriptive account of plant diversity and distribution in the Sperrgebiet, it is evident that species richness mirrors habitat diversity. The Klinghardt mountains with their varied geology and landforms, the Heioab-Aurus range and associated inselbergs, as well as the Obib mountains are by far the most species-rich landscapes. Where special bioclimatic conditions prevail, for example associated with the influence of fog in the coastal areas, many species restricted to these areas evolved (Burke 2004).

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An analysis of the risk of collisions between aircraft and vultures in Namibia

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ABSTRACT

Collisions between aircraft and birds and other animals occur frequently and are known in the aviation industry as wildlife strikes. They are considered to be one of the most serious safety and financial risks to the global aviation industry. The International Civil Aviation Organisation, a United Nations specialised Agency, requires that the appropriate authority shall take action to eliminate or to prevent the establishment of any source which may attract wildlife to the aerodrome, or its vicinity, unless an appropriate wildlife assessment indicates that they are unlikely to create conditions conducive to a wildlife hazard problem. Namibian airports reduce the wildlife strike risk by managing the airport habitat and actively chasing birds and other hazardous animals away. The bird strike risk in airspace between airports is not managed or assessed in Namibia. Following one White-Backed Vulture strike and several reports of near-misses with vultures by pilots of small aircraft, this study investigated possible collision hotspot areas considering small commercial aircraft flight paths and vulture movement areas. The study used spatial proximity analysis and temporal overlap to compare telemetry and nesting location data for the three most commonly encountered vulture species to flight paths and times of small commercial aircraft. Collision risk hotspots were identified over three national parks: Etosha, Waterberg and the Pro-Namib portion of the Namib-Naukluft. Ascending from, or approaching, Hosea Kutako International Airport from the east was identified as a particular risk for White-backed Vulture conflict, while risk of Lappet-faced vulture strikes was high to the east of Walvis Bay airport. Flight times of vultures and aircraft corresponded greatly, increasing the collision risk. The recommendations of this work are that pilots of small commercial aircraft should be made aware of particular risk areas, and that landing at Hosea Kutako from the east, or taking off in an easterly direction should be minimised when wind conditions allow, to reduce vulture collision risk.

Keywords: aircraft; Cape Vulture; Lappet-faced Vulture; Namibia; White-backed Vulture; wildlife strike

INTRODUCTION

Collisions between aircraft and birds and other animals, known as wildlife strikes, are a safety and financial hazard to the global aviation industry. The International Civil Aviation Organisation, a United Nations specialised Agency, requires that the appropriate authority shall take action to eliminate or to prevent the establishment of any source which may attract wildlife to the aerodrome, or its vicinity, unless an appropriate wildlife assessment indicates that they are unlikely to create conditions conducive to a wildlife hazard problem (ICAO Airport Services Manual 2012).

In Namibia, the requirement of registered airports to manage the wildlife strike risk is reflected in the Namibian Civil Aviation Act (6) of 2016. Research into the causes of wildlife strikes has been conducted at Hosea Kutako International and Eros airports. Since the majority of wildlife strikes occur at airports and in their direct vicinity (Hauptfleisch 2014, Hauptfleisch & Avenant 2015, Hauptfleisch & D'Alton 2015), none of this research has focused on the airspace between airports. Following one White-Backed Vulture strike and several reports of near-misses with vultures by pilots of small aircraft, the need arose to acquire more knowledge about the flight altitude, time and behaviour of vultures to be able to compare these parameters with aircraft flying in Namibia.

Of the five species of vulture (Family Accipitridae) occurring in Namibia, the movement and nesting of three: White-backed (*Gyps africanus*) (WBV), Lappet-faced (*Torgos tracheliotos*) (LFV) and Cape (*Gyps coprotheres*)(CV) (Figure 1), have been thoroughly studied in Namibia and other parts of southern Africa (Anderson 2004, Bamford *et al.* 2007, Mendelsohn & Diekmann 2008, Hancock 2017, Kolberg 2017). Breeding observations of these three species within Namibia have also been recorded (Diekmann *et al.* 2004, Mendelsohn & Diekmann 2008, Kolberg 2017). While Figure 1(c) shows a limited range of CV in Namibia, subsequent work of Mendelsohn & Diekmann (2008) found CV to forage far more widespread across Namibia All the above mentioned studies have shown that the movement

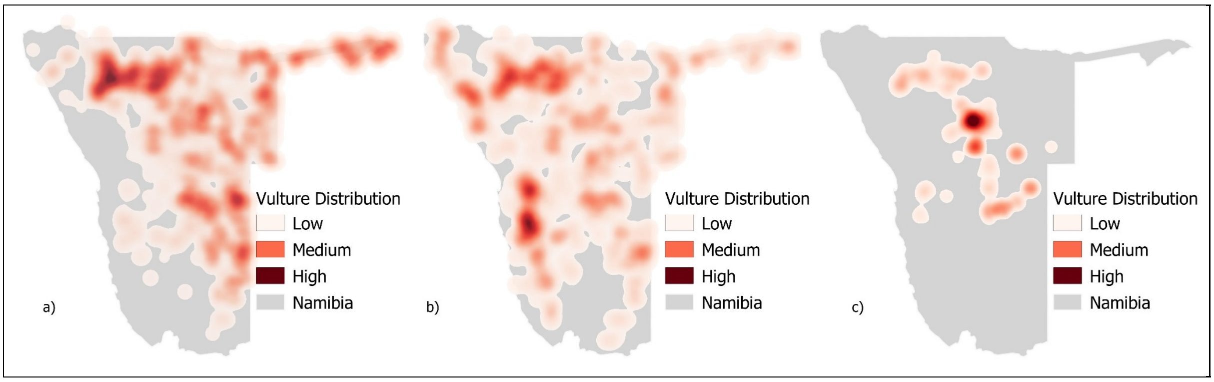

***Figure 1**: Distribution of (a) White-backed, (b) Lappet-faced and (c) Cape Vulture within Namibia (Data Source: EIS – adapted from SABAP ("Southern African Bird Atlas Project 2")).*

ranges of vultures within Namibia and the surrounding countries is vast. Single vultures tracked in Namibia have been recorded to visit as far afield as Angola, Zambia, Botswana, South Africa and Zimbabwe (Mendelsohn & Diekmann 2008, Hancock 2017).

Vulture behaviour in terms of movement patterns, soaring height and range extent makes them potentially vulnerable to interactions with aircraft (DeVault *et al.* 2005, Avery *et al.* 2011). Additionally, the studies of vulture movements in Namibia to date have not investigated their movement with respect to interactions with aircraft flight paths. Spatial analysis and statistics provide a means to demonstrate such interactions. In ecology, most spatial studies focus on the behaviour of a single species, however with increasing environmental impact legislation being implemented for the approval of infrastructural developments (Government of the Republic of Namibia 2007), the focus is shifting toward a better understanding of human-wildlife conflicts. On the topic of how vultures interact with infrastructural development, there have been a number of studies which involve potential interactions with wind farms (Garvin *et al.* 2011). In particular, it has been shown that without appropriate consideration, wind farms will negatively impact vulture populations. Walter *et al.* (2012) used spatial analysis to provide recommendations to reduce collision risks between a marine corps air station and both Black and Turkey Vultures (family Cathartidae, not Namibian). Similar to these studies, Namibian research conducted by the Wildlife and Aircraft Research Namibia Project (WARN) (Hauptfleisch & Avenant 2015, Hauptfleisch & Dalton 2015) focused on the airport surveillance radius and not on the larger airspace.

Unlike regional and international commercial flights, tourist/scenic flights are flown in smaller planes at lower cruising altitudes (approximately 600 m above sea level) (Scenic Air, pers. comm.). These flights occur frequently over sites located in natural areas where vultures are known to breed and/or search for food (Fly-In Safaris Scenic Flights 2019). Thus, we propose that within Namibia there are potential risks specifically between tourist/scenic flights and vultures.

In this research we used spatial proximity analysis to investigate hotspots for potential interactions between vultures and tourist aircraft, both within the airport surveillance radius and across Namibia. We analysed historical and current telemetry and nesting data for the WBV, LFV and CV. These data were combined with data from aviation flight paths, enabling us to determine their interaction potential. Based on our findings, recommendations are made regarding aviation flight planning parameters such flight paths and flight times in order to reduce the collision risk.

METHODOLOGY

Study Area

Namibia is an arid to semi-arid country covering approximately 854,000 km^2. With 43.6 % of the country under wildlife related land-uses, including national parks and conservancies (NACSO 2017) (Figure 2), its diversity and density of wildlife, including avian species, is high and even increasing. With extensive livestock farming dominating much of the remaining rural areas and human population density being low, scavengers such as vultures are widespread (SABAP 2016) (Figure 1) and relatively abundant compared to other parts of southern Africa (Simmons *et al.* 2015).

There are 11 airports in Namibia that are licensed by the Namibia Civil Aviation Authority (NCAA) (Figure 2), and over 200 private airstrips. In this study we focus on licensed airports, as these are expected to comply with civil aviation legislation regarding the monitoring of wildlife strikes and carry the largest number of flights.

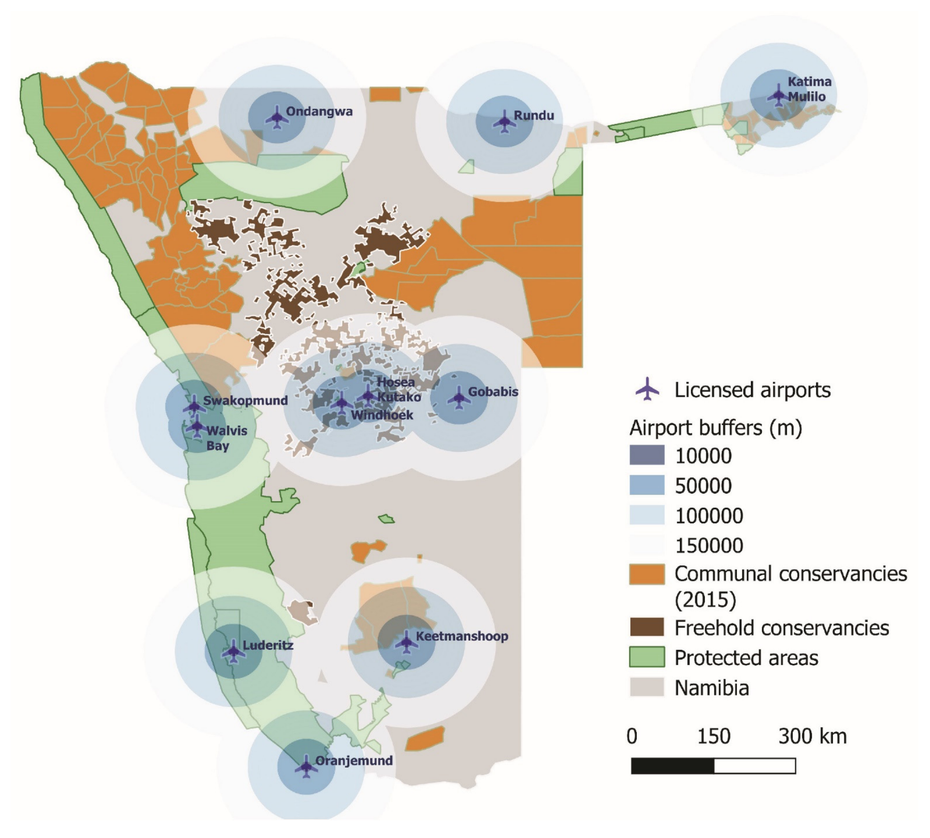

***Figure 2**: The location and airport zone buffers of the licensed airports considered in this study in conjunction with the various types of managed conservation areas (communal, commercial and protected areas) within Namibia. (Source: GIS data sourced NAC 2020 and Mendelsohn 2010).*

Data source

Spatial data used for this study comprise multiple datasets collected between January 2004 and October 2018 (Table 1). The vulture data include a combination of vulture telemetry data obtained from GPS collars and field observations of nesting sites acquired from multiple studies as listed in Table 1. Since nests are often used over multiple years, the individual bird identification tags or rings were used to remove nest records collected multiple times over successive years. Aircraft flight data were acquired from a Namibian tourist flight operator (Scenic Air) which uses onboard GPS trackers in its aircraft. A month's worth of flight tracking data is stored online in a running file and the company only downloads these files when required. The study acquired nine months of flight tracking data comprising 18,290 location points representing 3048 flying hours.

***Table 1**: Description of acquired data used for the spatial analysis in this study. Information includes: data description, source, period of data collection, the number of records and the time interval between recordings of the GPS tracked data. Note that the data description captures the combined datasets from individual sources. The time frame for individual collars differed, based on the operational time frame of the GPS collar.*

Spatial data	Source	Number of records	Time interval	Date range
Cape Vulture (9 individuals)	Mendelsohn & Diekmann 2008	86,504	1 hour	01/2004-05/2010
Lappet-Faced Vulture (10 individuals)	Hancock 2017	28,897	2 hours	11/2012-01/2017
White-backed Vulture (full dataset – 13 individuals)	Faustino 2020	408,941	10 minutes	03/2017-10/2018
White-backed Vulture (subset – 8 individuals)	Faustino 2020	256,992	10 minutes	02/2017-03/2017; 07/2017-01/2018
Nesting sites (2 species)[a]	Kolberg 2017	3,040	Annual nest records – multiple use of nests removed	03/1991-10/2016
Aircraft flight data (recordings from 18 pilots)	Scenic Air GPS on-board instruments	18,290	10 minute intervals, 3048 flying hours	02/2017-03/2017; 07/2017-01/2018
Licenced airport locations	NAC 2020	11 airports		2006

[a] Nesting sites of only Lappet-faced and White-backed Vulture species were used in the nesting site analysis.

Data preparation and analysis

To analyse potential spatial overlap or spatial interaction between vultures and aircraft within Namibian airspace, proximity analysis was conducted between these datasets (Milne *et al*. 1989). The analysis was subdivided into two components. The first analysed potential interaction within the airport surveillance zones (ASZ) and the second component considered potential interaction during flight.

The ASZ includes the 13 km radius within which the international regulations recommend to manage the wildlife strike risk (ICAO 2012). For this study, the ASZ was extended to buffer zones with distances 10, 50, 100 and 150 km surrounding each airport (Figure 2). The furthest was selected as commercial airlines ascend to cruise altitude at this distance (pers. comm. M. Botger; X. Schoeman) whereas other aircraft types use various shorter distances (Figure 2).

The second component considered potential interactions during flight. Flight data for aircraft were obtained as individual points. Using the "Points to Path" plugin in QGIS , the individual flight paths for the different routes were generated. Multiple flight lines followed similar paths between the different destinations. To simplify the analysis a central flight path was manually defined for each route. As a result of the deviations flown for each route, it is not practical to look at interactions directly along a single flight line. Thus, around each flight line multiple buffer rings were defined at 5, 10, 15, 20 and 25 km from the central flight lines for each flight route (e.g. Eros Airport to Rundu Airport). Interactions with the vultures were then analysed within these buffered flight areas (Figure 3). It must be noted that the flight paths do not all connect between the licensed parastatal airports. As indicated previously these flight paths are derived from the tourist aircraft that often use private airports, which are often based at tourist lodges within Namibia.

For the vulture data (Table 1), all data points available to this study within CV, LFV and nesting sites (NS) datasets were used in the analysis. Since vultures used the same nests on multiple occasions, density of nest sites was not considered in analyses, only nest locations. For some of the collared WBV data, there were readings at a higher frequency than 10 minute (the frequency of the aircraft flight data), therefore to expedite data processing time and enable comparison between the WBV and flight data, all WBV data were subset down to 10 minute intervals. This resulted in a total of just under 409,000 data points for WBV. Of the four vulture datasets, only some of the WBV data overlapped with the time frame of the aircraft flight data for which a subset was created (Table 1). This dataset was firstly used to determine if the spatial range of the data differed substantially from the full WBV dataset, and secondly to enable a direct comparison on potential flight interaction risks. It should be noted that analysis was also conducted on the CV dataset, however CV are thought to no longer breed within

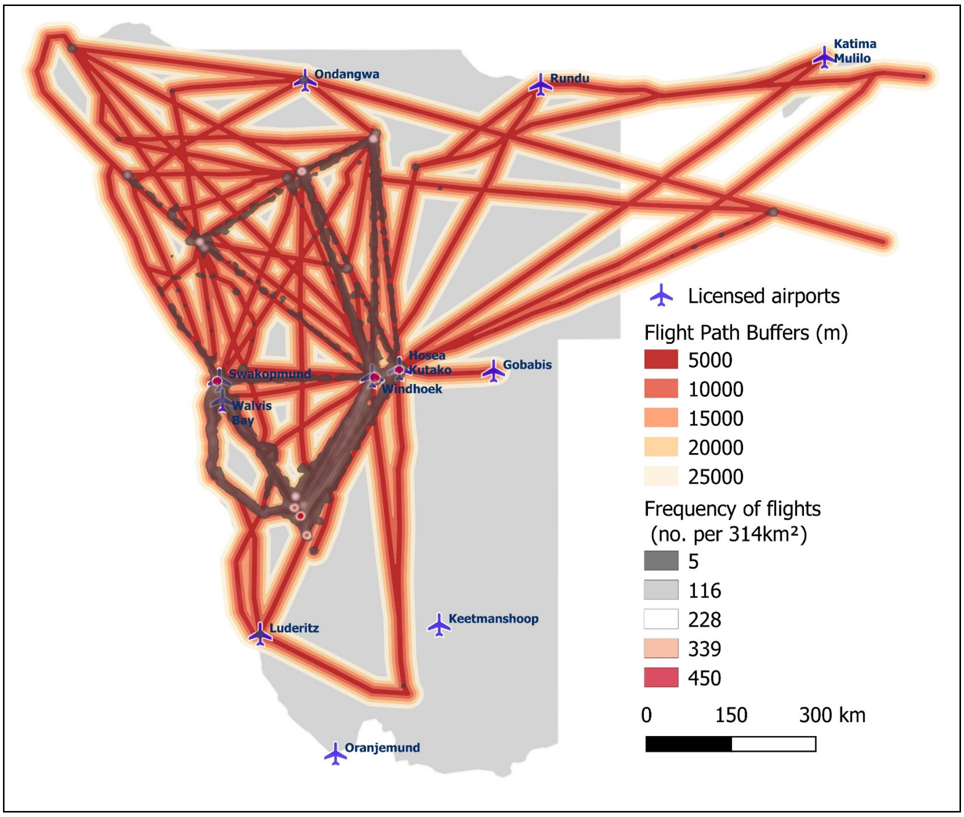

Figure 3*: The derived flight path areas and the frequency of flights within these flight path areas. Frequency was calculated as the number of flight location points that occurred within a 10 km radius. For ease of interpretation all areas with fewer than five points within a 10 km radius are not displayed.*

Namibia (Simmons *et al.* 2015), and the CV dataset is rather outdated. No current study is being conducted on breeding of the species in Namibia, therefore it cannot be verified whether the species is in fact extinct as a breeding species in Namibia or not.

All spatial analyses were conducted in QGIS 3.4.2 (Madeira). Two forms of spatial analysis were conducted to evaluate the potential risks between vultures and aircraft within Namibia. The first of these was a visual spatial analysis, and the second a numeric analysis of potential interactions both in-flight and when approaching landing at any of the licensed airports.

In the visual analysis, heat maps of the frequency of either nesting data or telemetry recordings (GPS collar data) were derived for the 4 different vulture datasets (Table 1). The heat maps were calculated as the number of points recorded within a 10 km radius of the centre of each 1 km^2 pixel. For all the visualisations, pixels with fewer than 5 points per 314 km^2 were masked out to focus on the areas with higher potential risk of interaction. These visualisations were illustrated in combination with the flight paths of aircraft and airport buffer zones and used to identify the highest potential conflict areas - a useful visual result for airline and airport operators.

For the flight interaction risk analysis all vulture points (sightings or recordings) that fell within aircraft flight paths or airport ASZ areas were summed and the percentage of the total number of recordings were calculated for each buffer area. This enabled an incident probability analysis to determine the likelihood of potential interaction between aircraft and vultures.

To verify the potential time clashes between vultures and aircraft, the time of day that the vulture data points occurred within the interaction areas (flight paths and ASZ) was also considered. This provided insights about times of day the probability of interaction was highest. The time of day for the vulture locations were categorised and summed into four categories: “morning” (05h00-10h00), “midday” (10h00-14h00), “afternoon” (14h00-18h00) and “evening” (18h00-05h00). Vulture roosting, feeding, thermal airflow use, climbing and prey detection behaviour (Hockey *et al.* 2005) informed the determination of time categories.

RESULTS AND DISCUSSION

The movement of the collared birds for all three vulture species obtained for this study (Figure 4) aligns well with the distribution of the three vulture species as per distributions maps adapted from the South African Bird Atlas project (“Southern African Bird Atlas Project 2”) (Figure 1). This comparison represents a consensus regarding point densities for the WBV and to an extent CV. The densities for both these species show a concentration over Etosha National Park and for CV also over the Waterberg National Park. WBV movement data show three additional hotspots which appear to be linked to commercial rangelands not associated with any of the conservation areas marked in Figure 4. The LFV observations exhibit the highest densities in the central-south west of Namibia in the Bird Atlas project, but in our study the collared birds spent significantly more of their time in the central-south east of the country. This may be due to the birds having been collared in western Botswana and may not represent the Namibian population completely. More recent studies (Hirschauer *et al.* 2017, Phipps *et al.* 2017) show the distribution of CV to include areas west and south of Windhoek in addition to the hotspots identified in our assessment.

With respect to potential interactions with tourist aircraft, it is seen that over 45 % of the observed GPS points for WBV (and the subset data) and CV occur within 10 km of the central flight lines taken by the tourist aircraft (Table 2) and over 65 % of recorded nests of WBV Vultures occur within 5 km of the centre of flight lines between most-used airports (Table 2). Combining the visual (Figure 4) and numeric assessments (Table 2), it would appear that greatest tourist flight risk interactions are likely to occur in the vicinity of the Etosha National Park and

***Table 2**: The cumulative percentage of vulture observations (either visually observed vulture nests, or from GPS collared vultures) that fell within and the remainder that fell outside of the flight paths of the aircraft.*

Distance (km)	**Nesting**			**Vulture GPS Recordings**			
	All Nests (%)	**WBV (%)**	**LFV (%)**	**WBV (%)**	**WBV subset[a] (%)**	**LFV (%)**	**CV (%)**
5	31.72	66.90	9.49	23.63	24.84	0	30.27
10	38.63	72.00	17.54	47.01	49.34	0	49.28
15	67.37	76.75	61.44	60.82	64.36	0	56.21
20	87.92	87.15	88.41	73.19	76.87	0	60.13
25	93.66	91.66	94.92	80.40	80.82	0	62.02
Beyond	6.34	8.34	5.08	19.60	19.18	100	37.98
Total Observations	**5,265**	**2,039**	**3,226**	**408,941**	**256,992**	**28,896**	**86,503**

[a] *subset of WBV GPS recordings that coincide with the flight data from the tourist airplanes.*

the Waterberg Plateau Park. The high prevalence of vultures in the vicinity of the Waterberg Plateau Park is likely as a result of the vulture restaurant which was at the time situated at Rare and Endangered Species Trust (REST) at Waterberg. The feeding site was abandoned when REST moved to the Otjiwarongo area in 2016.

None of the collared LFV used in this study interacted within a 25 km distance of the identified tourist flight paths (Table 2), thus we conclude that there is a low risk of potential interactions. The telemetry data however contradicts the nest locations of the LFV where just under 10 % of the nests are found to occur within 5 km from the flight path, and 50 % of all LFV nests were observed within 15 km of flight paths (Table 2). Based on this and noting the already mentioned discrepancy between the distribution of the location data and the distribution maps produced by the Bird Atlas Project, we believe our results based on the LFV GPS recordings should be treated with caution.

For the two most prevalent nesting species in Namibia, WBV have most plotted nests in the vicinity of the Etosha National Park and on commercial farmlands east of Hosea Kutako International airport (Figure 1). LFV similarly have many recorded nests in Etosha NP, but most of the recorded nests occur along the eastern boundary of the Namib-Naukluft National Park. For all nests, there appears to be a high potential risk of in-flight interaction; more than 60 % of the nest sites occur within 15 km of the central flight line (Table 2). The Namib-Naukluft LFV nesting sites also pose potential risks around Walvis Bay Airport with flights travelling to Sossusvlei exhibiting the highest potential risk. This risk is intensified during egg-incubating and chick-rearing activities, with peak egg laying season between May and July with an incubation period of approximately 2 months and chicks fledging after approximately 125 days (Hockey *et al*. 2005). Risk for aircraft collisions are likely to be high throughout this period as breeding pairs will increase foraging flights to feed their chicks. Fledging birds (likely between September and October) would also add to this risk, in the absence of the necessary flight experience to avoid collisions.

In contrast to the high numbers (39-49 %) of potential vulture-aircraft interactions that could occur within

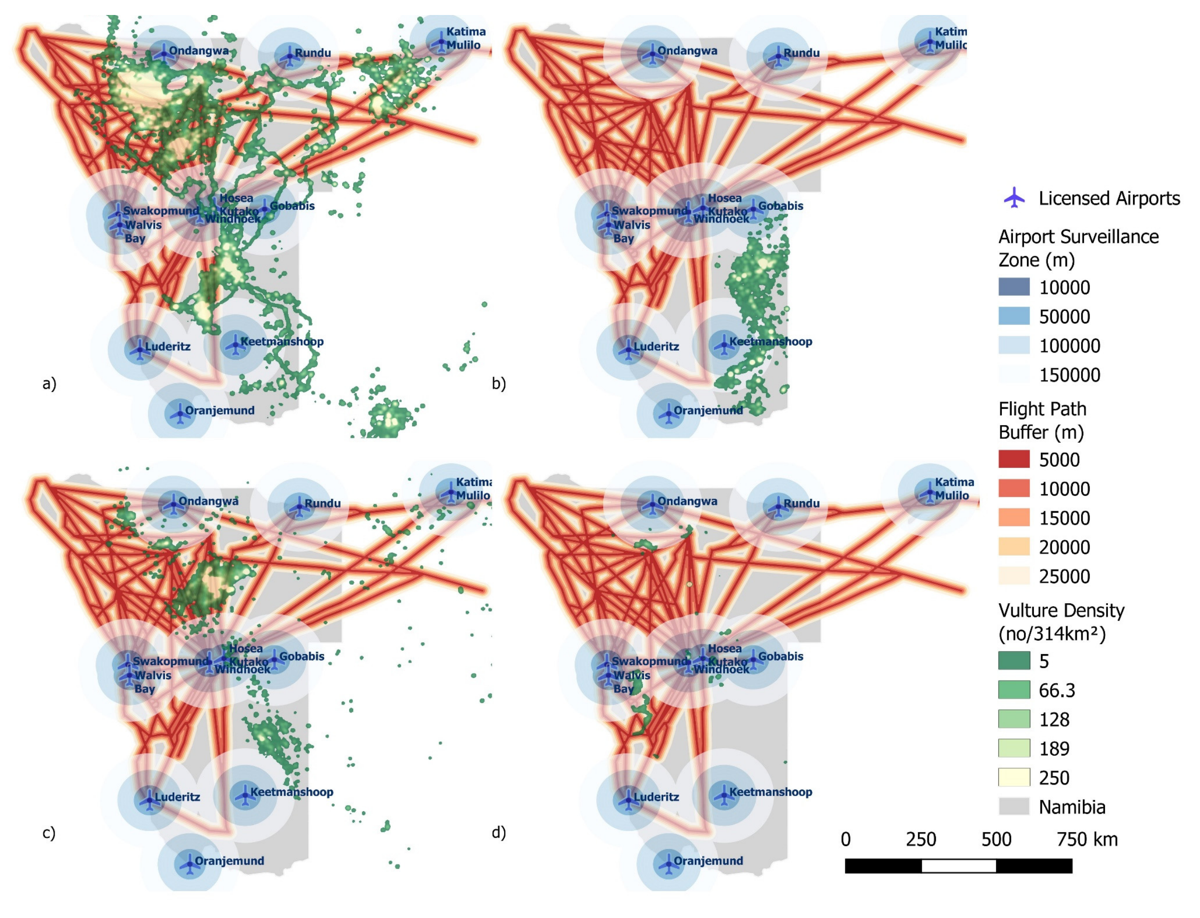

Figure 4: *Density of a) White-backed, b) Lappet-faced, c) Cape Vulture and d) Nesting vultures in relation to flight paths of tourist airlines and within the airport surveillance zones of Namibia's licensed airports.*

***Table 3**: The cumulative percentage of vulture observations (either visually observed vulture nests, or from GPS collared vultures) that fell within, and the remainder that fell outside, the airport surveillance zones.*

Distance buffer from airport (km)	**Nesting**			**Vulture GPS Recordings**			
	All Nests (%)	**WBV Nests (%)**	**LFV Nests (%)**	**WBV (%)**	**WBV subset[a] (%)**	**LFV (%)**	**CV (%)**
10	0.13	0.29	0.03	0.10	0.18	0.00	0.01
50	9.12	21.38	1.36	0.70	0.91	0.02	0.59
100	55.16	29.08	71.64	6.00	4.17	10.26	1.63
150	73.96	53.46	86.92	41.00	52.19	32.51	5.30
Beyond	26.04	46.54	13.08	59.00	47.81	67.49	94.70
Total Observations	**5,265**	**2,039**	**3,226**	**408,941**	**256,992**	**28,896**	**86,503**

[a] subset of WBV GPS recordings that coincide with the flight data from the tourist airplanes.

10 km of flight lines (Table 2), the number of potential interactions within 10 km of the airport surveillance zone (ASZ) for both nesting and GPS collared vultures, were below 1 % (Table 3). A specific risk emerges with LFV, where 70 % of nests were found within 100 km of the airports, mostly within the range of Walvis Bay airport. Up to 10 % of the GPS collared LFV found to be overlapping with the ASZ at distances of up to 100 km, were also found to overlap with the two licensed airports of Gobabis and Keetmanshoop.

For both WBV and LFV, many birds have been observed to nest within the approach distance for commercial aircraft to the Hosea Kutako International airport (WARN 2014). Most of these nesting sites are to the east of the Hosea Kutako airport in the Seeis riverbed, one of the primary approach directions (into Runway 08) taken by commercial aircraft. In the study by DeVault *et al.* (2005) in which they found potential flight interaction risks with military aircraft, the authors proposed revising aircraft flight schedules and landing directions. Whether such a recommendation

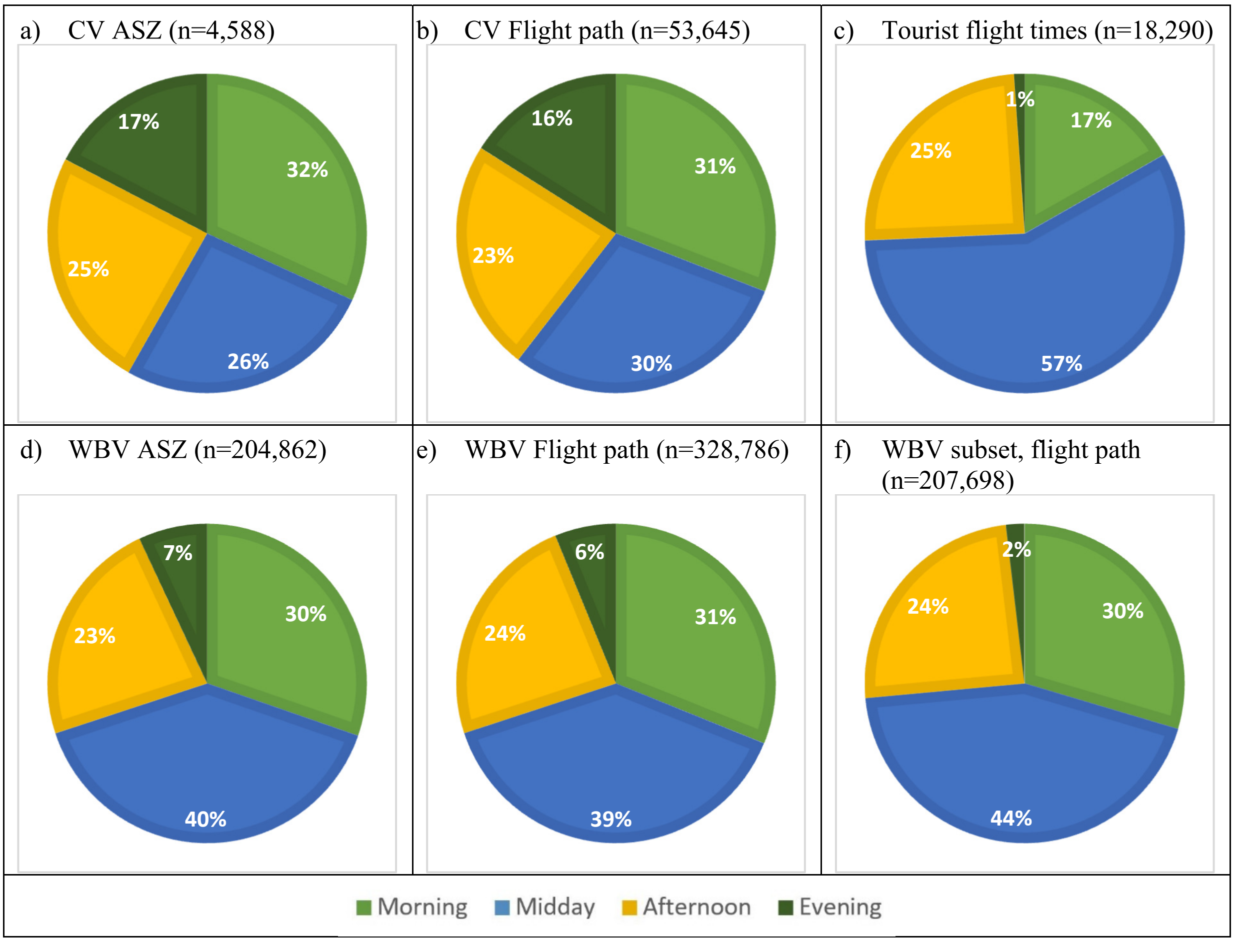
a) CV ASZ (n=4,588)
b) CV Flight path (n=53,645)
c) Tourist flight times (n=18,290)
d) WBV ASZ (n=204,862)
e) WBV Flight path (n=328,786)
f) WBV subset, flight path (n=207,698)

***Figure 5**: Percentage of the total number of GPS observations (in parenthesis) of the Cape Vultures (CV) and White-backed Vultures (WBV) that fell within the airport surveillance zones (ASZ) and flight paths, broken down into the time of day that tourist aircraft were recorded to be flying.*

for focusing on a west to east landing at Hosea Kutako would be practical requires further investigation.

The majority of daily vulture activity was recorded during the morning (05h00-10h00) and up to midday (10h00-14h00) (Figure 5a,b,d-f), which is consistent with the literature (Anderson 2004, Hockey *et al.* 2005, Murn & Anderson 2008). Similarly, most tourist flights took place during the midday time period (Figure 5c), increasing the temporal collision risk between smaller aircraft and vultures. From our dataset, CV appear to have been substantially more active than WBV throughout the late afternoon to evening (beyond 18h00) (Figure 5 a,b vs. d-f).

CONCLUSION

Our study found a low risk of interaction between aircraft and vultures within the direct ASZ which is monitored by licensed airports, however, we found that up to 10 % of nesting vultures are a risk to both commercial and tourist aircraft on approach and climb phases within 50 km of the airports. Hosea Kutako International and Walvis Bay airports (Namibia's most important international airports), have the highest potential risk of vulture interactions during approach and climb.

The risk of in-flight interactions between tourist aircraft and vultures seems most likely in the vicinity of Etosha and Waterberg Plateau National Parks, and this is further exacerbated by the fact that both vultures and tourist aircraft are simultaneously most active at similar altitudes during morning and midday hours.

To strengthen the spatial analysis conducted in this study, it would be valuable to obtain data from both flights and vultures which are coincident in time. Additionally, this work would benefit from obtaining in-flight altitude values for the aircraft, to compare with altitude data collected by vultures, since aircraft altitude data were unavailable for this study. This additional data at coincident times, would enable a three-dimensional analysis based on observed interaction risks between aircraft and vultures to be carried out.

ACKNOWLEDGEMENTS

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Soil indicators for restoration monitoring in arid regions – a case study from the central Namib Desert

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ABSTRACT

Soil properties are indicators for ecological processes and thus contribute to determining “functional and self-sustaining ecosystems” in a rehabilitation context. In a recovering ecosystem these indicators are expected to follow a trend towards a benchmark. Whether such a trend can be observed in rehabilitation projects in an arid environment was the question of this study. Soil properties of restored areas with six different treatments and corresponding reference sites were analysed at Trekkopje Mine in the central Namib Desert over six years. Soil properties which were reasonably stable over the monitoring period in reference sites, and not even affected by rainfall patterns, were pH, organic carbon, calcium, potassium, magnesium and clay content. The chemical indicators were likely linked to the treatments, although clear patterns had not yet developed. Organic carbon content was, however not linked to treatment or standing biomass. The best re-vegetated sites showed the lowest organic carbon, and thus no link between standing biomass and soil organic carbon. This may indicate that factors other than standing biomass control soil organic carbon and therefore call into question its use as an indicator of soil fertility in arid, recovering ecosystems. Control, scarified and topsoil-treated sites showed a clear trend in declining calcium, possibly as a result of the exposed, initially highly calcareous subsoil and subsequent leaching. Therefore, only one short-term soil indicator was supported by this study and more time and possibly a larger sample size are needed to show trends in other soil properties. Long-term data collection which consistently applies the same monitoring protocol is therefore essential in an arid environment and longer time intervals between monitoring events (e.g. 2-3 years) can be considered, if costs need to be reduced.

Keywords: completion criteria; mining; Namib Desert; rehabilitation; soil fertility; substrate treatments

INTRODUCTION

Restoration projects often strive to provide a “functional ecosystem which is self-sustaining” (Grant & Koch 2007; McDonald *et al.* 2016). In practice this means the restored ecosystem needs to be physically and biochemically stable and support adequate biodiversity in the long term. Evaluating restoration success requires the measurement of a suite of indicators that are recommended to cover the ecosystem attributes diversity, structure and processes (Ruiz-Jaen & Aide 2005; Alday *et al.* 2011). Soil properties and soil nutrient status are therefore expected to be included in restoration monitoring programmes, as these are a measure of ecological processes taking place in a restored ecosystem (Tongway & Hindley 2004). Ecological restoration has been defined as “setting natural communities on a trajectory of recovery within the bounds of what could be expected naturally within the target area” (Society for Ecological Restoration 2005). Long-term measurements are therefore expected to show a trend towards an accepted benchmark with time, which is usually a comparable undisturbed habitat.

Despite a vast body of literature on the practice and monitoring of restored ecosystems (e.g. Whisenant 1999), including studies from arid areas (Holm *et al.* 2002; Bestelmeyer *et al.* 2006), the question of recovery time has not been adequately addressed. Ecological processes in arid areas are inherently slow (Polis 1991) and driven by pulses of rainfall (Noy-Meir 1973). Recovery can therefore be expected to take well over a century in some areas (Bolling & Walker 2000).

Mining in the central Namib Desert has intensified over the last decade and three new uranium mines have been established. Developing site-specific restoration measures is therefore crucial and evaluating these requires monitoring. The study was carried out at Orano Mining Namibia’s Trekkopje mine, where a pilot project to develop appropriate rehabilitation methods was set up in 2010. Different surface treatments are being tested in these rehabilitation trials. Soil properties are one of the monitoring variables and expected to provide an indicator for ecosystem processes (Tongway & Hindley 2004; Ruiz-Jean & Aide 2005). Annual vegetation monitoring was initiated in 2011 while

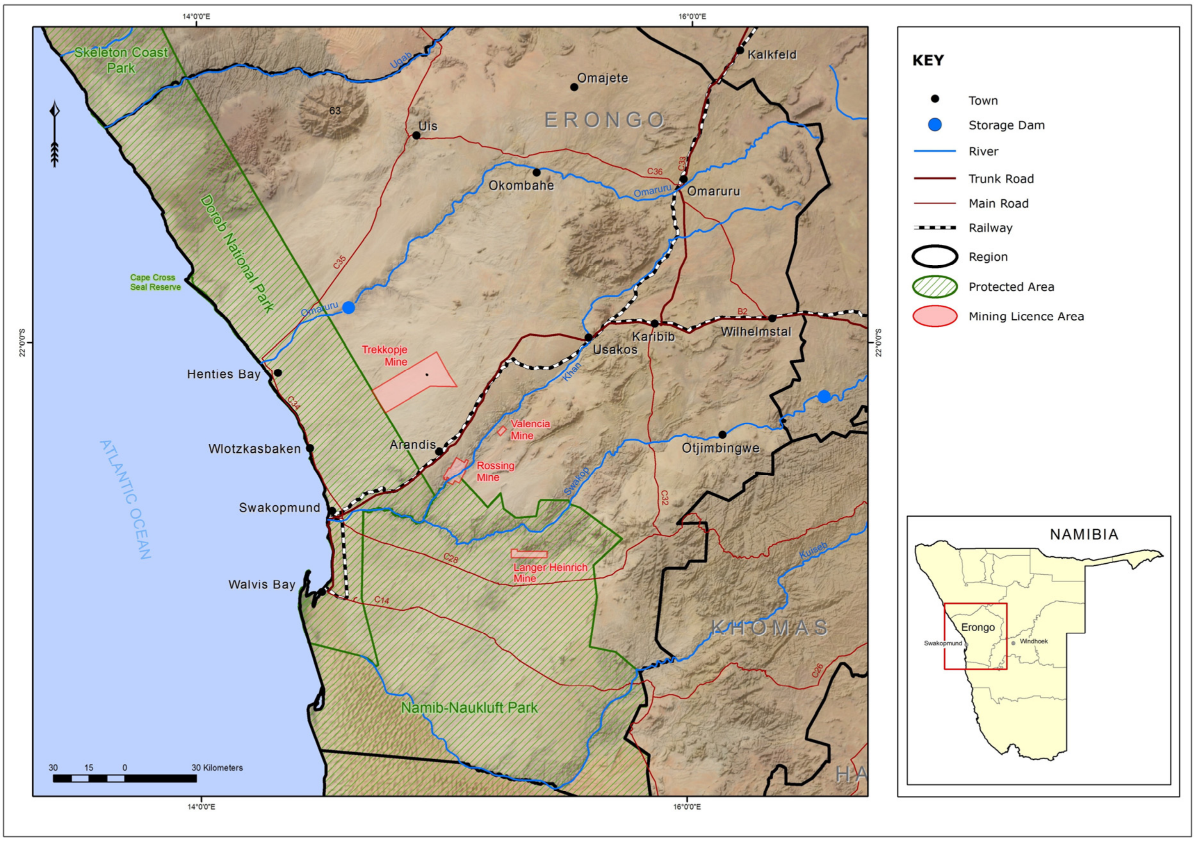

Figure 1: *Location of study area and rehabilitation trial site (• inside mining licence area) in Namibia (map credit: Orano).*

soil sampling, as described in this study, covers the monitoring period 2012-2017. This case study reports on six years of soil property monitoring.

MATERIALS AND METHODS

Study area

Orano's Trekkopje Mine is located in the central Namib Desert in Namibia. The mine is positioned on a gently sloping gravel plain at approximately 550 m altitude, some 40-60 km east of the Atlantic coast (Figure 1). It is dissected by a network of largely westwards trending, shallow, dry water courses. The vegetation comprises ephemeral grassland and dwarf shrubland, dominated by various *Stipagrostis* species. *Zygophyllum stapffii* and *Arthraerua leubnitziae* are the dominant shrubs, but perennial plant cover is largely restricted to the dry water courses and reaches no more than 20 % cover (A. Burke, pers. obs.). Ephemeral plant cover is directly linked to rainfall and in good seasons can reach up to 50 %. Soils are poorly developed calcareous calcisols and gypsisols, with saline and gypsum accumulations as well as local biological and chemical crust formation.

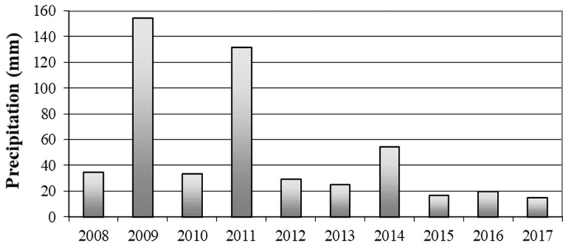

Figure 2: *Total rainfall during the rainy season October – September (e.g. 2016 comprises rain between 1st October 2015 and 30th September 2016) at Trekkopje Mine in the central Namib Desert.*

Mean annual rainfall in the study area was modelled to range between 40 and 50 mm (CSIR 1997), with most rains falling in late summer (March-May). This was confirmed by an average of 47.5 mm measured over a 10-year period at the site (Turgis Consulting 2008). Rainfall is highly variable between years and often patchy. Rainfall seasons with over 100 mm are rare and were only recorded twice during the monitoring period (Figure 2). The prevailing wind is south-westerly, but strong, very dry easterly 'berg' winds occur during the autumn and winter months. Temperatures range between an average minimum of 8 ºC to an average maximum of 32 ºC (Mendelsohn *et al.* 2002). Rainfall in the observation period exceeded the expected annual mean three times – in 2009 with 154.6 mm, 2011 with 134 mm and in 2014,

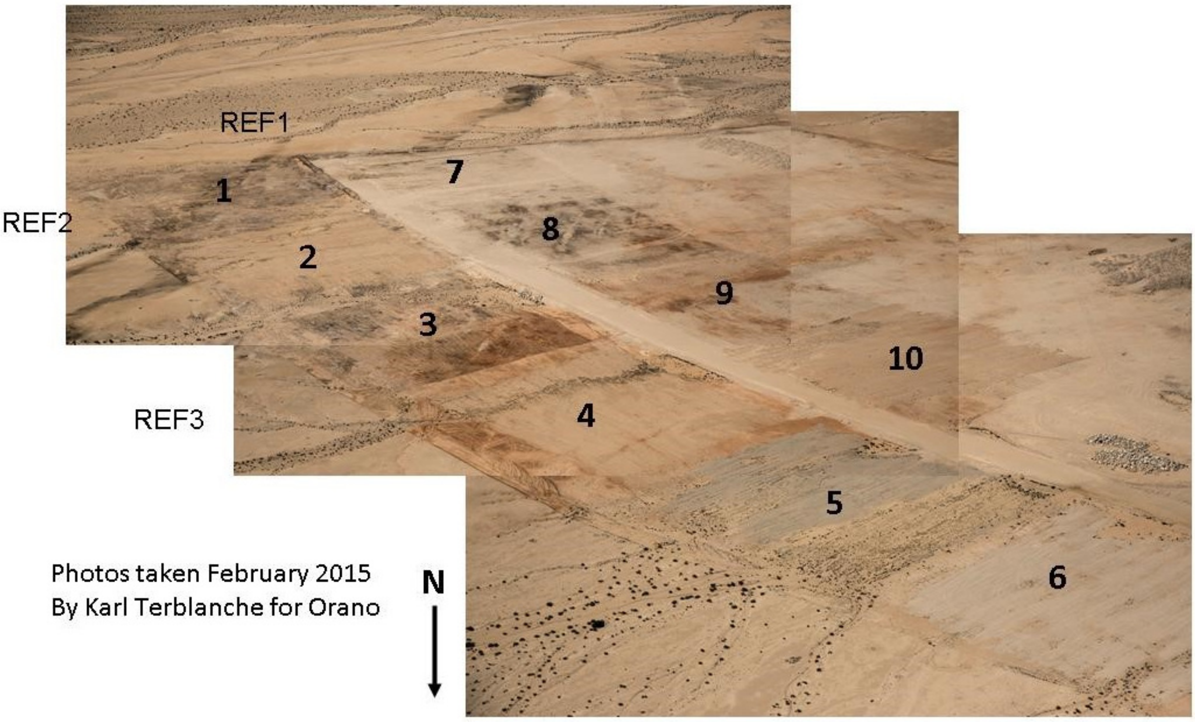

Figure 3: *Layout of rehabilitation site at Trekkopje Mine in 2015 (photo credit: Orano).*

when a total of 53.7 mm was measured. All other years were below average (Figure 2).

The mine is located on a gently west-sloping peneplain where runoff occurs as short-lived flows in response to rainfall in the catchment area. Evidence of runoff in the study area is in the form of shallow, sandy ephemeral drainage lines and sheet-wash surfaces. The streams terminate on the gravel plains west of the mine.

The uranium deposits lie close to the surface in calcium carbonate-cemented (calcrete) conglomerates of Tertiary age that fill palaeochannels incised into Precambrian/Cambrian meta-sedimentary rocks and intrusive granites. Trekkopje mine plans to use a strip-mining process that allows progressive rehabilitation as the ore body is excavated. The tailings from an alkaline leach process on an on-off heap leach pad will be backfilled into the open pit. Besides the backfilled areas, man-made landforms remaining after mining will include areas disturbed by infrastructure such as processing plants, offices and workshops, evaporation ponds, waste rock dumps and linear infrastructure such as roads, power lines and pipelines.

Post-mining land use is expected to be wildlife conservation and tourism as the mine is situated within a communal conservancy. The main question with regard to rehabilitation is whether these man-made landscapes can support the natural establishment of vegetation within a reasonable timeframe, for example one human generation. Restoration trials were set up with the main purpose of simulating the post-mining landscape and monitoring the re-establishment of natural vegetation.

Restoration trials

The test site covers 10 ha of a levelled former stockpile area and consists of ten 100 x 100 m plots with different surface treatments (Table 1). It was established in 2010 at the approximate geographic position: latitude 22º12'S, longitude 14º52'E (Figure 1). The eastern half of the area had been stripped of topsoil (Figure 3). The western part was covered with a layer of conglomerate as a base. The surface of this layer was compacted by the movement of heavy equipment. The rehabilitation trials were designed to answer the question whether vegetation would be able to re-colonise the disturbed areas without restoration measures or if interventions such as scarifying the compacted surface (Figure 4), replacing topsoil or applying some other fine-grained material like granite crusher dust or heap leach tailings would be required.

The first six 100 x 100 m plots in the eastern part were completed in December 2010 with six different treatments (Table 1), while the remaining four plots in the western part were completed in March 2011.

Figure 4: *The scarified surface of conglomerate still shows no plant growth after six years (photo: A. Burke).*

The southern half of this area was stripped of all conglomerate, while conglomerate was left on the northern half. The "controls" are disturbed areas which received no treatments. Three reference sites of comparable habitats, which provide the best approximation of the natural ecosystem before disturbance, were established in the vicinity. The sites were left to recover naturally, meaning that no irrigation, seeding or re-vegetating was undertaken. During an exceptionally good rainy season in 2011 runoff from shallow water courses to the east of the trials penetrated the trial area and flooded part of areas 4, 5 and 6. As these areas were rapidly colonised by plants, these flooded areas were considered an additional treatment and called "inflow" areas (Figure 5).

Field surveys

Soil was sampled after the rainy season (usually April-June) each year for six years during the period 2012-2017. Approximately 500 g of soil of the top 10 cm was collected within each trial and reference site. Three soil samples were taken randomly at each treatment and the reference sites. To be cost-effective, the three subsamples per treatment were then bulked for laboratory analysis.

Soil laboratory analysis

The soil samples were subjected to a standard farm soil analysis by Analytical Laboratory Services in Windhoek. This included pH (H_2O) (2:5), electric conductivity (ECw) (2:5), $CaCO_3$ (acid neutralisation, % $CaCO_3$ equivalent), organic carbon

Table 1: *Rehabilitation trial treatments at Trekkopje Mine ('Named' refers to the group of treatments under which the results of the soil samples were reported).*

Code	Treatment	Named
1	Area levelled to serve as a control	control
2	Application of a 10 cm thick layer of stored topsoil, 1 year old	topsoil
3	Scarifying (depth: ± 20 cm)	scarified
4	Scarifying and topsoil application (same topsoil as 2) plus inflow	topsoil
5	Application of granite crusher dust plus inflow	granite
6	Area covered in tailings plus inflow	tailings
7	Conglomerate removed to serve as control	control
8	Conglomerate removed and surface scarified	scarified
9	Conglomerate left and surface scarified	scarified
10	Conglomerate left and topsoil application (same topsoil as 2)	topsoil

Figure 5: A good rainy season generated inflow into one of the restoration trials, resulting in an immediate response of the vegetation (photo: A. Burke).

(Walkley-Black), organic carbon (calculated factor=1.724) and plant available P (Ohlsen *et al*. 1954). Extractable Na, K, Mg, Ca were measured using 1M ammonium acetate (pH 7.0) followed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). A particle size analysis used the pipette method (Analytical Laboratory Services 2012).

Data analysis

Soil properties that showed differences between treatments and reference sites and that are commonly used as indicators in soil studies were selected for further analysis. Means and standard deviations were calculated per treatment and per year and illustrated in graphs. Data were plotted and one outlier was removed (calcium content in one reference site in 2017 was measured 9 times higher than the highest previous record and was omitted).

Soil properties express themselves at a microhabitat level, although sampling is usually undertaken at a habitat level. For example on plains, considered a habitat in this study, there can be shallow furrows and depressions which are considered as microhabitats in this context. The variability of the data therefore has to be taken into account. In order to compare variability between different soil properties, the coefficient of variation was calculated by dividing the standard deviation of each treatment and soil property by its mean (Fowler & Cohen 1992).

RESULTS

Patterns of soil properties

Except for pH, clay content and organic carbon, soil properties showed a large range of values. For example electric conductivity ranged from 6.5 to 3,050 mS/m, calcium from 2,600 to 31,900 mg/kg, potassium from 32 to 308 mg/kg, magnesium from 22 to 458 mg/kg and phosphorous from 0.01 to 30 mg/kg. In all soil properties the highest value was at least ten times the minimum value.

Despite these considerable ranges, patterns were remarkably similar for five of the measured soil properties. Controls, topsoil-treated and scarified sites all showed higher electric conductivity, sodium, calcium, potassium and organic carbon content than the reference sites (Figures 6-8). Magnesium content was only higher in controls and scarified sites (Figure 8c). Calcium content in the inflow areas measured at an intermediate level (Figure 6c). Granite crusher dust and tailings-treated sites, inflow and reference sites showed the lowest values in electric conductivity, sodium, potassium and organic carbon content (Figures 6-8). Electric conductivity of tailings material is similar to the reference and inflow areas. Considering the soil properties individually, electric conductivity and sodium content are closely linked and show almost identical patterns (Figure 6a and 6b), indicating that sodium salts are likely the foremost contributor to the salinity of the various substrates overall.

Table 2*: Coefficient of variation (standard deviation/mean) for soil properties at Trekkopje Mine for different treatments. (All values >1 indicate that the standard deviation is greater than the mean (bold); n=sample size for laboratory analysis, composed of three bulked field samples per year and treatment). The sample size for treatments differ because some treatments were duplicated and additional samples were taken in the field when required.*

	EC	Na	Ca	OC	pH	clay	K	P	Mg
Control (n=10)	0.63	0.73	0.29	0.93	0.04	0.37	0.59	0.77	0.59
Topsoil (n=17)	0.55	0.73	0.35	0.35	0.04	0.39	0.36	**1.06**	0.48
Scarified (n=14)	0.49	0.58	0.40	0.68	0.02	0.38	0.33	0.54	0.41
Granite (n=6)	0.23	**1.16**	0.42	0.83	0.02	0.36	0.18	0.43	0.48
Tailings (n=6)	0.46	0.87	0.91	**1.10**	0.09	0.55	0.33	0.89	0.24
Inflow (n=16)	0.71	**1.76**	0.74	0.96	0.03	0.43	0.48	**1.25**	0.47
Reference (n=17)	**1.58**	**1.75**	0.33	0.67	0.05	0.74	0.90	**1.20**	0.67

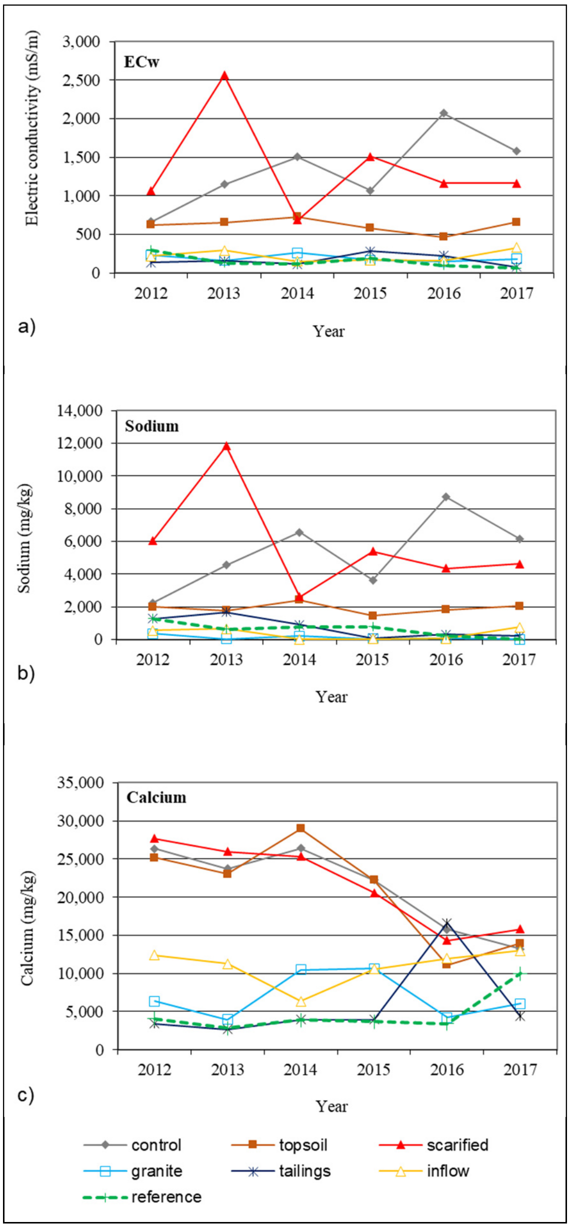

Figure 4*: Mean of soil properties at Trekkopje Mine in the central Namib Desert on rehabilitated surfaces: a) electric conductivity, b) sodium content and c) calcium content (n=1-3 for treatments and 9 for reference from 3 bulked subsamples per treatment and year).*

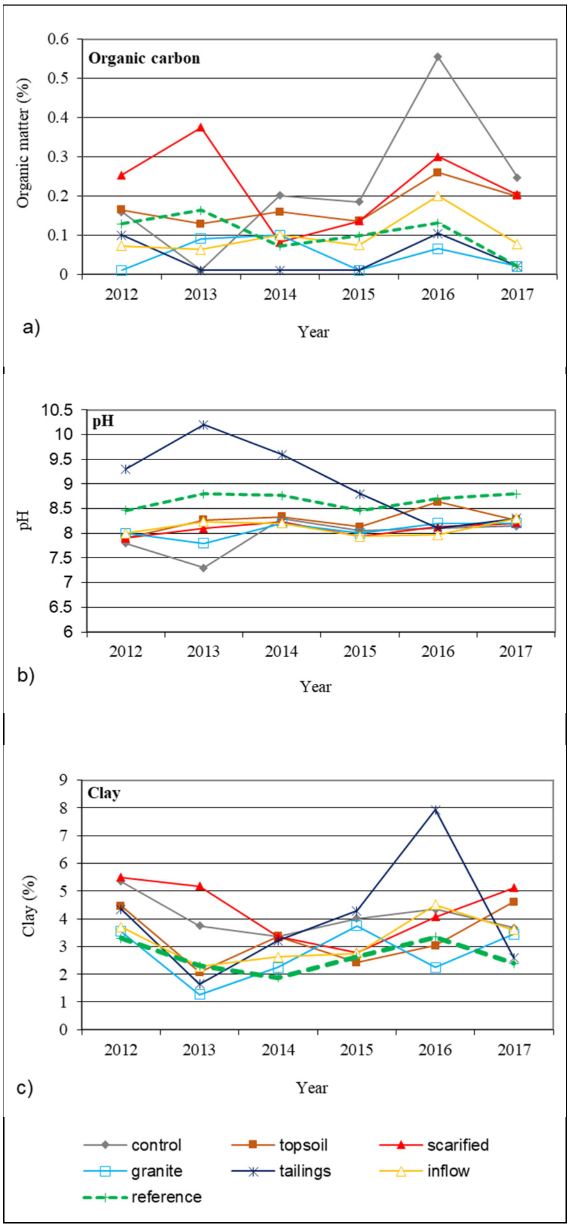

Figure 5*: Mean of soil properties at Trekkopje Mine in the central Namib Desert on rehabilitated surfaces: a) organic carbon content, b) pH and c) clay content (n=1-3 for treatments and 9 for reference from 3 bulked subsamples per treatment and year).*

Variability of soil properties

The greatest variability (i.e. coefficient of variation) was shown in electric conductivity, sodium content and phosphorus content, while pH showed the lowest variability overall, followed by potassium, clay and magnesium content (Table 2). Soil properties that remained comparatively stable in the reference sites over the years overall were calcium content (Figure 6c), organic carbon (Figure 7a), pH (Figure 7b), clay content (Figure 7c), potassium (Figure 8a) and magnesium content (Figure 8c).

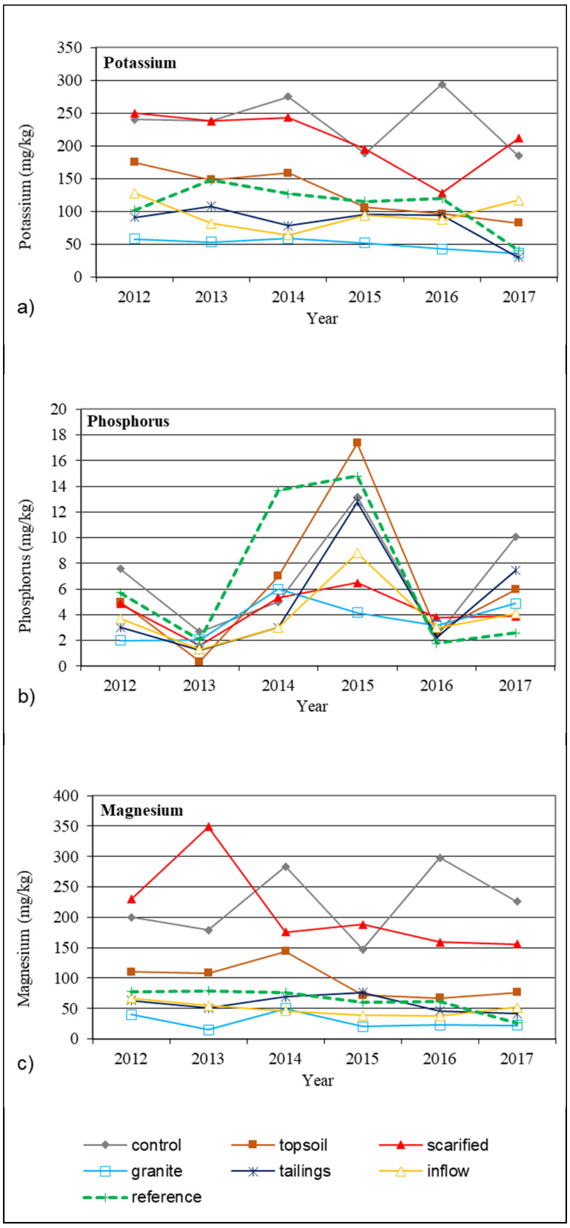

Figure 6: *Mean of soil properties at Trekkopje Mine in the central Namib Desert on rehabilitated surfaces: a) potassium, b) phosphorus and c) magnesium content (n=1-3 for treatments and 9 for reference from 3 bulked subsamples per treatment and year).*

Trends over time

On rehabilitated sites, trends of declining calcium content were found for the control, topsoil-treated and scarified sites (Figure 6c). The pH declined on the tailings-treated site (Figure 7b) from very high values due to residual alkaline leach reagents (sodium carbonate and bicarbonate) being flushed out. Declining potassium concentrations were observed on the topsoil and granite crusher dust treated sites (Figure 8a).

Effect of rainfall

None of the soil properties showed a direct correlation with rainfall, although phosphorus content increased steeply on the reference sites in 2014 and remained high in 2015, which could be linked to the rains in 2011 and 2014 (Figure 1). However, it also increased in all other treatments, with a particularly steep increase in control, topsoil and tailings-treated sites (Figure 8b) and a slight increase was indicated in 2017 in all sites without significant rains. A direct link to rainfall is therefore unlikely.

DISCUSSION

Soil properties are meant to be indicators of ecosystem processes in restoration monitoring. If restoration is successful they are expected to show a trend towards a biochemically stable situation, closely resembling the parameters in comparable natural habitat. While this has been demonstrated in restoration projects in mesic (Campbell 2002) and semi-arid (Alday *et al.* 2011) environments, little information is available for arid environments. This is partly because ecological processes are extremely slow, and most studies are not sufficiently long-term to show these trends. But it may also mean that arid ecosystems, that follow pulsed processes (Noy-Meir 1973), do not naturally show stable conditions in soil properties. However, restoration monitoring is expected to include “process” indicators and soil properties have been advocated in most restoration guidelines (e.g. Tongway & Hindley 2004; SER 2005; McDonald *et al.* 2016). Six years of monitoring soil properties at Trekkopje Mine in the central Namib Desert provided some insights regarding trends in soil properties in an arid environment in less than a decade and is presented here as a case study.

Variability of data

The variability of soil properties in the natural environment needs to be addressed to select appropriate properties against which the rehabilitated sites can be measured. Variability may be a result of (1) inherently fluctuating conditions in an arid ecosystem (Francis *et al.* 2007) or (2) related to micro-topography, which could cause differences even within one treatment, for example between mounds and furrows (Banning *et al.* 2008) and (3) the fact that arid ecosystems have likely the greatest spatial variation in soil properties of any ecosystem (Crawford & Gosz 1982). This is due to patchy rainfall, uneven vegetation cover which can create 'fertile islands' (Schlesinger *et al.* 1996) and micro-topography.

To overcome this inherent variability, sufficient soil subsamples have to be collected for bulking before laboratory analysis. However, there is considerable debate around the appropriate size of subsamples for bulking, ranging from two (University of Cornell 2015) or four subsamples (Environment Protection Authority 2005) to 40 in agricultural studies (Adetunji 1994). Practical considerations such as available budget, time and logistics influence the opted for sample size and three discrete subsamples were therefore selected in this study. The number of subsamples for bulking was perhaps insufficient to account for the spatial variability within each treatment site. Nevertheless, the reference sites in this study showed reasonable stability in the properties calcium content, organic carbon, pH, clay content, potassium and magnesium content which showed relatively low variability in the data (Table 2) and remained comparatively constant over the years (Figures 6-8). These soil properties were not even affected by rainfall patterns over the monitoring period, indicating that the number of subsamples for bulking may have been sufficient in this instance.

Differences between treatments

In contrast to this relative stability in some soil properties at the reference sites, all investigated soil properties, except for clay content, showed differences between the various restoration treatments. The controls, topsoil-treated and scarified sites had higher electric conductivity, calcium, potassium and organic carbon concentrations than the reference sites. Calcium and potassium may have been made available by the mechanical action of scarifying and the handling of topsoil with machinery which breaks up the soil structure.

The higher values of electric conductivity and calcium in the topsoil-treated sites are surprising, as they should be similar to the reference sites. However, stripping of topsoil was not always done according to specifications and saline and alkaline subsoil material may have been mixed in with the topsoil.

Therefore control, scarified and to some extent topsoil-treated sites present samples of subsoil. This subsoil is derived from conglomerate of ancient paleochannels which are highly variable and consist of mainly conglomerate with lenses of sand, clay and silt (Orano, internal geological report). The conglomerate is made up of debris of dolerite, gneiss, granite, marbles, pegmatite and quartz. It is cemented largely by calcite, and to a lesser extent by dolomite and the sulphates celestine and barite. The upper conglomerate unit has been cemented by gypsum. Gypsum or a thin cover of alluvium overlay the conglomerate (Orano, internal geological report). Calcium is therefore a major chemical element in the subsoil which explains the high calcium values found in the control, scarified and topsoil-treated soil samples (Figure 6c). Also, higher electric conductivity could be expected in subsoil, which was confirmed when the subsoil EC was measured at various sites on the mine (S. Müller, pers. obs.).

The higher organic carbon content in the soil of rehabilitated sites is more difficult to explain, because it is delinked from patterns in standing biomass (vegetation). The most vegetated sites are those which received water inflow and they rank low in soil organic carbon content (Figure 7a). In these areas vegetation cover was even higher than for the reference sites in some years (A. Burke, pers. obs.), but this is clearly not reflected in organic carbon content of the soil. There could be three reasons for this: (1) The breakdown of the vegetation and incorporation of organic matter in the soil takes longer than five years in this environment. The highest vegetation growth was observed in 2012 after the 2011 rainy season and litter from this exceptional growth should be detected in the soil by now, if it was broken down immediately *in situ*. (2) Organic carbon content in the soil may not be determined by the standing vegetation, but by wind-blown detritus collecting in suitable micro-catchments on the soil surface in this arid environment. Windblown detritus was observed in the rehabilitated areas and this would also explain why the least vegetated sites – hardly any vegetation growth has been observed in controls and scarified sites, and very little in the topsoil-covered areas – showed the highest organic carbon content (Figure 7a). (3) Organic carbon concentrations only reached a maximum of 1 % and this generated such low values that the results would be spurious. Yet these low values in organic carbon correspond with other records from the central Namib, where 0.2-0.8 % organic carbon content was measured in topsoil along a transect from the coast to the base of the escarpment (Scholz 1963), and only 0.03 % organic matter was measured in a calcareous soil on the gravel plains near the research station Gobabeb (Scholz 1972) and 0.2 % in a gypsisol at the coast (Petersen *et al.* 2010). Elsewhere, arid medium-textured and fine-textured soils in India were also reported with a very low organic carbon content (0.05-0.4 %) (Praveen-Kumar *et al.* 2009). These low values are therefore expected in an arid environment. Clay content influences organic carbon (Praveen-

Kumar *et al*. 2009; Petersen *et al*. 2010), but since there were no major differences between the treatments this could not explain the distribution of organic carbon.

Soil properties at other arid sites

The clay fraction of central Namib plain soil samples ranged 1.8-5.3 %, and was 0.5 % at Gobabeb (Scholz 1963, 1972), which is within the range of the values measured at Trekkopje. Measurements of soil pH in the coastal central Namib (gypsisol) indicated a mean of 8.3 and mean electric conductivity of 200 mS/m (Petersen *et al*. 2010), which corresponds well with the measurements at the Trekkopje reference sites. At a mine site near the escarpment a pH of 8.1-8.75, organic carbon of 0.07-0.17 % and clay <6 % were measured in colluvial soils. Plant available phosphorus was reported at below 10 mg/kg in arid soils in India (Praveen-Kumar *et al*. 2009). The measured values of these soil properties at Trekkopje are therefore not unusual.

Trends over time

If rehabilitation has been successful, then a trend in indicators is expected towards the values measured at reference sites. In this study only two consistent trends were shown in variables which were also relatively stable at the reference sites: declining calcium content on the control, topsoil-covered and scarified sites (Figure 6c), and declining pH on the tailings.

Regarding the trend in pH, the tailings were treated with sodium bicarbonate and sodium carbonate during the leaching process resulting in a very high pH which is slowly declining to approach the pH of the reference sites. The uranium ore was then washed with fresh water before the start of alkaline heap leaching to remove salts such as sodium chloride, sodium sulphate and some of the calcium sulphate. Diverting from these trends is pH which was higher at tailings-treated and reference sites. This trend is therefore not natural, but man-made.

The declining trend in calcium on control, scarified and topsoil-treated sites could be due to the fact that large amounts of calcium were now exposed from the subsoil and gradually leached from the soil. Interestingly no such trend was shown in salinity at these sites, which according to the expected soil development processes should also be showing a decline over the years. However, this trend may be masked by the high variability in the soil and only evident in calcium because calcium content was initially extremely high.

Effect of rainfall

Only phosphorus content indicated a link to rainfall pattern with a large spike in phosphorus after the 2014 rains in the reference sites, but also evident at all other sites (Figure 8b). Phosphorus is believed to be in low supply in arid region soils (Praveen *et al*. 2009), which was supported by this study. It is also affected by carbonate, alkaline and calcic soils which bind phosphorus in insoluble form (Lajtha & Schlesinger 1988). Both the low content overall, and the effect of these alkaline soils may influence the results and not show consistent patterns or trends. The influence of rainfall needs to be seen in the light of these other variables. Soil processes in arid environments are not only driven by water availability, but the effect of light (photodegradation) and spatial heterogeneity also need to be taken into account (Austin 2011). Subsurface processes often have unique controls which are not directly linked to positive precipitation/primary production relationships (Austin 2011). In fact, decomposition in deserts is not necessarily correlated with annual precipitation, as demonstrated by a 10-year study in North America (Vanderbilt *et al*. 2008).

Carbonates accumulate during and after rains at the depth of water penetration in the soil (Crawford & Gosz 1982). As rainfall is extremely patchy in deserts this can result in a very uneven distribution of carbonate layers in the soil (Mac Mahon 1981). This relates to the contemporary carbonate distribution as much is represented by remnants of calcrete layers in the soil profile that were laid down in the past during more humid conditions. Another factor contributing to spatial heterogeneity of desert soils is the intensity of rainfall. Rains often fall in storm events which results in sheet wash and overflowing washes and rivers, depositing alluvial debris (Crawford & Gosz 1982).

The spike in available phosphorous at all sites in 2014 and 2015 could be related to a slow release of phosphorous following the 2011 rains, followed by a further stimulus of rain in 2014. Decomposition rates in deserts are very low (Fernandez *et al*. 2004) and it would therefore not be surprising if it takes three to four years until organic matter is broken down into available nutrients. The lack of a direct link between organic matter and soil organic carbon content may further support this hypothesis.

Towards soil indicators

In view of mostly inconclusive results, it is difficult to single out soil properties that may make useful indicators in this environmental setting in the short term. Calcium content is the only variable which, with some extrapolation, indicates an overall decline in the rehabilitated sites and thereby some form of soil development. In the natural course of events this is expected because the removal of calcium is the next step in soil development, once soluble salts have been removed. So far calcium content therefore provides the only usable indicator in the short term.

Soil organic content has always been advocated as a key indicator for soil fertility (Ruiz-Jean & Aide 2005), but the results of this study call this practice into question in arid areas. Organic matter content may not be an appropriate soil fertility indicator here, either because of the long lag period in the breakdown of organic matter or because this indicator is not directly affected by standing biomass and therefore does not necessarily guarantee that soils with high organic matter content are also best suited to support vegetation development.

Ultimately critical benchmarks in soil properties which facilitate plant establishment need to be established. Half of the rehabilitated sites (control, scarified and topsoil-treated) are presently sodic, saline and alkaline and therefore from a biochemical perspective unlikely to support the establishment of a lasting plant cover. Soil treatments may therefore be required to reduce salinity and sodicity. On the other hand, many desert plants are adapted to cope with high salinity (Evenari *et al.* 1982) and this may be less of a problem than anticipated. Surprisingly, annual grass established well after a reasonable rain event on another rehabilitated site on Trekkopje Mine with similarly "unsuitable" soil conditions (measured, but not presented here). This could be explained by the leaching of salts and loosening of the crust of the surface layers which was adequate to make the substrate suitable for the germination of grass. Whether this was a once-off event or the initiation of more permanent plant cover needs to be monitored.

Soil-plant relationships are poorly understood on a species-level for plant species in the study area and salinity tolerance levels are unknown. A study along a north-south transect through Namibia's semi-arid savanna and desert regions demonstrated well that plant species richness is likely influenced by salinity, clay content and pH (Medinski *et al.* 2010). Electric conductivity of 100 mS/m for example was cited as a threshold for supporting reasonable species richness (Medinski *et al.* 2010). Although salt tolerance levels of many cultivated plants have been established (e.g. Abbas *et al.* 2015; Demiral 2017; Kalantari *et al.* 2018), only some desert plants have been investigated. *Suaeda vera* can tolerate up to 1930 mS/m (Herrero & Castaneda 2013) and *Salsola soda* up to 1000 mS/m (Centofani & Banuelos 2015), which means most of the rehabilitated sites would be suitable for these two highly salt-tolerant species, if salinity was the only limiting factor. However, these two species are adapted to very high salinity and therefore exceptions – most Namib perennials likely require lower salinity levels to maintain healthy populations.

Implications for restoration monitoring

The monitoring of soil properties of rehabilitated sites at a mine in the central Namib illustrates the challenges restoration practitioners face when working in arid environments, which are similar to rehabilitated sites in other parts of the world (Lamp *et al.* 2015). Six years of monitoring soil properties generated inconclusive results. The question which treatments would provide the most effective restoration method could therefore not be answered. This means that much longer monitoring timeframes are needed, perhaps other indicators need to be included and the sampling intensified. Alternatively, the conventional approach to selecting monitoring parameters for restoration needs to be revisited in arid areas in favour of different methods altogether to demonstrate an "ecologically functioning" ecosystem. Researchers have suggested "state-and-transition" models (Westoby *et al.* 1989; Hobbs *et al.* 2014) as a more appropriate benchmark in arid ecosystems. However, this requires that the variables driving individual "states" and potential thresholds for tipping points in particular environmental settings are well understood at a habitat level.

This is not the case in the central Namib and collecting more information on ecological processes is therefore required in the meantime. Despite the fact that, apart from calcium content, no other soil properties showed clear trends, a standard farm analysis of the soil should be continued as part of the monitoring programme. However, the number of subsamples for bulking should be increased and tested whether this reduces in-site variability of soil properties. (1) Trends may emerge in other properties after a longer time and (2) these properties are required to calculate other indices of soil fertility and characterisation. If costs are a limitation, monitoring frequencies could be reduced to two- or even three-year intervals. Exceptional rainfall seasons, however, should always be monitored as this is when changes are likely to be detected.

Although this study by sampling is a case study and limited to descriptive statistics, several case studies investigating the same questions and showing similar results may eventually allow the drawing of generalised conclusions (Tavares *et al.* 2016). Presentation of these monitoring data also provides information to other researchers in this field and assists in designing appropriate monitoring protocols. Most restoration projects do not plan for long timeframes (Ngugi & Neldner 2015), but this study indicates that it is compulsory in an arid setting and long-term data collection which consistently applies the same methodology is essential.

CONCLUSIONS

Rehabilitated sites in the arid Namib Desert showed no clear trends in soil properties over a six-year monitoring period, except in calcium content at subsoil-dominated sites. Soil organic carbon content was not correlated with standing biomass and it is therefore questionable whether it provides a suitable indicator for soil fertility in arid regions in a restoration context.

Long term, site-specific monitoring is needed in arid regions to illustrate recovery of disturbed sites by means of process indicators. However, whether benchmarks derived from comparable natural environments can ever be reached within the timeframe usually applied to restoration projects is questionable.

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Plant endemics of the Tsau‖Khaeb (Sperrgebiet) National Park

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ABSTRACT

Endemic plant species of the Tsau‖Khaeb (Sperrgebiet) National Park in south-west Namibia were determined by reviewing spatial distribution data. These included accessible data sources at the National Botanical Research Institute in Namibia and online as well as published literature. A total of 31 strict park plant endemics, which includes 11 local endemics, was identified. Another 33 taxa are considered broader park endemics, as these can also be found just outside the borders of the park. The level of protection a taxon should receive increases with decreasing range size, making the local endemics good indicators for environmentally very sensitive habitats.

Keywords: endemic; Namib Desert; Namibia; range size; red data; Sperrgebiet; Succulent Karoo Biome; Tsau‖Khaeb National Park

INTRODUCTION

Every country has an obligation to protect its endemic species. In practical terms this is the responsibility of conservation staff. They have a particular duty to protect and manage the endemic species which occur within their respective areas. To do this effectively conservation staff need to know which species are endemic to a particular area.

Over the past three years there has been renewed focus on the Tsau‖Khaeb (Sperrgebiet) National Park (TKSNP) by the Ministry of Environment, Forestry and Tourism in order to better manage natural resources and develop tourism in the park. Park staff have a special responsibility to ensure that populations of species endemic to the park are not compromised by inconsiderate developments. The park is a recognised centre of plant endemism in Namibia (Van Wyk & Smith 2001, Craven 2002), but no list of plant endemics has been published to date. A list is necessary because:

1) The park is endowed with the richest flora anywhere in Namibia (Burke & Mannheimer 2004).

2) The largest component of this rich flora at a family level, the Aizoaceae (or Mesembryanthemaceae, also known as mesembs, vygies or midday flowers) is a fast and still evolving group of succulent plants (Klak *et al.* 2004). As a consequence these plants undergo constant taxonomic changes (e.g. Klak *et al.* 2007, Snijman 2013). Keeping up-to-date with these changes is a challenge.

3) Endemism requires a clear definition of area under investigation to be meaningful. For example, country boundaries are useful for administrative purposes, but often irrelevant in an ecological context. Geographic boundaries such as those defined by watersheds, mountains ranges or rivers are far more real in the natural world. However, protected area boundaries are useful for management purposes.

The aim of this paper is to present an account of the plants endemic to the TKSNP in south-west Namibia, present a management-orientated concept of endemism and describe the process, reasoning and information that led to this account.

METHODS

Study Area

The TKSNP is situated in the south-westernmost corner of Namibia. It is bordered by the Orange River in the south, the Namib Sand Sea in the north and the Atlantic coast in the west (Figure 1). The eastern boundary runs at some 75 to 100 km distance from the coast along the base of the escarpment. The climate is arid, with annual mean rainfall of 17 mm at Lüderitz and approximately 50 mm at Oranjemund and Rosh Pinah. The area lies in a transitional zone of winter- and summer rainfall in southern Africa. Fog occurs regularly and almost constant, strong, south to south-westerly winds batter plants, animal life and landforms. Landforms are varied, dictated by the underlying geology, and form an interlaced mosaic of vast sand plains, gravel and calcrete pavements, shifting dunes, inselbergs, pans, dry rivers and mountain ranges.

The vegetation of the study area is succulent shrubland of the Succulent Karoo Biome and grassland and shrubland of the Nama Karoo and Desert Biomes. Plant diversity is high and over 1,000 vascular, indigenous plant species have been recorded in the park (Burke & Mannheimer 2004).

Data compilation

The list of endemics was compiled from distribution data obtained from the Botanical Research and Herbarium Management System (BRAHMS) of the National Botanical Research Institute (NBRI), Windhoek, Namibia, and the published species list for the Sperrgebiet (Burke & Mannheimer 2004) as a starting point. Additional records and taxonomic changes were added from the literature, internet sources and own field observations. Table 1 lists the reviewed sources. This also includes references to species which were later excluded from the lists of endemics. Most data are held in a quarter degree grid resolution (15 minute intervals on a longitude-latitude grid), and these spatial data were used to map species' distributions.

Clear definitions of the area to which a species is endemic are required. As this is a study in a local context and needs to be useful for management purposes, we have been specific in the definitions (Table 2). Summary data are compiled for the number of taxa, which includes species, subspecies and varieties where applicable.

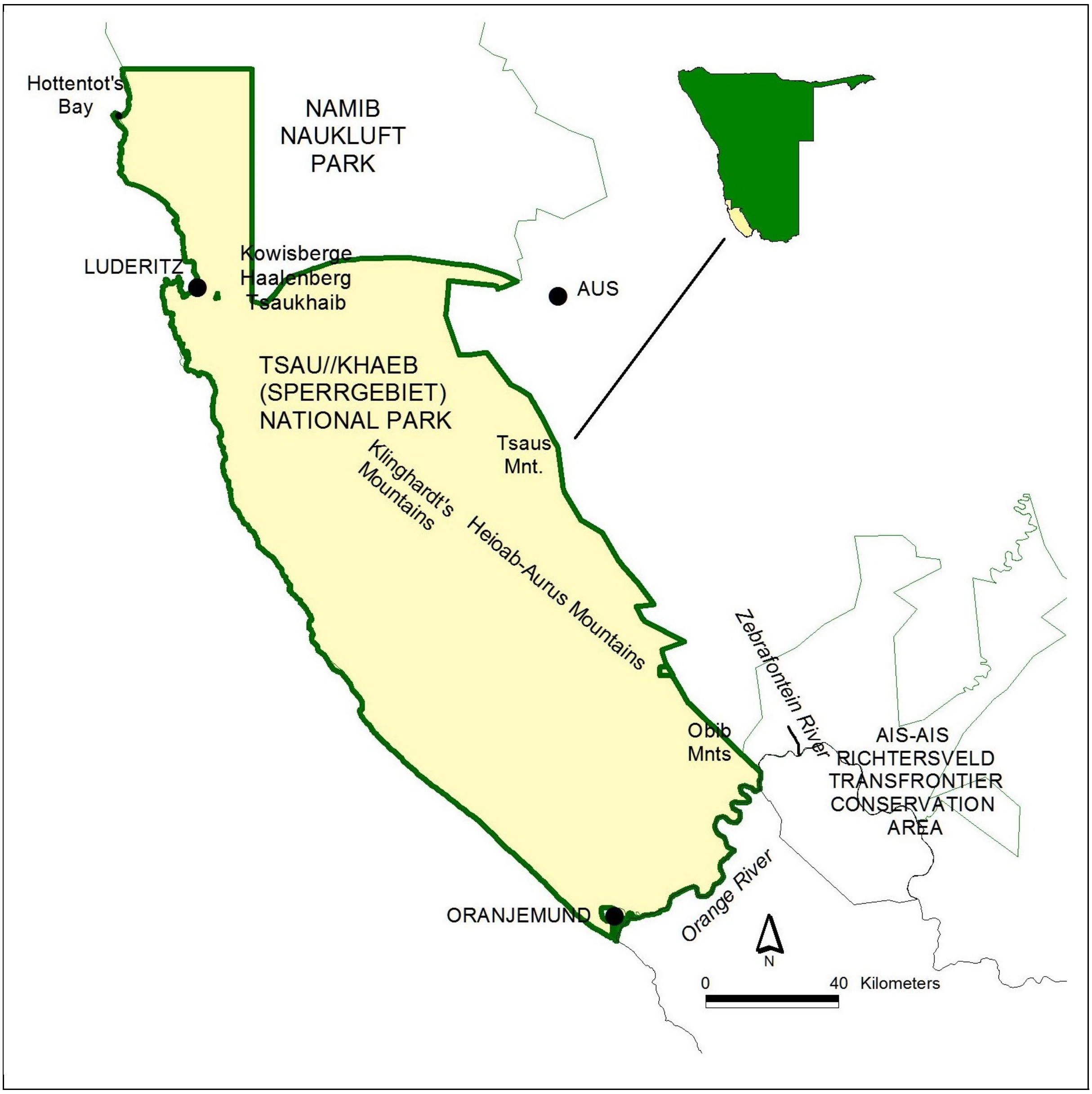

__Figure 1:__ Location of Tsau‖Khaeb (Sperrgebiet) National Park, landmarks and adjoining conservation areas.

Table 1: *Sources reviewed to assess taxonomic status and geographic distribution of plant species potentially endemic to the Tsau||Khaeb (Sperrgebiet) National Park.*

Source	Information	Comment
Databases		
BRAHMS database of the National Botanical Research Institute in Windhoek	List of species for all quarter degree squares covered by the park	Data not completely up-to-date
BRAHMS online	Open access distribution records of specific species	Few TKSNP endemics included
SANBI Red List	Red List assessments of South African species	If included, then not endemic to the Sperrgebiet
BIOTA	Online BIOTA southern Africa plant species list of observatories	
World Flora online	Kew Botanic Gardens' comprehensive plant list of the world	
JSTOR	Digital library of academic literature	
Literature		
Merxmuller & Schreiber (1966)	*Pelargonium sibthorpiifolium*	
Marais (1966), Schreiber (1979)	*Heliophila obibensis*	
Schreiber (1968), Liu *et al*. (2007)	Revision of *Marlothiella gummifera*	
Herre (1971)	Genera Mesembryanthemaceae	
Botschantzev (1973, 1974, 1978)	*Salsola namibica*, *S. schreiberae*, *S. dolichostigma*	
Obermeyer (1976)	*Frankenia pomonensis*	
Van der Walt & Vorster (1981)	*Pelargonium cortusifolium*	
Barker (1983, 1987)	new *Lachenalia* species	
Duncan (1998)	*Lachenalia nutans*	
Hartmann (1998)	*Amphibolia*, *Antimima* and *Eberlanzia*	
Smith *et al*. (1998)	Mesembryanthemaceae genera	
Gibbs Russel (1991), Launert (1968-1972)	*Stipagrostis*	
Williamson (1992, 1995, 1998)	*Bulbine francescae*, *Crassula aurusbergensis*, *Tylecodon aurusbergensis* and *T. aridimontanus*	
Perry (1994)	*Eriospermum buchubergense*, *E. halenbergense*	
Snijman (1994)	*Strumaria phonolithica*	
Rundel *et al*. (1999)	Species investigated in Richtersveld include some supposed Namibian endemics	
Van Wyk & Smith (2001)	Gariep endemics	
Cole (2000, 2005)	*Lithops hermetica*, *Lithops*	
Vollesen, (2000)	*Blepharis meyeri*	
Craven (2002), Craven & Vorster (2006)	List of endemic plant species for Namibia	
Hartmann (2002)	Handbook of succulent plants	
Hammer (2002)	*Conophytum* species	
Germishuizen & Meyer (2003)	Distribution of southern African plant species	
Nussbaum (2003)	List of species from vegetation types in the Richtersveld	
Burke & Mannheimer (2004)	Plant species list for the Sperrgebiet	
van Jaarsveld & Koutnik (2004)	*Cotyledon* and *Tylecodon*	
Loots (2005)	Distribution of prioritised plant species evaluated against IUCN Red List criteria	
Mannheimer (2006)	Revision of *Dracophilus*, *Juttadinteria* and *Namibia*	
Mucina *et al*. (2006)	Species lists for southern African vegetation types	
Klak *et al*. (2007)	Revision Mesembryanthemaceae	
Jürgens *et al*. (2010)	BIOTA data (Volume 1)	
van Wyk *et al*. (2010)	*Polemanniopsis namibensis*	
van Jaarsveld & Swanepoel (2011)	*Tylecodon paniculatus*	
Goldblatt & Manning (2013)	new *Moraea* in Aurus mountains	
Klaassen & Kwembeya (2013)	Species considered endemic to Namibia	
Snijman (2013)	Extra Cape flora (Namaqualand and southern Namib)	
Bruyns (2014)	Latest treatment of Apocynaceae in Namibia	
Kolberg & Van Slageren (2014)	*Pteronia*	
Jainta (2017)	*Lithops*	
Boatswright (2018)	*Calobota namibensis*	

Table 2: *Definitions of endemism used to categorise plant species in Tsau||Khaeb (Sperrgebiet) National Park (TKSNP).*

Endemism	Definition
Local endemic	TKSNP endemics which are presently only known from one or two localities or quarter degree squares within the park.
TKSNP endemic	Restricted to within the boundaries of the TKSNP.
TKSNP – NNP endemic	Main distribution is in TKSNP, but also occurring marginally in Namib-Naukluft park (NNP), such as Spencer Bay, Haalenberg, Kowis mountains and other inselbergs in the southern Namib sand sea.
TKSNP – Aus endemic	Main distribution is in TKSNP, but also recorded at Aus.
TKSNP – Orange River endemic	Main distribution is in TKSNP, but also recorded just south of the Orange River and in the Richtersveld, but not extending east of the Zebrafontein River.

RESULTS AND DISCUSSION

Overall summary

Based on our definitions and currently available data, there are presently 31 strict TKSNP endemics (Appendix 1). These comprise 11 local endemics and 20 spatially less restricted taxa. Fourteen taxa also occur nearby in the Namib-Naukluft Park, mostly just north of the public road from Lüderitz to Aus. Another three taxa are also recorded at Aus and 16 taxa also occur across the Orange River in South Africa. This amounts to a total of 64 plant taxa which can be considered endemic to the park in a broader sense. This will need to be reviewed and updated when new information becomes available.

Local endemics

Except for *Salsola hottentottica*, this group includes only taxa growing in mountain, inselberg or otherwise rocky habitats. Such local endemics are found in the Klinghardt, Tsaus, Obib and Aurus mountains. They are often habitat specialists and therefore very rare. *Lithops hermetica* for example, is found on light-coloured, calcareous substrate within darker limestone on the Tsaus mountains (Jainta 2017). This is possibly one of the harshest environments in which *Lithops* can be found (Loots 2019). One of the two miniature *Tylecodon* species, *T. aurusbergensis*, only grows under shaded overhangs or in cracks of steep, south- to west-facing slopes of inselbergs or mountains. Two *Conophytum* species, *C. taylorianum* subsp. *taylorianum* and *C. klinghardtense* subsp. *baradii* are only known from one or two localities, respectively. Whether this indicates habitat specificity or simply a lack of distribution data requires some further investigation (Young, pers. comm., May 2019).

The local endemics present a variety of growth forms. These include dwarf succulents, for example *Conophytum klinghardtense* (both subspecies), *Lithops hermetica*, *Tylecodon aridimontanus* (Figure 2) and *T. aurusbergensis*, herbs (*Heliophila obibensis*), shrubs (*Blepharis meyeri*), as well as bulbs, for example *Eriospermum buchubergense* and *Lachenalia nutans*. Point or local endemics are inevitably also strict park endemics. The list of local endemics is, however, likely to change once more distribution data become available. Some of these plants are extremely cryptic and difficult to identify and may have been overlooked in field surveys. Others, such as the elusive bulb *Eriospermum buchubergense*, have only been observed once. However, for management purposes local endemics and their habitats deserve the highest protection until it is proven that they are not as limited in distribution as presently known. This follows the precautionary principle recommended in environmental management and red-listing procedures (Keith *et al.* 2000, Matsuda 2003).

TKSNP endemics

The strict park endemics largely comprise plants growing in the coastal area and therefore within the fog belt, such as *Brownanthus namibensis*, *Euphorbia verruculosa*, *Frankenia pomonensis* (Figure 2), *Marlothiella gummifera* and *Namibia cinerea*, or plants restricted to mountains and inselbergs. Examples of the latter are *Antimima aurasensis*, *Crassula aurusbergensis*, *Eriocephalus klinghardtensis* and a recently found new species of *Ornithogalum*. Only *Drimia secunda* and *Polemanniopsis namibensis* do not neatly fit into these two categories. *Drimia* grows on sand plains throughout the park and *Polemanniopsis* on plains and rocky ridges in a few scattered localities north and south of the Kaukausib valley.

TKSNP – NNP endemics

All endemics growing on the northern inselbergs of the park, such as Kowis mountains and Haalenberg, invariably also occur in the Namib-Naukluft Park as these mountains stretch across the park boundary. Some coastal endemics occur further north than the park boundary at Hottentot's Bay such as *Ectadium virgatum* subsp. *latifolium*, *Eremothamnus marlothianus* and *Pelargonium cortusifolium*. The TKSNP-NNP endemics also represent all growth forms, except for herbs. Most are however either shrubs or compact leaf-succulents.

***Figure 2:** Selected plant endemics of the Tsau‖Khaeb (Sperrgebiet) National Park (Photos: A. Burke). a)* Polemanniopsis namibensis *grows in a few isolated populations in the northern part of the park; b) The local endemic* Tylecodon aridimontanus *is presently only known from the Heioab mountain; c)* Hoodia officinalis *subsp.* delaetiana *growing from cracks in the Klinghardt Mountains; d)* Frankenia pomonensis *is restricted to the Sperrgebiet's coastal area.*

TKSNP – Aus endemics

Three species with their main distribution in the TKSNP have also been recorded at Aus, just outside the park boundaries: the bulbs *Oxalis luederitzii* and *Trachyandra lanata* and the grass *Stipagrostis lanipes*.

TKSNP – Orange River endemics

Another 15 species with their main distribution in the TKSNP extend across the Orange River into South Africa. With three exceptions, the shrubs *Cynanchum meyeri*, *Rhyssolobium dumosum* and *Salsola araneosa*, these are all succulents and include one succulent herb, *Synaptophyllum juttae*. *Lithops herrei*, which also occurs south of the Orange River in South Africa, is in the process of being merged with *L. optica* (Loots *et al*., in prep). *Lithops optica* was formerly classified as a TKSNP endemic, but can now only be considered a TKSNP – Orange River endemic. The distribution of *Rhyssolobium dumosum* is not entirely clear. There is a record from Vioolsdrif in South Africa which is east of the Zebrafontein River. However, since this is the only record of *R. dumosum* so far east we have provisionally included the shrub in the list of Sperrgebiet – Orange River endemics. *Juttadinteria deserticola* is included in this group, but its range also extends north into the Namib-Naukluft Park. It could have been counted in either category.

The level of plant endemism in the TKSNP is exceptional and likely not surpassed by any other park in Namibia. Parks in South Africa in the Succulent Karoo Biome, however, likely match this level of endemism. The Richtersveld National Park for example, which is less than 10 % of the size of the TKSNP has at least 16 plant endemics (Williamson 2002).

Taxonomic uncertainties

Although we have strived to use only reliable information when compiling species distributions, errors through misidentification are not completely eliminated. Difficult groups of plants to identify are for example the *Antimima* and *Salsola* species, and South African and Namibian botanists treat certain groups differently.

The genus *Salsola*, for example has been split into innumerable species (Botschantzev 1974) and the validity of this taxonomic treatment needs to be confirmed (Kadereit, Mucina, pers. comm., October 2019). *Salsola namibica*, for example, was considered a Namibian endemic by the NBRI, but we have found records from the Richtersveld (Mucina *et al*. 2006). This is one case where possibly a different interpretation of the taxonomic treatment of *Salsola* by Botschantzev (1974) has been adopted by Namibian and South African botanists. Another example is *Antimima perforata* which is considered endemic to Namibia in the NBRI's species list (Kwembeya & Klaassen 2013), but has been recorded in Namaqualand (Nussbaum 2003). Whether this is a different interpretation of the taxonomic treatment or indeed a new distribution record requires further investigation in the field. This challenge has also been noted by Craven in her studies of the endemic flora of Namibia (2002, 2009).

The *Salsola* species received intensive review for this paper but there are conflicting records and we finally followed Botschantzev's (1974) synopsis and eliminated all species which he indicated to also occur in South Africa. This means *Salsola luederitzensis* is no longer considered endemic as indicated in the NBRI's plant species list (Kwembeya & Klaassen 2013). *Salsola schreiberae* has in the meantime also been recorded on a farm neighbouring the Sperrgebiet and, although remaining a Namibian endemic, it is no longer considered a TKSNP endemic. Thus only *S. hottentottica* remains as a local endemic, so far only recorded from Hottentot Bay. As evident by the confusion reigning even amongst specialists, the genus *Salsola* requires some urgent attention. The Namibian species of *Salsola* have all been transferred back to *Caroxylon* (Mucina 2017), but the NBRI will retain them as *Salsola* for the time being (Chase, pers. comm., October 2019).

There are also potential identification errors in the Namibian plant database. There are records of *Pelargonium cortusifolium* from far inland on the Orange River, although it is assumed to be a coastal species. It is very difficult to differentiate *P. cortusifolium* from *P. crassicaule* and that could have resulted in a misidentification. We have therefore included *P. cortusifolium* in the current list of TKSNP endemics.

Ectadium latifolium was merged with *E. virgatum* on the plant species list for Namibia (Kwembeya & Klaassen 2013). Yet it is a valid subspecies according to World Flora online (World Flora online 2019) and is now recognised as *E. virgatum* subsp. *latifolium*.

One species was excluded because of doubtful taxonomic status: *Crassula luederitzii*. This is considered to be a synonym of *C. capitella* subsp. *thyrsiflora* (World Flora online, accessed September 2019). The species *Dracophilus proximus* and *D. montis-draconis* were merged with *D. dealbatus* and *Juttadinteria suavissima* was partly merged with *J. ausensis* and partly with *J. deserticola* after Mannheimer's (2006) revision. The status of *Juttadinteria kovisimontana* was not entirely clear and has been recommended for further studies (Mannheimer 2006). We have included *J. kovisimontana* in the current list of endemics.

Practical implications for management

By providing a detailed description and in-depth analysis of the status of endemic plants in the TKSNP, we urge natural resource and park managers to adapt their management of endemics to the conservation needs of these plants. As a general principle, the level of protection a plant species should receive increases with decreasing range. Thus the local endemics and their habitats should receive the highest protection, followed by park endemics and then the broader park endemics. Although the range size does not provide an indication of abundance, it is the closest proxy for rarity that is presently available. The next step in raising the status of TKSNP endemics will be a thorough revision of their current evaluation against red-list criteria and determining the population status of selected range-restricted species (e.g. Cousins *et al*. 2014, Phama *et al*. 2014).

CONCLUSIONS

Knowing which endemics are present is important in order to apply appropriate management strategies, such as using endemics as indicators for environmentally sensitive habitats and locations and developing suitable protection measures where necessary. Despite some taxonomic uncertainties, 31 plant species are presently considered strictly endemic to the TKSNP. Although detailed accounts have so far not been published, it is very likely that no other national park in Namibia can match this level of plant endemism.

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Appendix 1. *Plant endemics of the Tsau‖Khaeb (Sperrgebiet) National Park, endemism defined as in Table 2.*

1. Local endemics

Blepharis meyeri
Conophytum klinghardtense ssp. *baradii*
Conophytum klinghardtense ssp. *klinghardtense*
Conophytum taylorianum ssp. *taylorianum*
Eriospermum buchubergense
Heliophila obibensis
Lachenalia nutans
Lithops hermetica
Salsola hottentottica
Tylecodon aridimontanus
Tylecodon aurusbergensis

2. Strict TKSNP endemics

Antimima aurasensis
Antimima dolomitica
Brownanthus namibensis
Bulbine francescae
Crassula aurusbergensis
Crassula elegans ssp. *namibensis*
Drimia secunda
Eriocephalus klinghardtensis
Euphorbia verruculosa
Fenestraria rhopalophylla
Frankenia pomonensis
Hoodia officinalis ssp. *delaetiana*
Lessertia cryptantha
Marlothiella gummifera
Namibia cinerea
Ornithogalum sp.nov.
Polemanniopsis namibensis
Psammophora saxicola
Pteronia spinulosa
Strumaria phonolithica

3. TKSNP endemics and also extending into NNP

Amphiglossa thuja
Conophytum halenbergense
Ectadium virgatum ssp. *latifolium*
Eremothamnus marlothianus
Eriocephalus kingesii
Eriospermum halenbergense
Juttadinteria kovisimontana
Juttadinteria simpsonii
Calobota namibensis
Lithops francisci
Namibia ponderosa
Pelargonium cortusifolium
Salsola dolichostigma
Trachyandra peculiaris

4. TKSNP endemics and also recorded at Aus

Oxalis luederitzii
Stipagrostis lanipes
Trachyandra lanata

5. TKSNP endemics and also occurring just south of the Orange River

Antimima buchubergensis
Antimima perforata
Astridia hallii
Cynanchum meyeri
Euphorbia angrae
Juttadinteria albata
Juttadinteria deserticola
Lithops optica
Othonna clavifolia
Pelargonium sibthorpiifolium
Psammophora longifolia
Rhyssolobium dumosum
Ruschia pollardii
Salsola araneosa
Synaptophyllum juttae
Tridentea pachyrrhiza

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A perfect storm? The impact of COVID-19 on community-based conservation in Namibia

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Abstract

We report on a rapid survey of five communal-area conservancies in Namibia to understand initial impacts on community-based conservation of national and international policies for dealing with the COVID-19 pandemic. Namibia's Community-Based Natural Resources Management (CBNRM) programme has been growing for over 30 years, with high economic reliance on tourism and conservation hunting. We review the interrelationships between COVID-19, CBNRM, tourism and hunting, and discuss our findings under eight interlocking themes: 1) disruption to management and regular operational processes of conservancies, including 2) effects on conservancy wildlife patrolling and monitoring; 3) losses of revenue and cash flow in conservancy business operations; 4) impacts on Joint-Venture Partnerships; 5) impacts on employment opportunities and local livelihoods; 6) effects on community development projects and social benefits, including 7) disruption to funded projects and programmes; and 8) lack of technical capacity regarding communication technologies and equipment. In our conclusion we discuss tensions between an assumption that normal business can or will be resumed, and calls for the COVID-19 pandemic to create an opportunity for global choices away from 'business-as-normal'. It is too early to tell what mix of these perspectives will unfold. What is clear is that communal-area conservancies must derive benefits from conservation activities in their areas that are commensurate with their role as key actors in the conservation of Namibia's valuable wildlife and landscapes.

Keywords: communal-area conservancies, Community-Based Natural Resource Management (CBNRM), conservation hunting, COVID-19 pandemic, Namibia, rural livelihoods, tourism, wildlife

1. Introduction

> "*COVID-19 is testing the years of investment in CBNRM across all thematic areas. If this global pandemic is not well managed both in Namibia and globally the CBNRM programme will be on the edge of falling apart, given the umbilical cord of the programme attached to conservation hunting and tourism.*"
> (Teo Ntinda, Namibia Development Trust (NDT), April 2020).

We report on a rapid survey conducted in April 2020 to assess the initial impacts of the COVID-19 virus and associated social distancing and travel restriction regulations on communal-area conservancies in Namibia. The survey investigated the effects of COVID-19 on community participation in, and benefits from, Namibia's Community-Based Natural Resources Management (CBNRM) programme. In doing so it provides some space for conservancy managers, committee members, residents and workers to share their experiences and perceptions of the first weeks of this unprecedented event.

Since independence, CBNRM has been a key contributor to economic development and environmental conservation in Namibia's rural communal areas (Biesele & Hitchcock 2011, Naidoo *et al*. 2016, Jacobsohn 2019). Following the proclamation of legislation to formalise Namibia's CBNRM programme in 1996, community-based conservation and tourism have succeeded in growing both income and capabilities for many rural Namibians, whilst also leading to sustained and increased wildlife populations in Namibia's communally-managed areas. Critical for this success is the establishment of conservancies in Namibia's remaining communally-managed areas, in which conservation practice is devolved to some extent to locally-run institutions that have rights to manage, utilise and benefit from local natural resources and wildlife (Snyman 2014, Naidoo *et al*. 2016, MET/NACSO 2018).

The location and tenure of these communal-area conservancies are an outcome of Namibia's specific historical circumstances. This history gave rise to a division between surveyed freehold farms allocated to settlers by the country's colonial and apartheid governments, separated from areas forming so-called 'Native Reserves' and 'Homelands' where peoples autochthonous at the advent of colonial rule were constrained to live and that have remained under communal forms of tenure and management (Sullivan 2018). Part of a broader movement towards CBNRM and diversified livelihood possibilities in southern Africa from the early 1990s onwards (Fabricius *et al*. 2004), at the time of writing, Namibia has 86 registered communal-area conservancies, with some 227,941 people residing in these conservancies (MET/NACSO 2020).[1]

The unprecedented current pandemic of COVID-19 is forcing review of how conservation in rural areas can remain viable amidst such disruption, and how communal-area communities can continue to derive benefits from conservation activities (Kaelo *et al*. 2020). COVID-19 is already impacting the world's economies in many sectors (Ozili & Arun 2020) and community-based conservation is not spared. Although presumably a temporary measure, a primary current challenge for day-to-day conservancy work relates to social distancing, which affects the ability of managers and members to meet each other and thus impacts on community participation dimensions of CBNRM. Wildlife populations require ongoing management, including for population monitoring, protection and human-wildlife conflict (HWC). It is thus crucial to understand how the innovative models for wildlife management applied by different conservancies are affected by these new circumstances. Given the dependence of communal-area conservancies on hunting and tourism as their main sources of income, it is also critical to understand how the current international and national lock-down and travel ban is affecting these sources of income to conservancies and their inhabitants.

We proceed by first providing some background to the COVID-19 / CBNRM web of interconnections in Namibia's communal-area conservancies. We then report on our rapid response telephone survey with respondents in five of Namibia's communal-area conservancies (see Section 3 on methods, and Section 4 on findings). We close with a brief conclusion observing that present uncertainty arises in part from a tension between assumptions that normal business can or will resume, and calls for the COVID-19 pandemic to create an opportunity for global choices away from 'business-as-normal'.

2. Outlining the COVID-19 / CBNRM web in Namibia's communal-area conservancies

COVID-19 is a highly contagious disease caused by a newly evolved coronavirus (World Health Organisation 2020) which has caused an outbreak of respiratory illness globally (Sauer 2020). The human-to-human transmission of COVID-19 is believed to have emerged in China in December 2019. Early hypotheses of the spread of the virus are linked to a wet market (i.e. a market selling wildlife, fresh meat and fish) in Wuhan, China, from which it spread to nearly every country worldwide (Sauer 2020), prompting the World Health Organization (WHO) to declare the coronavirus (COVID-19) a global pandemic. As of 28 June 2020, some 9.8 million coronavirus cases have been confirmed worldwide, with 495,760 deaths in 216 countries (World Health Organisation 2020). Namibia has reported an increase in COVID-19 cases from 8 in March to 183 cases as of 28 June 2020 (The Namibian 2020). The high rate of transmission and the fact that no specific cure or treatment have yet been found is causing global anxiety.

The Namibian government declared a state of emergency and national lockdown in March 2020 with immediate effect (The Namibian 2020, Jantze 2020). The country's national borders were closed, and Namibia's National Parks were closed to tourists from 18 April to 5 May (CGTN Africa 2020). Travel within the country was restricted, social gatherings were banned, and social distancing was enforced (Jantze 2020). The restrictions prevented tourists from visiting Namibia and continue to reduce travel within the country, constraining gatherings of people in venues served by the hospitality industry (such as restaurants, bars, conference facilities and hotels).

These travel restrictions have clear impacts on the country's tourism industry, a priority strategic sector for the country's socio-economic development and employment (Kavita & Saarinen 2016) that has exhibited dramatic growth since independence. Under normal circumstances, tourism is Namibia's third largest sector in terms of Gross Domestic Product (GDP), contributing in 2015 around N$ 15.1 billion to the broader national economy (10.2 % of GDP) and providing 100,700 jobs (14.5 % of total employment) (Namibia Tourism Board 2016).[2] Since the onset of COVID-19, however, significant retrenchments of staff in major tourism and hospitality businesses have already occurred (Ngatjiheue 2020). Much of Namibia's tourism in communally-managed areas (as well as elsewhere), is linked to wildlife conservation and trophy-hunting (Naidoo *et al*. 2016). Through wages and salaries these businesses provide the greatest sources of cash income to households in communal-area conservancies (Long 2004, MET/NACSO 2018), although financial gains at household level remain limited with most conservancy collective revenue going towards operating costs (Silva & Mosimane 2013, Schnegg & Kiaka 2018). Data for 2018 from the Ministry of Environment and Tourism (MET, now Ministry of Environment, Forestry and Tourism, MEFT) and the Namibian Association of CBNRM Support Organisations (NACSO) (MET/NACSO 2020) indicate that: 38 conservancies were directly involved with tourism activities, including 61 joint-venture tourism agreements with enterprises employing 1,175 full-time and 50 part-time staff; conservancies hosted some 48 conservation hunting concessions with 159 full-time and 119 part-time staff members; and community-based conservation through conservancies and community-forests had a return of N$ 147 million, of which Joint-Venture tourism accounted for

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[1] Figures held by the Namibian Association of CBNRM Support Organisations (NACSO) at http://www.nacso.org.na/conservancies#statistics, last accessed 25 June 2020.

[2] Currencies are currently quite volatile. At the time of first submission of this article, US$ 1=N$ 18.22 (19 May 2020), and at the time of revised submission US$ 1=NS$ 17.38 (25 June 2020) (figures from https://www.xe.com/).

approximately 64 % of cash income and in-kind benefits to these local institutions and their members. Paxton (2020) estimates that the general effect of the pandemic in Namibia will cause losses of N$ 55.3 million in annual tourism revenue and N$ 60.4 million in salaries to staff living in conservancies.

Conservancies in Namibia's remaining communal areas play a large role in supporting Joint-Venture (JV) tourism and hunting enterprises linked with wildlife conservation (MET 1995, MET/NACSO 2018). In turn, conservation in communal-area conservancies is primarily identified with conservancy employment (Snyman 2014, MET/NACSO 2018) as well as tourism and trophy-hunting incomes (Thakadu *et al*. 2005, Spiteri & Nepal 2008, Naidoo *et al*. 2016, Cooney *et al*. 2017, MET/NACSO 2018). These structural CBNRM interconnections mean that COVID-19 and its associated restrictions are precipitating a 'perfect storm'[3] of impacts deriving from these interconnections. Specifically, losses of tourism-related jobs and future opportunities in areas where tourism is one of few employers, may impact negatively on peoples' perceptions towards tourism and its links with conservation (Snyman 2014, Greenfield & Muiruri 2020). In addition, and international controversies notwithstanding (see summary in Koot *et al*. 2020), it has been shown elsewhere that if trophy-hunting (reframed in Namibia as 'conservation hunting'[4]) and associated revenue becomes non-viable, then this might have negative effects on both income and (attitudes to) wildlife populations (Cooney *et al*. 2017, Mbaiwa 2017). This might especially be the case in Namibia where conservation hunting has been observed to contribute higher incomes to conservancies than tourism in some cases (Naidoo *et al*. 2016)[5]. These circumstances also sit within a growing debate on the banning of wildlife trade so as to prevent future pandemics and which could potentially affect the export of hunting trophies, as well as discussions regarding COVID-19 recovery and how countries can rebuild their economies (Paxton 2020).

Associated socio-economic impacts may include reduced income to support social development projects and provide financial sustainability to compensate communities for losses incurred due to HWC, and reduced possibilities for diversified income-generation based on natural products, including the sale of crafts and indigenous plant products (Cole 2014, MET/NACSO 2018, 2020)[6]. From the perspective of wildlife conservation specifically, and given that a key part of conservancy employment relates to wildlife patrols and monitoring, connected concerns relate to the ability of community-based conservation organisations to safely sustain these activities (Namibia Economist 2020, Paxton 2020, Roth 2020, Shikongo 2020, Somerville 2020).

This brief review of literature suggests that the impacts of COVID-19 on the web of community-conservation enterprises and concerns will be severe, in both extent and magnitude. The remainder of this paper reports on the presently experienced and perceived implications of COVID-19 on communal-area conservancies, drawing on telephone interview material with respondents in five of the country's conservancies.

3. Research Methods

A semi-structured telephone interview survey with supporting WhatsApp communications was carried out by between 5th and 15th of April in five of Namibia's communal-area conservancies, drawing on principles for 'rapid rural appraisal' (Chambers 1984) in a time when the country's stage one lockdown meant that travelling and social interactions were prohibited. Our selected conservancies were King Nehale (Oshikoto, north-central), Ehirovipuka (Kunene, north-west), Tsiseb (Erongo, north-west), Wuparo (Zambezi, north-east) and Nyae Nyae (Otjozondjupa, east) (see Figure 1 and Table 1). They were selected to represent different regions in Namibia, as well as to allow us to build on demographic and other information already gathered for these conservancies through their inclusion in studies carried out recently by the University of Namibia[7]. We followed a 'snowball sampling' methodology (Monette *et al*. 2018) by calling focal people in our sampled conservancies who spoke to and led us to other committee, staff and community members, as well as a JV investor and lodge manager in Ehirovipuka and Wuparo conservancies respectively. This approach meant that

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[3] A 'perfect storm' is a phrase used in English to describe a rare combination of events or circumstances that occur together, usually creating a very challenging situation.

[4] See, for example, https://www.conservationhunting.com/.

[5] In 2018 conservation hunting (including all cash income and meat distributed to conservancies and members) accounted for N$ 34,463,053, or 23.4 % of conservancies' cash income and in-kind benefits (MET/NACSO 2020). Note, however, that some care is needed in calculating monetary values for game meat from weight prices for meat from domestic livestock. These different kinds of meat may not be considered to have equivalent local values, and such calculations may thus over-estimate monetary values for game meat (see discussion in Sullivan 2018).

[6] The harvesting of organically certified devil's claw (*Harpagophytum procumbens*) and *Commiphora* resin in particular generate income in the north-east and north-west respectively (Cole 2014). Craft production enabled by craft markets established by conservancies and linked with tourism provide a steady income to producers who are often women, with some N$ 1,748,405 generated in recent annual income (MET/NACSO 2020).

[7] Recent research activities in the study areas focused on in this paper include (a) work on Nyae Nyae Conservancy (Lendelvo *et al.* 2019), (b) gender and stakeholder assessment for a recent UNDP (United Nations Development Programme) and MEFT project on Human-Wildlife Conflict and Wildlife Crime in Namibia (2019) of which Tsiseb, Wuparo, Ehirovipuka and King Nehale are among the focal conservancies; (c) UNAM/MRC (University of Namibia/Multidisciplinary Research Centre) funded projects in 2018/9 on HWC in Wuparo and King Nehale Conservancies – work from both these latter projects has been submitted for publication.

Table 1: *Key characteristics of five surveyed communal-area conservancies, drawing on survey data and data held by the Namibian Association of CBNRM Support Organisations (http://www.nacso.org.na/conservancies, last accessed 25 June 2020).*

Conservancy	Region	Location	Neighbouring National Park (NP)	Date Conservancy Gazetted	Area (Km^2)	No. Members	Management Structure	Traditional Authority (TA)	Income-generating activities
King Nehale	Oshikoto	North-central	Etosha NP	September 2005	508	5,069	20 Management Committee members from 10 conservancy centres – 60 % of the committee members are female	Ondonga TA, 2 reps. on conservancy committee	Tourism; hunting; craft shop; trophy hunting; own-use hunting; Kalahari melon seed harvesting
Ehirovipuka	Kunene	North-west	Etosha NP	January 2001	1,980	Approx. 1,426	Management Committee of 12 men; Executive Committee of six members; staff of five; Community Game Guards, one Field Officer and one Community Activator; wildlife monitoring using annual road-based count and Event Book monitoring system.	Two main TAs, Tjijahura TA and Muzuma TA with no reps. on conservancy committee	Trophy-hunting; own-use hunting; Tourism Concession fees
Tsiseb	Erongo	North-west	Dorob NP	January 2001	7,913	2,636	Management Committee of 12 men and four women; Executive Committee of six members; staff of three Game Guards, a Manager, an Office Clerk and a Cleaner; wildlife monitoring using annual road-based count and Event Book monitoring system	Dâure-Daman TA, 1 rep. on conservancy committee	Trophy hunting; own-use hunting; Joint-Venture tourism agreement with Brandberg White Lady Lodge; community campsite (Ugab Campsite); Information Centre with Daureb Crafts; semi-precious stone market; Daureb Mountain Guides
Wuparo	Zambezi	North-east	Mudumu NP and Nkasa Rupara NP	December 1999	148	1,027	Management Committee of two women and eight men; Executive Committee of six members; staff of seven Community Game Guards, a Manager, a Community Resource Monitor, a Treasurer and a Secretary; wildlife monitoring using annual count on foot and Event Book monitoring system	Mayeyi TA, 1 rep. on conservancy committee	Community campsite (Wuparo Campsite); trophy hunting; crafts; Rupara Environmental Centre
Nyae Nyae	Otjozondjupa	East	Khaudum NP	February 1998	8,992	3,156	Conservancy Board of six women and 13 men; Management Committee of six members; staff of ten Community Rangers, a CBNRM Field Officer, a Project Manager, a Public Relations Manager, four members of the water team, four Junior Teachers, a Pre-School Teacher and an Education Coordinator; wildlife monitoring using annual full moon count and Event Book monitoring system	Ju|'hoansi TA, no reps. on conservancy committee	Joint-Venture tourism agreements with Nyae Nyae Fly-In Camp and Nyae Nyae Safari Camps; community campsites; craft centre; trophy hunting; devil's claw (*Harpagophytum procumbens*) harvesting

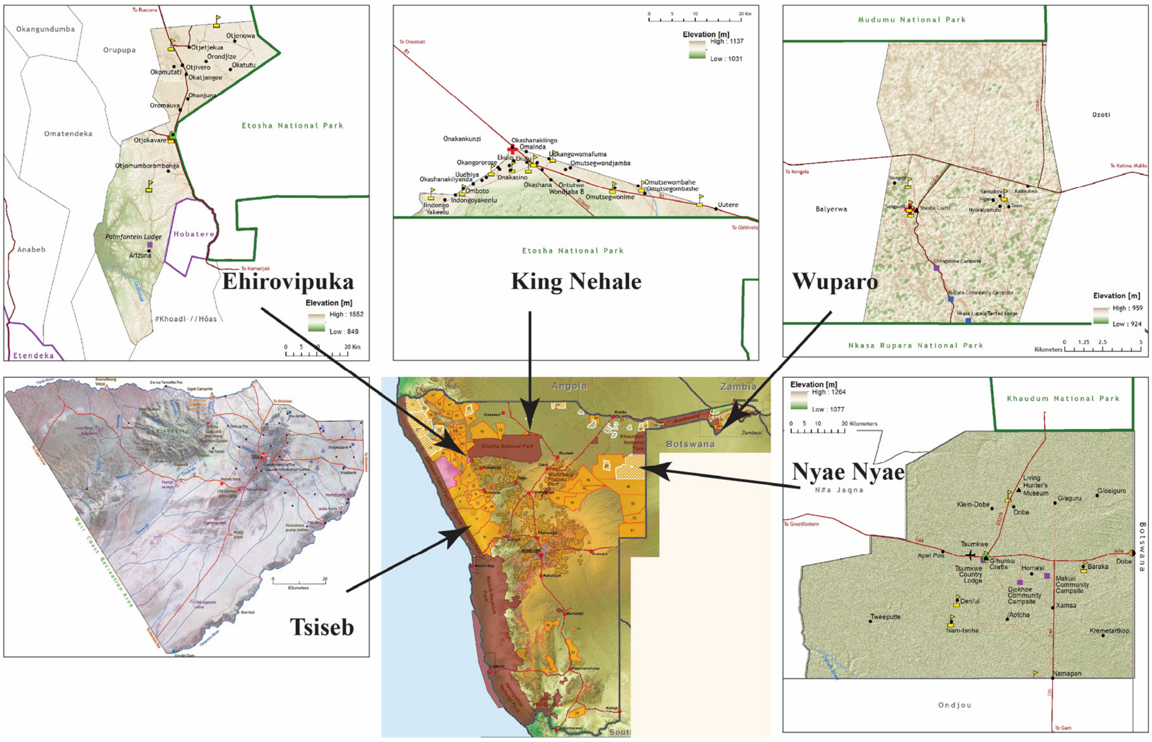

Figure 1: Map showing the boundaries and location of the five studied conservancies. Adapted from information hosted by the Namibian Association of CBNRM Support Organisations (NACSO) (www.nacso.org.na).

***Table 2:** Number and breakdown of conservancy respondents in telephone and WhatsApp survey between 5th and 15th April 2020, concerning the impacts of COVID-19 and associated policies on communal-area conservancies in Namibia.*

Conservancy	**Respondents**
Tsiseb	Telephone interviews with 15 community members at farms in all four zoned areas of the conservancy. Information was also solicited from 5 conservancy management committee members through a WhatsApp platform for the conservancy management committee.
Ehirovipuka	Telephone interviews with 15 community members of the conservancy and 5 conservancy management committee members, plus telephone interview with Joint Venture investor.
Wuparo	Telephone interviews conducted with 5 respondents from the conservancy, including the conservancy chairperson, a lodge manager, two lodge/campsite staff and one senior game guard.
Nyae Nyae	Telephone interviews with the conservancy manager, two management committee members and five conservancy members.
King Nehale	Telephone interviews conducted with 15 community members and 3 conservancy management committee members.

***Table 3:** Series of interconnected questions forming the basis for the semi-structured telephone interview survey with conservancy respondents.*

#	**Question**
1	What changes has COVID-19 brought about in the operations of your conservancy?
2	In what way has this pandemic affected conservancy members?
3	How is the management of the conservancy and monitoring of wildlife affected?
4	How are conservancy staff members operating? What has happened to the staff of campsites and lodges?
5	How is the conservancy management communicating with the staff and members?
6	How are hunting and tourism establishments affected at present?
7	How is the implementation of funded projects affected by COVID-19?
8	What measures did the conservancy put in place to protect staff and members against COVID-19?
9	What are the capacity constraints faced by the conservancy to manage wildlife, staff, and members during this time?
10	What are the major present challenges to the conservancy?
11	What kind of support is the conservancy currently receiving to address some of these challenges? And from whom?
12	What kind of urgent assistance does the conservancy require from the government and other partners?

perspectives were shared through multiple calls and other telephonic exchanges (e.g. through WhatsApp) by 72 respondents in total, as indicated in Table 2. We asked these individuals a series of interconnected questions regarding how conservancies are responding to the COVID-19 crisis, and how national and international policies for dealing with the crisis are impacting on them (see Table 3). A qualitative data analysis technique of coding interviews for themes and subthemes was used. Eight key themes stood out in our review and analysis of this interview material (see Section 4) which we clarify by using selected anonymised transcript quotes to illustrate each of these themes (these are slightly edited in some places for clarity). We have elected to foreground the realities and perceptions for respondents 'on the ground' through including transcripts that sometimes make apparently similar points. In doing so we illustrate systemic aspects of COVID-19 impacts across the different settings of our five sampled conservancies, as well as the ways that subtle differences of experience and perception amongst our rural area respondents are also apparent.

4. Findings

The primary impacts of policy responses to COVID-19 suggested by our telephone survey with conservancy management committee members, staff and conservancy members are summarised in Table 4. Each of these key interrelated impacts are elaborated in more detail below where we also identify ways in which conservancy managers and committees have attempted to respond to the unforeseen challenges of present circumstances.

Table 4. *Common impacts of COVID-19 and associated policies on five sampled conservancies, April 2020.*

Impacts	Key specific issues
1. Disruption to management and regular operational process of conservancies	Cancellation of management meetings. Cancellation of the Annual General Meeting (AGM). Cessation of recruitment and training of new staff members. Lack of preparedness and proactive strategies.
2. Effects on conservancy wildlife patrolling and monitoring	Reduced wildlife patrolling and monitoring leaving conservancies vulnerable to illegal wildlife hunting (poaching). Increased incidents of Human-Wildlife Conflict (HWC) (linked with reduced patrols), with reduced reporting and investigations. Reduced joint wildlife monitoring and anti-poaching patrols between the conservancy and the Ministry of Environment, Forestry and Tourism (MEFT).
3. Losses of revenue and cash flow in conservancy business operations	The ban on international travel has disrupted tourism, trophy hunting and community-based enterprises causing losses of income for conservancies. Tourists and hunters have cancelled bookings. In some cases tourists have had to be refunded for cancelled bookings. Loss of income, challenging the financial sustainability of conservancies.
4. Impacts on Joint Venture partnerships	Due to a lack of income, some investors are unable to settle the full amount of guaranteed fees to conservancies, as per Joint Venture agreements. Uncertainty amongst conservancies and Joint Venture partners regarding the implications for legal agreements, partnership futures, and the way forward. A halt of social benefits, cash dividends for conservancy members, and game meat distribution, causing income and food insecurity.
5. Impacts on employment and local livelihoods	Temporary closures of tourism and hunting enterprises has resulted in laying off employees and cutting costs including salaries and wages. Loss of employment and income-generating activities have impacted local livelihoods, including through reduced shoot-and-sell hunting.
6. Effects on community development projects and social benefits	Community developments projects have been disrupted. Conservancy funds are being used for core operational costs, with insufficient funds to invest in community development projects.
7. Disruption to donor-funded projects and programmes	Most community projects are donor-funded, and some projects have been put on hold until further notice.
8. Lack of technical capacity for communication technologies and equipment	Communication barriers as a result of poor telecommunications network coverage are negatively affecting communication between management and communities, at a time of increased COVID-19-related reliance on telephone communication between conservancy committee members and conservancy members. Unable to participate in education activities *per se*. Misinformation and lack of information regarding the outbreak of the pandemic, generating fear and confusion in rural populations.

4.1 Disruption to management and regular operational processes of conservancies

Unsurprisingly, all interviewees indicated that the pandemic has disrupted the regular management and operation of conservancies. Recommendations for social distancing and working from home so as to curb the spread of the virus resulted in the cancellation of management and conservancy meetings. Since conservancies are social institutions requiring the participation and consent of community members over management decisions, social distancing requirements constitute a large impact on the day-to-day running of conservancies. Annual General Meetings (AGM) were particularly affected due to the prohibition of gatherings throughout the country (Namibia Legal Information Institute 2020), especially given that the quorum required for decisions to be valid is 70 people for some conservancies. CBNRM policies encourage communities to participate meaningfully in conservancy matters and natural resources management (Blackie & Ricart Casadevall 2019), and this participation is seriously challenged by present circumstances.

The conservancy manager of Wuparo Conservancy indicated that in response to these circumstances they had implemented a door-to-door consultation and information-sharing mechanism. Whilst effective for communication purposes, this was ineffective for community decision-making and the AGM quorum and thus, as Wuparo conservancy manager described, "decisions about anything are currently on hold". Some conservancies such as Nyae Nyae indicated that the lack of preparedness regarding the pandemic resulted in reactive decision-making caused by fear of the pandemic. For instance, a decision was taken to close the conservancy office without proper discussion or consultation with the communities and staff, leading a Nyae Nyae respondent to state that:

> *"Communication to the staff was made improperly by the management, with the decision of office lockdown without identification of how essential services will be sustained. The staff were not informed in full detail of why the conservancy should lockdown, only in general from ongoing news about the pandemic which the staff members at least knew about. The decision of office lockdown was taken abruptly, in the absence of others including the conservancy manager."*

The King Nehale Conservancy management committee understood that the requirement to halt any type of meetings, received in an official letter, was a direct mandate from the MEFT. Coupled with fear of contracting the virus, the conservancy decided to become dormant, with the exception of making payments to staff members:

> "*In line with the Minister of Environment, Forestry and Tourism directive in a letter dated 26 March 2020 to communal conservancies prohibiting face-to-face meetings (including planning meetings and management committee meetings), management has been put on hold until the situation normalises. There is fear among the committee too, of contracting the virus, thus most of our activities are at a halt, because prevention is better than cure and the risk is too high to try keep operating.*"

Respondents also thought that government and responsible institutions delayed sending out clear, truthful and timely information to conservancies regarding the pandemic. This meant they had to rely initially on information from the media and word of mouth to make decisions, which resulted in making reactive decisions.

4.2 Effects on conservancy wildlife patrolling and monitoring

This latter point is compounded by the ways that social distancing resulted in a reduced number of game guards patrolling and monitoring wildlife populations, with conservancy respondents voicing concern that these policies may be leaving conservancies vulnerable to wildlife crimes. At the time of our survey, King Nehale Conservancy had only one game guard patrolling the conservancy, and Wuparo, Tsiseb and Ehirovipuka conservancies had divided their game guards into small groups of two to three game guards with allocated duty posts to work from. Game guards themselves are fearful of contracting the virus, and their safety is also compromised by having fewer guards in a context in which poachers are always armed. A management committee member of King Nehale Conservancy thus indicated that:

> "*The only active game guard has been advised to avoid interaction with other conservancy members. The conservancy fear is that they cannot afford to be held responsible for any staff contraction of illness or death, should this happen by compelling staff to go to work as usual.*"

The mobile community game guard system is an important way in which conservancies contribute to conservation, not only through monitoring of natural resources such as wildlife, but also through improved flows of information and communication between the conservancy office, leaders and membership. It is often through community game guards that communities can voice their concerns, receive clarification on issues or make a report to the conservancy. Given the present relative absence of community game guards, conservancy management committees are assuming that local hunters or 'poachers' may be taking advantage of the pandemic to carry out 'wildlife crime' and poaching activities:

> "*There have been cases of poaching recorded in Amilema and Omboto among other places, and in areas adjacent to the conservancy area alongside Etosha National Park. The conservancy is being challenged by a lack of patrolling vehicles and poachers are using the COVID-19 fear and lockdown as an opportunity for their damaging practices.*"
> (Respondent in King Nehale Conservancy)

The Wuparo Conservancy management committee also indicated that some gunshot incidents had been heard in the conservancy, and patrolling has shown that local hunters are using dogs as an escort to assist hunting. What was not indicated clearly in our interviews is whether or not joint wildlife monitoring and anti-poaching patrols between the conservancy and MEFT have been reduced.

Additionally, some conservancy members, especially those whose conservancies are located adjacent to Etosha National Park (King Nehale and Ehirovipuka), indicated that since the pandemic and lockdown measures they are subject to frequent occurrences of HWC incidents, but that reporting and investigations of such incidents is ineffective. Generally, villages near National Parks and tourism areas suffer greater damage through HWC than others (Lendelvo *et al.* 2015). Conservancy interviewees expressed the following concerns:

> "*At the moment the conservancy does not have enough human resources to effectively monitor wildlife and investigate human-wildlife conflict incidents. The conservancy Acting Coordinator is regularly receiving HWC victims at the office from all over the conservancy. In the absence of the three game guards whose employment is halted due to lockdown, communities will unfortunately continue suffering from HWC with no one to investigate their HWC incidents. Nor will they be on the alert for the possible presence of predators in the area for proactive actions.*"
> (Respondent in King Nehale Conservancy)

> "*HWC is increasing on a daily basis. As we speak, poaching remains a thorn in the flesh as our monitoring intensity is reduced [due to the lockdown]. Only today I attended a HWC case of a leopard that killed five goats, two dogs, two cats and some poultry in a kraal and around the vicinity of the lodge premises.*"
> (Manager, Tsiseb Conservancy)

> "*Last week a lion killed 15 cattle from the community, and the people themselves killed the lion. We are suffering a lot from HWC and with this COVID-19, people cannot report such cases and there is no one to investigate so that they can be duly compensated for the loss they suffer.*"
> (Member of Ehirovipuka Conservancy)

These impacts are sometimes occurring in a context in which conservancies claim that MEFT has not been compensating communities for HWC, despite reports being made, thus:

> "*The Ministry of Environment, Forestry and Tourism have not contributed to the scheme for three years now even though farmers are incurring losses.*"
> (Respondent in Wuparo Conservancy)

4.3 Losses of revenue and cash flow in conservancy business operations

As described in Section 2, tourism and hunting operations are major income-generating activities for communal-area conservancies in Namibia. Loss of income to conservancies due to COVID-19 and associated policy responses was thus expressed in our interviews as a major issue of concern. The ban on international travel has disrupted the generation of income from trophy-hunting and community-based enterprises (including lodges, campsites and craft shops), causing losses of income for conservancies, their inhabitants and Joint-Venture Partnerships. All conservancy management interviewees with conservancy-associated tourism enterprises indicated that they have experienced cancellations of accommodation and hunting bookings, and in some cases tourists who paid in advance had to be refunded. The King Nehale Conservancy is also concerned about reduced income from their shoot and sell quota which they anticipate will be limited due to the COVID-19 restrictions combined with the effects of recent drought on wildlife populations.

As a result of the loss of income, conservancies are relying on savings from previous years to cover operational costs, including staff salaries, leading to fears that any further loss of income will seriously challenge the financial sustainability of conservancies. The implication is that conservancies will require large amounts of external financial assistance if they are to operate as before. These fears are illustrated in the following excerpts from interview transcripts:

> "*The conservancy is worried about the commitment from an operator to conduct hunting. Guaranteed payment was a safety net for conservancies. Since the lockdown was declared, nothing has been sold in the conservancy craft shop (Tulongeni Craft Shop). The conservancy also used to sell their crafts at various trade fairs, SME (Small and Medium Enterprises) exhibitions, festivals, etc. which at the moment is not the case, resulting in loss of income to members.*"
> (Respondent in King Nehale Conservancy)

> "*Hunting is badly affected. Presently all hunting permits have been withheld until lockdown is over. Most hunters to the conservancy are from European countries which are the most affected by the pandemic. As the lockdown continues there might be a drop to the annual income [of the conservancy] from hunting.*"
> (Respondent in Nyae Nyae Conservancy)

> "*The conservancy has no proper income. There is some money but we are not certain if it will cover all the necessary costs. If COVID-19 happens to cease after two months the hunters will be on a continuous hunting spree which will chase away animals and this will, in turn, be a problem for the conservancy.*"
> (Respondent in Wuparo Conservancy)

> "*As a conservancy, we are faced with cash flow problems as our sources of income are from tourism and hunting. Due to COVID-19, our projected cash-flow will be affected. As of now we will no longer have funds for the field operation and payments of employees and the office administration. We have projected a loss of N$ 170,000 [during 2020] due to COVID-19.*"
> (Respondent in Ehirovipuka Conservancy)

4.4 Impacts on Joint-Venture Partnerships

According to Zambrano & Potma (2020), the COVID-19 pandemic affects tourism alongside conservation concerns, such that tourism and conservation are affected in parallel with the closure of tourism and hunting activities causing losses of income and investments for conservancies and conservation efforts. Some investors were noted to be unable to settle the full amount of guaranteed fees to conservancies, as per signed agreements. Moreover, the conservancy and Joint-Venture Partnerships (JVP) with hunting operators and lodge investors are uncertain about future partnerships, given that continuity requires broader economic stability.

Fears regarding the sustainability of JVPs were apparent amongst our conservancy respondents. Concerns were expressed, for example, that the current JVP between the Gondwana Collection investor and King Nehale Conservancy might be adjusted in a way that would negatively affect the conservancy. The JVP investor with Ehirovipuka is also reportedly uncertain about their December 2020 payment for this year's business.

4.5 Impacts on employment opportunities and local livelihoods

These impacts have begun to be felt on the ground. The temporary closure of tourism and hunting enterprises which were primary avenues of employment for conservancy inhabitants has resulted in sending employees on unpaid leave, laying off contract employees, and cutting costs including salaries and wages. All the conservancies during the period of data collection in April 2020 indicated a reduction in employee's salaries by 50 %. Given that salaries in the tourism and trophy-hunting industries are often already quite low (Stamm 2017, Hewitson 2018), this reduction is devastating.

Although no conservancy employees have yet been retrenched as a result of the virus, there is fear of future retrenchment of conservancy staff members should pandemic circumstances persist, thus:

> "*A few staff are making sure that the daily operations of the campsites and lodge are afloat, but with time the lodges might have to close down. The management of the lodges and campsites might be forced to let the remaining few staff leave work and return only after the operations are back to normal.*"
> (Respondent in Tsiseb Conservancy)."
>
> "*It will be worse if the pandemic continues for longer as the conservancy will lose income, workers will be retrenched, poaching will drastically increase, community livelihoods will decline while poverty and hunger will increase, and JV agreements are likely to be terminated.*"
> (Respondent in King Nehale Conservancy)
>
> "*The Joint Venture Partner has let some staff members go because the owner is not able to pay the salaries of the staff members.*"
> (Respondent in Ehirovipuka Conservancy)

The above statements signal both the importance of tourism and hunting incomes for local livelihoods and wildlife conservation, and their vulnerability to disruption due to international circumstances. According to McNamara *et al*. (2015), the trophy hunting season in Namibia lasts for 10 months each year, starting on 1 February and ending on 30 November, although hunting months and quotas vary from conservancy to conservancy. Taking into consideration three months without hunting and the cancellation of future hunting bookings, some conservancies have expressed concern about the loss of trophy-hunting related incomes specifically, while others are hopeful that the remaining months of the season might yield positive outcomes. Impacts on local livelihoods at household levels are reportedly becoming evident, and conservancy contributions towards livelihoods through cash dividends and game meat distribution to members may be negatively affected if trophy-hunting and tourism do not recover. In keeping with Namibia's CBNRM model, concern was also expressed by respondents that if local conservancy/conservation-linked incomes and livelihoods are severely affected for an extended period of time, people may begin illegal hunting as a means of generating livelihoods.

4.6 Effects on community development projects and social benefits

Four of the five conservancies indicated they had community development projects and social benefits planned for this year (2020), but that these initiatives have been halted due to present COVID-19-related circumstances. Funding has been disrupted and the use of conservancy funds as investments in these projects (MET/NACSO 2018) is considered non-viable due to uncertainty regarding the sustainability and recovery of tourism and trophy-hunting following the pandemic. Members of the conservancies raised these concerns:

> "*The pandemic has disrupted ongoing projects, for instance, the water and electrification projects that were at present under construction. The disruption has been a disappointment to the members as they anticipated being able to light up their homes with electricity before the end of the year. Project extension is now inevitable and projects might take longer than envisioned as most of the financing will have been depleted through operational activities, and the possibilities of replenishing this finance are dependent on trophy hunting.*"
> (Member, Wuparo Conservancy)
>
> "*Subsequently, an amount of N$ 578,382 was approved by the AGM during 2019/2020 for community benefit distribution through community development projects, support to HWC Self Reliance Scheme, community hall establishment, supporting the San community with shelter provision and support to their school-going children, earth dam excavation, etc. With COVID-19 the above projects will no longer materialise. The official opening ceremony of the JV lodge [with Gondwana Collection] has also been postponed until further notice.*"
> (Member, King Nehale Conservancy)
>
> "*We had plans this year to give seeds to farmers and start a community garden, as well as starting the people-park wildlife core-area with women involved in conservation. There was also some ongoing construction at the lodge. All this has been stopped due to COVID-19. Due to the drought we faced in recent years our wildlife has died, and the hunting quota was also reduced. Now COVID-19 is adding to these problems. After this we cannot generate money like before.*"
> (Member, Ehirovipuka Conservancy)

The King Nehale Conservancy additionally indicated that additional income expected from a traversing rights concession[8], for which a contract was to be signed with the operating company before May 2020, will not be forthcoming as the contract has been postponed. The Nyae Nyae Conservancy indicated that plans for village water point maintenance for ongoing water supply at villages, especially for reported water faults, will be difficult to fulfil due to reduced incomes.

Given these circumstances assistance is sought, especially to support planned community development projects and operation costs:

> "*Over the next 2 years, and while the Government is looking at communal conservancy relief packages for during and post COVID-19, NGOs and MEFT should take full responsibility to fund the activities mentioned so as to allow conservancies to mitigate impacts of COVID-19.*"
> (Respondent in King Nehale Conservancy)
>
> "*The Government or any good Samaritans and NGOs need to assist us with a little income as a fall-back plan for jobs lost, as this could result in many illegal activities such as poaching that could disturb conservancy operations.*"
> (Respondent in Wuparo Conservancy)
>
> "*Now we are relying on money paid by the investor in the sustainable wildlife trust to pay the game guards. If the investor stops paying this money we don't know how we will pay the game guards, and also if the money from the social security payments does not come through, we don't know how we will survive as a conservancy, so we need serious help.*"
> (Respondent in Ehirovipuka Conservancy)

4.7 Disruption to donor-funded projects and programmes

Four of the five sampled conservancies indicated that COVID-19 has led to donor funding by institutions such as the Worldwide Fund for Nature (WWF), European Union, Integrated Rural Development and Nature Conservation (IRDNC) and the Indian government being put on hold until further notice. In contexts where donor grants are linked to community development projects, a shortfall in financing can be one of the hindrances to achieving community development projects (Gachui 2017). Funded projects related to community development and mitigating HWC are reportedly disrupted although not cancelled:

> "*The pipeline funded by the European Union is also negatively affected.*"
> (Respondent in King Nehale Conservancy)
>
> "*One of the paused projects of substantial importance is that of the Lion Proof Kraals funded by WWF and envisioned to start soon – although there is no intention of cutting or cancelling it. Also, the Predator*

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[8] A concession in which the concession holder enjoys exclusive rights to tourism income gained from traversing over a tract of land.

> *Scheme providing income for every carnivore spotted in the conservancy (for example on a game drive) has been put on hold due to the travel ban, as it was dependent mostly on funding from tourists."*
> (Respondent in Wuparo Conservancy)
>
> "*Projects we were anticipating such as human-wildlife projects to establish solar water taps for elephants, Geopark to work with small miners, and an irrigation project to strengthen food security for communities: some of these have been put on hold while others are cancelled due to the outbreak of COVID-19."*
> (Respondent in Tsiseb Conservancy)
>
> "*We had a project which was to be funded from India to establish a people-park core wildlife area to fight illegal hunting. There was also a project funded by UNDP to assist with HWC. These have now stopped, and during COVID-19 we are also experiencing high incidents of illegal logging and harvesting of our forest timber and the collection of firewood: we need funding and assistance to stop this."*
> (Respondent in Ehirovipuka Conservancy)

Before the outbreak of the pandemic, some conservancies indicated they were already experiencing challenges which have been exacerbated by the pandemic, as summarised in Table 5. For instance, King Nehale Conservancy had shortages in conservancy staff members, including a conservancy coordinator and game guards, which have been exacerbated by the pandemic as the conservancy was unable to proceed with the recruitment process for vacant positions. Similar reports were received from Wuparo Conservancy.

Table 5: *Summary of findings from the Conservancies. Key: X = effect indicated, - = not indicated.*

Conservancy	Shortage of conservancy staff	Disruption of hiring, staff training, and assessments	Community projects	Lack of HWC offsets from the MEFT	HWC and poaching a serious concern	The projected loss of income due to COVID-19
King Nehale	X	X	X	-	X	X
Ehirovipuka	-	-	X	X	X	X
Tsiseb	-	-	X	-	X	X
Wuparo	X	X	-	X	-	X
Nyae Nyae	X	-	X	-	X	X

Conservancy	External support acquired during COVID-19
King Nehale	National COVID-19 precautionary advice.
Ehirovipuka	No external support, the conservancy provided the community members and staff with sanitisers.
Tsiseb	No external support, Conservancy provided the members and staff with sanitisers and advise on social distancing and permitted staff to work from home.
Wuparo	The Ministry of Health and Social Services has provided training to the communities on COVID-19.
Nyae Nyae	Formed a COVID-19 Task Force between Nyae Nyae Conservancy,Tsumkwe TUCSIN, Namibian Police Force, Ministry of Health and Social Services, Community Churches and Tsumkwe Constituency Office, to raise awareness, provide information on COVID-19, distribute soap for basic hand washing and encourage social distancing behaviour among members at different villages.

Amidst the pandemic, three of the five conservancies indicated that prior to and during the data collection period the conservancies had not received any external assistance to curb the virus. Some conservancies relied on the national news for information on COVID-19 precautionary advice, while others had to improvise and buy their own sanitisers and masks to distribute to the conservancy communities. Wuparo Conservancy indicated that support was received from the Ministry of Health and Social Services, providing communities with training and information mobilisation on COVID-19, but this was not enough as they lack hand sanitisers and have thus requested assistance in the form of the donation of water tanks and soap for game guards to use in the field. The committee noted that the conservancy was not financially stable enough to cover additional costs, given that the conservancy has already organised a cost-cutting strategy to keep the conservancy functioning.

The Nyae Nyae Conservancy also indicated that the conservancy is experiencing shortages in funds in the conservancy's reserve account, and the management was not sure as to how funds could be mobilised to provide membership benefits and conservancy operational costs. The conservancy described disruptions in its service delivery and social responsibilities like transportation for sick people to the clinic. It indicated that the conservancy had joined the programme by the University Centre for Studies in Namibia (TUCSIN) in Tsumkwe, Namibian Police Force, Ministry of Health and Social Services, Community Churches, and the Tsumkwe Constituency Office, to form a task force responsible for village mobilisation amidst the pandemic. Although the task force was still in the planning stages during our data collection period, the conservancy requested that to fight the virus, they needed to be assisted with sanitiser equipment to help prevent its spread. They recommended that relevant information be shared on large display platforms by the Ministry of Information and Communication's media crew, and on radio stations in all Namibia's different languages. As discussed above, this is to help prevent the spreading of misinformation about the pandemic. Tsiseb and Ehirovipuka Conservancy management expressed major concerns around the lack of technical capacity to draw up funding proposals and requisitions prior to and amidst the COVID-19 pandemic.

4.8 Lack of technical capacity for communication technologies and equipment

A specific concern raised by some respondents is that a lack of proper communication technologies and equipment, especially official platforms, is leading to the sharing of misinformation. This aspect is linked especially with reliance on secondary information platforms such as social media and word of mouth from neighbours, which has caused fear and confusion about the pandemic in rural communities. Indeed, at the initial outbreak of the pandemic, the sharing of false information on social media regarding COVID-19 outbreaks and remedies in Namibia, prompted Namibia's United States of America's country director for Diseases Control and Prevention (CDC) to write a press release warning the public against being compelled by such myths (Kavhu 2020).

Given the constraints on physical gathering and meetings, conservancies have had to devise different mechanisms to continue communicating with mobile phones and apps such as WhatsApp proving essential in this regard:

> "*We mostly use our mobile cell phone to communicate through WhatsApp, Facebook, or emails so that each member and staff is updated with what's happening.*"
> (Respondent in Tsiseb Conservancy)

Conservancy leaders indicated that communication has been challenging, however, due to poor network coverage in most rural areas, which makes working from home ineffective and often impossible. Other conservancies indicated that regardless of the availability of mobile phones poor network coverage makes communication problematic. Others felt that they lacked the capacity to communicate through mobile phones to the full conservancy population, stating that it is costly as the management committees have to utilise their personal income to buy airtime or data in order to make phone calls to update everyone:

> "*Not everyone can participate through the phone, some people respond late as response rates differ from person to person and for one to have a decision the conservancy is required to call everyone which isn't plausible considering the number of members in the conservancy.*"
> (Respondent in Wuparo Conservancy)

> "*Lack of communication gadgets and means (such as laptops, 3 or 4 Gs, electricity at staff homesteads) remains a constraint for the conservancy coordinator to effectively communicate with stakeholders. The management committee are volunteering and do not even get airtime allowances to advance active communications during this time. In addition to their existing struggles, COVID-19 requires extraordinary commitment from them to pull through the pandemic.*"
> (Respondent in King Nehale Conservancy)

Respondents in Ehirovipuka Conservancy stated that they experience network problems and only a few people in the Conservancy have access to smart phones, while Nyae Nyae is mostly inhabited by the marginalised Ju|'hoansi San people with a low literacy rate and very limited access to any kind of mobile phones.

5. Conclusion

Our rapid survey of information for five conservancies indicates (unsurprisingly) that the state of emergency in 2020 associated with COVID-19 and linked regulations has caused major disruption to Namibia's CBNRM programme. The effects of the pandemic on tourism and hunting operations were felt by conservancies across the country, bringing out vulnerabilities linked with CBRNM's dependence on these two interconnected sectors as well as seriously hindering conservancy management and operational plans. Given that the recovery time after such disease outbreaks has in the past averaged around 19.4 months, it can be assumed that these impacts on travel and tourism will continue for some time, even after the lockdown is lifted (Paxton 2020). Namibia's MEFT has already responded by aiming to strengthen the resilience of community-based conservation and livelihoods in Namibia. A one-off emergency fund of around N$ 26 million to support conservancies and community forests has been mobilised from both national and international partners, including the Environmental Investment Fund of Namibia (EIF), Nedbank Namibia, Namibian Chamber of Environment (NCE), B2Gold, World Wildlife Fund, German Corporation for International Cooperation (GIZ) and the KfW banking group.[9] The fund is particularly directed towards ongoing conservation activities such as the payment of wages for game guards including lion and rhino rangers, Human-Wildlife Conflict interventions and some governance aspects.

It is worth noting that the present COVID-19 pandemic is perhaps a once in 100-year event, and our observations here need to bear this in mind. At the same time, many analysts and commentators express concerns that unprecedented anthropogenic disruptions to habitats may increase the likelihood of future pandemics, for example, through increasing

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[9] See http://www.ccf-namibia.org/

the possibility that diseases may ‘jump’ from animal hosts to humans (Madhav *et al*. 2018). An argument also made is that the present pandemic is, or should be, a call not to return to ‘business as normal’ once the spread of the virus is in decline (for example, Friends of the Earth International 2020). Such calls are made partly in recognition that the hyper-mobility underscoring ‘ecotourism’ and other forms of ‘high-end’ nature consumption is a contributor to planetary habitat alterations linked with climate change.

Namibia’s conservancy economy, with its systemic dependence on international travel and profitable business ventures, might be able to fully resume after COVID-19. For it to do so, conservancy business partners will need to be able to survive the pandemic so that their wealth-generating activities can be directed towards providing employment in wildlife-related tourism enterprises, as well as honouring Joint-Venture agreements with conservancies. At the same time, a real concern precipitated by the pandemic is the question of how conservation will remain viable in Namibia’s communal-areas if these radically disrupted circumstances continue, given current CBNRM policy that tightly couples conservation activity with local receipt of tourism and hunting incomes.

The disruption of ‘business as usual’ may also be ‘an opportunity to question inherited assumptions, refine existing models, and improve conservation practices’ (Kaelo *et al*. 2020). Possibilities here include engaging more deeply with the unsustainable inequities that also thread through the CBNRM model as currently designed, as well as with the broader environmental and social implications of a model that relies on expanding international air travel and high-impact lifestyles. The livelihoods and autonomy of communal-area conservancy residents need to be invested in, in ways that might imply more systemic redistribution of resources and investments in diversified livelihood structures that are perhaps less dependent on tourism and hunting incomes. Clearly, though, it is too early to know what the outcomes of present circumstances will be, even in only a few months’ time. The COVID-19 pandemic is perhaps the greatest test to date of the resilience of Namibia’s CBNRM model. It is certainly a key moment for research to assist with documenting how conservancy staff and members understand and respond to the challenges they now face. We hope the rapid survey reported in this article is useful in this regard.

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First confirmed record of green turtle (*Chelonia mydas*) nesting along the Namibian coast

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Introduction

Green turtle *Chelonia mydas* (Linnaeus, 1758) are known to occur along the Namibian coast, with most published sightings from the Kunene River mouth area (Tarr 1987, Griffin & Channing 1991, Simmons *et al*. 1993, Anderson *et al*. 2001, Griffin 2003, Paterson 2007, Elwen & Braby 2015, Cunningham *et al*. 2018). However, there has been much speculation regarding actual breeding along the Namibian coast.

Most authors indicate that green turtles are not known to breed along the Skeleton Coast, but probably only occasionally exit for basking (Tarr 1987, Branch 1998, Boycott & Bourquin 2000, Griffin 2003, Bonin *et al*. 2006). There are relatively few green turtle rookeries along the eastern Atlantic seaboard with the most significant nesting site being in Guinea Bissãu and smaller numbers nesting on Bioko Island, Gabon, and in the Cabinda and Namibe Provinces in Angola where nesting takes place between December and March (Branch 2008). Weir *et al*. (2007) indicate that concentrations of adult and juvenile green turtles are known from Foz de Cunene and that breeding occurs in the Namibe Province in Angola, just north of the Kunene River (Foz de Cunene is actually inland along the Kunene River, but the reference is presumed to refer to the Kunene River mouth area). Griffin (2003) assumes that the Namibian green turtles originate from the known nesting beaches in southern Angola and even the southern Indian Ocean.

As far as we could determine there are only two previous references to actual green turtle breeding along the Namibian coast, by Haacke (Sandwich Harbour) and Fourie (Kunene River mouth, 1958), but both are anecdotal (Tarr 1987).

Nesting observation

On 4 February 2020 at 17h00, on a warm, sunny wind still day, an adult female of approximately 1 m in width was encountered closing a nest in typical fashion – i.e. projecting sand backwards with powerful thrust of the fore flippers (Figures 1 and 2). This was observed from 17h00 until 17h30 when the turtle returned to the sea (Figure 3). It was low tide during the observation period and the nest was located approximately 10 m above the high water mark on the spit of sand between the Kunene River mouth and the estuary (S17°15.571′ & E11°45.102′). Although actual egg laying was not

Figure 1: *Green turtle at nesting site at the Kunene River mouth (Photo: J. van Rooyen).*

Figure 2: *Green turtle projecting sand backwards whilst covering up the nest (Photo: J. van Rooyen).*

observed, the action of the female green turtle was typical of nest closure after depositing eggs (Figures 1 and 2). Furthermore, she was visibly exhausted and rested whilst closing the nest as well as when she returned to the sea (Figure 3). Egg laying usually occurs at night during high tide (Bonin *et al*. 2006, Spawls *et al*. 2006), hence this record is somewhat unusual in the time of day. The nesting site was marked with driftwood in an attempt to deter people from driving over and damaging the nest. Hatching typically occurs after 54 and 74 days of incubation (Bonin *et al.* 2006). On 3 May 2020 (89 days after egg laying) the nest was partially opened confirming the presence of eggs (Figure 4). On 5 July 2020 – 5 months since egg laying occurred – there was still no sign of hatching, probably indicating a futile effort for this Namibian breeding attempt. Green turtles are not known to breed in similar cold coastal areas in Chile (Donoso *et al.* 1999, Sarmiento-Devia *et al.* 2015) with the most southerly breeding record along the South American coast known from Peru, albeit at a lower latitude – e.g. 3°41′00.8″S and 80°41′19.9″W (Forsberg *et al.* 2012). The cold ambient temperatures along the Namibian coast and occasional inundation of the nest during high tide resulting in wet nest conditions probably inhibit egg development.

Figure 3: *Green turtle returning to the sea after covering up the nest (Photo: J. van Rooyen).*

Figure 4: *Eggs confirmed from nest on 3 May 2020 (Photo: J. van Rooyen).*

Green turtles are protected in Namibia under the Marine Resources Act No. 27 of 2000 while the IUCN (2020) classifies green turtles as Endangered due to a decreasing population trend and a decrease in or widespread disturbance of nesting sites. Documenting and protecting potential nesting sites of this species is therefore of conservation importance. Although this was a single nesting event and may not be significant in terms of world-wide population numbers, it is the first published nesting observation for Namibia. Moreover, as breeding sites further north in Angola have declined in recent decades (Weir *et al*. 2007), this area may become an important regional nesting area to conserve.

The Kunene River mouth area and estuary is viewed as the most important habitat along the northern Namib coast (Cunningham & Jankowitz 2010) as well as a site of special ecological importance in Namibia for both sea turtles and migrant shorebirds (Curtis & Barnard 1998). On the terrestrial side, the Kunene River is the only perennial river in this otherwise extremely arid environment, which adds to its overall ecological importance. The Kunene River mouth is formally protected within the Skeleton Coast National Park, and potentially even qualifies as a Ramsar site, although it has not yet been thus designated (Shaw *et al*. 2004). The warmer water in the estuary likely offers the turtles respite from the cold Benguela Current offshore (Boycott & Bourquin 2000, Alexander & Marais 2007). If this area becomes a regular nesting site for *Chelonia mydas*, it will add to its ecological value and the need for its continued protection.

This sighting is viewed as the first confirmed nesting site of green turtle published for Namibia, and furthermore confirms the importance of the Kunene River estuary, not only for avifauna, but as a potential green turtle breeding site.

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Melissotarsus Emery (Insecta: Hymenoptera: Formicidae), a new country record for Namibia

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Introduction

The ant genus *Melissotarsus* is widespread in the Afrotropical region, but less often collected. They possess a number of unusual characteristics. They nest in cavities that they chew out of healthy wood, and many aspects of worker morphology represent adaptations to wood chiselling. Most noticeable are the middle pair of legs that are permanently bent upwards to provide additional leverage against the tunnel roof during chewing, in fact, because of this workers are unable to walk normally in an unconfined space (Khalife *et al.* 2018). The ants live in a symbiotic relationship with armoured scale insects (Hemiptera: Diaspididae) that they tend inside their nests (Ben-Dov & Fisher 2010). The nests provide protection for the scale insects, while the ants feed off the wax and other secretions that normally build the armoured coverings of the scale insects (Peeters *et al.* 2017). Because the diaspidids themselves feed on sap, the ant nests are largely restricted to the living sap-carrying layers just under the bark, meaning that the ants can potentially kill their host plants by interrupting sap flow. The worker ants do not forage and never leave the nests, of which there is often very little surface trace. Nest breaches are fixed by workers with a mixture of silk and wood fragments: *Melissotarsus* are some of the very few ants that are able to produce silk, from glands below the head, and they spin it with specialised front tarsi (Fisher & Robertson 1999).

Observations

In January 2020 a Windhoek resident approached the National Museum of Namibia with some ant specimens that had caused damage to trees in her garden. Upon examining the site, three different carob trees, *Ceratonia siliqua*, were observed to be affected, with some branches already dead. Eradication attempts by the owners had altered the appearance of nests and bark in most cases, but one unaffected area remained where silk-lined covered surface runways overlay subsurface tunnels with scattered small openings connecting the tunnels and runways (Figures 1, 2). Most consulted literature sources remark on the usual absence of surface traces of *Melissotarsus* nests, so this was an atypical nest configuration but one similar to that previously described by Prins *et al.* (1975). Two completely dead non-indigenous *Aloe* species on the same property and a palm tree on an adjacent property were pointed out to me as having died from the same cause. Ben-Dov & Fisher (2010) had previously listed at least 23 different tree species that host *Melissotarsus*, but remarked that the list included no monocotyledons. *Melissotarsus* make their burrows mainly in the cork cambium (Mony *et al.* 2013), a layer that is absent in most monocotyledons. I was only able to examine the aloes in the present case and the presence of soil inside the stems suggested that the already dead plants had been eaten by termites. Windhoek was at that time experiencing a severe drought with restrictions on watering of garden plants and it is more likely that these particular monocotyledons had died of drought than of damage by *Melissotarsus*.

Figure 1: *Covered surface runways of* Melissotarsus emeryi *on tree branch.*

Figure 2: Melissotarsus emeryi *runways with cover partly removed to show connecting holes to corresponding subsurface nest cavities.*

Figure 3: Melissotarsus emeryi *workers. Note the upturned middle legs. Scale bar: 1 mm.*

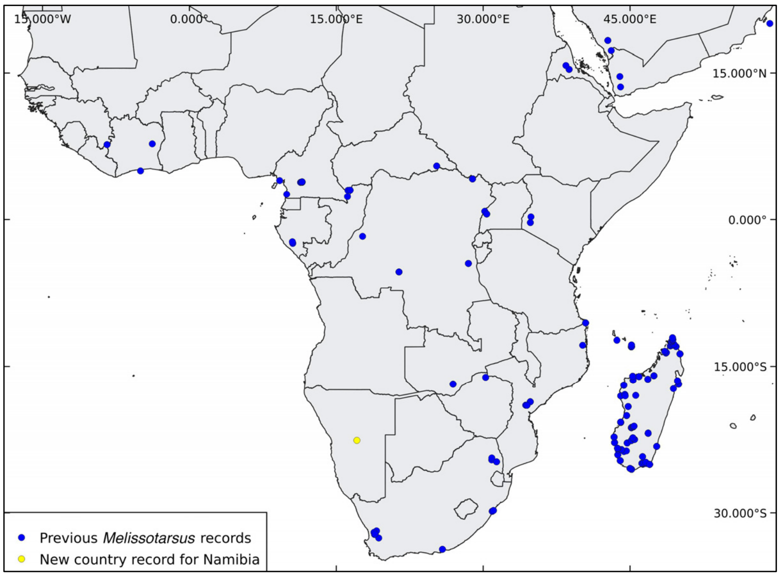

Figure 4: *Known distribution of* Melissotarsus, *all species combined. Data sources: AntWeb (2020) version 8.40.1; Global Ant Biodiversity Informatics (GABI) Project, data release 1.0 (Guénard et al. 2017).*

The ants, all worker caste, were identified with the help of Fisher & Bolton (2016) and Bolton (1982) as *Melissotarsus emeryi* Forel (Figure 3). The genus had not been recorded from Namibia before (Figure 4). Based on my assessment of climate and habitat at the southern African *Melissotarsus* localities with which I am familiar, I would expect them to occur naturally in savanna woodland in north-eastern Namibia, but probably not in the arid savanna of central Namibia. If this is correct it might mean that they were artificially introduced to Windhoek through the importation of infested live wood from an area where they do occur.

Material examined: 9 exx.; NAMIBIA, Khomas Region, Klein Windhoek at: 22.5660 S, 17.0990 E, 20.I.2020, A. Oosthuizen. National Museum of Namibia accession number SM H 65918.

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New plant records: updating Namibia's botanical checklist

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Abstract

Several plant species have been recorded from Namibia for the first time, and 39 new species have been described to science since the publication of 'A checklist of Namibian Indigenous and Naturalised Plants' (Klaassen & Kwembeya 2013). A list of these first records and newly described species for Namibia is provided and will be incorporated into the revised Namibian checklist which will be both published in the series 'Occasional Contributions of the National Botanical Research Institute' and made available on-line once complete.

Keywords: checklist, flora, Namibia, new records

Introduction

Namibia, a predominantly arid country, has a flora of 4 483 indigenous and naturalised plant taxa, consisting of 195 families and 1 127 genera of which 18% are categorised endemic or near endemic to the country (Klaassen & Kwembeya 2013). The occurrence of plant species in Namibia is highly influenced by rainfall, with the lowest rainfall in the south and west of Namibia (Namib Desert) and the highest rainfall in the north-east (Zambezi Region). However, low rainfall in the north-west and south-west of the country is not an indication of either low plant diversity or low endemism, in fact it is the opposite. The Tsau‖Khaeb National Park (Sperrgebiet) in the south-west of Namibia, falls within the Gariep Centre of Endemism, an area presumed to hold the richest variety of succulents on earth (van Wyk & Smith 2001); whilst the north-west of Namibia falls within the Kaokoveld Centre of Endemism, an area known for its high numbers of endemics (Maggs *et al*. 1994, 1998, van Wyk & Smith 2001, Craven & Vorster 2006, Craven 2009).

New plant species described and recorded from Namibia

Since the publication of 'A checklist of Namibian Indigenous and Naturalised Plants' (Klaassen & Kwembeya 2013), one new family, four new genera and 39 species, subspecies or varieties have been newly described and 29 previously described species have been recorded for the first time in Namibia. These discoveries have been made through field collection and/or re-determination of existing herbarium specimens housed at the National Herbarium of Namibia (WIND) by national and international plant specialists through plant family revisions as part of the Flora of Namibia project.

A list of these new plant records and newly described species for Namibia were extracted from the Botanical Research and Herbarium Management System (BRAHMS) (WIND 2020), WIND's in-house database, which holds over 95 000 records of Namibia's indigenous and naturalised flora and is presented in Table 1 and 2.

Potential new plant records and undescribed species for Namibia

WIND's collections have been amassed over four decades through botanical expeditions and are presented in Namibia's 2017 botanical collecting intensity map (Figure 1), which indicates the number of plant vouchers collected per Quarter Degree Square (QDS). In addition, this map shows areas of focused plant collection; these focal areas are indicative of being botanically interesting, easily accessible and usually well-populated.

'Focused' plant collecting in Namibia has resulted in a skewed representation of Namibia's species distribution, leaving large areas of Namibia under collected, indicated in Figure 1 by white and yellow squares (0-20 vouchers per QDS). Many of these under collected areas were labelled as 'less interesting' as they hold few endemics. However, additional botanical collection in these 'less interesting' areas will provide a more accurate representation of Namibia's plant species distribution with the possibility of finding new plant records for Namibia; while continued collection in the areas of botanical interest could result in the discovery of new undescribed species to science.

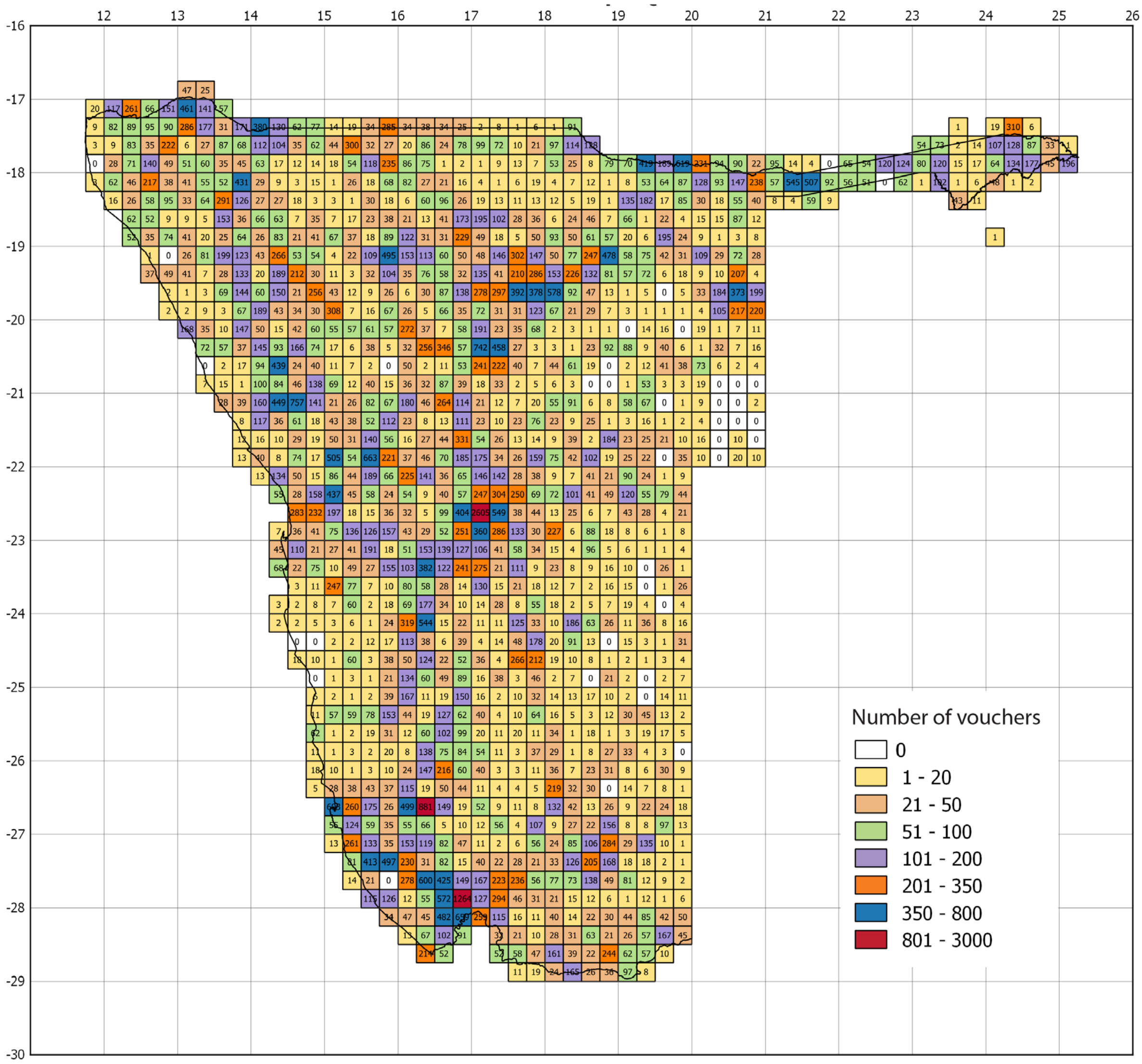

Figure 1: *Botanical collecting intensity map for Namibia, indicating number of plant vouchers collected per quarter degree square up to August 2017. (Source: WIND 2020).*

Table 1. New plant taxa records for Namibia since Klaassen & Kwembeya (2013).

Family	Genus species	Region	Source
Acanthaceae	*Petalidium huillense* C.B.Clarke	Kunene	WIND (2020)
Aizoaceae	*Cleretum papulosum* (L. f.) L.	Karas	WIND (2020)
Apocynaceae	*Periglossum mackenii* Harv.	Okavango	Bruyns (2014)
Araliaceae	*Cussonia angolensis* (Seem.) Hiern	Kunene	WIND (2020)
Asteraceae	**Acanthospermum australe* (Loefl.) Kuntze	Omaheke	WIND (2020)
	Gymnanthemum coloratum (Willd.) H.Rob. & B.Khan	Kunene	Swanepoel & van Jaarsveld (2015)
	Pteronia anisata B.Nord.	Karas	Kolberg & van Slageren (2014)
	Linzia rosenii (R.E.Fr.) H. Rob., Skvarla & V. A. Funk	Zambezi	Robinson *et al.* (2016)
	Gloriosa sessiliflora Nordal & Bingham	Zambezi	Nodal & Bingham (1998)
Convolvulaceae	*Cuscuta australis* R. Br.	Khomas	WIND (2020)
	Paralepistemon shirensis (Oliv.) Lejoly & Lisowski	Kunene	WIND (2020)
Fabaceae	*Aeschynomene cristata* Vatke	Zambezi	WIND (2020)
	Indigofera benguellensis Baker	Kunene	WIND (2020)
	Indigofera brachynema Gillett	Okavango	WIND (2020)
	Indigofera tinctoria L.	Zambezi	WIND (2020)

Geraniaceae	*Pelargonium albersii* M.Becker	Karas	Becker (2008)
	Pelargonium anauris M.Becker & F.Albers	Karas	Becker & Albers (2008)
Hyacinthaceae	*Ornithogalum decus-montium* G.Will.	Karas	WIND (2020)
Menispermaceae	*Tinospora caffra* (Miers) Troupin	Okavango, Zambezi	WIND (2020)
Moraceae	*Ficus sur* Forssk.	Kunene	Swanepoel & van Jaarsveld (2015)
Orchidaceae	*Habenaria kilimanjari* Rchb.f.	Zambezi	Bytebier & Mannheimer (2016)
Orobanchaceae	*Hyobanche glabrata* Hiern	Karas	WIND (2020)
Oxalidaceae	*Oxalis canaliculata* Dreyer, Roets & Oberl.	Karas	WIND (2020)
	Oxalis petricola Dreyer, Roets & Oberl.	Karas	WIND (2020)
Poaceae	*Eragrostis leptotricha* Cope	Otjozondjupa	Fish *et al.* (2015)
Sapindaceae	*Zanha africana* (Radlk.) Exell	Kunene	Swanepoel (2012a)
Scrophulariaceae	*Anticharis angolensis* B.Nord.	Kunene	Nordenstam (2013)
	Aptosimum molle Skan	Kunene	Kolberg & van Slageren (2016)
	Aptosimum pumilum (Hochst.) Benth.	Okavango, Oshikoto	Kolberg & van Slageren (2016)

* introduced

Table 2. New plant taxa described for Namibia since Klaassen & Kwembeya (2013).

Family	**Genus species**	**Region**	**Source**
Acanthaceae	*Acanthopsis adamanticola* H.M.Steyn	Karas	Steyn & van Wyk (2015)
Aizoaceae	*Lithops pseudotruncatella* (A.Berger) N.E.Br. subsp. *schoemanii* A.R. Earle & Uijs	Hardap	Earl & Uijs (2019)
Anthericaceae	*Chlorophytum boomense* Kativu	Karas	Kativu & Bjora (2016)
Asphodelaceae	*Aloe huntleyana* van Jaarsv. & Swanepoel	Kunene	van Jaarsveld & Swanepoel (2012)
Asteraceae	*Crassothonna agaatbergensis* Swanepoel	Kunene	Swanepoel & de Cauwer (2019)
	Dauresia flava B.Nord.	Karas	Nordenstam (2011)
	Gorteria warmbadica Stangb. & Anderb.	Karas	Stångberg & Anderberg (2014)
	Namibithamnus dentatus (O. Hoffm.) H. Rob., Skvarla & V.A. Funk	Kunene	Robinson *et al.* (2016)
	Namibithamnus obionifolius (Merxm.) H. Rob., Skvarla & V.A. Funk	Erongo, Otjozondjupa	Robinson *et al.* (2016)
	Nolletia annemarieae P.P.J.Herman	Kunene	Hermann (2013)
	Nolletia annetjieae P.P.J.Herman	Hardap	Hermann (2013)
	Nolletia vanhoepeniae P.P.J.Herman	Hardap, Omaheke	Hermann (2013)
	Nolletia welmaniae P.P.J.Herman	Kunene	Hermann (2013)
Brassicaceae	*Lepidium seydelii* Al-Shehbaz	Khomas	Al-Shehbaz (2016)
Capparaceae	*Maerua sebrabergensis* Swanepoel	Kunene	Swanepoel (2015)
Colchicaceae	*Androcymbium etesionamibense* U.Müll.-Doblies & D.Müll.-Doblies	Karas	Müller-Dobblies & Müller-Dobblies (2002)
Euphorbiaceae	*Erythrococca kaokoensis* Swanepoel	Kunene	Swanepoel (2019)
	Euphorbia corneliae Bruyns	Karas	Bruyns (2018)
	Euphorbia melanohydrata Nel subsp. *conica* Swanepoel	Karas	Swanepoel (2012b)
	Euphorbia otjipembana Leach subsp. *okakoraensis* Swanepoel	Kunene	Swanepoel (2013)
	Euphorbia otavibergensis Bruyns	Otjozondjupa	Bruyns (2018)
	Euphorbia rimireptans Swanepoel, R.W.Becker & Alma Möller	Kunene	Swanepoel *et al.* (2019)
	Euphorbia subsalsa Bruyns subsp. *otenzii*	Kunene	Bruyns (2018)
Fabaceae	*Crotalaria giessii* M.M.le Roux & B-E.Van Wyk	Karas	le Roux & van Wyk (2013)
	Crotalaria kolbergii M.M.le Roux & B-E.Van Wyk	Karas	le Roux & van Wyk (2013)
	Indigofera kavangoensis Schrire	Okavango, Zambezi	Schrire (2012)
	Oberholzeria etendekaensis Swanepoel, M.M.le Roux, M.F.Wojc. & A.E.van Wyk	Kunene	Swanepoel *et al.* (2015)
Hyacinthaceae	*Desertia luteovirens* Mart.-Azorín, M.Pinter & Wetschnig	Karas	Martínez-Azorín *et al.* (2015)
Iridaceae	*Moraea thermarum* Goldblatt & J.C.Manning	Karas	Goldblatt & Manning (2013)
Lamiaceae	*Ocimum sebrabergensis* Swanepoel & van Jaarsv.	Kunene	Swanepoel & van Jaarsveld (2019)
Menispermaceae	*Tinospora fragosa* (I.Verd.) I.Verd. & Troupin subsp. *kaokoensis* van Jaarsv.	Kunene	van Jaarsveld (2016)
Nyctaginaceae	*Boerhavia orbicularifolia* Struwig	Hardap, Karas, Kunene	Struwig *et al.* (2015)

Pedaliaceae	*Dewinteria petrophila* (De Winter) van Jaarsv. & A.E.van Wyk	Kunene	van Jaarsveld & Swanepoel (2007)
	Rogeria adenophylla J.Gay ex Delile subsp. *rosea* Bedigian	Kunene	Bedigian (2013)
	Rogeria armeniaca Bedigian	Kunene	Bedigian (2013)
Scrophulariaceae	*Anticharis namibensis* B.Nord.	Karas	Nordenstam (2013)
	Anticharis kaokoensis B.Nord.	Kunene	Nordenstam (2013)
	Aptosimum radiatum Kolberg & Van Slageren	Kunene	Kolberg & van Slageren (2016)
Tiganophytaceae	*Tiganophyton karasense* Swanepoel, F.Forest & A.E.van Wyk	Karas	Swanepoel *et al.* (2020)

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Announcement of changes to Namibian Journal of Environment sections

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Abstract

This announcement serves to alert authors to recent changes in the journal's sectional arrangement.

Changes to Namibian Journal of Environment sections

The Namibian Journal of Environment has hitherto published papers in two sections, defined as follows:

- Section A: Peer-reviewed papers includes primary research findings, syntheses and reviews, testing of hypotheses, in basic, applied and theoretical research.
- Section B: Open articles will be editor-reviewed. These include research conference abstracts, field observations, preliminary results, new ideas and exchange of opinions, book reviews.

Following discussions, the following new sectional arrangement was approved by the Editorial Committee and will apply as of 28 September 2020:

- Section A. Research articles. High quality peer-reviewed papers in basic and applied research, conforming to accepted scientific paper format and standards, and based on primary research findings, including testing of hypotheses and taxonomical revisions.
- Section B. Research reports. High quality peer-reviewed papers, generally shorter or less formal than Section A, including short notes, field observations, syntheses and reviews, scientific documentation and check-lists.
- Section C. Open articles. Contributions not based on formal research results but nevertheless pertinent to Namibian environmental science, including opinion pieces, discussion papers, meta-data publications, non-ephemeral announcements, book reviews, correspondence, corrigenda and similar.
- Section D. Memoirs. Peer-reviewed monographic contributions and comprehensive subject treatments (> 100 pages), including collections of related shorter papers like conference proceedings.

Section A remains essentially unchanged from before. The former section B conceptually becomes two new sections: B and C.

The new section B reflects the *status quo* of what the original section B had become over time. Despite the stated description of the old section, the majority of papers published in section B to date had indeed undergone peer-review. The new section resolves the discrepancy between the former section description and its actual content, allowing authors to receive due credit for future section B papers.

Section C accommodates those elements of the original section B that can no longer fit in the new section B. It recognises the need to occasionally publish on matters that do fall within the scope of the journal, but do not represent conventional research results, nor lend themselves to traditional peer-review. Section C contributions will undergo informal review as needed, in addition to the normal editorial oversight. The current announcement is the first section C contribution.

Section D will in future allow the conditional publication of two kinds of bulky submissions that require a different approach compared to normal NJE papers: unusually large contributions and collections of papers that require publication as a unit. Prospective submitters should consult with the editor beforehand.

Papers published before today will not be changed retrospectively. Their cover sheets with section definitions as they were at the time of publication will remain. The new sections will apply to subsequently published papers only.