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The importance of large pans and surrounding bushveld for black rhino (*Diceros bicornis* ssp. *bicornis*) habitat use in the Kalahari: implications for reintroduction and range expansion

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ABSTRACT

In the Kalahari region of southern Africa, recurrent droughts can affect local livestock production and even lead to the loss of traditional farmland. As a result, the wildlife economy has grown in importance as a profitable approach to the sustainable use of native game species adapted to these challenging climatic conditions. This has led to restoration efforts in the region that have brought back wildlife including the critically endangered black rhino (*Diceros bicornis*). To understand the interrelationship between a reintroduced black rhino population and a rural Kalahari wildlife reserve, this research project aimed to decode the key drivers of black rhino habitat use based on a multiscalar approach of combined aerial and ground information on ecogeographical variables (vegetation and artificial habitat components) together with spatial rhino location and individual movement data. On average, black rhino home ranges were found to be 67 ± 20 km^2, with core areas of 24 ± 11 km^2. These are predominantly covered by the landscape types of bushveld and calcareous pans. Analysis of the different landscape factors present in the reserve showed that vegetation heterogeneity, vegetation density, vegetation damage, browse availability and waterhole density were significantly higher in the pooled core areas of the total population compared to less frequented areas. Furthermore, a binary logistic regression model predicted that browse availability and vegetation heterogeneity of medium to large woody species to be the most significant effect on black rhino habitat use. The model also showed a negative correlation with *Acacia* spp. saplings, which can be explained by the decline or absence of saplings in the core areas due to the continuous feeding pressure of black rhinos and other herbivores. Evaluation of black rhino habitat use and spatial distribution indicates a strong preference for the mosaic of microhabitats around calcareous pans and surrounding lunette dunes covered by bushveld. Together with the year-round availability of water (rain-fed lakes and artificial waterholes), these focal points are of high ecological importance and provide suitable habitat conditions that may highlight the potential for further black rhino reintroduction and range expansion, as well as general rewilding efforts in the region.

Keywords: biodiversity, browse, bushveld, carrying capacity, drought, ecogeographical variables, home range, Namibia, rewilding, rhino conservation, spatial distribution, vegetation, wildlife economy

INTRODUCTION

Over the past century, the translocation of wild animals has become an important tool for managing, restoring and enhancing declined populations (Langridge *et al.* 2020). Translocated animals must adapt to a new environment and quickly establish natural behavioural patterns, which are part of the acclimatisation process (Mazess 1975, Göttert *et al.* 2010). The conservation of the black rhinoceros (*Diceros bicornis*) is a good example of how translocations of individuals and small populations have helped expand the species into its former range and increase overall population numbers (Göttert *et al.* 2010).

With the establishment of rhino sanctuaries throughout the African continent, rhinos can be reintroduced into protected areas where they have gone locally extinct in the past. For several decades, translocation has been a common practice, taking place from high-risk areas and government lands to private lands (Emslie & Brooks 1999). In comparison to large state-owned national parks, such sanctuaries can be found in established private wildlife reserves or game farms which are safeguarding other wild animals in a confined area. In some cases, the protective attributes of these sanctuaries outweigh their habitat suitability (Adcock *et al.* 1998, van der Heiden 2005). As an example of such range expansion projects, Namibia's Black Rhino Custodianship Programme (BRCP) is a rhino conservation success story built on nationwide rhino sanctuaries, spread across 10 communal conservancies and 25 freehold ranches. It also embodies several aspects of effective ecological population management in line with international guidelines (Kötting 2020, Muntifering *et al.* 2023).

Conservation of the black rhino in Namibia faces chronic challenges, i.e., despite an ongoing poaching crisis, some local populations continue to exceed the carrying capacity of conservation areas. Maintaining and expanding this conservation programme is expensive, and generating sufficient revenue is a challenge (Kötting 2020). While many privately owned areas in the central and northern regions of Namibia are already part of the programme, other areas are becoming increasingly important for potential reintroduction and range expansion. An example of this is the Kalahari region in central-eastern Namibia, which has received limited attention from the conservation programme to date, despite representing a large proportion of Namibia's land area (Kötting 2021). Precolonial historical records indicate that both species of rhino were once common in central-eastern Namibia (today's Omaheke region, part of the Kalahari ecosystem), making the Kalahari an important refuge for both rhino and many native wildlife species (van Rooyen *et al.* 2008, Wallgren *et al.* 2009, Sullivan *et al.* 2021).

A principal geomorphic feature of this semiarid landscape is depressions or pans, which vary in size and which are scattered throughout the entire region. The pans are important temporary water reservoirs during the rainy season and are characterised by relatively high mineral content and, in some cases, perennial grass cover (Lancaster 1974, Parris & Child 1973). Wind erosion deposits sediment from the pans into the surrounding area to form flanking lunette dunes (Haddon 2005). The pans and their surroundings contain a high diversity of vegetation and landscapes, are critical for wildlife species, and are particularly selected and used for keeping livestock from nearby settlements (van Rooyen & van Rooyen 1998, Parris & Child 1973). As many parts of the central and southern Kalahari have been converted to pastoralism, human activities such as overgrazing by livestock have had a negative impact on vegetation conditions around the pans, resulting in bush encroachment and reduced amounts of perennial grasses and plant litter (Parris & Child 1973, Moleele & Mainah 2003, Wallgren *et al.* 2009).

The Kalahari is affected by extreme weather events such as recurrent droughts, which threaten the livelihoods of local communities and lead to increased livestock mortality, crop failure and even loss of farmland (Mogotsi *et al.* 2013). Although droughts have occurred throughout history, ongoing climate change is accelerating and amplifying these events, leaving poorer households with limited resources to adequately cope and adapt (Mogotsi *et al.* 2011, 2013). A common consequence is an increase in internal displacement and migration (Adaawen *et al.* 2019).

The combination of such critical environmental, socioeconomic and climatic factors is encouraging a rethink of land use patterns in many regions of Africa, with an increased emphasis on the sustainable use of wildlife, which is more adaptable to challenging site factors than traditional livestock. The wildlife economy is a diverse sector that combines ecotourism, the sale of live animals, various forms of hunting and meat production (Child *et al.* 2012). This profitable approach has extended to the Kalahari, enabling rewilding efforts to restore ecological balance and promote biodiversity, particularly for threatened and keystone species such as the black rhino. As an example, Kuzikus Wildlife Reserve (KWR), a former cattle farm negatively affected by decades of livestock grazing, has been transformed into a wildlife sanctuary, with more than 40 years of ecological restoration. The reserve's main source of income is ecotourism, but it is also a representative site for the BRCP, providing suitable conditions for analysing habitat use in the Namibian Kalahari and investigating the ecosystem's value for black rhino reintroduction and range expansion. KWR was approved as one of the first reintroduction sites under the programme in the late 1990s and over the past 25 years the population has grown remarkably. Its high population growth rate of 9% lies above the Namibian BRCP average of 7.9% (net of translocation) and 8.5% (net of translocation and poaching), as well as the IUCN benchmark of 5% (Emslie *et al.* 2019, Sullivan *et al.* 2021, Reinhard & Reinhard 2022).

Several studies have addressed the issue of black rhino habitat use, resource selection, spatial distribution and habitat suitability assessment, testing different methods and models. One of the recent studies from 2015 used random forest models to predict habitat use (Lush *et al.* 2015), another from 2012 focused on logistic regression and Bayesian Information Criterion (Buk 2012), Simon Morgan (2010) included a maximum entropy (Maxent) model and van der Heiden (2005) worked with a utilisation distribution. As the first black rhino home range and habitat use study of its kind in this landscape and ecoregion of Namibia, it is important to understand the full picture of how specific ecogeographical variables (EGVs) of the Kalahari ecosystem, as well as species–habitat interactions, affect the spatial distribution of a reintroduced black rhino population. This, in turn, may help to maintain viable populations, improve local management strategies and even promote further conservation efforts in the Kalahari ecosystem (Göttert *et al.* 2010, Morgan 2010).

METHODS

Study site and landscape

The study took place in the Kuzikus Wildlife Reserve which is located approximately 150 km southeast of the Namibian capital, Windhoek, at 23°16’–23°26’S and 18°33’–18°48’E. The private reserve covers around 115 km^2, lies about 1,350 m above sea level and is mostly flat, except for three dunes of about 15 m in height. It is surrounded by a perimeter fence, and the lodge and staff village have an additional interior fence. Ecotourism has been active in the reserve since 2005 and includes regular human activity, mostly focused on guest-related activities such as game drives, nature walks and horse riding, as well as management activities such as road, waterhole and fence maintenance, anti-poaching patrols, and occasional game management and ecosystem drone mapping operations.

KWR can be divided into six different vegetation types, comparable to those of the Kalahari Gemsbok National Park in South Africa (now part of the Kgalagadi Transfrontier Park) (van Rooyen *et al.* 2008, Sterk 2019). The area belongs to the southern Kalahari, part of the Acacia Tree-and-Shrub Savanna biome (Figure 1) (Atlas of Namibia Team 2022). The most common vegetation type, the low duneveld, occupies 46% of the reserve and is characterised by *Acacia erioloba* and *Schmidtia kalahariensis*. In contrast, the bushveld covers almost the other half of the landscape and is dominated by different *Acacia* spp., mainly *Acacia mellifera*. As the bushveld appears to vary locally, two parameters (bush density and dominant species present) were used to differentiate bushveld, resulting in three distinct bushveld types (mixed bushveld, open *A. hebeclada* bushveld and dense *A. mellifera* bushveld). Depressions are found in 12 calcareous pans, two of which are large (1.9 and 0.8 km^2). The sandy grassveld forms the landscape between the high dunes and contains a very low proportion of woody vegetation.

Previous study

The home range and habitat use analysis follows up on a previous study on the carrying capacity of black rhinos in the KWR from 2018 to 2019, and integrates its findings on how habitat and food resources limit population growth. For KWR, the Southern African Development Community’s Rhino Management Group (SADC RMG) Black Rhino Carrying Capacity model v.2 predicts a total browse availability score of 7.95% and a mean ecological carrying capacity estimate of 11 black rhinos on the 115 km^2 property (Table 1) (Sterk 2019). Black rhino browse availability (BA) is defined as the landcover which describes the percentage of available food plants in a three-dimensional space between 0 and 2 m height (Adcock 2017).

Study population and other herbivores

During the period of data collection, ten individual black rhinos were present in the reserve; two territorial bulls, two subadult bulls and three adult cows, each accompanied by one calf. Each individual was given a name and all adult animals have specific ear notches to facilitate identification. The reserve

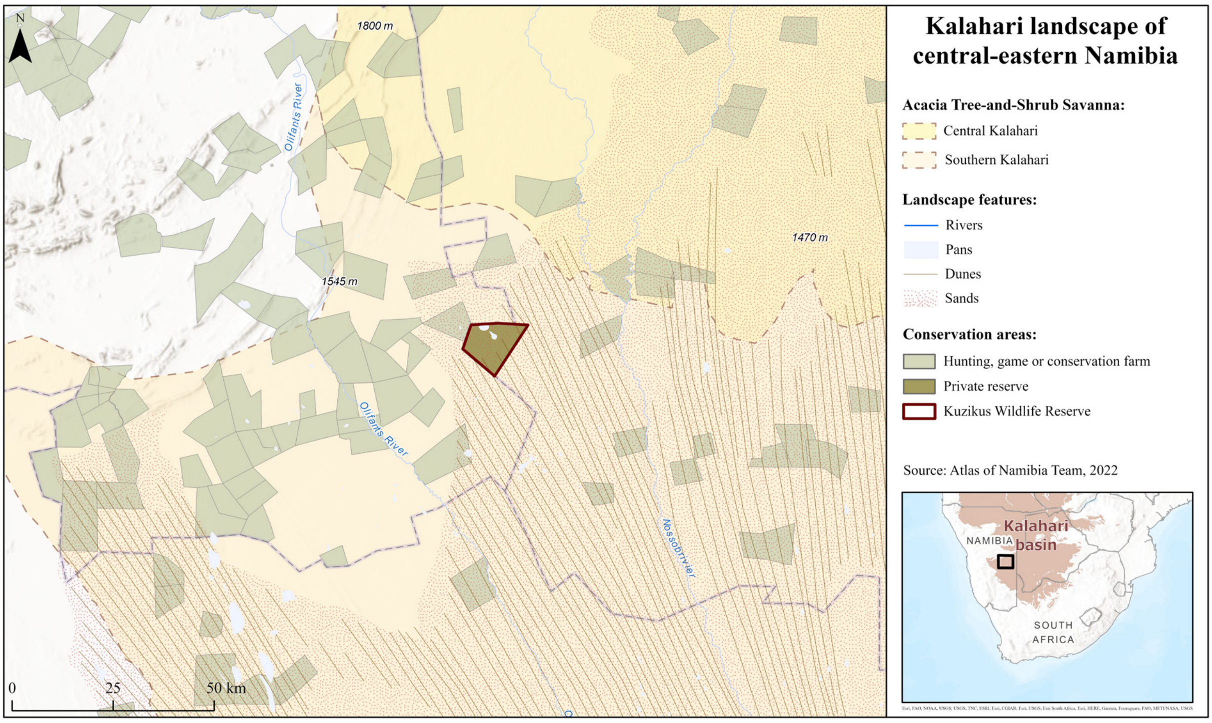

Figure 1: *Map of the Kalahari landscape (Namibia) showing the location of Kuzikus Wildlife Reserve within the Kalahari, the extent of the Acacia Tree-and-Shrub Savanna, characteristic landscape features and conservation/wildlife areas (Atlas of Namibia Team 2022).*

Table 1: *Average black rhino browse availability values for each vegetation type found in Kuzikus Wildlife Reserve expressed as the percentage of land cover. Analyses were done using the black rhino carrying capacity model v2 (Sterk 2019).*

	Low duneveld	**Mixed bushveld**	**Dense bushveld**	**Open bushveld**	**Sandy grassveld**	**Pan**
Average browse availability	5.7%	9.7%	12.4%	1.2%	0.2%	0.9%
Percentage of land area	46.0%	32.0%	17.5%	1.1%	0.5%	2.9%
Vegetation type contribution to total browse availability score	2.622%	3.117%	2.167%	0.013%	0.001%	0.027%
Total browse availability score for Kuzikus Wildlife Reserve: 7.95%						

also hosts several species of browsing herbivores that compete with black rhino, including Angolan giraffe (*Giraffa giraffa angolensis*), common eland (*Taurotragus oryx*), greater kudu (*Tragelaphus strepsiceros*), gemsbok (*Oryx gazella*), common impala (*Aepyceros melampus*), springbok (*Antidorcas marsupialis*), common duiker (*Sylvicapra grimmia*), and steenbok (*Raphicerus campestris*).

Data collection

Home range studies, as well as understanding habitat use, require a large number of location points from individual black rhinos for statistical analysis. This is typically achieved using VHF and GPS collars (horn implants or anklets) (Seidel *et al.* 2019). Darting and collaring rhinos is a costly operation involving helicopters, vets, ground staff, drugs, and technical equipment, and is also stressful for the rhinos (Morkel 1994). To avoid such events, a mix of sampling methods was used in this study. Georeferenced location data points were collected over a period of ten months (between June 2021 and April 2022). Data collection consisted of direct field observations, via identified footprints, evaluated night-vision camera trap images, operational drone flights for anti-poaching and ecosystem mapping, and external data points from other reserve staff.

The approach to visually locate individuals and map corresponding footprints was based on a stratified random survey method, with the reserve divided into four zones. Within each zone, vehicle and random off-road foot patrols were conducted to monitor rhino activity. Zones were then rotated on a daily basis, with the reserve's road network allowing rapid access to all areas. In open areas, rhinos could be spotted at distances of more than 1 km. Random foot patrols were also conducted frequently to access areas of dense vegetation with limited visibility, looking for rhino tracks and signs. Two night-vision camera traps were placed at waterholes, salt rocks, dung middens and rhino 'highways', rotating between these sites every 3–4 days, while an additional six camera traps were placed at random locations within the reserve and moved to a different site each week. To avoid bias caused by frequent rhino activity around waterholes, information on their location was placed on identified trails that were at least 250 m away from the waterholes.

To link rhino footprints to individuals, each rhino was tracked at least once at the beginning of the study to obtain clear footprint images in bare substrate, resulting in a verified identification catalogue. Subsequently, when rhino tracks were found, footprint identification was based on visual comparison of heel line patterns, which are unique to each rhino. This non-invasive approach can be reliable with high accuracy in small populations (Jewell *et al.* 2020).

Sightings were added into the database if separated by at least one day, implying that information on each individual rhino could only be recorded once a day. Nearly all activities were conducted either in the early morning or late afternoon hours, as most of the rhinos were active at these times. All rhino related data include information on date, time, ID of the individual, its behaviour, whether there was a change in behaviour caused by the observation and the method used for data collection. To map rhino locations, GPS data points were logged on the ArcGIS Explorer App for IOS (Esri Inc. 2018–2020).

Habitat use was determined taking different EGVs into consideration. Based on literature review, the following variables were chosen for their important role in rhino habitat use and preference: 'browse availability' (related to the vegetation type); 'vegetation density'; 'vegetation heterogeneity'; 'vegetation damaged by rhinos'; '*Acacia* spp. sapling distribution'; 'availability and distance of permanent water points'; 'intensity of road use' (van der Heiden 2005, Morgan 2010, Buk 2012, Lush *et al.* 2015).

In November 2021, as part of the Kuzikus Mapping Project (see https://kuzikus-namibia.com/research), a two-week drone mission using a SenseFly eBeeX fixed-wing aircraft, flown at an altitude of 160 m, collected 3 cm high-resolution RGB imagery to build an aerial imagery database of the entire reserve. The mission was timed to capture medium to large vegetation at the end of the dry season and just before the first rains of the wet season, allowing optimal visualisation and accurate delineation of landscape and vegetation components. These high-resolution drone images, supplemented by publicly available satellite data and validated through a ground-truthing process, were used to map all distinctive landscape features, vegetation types, their densities and artificial elements (waterholes, fences, buildings and roads) within the reserve's infrastructure. These digitised features were then integrated into ArcGIS to create a geospatial 'digital twin' with defined boundaries of the different features (Esri Inc. 1999–2019).

During the same period, a vegetation survey of the reserve was carried out. For this purpose, a digital grid consisting of square grid cells measuring 750 m x 750 m was created over the study area using ArcGIS. A total of 260 cells were generated, and the midpoint of each cell was marked as the location for establishing vegetation plots (Esri Inc. 1999–2019). Consequently, the vegetation data obtained from each plot represented the corresponding grid cell. Along the reserve boundary, plots were positioned as centrally as possible.

The 50 m diameter vegetation plots were used to manually record key aspects of the vegetation, consisting of the vegetation heterogeneity (number of woody species), the extent of damage caused by black rhino browsing (expressed as a score) and the presence of *Acacia* spp. saplings (counted individuals). In addition, browse availability values derived from data from the previous carrying capacity study were assigned to the different vegetation types found in the reserve. These relative values were also integrated into the corresponding grid cells.

On completion of the plot survey, the response data for each vegetation variable was divided into four categories (absent/very low, low, medium and high) and assigned accordingly, resulting in a scorecard. This helped to better visualise the data in the next step (Table 2).

For the artificial habitat features, the availability, distances and densities of water points were assessed using the digital twin, while road transects were assigned to a specific category indicating the frequency of weekly use. Subsequently, these data were also integrated into the grid cell database.

Data analysis

Based on the rhino location points, individual home ranges were estimated and combined to a pooled population model using the Kernel Utilisation Distribution (KUD) estimation in R with the package 'adehabitatHR' (Calenge & Fortmann-Roe 2015).

When examining habitat use, the characteristics of the core ranges were particularly considered, which are salient areas that include 50% of all the nearest location points, demonstrating a direct preference for the area (Lent & Fike 2003).

Chi-squared and Fisher's tests were applied to assess significant differences between vegetation types within the core and peripheral areas of the rhino range. In addition, analysis of variance (ANOVA), T-tests and Tukey tests were used to determine significant differences in the distributions of vegetation heterogeneity, vegetation density, damaged vegetation, waterhole density, waterhole distance and road transect (use categories) between the core and peripheral areas (*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$).

To evaluate the interaction of EGVs and their impact on rhino habitat use, multicollinearity between the single variables was calculated using a variance inflation factor (VIF). A value of 1 indicates no correlation, a value between 1 and 3 indicates a moderate correlation and values > 3 represent strong correlations and can be excluded as coefficient estimates, while p values in the regression output are likely to be unreliable (R Core Team 2018, Statology 2021).

Secondly, a binary logistic regression model (BLRM) and the odds ratio of each variable was calculated using the grid cell database combined with the response variable 'core area' ('Yes' or 'No') (Harrell 2015).

Table 2: *Ecogeographical variables scorecard by category per 50 m diameter vegetation plot, including vegetation damage (score), vegetation density (number of trees and bushes), vegetation heterogeneity (number of woody plant species),* Acacia *spp. saplings (number of saplings), browse availability (score) grouped into to four categories (absent/very low to high).*

Category	**Vegetation damage**	**Vegetation density**	**Vegetation heterogeneity**	***Acacia* spp. saplings**	**Browse availability**
	(score)	(Number of trees and bushes)	(Number of woody plant species)	(Number of saplings)	(score)
Absent/very low	0 – < 1	0	0 – 2	0	0 – < 3.25
Low	1 – < 3	< 20	3 – 4	1 – 3	3.25 – < 6.5
Medium	3 – < 5	20 – 40	5 – 6	4 – 6	6.5 – < 9.75
High	≥ 5	≥ 40	≥ 7	≥ 7	≥ 9.75

The model was checked in advance for its meaningfulness. This included an omnibus test to find out whether the test model makes a significant explanatory contribution compared to the null model. A chi-squared probability was identified for this and checked if the R-squared value can be applied as a goodness-of-fit measure for logistic regression models using the Nagelkerke method (Nagelkerke 1991).

The odds ratio (OR) is a useful way of assessing the likelihood of an outcome occurring given a particular exposure. If the OR value is > 1, an increased occurrence of the event can be expected. An OR value < 1 indicates a decreased occurrence of the event (Tenny & Hoffmann 2021). In terms of black rhino habitat use, this means that if the categorical value of each variable increases by one unit, the probability of an area being considered a rhino core area will either increase or decrease by the given OR value.

RESULTS*

**Maps showing rhino locations, home ranges, habitat use, or reserve infrastructure are withheld for security reasons.*

A total of 518 rhino location points were recorded during the study. Direct observations provided 296 data points, 167 were derived from footprints, tracks and signs associated with individual rhinos, 52 data points are from camera traps and three individuals were spotted during operational drone flights.

Due to the topography, the black rhino population has access to almost the entire available area within the perimeter fence, excluding the inner fenced reserve infrastructure. The pooled spatial distribution of all individuals covers 112 km^2 (95% isopleth) and core areas 60 km^2 (50% isopleth). The following spatial categories refer to the core and peripheral areas of the home ranges. Unused areas are almost non-existent and of no further significance.

The spatial distribution of the population is largely based on the two separate home ranges of the two dominant bulls, Columbus and Hermes. In contrast, the home ranges of females and subadult bulls show that they predominantly share the same areas, are similar in size and fully overlap with the core area of Columbus. On average, individual home ranges are 67 ± 20 km^2 (95% isopleth) and core areas are 24 ± 11 km^2 (50% isopleth) (Table 3).

Vegetation types vary significantly between the core and peripheral areas of the pooled total rhino population range (Fisher's test: $p < 0.0005$***). The core areas are dominated by bushveld types, which occupy 70% of the area, while low duneveld occupies 25% and pans 5%. No sandy grassveld was recorded in the core areas. On the other hand, low duneveld is the most common vegetation type in the outer areas of the pooled home ranges, covering more than 70%. Mixed bushveld and dense bushveld cover comparatively less land at 19% and 9% respectively. Calcareous pans were not found to be used in the peripheral areas (Figure 2).

During the spring season in September and October, a shift in the range of female rhinos was observed. At this time, they mainly visited the dune system. During the remaining months of the study period, the females remained in the bushveld areas of the reserve. The 50% isopleth of their range was 18 km^2 in spring and 12 km^2 during the rest of the year. No seasonal shift in the distribution of bulls was observed.

Data analysis of the natural EGVs present in the wildlife reserve showed vegetation heterogeneity ($p < 0.0001$***), vegetation density ($p = 0.0063$**), vegetation damage ($p = 0.0004$***) and browse availability $p = 0.0005$***) were significantly higher in the pooled core areas of the total population compared to the less frequented peripheral areas. No significant differences in the number of *Acacia* spp. saplings were found between the two types of areas ($p = 0.240$) (Figure 3).

Table 3: *Home range size estimation (50% and 95% isopleths) for individual rhinos in the Kuzikus Wildlife Reserve (including information on sex and year of birth) and ratio of 50% isopleth size to 95% isopleth size. For females, calf names and year of birth are shown in brackets.*

ID adults (and calves)	Sex	Year of birth	Sample contribution (n)	50% isopleth (core area) in km²	95% isopleth (home range) in km²	Ratio 50% to 95% isopleth
Columbus	male	1992	92	45	91	0.49
Hermes	male	2002	102	8.5	25	0.34
Hector	male	2016	68	25	71	0.35
Helia (Hades)	female (male)	2007 (2021)	71	22	64	0.34
Juno (Jonas, Jakari)	female (male, male)	2005 (2015, 2019)	110	18	67	0.27
Kenia (Kauri)	female (female)	2008 (2021)	75	23	69	0.33

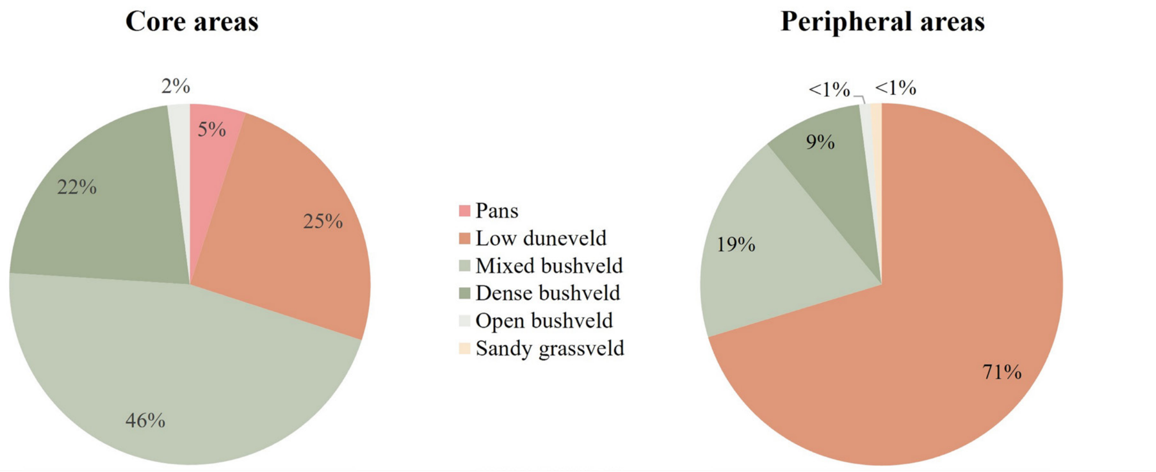

Figure 2: *Distribution of vegetation types within black rhino core areas and peripheral areas in the Kuzikus Wildlife Reserve.*

For the artificial habitat variables, we found that waterhole density is significantly higher in the core areas of the pooled rhino home ranges (1.8 waterholes per 10 km²) compared to the peripheral areas (0.6 waterholes per 10 km²) ($p = 0.0002$***). However, there is no statistically significant difference between the two area types in terms of mean distance between nearby waterholes ($p = 0.091$) and the frequency of road use ($p = 0.065$) (Table 4).

Within the binary logistic regression, the variables were first tested for multicollinearity. No values were excluded from further interpretation as none exceeded a value of 3. The highest correlation is between vegetation density and browse availability ($r = 0.736$). The correlation coefficient between vegetation density and vegetation heterogeneity is similarly high at 0.699. Vegetation heterogeneity together with browse availability also have a moderate correlation coefficient of 0.559. The remaining coefficients are all below 0.5, indicating a lower degree of correlation and even weak negative correlations (Table 5).

Binary logistic regression model

Using an omnibus test, the chi-squared probability was found to be significant for its explanatory contribution compared to the null model ($p < 0.0001$***). As a measure of goodness-of-fit for logistic regression models, the Nagelkerke R-squared value of 0.43 indicates a medium to strong

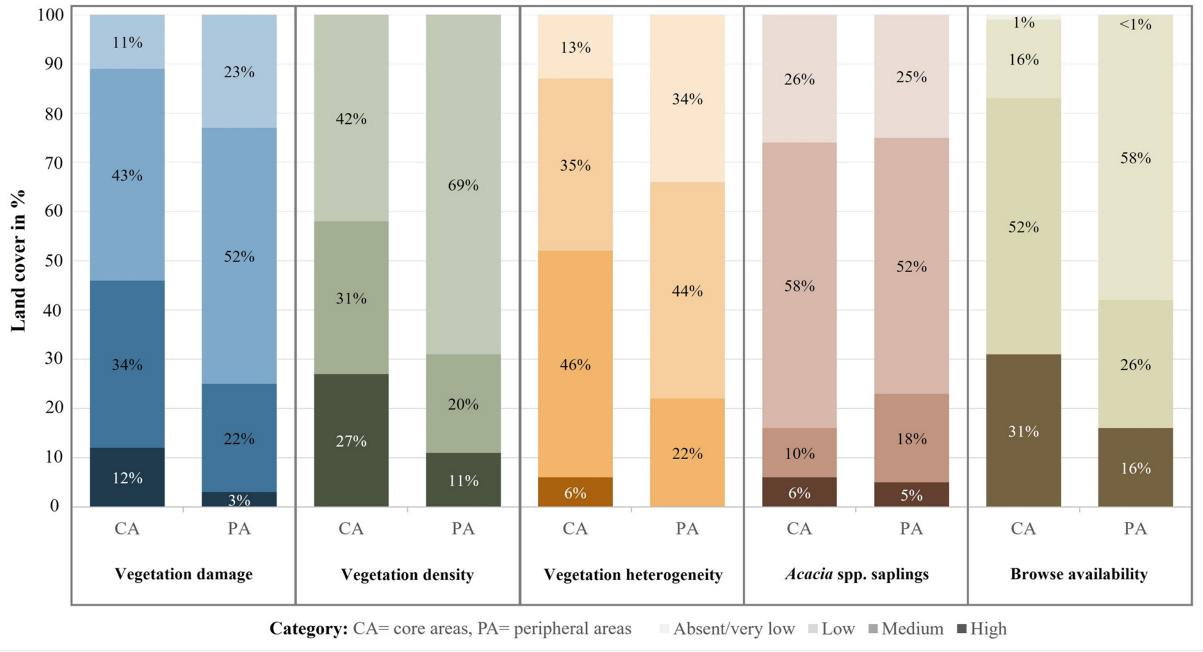

Figure 3: *Effect of ecogeographical variables (EGV) (vegetation damage, vegetation density, vegetation heterogeneity,* Acacia *spp. saplings and browse availability) on black rhino habitat use in the Kuzikus Wildlife Reserve.*

***Table 4:** Waterhole distribution and road use intensity by black rhino in the Kuzikus Wildlife Reserve.*

Artificial habitat features		
	Core areas	**Peripheral areas**
Waterhole distribution		
Density	1.8/10 km^2	0.6/10 km^2
Mean distance	3.2 km	3.5 km
Road usage (frequency)		
Once a day or every second day	10.2 km	6.8 km
Every 3–4 days	37 km	15.5 km
Less than once a week	31.5 km	39.7 km

relationship and corresponds to real world phenomena (Nagelkerke 1991).

The BLRM results show vegetation heterogeneity (p = 0.007**) and browse availability (p = 0.008**) have the most significant effect on the utilisation of the investigated areas as rhino core range (Table 6). The number of *Acacia* spp. saplings also has a significant but negative effect (p = 0.01*).

Odds ratio

Vegetation heterogeneity has the highest value (OR = 2.2), which means that an area is 2.2 times more likely to be used as a core area by black rhino if woody plant diversity increases. The two categories of vegetation density and browse availability would also increase rhino occurrence by a factor of > 1.5. The presence of waterholes and vegetation damage by rhinos have lower values (OR = 1.3). However, the intensity of road use and the number of *Acacia* spp. saplings have negative OR values (Table 7). Increasing the categorical values of these two variables reduces the likelihood of areas being classified as rhino core range.

DISCUSSION

Home ranges

Across the African continent, black rhino home ranges vary widely, from small (3 km^2) in humid and subtropical areas to extremely large (300 km^2) in arid areas such as northwestern Namibia (Plotz *et al.* 2016). With an average annual rainfall of approximately 210 mm, the Kuzikus Wildlife Reserve lies in the middle range of Kalahari rainfall (150–300 mm) (Wasiolka & Blaum 2010). Large home range sizes would be expected in such an environment, but the maximum distribution of 115 km^2 cannot be exceeded as the perimeter fence limits the space available to rhinos. The home range sizes of rhino bulls vary considerably across the reserve, reflecting similar findings from Hluhluwe-Imfolozi Park in South Africa (Reid *et al.* 2007). At 62 ± 28 km^2, the mean home range size of bulls is also smaller than in other arid rhino habitats in South Africa (Lent & Fike 2003). On the other hand, females tend to have larger territories than bulls (Reid *et al.* 2007), which is also somewhat evident here (67 ± 2 km^2).

***Table 5:** Matrix of correlation coefficient values between each ecogeographical variable and variance inflation factor.*

	Vegetation density	Vegetation heterogeneity	Browse availability	Vegetation damage	Saplings count	Waterholes	Road use intensity
Vegetation density							
Vegetation heterogeneity	0.699						
Browse availability	0.736	0.559					
Vegetation damage	0.447	0.496	0.386				
Saplings count	0.382	0.228	0.253	0.170			
Waterholes	0.151	0.238	0.208	0.160	0.002		
Road use intensity	0.129	0.191	0.170	0.043	0.051	0.134	
Variance inflation factor	2.932	1.895	1.987	1.219	1.870	1.081	1.067

***Table 6:** Results of the binary logistic regression model including estimates, standard error, z and p values for each ecogeographical variable.*

	Estimate	Standard error	z value	p value	Significance
(Intercept)	-4.152	0.864	-4.807	$1.53e^{-06}$	***
Vegetation density	0.612	0.340	1.799	0.072	
Vegetation heterogeneity	0.776	0.290	2.674	0.007	**
Browse availability	0.597	0.225	2.652	0.008	**
Vegetation damage	0.270	0.232	1.167	0.243	
Saplings count	-0.652	0.256	-2.549	0.011	*
Waterholes	0.286	0.682	0.419	0.675	
Road use intensity	-0.236	0.155	-1.519	0.129	

The home range and carrying capacity analysis suggests that there is insufficient space for more than two dominant rhino bulls. This should be taken into account in the population management and in the BRCP to avoid increased bull mortality due to excessive fighting. Therefore, it is recommended to remove 2–3 subadult bulls from the reserve as soon as they attain maturity and are no longer dependent on their mothers.

Seasonal shift of home ranges

In large natural environments as well as in small, fenced conditions, it is known that black rhinos and other megaherbivores shift their spatial distribution between dry and wet seasons (Shannon *et al.* 2006, Reid *et al.* 2007). The observed spatial shift of the females' home ranges towards the dune system coincided with the beginning of the *Acacia* blooming during springtime. In the Kalahari, *A. erioloba* and *A. mellifera* flower at the end of the cool, dry wintertime and set fruit before the start of the rainy season (Sekhwela & Yates 2007). In the months of September and October, all rhino cows were regularly found in this part of the reserve. During this period, *A. mellifera* flowered profusely 3–4 weeks before bushes elsewhere in the reserve. The reason the *Acacia* bloom starts earlier on the dune crest is unknown. A possible explanation might be the increased amount of sunshine due to direct exposure of the dune crests and less frost during the winter compared to the dune valleys and plains. Although rhino tolerance for more open vegetation increased during this period, isolated islands of dense bush providing cover and shade were still important as they were frequently visited and used for daytime resting.

Habitat use

The multiscalar overlay of spatial habitat and vegetation information, in combination with the defined home ranges, allows us to determine how ecogeographical factors, the seasonal variation in resources, and social interactions between the individuals influence habitat use by the black rhino population in the KWR. These results correlate with the findings that herbivores typically respond adaptively to spatial and temporal changes in resource availability and suitability while significantly redesigning their environment (Owen-Smith 2010). In the Kalahari, suitable local environmental conditions are found to be a combination of high vegetation heterogeneity and high browse availability, which are the strongest predictors of rhino habitat use. This is particularly evident around calcareous pans flanked by lunette dunes and the surrounding bushveld, which create a mosaic of microhabitats and form the core areas of all individual home ranges. These focal points regularly host the entire black rhino population at the same time, making them highly valuable congregation sites for socialising (van Rooyen *et al.* 2008).

Vegetation density, heterogeneity and browse availability

When comparing the two prominent vegetation types in the KWR, black rhino habitat use shows a clear preference for bushveld, with the three types of bushveld accounting for 70% of the core areas, compared to 71% covered by low duneveld in the peripheral areas of the home ranges. Here, the bushveld areas can be attributed to the high browse availability scores. In these areas, vegetation density is also positively correlated with browse availability. Although vegetation density was not identified as a main driving factor in habitat use, dense bush thickets or bush islands jutting out from more open landscapes were often recorded as foraging and resting sites, providing cover, shade and increased browse availability. As also shown in the arid northwest of Namibia, the intensive use of certain areas by black rhino is directly related to browse availability (Shivute 2008). In contrast, the large calcareous pans make up only about 3% of the total area and have a comparatively low browse availability value due to their sporadic or low vegetation height. Nevertheless, they are preferred and frequently visited by rhinos. This can be explained by the heterogeneity of the vegetation which is associated with a higher species composition of preferred browsable species (especially small shrubs and herbs). These foraging areas contain multiple microhabitats within a vegetation community and are selected over other areas (Buk & Knight 2010). Particularly during the dry season, this may also have a positive effect on individual fitness to compensate for the lack of nutrient intake when favourable plant species become less available (Oloo *et al.* 1994).

Damage to vegetation as a result of browsing

In the KWR, patches of vegetation with broken branches or even trees and bushes that had been completely toppled by rhinos were common. In response to browsing pressure, field observations suggest a different growth form for *Acacia erioloba*, which is more horizontal (as a result of being pushed by rhinos and continuing to grow) (Amanyanga 2017). It was also observed that isolated bushes or

Table 7: *Odds ratio of each ecogeographical variable included in the binary logistic regression model.*

	Vegetation density	Vegetation heterogeneity	Browse availability	Vegetation damage	Saplings count	Waterholes	Road use intensity
Odds ratio	1.844	2.173	1.816	1.310	0.521	1.331	0.790

bushes in clusters surrounded by open areas showed more damage than individuals within bush thickets. The open space around the bushes could explain why these bushes are more often targeted, as they are easier to approach and feed on. It is difficult to determine the extent to which rhinos affect plant growth in the reserve. However, there is a significant negative impact in certain areas and on certain plant species. Rhinos usually feed on a wide variety of plants, but often a limited number of species contribute to most of the ingested biomass (Loutit *et al.* 1987, Muya & Oguge 2000). This is consistent with observations of rhino feeding behaviour in the study area, while the increased feeding pressure on specific woody plant species in the KWR confirms the preference for *Acacia* species and *Grewia flava* (Shaw 2011). These are complemented by *Catophractes alexandri*, which is known to contribute a large proportion of the diet throughout Namibia, particularly in Etosha National Park (Joubert & Eloff 1971, Curtis & Mannheimer 2005). With key forage species under constant browsing pressure, with no rest for regrowth and little chance of survival, a long-term decline in browse availability can be expected. This could have negative impacts on black rhino population size and reproduction rates, as suggested by a similar scenario with *A. haematoxylon* in the southern Kalahari of South Africa (Shaw 2011). In order to adapt to the potential depletion of key resources in fenced areas through increased browsing pressure, possible measures could include reducing herbivory by fencing off severely degraded areas, managing black rhino numbers and other browsing game species that directly compete with them (Redick & Jacobs 2020). In particular, the argument for increasing the range of black rhino through land expansion should be considered.

Conversely, rhino impacts can also be positive at both macro- and microhabitat levels. Like other megaherbivores, black rhinos are considered to be ecological engineers (Owen-Smith 1998). In particular, through their feeding behaviour and dispersal, black rhinos have great potential to alter the structure of landscape vegetation. Observations in the KWR have shown that a variety of other smaller animal species benefit from the fallen branches or toppled bushes. For instance, they provide new hiding places and make leaves more accessible, increasing browse availability for springbok, common duiker and steenbok, amongst others (Amanyanga 2017). Seed pod ingestion and excretion in moist dung also aids seed dispersal and germination; germination is often higher when seeds have been previously ingested by herbivores (Miller 1995).

Acacia spp. saplings

At the landscape level, the distribution of the age structure of *Acacia erioloba* in KWR is mostly homogeneous. This means that in certain areas, young and middle-aged individuals are absent while the population continues to age. This picture clearly stands out from that of the surrounding livestock farms, where the tree population consists of a diverse age structure. The absence or limited growth of young saplings in the KWR can be attributed to the impact of browsing herbivores. On livestock farms herbivory is mostly through grazing rather than browsing; this results in higher surviving rates of saplings and in heterogenous tree populations. Conversely, the risk of overgrowth and woody encroachment is higher on livestock farms (Riginos & Young 2007).

However, the absence of *Acacia* spp. saplings is widespread throughout the entire reserve and does not only occur in highly frequented rhino areas. A density-dependent mortality among young *Acacias* has been observed in other areas of the Kalahari, as they often do not survive in direct resource competition with similarly old individuals or with dense grass cover (Skarpe 1991, Riginos & Young 2007). Additionally, an increased mortality in middle-aged *Acacias* is also known in the region (Moustakas *et al.* 2006).

The BLRM has shown a significant negative correlation predicting habitat use of black rhinos. This means that areas which are favoured as feeding grounds have a low number of saplings. It can be assumed that these areas contained higher numbers of saplings in the past, which continuously decreased over time due to feeding pressure of the rhinos and other herbivore species and now result in the absence or low amounts of surviving individuals. It is also known that rodents as well as invertebrates can have substantial impacts on the survival rates of saplings (Riginos & Young 2007).

Artificial habitat components

No general avoidance of habitat use was observed in areas frequently traversed by vehicles. In this context, flight distances were recorded for individual rhinos, limited to an average of 200 m and varying considerably between individuals (from 0 to a maximum of 1,200 m). Here, adjacent areas of dense vegetation appear to have a positive effect on reducing flight distances compared to more open areas. In addition, it is still uncertain whether increased human activity has a direct impact on black rhino habitat use. In the KWR, contrasting scenarios were observed. First, one habituated adult bull showed minimal signs of avoiding human presence, as evidenced by its frequent proximity to residential structures. In contrast, all females and their calves appeared to actively avoid human occupied areas. However, this behaviour may also be influenced by the less favourable habitat conditions in these areas.

It is well known that black rhinos usually drink daily and often spend time at waterholes, especially at night when social gatherings are common. Waterholes therefore play an important role in the social life of rhinos (Schwabe *et al.* 2015). They also provide mud wallows, which are used for cooling down the rhinos' bodies and for skin care (Joubert & Eloff 1971). However, no direct influence of waterhole availability on rhino habitat use was found, as the waterholes are well distributed and evenly spaced across all regions of the reserve. It is possible that the likelihood of waterholes being visited regularly is affected by the surrounding suitable habitat that can be used on the way to or from the waterhole. In this context, it is worth reiterating the importance of waterholes at calcareous pans in conjunction with adjacent feeding areas, as they provide suitable areas for general daily food, minerals and water intake, as well as for social interactions, which is presumably why these habitats are used most frequently by all individuals. Artificial waterholes constructed at the pans are therefore essential to provide a constant supply of water during the dry season, while abundant rain in the wet season can flood the pans and create large lake systems.

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

Given the suitable conditions and landscape characteristics for black rhino found around large calcareous pans, these findings serve as a possible explanation for the high population growth in KWR, as well as for the eastern region of Namibia (Muntifering *et al.* 2023). Successful rewilding efforts in the region have been shown to restore ecological balance and promote biodiversity, especially for threatened species such as the black rhino. With rewilding efforts, the Kalahari could become an important base for the conservation of the southwestern black rhino (*Diceros bicornis* ssp. *bicornis*) population in the future.

When considering further reintroductions of black rhino into the sparsely populated central or southern Kalahari, sites with one or more large pans in conjunction with surrounding belts of diverse and dense vegetation should be favoured. The diverse habitats and vegetation types around the pans can be used to compensate for less suitable adjacent areas. Alternatively, or in addition, riverine landscapes in this region also contain a high diversity of vegetation that could also provide suitable black rhino habitat (van Rooyen & van Rooyen 1998). By prioritising the restoration of natural processes of these characteristic landscape features, abandoned or degraded farmland containing pans and/or rivers may provide rewilding opportunities, where black rhino reintroduction can play an important role (Monbiot 2013). As natural ecosystem engineers, black rhinos are critical for ecosystem functioning. They can shape open landscapes, reduce bush encroachment, transport seeds and nutrients, and influence species composition and carbon storage in ecosystems, which in turn may benefit other native species and the wildlife economy as a whole (Seidel *et al.* 2019).

Achieving this would require carefully considered actions (e.g., management of natural resources and reserve infrastructure, security measures, community engagement), which could help manage existing hazards, such as the high number of livestock fences or the lack of adequate water points (Emslie & Brooks 1999, Ferguson & Hanks 2010).

This information, together with the other suitability parameters of the official assessment protocol, can be used to evaluate sites for black rhino custodianship applicants in the Kalahari. In particular, the habitat objective can consider identified region-specific conditions such as the presence, size and number of pans and their surrounding vegetation heterogeneity and characteristics (MEFT 2020). This may help inform the decision-making process for assessing future rhino conservation areas to further increase the population and range of black rhino throughout the region.

RESEARCH PERMIT

For this study, an official research permit (RPIV01042024) was issued by the National Commission for Research, Science and Technology of Namibia (NCRST) with the approval of the Ministry of Environment, Forestry and Tourism in April 2021.

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Ecological niche modelling of tree and wood pipits in southern Africa and adjacent countries may help to delimit distributions based on citizen science data

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ABSTRACT

Distribution maps are generally based on documented records rather than true occurrence patterns. This may be problematic for cryptic, under-reported species that occur in areas poorly covered by observers. Species distribution models may help overcome this challenge. Here, all available records of the migratory *Anthus trivialis* (tree pipit) and resident *Anthus nyassae* (wood pipit) for southern Africa and adjacent areas were assembled to train generalised linear models, random forest and gradient boosting machine species distribution models. Sampling pseudo-absences from a common species' similarly biased records helped to account for the spatial sampling bias present in the data. The model outputs suggest that *A. trivialis* and *A. nyassae* display a latitudinal habitat suitability gradient in the area of interest, opposing a latitudinal reporting gradient. The migratory behaviour of *A. trivialis* may blur its ecological niche. More and more reliable field observations are needed to confirm these findings. This study provides a clear framework to assist distribution delimitations from citizen science data by counteracting observer and sampling biases.

Keywords: *Anthus nyassae*, *Anthus trivialis*, citizen science, distribution, ecological niche model, species distribution model

INTRODUCTION

Delimiting species distributions can be a challenging endeavour, as it attempts to discretize different levels of abundance from data that are often incomplete. The recent emergence of citizen-science platforms such as SABAP2 (Second Southern African Bird Atlas Project) (Brooks and Ryan 2023) has generated a wealth of data that can help improve the delimitation of distributions. However, sampling and observer biases in the data (Kosmala *et al.* 2016) may distort the results of these efforts. As such, distribution maps based on citizen science, while spatially detailed compared to broad, expert-drawn range maps, may condense observations rather than delimiting the true occurrence patterns of a species.

SDMs (Species Distribution Models, introduced by Guisan *et al.* 2017, Guisan and Zimmermann 2000) may help to overcome this challenge by generating habitat models through the correlation of a taxon's current presence or absence with prevailing environmental conditions. Thus, the models can be useful in detecting areas in which species may be under-recorded.

Anthus trivialis (tree pipit) is a non-breeding palearctic migrant in sub-Saharan Africa, mainly present from October to March. It shares its woodland habitat with the resident *Anthus nyassae* (wood pipit). Few studies have examined the status and distribution of *A. trivialis* and *A. nyassae* in sub-Saharan Africa (Clancey 1987, 1989, 1990, Adams *et al.* 2022). The available distribution maps of the two species vary significantly between sources due to poor observer coverage in certain areas (Clancey 1987, 1989, 1990, BirdLife International 2016, 2018). Furthermore, both species may be challenging to identify due to their cryptic appearance. They thus provide good examples and materials for testing whether available records spatially reflect their ecological niche, as modelled by SDMs.

METHODS

The study area covered Angola, Zambia, Malawi, Mozambique and countries to the south within which the area of interest was further delimited by both data availability and the centroids of the distribution of *A. nyassae* and the wintering distribution of *A. trivialis*, respectively. All available records of the two species in the area of interest were gathered by consulting eBird (Auer *et al.* 2022), GBIF (Global Biodiversity Information Facility) (multiple sources outlined below), accessed through rgbif (Chamberlain *et al.* 2023), iNaturalist (iNaturalist contributors 2023), ABAP (African Bird Atlas Project), accessed through SABAP2 (Brooks and Ryan 2023) and termed SABAP2 thereafter, SARBN (Southern African Rare Bird News) (SARBN 2023), SAFRING (South African bird ringing unit) (SAFRING 2023) and BirdPix (Navarro 2023).

Except for the SAFRING data and some GBIF entries, which are part of museum collections or other scientific occurrence datasets (multiple sources outlined below), all records are citizen science based. The datasets were cleaned of duplicates and merged (Table 1). Although partially overlapping, eBird and GBIF provided the most data, followed by SABAP2. The majority of data were recorded in recent years.

Based on the ecology of *A. nyassae* and *A. trivialis* (Chittenden *et al.* 2018), seven environmental predictors were selected (Table 2) that appeared meaningful in determining the ecological niche of the two species. Although *A. trivialis* is only present in the region during the local summer months, the selected predictors quantifying precipitation and temperature span the whole year for both species, as the prevailing environmental conditions during the local summer months are dictated by the climatic conditions across all seasons. For example, winter temperatures may affect food availability during the summer, and the vegetation in winter rainfall areas does not rely on precipitation during the presence of *A. trivialis*. Furthermore, rare overwintering birds have been recorded (Chittenden *et al*. 2018).

All data were acquired and converted into rasters with a spatial resolution of 1 km using Google Earth Engine (https://earthengine.google.com). The predictors and records were loaded into the R statistical package (R Core Team 2018). An auto-correlation analysis yielded Pearson's correlation coefficients below 0.6 for all combinations, ensuring limited covariance between predictors. Duplicate data points at 1 km resolution were removed. Sampled SABAP2 occurrences of the fork-tailed drongo (*Dicrurus adsimilis*) (Brooks and Ryan 2023), a common bird present throughout most of southern Africa, served as pseudo-absences to counter the spatial sampling bias in the available records of *A. nyassae* and *A. trivialis* (Kramer-Schadt *et al.* 2013). The apparent habitat requirement of *D. adsimilis* is the presence of wooded cover, the same prerequisite for the occurrence of *A. nyassae* and *A. trivialis* (Chittenden *et al.* 2018). Thus, this step assumes that the absence of an observation of *D. adsimilis* at a given location implies a high probability that the location has not been sufficiently covered by observers to detect the presence of *A. nyassae* and *A. trivialis*.

Three distinct SDMs were run for each species in R (R Core Team 2018), namely GLM (Generalised Linear Model), RF (Random Forest), and GBM (Gradient Boosting Machine) models. For the former, a set of 2,500 pseudo-absences was used, while for the two latter, this number was reduced to 500 to approximately match the number of presences, as recommended for tree-based algorithms (Guisan *et al.* 2017). The GLMs were fitted using linear and quadratic terms as well as a stepwise variable selection based on the AIC (Akaike Information Criterion). A minimum of 10 observations was kept for every node, and 500 trees were grown for the RF models using the ranger package (Wright *et al.* 2023). The GBMs were fitted with a minimum of 10 observations per node, 500 trees, a learning rate of 0.1, and 10 cross-validation folds using the gbm package (Greenwell *et al.* 2022). All models were trained on all available occurrences except for the

Table 1: *Number of reported occurrences of* Anthus nyassae *and* A. trivialis *and time spans covered by cleaned datasets used in species distribution models. The indicated time span for GBIF is based on a minority of dated records. N/A: not applicable.*

Data source	***Anthus nyassae***		***Anthus trivialis***	
	Records	**Years**	**Records**	**Years**
eBird	315	1971–2023	137	1971–2023
GBIF	268	(2015–2023)	206	(2015–2023)
iNaturalist	22	2011–2023	16	2014–2023
SABAP2	127	2008–2023	60	2010–2023
SARBN	N/A	N/A	6	2013–2019
SAFRING; BirdPix	33	2006–2021	14	1960–2022
Total	**717**	**1971–2023**	**418**	**1960–2023**

Table 2: *Environmental predictors included in the species distribution models for* Anthus nyassae *and* A. trivialis*. An autocorrelation test yielded Pearson's correlation coefficients below 0.6 for all combinations.*

Predictor	Ecological Scale	Source
Annual mean temperature	Climatic	Karger *et al*. (2017)
Annual precipitation	Climatic	Karger *et al*. (2017)
Elevation	Topographic	Amatulli *et al*. (2021)
Tree density	Ecological	Crowther *et al*. (2015)
Leaf area index	Ecological	Myneni *et al*. (2021)
Human development	Anthropogenic	Tuanmu & Jetz (2014)
Landscape intactness	Anthropogenic	Potapov *et al*. (2008)

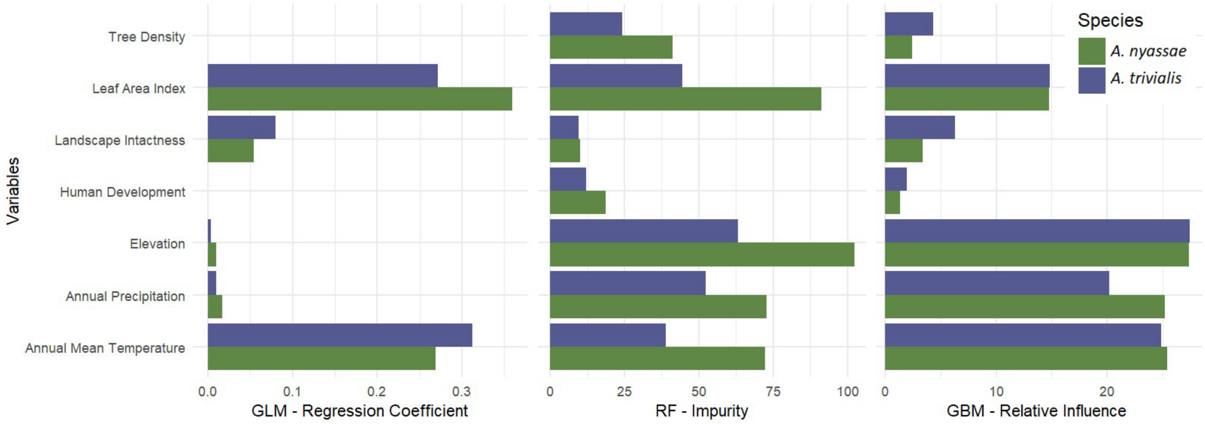

***Figure 1:** Predictor importance across three species distribution models of two species of pipits (*Anthus nyassae *and* A. trivialis*). Generally, the climatic predictors (annual mean temperature and annual precipitation) performed best in explaining habitat suitability for both species, followed by topography and leaf area index. The tree-based algorithms (RF: Random Forest model; GBM: Gradient Boosting Machine model) yielded more balanced predictor importance values than the GLM (Generalised Linear Model). For the latter, only the coefficients of the linear terms are illustrated, as all regression coefficients of the quadratic terms were < 0.01. Furthermore, the stepwise variable selection based on Akaike Information Criterion excluded tree density and human development from the models.*

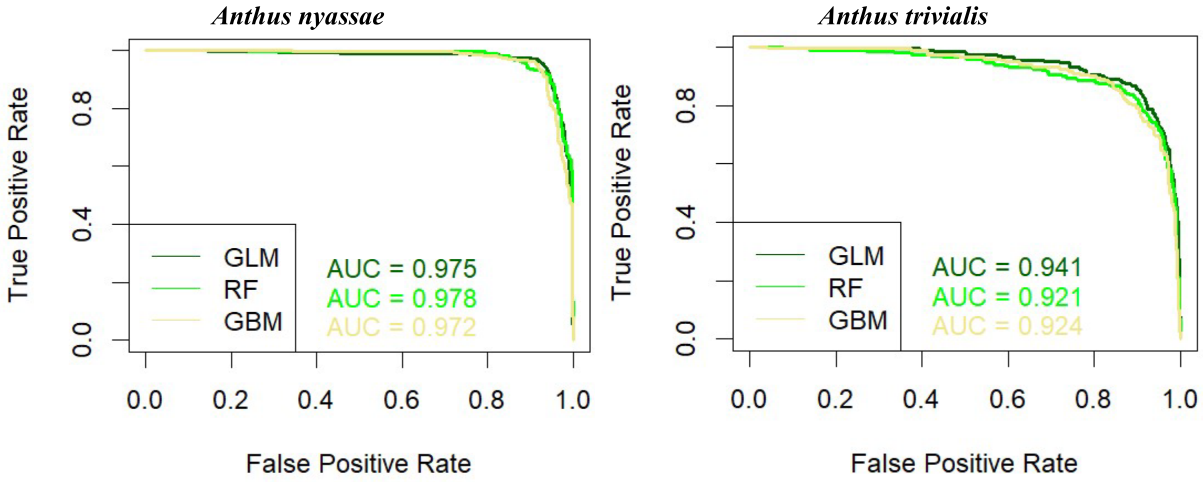

***Figure 2:** Receiver Operating Characteristic (ROC) curves and Area Under Curve (AUC) values for three species distribution models of two species of pipits (*Anthus nyassae *and* A. trivialis*), generated from five-fold cross-validation. All models performed well for both species (Swets 1988). GLM: Generalised Linear Model; RF: Random Forest model; GBM: Gradient Boosting Machine model.*

SAFRING (SAFRING 2023) and BirdPix (Navarro 2023) datapoints. The latter were used for a visual comparison with the model predictions (Figure 1), as ringing data and reports covered by photographs are more reliable than ordinary citizen science records. The low number of data points and the sampling bias present in the SAFRING and BirdPix data prevented a computationally independent validation approach. Instead, a five-fold cross-validation was used to evaluate the models based on the ROC (Receiver Operating Characteristic) curve and AUC (Area Under Curve) values (Figure 2). The generated prediction layers were visualised using QGIS (QGIS Development Team 2023). For *A. nyassae*, the RF model was used to produce a projection, while for *A. trivialis*, the GBM was chosen based on model performance (high AUC values) and conservatism in predicting suitability (the model predicts high suitability less often).

RESULTS

All models performed well in terms of predictive performance. The Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC) curves were all above 0.9, indicating good predictions (Swets 1988) (Figure 1). The climatic predictors performed best, and the anthropogenic variables (Table 2) performed worst in explaining habitat suitability for both species (Figure 2). Predictor

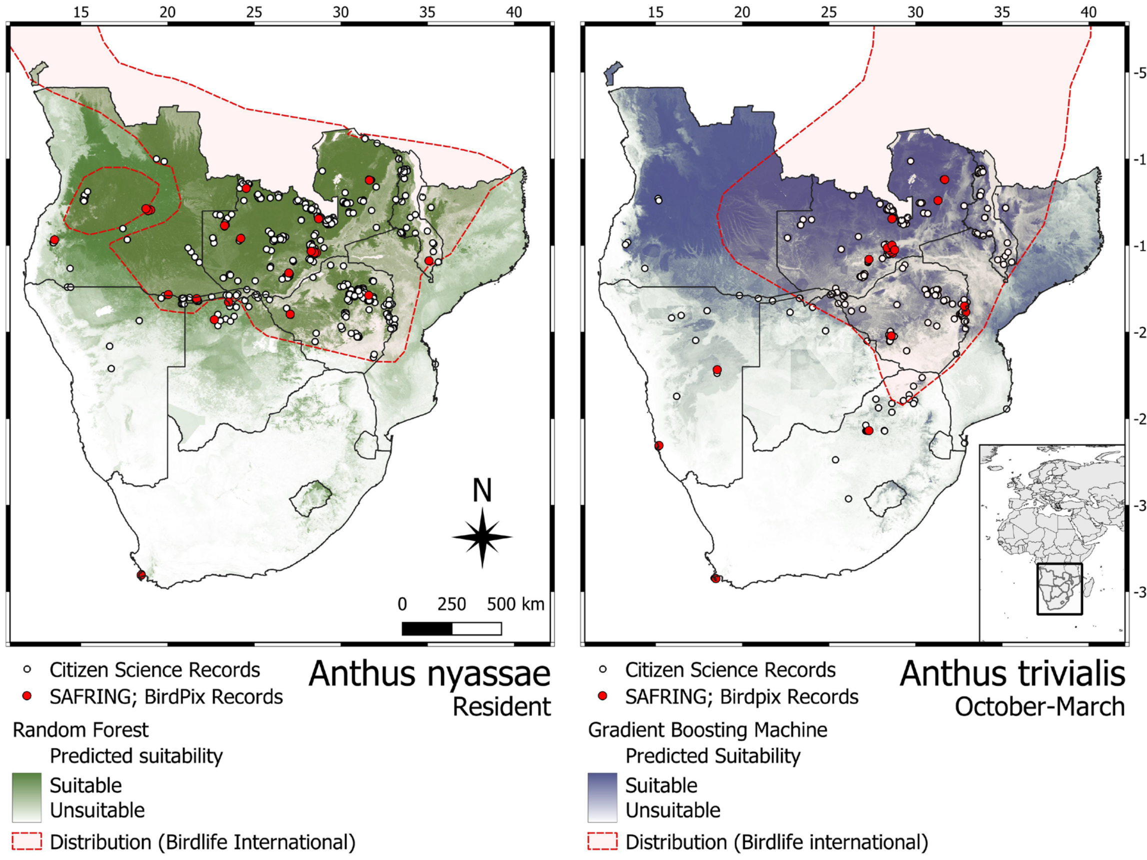

***Figure 3:** The white circles locate all available records for* A. nyassae *(left) and* A. trivialis *(right) in southern Africa and adjacent countries. The red polygons correspond to the (wintering for* A. trivialis*) distribution (BirdLife International 2016, 2018). The shades of green (*A. nyassae*) and blue (*A. trivialis*) show the potential distribution based on habitat suitability, as suggested by the random forest model (*A. nyassae*) and gradient boosting machine (*A. trivialis*) models.*

importance values were generally lower for *A. trivialis* than for *A. nyassae*, coinciding with slightly lower AUC values for *A. trivialis* (Figure 1, Figure 2).

The resulting habitat suitability maps (Figure 3) suggest that *A. nyassae* and *A. trivialis* display a latitudinal occurrence probability gradient: both species appear to be rare in the southern parts of the study area and more common further north. This contrasts with a latitudinal reporting gradient, as relatively few occurrences have been reported from potentially suitable areas such as Angola or northern Zambia.

DISCUSSION

The output suggests that current distribution maps exclude areas suitable for the potential occurrence of *A. trivialis* and *A. nyassae*, perhaps because they have been poorly covered by observers. Further exploration of the areas in question may yield new records of both species.

The strong model performances (Swets 1988) indicate a clear delimitation of the ecological niches of both species: the birds can generally be found in broadleaved woodlands at 800 or more meters above sea level, with at least 500 mm of annual rainfall. Unlike the resident *A. nyassae*, *A. trivialis* is only present in sub-Saharan Africa from October to March. The migratory behaviour may be reflected in the marginally poorer performance of the models in predicting its presence or absence (Figure 1) and the generally slightly lower predictor importances (Figure 2). Temporal fluctuations in the migratory patterns of *A. trivialis* due to varying food availability or weather conditions between years may further blur the picture.

Several sources of bias in the occurrence data need to be considered to contextualise the model outputs. Observer biases are inevitable in the context of both citizen science projects, such as eBird (Auer *et al.* 2022), iNaturalist (iNaturalist contributors 2023), or SABAP2 (Brooks & Ryan 2023), and platforms that are partially fed by citizen science, including GBIF (multiple sources outlined below). While the amount of data produced by many citizen scientists may make up for the quality trade-off (Kosmala *et al.* 2016), data quality control mechanisms may not always be able to flag faulty records. *Anthus* pipits can be notoriously difficult to identify even for specialists; hence, citizen science records should be approached with cautious scepticism. Although scarce, data provided by ringers or backed with photographs are far more reliable and may help to validate both other records and model outputs (Figure 2).

Furthermore, occurrence data may often be subject to a strong sampling bias as more accessible areas attract more observers (Kosmala *et al.* 2016). As opposed to SABAP1 (1987–1991), SABAP2 (Brooks & Ryan 2023) does not entail spatially systematic observations throughout the region (Bonnevie 2011). Instead, the observer decides where to observe. As such, the discrepancy between the model outputs and the number of reported sightings of *A. trivialis* around Gauteng, South Africa, is somewhat expected. On the other hand, the lack of records from central Angola for both species may be due to a lower observer density and less to the species absence. Choosing to sample pseudo-absences from a common species that shows the same sampling bias as the target species appears to be an efficient strategy to counteract this constraint in the modelling process (Kramer-Schadt *et al.* 2013).

The conclusions suggested by the model outputs need to be considered with caution. SDMs attempt to model a taxon's fundamental niche from occurrences that reflect the realised niche (Guisan *et al.* 2017). This can be problematic when niche parameters that are not captured by the model dictate where a species can occur, such as biotic interactions. While the output of this study may guide efforts to locate species where they have not been previously recorded, field records are needed to generate the final evidence.

Applying this approach to other cryptic and potentially under-reported species occurring in areas yet poorly covered by observations may help to delimit distributions through citizen science. However, due to the correlative nature of SDMs, their output provides merely an indication of where a species may occur, while conclusive evidence remains dependent on field data.

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ADDITIONAL RESOURCES

The following GitHub repository provides this study's Google Earth Engine script that was used to acquire and preprocess the predictors, as well as the R script that was used to preprocess the data and run the models: https://github.com/Manuel-Weber-ETH/Anthus_nyassae_trivialis.git

Factors affecting smallholder subsistence farmers' drought adaptation and resilience: a case study from northern-central Namibia

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ABSTRACT

A large proportion of households in northern Namibia rely on agriculture for livelihoods, yet the area is highly susceptible to drought shocks. Therefore, these households must employ strategies to adapt and mitigate the consequences of drought. This study aimed to identify factors affecting smallholder subsistence farmers' vulnerability and adaptation to drought in Oshipya District, Etayi Constituency, Omusati Region in northern-central Namibia (NCN). Data on drought *ex-ante* and *ex-post* coping mechanisms and sociodemographic characteristics were collected from 80 randomly selected smallholder farmers using a structured questionnaire. Levels of drought resilience and vulnerability were estimated using a Rasch model. Farmers were categorised according to asset ownership using a multivariate cluster analysis technique, while a principal component analysis was used to estimate wealth scales. Furthermore, a general linear model was employed to assess factors affecting variability in household vulnerability and resilience to drought shocks. Gender of household head, marital status, membership of a farming organisation, household size, type of farming activities and farm size significantly affected farmers' drought resilience levels. Combined crop-livestock farmers were more resilient than livestock or crop farmers while the level of drought adaptability increased with the size of the farm, years of farming experience and membership of a farming organisation. On the other hand, household size significantly affected vulnerability levels, with large households being more susceptible to the effects of drought. We encourage farmers to diversify their farming activities, diversify sources of livelihoods and join farming organisations to gain knowledge on drought mitigation. Furthermore, smallholder farmers should be better prepared for drought through infrastructure development, training, and provision of support services to make them self-reliant and hence reduce government expenditure on drought relief programmes.

Keywords: coping mechanisms; drought; Namibia; resilience; smallholder farmers; vulnerability

INTRODUCTION

Northern-central Namibia (NCN) is semiarid, characterised by high temperatures, low rainfall and prolonged dry seasons (Davies 2017, Shikangalah 2020) with exceedingly high evaporation rates above 3,000 mm per annum (Koeniger *et al.* 2021, World Bank Group [WBG] 2021). The Namibian climate is becoming increasingly hotter and drier (Davies 2017) and droughts and other climate-related hazards are prevalent and becoming more worrisome to rural communities that rely on agriculture as a livelihood source. These hazards render crops and livestock less productive (Angula & Kaundjua 2016, Davies 2017, Nangolo & Alweendo 2020). Drought is defined as a prolonged period of no to low rainfall that leads to water shortage, causing detrimental effects on the productivity of land, food and feed security, thus affecting human, animal and plant life.

In this study, **drought coping strategies** refer to a set of short-term measures households adopt in response to immediate and irregular decline in access to food, water and feed due to drought consequences, and make short- and long-term contingencies in preparation for future droughts. Drought adaptation means anticipating and taking appropriate actions to prevent or minimise the adverse effects of drought (European Commission [EU] 2016). **Resilience** focuses on preparing communities for future drought, employing means to endure, withstand and recover from such events (Department of Environmental Protection 2022, Mehryar 2022) and measures a household's ability to employ risk reduction measures to guard against the devastating effects of drought shocks. On the other hand, maladaptation refers to actions intended to reduce the impacts of drought and other climate change hazards that actually create more risks and vulnerability (Beddow 2022). **Vulnerability** is defined by Pachauri *et al.* (2014) as a function of adaptive capacity and propensity or predisposition to be adversely affected, and it gives a measure of the crisis control mechanisms that households utilise to mitigate shocks after a drought has already occurred which might put them at risk if they affect their socioeconomic status. Such measures mainly have negative effects on the economic status of households as they may have to resort to disposal of productive assets.

Although Namibia is susceptible to drought, agriculture is still one of the main livelihood sources, with more than 70% of the Namibian population directly or indirectly relying on it (MAWF 2015, GIZ 2022). The country's agricultural sector is dominated by livestock farming, followed by crop farming, and the economy is heavily dependent on agricultural products, which contribute between 4% and 6.6% to the Gross Domestic Product (GDP) (excluding contribution from fish) (GIZ 2022, MeatCo 2022) making the sector a vital source of livelihood through employment creation, food security, income generation and poverty alleviation. Due to climate change, most subsistence farmers in NCN no longer produce sufficient crops to last until the next harvesting season (MAWF 2015).

Farmers in Omusati, Ohangwena, Oshikoto and Kavango regions rely predominantly on subsistence production in addition to salaries and wages (Nyadinga 2012, NSA 2018). Frequent droughts have decimated livestock and also led to crop failures. The effects of drought are worsened by the fact that subsistence farming households are mainly reliant on rain-fed agriculture (Ndlovu 2009, African Adaptation Project 2010). Because of high incidents of drought in the northern parts of Namibia, it is important for these communities to be able to prepare for and cope with consequences of drought (GIZ 2022).

Due to reoccurring droughts and other climate change hazards within the country, the Namibian government developed a National Climate Change Policy (MET 2011) which elaborates on climate change adaptation in Namibia, as well as the National Climate Change Strategy and Action Plan (NCCSAP) (MET 2015) aimed at guiding national activities and measures to mitigate climate change hazards. These policies encourage individual farmers to adopt self-reliant approaches to drought risk mitigation to reduce overdependence on aid from the government and other non-governmental relief agencies, with financial assistance and food interventions only to be considered in the event of an extreme drought. Some community-based adaptation programmes such as the five-year (2015–2019) Scaling Up Community Resilience to Climate Variability and Change in Northern Namibia, were implemented by non-governmental organisations in liaison with the then Ministry of Agriculture, Water and Land Reform (MAWLR), the Ministry of Environment and Tourism (MET), Regional Councils and Traditional Authorities to address drought and water scarcity, land degradation and deforestation; and planting of flood and drought-resistant crops to enhance agricultural production and food security. After such interventions very few studies have, however, been done to assess the level of adaptation and resilience to drought and to evaluate the factors that might affect households' ability to cope.

The factors that affect farmers' ability to adopt drought coping mechanisms need to be evaluated as this might guide policy formulation and implementation. Angula & Kaundjua (2016) applied a Climate Vulnerability and Capacity Analysis (CVCA) framework (CARE International 2019) and social vulnerability approach to assess the factors contributing to subsistence farmers' vulnerability to impacts of climate change in the regions within NCN (Ohangwena, Oshana, Oshikoto and Omusati). Their findings revealed that households have low levels of adaptation and mitigation due to a combination of cultural, social and political factors; overreliance on rain-fed subsistence agriculture; adult and elderly population; high levels of unemployment; and lack of land tenure. The coping strategies implemented by households in the NCN included destocking, selling livestock to buy food, nomadic pastoralism, planting of drought-resistant crop varieties, reliance on government disaster response, supplementing agricultural activities with income generation, remittances and pensions funds. However, no long-term coping mechanism was observed. Angula & Kaundjua (2016) recommended that future research should apply CVCA and vulnerability indices to contextualise vulnerability assessment at local and household level, including more gender disaggregated research.

Several studies on drought coping strategies have been undertaken in southern Africa. Mdungela *et al.* (2017) used a Multinomial Probit Model to determine the factors affecting the choice of drought coping strategy. Destaw & Fenta (2021) analysed the determinants of farm level adaptation measures in Africa using a Multinomial Logit Model, while Rakgase & Norris (2014) applied this model to assess the factors affecting household use of adaptation strategies in South Africa. Uddin *et al.* (2014) rejected the Linear Probability and Probit Models in favour of a Logistic Model and assessed the factors affecting household use of adaptation strategies in South Africa and Bangladesh, respectively. One weakness of multinomial choice models is that they present different coping strategies as possible response options of a single multi-category question. However, one household may employ more than one coping mechanism and this might make modelling challenging. Those who applied a binary logistics model might therefore need a separate model for each coping strategy. To the best of our knowledge, no study has estimated resilience and vulnerability levels on a continuous continuum as well as determining the factors that affect a household's ability to cope with drought based on such a measure. The current study applied statistical modelling to rank a household's ability to adapt to drought coping mechanisms on a continuous scale, exploring the factors that are influential in the household's choice of coping mechanisms.

METHODS

Study area and data collection

The case study was conducted in Oshipya District, Etayi Constituency, situated in north-central Namibia, approximately 60 km northwest of Oshakati (Figure 1). Data were collected through a cross-sectional survey in September 2020, after the 2019/2020 drought. The Omusati Region was selected since it has the highest proportion of the population reliant on subsistence farming (NSA 2018) and is highly susceptible to drought and other natural shocks. The dry season lasts from May to October, and the rainy season extends from November to April (Hiyama *et al.* 2017). The targeted population comprised of approximately 260 small-scale farming households in nine villages. Eighty (80) households were randomly selected from five of the nine villages randomly selected for the study. This study extends a preliminary analysis of this data set presented in Charamba *et al.* (2021).

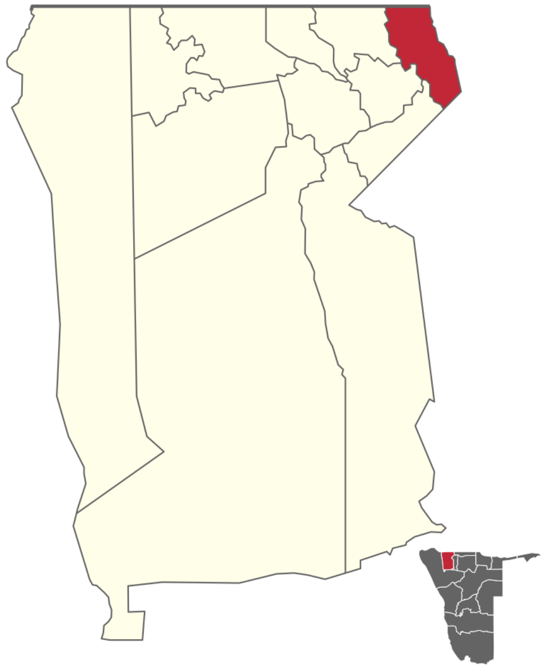

Figure 1: *Etayi Constituency (red) in Omusati Region (yellow) in Namibia (grey). Source: NordNordWest (2019).*

Estimation of resilience and vulnerability levels

The study analysed data collected through the administration of a structured questionnaire covering aspects of household socioeconomic and demographic characteristics, *ex-ante* adaptation coping strategies and *ex-post* maladaptation coping strategies employed to guard against the effects of drought (Appendix 1). *Ex-ante* coping strategies are those strategies employed by households to reduce the risk of drought *a priori*, that is, before the drought has occurred, while *ex-post* strategies are *a posteriori* strategies employed by households to mitigate the risk of the drought that has already occurred; these may cause additional risks to the households. The *ex-ante* strategies included: planting of drought-resistant crops; crop diversification to spread the risk; conservation agriculture; fencing of grazing areas and water sources; planting of fruit trees; irrigation of crops; preservation of pearl millet stalks to use as animal feed during times of drought; and livelihood diversification such as owning a small shop. The *ex-post* coping strategies included: the dispersal of family members; seeking and eating wild and unpreferred foods; disposal of productive assets and livestock to buy food; and borrowing and begging from neighbours.

The household drought resilience and vulnerability levels were measured as latent variables on an interval continuum from the *ex-ante* and *ex-post* coping strategies, respectively by employing a two-parameter logistic (2PL) regression Item Response Theory (IRT) model (see Charamba *et al.* 2021). The scales were measured with an arbitrary zero (0) midpoint and the unit of measurement of one (1) ranging from $-\infty$ to $+\infty$ although the practical application measurements are usually between -3 (very low) and +3 (very high) (Tommy & Udo 2019, Columbia University 2022). In this study the scale was continuous, ranging from -4 (poor) to 4 (high) with an expected average of 0. The theory is based on the notion that different items (coping strategies) have different levels of difficulty, that is, some are easily implemented and some are more difficult to do.

Data analysis

An unsupervised hierarchical cluster analysis was employed to categorise households according to assets and livestock ownership while principal components analysis (PCA) was used to derive indices for livestock and assets ownership on a continuum, where the first principal component was used for further analysis. A general linear model (GLM) was used to assess the household sociodemographic and socioeconomic factors that affect household vulnerability and resilience to drought shocks. Partial eta-squared (see Zach 2021) and Cohen's f effects size (Cohen 2013) were used to quantify the magnitude of the differences between category means. Cohen's effect size was employed as it quantified the magnitude of the effect size beyond the p-value which can lead to the conclusion that the effects are significant without quantifying them. The effect size takes on value 0 (zero) when the null hypothesis cannot be rejected and a non-zero value when the null hypothesis is rejected and hence it serves as an index of the degree of departure from the null hypothesis. The proportion of variance in the dependent variable explained by the factor (Partial eta-squared, η^2) was computed using equation (1):

$$(1)\ \eta^2 = \frac{SS_{Between(effect)}}{SS_{Between(effect)}+SS_{Error}} = \frac{SS_{Between(effect)}}{SS_{Total}}$$

where SS is Sum of Squares. For example, a value of $\eta^2 = 0.15$ implies that 15% of the total variability can be accounted for by that variable. Cohens f effect size was then calculated using equation (2):

$$(2)\ f = \sqrt{\frac{\eta^2}{1-\eta^2}}$$

Effect sizes less than 0.10 are considered non-significant while effects between 0.10 and 0.24 are considered small. Effects between 0.25 and 0.40 are medium sized while those above 0.40 are large effects (Cohen 2013).

RESULTS

Sociodemographic characteristics of respondents

Tables 1 and 2 show the descriptive statistics of sociodemographic and socioeconomic characteristics of respondents, respectively.

Table 1: *Sociodemographic characteristics of respondents to a structured questionnaire in northern-central Namibia (n = 80).*

Characteristic	Number	Percentage
Age of respondent		
25–34	5	6.3
35–44	15	18.8
45–54	11	13.8
55–64	23	28.8
65+	26	32.5
Gender		
Male	51	63.8
Female	29	36.3
Marital status		
Married	20	25.0
Single	33	41.3
Widowed/widower	27	33.8
Level of education		
None	13	16.3
Primary	39	48.8
Matric	7	8.8
Tertiary	21	26.3
Household size		
0–4	29	36.3
5–8	39	48.8
9–12	12	15.0
25–34	5	6.3

Table 2: *Socioeconomic characteristics of respondents to a structured questionnaire in northern-central Namibia (n = 80).*

Characteristic	Number	Percentage
Farming experience (years)		
0–4	12	15.0
5–14	13	16.3
15–24	10	12.5
25–34	17	21.3
35–44	9	11.3
45+	19	23.8
Farm size (ha)		
< 1	3	3.8
1–2	31	38.8
3–5	19	23.8
6+	27	33.8
Type of farming activities		
Livestock production	2	2.5
Mixed farming	55	68.8
Crop husbandry	23	28.8
Off-farm activities		
Formal employment	9	11.3
Non-formal	40	50.0
Pension/remittances	27	33.3
Plant fruit trees	17	21.3
Own small shop	3	3.8

Most households were headed by males (male = 63.8%; female = 36.4%); the respondents were largely not married (75%) and majority had at least primary education (83.7%).

The results in Table 2 show that 68.8% of the sampled households practiced mixed farming; 85% of the respondents had farming experience of at least 5 years; the majority (57.4%) owned 3 ha of land or more; and all respondents had additional sources of livelihood besides agriculture. Most households (85%) owned some assets such as cars, wheelbarrows, and livestock; about 10% of households had disposed of their assets to buy food in a drought period.

Household resilience and vulnerability levels

Figure 2 shows the household resilience and vulnerability levels estimated using the 2PL model.

The sample estimates of the household levels of vulnerability to effects of drought ranged from -2.93 (the least vulnerable) to 3.21 (the most vulnerable) relative to the group with an average of -0.64 ± 0.17 (mean ± SE). Household resilience levels ranged

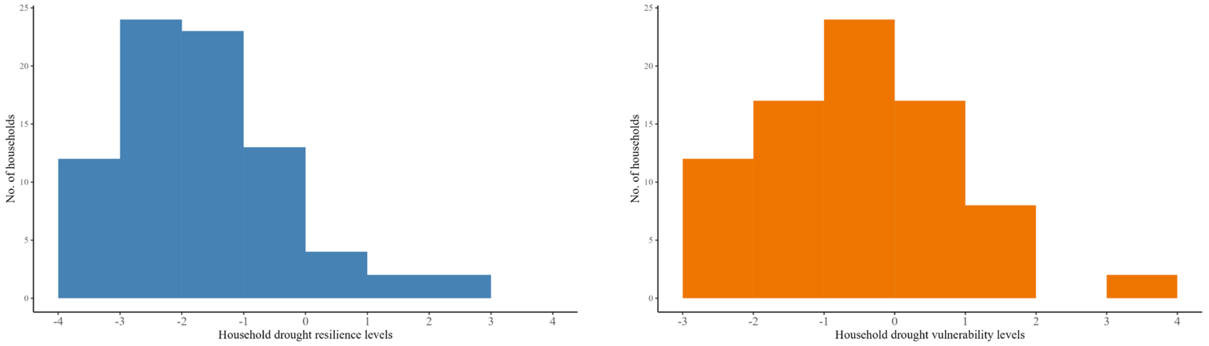

Figure 2: *Distribution of the level of resilience (left) and vulnerability (right) to drought of 80 households in northern-central Namibia measured as latent variables on an interval continuum from the* ex-ante *and* ex-post *coping strategies, respectively by employing a two-parameter logistic (2PL) regression Item Response Theory (IRT) model.*

from -3.32 (less resilient) to 2.22 (most resilient) relative to the group (-1.46 ± 0.14; mean ± SE). About 75% of the respondents were ranked below zero on the resilience/preparedness continuum. On the other hand, about 35% of the households were ranked above zero on the vulnerability scale.

Figure 3 shows the scree plot of eigenvalues and the variables plot for the variables used in computation of the first principal component (livestock index). The first principal component accounted for 36% of the variation. All the variables are positively correlated as they point in the same direction (positive) although sheep ownership is not strongly related to the other livestock and contributed more variation.

From the results shown in the scree plot in Figure 3, the first principal component for assets PCA, used as the asset index in the GLM, accounted for about 35% of the total variation. Mobile phone, TV and wheelbarrow ownership contributed more to the principal components.

Factors affecting household resilience and vulnerability to drought

A weak Pearson correlation coefficient of -0.092 was observed between household vulnerability and resilience levels. Table 3 gives the results for the factors affecting household resilience and vulnerability to drought.

Membership of a farming organisation, gender of household head, type of farming activities, household size and asset ownership all had a significant impact on the variation in households' levels of resilience to effects of drought (Table 3). Membership of a farming organisation had a large effects size ($f = 0.43 > 0.40$) while the type of farming activities had medium effect size ($f = 0.25 \leq 0.29 \leq 0.40$). The marital status and gender of household head, household size and years of farming experience had smaller effect sizes ($0.10 \leq f \leq 0.24$). On the other hand, awareness of the impeding drought and level of education were among the factors that were not significant ($f < 0.10$) in the model.

Table 3: *Factors affecting households' resilience and vulnerability to drought in northern-central Namibia (n = 80).*

	Resilience		**Vulnerability**	
Factor	**Partial Eta Squared (η^2)**	**Cohen's f**	**Partial Eta Squared (η^2)**	**Cohen's f**
Gender of household head	0.050	0.23*	0.005	0.07
Marital status of household head	0.005	0.13*	0.001	0.03
Membership to farming organisation	0.158	0.43***	0.023	0.15*
Type of farming activities	0.080	0.29**	0.030	0.18*
Drought awareness	0.007	0.08	0.002	0.05
Farm size	0.001	0.03	0.003	0.05
Age of household head	0.002	0.05	0.001	0.03
Household size	0.026	0.16*	0.058	0.25**
Years of farming experience	0.023	0.15*	0.042	0.21*
Asset index	0.003	0.06	0.078	0.29**
Livestock index	0.004	0.06	0.011	0.11
Years of education	0.006	0.08	0.016	0.13*

small effect size; ** medium effect size; * large effect size.*

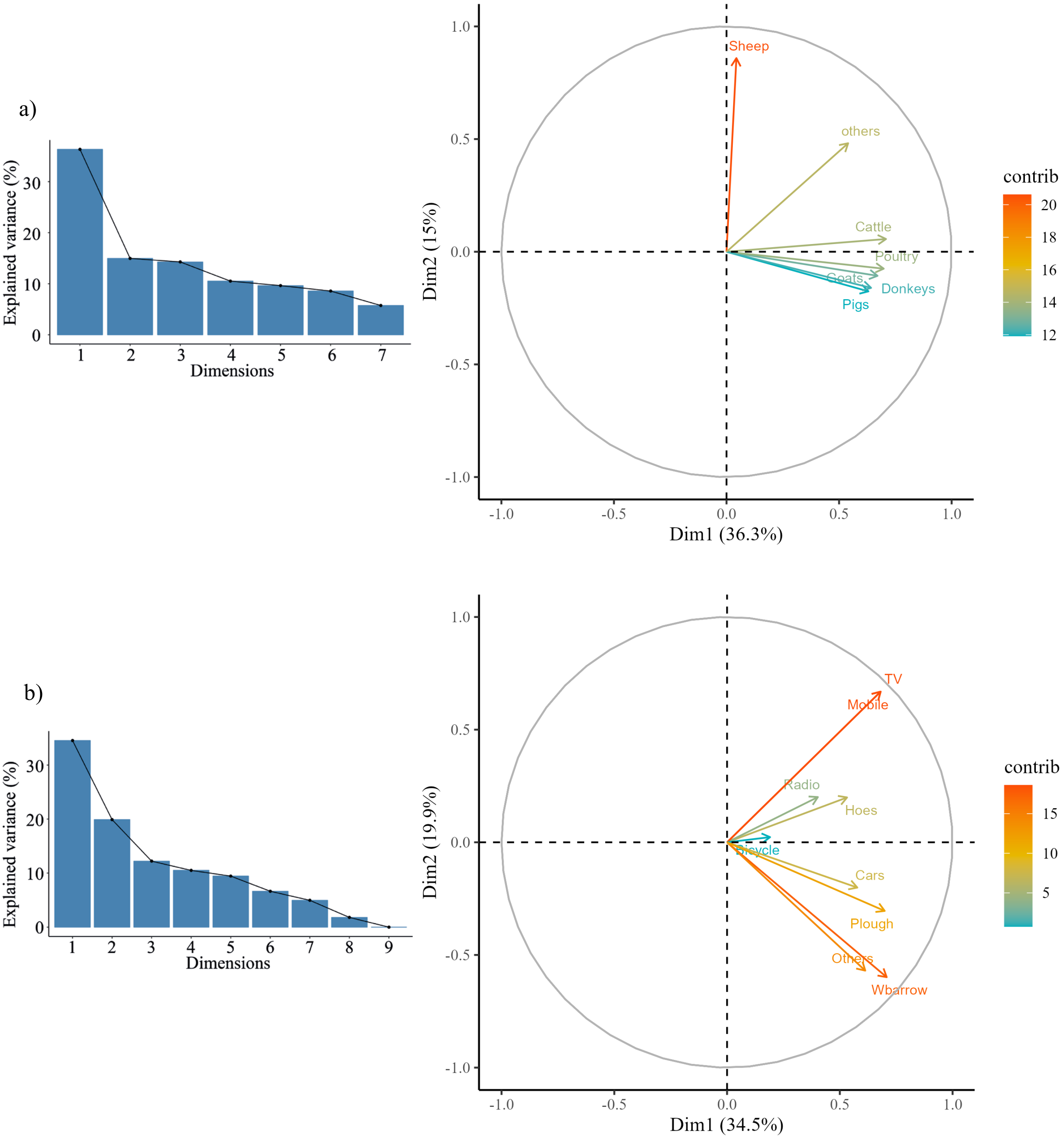

Figure 3: *Principal components analysis scree plots and variable biplots for the computation of a) livestock index and b) assets index.*

Appendix 2 gives the model parameter estimates from the GLM. The regression coefficients indicate that male farmers were more resilient than female farmers ($B = 0.558$) while married farmers were more resilient than single farmers ($B = 0.337$). Farmers belonging to a farming organisation were 2.482 units more resilient than those who did not. Increase in household size ($B = 0.060$) and increase in farming experience ($B = 0.016$) increased household resilience to drought.

The factors that affected households' vulnerability to drought are shown in Table 3. Membership of a farming organisation, type of farming activities, household size, years of farming experience, livestock index, asset index and years of education significantly affected household levels of vulnerability with small to medium effect sizes ($0.1 \leq f \leq 0.4$).

Appendix 3 shows the GLM parameter estimates (B) for households' vulnerability to drought. Farmers who do not belong to a farming organisation were more vulnerable to drought ($B = 1.099$) than farmers who did belong to one. Furthermore, livestock farmers ($B = -1.663$) were less likely to be vulnerable

Table 5: *Comparison of resilience and vulnerability levels of households employing different types of drought coping strategies in northern-central Namibia (n = 80).*

	Resilience		**Vulnerability**	
Livelihood strategy	**Mean**	**Standard error**	**Mean**	**Standard error**
Borrow	-3.32^{a}	0.18	-1.77^{a}	0.26
None	-2.13^{a}	0.20	-0.99^{a}	0.31
Own a small shop to earn money	-1.26^{ab}	0.54	-0.69^{a}	0.38
Preserve pearl millet stalks for animals	-0.93^{b}	0.00	-0.61^{a}	1.16
Plant fruit trees to eat.	-0.90^{b}	0.36	-0.52^{a}	0.41
Partial eta squared (η^2)	0.265		0.009	
Cohen's f	0.60		0.09	

^{ab} Means with different superscripts differ significantly

compared to crop and mixed crop-livestock farmers. Increase in household size increased ($B = 0.117$) vulnerability, while increase in asset ownership ($B = 0.442$) and increase in years of education reduced ($B = 0.040$) vulnerability levels. However, when the livestock herd increased, vulnerability increased ($B = 0.042$).

Information dissemination

The results indicate that 72.5% of the respondents were aware that there was going to be a drought in 2019 while 27.5% claim not to have had prior knowledge of the upcoming drought. Table 4 gives the media sources that the households used to obtain weather and climate change awareness information disseminated by the meteorological services department. Approximately 30% of the respondents had no access to meteorological information and 87.5% of these households were often not aware of the forthcoming drought.

Diversification of farming activities

A significant proportion (61%) of the sampled households did not diversify their livelihood sources in preparation for the forthcoming drought of 2019, while about a third preserved pearl millet stalks to use as animal feed. Some households also planted fruit trees to support long-term resilience. Few households diversified livelihoods by owning a shop and/or borrowed money and food supplies from neighbours. Results from one-way analysis of variance (ANOVA) (Table 5) showed a significant ($f = 0.60 > 0.40$) difference in the resilience levels for different livelihood activities although the difference between the vulnerability levels was not significant ($f = 0.09 < 0.10$). The results show that it was the least resilient households (mean = -3.32) and more vulnerable households (mean = -1.77) that resorted to borrowing when drought occurred.

DISCUSSION

Factors affecting smallholder farmers' resilience and vulnerability to drought

Male farmers, farmers who are members of farming organisations, livestock farmers, large households, married farmers and farmers with more farming experience were more resilient to drought than their counterparts (Cohen's f effect sizes ranging from small to large effects). On the other hand, households with more years of farming, farmers with more years of education and farmers with more assets are less vulnerable to drought. However, large families and families with more livestock are more vulnerable to drought consequences when the drought has already occurred. The results from the ANOVA revealed that resilience levels were significantly affected by livelihood activities, although the difference between the vulnerability levels was not significant. More vulnerable households and households that were less resilient to drought resorted to borrowing to mitigate consequences of drought.

Table 4: *Media sources utilised by households in northern-central Namibia for receiving drought awareness information (n=80).*

Medium	**Households using media (%)**	**Households using media being aware of impending 2019 drought (%)**
None	30.0	12.5
Television	3.8	33.3
Radio	37.5	100
Newspaper	1.3	100
Friends and family	6.3	100
Cellphone messages	21.3	100

Household size

The size of the household influenced resilience to drought, with larger households being more resilient. These results were in agreement with Deressa *et al.* (2010), Opie (2011) and Marie *et al.* (2020) who argued that households with large family sizes were more likely to adopt and use more intensive coping strategies because they had a greater labour pool. Tazeze *et al.* (2012), on the contrary, observed household size to negatively affect coping mechanism adoption and adaptation to climate change, attributing the negative effect to the higher likelihood for the large families to be compelled to divert part of their labour force to off-farm activities in an attempt to earn more income, and in order to ease the consumption pressure. This apparent contradiction in results might be related to different analysis methods used. Nyangena (2008) conducted a study in rural Kenya and concluded that large families can practice multiple cropping and diversify their cropping varieties whereas smaller families tend to be restricted to monocropping with a livestock activity. However, the current study shows that if a drought has already occurred, larger households were more vulnerable, most likely because they require more food resources.

Gender of household head

The gender of the household head had a significant effect on drought resilience with male-headed households being more resilient compared to their female-headed counterparts. This concurs with the findings from other studies that show that male-headed household members were more risk averse and had more access to information, land and other resources, had a better appreciation of climate change and hence had higher likelihood of adopting drought coping strategies than their female counterparts (Ajao & Ogunniyi 2011, Ofuoku 2011, Opie 2011, Tazeze *et al.* 2012, Legesse *et al.* 2013). Gender was also noted by Angula & Menjono (2014) and Angula & Kaundjua (2016) to significantly affect the levels of vulnerability for households in the northern regions of Namibia. Their study noted that men had more access to information and had more technical skills in some cases due to having been employed on commercial farms.

Angula & Menjono (2014) and Angula *et al.* (2021) reiterated that climate change impacts are not gender neutral. Women and men are not equally vulnerable to climate change effects and their adaptive capacities are different. Angula *et al.* (2021) reiterated that gender-blind climate change initiatives could exacerbate existing gender inequalities and undermine sustainable climate change activities, pointing to gender imbalances in leadership and inequalities in local community resource management as some of the causes. As such, they proposed that for climate change resilience to be achieved, gender mainstreaming and women empowerment in community-based climate change and adaptation interventions should be encouraged. Conversely, Moyo *et al.* (2013) found that gender of household head had no effect on household ability to employ drought coping mechanisms. In the current study, gender did not significantly affect vulnerability levels to a drought that had already occurred.

Farm size

Farm size did not significantly affect a household's choice of drought coping strategies. These results contradict results from several other studies (Ajao & Ogunniyi 2011, John *et al.* 2011, Ofuoku 2011, Legesse *et al.* 2013, Mdungela *et al.* 2017) that found farm size significantly influenced coping strategy adaptation, with lack of adequate land being a major barrier to climate change adaptation. According to McBride & Daberkow (2003) there may be a critical lower limit on farm size that prevents smaller farms from adopting climate change strategies, given the uncertainty and costs associated with innovation. Households owning smaller farms were less likely to innovate, because they were more risk averse. Opie (2011) observed land size to significantly affect asset-based strategy and mixed strategy coping mechanisms but not food-based strategy. Maddison (2006) and Hassan & Nhemachena (2008) concurred with this result, arguing that farmers with large land areas had more land to allocate to soil conservation and other strategies than those with small pieces of land.

The current study found households with larger farms were less vulnerable to drought. This is probably because they were likely to have more farm produce and more pasture and fodder for their livestock, in addition to having more land to diversify their farming activities. The households with larger farms were also likely to have higher yields in the more favourable years which could be stored and used during the lean years. The contradictory results observed in the current study were probably related to severe land degradation, which necessitates betters soil fertility management to obtain reasonable yields, even in good rainfall years. Hence farm size may make little difference to vulnerability, in the absence of adequate manure to fertilize the land or where land management practices are inappropriate.

Type of farming activity

The type of farming activity significantly affected the level of resilience, with livestock husbandry farmers and those who practised mixed farming being more resilient than crop farmers. Crop and livestock integration, diversification of livestock and crops, changing farming location and timing are some measures to be included in a repertoire of adaptation measures (IFAD 2010). The soils in the NCN are heavily leached with low organic matter content (Keyler 1995, Prudat *et al.* 2018) and poor moisture retention contributing to poor crop yields. Livestock are more resilient as they can utilise poor quality forage and also mopane shrubs to survive. Thus crop-livestock farmers and those with livestock tend to fare better than those entirely dependent on crops during drought years. Hassan & Nhemachena (2008), in agreement with the current study, identified diversification into multiple crops and mixed crop-livestock system, switching from crops to livestock and switching from dryland to irrigation as possible ways of mitigating the effects of climate change in different parts of Africa.

Level of education
The results of this study show that education level does significantly affect household resilience to drought, that is, it does not affect households' ability to employ drought preparedness strategies. The current findings concur with other studies (John *et al.* 2011, Moyo *et al.* 2013, Mdungela *et al.* 2017) that observed the level of education to have no significant effects on households adopting drought coping mechanisms. Contrary to the current findings, other studies concluded that education increases households' chance to adapt as it increases households' understanding of climate change and awareness of different coping alternatives (Deressa *et al.* 2010, Ofuoku 2011, Nti 2012, Tazeze *et al.* 2012, Rakgase & Norris 2014, Alam 2015). Education level and receptivity to new innovations are just pieces of a puzzle; coping with the effects of drought and climate change in general also requires support systems by way of secure land tenure, infrastructural development (for example irrigation systems), access to credit, improved marketing, improved seed (e.g., drought tolerant varieties) and improved extension and veterinary services. However, education levels affected household vulnerability levels, implying that more educated household heads are less likely to employ coping mechanisms that make them more vulnerable to drought consequences. This is probably because those with a higher level of education were more likely to have other sources of income, allowing them to employ better drought mitigation strategies if a drought had already occurred.

Farming experience
Farming experience significantly affected household drought coping strategies with experienced farmers seemingly being more resilient. Experienced farmers were probably more knowledgeable about ways of mitigating drought and were more likely to adapt. In addition, they were more likely to use indigenous knowledge systems to better forecast weather than less experienced farmers. These results concur with the findings of John *et al.* (2011) and Mdungela *et al.* (2017) who concluded that farmers with experience were more likely to adopt drought coping mechanisms and hence reduce vulnerability to drought effects. Ofuoku (2011) observed that experienced households had a better understanding of climate change, while Hassan & Nhemachena (2008) also argued that the more experienced the farmers were, the more likely they were to adopt drought coping mechanisms. They propounded that experienced farmers had better knowledge and information on climate change and agronomic practices that they could use to cope with climate change. They may, for instance, store crop stover (residue) such as pearl millet and sorghum stalks, cow pea haulms; they may also have their animals distributed among distant relatives hence reducing livestock loss; they may also be able to better utilise encroacher bush species for animal feed.

Age of farmer
In this study, the age of the farmer was not significant in determining the household level of resilience and vulnerability to drought. Nevertheless, elderly farmers were more experienced in farming and had more indigenous and technical knowledge on drought preparedness and mitigation. They may also have better networks, which could serve as a social safety net in cases of drought. In addition, they were likely to be more experienced in forecasting upcoming droughts. The current findings do not agree with the studies of Ajao & Ogunniyi (2011), Opie (2011) and Tazeze *et al.* (2012) who found age to significantly affect household adaptation with older household heads having higher chances of adopting drought coping mechanisms. On the other hand, these results concur with the findings of Hassan & Nhemachena (2008), John *et al.* (2011) Moyo *et al.* (2013) and who observed the age of the household head not to be a significant factor in adopting coping mechanisms. Hassan & Nhemachena (2008) suggested that it is experience rather than age that matters for adaptation to climate change but failed to add that experience comes with age. However, the two are usually correlated and thus in the current study, their effects were similar.

Asset and livestock ownership
Asset ownership had a medium effect size on the drought adaptation for households. This agrees with Opie (2011) who observed the adoption of coping strategies to be associated with household assets such as land, livestock and other household assets; with farmers having more assets highly likely to adopt drought coping mechanisms. Deressa *et al.* (2010) and Tazeze *et al.* (2012) observed livestock ownership to significantly increase household probability to adapt. Legesse *et al.* (2013) also argued that herd size significantly affected coping strategy adoption, with households with larger herds more likely to adapt. Households with more assets are less vulnerable to consequences of drought probably because they have more resources with which to

handle drought. Wealthier families are also likely to take more risk and easily adopt new technologies and innovations (e.g., storage tanks for pearl millet, irrigation, urea-molasses blocks, planting of fruit trees, fencing off land), which may improve their resilience to drought. It could be argued that possession of more assets is a proxy for family wealth, implying that families with more assets would be in a better position to withstand the effects of drought and climate change in general.

Membership of farming organisations

Membership of a farming organisation improved household resilience to drought. This is probably because the households belonging to farming organisations were trained on drought adaptation and mitigation strategies, making them more prepared to deal with consequences of drought. They might also have better access to improved farming practices (e.g., use of molasses-urea blocks, early planting, manure application techniques, water harvesting techniques, forage production for livestock, improved animal health care) and better access to input supplies and markets. These findings were in agreement with those of Nti (2012) who reported that membership of farm organisations positively affected households' ability to adapt to the effects of drought.

Information dissemination, early warning signals and awareness

Farmers' awareness of the impending drought did not significantly affect household resilience and vulnerability to drought. This is probably because most households were aware of the forthcoming drought making the comparison between those who were knowledgeable and those with limited access to information difficult to assess. Moreover, it was not very clear from the data collected at what time the households became aware of the drought. The current results contradict the findings of Ndlovu (2009), Ofuoku (2011), Jordaan (2012) and Mdungela *et al.* (2017), who found that farmers who received information prior to drought had higher chances of adopting to drought coping strategies. However, studies in north-central regions of Namibia (Angula & Kaundjua 2016) have revealed poor warning systems for forecasting rainfall and temperature, limited access to information and eroded agroecological indigenous knowledge to be among the factors compounding households' vulnerability to drought and other climatic shocks. Notwithstanding access to information having non-significant effects in the current study, the African Adaptation Project (2010) advocated the need for early warning systems to enhance coping strategies with regards to potential disasters such as extreme drought. Kuvare *et al.* (2008) observed that early warning management systems were inadequate, leaving the government and communities ill-prepared to deal with large humanitarian emergencies.

Diversification of livelihood activities

Although the average resilience levels for households that owned a shop and those who planted fruit trees were still low, they were significantly higher than for those who relied on farming activities alone. These is probably because households that diversified their livelihood activities had alternative food, feed and income sources compared to those that did not and thus were less likely to deploy asset-depleting coping strategies. In addition, fruit trees were important for nutrition and contributed to food security during drought periods; they might also be a source of income for households with enough to sell and provide shade for humans and livestock during drought and hot seasons. In addition, some fruit trees such as guavas and mango trees are also good for carbon sequestration (Shinde *et al.* 2015), which reduces the amount of carbon dioxide in the atmosphere, thereby reducing global climate change. The low proportion of households that diversified their livelihood sources agrees with Angula & Kaundjua (2016) who identified the low capacity to diversify livelihood activities beyond subsistence agriculture as one of the barriers to climate change adaptation in north-central Namibia.

CONCLUSIONS

Membership of farming organisations reduced vulnerability levels probably because members were better informed and may have improved access to inputs and marketing opportunities. Hence formation of farmers' organisations should be encouraged. Evidence suggested a disparity in resilience and vulnerability based on the gender of the household head. This may call for gender mainstreaming in farmer training and support services, bearing in mind the differential access to resources and information. Households should be encouraged to diversify their farming activities, receive training in conservation agriculture and rehabilitate degraded rangelands. Households should be encouraged to leverage the available pool of labour to increase resilience through: diversification of livelihoods by engaging in other income earning activities; increasing crop diversity; planting of fruit trees; fodder production and conservation (hay, silage); and making better use of crop residues for livestock feeding, for instance by urea treatment. This is particularly pertinent to large households to reduce their vulnerability to drought effects. More farmer training and extension services are needed to improve households' capacity for drought adaptation and mitigation. Training should go hand-in-hand with improved infrastructure (e.g., for irrigation, food and feed storage), access to credit, improved markets, veterinary services, research support and policy reforms on secure land tenure. Households should be empowered through measures that enhance drought risk preparedness enabling them to better cope with climate change effects.

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Appendix 1: Structured questionnaire covering aspects of household socioeconomic and demographic characteristics, *ex-ante* adaptation coping strategies and *ex-post* maladaptation coping strategies employed to guard against the effects of drought by households in northern-central Namibia (n = 80).

My name is Dorthea K. Shiimi, a fourth-year student at the University of Namibia Department of Agricultural Economics. I am carrying out a survey for my research project in order to collect information on farmer's climate change adaptation and mitigation strategies, this questionnaire is sent to you for academic and scientific purposes. The information collected from you is highly privileged and will be kept confidential. You are free to withdraw from the interview at any time. Thanks in advance for your cooperation.

Interviewee Consent

Name of Interviewee: ....

Date: ....

District: …………………………………………………………………………….

Village name: ……………………………………………………………………….

Contact details: …………………………………………………………………………

I………………………………………………………………………………. (Surname & Initials) hereby acknowledge that I have read the interview's purpose and have given my consent to participate in it as a respondent.

Signature: ....

Section A: Household socio-demographic information

1. Age of respondent: ....

2. Gender of respondent

1. Male ☐ **2. Female** ☐

3. Marital status
1. Married ☐ 2. Single ☐ 3. Divorced ☐ 4. Widowed 5. Separated

4. What is the highest grade/education level achieved?
1.No Formal education ☐ 2. Primary ☐ 3. Secondary ☐ 4. Tertiary ☐

4b. Years of formal education…………………………… (Years)
5. Household size……………………………

6. For how long have you been farming? ……………………. (years)

7. Type of farming activity
1.Livestock farming ☐ 2. Crop farming ☐ 3. Mixed farming ☐

8. Are you a member of any farmers' organization?

1. Yes ☐ **1. No** ☐

9.Do you own any livestock?

1. Yes ☐ **1. No** ☐

9a. If yes, how many of the following livestock do you own?

Type of livestock	Number owned
1.Cattle	
2.Goats	
3.Sheep	
4.Chicken	
5.Pigs	
6.Donkeys	
7.Other (specify)	

10.Do you own any household assets?

1. Yes ☐ **1. No** ☐

10a. If yes, how many of the following assets do you own?

Type of livestock	Number owned
1.Cars	
2.Wheelbarrows	
3.Cellphones	
4.Donkey carts	
5.Plough	
6.Cultivators	
7.Hoes	
8.Other (specify)	

Section B: Respondents' drought perception and awareness

1. What do you understand by drought?

………
………
………
………………………………….

2. Were you aware of impending drought incidence before its onset?

1. Yes ☐ **1. No** ☐

2a. If yes, through which medium did you receive the information from? Tick all that apply

Media	Tick
1. TV	
2. Radio	
3. Newspaper	
4. Farmer organisation	
5. Friends and neighbours	
6. Extension officers	
7. Other (specify)	

Section C: Effects and responses on the livestock herds

1.Do you own any livestock?

1. Yes ☐ **2. No** ☐

2. Did you experience any problems in availing water for your livestock during the drought?

1. Yes ☐ **3. No** ☐

2.a If yes, how were your livestock affected?
1. Not severe ☐ 2. Moderately severe ☐ 3. Very Severe ☐

3. How many water sources did you have access to for your livestock before the onset of the drought? ……………………………………..

4. What type of water sources were they and what were the distances to these sources? (provide distance to the water source in km)

Type of water source	Before drought	During drought
1. Stream		
2. Borehole		
3. Digging in stream beds		
4. Ponds		
5. Concrete in ground		
6. Concrete above ground		
7. Reservoir/dam		
8. Others*		

*Specify

5. How many grazing sites do you have access to? ....

6. What was the distance to the primary grazing sites? ……………… (km)

7. Did you experience any problems in availing feed/pasture for your livestock during the drought?
1. Yes ☐ **2. No** ☐

7a If yes, how were your livestock affected?
1. Not severe ☐ 2.Moderately severe ☐ 3.Very Severe ☐

8. What was the most significant livestock management change you experienced during droughts?
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
…………………………………………………………………

9. Did you fence to protect the water source?
1. Yes ☐ **1. No** ☐

10. Did you fence to protect the grazing areas for your livestock?
1. Yes ☐ **1. No** ☐

11. Did you prepare for feed for your animals before the onset of the drought?
1. Yes ☐ **1. No** ☐

11a If yes, what form of preparation did you make (tick all that apply)

Preparation made	Tick
1. Preserved pearl millet stalks for animals	
2. Preserve uncultivated land for animals	
3. Other (specify)	

12. Did you move your livestock to areas with better grazing pasture (eg cattle posts)?
1. Yes ☐ **1. No** ☐

Section D: Effect and response on crops

1. Do you practice crop farming?
1. Yes ☐ **1. No** ☐

1a. If yes, what area of land do you cultivate during normal seasons and drought periods?

Period	Land area (Ha)
Normal period	
Drought period	

2. To what extent did the drought affect your crops?
1. Not affected ☐ 2. Not severe ☐ 3. Moderately severe ☐ 4. Very Severe ☐

3. At what growth stage did you lose your crops because of the drought?
1. Germination ☐ 2. Vegetation ☐ 3.Reproduction stage ☐ 4. Seed formation ☐

4. How was your crop yield affected?
1. Not severe ☐ 2. Moderately severe ☐ 3. Very Severe ☐

5. Did you have to change your cropping system during the drought period?
1. Yes ☐ **1. No** ☐

5a. If yes, what type of cropping system did you employ during the drought period? Tick all that apply.

Cropping system	Tick
1. Intercropping	
2. Wide spacing	
3. Shifting to quick maturing crops	
4. Planting drought-resistant varieties	
5. Cultivation of vast areas in different directions	
6. Crop rotation	
7. Conservation agriculture	
8. Other (specify)	

6. Did you plant drought-resistant varieties/crops?
1. Yes ☐ **1. No** ☐

6a. If yes, which drought-resistant crops/ varieties did you grow?
……
……
………………………………………………………

7. Did you irrigate crops during the drought
1. Yes ☐ **1. No** ☐

7a. If yes, which irrigation system did you employ?
1. Mini irrigation system ☐ 2. Hand irrigation ☐

Section E: Farmers' Strategies in response to consequences during drought

1. Did of preparation for the welfare of your household before the onset of the drought?
1. Yes ☐ **1. No** ☐

1a. If yes, what kind of preparation did you put in place? (Tick all that apply)

Preparation strategy	Tick
1. Save pension money to buy food	
2. Own a small shop to earn money	
3. Plant fruit trees	
4. Borrow money to stock food	

2. Did you draw upon stored foods during a drought?
1. Yes ☐ **1. No** ☐

4. Did you seek wild fruits or hunt animals as a result of food shortage during drought?
1. Yes ☐ **1. No** ☐

5. Did you render services or assistance in exchange for food during these periods?
1. Yes ☐ **1. No** ☐

6. Did you have to disperse family members during any phase of drought in order to meet family needs?
1. Yes ☐ **1. No** ☐

7. Were you forced to seek employment elsewhere during the drought period?
1. Yes ☐ **1. No** ☐

7.1 If yes, did you get employment within your locality or you had to migrate?
1. Within locality ☐ **2. Migrate** ☐

8. Did you have to borrow food or rely on help from friends and relatives at some point during the drought?
9. Did you sell or pledge any productive assets in order to buy food during a drought?
1. Yes ☐ **1. No** ☐

10.1 If yes, what type of assets did you sell………………………………………………..
11. Was selling your assets able to achieve the aim of sale?
1. Yes ☐ **1. No** ☐

11a. If not, what was the reason why not?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………

12. Can you conclude that the coping mechanisms you adopted helped to ease the effect of drought on your household?
1. Yes ☐ **1. No** ☐

12a. Why or why not?
……………………………………………………………………………………….……..…
…......…………………………………………………………..……….…………..…....…
…………………………………………………….……....……......................................
....

Section F: Section for village-level coping strategies

1. Are there any village forest reservation strategies or laws in place that prohibit farmers from cutting down trees?
1. Yes ☐ **1. No** ☐

2. Are there any village soil conservation techniques in place?
1. Yes ☐ **1. No** ☐

3. Are there any of the following community projects in the area?
3.1 Community dam?
1. Yes ☐ **1. No** ☐

3.2 Fish farming project?
1. Yes ☐ **1. No** ☐

3.3 Irrigation project in the area?
1. Yes ☐ **1. No** ☐

Appendix 2: Parameter estimates for the general linear model on factors affecting household drought resilience of households in northern-central Namibia (n = 80).

Parameter*	B	Standard error	Lower bound	Upper bound
[Gender = Male]	0.558	0.299	-0.039	1.156
[Gender = Female]	0			
[Marital status = Married]	0.337	0.310	-0.017	0.583
[Marital status = Single]	0			
[Farm organisation* = No]	-2.482	0.705	-3.889	-1.074
[Farm organisation = Yes]	0			
[Farm activities = Livestock]	1.770	0.932	-0.091	3.631
[Farm activities = Crop]	-0.335	0.387	-1.107	0.437
[Farm activities = Mixed]	0			
Household size	0.060	0.045	-0.030	0.150
Years of farming experience	0.016	0.013	-0.009	0.041

**Farm organisation refers to whether household had membership to a farming organisation or not. Farm activities refers to the type of farming activities in which the household was engaged.*

Appendix 3: Parameters from the general linear model of factors affecting household vulnerability to drought for households in northern-central Namibia (n = 80).

Parameter*	B	Standard error	Lower bound	Upper bound
[Farm organisation* = No]	1.099	0.902	-0.703	2.900
[Farm organisation = Yes]	0			
[Farm activities = Livestock]	-1.663	1.193	-4.044	0.719
[Farm activities = Crop]	-0.324	0.495	-1.312	0.664
[Farm activities = Mixed]	0			
Household size	0.117	0.058	0.002	0.233
Years of farming experience	-0.029	0.016	-0.061	0.004
Asset index	-0.442	0.183	-0.807	-0.078
Livestock index	0.042	0.248	-0.454	0.538
Years of education	-0.040	0.065	-0.169	0.089

**Farm organisation refers to whether household had membership to a farming organisation or not. Farm activities refers to the type of farming activities in which the household was engaged.*

An evaluation of the simultaneous utilisation of the northern Namib coastline by desert-adapted lions (*Panthera leo*) and recreational shore anglers, during the 2022/2023 Torra Bay Campsite season, in the Skeleton Coast National Park

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Abstract

Since 2017 desert-adapted lions (*Panthera leo*) that occupy large sections of the Skeleton Coast National Park and the Northern Namib in Namibia have expanded their movements along the arid coastline and increased their use of marine food items in the inter-tidal zones. The annual opening of the Torra Bay Campsite during the December/January holiday period for offshore line fishing has raised increasing concerns of conflict between lions and anglers. During the 2022/2023 season the simultaneous use of the Torra Bay coastline by anglers and lions was evaluated. One lioness utilised the Torra Bay coastline for 34 days or 50% of the Torra Bay season. She adapted her activity patterns by hunting along the inter-tidal zones at night and retreated inland during the daytime and avoided interactions with anglers. Notwithstanding, the lioness continued to utilise the coastal habitat and prey on marine food items, particularly Cape fur seals (*Arctocephalus pusillus*) that contributed 78% of her biomass consumption. An awareness campaign with regular updates on five social media platforms in combination with the constant presence of conservation authorities may have contributed to public awareness, respectful behaviour from Torra Bay visitors and no incidents of conflict.

Keywords: African lion, angling, coastal habitat, Cape fur seal, human-lion conflict, marine diet, Namibia, *Panthera leo*

Introduction

For many decades the Namibian coastline has been renowned for its offshore line fishing opportunities (Kirchner *et al.* 2000). In recent years the northern section of the coastline that includes sections of the Skeleton National Coast Park (SCNP) has become particularly attractive to anglers. The seasonal access to the Torra Bay Campsite and the designated angling area, from December to January, has attracted large numbers of anglers that have unfettered access to almost 20 km of the coastline. It includes several ecologically sensitive areas, such as the Koigab Cape fur seal (*Arctocephalus pusillus*) breeding colony, the unique geological formations at the Uniab waterfall and the Holocene archeologic settlements scattered inside the Uniab Delta (Kinahan 2020).

Torra Bay has a colourful history that began in 1955 when livestock farmers from the Welwitschia area (now known as Khorixas) obtained permission from the Outjo Magistrate to establish a seasonal holiday location in the area of the Uniab River mouth (Bridgeford pers. com. 2023). During that period the area was still part of the Etosha Game Park that was only reduced to its current size by the Odendaal Commission in 1970 (Berry 1997). During those early years it is believed that farmers travelled to the area with livestock (sheep & chickens) and camped at various locations, such as James Bay (Paterson pers. com. 2023). The December to January seasonal camping at Torra Bay was formalised with the proclamation of the Skeleton National Coast Park in 1971 (Mendelsohn *et al.* 2002). A proposal during 1986/7 to keep Torra Bay Campsite open all year round was successfully blocked by the traditional Torra Bay visitors, who would book their campsite spots for the entire two months and travel regularly between their farms and Torra Bay (Paterson pers. com. 2023). This tradition still continues today, albeit at a much lower scale. The Torra Bay Campsite has since become a popular holiday destination for all Namibians and occasional visitors from abroad (Kazeurua 2018).

The historic presence of lions and other large carnivores utilising the coastal habitat along the SCNP, and in particular the Uniab Delta area, has been well documented (Bridgeford 1985, Shortridge 1934, Stander 2019). During the 1980s the combination of hyper-arid conditions and livestock farming along the borders of the SCNP (Carter 1990) led to excessive human-lion conflict, which resulted in the local extinction of free-ranging lions in the SCNP and surrounding areas (Stander *et al.* 2018).

Following the independence of Namibia in 1990, favourable conditions that included a stable political environment, the formation of communal conservancies, the growth of eco-tourism and increased rainfall patterns, resulted in the recovery of wildlife populations (Jones 1999, Owen-Smith 2011). By the end of 2002, the lion population had increased sufficiently to reoccupy sections of the SCNP, and by 2012 five prides occupied permanent home ranges in the SCNP that included the coastal habitats (Stander 2019). The knowledge or "culture" of utilising the rich marine food resources along the intertidal zones had been lost during the population decline of the 1980s. It was only in 2017 that lionesses from two prides rediscovered the marine food resources and began utilising marine species such as Cape fur seals and cormorants (*Phalacrocorax* spp.) on a regular basis (Stander 2019).

The rediscovery of Cape fur seals and other marine food items by the desert-adapted lion population is a significant development from both a biological and conservation point of view. It is the only place on the African continent where a large apex carnivore species utilises marine food resources. Terrestrial carnivores that prey on marine species are referred to as maritime carnivores (Carlton & Holder 2011) because they, like some other mammal species, utilise food resources from two different trophic zones. The importance of maritime mammals to the global ecology has often been underappreciated (Carlton & Holder 2011); their reliance on marine food has benefits to the flow of nutrients between the zones and is important to global food webs (Polis *et al*. 1997).

Desert-adapted lions have large home ranges to cope with the variability and low density of prey animals. In recent years this has resulted in all the major prides and groups of lions being involved in incidents of human-lion conflict (Stander *et al*. 2018). Those lions that have subsequently discovered the marine food resources, however, have not yet returned to the communal conservancy areas where people live with livestock. It is important for the conservation of the desert-adapted lion population and the mitigation of human-lion conflict that they can continue to utilise the marine food resources as an alternative to livestock (Stander 2019).

During the two-month period of the Torra Bay Campsite season (1 December 2022 to 31 January 2023), only one lioness utilised the area demarcated for recreation. The Ministry of Environment, Forestry & Tourism (MEFT) and Desert Lion Conservation (DLC) collaborated during the two-month period to monitor the movements and behaviour of the lioness, and to address any potential incidents of conflict.

Methods

Study area

The study area covered the central section of the SCNP and focussed on the entire area demarcated for Torra Bay Campsite visitors (Figure 1). Guided by the movements and home range of the lioness, the study area was expanded to also include the coastal zone west of the dune-belt; from Terrace Bay in the north to the Huab River in the south.

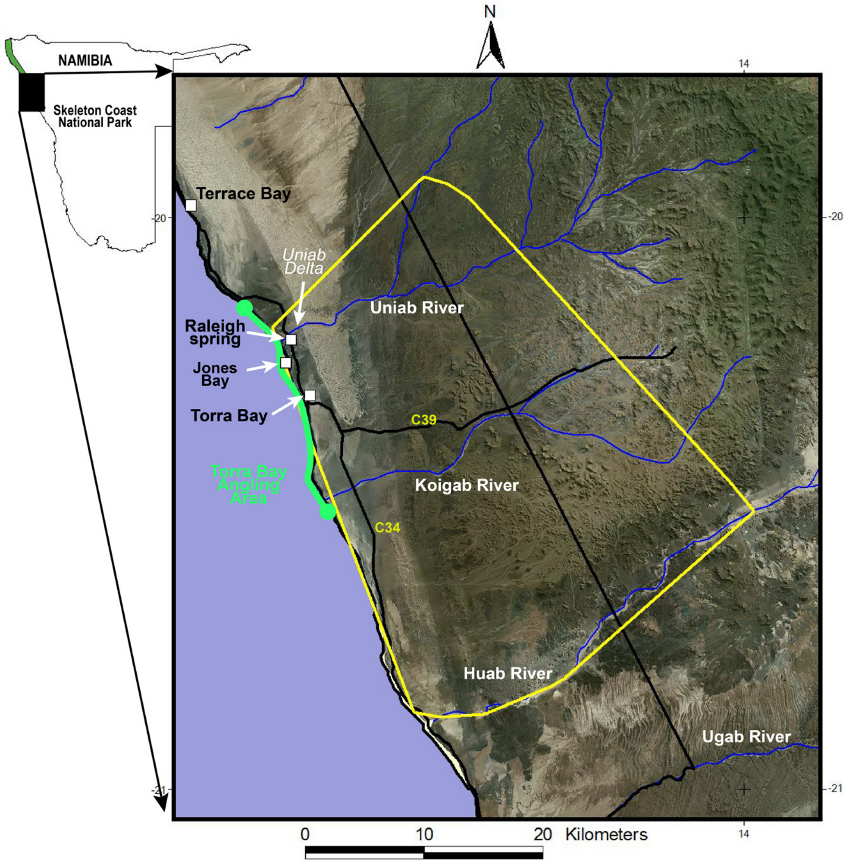

Figure 1: *The study area centred around the Torra Bay Campsite angling area, the Uniab Delta and the Koigab area that includes the home range of the lioness (yellow polygon), in the south-central section of the Skeleton Coast National Park, Namibia.*

Observations, data capture and analysis

The lioness (Xpl-108) was one of a litter of three females born in mid 2013. Their mother, Xpl-45, exposed the three siblings to the Uniab Delta and passed on the knowledge of the marine food resources during mid-2017. The three young lionesses regularly returned to the Uniab Delta and utilised the marine foods at varying frequencies. Typical of lion fission-fusion grouping patterns (Schaller 1972), the lionesses often spent time together as well as extended periods apart that is a function of their large home ranges and low prey densities (Stander *et al*. 2018). At the age of 9 years, Xpl-108 was fitted with a satellite/VHF radio collar programmed to record hourly GPS positions and emit a constant motion-sensitive VHF signal. Observations started on 19 November 2022 (one week prior to the opening of Torra Bay) and continued until the end of January 2023. The movements and activities of the lioness were recorded over 24-hour cycles for a total of 70 days. For the periods that the lioness moved in the coastal zone and inland up to a distance of 15 km from the coastline, she was kept under 24-hour visual observation. Her movements further inland were monitored via satellite. Observation data were divided into seven consecutive 10-day periods to facilitate the calculation of fluctuations and changes in the movements and behaviour of the lion in relation to tourism and angling activities at Torra Bay Campsite.

A research vehicle was equipped with an array of night-vision and data recording systems. A built-in local area Wi-Fi network and server, which formed the backbone of the data recording process, recorded continuous video images from five infrared security cameras that were mounted on strategic points of the vehicle. With the addition of a thermal camera, linked to the directional VHF radio telemetry antenna, and a high resolution IR video camera, the research vehicle could be driven in total darkness and the lioness observed without disturbance.

Distances moved were calculated from hourly GPS locations and home range estimates were based on the minimum convex polygon method (MCP; Harris *et al*. 1990). Food intake and biomass consumed followed standard procedures using the average mass of an adult female (or adapted when the age and size of the prey animals were observed) minus 40% (for larger prey >50 kg) and 25% (smaller prey 5–50 kg) of inedible parts (Packer *et al*. 1990, Stander 1992). When predation and feeding behaviour could not be observed visually, due to fog or inaccessible terrain, the information was obtained the following day using spoor reconstruction and inspection of carcass remains (Liebenberg 1990, Stander *et al*. 1997).

During the daylight hours the lioness generally rested amongst vegetation or between hummocks. In an effort not to attract the attention of visitors, the research vehicle was parked on a high vantage point approximately 800 metres to 1 km away from the lioness. Surveillance cameras with powerful lenses or a spotting scope were used to monitor the lioness and the movements of visitors during the day. Motion detection events were set up on the surveillance cameras to assist with the monitoring and counting of tourist vehicles driving along the main road.

Social Media and Communications

Updates on the activities of the lioness and the Torra Bay visitors were made daily. A map of her movements, accompanied by photos of that day and short video clips (± 1 min) were edited and prepared from the research vehicle. Every second or third day this information was copied onto a memory flash-drive, packaged, and sent to Swakopmund via Namibia Wildlife Resorts (NWR) and visitors leaving the park.

In Swakopmund the information was edited and sent to the Netherlands where it was prepared for social media release. The DLC website (https://www.desertlion.info/) is the main communication platform, where the News section covers the current affairs. Sections of this information was then posted on other web platforms, like YouTube, Instagram & Facebook, with references back to the full report on the website.

The success of the monitoring exercise relied on dependable communication between the research vehicle and other involved parties, specifically DLC personnel both on site near Torra Bay and in Swakopmund, as well as the MEFT and NWR staff members at Torra Bay. It was also essential that the research vehicle and DLC personnel could at any stage retrieve the latest GPS position of the lion. As such, the research vehicle and DLC support vehicles were equipped with "Rover Units". These units were developed locally by Wide Horizons and DLC to communicate via satellite with a centralised server in Swakopmund, which then forwarded messages between the relevant parties. Messages were relayed either via SMS to a cell phone, or via satellite to other Rover units. The units were also used to retrieve the latest GPS position of lions fitted with satellite collars from the central server.

Results

Lion movements and behaviour ecology

During the 70-day period the lioness (Xpl-108) moved over a home-range area of 5,905 km^2 (Figure 2). She walked a total distance of 742 km at an average of 11.1 km/day (range: 0.2–43.3 km/day), and spent 34 days inside the Torra Bay Campsite area, as indicated by her movements and daily resting sites (Figures 3a, b & c). Apart from five days in the southern section (Figure 3a), near the Koigab seal colony, the lioness spent most of her time (n = 29 days) between Torra Bay and the mouth of the Uniab River, during two visits to the coastal habitat (Figure 3b, n = 20 days & Figure 3c, n = 9 days).

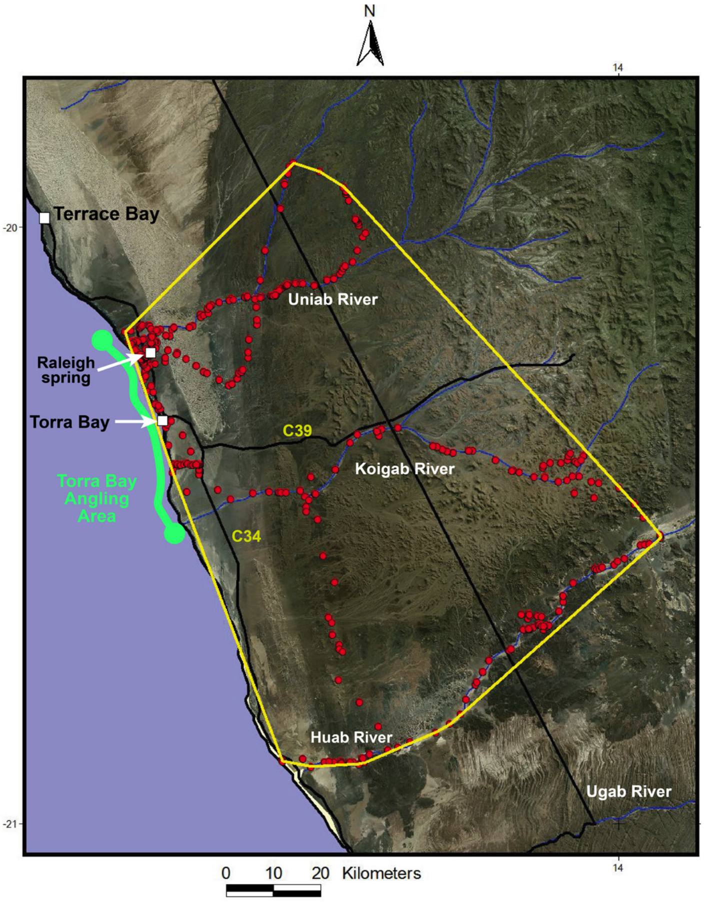

Figure 2: *Movement patterns of lioness (Xpl-108) and estimated home range size (MCP) of 5,905 km² over a 70-day period.*

During this period the lioness killed or scavenged a total of 30 prey animals, with the majority of her food consisting of Cape fur seals (Table 1). These food items amounted to a total estimate of 425 kg edible biomass and an average per capita food intake of 6.1 kg per day. This compares favourably with general food requirements for lions that varies between 5 kg and 8.5 kg/lioness/day (Packer *et al*. 1990, Stander 1992).

In total the lioness spent marginally more time in the coastal and beach habitats compared to the riverbeds, gravel plains and mountains of the inland habitat (Figure 4). The movement patterns and utilisation of the three main habitat types, however, varied substantially over the two months when the data were separated into seven consecutive ten-day periods (Figure 4).

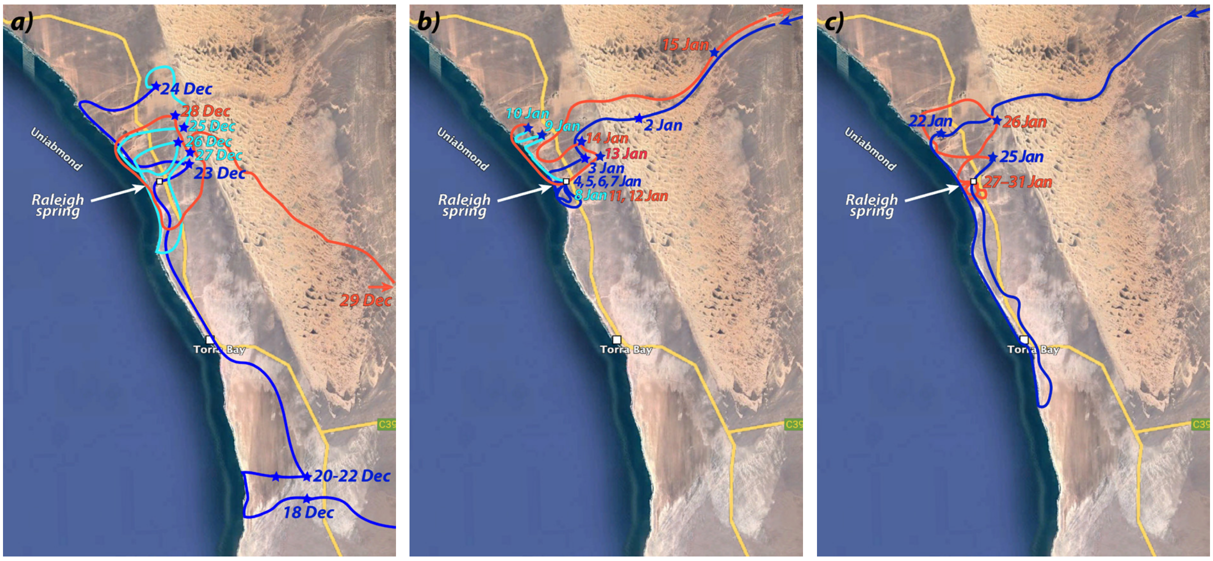

Figure 3: *Daily movements of lioness (Xpl-108) in the Torra Bay Camping area during: a) December 2022, b) early-mid January 2023 and c) late January 2023. Blue stars indicate daytime resting spots with dates (except when lioness was at Raleigh spring) and coloured lines depict night-time movements.*

The entire coastal habitat, which includes the dunes and the beaches, was significantly more productive for the lioness during the 70-day period (Table 2). During her inland visits the lioness walked longer distances (Student's t-test, $t = 2.09$, $p < 0.05$) and did not meet the minimum required food intake of 5 kg/day. The regular visits to the coast and the availability of marine food items, like Cape fur seals, enabled the lioness to increase her average daily food intake to 6.1 kg/day.

The importance of the coast and the marine food items is illustrated further when comparing energy expenditure, such as kilometres travelled per day, and food intake over the consecutive ten-day periods (Figure 5). During the third ten-day period (9–18 December 2022) the lioness walked 300 km at an average of 12.9 km/day without finding any food. Her return to the coast for the following 20 days, however, resulted in higher levels of food intake and substantially lower energy expenditure. A similar pattern of high energy output was evident during her third trip inland with an increase in food intake when she returned to the coastal habitat at the end of January 2023.

Table 1: *Total number of prey animals captured or scavenged by lioness (Xpl-108) over the 70-day study period.*

Prey species	Age	Number
Gemsbok (*Oryx gazella*)	Sub-adult	1
Springbok (*Antidorcas marsupialis*)	Sub-adult	2
Cape fur seal (*Arctocephalus pusillus*)	Adult	4
	Juvenile	8
	Pup	12
Egyptian goose (*Alopochen aegyptiacus*)	Adult	2
Copper shark (*Carcharhinus brachyurus*)[1]	Young adult	1
Total		30

[1] *Copper (or Bronzy) shark scavenged and partially eaten.*

Interactions with tourist and anglers from Torra Bay Campsite

During the peak visitor period (20 December 2022 to 10 January 2023), when the lioness rested at Raleigh spring, between 68 and 193 vehicles drove past the spring along the main C34 road per day. Peak hours were during the morning (08h00–11h00) and the late afternoon (16h00–18h00) when between 14 and 32 vehicles were counted. The majority of vehicles (65%) simply drove past the spring without taking notice, whereas 15% slowed down or stopped briefly. A surprisingly large number of vehicles (20%) stopped, scanned the area and waited for an opportunity to view the lioness (Figure 6). It was pleasing to observe that none of the passengers of the vehicles that showed interest in the lion got out of their vehicles. On the few occasions that the lioness was visible from the main road, a total of eight vehicles spotted the lioness and observed her for up to two hours, whilst 34 vehicles drove past without looking.

During the 34 days that the lioness spent inside the Torra Bay Campsite area, she moved onto the beach at night on 25 occasions, only to return to Raleigh spring or other vegetation cover before daylight. When the lioness first arrived at the coast, after the opening of Torra Bay on 18 December 2022, she rested on a high lookout point for the entire day, where she observed all the vehicles and anglers moving up and down the coastline. That night she approached the beach with caution and after killing a large adult Cape fur seal during the early morning hours, she made an extraordinary effort to

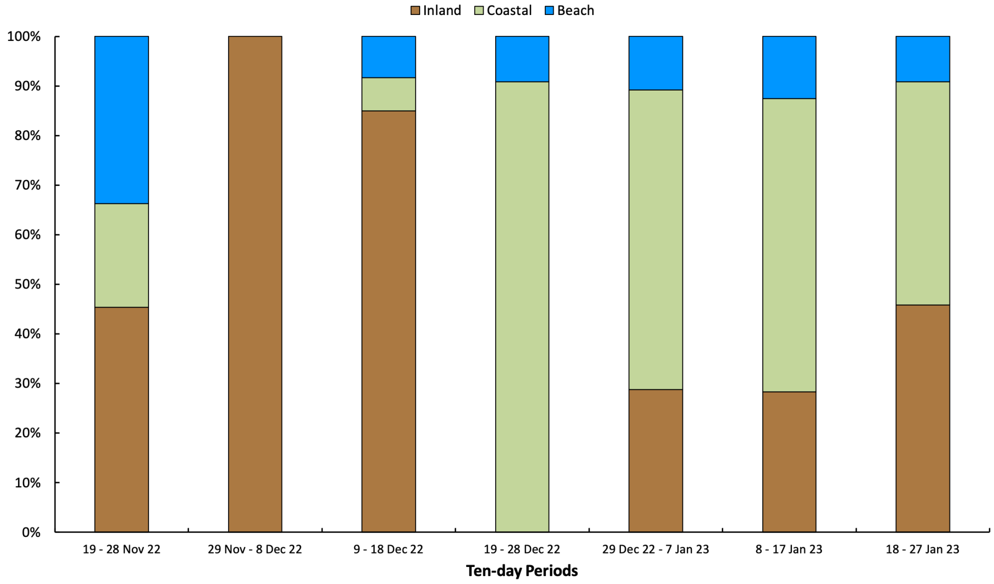

Figure 4: *Proportion of time spent in three habitat types during seven consecutive ten-day periods by lioness (Xpl-108) over the 70-day study period (n = 1680).*

drag the carcass 4.1 km inland, across a large salt pan and to the top of a high granite hill. She lay there for three days eating and watching the vehicle and people activities on the beaches. Showing remarkable awareness and adaptation to the new dynamics in her usual hunting grounds, the lioness changed her behaviour and refrained from spending any time on the beaches during the daytime (see Figure 4). During the ten-day period prior to the opening of Torra Bay, the lioness spent double the amount of time on the beach (Figure 7).

Most tourists were understanding and respectful of the presence of the lioness in the area. Many visitors expressed a keen interest in observing the uniquely desert-adapted Skeleton Coast lions. On 13 occasions visitors attempted to drive off-road, which is illegal according to the permit conditions of the SCNP, to either approach the lioness or the research vehicle. A strong strobing flashlight was used to attract their attention and hand signals were used in an effort to ask vehicles not to approach. The method was successful, and people respected the requests. There were only two high-risk incidents and both involved the lioness approaching anglers that were still active and out of their vehicles after sunset. The flashing strobe light was again effective in alerting the tourists and preventing further escalations.

***Table 2:** Comparison between habitats, the distances travelled per day and the per capita food intake acquired by lioness (Xpl-108) over a consecutive 70-day period.*

Behaviour ecology	**Habitat type**		**Total**
	Inland (East of the dunes)	Coastal (Dunes to the ocean)	
Average distance walked (km/day)	13.2 km	8.4 km	**10.8 km**
Standard error	± 1.52	± 0.56	
Range	0.2–43.3 km	0.6–38.4 km	**0.2–43.3 km**
n	35	35	**70**
Average food intake (kg/day)[1]	2.8 kg/day	10.2 kg/day	**6.1 kg/day**
Total biomass	96 kg	329 kg	**372 kg**
n	35	37	**70**

[1] Food intake is based on estimated eatable biomass consumed

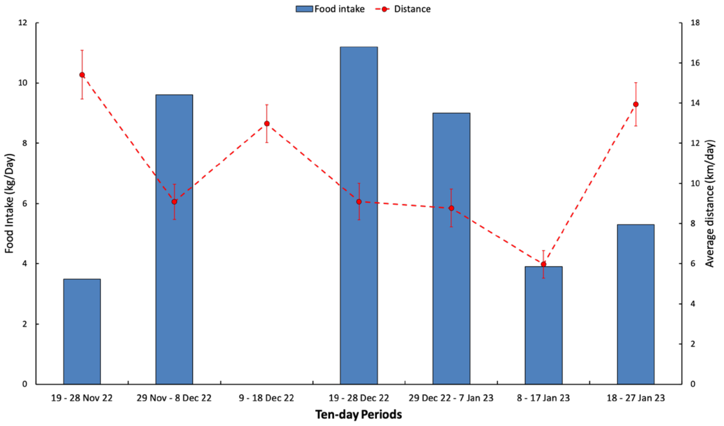

***Figure 5:** Daily food intake and average daily distances walked by lioness (Xpl-108) during seven consecutive ten-day periods over two months (n = 893).*

Communications, social media and information dissemination

The vehicle "Rover Units" and satellite communications via the centralised server in Swakopmund provided regular and reliable communications as well as hourly updates on the position of the lioness when it was needed. The process also ensured that the local authorities (MEFT & NWR office at Torra Bay) were kept up to date with the movements and activities of both the lioness and visitors, and that MEFT were alerted of potential conflict situations and illegal activities, such as off-road driving, by visitors.

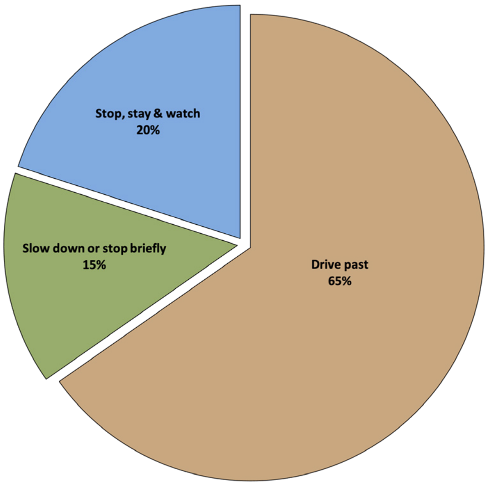

***Figure 6**: Summary of the behaviour of visitors driving past Raleigh spring when lioness (Xpl-108) was resting in the reeds (n = 195).*

The regular dissemination of digital information on social media, both in terms of quantity and quality, resulted in a substantial increase in views of both new and returning visitors on all five social media platforms. Although the impact of the regular media updates cannot be directly quantified in terms of causality, it is our impression that it contributed to mostly favourable public awareness. The public awareness was not only evident amongst Torra Bay Campsite visitors, but was also noticeable from Namibia at large, as well as South Africa and abroad. The distribution of regular and current information in combination with the constant presence of both the MEFT and DLC research vehicle are believed to have contributed to public awareness and the prevention of potential conflict between anglers and the lioness.

Figure 7: *The lioness (Xpl-108) spending the day on the beach inside of Torra Bay Campsite area one week before the opening of the 2022/2023 season.*

Conclusion

During the two-month period between 1 December 2022 and 31 January 2023 the lioness spent 34 days inside the Torra Bay Campsite area and continued to utilise Cape fur seals as her main source of food. Notwithstanding, the lioness adapted her movements and behaviour to avoid interactions with the large number of vehicles and people moving along the beaches during the daytime. She hunted and searched for prey along the coastline at night and retreated inland to rest inside thick reed-beds or narrow gorges during the day. Her movements inland resulted in low food intake and high energy expenditure levels. As a result, she returned to the coast regularly where the availability of marine food items significantly increased her daily per capita food intake whilst moving shorter distances per day and expending less energy.

The regular posting of current information on the activities and whereabouts of the lioness on a range of social media platforms, appeared to have increased awareness amongst the public and visitors to Torra Bay Campsite. There were no incidents of conflict between the Torra Bay visitors and the lioness. This may also be due to the constant presence of the DLC research vehicle when the lioness was inside the Torra Bay Campsite area. On eight occasions the lioness was observed by visitors that where patient and waited inside their vehicles for an opportunity to view her. The number of vehicles that attempted to drive off-road towards the lioness, however, is alarming, and without the presence of the research vehicle and the MEFT, these events may have escalated and resulted in conflict.

The presence of large maritime carnivores, and in particular an apex predator such as the lion, along the African coastline and moving onto beaches is unique to Namibia. The potential tourism value of seeing a free-ranging lion on a beach in the SCNP is arguably enormous. Future tourism developments in the SCNP would be wise to consider the value of this unusual phenomenon and to develop ecologically sensitive tourism concessions that focus on the distinctive ecological, geological and archaeological characteristics of the region, rather than continuing with a 70-year old tradition of relatively uncontrolled off-shore line fishing.

Acknowledgements

The research and monitoring were conducted in collaboration with the MEFT under the Research Permit No. AN202101033. We wish to thank the NWR staff based at Torra Bay Campsite for their support and assistance. Fascinating information on the history of Torra Bay was provided by Peter Bridgeford and John Paterson who have been working in the area for almost 50 years. Miles October & Barney Harmse from Paratus Africa are thanked for internet & communications support. Funding and logistical support were managed by the DLC where individual sponsors are acknowledged on the official website (www.desertlion.info). In particular, we wish to thank Griet van Malderen for sponsorship and Joe Noci for technical support.

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The lioness Xpl-108 looking over Jones Bay after sundown when all the anglers were back at the Torra Bay Campsite.

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Status, distribution and numbers of birds in the Ogongo Game Park, north-central Namibia

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Abstract

In 2012, a simplified territory mapping method was employed to study the distribution and numbers of all birds breeding in the Ogongo Game Park (OGP). OGP is situated approximately 50 km north-west of Oshakati, in the Outapi district, Omusati region, North-Central Namibia. The area of the park is approximately 1000 ha. The vegetation of OGP comprises mainly mopane savanna *Colophospermum-Acacia nilotica*. In total, 142 bird species were recorded: 101 breeding residents, 19 regular visitors, 10 irregular visitors, 3 vagrants, 10 Palaearctic migrants. Maps showing the distribution of identified territories are presented for all breeding species. The dominant species were Ring-necked Dove *Streptopelia capicola* (14.2%), Helmeted Guineafowl *Numida meleagris* (9.3%), White-browed Sparrow-Weaver *Plocepasser mahali* (9.3%) and Blue Waxbill *Uraeginthus angolensis* (8.3%). Nine other species were classified as subdominant, comprising a further 27.7% of all breeding birds.

Keywords: avian community, Cuvelai Drainage System, Namibia, Ogongo Game Park, survey

Introduction

The Ogongo Game Park (OGP) constitutes the final point of the Biodiversity Monitoring Transect (BMT), which runs from the Cape Peninsula through the arid west of South Africa (11 observatories) and Namibia (17 observatories) and ends in OGP (Hoffmann *et al.* 2010, Jürgens *et al.* 2010, Schmiedel & Jürgens 2010). The BMT is an international collaboration between Germany, South Africa and Namibia, aimed at providing information on biodiversity and its changes, especially those which might be caused by climate change. Avifauna constitutes one of the most important elements of this biodiversity project and as such needs to be thoroughly investigated and monitored.

Studies on bird assemblages have been conducted in the Cuvelai Drainage System (Kopij 2013, 2014a, 2014b, 2015, 2019, 2021) including the Ogongo area (Kopij 2013, 2014a, 2014b). To date, the assemblages in natural and semi-natural habitats were, however, studied only by means of the transect line method (Kopij 2013, 2014a, 2014b). This generates only relative (linear) population density estimations. Territory mapping methods have been previously applied in the urbanised habitats of Outapi (Kopij 2019) and Ongwediva (Kopij 2021). Population estimates generated by this method are considered to be accurate and close to total counts (Sutherland 1993, Bibby *et al.* 2012).

This study contributes further to our knowledge of the avifauna of OGP by quantifying all bird species breeding in OGP using a territory mapping method.

Study area

The UNAM Ogongo Game Park (OGP) was established in 1997. It is situated approximately 50 km north-west of Oshakati in the Outapi district, Omusati region, North-Central Namibia. OGP occupies an area of approximately 1 000 ha and is about 1 100 m above sea level (Figure 1).

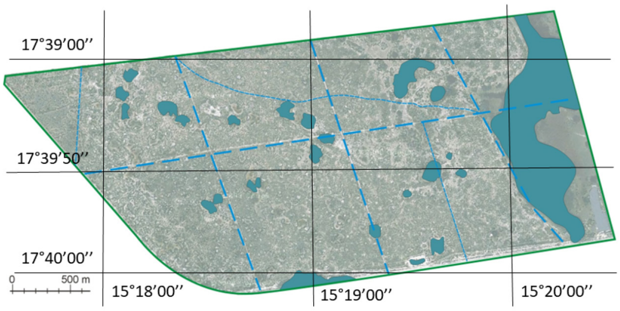

Figure 1: The study area: Ogongo Game Park (OGP). Green areas: oshanas, broken lines: roads, dotted lines: paths.

OGP is located in a prime summer rainfall zone, with mean annual precipitation of 400–500 mm (Mendelsohn, el Obeid, Roberts 2000; Mendelsohn *et al.* 2010; Mendelsohn & Weber 2011) and is regularly partially flooded during the rainy season (usually December–June). OGP is an extensive sandy plain with a total of 411 vascular plant species recorded across three vegetation classes

Figure 2: *a)* Acacia *savanna; b) mopane savanna, with Marabou Storks; c) fresh termite mound on the border of mopane and oshana.*

(Kangombe 2007). The three major vegetation classes are acacia savanna, mopane savanna and grassy plains (Figure 2). The acacia savanna is located in the north-western corner of the park, covering only c. 50 ha. It is fairly diverse, and composed mainly of *Acacia erioloba, A. nilotica, Hyphaene petersiana.* Other common tree species include *Combretum collinum, Terminalia sericea, Commiphora africana*, *Acacia siberiana* and *A. flecki*. The mopane savanna is much less diverse and strongly dominated by *Colophospermum mopane*, most of which are in young stage. This area covers most of the park's surface (c. 700 ha). The remaining c. 250 ha is covered by grasses and sedges and is flooded almost on a yearly basis. The most common grass species are *Schmidtia kalahariensis, Cynodon dactylon, Brachiara* spp., *Digitaria* spp., *Anthephora* spp., *Eragrostis* spp., *Enneapogon* spp. and *Panicum* spp. The eastern part of the reserve comprises a large oshana covered mainly with *Eragrostis* grasses. It typically retains rainwater for almost the whole year.

Methods

A simplified territory mapping method (Bibby *et al*. 2012, Sutherland 1996) was employed to identify the occupied territories of all pairs of all breeding bird species. The whole study area was surveyed four times in 2012. Six morning counts (between 06:00–07:00 and 09:00–10:00) were required to cover the whole study area. Complete surveys were conducted in May/June, July/August, September/October, and November/December.

All records of seen or heard birds showing breeding and/or territorial behaviour (including records of singing males) were plotted on a map using Garmin hand-held GPS. The grid size for the survey was 20 seconds (GPS), equivalent to 290 m. Birds were recorded on each side of the walking path up to a distance of 70–150 m. To increase detectability, during subsequent surveys the observer walked along an offset grid (different latitudes and longitudes). Special attention was paid to not record the same birds during the survey, and to record simultaneously singing males.

For species such as the Common Ostrich, Red-billed Buffalo Weaver, White-browed Sparrow-Weaver, Southern Red Bishop and Southern Masked Weaver, the number of breeding pairs was estimated based on the average number of females in the breeding colony/group. The number of breeding pairs of Helmeted Guineafowl was estimated by dividing the average number of birds in the breeding unit by two. The number of cooperatively breeding Red-faced Mousebird, Green Wood Hoopoe, and White-crested Helmetshrike was equal to the number of cooperatively breeding groups, regardless of the number of helpers present in each group. On their respective maps, colonies/groups, rather than single territories of these species, were plotted.

In addition to the main survey conducted in 2012, which aimed to estimate population densities of resident birds, observations of birds were also conducted in 2011 and 2013 in order to determine the status of all bird species (including

Figure 3: *Some bird species recorded in OGP during surveys in 2012. a) Openbill Storks; Yellow-billed Oxpecker; young Striated Heron.*

non-resident) recorded in OGP. The following terms were used to determine the status of each bird species: breeding resident (nesting in the study area); regular visitor (recorded in more than 50% of surveys, non-breeding); irregular visitor (recorded in less than 50% of surveys, non-breeding); vagrant (recorded only in 1–2 surveys); Palaearctic migrant (both regular and irregular visitors from the Palaearctic Region).

Dominance was calculated as the percentage of breeding pairs of a given species in relation to all breeding pairs of all species. A dominant species comprises at least 5% of all breeding pairs recorded, while subdominant species comprise 2–4.99%. Common and scientific species names of all bird species recorded are given in Table 1; nomenclature of names follows those in Chittenden *et al*. 2016.

Results

In total, 142 bird species were recorded in OGP in 2012: 101 breeding residents, 19 regular visitors, 10 irregular visitors, 3 vagrants, 10 Palaearctic migrants (Table 1, Figures 3–8). Among breeding residents, the dominant species were Ring-necked Dove (14.2%), Helmeted Guineafowl (9.3%), White-browed Sparrow-Weaver (9.3%) and Blue Waxbill (8.3%). Together they comprised 41.1% of all breeding birds (Table 1). The following species were classified as sub-dominant: Red-faced Mousebird, Fork-tailed Drongo, Namaqua Dove, Red-billed Buffalo Weaver, Southern Red-billed Hornbill, African Hoopoe, White-tailed Shrike, Southern Masked Weaver and Laughing Dove. Together they comprised 27.7% of all breeding birds.

During the survey 42 bird species were represented only by 1–2 breeding pairs, i.e. their population density was below 0.2 pairs per 100 ha. Population densities greater than 2 pairs per 100 ha were reached by 14 species (Table 1).

All territories identified for each breeding species are shown in Figures 4–8. Each dot on the map indicates an occupied territory. Dot size roughly reflects the territory size. For non-passerines it is therefore larger than for most passerines. Because some raptor species and few other species hold very large territories, these are shown as large circles.

Discussion

In 2012, the number of breeding bird species was exceptionally high in OGP. Some rare and elusive species (e.g., coursers, owls, nightjars, estrildid finches) may have been undetected. It should also be emphasised that some species (e.g., raptors and waterbirds) may nest in OGP irregularly, in some years only. In addition, population densities of some elusive species may have been underestimated. This is especially true regarding species with nocturnal activity, as counts were not conducted during the night. On the other hand, population densities of species with high vocal activity such as Acacia Pied Barbet, Blacksmith Lapwing, African Hoopoe, Green Wood Hoopoe, Common Scimitarbill, Southern Red-billed Hornbill, African Grey Hornbill, Ring-necked Dove, Laughing Dove, Namaqua Dove, Fork-tailed Drongo, White-browed Sparrow Weaver and Red-billed Buffalo Weaver are likely to be more accurate.

There is a lack of reliable quantitative population density estimations of birds (representative size of study plot, breeding pair as a census unit, territory mapping or total census methods) breeding in natural habitats, not only in Namibia (Kopij 2014), but in Africa at large (Urban *et al*. 1982–2004, Rowan 1983, Hockey *et al*. 2005). In comparison with urbanised habitats in the Cuvelai Drainage System (Kopij 2014a, 2019, 2021) the most striking difference is the proportion between the two most common dove species, the Ring-necked Dove and Laughing Dove. While in all urbanised areas in the Cuvelai Drainage System, the Laughing Dove strongly dominated over the Ring-necked Dove (Kopij 2014a, 2019, 2021), in natural savanna the reverse situation was recorded (this study). Population densities of the Southern Grey-headed Sparrow are low in both urbanised habitats and natural savannas, but the Blue Waxbill is common in both environments. The White-browed Sparrow Weaver is common in natural savanna, whereas it is rare in urbanised habitats. The reverse situation was recorded for the Southern Masked Weaver. Hornbills, wood hoopoes, Namaqua Dove, Fork-tailed Drongo, Long-billed Crombec and Rattling Cisticola bred in much higher densities in natural than in urbanised habitats. However, many bird species recorded as breeding in OGP were not recorded at all in urbanised areas (Kopij 2014a, 2019, 2021). This group includes common OGP species such as Helmeted Guineafowl, Spotted Thick-knee, Common Buttonquail and White-tailed Shrike.

The avian species richness in the pure stand of mopane savanna is low in comparison with acacia savanna (Kopij 2013, 2014a). The relatively high species richness in OGP, dominated by the mopane savanna, can be linked to exceptionally high rainfall in 2010/2011 wet season (numerous waterbirds recorded). Although most of the area of OGP is young mopane savanna, there is a small area with acacia savanna, which is also characterised by much higher avian species diversity (Kopij 2013, 2014a). The mopane savanna also has an abundance of large termite mounds (both functioning, recently abandoned and heavily eroded) often surrounded by a clump of trees and numerous shrubs. These sites break down the monotony of the mopane savanna, and greatly increase its biodiversity. A relatively high density of introduced ungulates may also play a role in this regard.

Table 1: Annotated checklist of bird species (listed in systematic order) recorded in Ogongo Game Park (*c.* 1 000 ha) in 2012. Number of breeding pairs/occupied territories is given for each breeding species.

Common species name	Scientific species name	Status	Number of pairs	Figure
Common Ostrich	*Struthio camelus*	breeding resident	4	4A
Helmeted Guineafowl	*Numida meleagris*	breeding resident	105	4A
Swainson's Spurfowl	*Pternistis swainsonii*	breeding resident	14	4B
Common Buttonquail	*Turnix sylvaticus*	breeding resident	3	6B
White-faced Whistling Duck	*Dendrocygna viduata*	regular visitor		
African Pygmy Goose	*Nettapus auritus*	breeding resident?	1	6C
Egyptian Goose	*Alopochen aegyptiaca*	irregular visitor		
Knob-billed Duck	*Sarkidiornis melanotos*	regular visitor		
Cape Teal	*Anas capensis*	regular visitor		
Red-billed Teal	*Anas erythrorhyncha*	regular visitor		
Southern Pochard	*Netta erythrophthalma*	breeding resident?	1	6C
Little Grebe	*Tachybaptus ruficollis*	breeding resident	1	6C
African Openbill	*Anastomus lamelligerus*	regular visitor		
Abdim's Stork	*Ciconia abdimi*	vagrant		
Woolly-necked Stork	*Ciconia episcopus*	vagrant		
Marabou Stork	*Leptoptilos crumenifer*	irregular visitor		
African Sacred Ibis	*Threskiornis aethiopicus*	irregular visitor		
African Spoonbill	*Platalea alba*	irregular visitor		
Dwarf Bittern	*Ixobrychus sturmii*	breeding resident	4	6F
Hamerkop	*Scopus umbretta*	breeding resident	6	5F
Black-crowned Night Heron	*Nycticorax nycticorax*	breeding resident	1	6F
Striated Heron	*Butorides striata*	breeding resident	1	6F
Squacco Heron	*Ardeola ralloides*	regular visitor		
Rufous-bellied Heron	*Ardeola rufiventris*	regular visitor		
Cattle Egret	*Bubulcus ibis*	regular visitor		
Intermediate Egret	*Egretta intermedia*	regular visitor		
Little Egret	*Egretta garzetta*	regular visitor		
Great Egret	*Ardea alba*	regular visitor		
Grey Heron	*Ardea cinerea*	regular visitor		
Black-headed Heron	*Ardea melanocephala*	regular visitor		
Purple Heron	*Ardea purpurea*	breeding resident?	1	6F
African Fish Eagle	*Haliaeetus vocifer*	irregular visitor		
Black-winged Kite	*Elanus caeruleus*	regular visitor		
Black Kite	*Milvus migrans*	Palaearctic visitor		
Yellow-billed Kite	*Milvus aegyptius*	breeding resident	4	6E
White-backed Vulture	*Gyps africanus*	irregular visitor		
Lappet-faced Vulture	*Torgos tracheliotos*	vagrant		
Bateleur	*Terathopius ecaudatus*	breeding resident	2	6D
Brown Snake Eagle	*Circaetus cinereus*	breeding resident	1	6D
Shikra	*Accipiter badius*	breeding resident	3	6E
Little Sparrowhawk	*Accipiter minullus*	breeding resident	1	6E
Common Buzzard	*Buteo buteo*	regular visitor		
Rock Kestrel	*Falco rupicolus*	regular visitor		
Grey Kestrel	*Falco ardosiaceus*	breeding resident	1	6E
Lesser Kestrel	*Falco naumanni*	Palaearctic visitor		

Red-footed Falcon	*Falco vespertinus*	Palaearctic visitor		
Amur Falcon	*Falco amurensis*	Palaearctic visitor		
Lanner Falcon	*Falco biarmicus*	irregular visitor		
Red-crested Korhaan	*Lophotis ruficrista*	breeding resident	1	6B
Common Moorhen	*Gallinula chloropus*	breeding resident	3	6C
Lesser Moorhen	*Paragallinula angulata*	breeding resident	1	6C
African Swamphen	*Porphyrio madagascariensis*	breeding resident?	2	6C
Spotted Thick-knee	*Burhinus capensis*	breeding resident	3	4A
Black-winged Stilt	*Himantopus himantopus*	irregular visitor		
Pied Avocet	*Recurvirostra avosetta*	irregular visitor		
Blacksmith Lapwing	*Vanellus armatus*	breeding resident	16	6G
Three-banded Plover	*Charadrius tricollaris*	breeding resident	2	6C
African Snipe	*Gallinago nigripennis*	breeding resident	1	6C
Wood Sandpiper	*Tringa glareola*	Palaearctic visitor		
Common Sandpiper	*Actitis hypoleucos*	Palaearctic visitor		
Namaqua Sandgrouse	*Pterocles namaqua*	regular visitor		
Ring-necked Dove	*Streptopelia capicola*	breeding resident	160	5H
Laughing Dove	*Streptopelia senegalensis*	breeding resident	24	5G
Mourning Collared Dove	*Streptopelia decipiens*	breeding resident	1	5G
Namaqua Dove	*Oena capensis*	breeding resident	46	6A
Grey Go-away-bird	*Corythaixoides concolor*	breeding resident	7	5B
African Cuckoo	*Cuculus gularis*	breeding resident	2	5C
Diederik Cuckoo	*Chysococcyx caprius*	breeding resident	1	5C
Klaas's Cuckoo	*Chrysococcyx klaas*	breeding resident?	1	5C
Western Barn Owl	*Tyto alba*	breeding resident	5	5F
Marsh Owl	*Asio capensis*	breeding resident	1	5F
Pearl-spotted Owlet	*Glaucidium perlatum*	breeding resident	2	5F
Rufous-cheeked Nightjar	*Caprimulgus rufigena*	breeding resident	1	5D
Common Swift	*Apus apus*	Palaearctic visitor		
African Palm Swift	*Cypsiurus parvus*	breeding resident	6	5D
Little Swift	*Apus affinis*	regular visitor		
Red-faced Mousebird	*Urocolius indicus*	breeding resident	12	5B
Lilac-breasted Roller	*Coracias caudatus*	breeding resident	5	4H
Purple Roller	*Coracias naevius*	breeding resident	2	5A
Woodland Kingfisher	*Halcyon senegalensis*	breeding resident?	2	5A
Pied Kingfisher	*Ceryle rudis*	breeding resident	2	5A
Swallow-tailed Bee-eater	*Merops hirundineus*	breeding resident	1	5A
Little Bee-eater	*Merops pusillus*	breeding resident	4	5A
European Bee-eater	*Merops apiaster*	Palaearctic visitor		
African Hoopoe	*Upupa africana*	breeding resident	35	4F
Green Wood Hoopoe	*Phoeniculus purpureus*	breeding resident	3	4G
Common Scimitarbill	*Rhinopomastus cyanomelas*	breeding resident	5	4G
Southern Red-billed Hornbill	*Tockus erythrorhynchus*	breeding resident	30	4D
African Grey Hornbill	*Lophoceros nasutus*	breeding resident	4	4E
Lesser Honeyguide	*Indicator minor*	breeding resient?	1	4C
Black-collared Barbet	*Lybius torquatus*	breeding resident	1	4C
Acacia Pied Barbet	*Tricholaema leucomelas*	breeding resident	10	4C
Golden-tailed Woodpecker	*Campethera abingoni*	breeding resident	2	4C
Rosy-faced Lovebird	*Agapornis roseicollis*	breeding resident	4	5E
Meyer's Parrot	*Poicephalus meyeri*	breeding resident	1	5E

White-tailed Shrike	*Lanioturdus torquatus*	breeding resident	27	7E
White-crested Helmetshrike	*Prinops plumatus*	breeding resident	6	7D
Crimson-breasted Shrike	*Laniarius atrococcineus*	breeding resident	5	7D
Brubru	*Nilaus afer*	breeding resident	4	7B
Black-backed Puffback	*Dryoscopus cubla*	breeding resident	2	7D
Brown-crowned Tchagra	*Tchagra australis*	breeding resident	7	7C
Southern White-crowned Shrike	*Eurocephalus anguitimens*	breeding resident?	2	7D
African Golden Oriole	*Oriolus auratus*	breeding resident	3	6H
Fork-tailed Drongo	*Dicrurus adsimilis*	breeding resident	56	7A
Cape Crow	*Corvus capensis*	breeding resident	1	6B
Pied Crow	*Corvus albus*	breeding resident	3	6B
Ashy Tit	*Melaniparus cinerascens*	breeding resident	1	6H
Rufous-naped Lark	*Mirafra africana*	breeding resident	2	7F
White-throated Swallow	*Hirundo albigularis*	breeding resident	5	7F
Lesser Striped Swallow	*Cecropis abyssinica*	breeding resident	5	7F
Long-billed Crombec	*Sylvietta rufescens*	breeding resident	16	7G
Willow Warbler	*Phylloscopus trochilus*	Palaearctic visitor		
Lesser Swamp Warbler	*Acrocephalus gracilirostris*	breeding resident	1	4H
Rattling Cisticola	*Cisticola chiniana*	breeding resident	13	8A
Zitting Cisticola	*Cisticola juncidis*	breeding resident	6	8A
Black-chested Prinia	*Prinia flavicans*	breeding resident	12	8B
Chestnut-vented Warbler	*Sylvia subcaelulea*	breeding resident	1	7F
Violet-backed Starling	*Cynnyricinclus leucogaster*	breeding resident	3	8C
Cape Starling	*Lamprotornis nitens*	breeding resident	1	8C
Yellow-billed Oxpecker	*Buphagus africanus*	breeding resident	7	8C
Groundscraper Thrush	*Turdus litsitsirupa*	breeding resident	11	8F
White-browed Scrub Robin	*Cercotrichas leucophrys*	breeding resident	1	6H
Familiar Chat	*Emarginata familiaris*	breeding resident	1	6H
Spotted Flycatcher	*Muscicapa striata*	Palaearctic visitor		
Ashy Flycatcher	*Muscicapa caerulescens*	breeding resident	1	7H
Scarlet-chested Sunbird	*Chalcomitra senegalensis*	breeding resident	3	8D
White-bellied Sunbird	*Cinnyris talatala*	breeding resident	2	8D
Southern Grey-headed Sparrow	*Passer diffusus*	breeding resident	5	7H
White-browed Sparrow-Weaver	*Plocepasser mahali*	breeding resident	105	8G
Red-billed Buffalo Weaver	*Bubalornis niger*	breeding resident	40	8G
Southern Masked Weaver	*Ploceus velatus*	breeding resident	27	8G
Red-headed Weaver	*Anaplectes rubriceps*	breeding resident	1	8G
Red-billed Quelea	*Quelea quelea*	regular visitor		
Yellow-crowned Bishop	*Euplectes afer*	breeding resident	2	8D
Southern Red Bishop	*Euplectes orix*	breeding resident	21	8D
Red-billed Firefinch	*Logonosticta senegala*	breeding resident	2	8E
Blue Waxbill	*Uraeginthus angolensis*	breeding resident	94	8F
Quailfinch	*Ortygospiza atricollis*	breeding resident	5	7H
African Pipit	*Anthus cinnamomeus*	breeding resident	1	7F
Black-throated Canary	*Crithagra atrogularis*	breeding resident	7	7C
Cinnamon-breasted Bunting	*Emberiza tahapisi*	breeding resident	4	8E
Golden-breasted Bunting	*Emberiza flaviventris*	breeding resident	6	8E

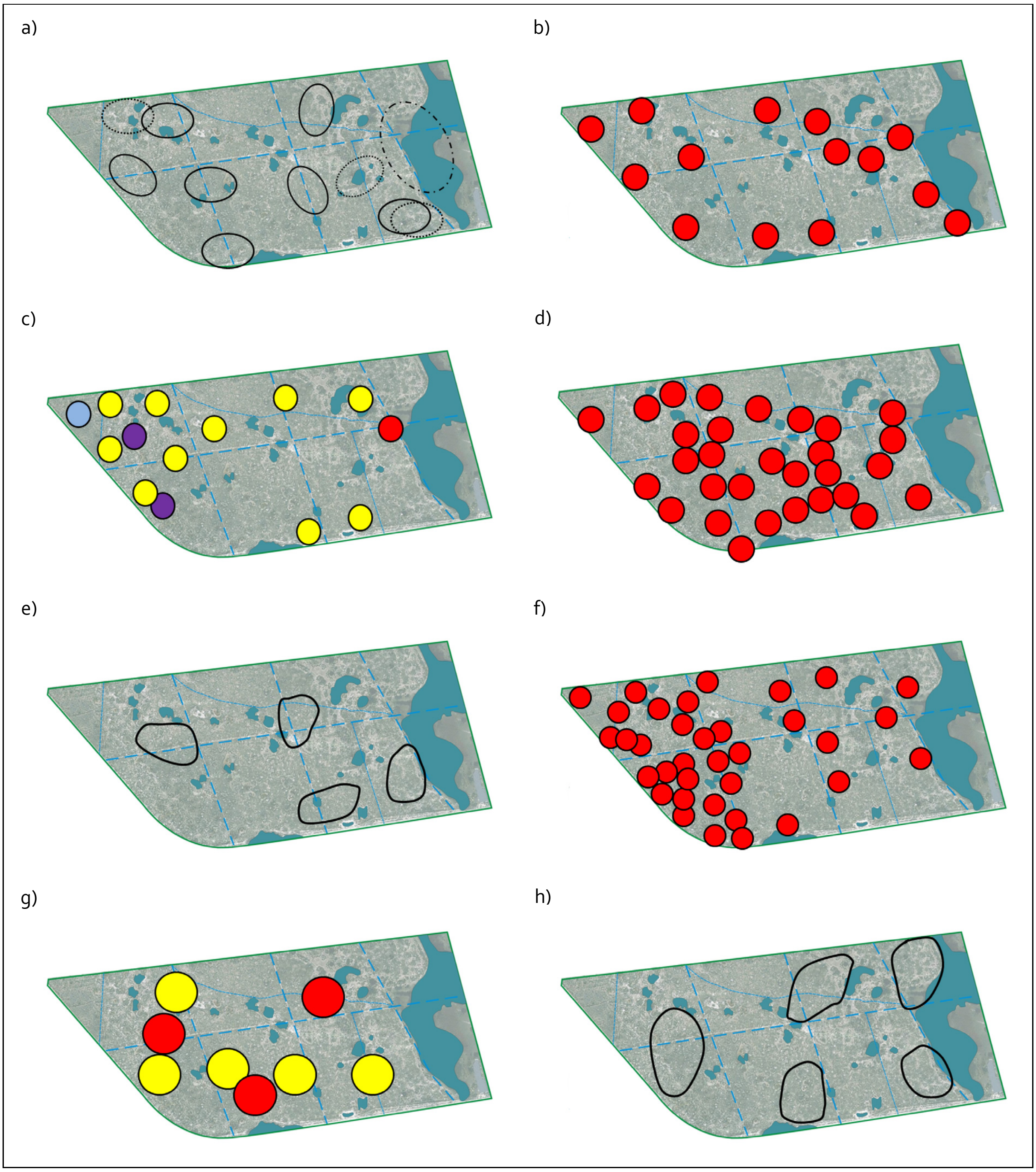

Figure 4: Distribution of breeding pairs/occupied territories of selected bird species in the Ogongo Game Park in 2012.
a) Common Ostrich (a reproductive group with male and 4 females; broken line), Helmeted Guineafowl (breeding groups, each one with 15-30 females; continuous line) and Spotted Thick-knee (occupied territories; dotted line);
b) Swainson's Spurfowl;
c) Lesser Honeyguide (red), Golden-tailed Woodpecker (purple), Black-collared Barbet (blue), and Acacia Pied Barbet (yellow);
d) Southern Red-billed Hornbill;
e) African Grey Hornbill;
f) African Hoopoe;
g) Cooperatively breeding Green Wood Hoopoe (red) and Common Scimitarbill (yellow);
h) Lilac-breasted Roller.

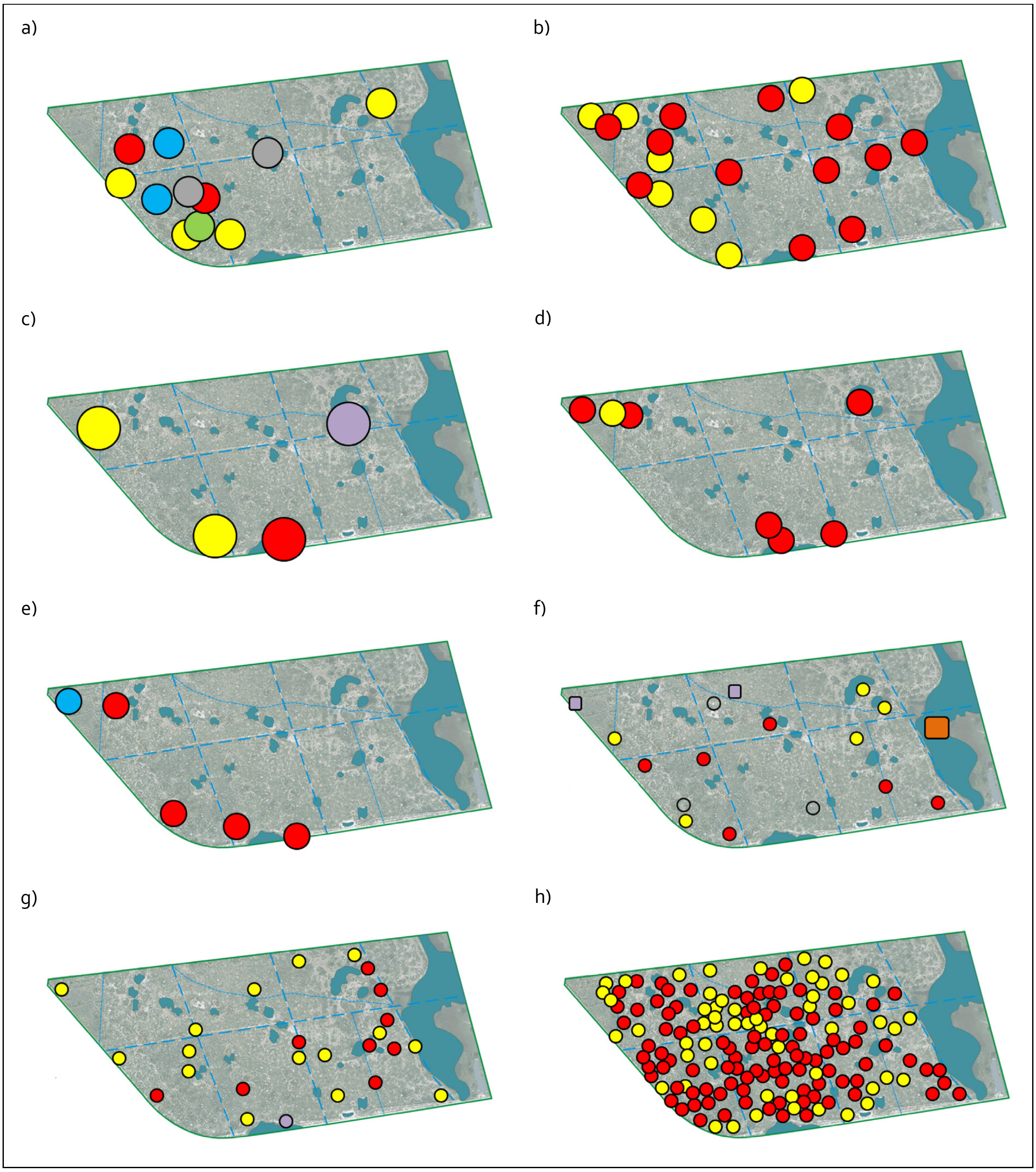

Figure 5: Distribution of breeding pairs/occupied territories of selected bird species in the Ogongo Game Park in 2012.

a) Little Bee-eater (yellow), Swallow-tailed Bee-eater (green), Woodland Kingfisher (blue), Pied Kingfisher (grey) and Purple Roller (red);

b) Grey Go-away-bird (yellow), and cooperatively breeding Red-faced Mousebird (red);

c) Diederik Cuckoo (red), Klaas's Cuckoo (purple), and African Cuckoo (yellow);

d) Rufous-cheeked Nightjar (yellow), and African Palm Swift (red);

e) Rosy-faced Lovebird (red), and Meyer's Parrot (blue);

f) Hamerkop (red – occupied nest, empty circle – unoccupied nest), Western Barn Owl (occupied nest - yellow), occupied territories of the Marsh Owl (orange), and Pearl-spotted Owlet (purple);

g) Laughing Dove (red – confirmed, yellow – not confirmed) and Mourning Collared Dove (purple);

h) Ring-necked Dove (red – confirmed, yellow – not confirmed).

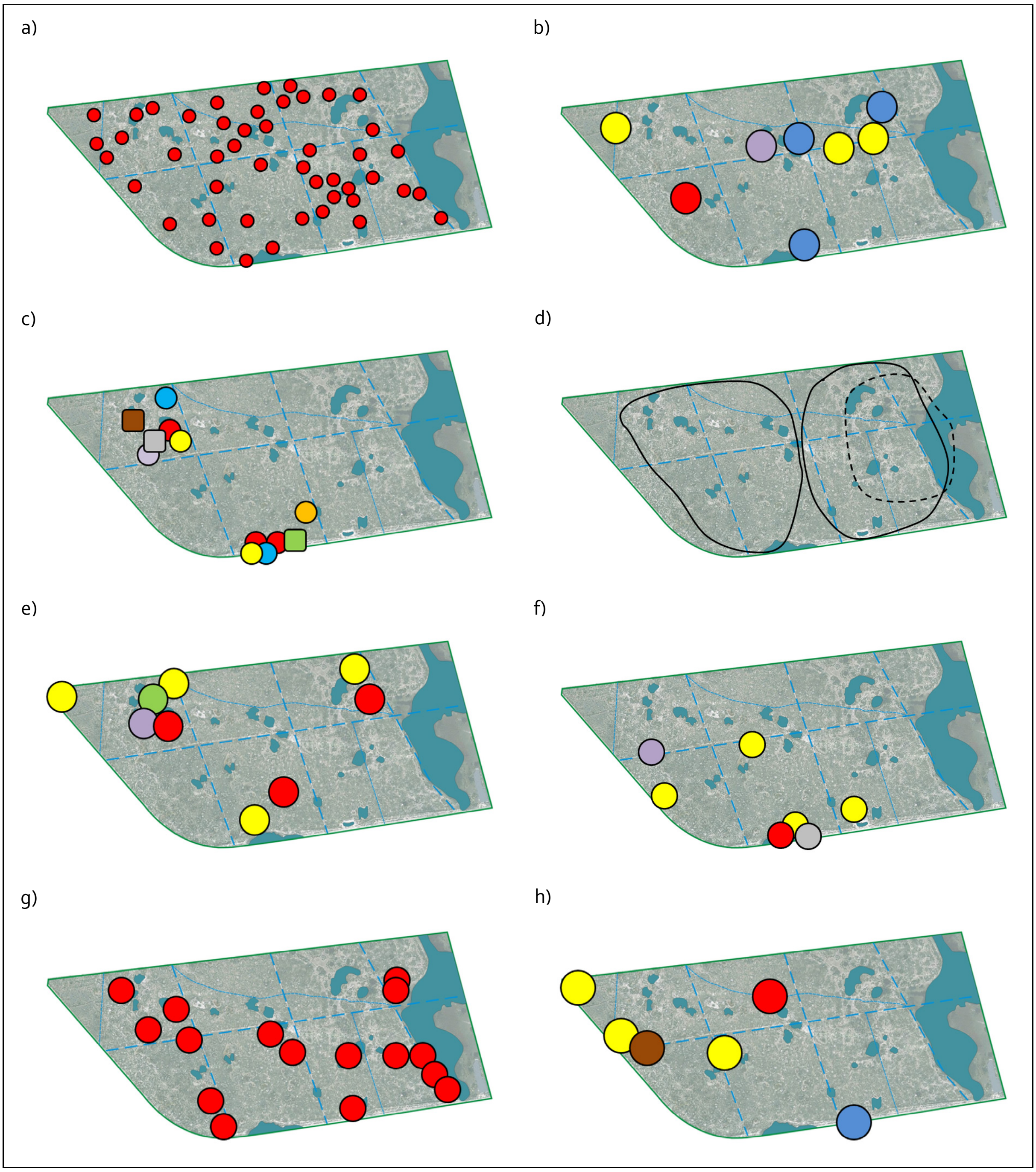

Figure 6: Distribution of breeding pairs/occupied territories of selected bird species in the Ogongo Game Park in 2012.
a) Namaqua Dove;
b) Red-crested Korhaan (red), Common Buttonquail (yellow), Pied Crow (blue), and Black Crow (purple).
c) Common Moorhen (red), Lesser Moorhen (orange), African Swamphen (yellow), Little Grebe (purple), Three-banded Plover (blue), African Snipe (grey), Southern Pochard (brown), and Pygmy Goose (green);
d) Bateleur (continuous line) and Brown Snake Eagle (broken line);
e) Yellow-billed Kite (yellow), Shikra (red), Little Sparrowhawk (purple), and Grey Kestrel (green);
f) Dwarf Bittern (yellow), Striated Heron (purple), Black-crowned Night Heron (grey), Purple Heron (red);
g) Blacksmith Lapwing;
h) African Golden Oriole (yellow), White-browed Scrub Robin (brown), Familiar Chat (blue), and Ashy Tit (red).

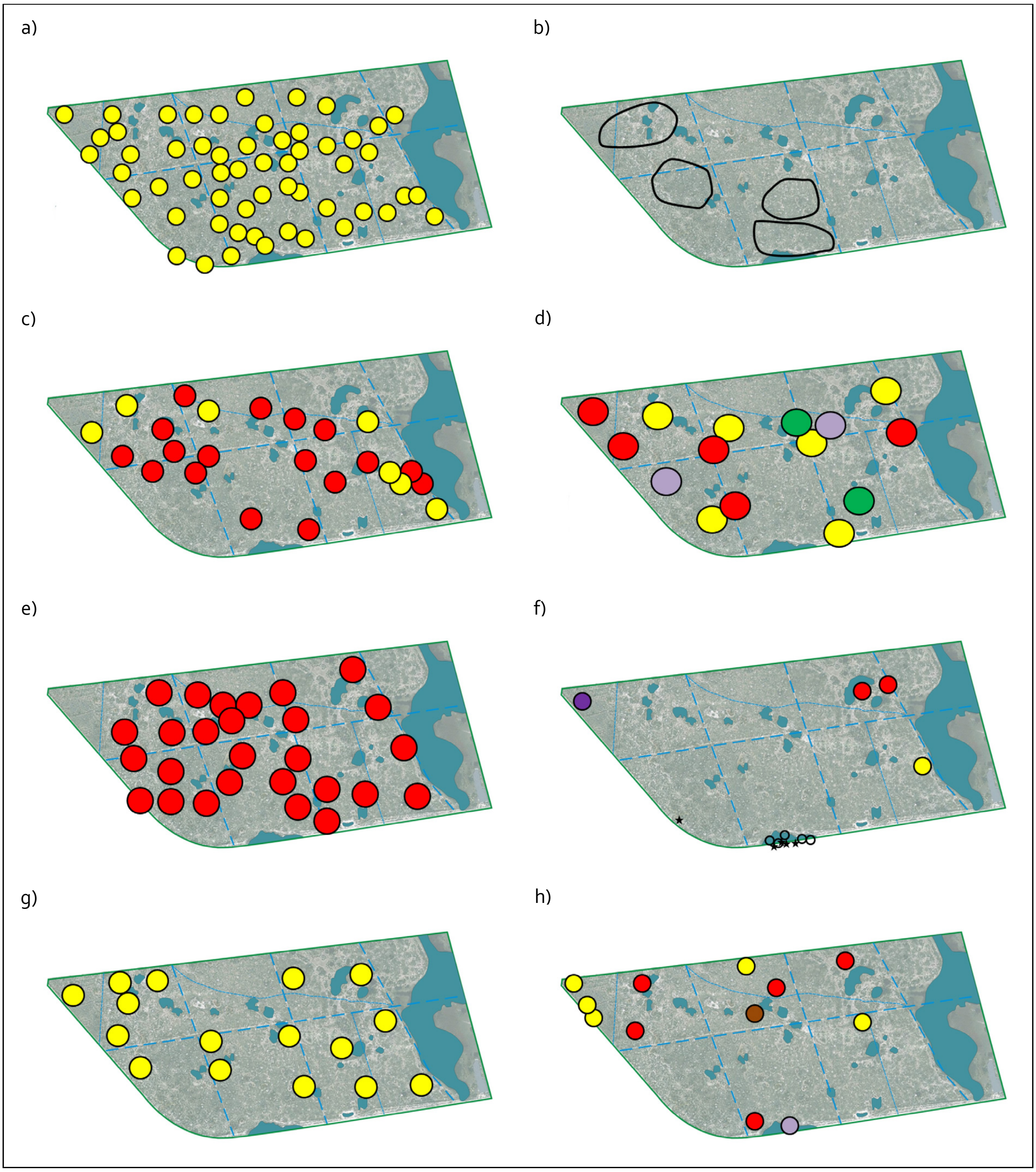

Figure 7: Distribution of breeding pairs/occupied territories of selected bird species in the Ogongo Game Park in 2012.
a) Fork-tailed Drongo;
b) Brubru;
c) Brown-crowned Tchagra (yellow), and Black-throated Canary (red);
d) Crimson-breasted Shrike (red), Southern White-crowned Shrike (purple), Black-backed Puffback (green) and cooperatively breeding White-crested Helmet-Shrike (yellow);
e) White-tailed Shrike;
f) Lesser Striped Swallow (circles), White-throated Swallow (asterisks), Rufous-naped Lark (red), African Pipit (yellow), and Chestnut-vented Warbler (purple);
g) Long-billed Crombec;
h) Lesser Swamp Warbler (purple), Ashy Flycatcher (brown), Quailfinch (red), and Southern Grey-headed Sparrow (yellow).

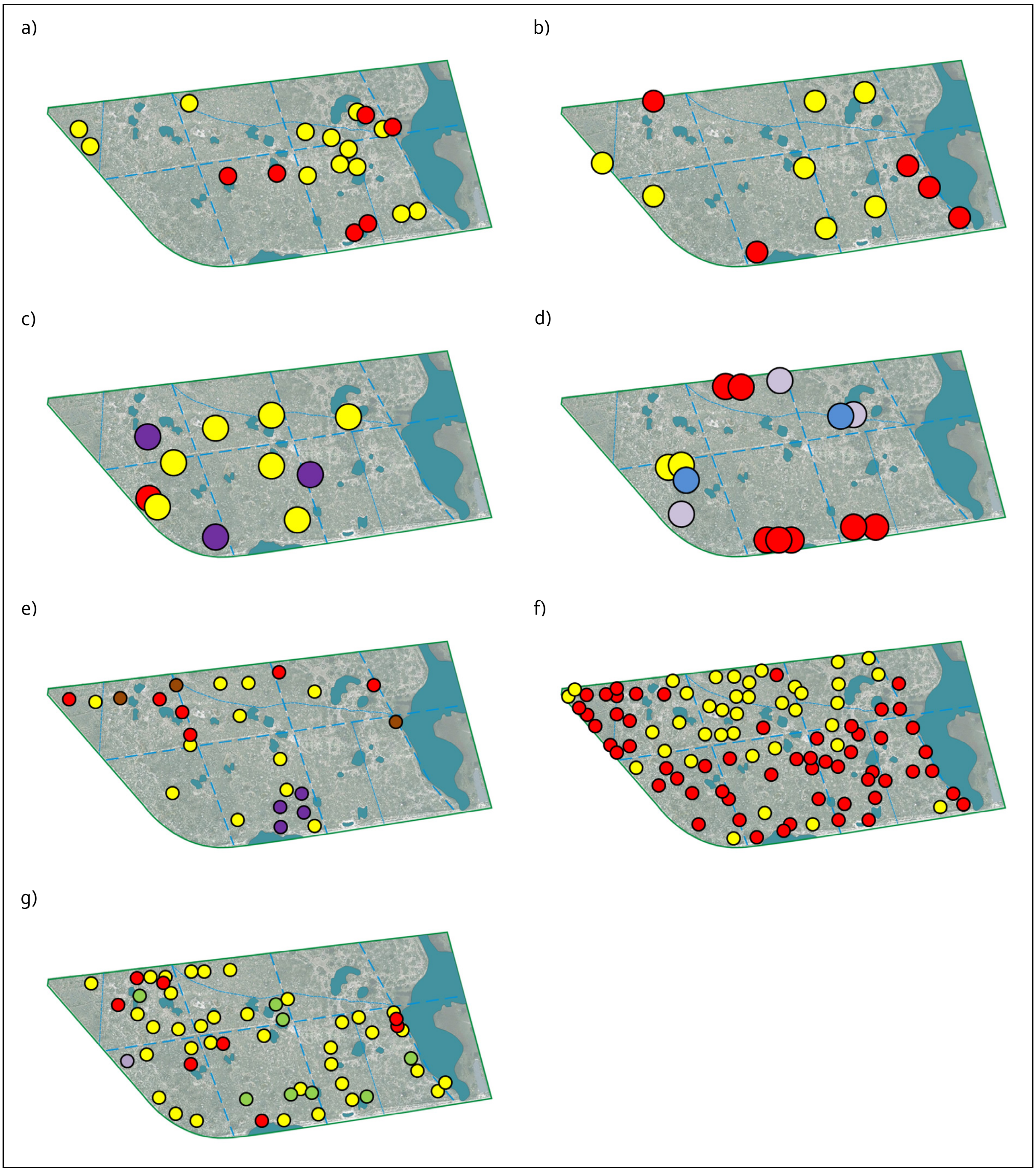

Figure 8: Distribution of breeding pairs/occupied territories of selected bird species in the Ogongo Game Park in 2012.
a) Rattling Cisticola (yellow), and Zitting Cisticola (red);
b) Black-chested Prinia (red – confirmed, yellow – not confirmed);
c) Yellow-billed Oxpecker (yellow), Cape Starling (red), and Violet-backed Starling (purple);
d) White-bellied Sunbird (blue), Scarlet-chested Sunbird (purple), Southern Red Bishop breeding groups (red), and Yellow-crowned Bishop (yellow);
e) Red-billed Firefinch (brown), Groundscraper Thrush (yellow), Golden-breasted Bunting (red) and Cinnamon-breasted Bunting (purple);
f) Blue Waxbill (red – confirmed, yellow – not confirmed);
g) White-browed Sparrow-Weaver breeding groups (yellow), Red-billed Buffalo-Weaver breeding groups (green), Red-headed Weaver (purple), and Southern Masked Weaver breeding groups (red).

Among species endemic to Namibia, the following were recorded in the OGP: White-tailed Shrike (as subdominant), and Rosy-faced Lovebird. Species especially important from a point of view of nature conservation included the Bateleur, Brown Snake Eagle, Grey Kestrel, Meyer's Parrot, Purple Roller, Pygmy Goose and Woodland Kingfisher. OGP also plays an important role as a refugium for such large terrestrial bird species as the Common Ostrich, Helmeted Guineafowl, Red-crested Korhaan and Spotted Thick-knee. Due to a heavy human pressure, these game species are rare in local areas outside OGP and are declining or locally extinct in the Cuvelai Drainage System.

OGP plays, therefore, an important role in the nature conservation of the Cuvelai Drainage System. This is the only protected area within this unique ecosystem (Mendelsohn *et al*. 2000, 2009; Mendelsohn & Weber 2011). It is, however, not a state protected area, and its conservation status is not legislated. OGP provides excellent opportunities to study the structure and function of the Cuvelai Drainage Ecosystem, as it is in relatively pristine state and is situated close to an institution of environmental higher education (Department of the Integrated Environmental Sciences of the University of Namibia). It is therefore highly recommended that the protected area be increased by inclusion of the larger oshana on the eastern border of this park and that its conservation status is legalised to safeguard it for future generations.

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How well do CHIRPS precipitation estimates relate to measured rainfall in Namibia?

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Abstract

Measured rainfall data from 33 ground-based rainfall stations were compared with rainfall estimates from CHIRPS (Climate Hazards Infrared Precipitation with Stations) across a rainfall gradient in central Namibia. There was close agreement between the two datasets across the interior of the country from the escarpment eastwards. However west of the escarpment the two datasets diverged. In this zone all CHIRPS estimates were higher than measured values and the seasonal variability of CHIRPS estimates declined towards the coast whereas measured rainfall variability rose. Quality assessments of CHIRPS in the literature have suggested there is a tendency for the model to overestimate the frequency of rainfall events, and to record low rainfall rather than zero rainfall in low rainfall areas. These effects may be exacerbated in Namibia by the prevalence of coastal fog. Increasing the number of reliable ground-based stations across the coastal zone may go some way to addressing the discrepancy in Namibia between CHIRPS estimates and ground measurements.

Keywords: CHIRPS, Namibia, rainfall, satellite data, weather station data

Introduction

Over recent decades several satellite-based rainfall datasets such as RFE2 (Estimated daily precipitation), ARC2 (Africa Rainfall Climatology) and TAMSAT (Tropical Applications of Meteorology using Satellite data) have been developed and utilised as tools for estimating rainfall. The accuracy of predictive gridded datasets has recently been improved with the introduction of methods which blend weather station data and satellite data, known as gauge-satellite approaches. One such dataset, designed to fill existing gaps in vector datasets by offering low output lag, high resolution, low bias and reasonable record length, is the CHIRPS (Climate Hazards Infrared Precipitation with Stations) dataset (Funk *et al.* 2015) which was developed to assist the Famine Early Warning Systems Network (FEWS NET). In the initial production of the CHIRPS dataset several validation case studies were undertaken in Columbia, Peru and south-western North America. Various assessments comparing the performance of several satellite-based products including CHIRPS have been published, for example Dinku *et al.* (2018) in East Africa, Toté *et al.* (2015) in Mozambique and Masauso (2018) in Namibia. Across the various products CHIRPS outperformed others in many scenarios and currently appears to be favoured for general applications. However, these studies also identified a performance decline with CHIRPS in certain regimes, particularly in coastal and lower rainfall areas. For example, in Peru Aybar *et al.* (2019) determined that CHIRPS severely overestimated precipitation on the Pacific coast leading to the development of a bespoke gridded dataset which incorporated a modification to CHIRPS in combination with two other gauge-based datasets. Assessments of CHIRPS' validity in other areas where weather processes are strongly influenced by a cold ocean system are limited, however.

The cold Benguela current has a strong impact on the weather regime in coastal parts of Namibia where fog and low cloud is a common occurrence, particularly in the central coastal area, and may extend as far east as the base of the escarpment (Andersen *et al.* 2019). The country is dry with an aridity index ranging from hyper-arid in the west to semi-arid in the north-east and with a coastal desert along its entire Atlantic Ocean border (Atlas of Namibia Team 2022). In general, Namibia's relief is characterised by a hyper-arid desert coastal plain (extending approximately 100 km inland), a narrow rocky escarpment zone and central ridge, followed by the interior plateau to the east (Atlas of Namibia Team 2022; Figure 1).

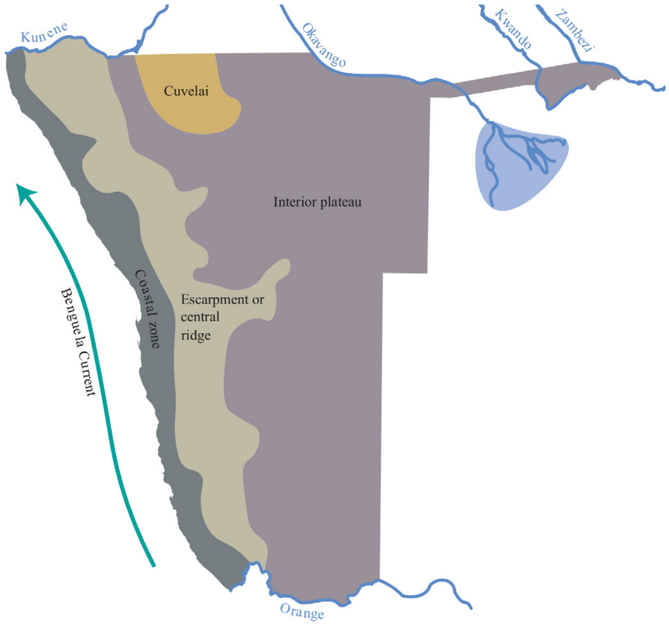

Figure 1: *Namibia's landform. Adapted from Atlas of Namibia Team (2022).*

Rainfall in Namibia is strongly seasonal with most rains falling between December and April. A complete rainfall season is commonly considered to extend from 1 July in one year to 30 June in the next. Average seasonal rainfall in Namibia is less than 100 mm in the western coastal parts increasing north-eastwards to over 600 mm in the Zambezi region (Mendelsohn *et al*. 2002; Figure 2).

This study focuses only on the performance of the CHIRPS dataset in an east-west continuum across the central rainfall gradient in Namibia, between the higher rainfall interior and the low rainfall coastal zone. I compare CHIRPS rainfall estimates with ground-based rainfall gauge measurements (hereafter referred to as stations) for 33 stations located between the west coast at Walvis Bay and around 475 kilometres inland to the east near the Botswana border. More specifically, I consider two questions: how do the measures and estimates of seasonal rainfall compare from east to west, and is variability within each dataset relatively constant along the gradient?

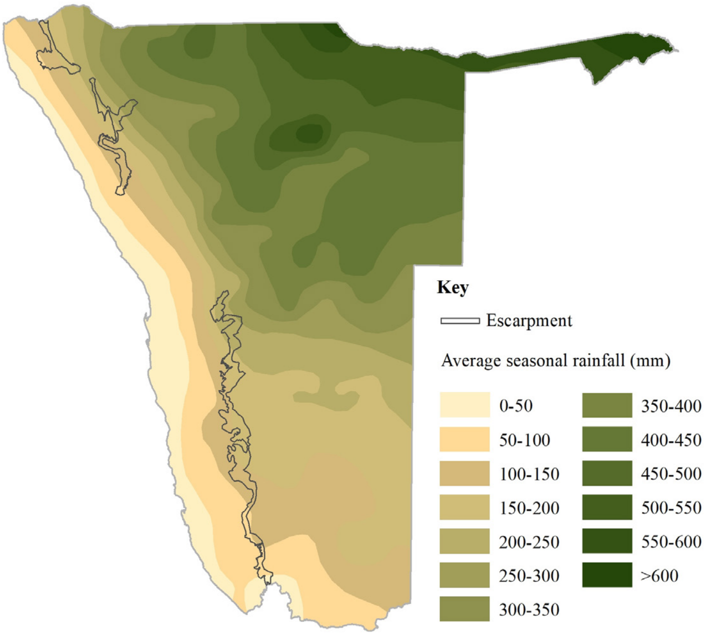

Figure 2: *Average seasonal rainfall (derived from kriging interpolation of station data) and the escarpment. Adapted from Mendelsohn* et al. *(2002).*

Methods

The CHIRPS dataset covers the period from 1981 to the present. This analysis covers the 40-year period from 1981-2020. Station data were available from the Namibia Meteorological Services (NMS) data and the SASSCAL (Southern Africa Science Service Centre for Climate Change and Adaptive Land Management) WeatherNet programme (http://www.sasscalweathernet.org). The number of complete annual rainfall seasons varied greatly across stations. The spatial distribution of stations is shown in Figure 3.

Most rainfall stations are located centrally and there are few within the coastal zone. Although stations introduced through the SASSCAL programme after 2010 fill some of the gaps in the central desert zone, data for most of these stations were limited to 8 seasons or fewer, and by several missing records for some months.

To assess the relationship between station records and CHIRPS estimates in an even spread across both the rainfall gradient and spatially across the country, a sample of representative stations was selected in a strip extending from the central coast around Swakopmund and Walvis Bay to 475 km inland. The shortest direct distance from each station to the nearest point of the coast was measured using a GIS.

Rainfall in Namibia is generally highly variable across seasons, both in terms of the amount of rain that falls and the timing of rainfall events, with approximately decadal cycles in seasonal rainfall peaks and troughs (Atlas of Namibia Team 2022). To capture the natural variation in seasonal rainfall only stations with more than 10 complete seasons were included in the selection. A season was considered complete if daily records were available for every day between July and

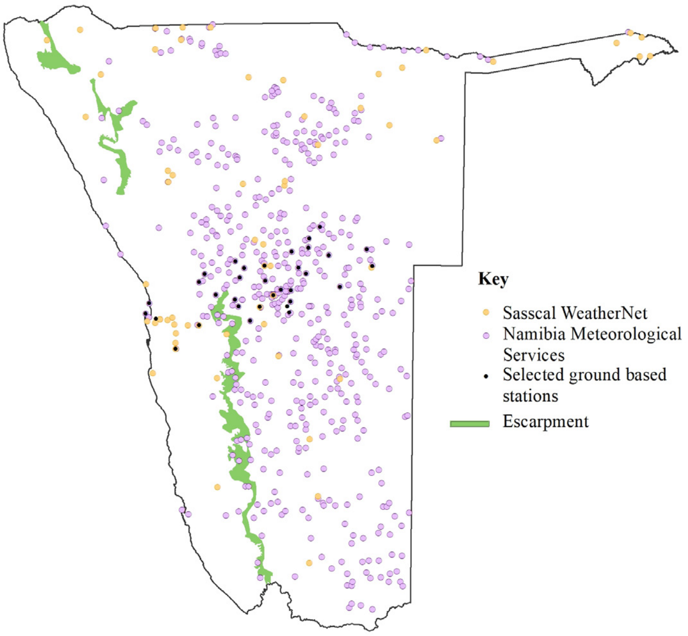

Figure 3: *Stations recording rainfall data in Namibia and rainfall stations selected for comparison of CHIRPS rainfall estimates and weather station rainfall data. From data supplied by Namibia Meteorological Services, Windhoek and http://www.sasscalweathernet.org.*

June. This provided a sample of 33 stations. Although over 80% of these stations had fewer than 30 seasons of complete data this was not considered a problem as the intention was not to compare *trends* between station data and CHIRPS but rather *value differences* for each season with complete data.

For each set of station seasons the corresponding CHIRPS estimates were extracted by grid cell using the zonal statistics tool in ARCGIS (ESRI 2013). The CHIRPS dataset provides estimates at 0.05° (approximately 5.5 km) grid resolution. The rainfall stations were ordered according to their distance from the coast and two simple analyses were performed:

1) Percentage difference between average station values and average CHIRPS values

$$\frac{\text{ABS (Average Station-Average CHIRPS)}}{\text{(Average Station+Average CHIRPS)/2}} \times 100$$

2) Coefficient of variation (COV) for both the rainfall station and CHIRPS values

$$\frac{\text{Standard Deviation Station}}{\text{Average Station}} \text{ x } 100 \quad \text{and} \quad \frac{\text{Standard Deviation CHIRPS}}{\text{Average CHIRPS}} \text{ x } 100$$

Results

A summary of statistical outputs is presented in Table 1. This includes the number of rainfall seasons, average seasonal rainfall (stations and CHIRPS), coefficient of variation (stations and CHIRPS) and the percentage difference between station and CHIRPS rainfall estimates.

CHIRPS estimates showed close agreement with measured station data between 140 and 475 km from the coast (Figure 4a). The most noteworthy contrast between the datasets however is evident between 140 km inland (the escarpment area) and the coast. Here CHIRPS estimates were consistently higher than measured rainfall, and between 50 km inland and the coast CHIRPS estimates steadily increased in contrast to the very low (and decreasing) rainfall station measurements. At the national scale, CHIRPS average rainfall patterns are very similar to station data east of the escarpment (compare Figure 2 with Figure 4b). However, west of the escarpment (excluding the Namib sand sea area) the 50-100 mm rainfall zone in the CHIRPS dataset extends further west than the same zone in the station data, and extends along the entire southern coastline. In parts of the Namib sand sea average rainfall estimates from CHIRPS are lower than those in the station dataset. The greatest contrast between the two datasets, however, is in the central coastal area and all along the northern coastline where CHIRPS average rainfall estimates increase near the coast and exceed 100 mm compared with rainfall averages of less than 50 mm in the dataset derived from station data.

The bias in CHIRPS rainfall estimates between the coast and the escarpment area is also illustrated in Figure 5 where a regression of CHIRPS estimates on station measurements, with a zero intercept, shows

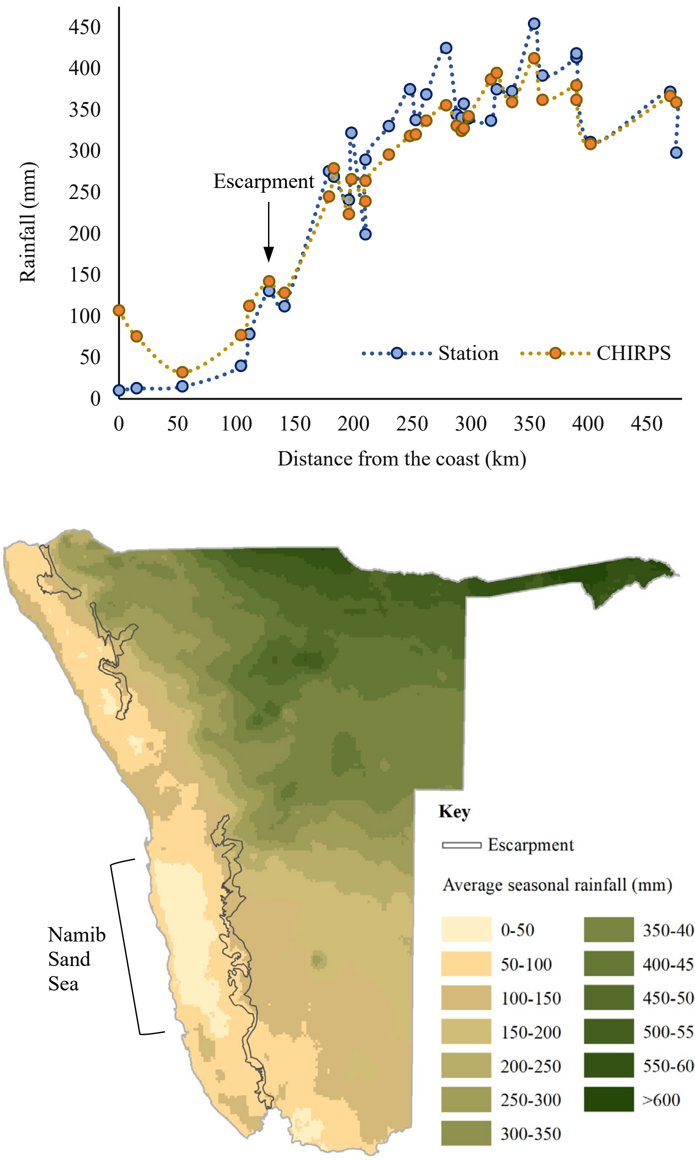

Figure 4: *a) Average seasonal rainfall with distance from the coast: measured rainfall versus CHIRPS estimates for 33 stations in Namibia (points) with smoothed trend lines (dotted lines); b) Average seasonal rainfall across Namibia from CHIRPS (1981-2020). Data downloaded from the FEWS NET data portal.*

Table 1: *Summary of average rainfall, coefficient of variation and percentage difference of average rainfall between measured rainfall and CHIRPS rainfall estimates for 33 stations in Namibia.*

Number	Rainfall station	Distance from coast (km)	Elevation (masl)	Rainfall seasons (n)*	Average rainfall recorded by rainfall station (mm)	Average rainfall recorded by CHIRPS (mm)	Percent difference of average rainfall	COV Station	COV CHIRPS	Latitude S	Longitude E
1	Pelican Point	0	< 10	17	6	67	166.3	160.6	7.0	-22.88	14.43
2	Swakopmund	0	< 10	19	14	147	164.4	115.9	11.6	-22.68	14.52
3	Walvis Bay Airport	15	93	15	13	75	142.7	145.6	20.5	-22.98	14.64
4	Gobabeb	54	407	28 (6)	15	32	73.8	104.9	21.2	-23.56	15.04
5	Ganab	104	1,000	13	40	77	63.6	48.9	13.3	-23.12	15.54
6	Dorstrivier	111	1,044	11	78	101	25.0	75.2	19.1	-22.30	15.57
7	Abbabis Ost	128	1,196	17	130	142	44.7	58.2	33.2	-22.65	16.45
8	Kaltenhausen	140	1,044	14	112	128	44.8	50.1	26.4	-22.55	15.90
9	Abochaibis	179	1,313	18	275	245	11.7	45.0	30.4	-22.65	16.30
10	Terra Rossa	183	1,677	27	269	279	3.7	39.9	28.9	-22.78	16.37
11	Westefallenhof	196	1,232	19	241	223	7.4	49.3	40.4	-22.23	16.40
12	Wilhelmstal	198	1,342	25	322	266	19.2	35.4	33.8	-21.92	16.32
13	Mahonda	210	1,824	14	199	239	18.3	37.8	19.9	-23.05	16.62
14	Erora Ost	210	1,331	18	289	264	9.2	43.6	25.2	-22.05	16.50
15	Claratal	230	1,933	35 (10)	330	295	11.1	36.6	32.2	-22.79	16.81
16	Otjiseva	248	1,401	35	375	318	8.6	45.3	33.9	-22.30	16.93
17	Okahandja	253	1,325	28	328	310	5.8	30.3	27.4	-22.01	16.92
18	Windhoek	262	1,735	39 (4)	368	337	9.0	49.8	34.3	-22.57	17.10
19	Bergvlug	279	2,017	30	425	355	17.8	38.2	33.0	-22.47	17.25
20	Binsenheim	288	1,751	31	344	330	4.1	46.5	34.3	-22.78	17.38
21	Rietfontein-Khomas	292	1,833	19	340	324	4.8	33.6	23.2	-22.90	17.42
22	Hohenau	294	1,789	18	357	327	8.7	37.8	25.6	-22.70	17.45
23	Hosea Kutako Airport	298	1,705	29	339	342	0.8	37.7	27.3	-22.48	17.47
24	Vooruitgang	317	1,609	12	337	387	13.8	33.2	17.4	-21.75	17.48
25	Otjikundua	322	1,765	21	375	395	5.2	28.8	30.8	-22.05	17.62
26	Okahua	335	1,652	29	372	359	3.6	37.5	28.6	-22.17	17.78
27	Ondunduwazarapi	354	1,654	31	454	412	9.6	39.4	28.8	-21.67	17.83
28	Hochveld	361	1,567	17	391	362	7.9	33.2	26.3	-21.48	17.87
29	Steinhausen	390	1,652	20	413	379	8.6	41.1	28.6	-21.82	18.25
30	Kalidona	390	1,522	27	364	331	9.4	31.8	20.5	-21.28	18.07
31	Witvlei	402	1,460	21	311	308	0.7	53.6	28.6	-22.42	18.48
32	Du Plessis	470	1,504	11	372	367	1.3	42.0	26.3	-21.70	19.03
33	Sandveld	475	1,521	16 (7)	298	359	18.6	47.4	29.7	-22.02	19.15

** Numbers in brackets indicate the number of rainfall seasons out of the total that were obtained from SASSCAL stations. All other season totals are from Namibia Meteorological Services.*

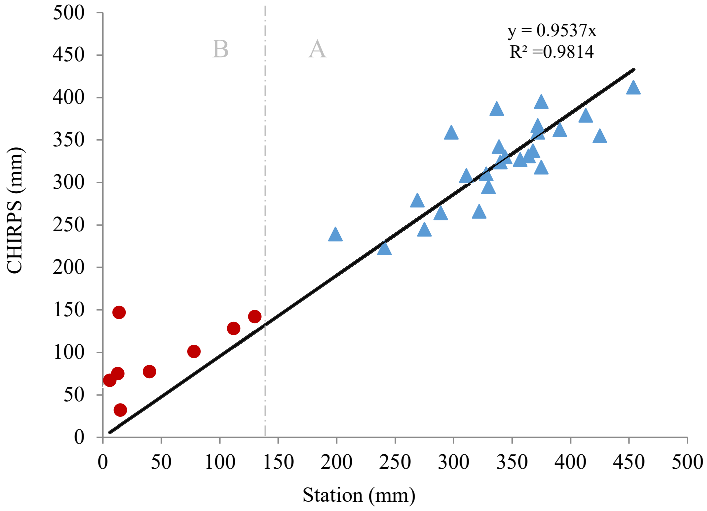

Figure 5: *Regression of average annual seasonal rainfall (CHIRPS) on measured rainfall for 33 stations in Namibia. Blue triangles indicate stations in zone A between 140 and 475 km from the coast. Red circles are stations in zone B between 0 and 140 km from the coast.*

that estimates from approximately 140 km inland to the furthest station east (475 km from the coast; hereafter referred to as zone A) are relatively evenly scattered above and below the line. By contrast, all 8 estimates west of 140 km inland (i.e. between 140 and 0 km from the coast, and referred to as zone B) were above the predicted line.

Expressing the difference between measured average seasonal rainfall and CHIRPS average estimates as a percentage may exaggerate the trend because regardless of which dataset is used average seasonal rainfall totals in the coastal zone are very low. However, what is apparent is the increasing divergence between the CHIRPS estimates and measured rainfall towards the coast (Figure 6a). In zone A, the difference between measured average seasonal rainfall and CHIRPS average estimates was less than 20%. However, in zone B, the percentage difference between the two values increased towards the coast to greater than 160%. At the national scale, the divergence of average rainfall estimates west of the escarpment between the two datasets results in a much higher percentage difference in this part of the country than elsewhere. The high values in the coastal zone in the southern part of the country arise from the fact that CHIRPS estimates in the eastern half of the sand sea are lower than station rainfall averages. Here (and in northern coastal parts of the country) both datasets are compromised by a lack of ground-based gauges (see Figure 3), referred to later in the Discussion.

Overall, there was a negative correlation between measured rainfall variability and distance from the coast ($r = -0.7$, $r^2 = 0.48$) but a weak positive correlation between rainfall variability and distance for CHIRPS rainfall estimates ($r = 0.51$, $r^2 = 0.26$).

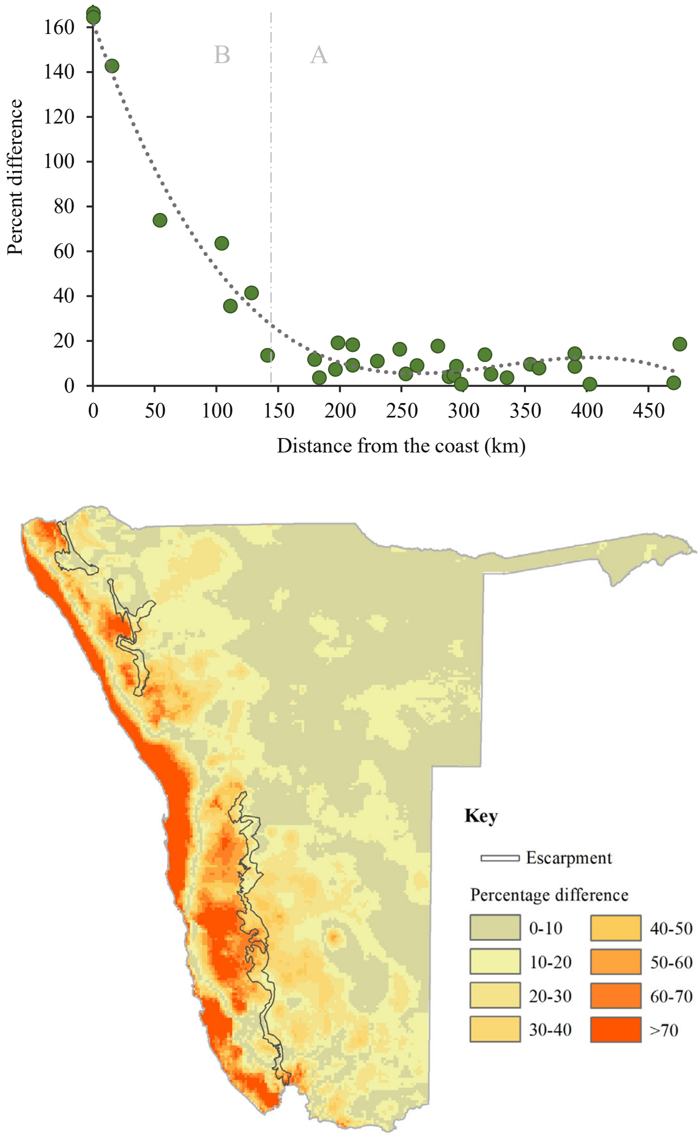

Figure 6: *a) Percent difference between weather station average seasonal rainfall values and CHIRPS average seasonal rainfall estimates for 33 stations in Namibia (points) with a polynomial trend line (dotted line); b) . Percent difference between weather station average seasonal rainfall values (Figure 2) and CHIRPS average seasonal rainfall estimates (Figure 4b) across Namibia.*

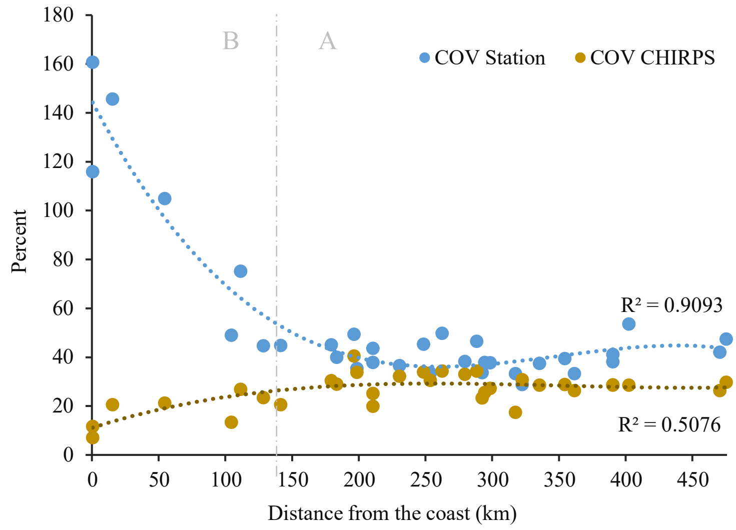

Figure 7: *Coefficient of variation for station rainfall measurements (blue circles) versus CHIRPS rainfall estimates (gold circles) for 33 stations in Namibia with a polynomial trend line fitted to each.*

In zone A (Figure 7) rainfall variability was fairly moderate, with the COV for stations falling within a range of 29-54% while CHIRPS values were lower and within the range of 17-40%. In zone B (Figure 7) the percentage COV values diverged markedly between the two datasets. Variability of rainfall for station measurements showed a continual increase rising from 45% to 160%. In contrast, variability in CHIRPS estimates showed a gradual decrease from around 20% to 10% with increasing proximity to the coast.

Discussion

The results found here mirror those found elsewhere in an area adjacent to a cold ocean (Aybar *et al*. 2019) and in eastern Africa and Mozambique. Toté *et al*. (2015) in their multi-product comparison, found that the relationship between CHIRPS and measured values was best in the higher rainfall central areas of Mozambique, but performance declined with proximity to the coast due to an overestimation of the frequency of rainfall events. Masauso (2018) found similar performance patterns comparing CHIRPS with other products, from a three-rainfall year analysis in Namibia.

In eastern Africa Dinku *et al*. (2018) found that in low rainfall locations the overestimation of rainfall area resulted in low CHIRPS rainfall estimates where ground-based products recorded zero rainfall. This was identified as the 'drizzle' effect. In the derivation of CHIRPS estimates, merging of ground-based data with satellite-based estimates is done at the pentad (5-day) time scale. Monthly values are derived from the sum of pentads while daily values are derived from partitioning the pentad values according to cold cloud duration (which discriminates between rain and no-rain events) (Dinku *et al*. 2018). Consequently, CHIRPS daily estimates tend to be much better aligned with actual rainfall events. However, monthly (and annual) rainfall total estimates remain inflated in low rainfall areas. In a simple test I chose an arbitrary rainfall season for Gobabeb (situated about 50 kilometers from the coast) and compared CHIRPS pentad estimates with rain gauge records. Very low rainfall estimates were recorded in the vast majority of pentads when there were only a handful of actual rainfall events recorded at Gobabeb in that season. This has the effect of moderating differences between seasonal estimates, resulting in reduced variability.

Precipitation - by definition - excludes fog because this is moisture that remains in the air. No mention is made directly of the influence of fog in the CHIRPS analysis. However, Dinku *et al*. (2018) suggest that 'satellites could overestimate rainfall over desert areas owing to sub-cloud evaporation'. In other words, estimates close to the coast might also be inflated as a result of satellite measurements that include moisture in the air that does not reach the ground. Fog and low cloud occur frequently in Namibia's coastal zone extending as far east as the escarpment, the distance at which we start to see a divergence between the two datasets (Figure 8). Fog also occurs more frequently nearer the coast, and this might explain to some degree the decline in variability and the rise in CHIRPS rainfall estimates from 50 km inland to the coast. Compare average seasonal rainfall in the coastal zone from CHIRPS estimates (Figure 4b) with ground-based measurements in the same area (Figure 2).

How does the divergence between measured rainfall and CHIRPS rainfall estimates near the coast influence the integrity of CHIRPS data as a proxy for rainfall? The two maps of coefficient of variation presented in Figure 9 demonstrate the contrast in the way that rainfall patterns might be interpreted, depending on the dataset used. Seasonal variability from measured rainfall (derived from around 300 stations indicated in Figure 3) shows highest variability in the coastal zone and southern interior (Figure 9a) in contrast to CHIRPS which suggests the escarpment zone has the highest rainfall variability with the lowest variability along the coast and to the south (Figure 9b). It is important to note that both analyses are to some extent compromised by the paucity of coastal rainfall stations. As CHIRPS is a blended dataset, the dearth of coastal stations limits the extent to which measured records can moderate the satellite-based estimates in this part of the country.

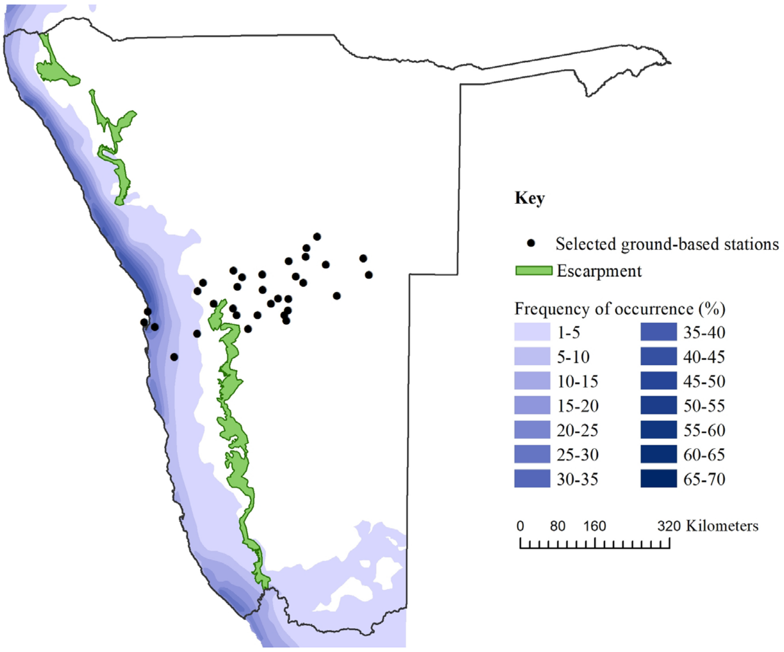

Figure 8: *The frequency of occurrence of fog and low cloud from 96 daily satellite scans in Namibia (between 2004 and 2017) in the context of the 33 selected ground-based weather stations used in this study. Data on fog from Andersen* et al. *(2019).*

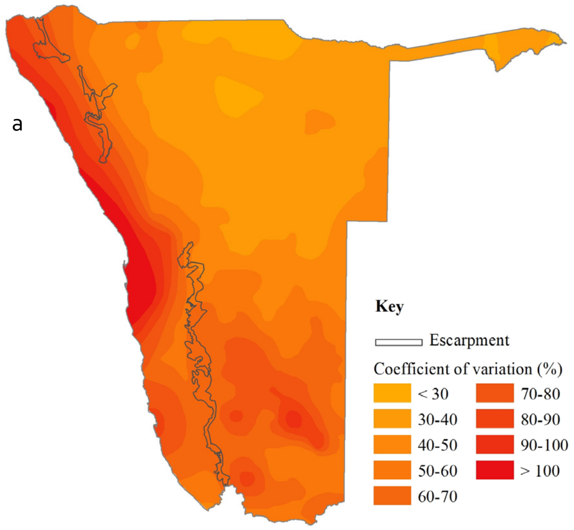

Figure 9*. Coefficient of variation interpolation from a) approximately 300 rainfall stations throughout Namibia, from Namibia Resource Consultants (1999) and b) CHIRPS rainfall estimates (1981-2020) downloaded from the FEWS NET data portal.*

Dinku et al. (2018) suggest that the future CHIRPS algorithm may incorporate a two-stage process at the blending stage, where initially, a rainfall probability factor is applied prior to any rainfall intensity adjustments. However, this would require the availability of an adequate selection of ground station records.

The consistent and increasing difference between the two datasets for all eight stations in zone B (Figures 5, 6 and 7) suggests that the divergence between the two datasets is not the consequence of a few aberrant ground stations. The results shown here, in combination with similar findings from other studies, point to the lack of suitability of the current CHIRPS dataset on its own for any rainfall-associated analyses west of the escarpment. Some effort should be put into addressing the paucity of ground-based station gauges in the coastal zone. This would allow for more accurate spatial analyses to be made of measured rainfall variability in the western parts of the country in addition to providing a means for future versions of the CHIRPS dataset and other blended satellite-based datasets to be more calibrated and aligned with measured rainfall.

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Red-backed Shrike (*Lanius collurio)* Linnaeus, 1758 on its non-breeding grounds: comparative biometrics, moult data and criteria to determine age and sex

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CONTENTS

ABSTRACT

Much is still unknown or unpublished in the Afrotropical literature concerning the complexity of the plumage features of the Red-backed Shrike (*Lanius collurio*). We present measurements, moult data and related observations for about 300 Red-backed Shrikes collected while ringing them in their non-breeding range in southern Africa. We discuss our findings on timing and progress of primary moult in adults and birds in their first year of life. We describe in detail plumage features for the determination of age and sex, and discuss colour and plumage variations in both sexes, especially females, and the occurrence of white wing patches in males. We give photographic evidence of the change of the bill colour during the non-breeding season and add notes on age and sex ratio, retraps and site fidelity. We also discuss the long-standing claims of Red-backed Shrike breeding in the southern hemisphere. Our field excursions between 2002 and 2022 were based mainly in Namibia during the Austral summer months, from November to April. We have included supplementary records of this species from Botswana and Zambia.

Keywords: Africa; age; breeding in wintering grounds; *Laniinae;* moult; Namibia; non-breeding; plumage; sex; Spiegel; white wing patch

1. INTRODUCTION

Much is still unknown or unpublished in the Afrotropical literature concerning the complexity of the plumage features of the Red-backed Shrike (*Lanius collurio*). These unknowns concern mainly plumage development from nestling to adult, variation in the colouration in young birds and adult females, and criteria to better distinguish between young and females (Figure 1).

Between 2002 and 2022 we undertook field excursions to southern Africa during the summer months from November to April. We present measurement and moult data from 102 adult and 197 first-year Red-backed Shrikes that we ringed in their non-breeding range.

2. SITES

Our data were collected in Namibia: in tree-and-shrub savanna on cattle farms (Farm Okatjerute near Witvlei and Farm Hamakari south of the Namibian Waterberg; Figure 2), in the Erongo Mountains and in the arid Nama Karoo on the eastern edge of the Namib-Naukluft Park (at Farm Sphinxblick). We also include records from Botswana and Zambia.

2.1 Distribution and sites

The Red-backed Shrike is a migratory species with a huge breeding range across Europe and into north-west Asia. The whole population spends the non-breeding season in southern and eastern Africa (Figure 3). For a detailed map of recorded sightings in the non-breeding grounds see the map of the Southern African Bird Atlas Project (https://sabap2.birdmap.africa/species/708).

Red-backed Shrikes were ringed in Namibia, Botswana and Zambia: in **Namibia**, on the farms Sphinxblick (22°29'S, 15°27'E), Hamakari (20°36'S, 17°20'E) and Okatjerute (22°21'S, 18°31'E), near Otavi 19°37'S, 17°11'E), in the Erongo mountains (21°29'S, 15°52'E), in Omaruru (21°20'S, 16°04'E) and at Spitzkoppe (21°50'S, 15°09'E); in **Botswana** in Maun (19°59'S, 23°25'E), Gaborone (24°40'S, 25°50'E) and at Lake Ngami (20°26'S, 22°49'E); in **Zambia** in Mutinondo (12°27'S, 31°17'E), the Mwinilunga district (11°19'S, 25°06'E) and in Choma (16°39'S, 27°04'E).

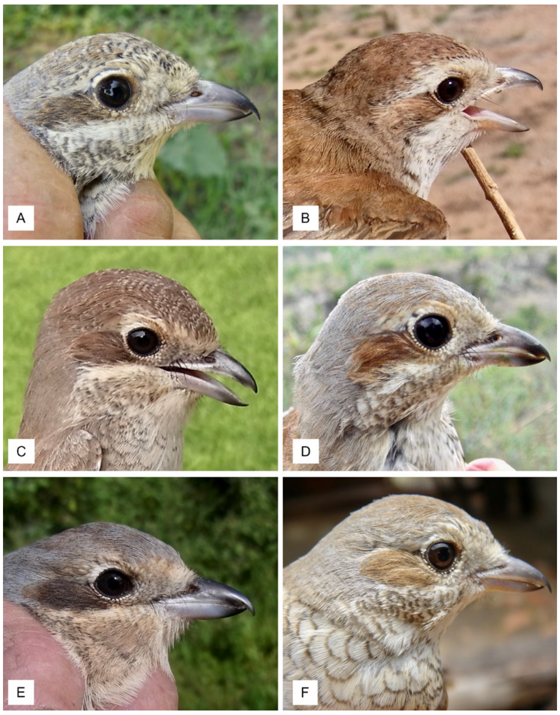


Figure 1: *The enormous variation of adult female Red-backed Shrikes ringed in southern Africa which presumably indicates provenience over a wide range. Observe the diversity of markings and colouration on top of the head, the throat, ear coverts and the supercilium. (A): Botswana, 28 January 2015; (B): Farm Sphinxblick, Erongo region, 6 January 2011;(C): near Witvlei, 30 March 2015; (D): Botswana, 1 December 2007; (E): near Witvlei, 28 March 2014; (F): Waterberg, Namibia, 15 January 2006.*

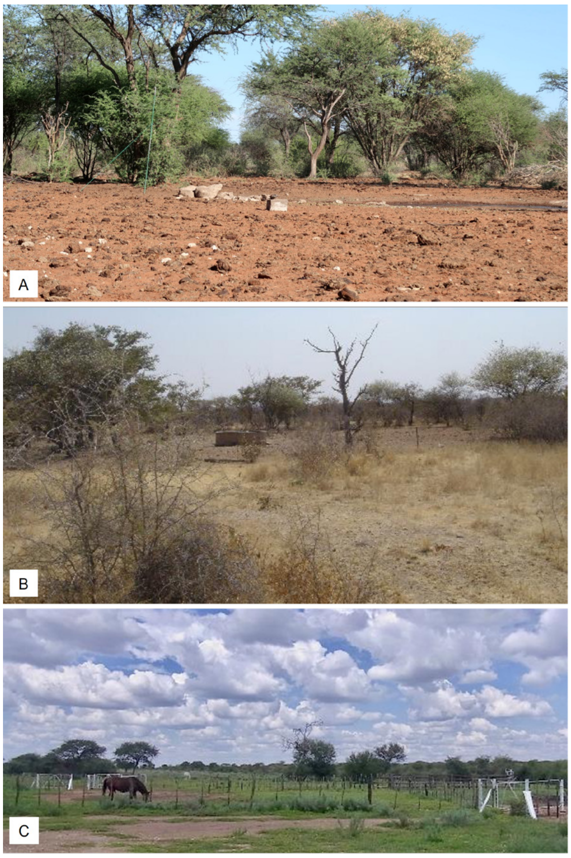


Figure 2: *Typical habitat of Red-backed Shrikes on farmland in the Acacia savanna of Namibia. (A, B) before rains, November 2016; (C) after rains, April 2015.*

3. METHODS

3.1 Bird ringing

Birds were ringed, and measurements and moult scores were taken in accordance with the guidelines of the South African Bird Ringing Unit's (SAFRING) Bird Ringing Manual (de Beer *et al.* 2001, based on Svensson 1984). Sex was determined by plumage, following the phenotypical characteristics described in the common and specialised European literature (i.e. Blasco-Zumeta & Heinze 2019; Bub 1981; Cramp & Perrins 1993; Harris & Franklin 2000; Shirihai & Svensson 2018; Yosef 2008; Yosef *et al.* 2019). All pictures were taken by the authors and in Namibia if not noted otherwise. See photographs of the locations in Bryson & Paijmans (2021, 2022).

3.2 Determination of age

The age description terminology is still not standardised, but differs across Africa and also widely between the continents (Schulze-Hagen 2019). We followed mainly Harris & Franklin (2000, pp. 50-51), Jenni & Winkler (2020b), Shirihai & Svensson (2018, p. 17).

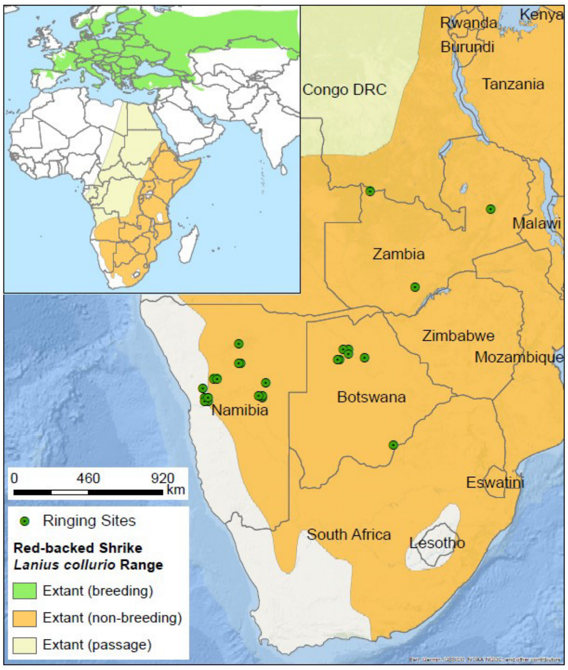


Figure 3: *Distribution map for the Red-backed Shrike, downloaded from www.iucnredlist.org on 18 May 2019. Green dots designate sites where data were gathered in the current study.*

We want to point out especially that the use of the term "juvenile", which is used in a wider sense for any kind of young bird, creates much confusion when a precise and differentiated determination of age is required. We used the term "juvenile" in a restricted sense. It describes a bird in its first year and until its post-juvenile moult, which sets in at 3-4 weeks, latest at three months, and ends at about four to six months if not interrupted by migration (Heinroth & Heinroth 1924-1926, cited in Cramp & Perrins 1993 p. 476). After the post-juvenile moult a bird will, in the restricted sense, show an immature plumage.

Age was determined by the pattern of the feathers and confirmed by abrasion and quality of the feathers and the colouration, shape and wear of the beak. Since the exact age of a young bird cannot be defined precisely, as a convention, the SAFRING age code 5 is usually applied by experienced ringers for migratory birds up to 31st December, and the SAFRING code 6 for birds after the 1st of January of the year after hatching. This is to take into account the growing maturity of the birds. (For SAFRING codes see de Beer *et al.* 2001).

3.3 Measurements

Table 1 presents our measurements of Red-backed Shrikes. The culmen was measured to the indentation on the front of the skull following the convention for the measuring of passerines (Demongin 2016, p. IX). For the general description of methods and measurements see Bryson & Paijmans (2021, 2022).

Table 1: *Average adult and first-year body measurements (incl. standard deviation, minimum and maximum measurements) of Red-backed Shrikes. Measurements are grouped by age, sex of adult birds and country. Sample sizes are shown in parentheses. We followed the convention of marking young individuals in the first calendar year with SAFRING Code 5, and in the second calendar year until the first northern migration with SAFRING Code 6, which enables us, with some uncertainty, to determine the age more precisely.*

Grouping	**Parameter**	**Wing (mm)**	**Tail (mm)**	**Tarsus (mm)**	**Culmen (mm)**	**Head (mm)**	**Mass (g)**
Adults SAFRING Code Age 4	Mean ± SD	91.8 ± 3.7	77.7 ± 3.4	23.9 ± 1.0	19.9 ± 1.0	38.7 ± 1.2	27.4 ± 2.3
	Min-max	80-104	70-93	21.6-27.2	16.2-22.2	31.7-40.8	19.7-37
	n	102	96	95	96	97	100
Adult Females	Mean ± SD	91.6 ± 2.6	77.2 ± 3.8	23.7 ± 1	19.9 ± 0.9	38.4 ± 1.5	27.1 ± 2.2
	Min-max	80-96	72-93	21.6-27	17.5-22	31.7-40.2	19.7-30.8
	n	41	39	38	39	39	39
Adult Males	Mean ± SD	92 ± 4.2	78.1 ± 3.1	24 ± 0.9	20 ± 1	38.8 ± 1	27.5 ± 2.4
	Min-max	82-104	70-92	22-27.2	16.2-22.2	34.1-40.8	23.4-37
	n	61	57	57	57	58	61
0-6 months SAFRING Code Age 5	Mean ± SD	91.4 ± 2.4	76.6 ± 3	23.5 ± 0.7	19.3 ± 2.4	38.6 ± 1.7	27.3 ± 2.7
	Min-max	86-97	71-87	21.9-25.2	16-28.6	36.7-48.2	22.7-36
	n	47	44	42	44	44	45
7-12 months SAFRING Code Age 6	Mean ± SD	91.5 ± 2.9	76.9 ± 3.3	23.7 ± 0.8	20.2 ± 1.4	38.7 ± 1.5	28.2 ± 3
	Min-max	82-101	69-88	20.6-25.3	16.4-29.8	29.2-41.3	21.5-39.7
	n	150	133	137	137	137	149
Namibian Adults only	Mean ± SD	92.4 ± 3.6	77.9 ± 3.7	23.9 ± 1	20.1 ± 0.9	38.8 ± 1	27.5 ± 2.5
	Min-max	80-104	70-93	21.6-27.2	16.2-22.2	34.1-40.8	19.7-37
	n	70	66	63	64	65	69
Botswanan Adults only	Mean ± SD	90.3 ± 3.6	77.3 ± 3	24 ± 1.1	19.6 ± 1.1	38.4 ± 1.6	26.8 ± 1.8
	Min-max	82-100	70-82	22-27	16.7-22.2	31.7-40	24.8-32.2
	n	29	27	29	29	29	28

4. TAXONOMY

Since the first descriptions by Linnaeus in 1758, several subspecies have been described, including *L. c. kobylini* (Buturlin), 1906 and *L. c. pallidifrons* Johansen, 1952 (1944) (Clancey 1973; Cramp & Perrins 1993; p. 459–460; Herremans 2005). In the empirical literature the species is considered to be monotypic (del Hoyo & Collar 2016; p. 340; Shirihai & Svensson 2018, p. 187) as proposed earlier by Stepanjan, 1978 (cit. in Cramp & Perrins 1993, p. 477).

This taxonomy was controversial (Yosef *et al.* 2019) until recent whole-genome sequencing. The result revealed "two major groups, with no clear geographical separation" (Pârâu *et al.* 2019, p. 1) and in a more recent study (Pârâu *et al.* 2022) the results showed genetic variability, but no indication of a "genetic structure in the Red-backed Shrike, suggesting a panmictic population. Panmixia is the genetic legacy of the widespread and continuous distribution of the species, high locomotion capacities, and, most importantly, the numerous ice ages from the past few million years, which forced various populations to retract to refugia and expand their ranges several times, and to interbreed both in the glacial refugia and during warm periods in Eurasia" (ibid. p. 1). These findings could explain the high variability of the phenotype in this species.

5. BREEDING

Breeding takes place in the northern hemisphere. Eggs are laid mainly from May to July, with a few records for August (Bub 1981, p. 105). The young fledge about 29 days after egg-laying, following 13-15 days incubation and a nestling period of 14-15 days, with a considerable variation for longer and shorter periods, and are independent about 14-35 days after hatching (Cramp & Perrins 1993). Birds in their first calendar year are under six months old when they arrive in southern Africa.

6. PLUMAGES AND MOULT

6.1 Plumages of the Red-backed Shrike

The exact number of distinguishable plumages of the Red-backed Shrike is still being discussed in the literature. Well researched and described are a first juvenile plumage, a post-juvenile plumage and an adult plumage. There is, though, a second (and possibly a third) growth phase of juvenile plumage, distinctly different in colour and quality, which can overlap with the post-juvenile moult (see Dorsch 1993; Berthold *et al.* 1970).

"The Red-backed Shrike is among the very few European passerines in which the feathers acquired during the post-juvenile moult are markedly different from those of adults (and hence called second juvenile plumage by Stresemann1963)" (Jenni & Winkler 2020b, p. 102). In fact, which might be the wide-reaching cause of the confusion with the term "juvenile", Stresemann himself called this plumage "juvenal" (i.e., first year) in contrast to the commonly used term "juvenile" (first feathering after down) plumage: This "second juvenal plumage differs from the first one only by its more durable structure. It becomes worn during migration from Europe to tropical Africa where it is replaced in December and January, thus after about four months, by the sexually dimorphic (and in the male quite differently colored) ... plumage of the adult bird. Its only reason for existence is that it is far better fit for long distance travel than the first juvenal plumage would be" (Stresemann 1963, p. 6).

Second year birds, on their second arrival in the non-breeding grounds, are not more than 18 months old. Birds at six months can be clearly distinguished, especially in the hand, from those at about 18 months on plumage criteria like abrasion and moult pattern. The question of a possibly distinct second-year plumage is discussed in section 8.2. Barring of the upperparts in females.

Migratory birds arrive on the non-breeding grounds with a varying number of feathers from the different phases. This should also be taken into consideration when defining the age. These processes have not been described in the southern literature and further research is needed.

6.2 Moult of the Red-backed Shrike

Adult Red-backed Shrikes undergo one annual partial and one annual complete moult. Due to the timing, the partial moult is called post-breeding moult, while the process of a complete moult in the southern hemisphere before the north-migration is named pre-breeding moult. While the progression of the complete moult can be well observed in the non-breeding grounds, the partial moult is quite unobtrusive and in Red-backed Shrikes, as in other trans-Saharan migrants, highly complex and still not fully researched (Jenni & Winkler 2012, pp. 19, 22).

Generally, first-year passerines undergo a post-juvenile, mainly partial moult after a few weeks of life and tune into the adult moult cycle by the end of their first year of life. But variations from this rule occur.

Further investigation suggests that the phases of partial and complete moult do not seem as segregated as described in literature. The moult process is possibly continuous at a low level, depending on the life circumstances and necessities of the different species (Jenni & Winkler 2020b, p. 183ff; Kees Roselaar, pers. comm. 2021).

The description of the moult process is summarised mainly from Bub (1981), Cramp & Perrins (1993), Harris & Franklin (2000), Jenni & Winkler (2012, 2020a, b) and Shirihai & Svensson (2018). See those papers for more details.

6.2.1 Moult in the northern hemisphere

First-year Red-backed Shrikes undergo a post-juvenile moult while still on the breeding grounds. This partial moult starts at the early age of 3-4 weeks after fledging and is completed at 8-10 weeks (Heinroth & Heinroth 1924-1926). It begins before the flight feathers and the tail are fully grown (Figure 4) (Harris & Franklin 2000), but is highly variable (Cramp & Perrins 1993, p. 476) (Figure 5).

Figure 4: *A juvenile of a few weeks old with yellow bill and yellow feet. The wing and tail feathers are still growing. The markings on the head and the underparts are still undefined and faint, the body feathers in general are "furry". Germany, September. Photo courtesy of Axel Wellinghoff.*

Figure 5: *First-year bird after post-juvenile moult with strongly marked coverts, mantle and rump, still furry and barred underparts, plain brown tail, well-marked cap and brown ear coverts. The horn-coloured beak shows a clear hook, a darker upper mandible, a yellow base and a thick, still yellow, gape flange. Cantabria, Spain, 27 July. Photo courtesy of Miguel Martín Diego.*

In adults, a partial moult also begins in July, and is often, like in first-year birds, not completed by September when the southern migration starts. If moult of the remiges starts already on the breeding grounds, it is then interrupted during migration. Other individuals do not start moult before migration, although they may begin to moult on stop-over sites before reaching non-breeding grounds.

Both adult and first-year Red-backed Shrikes complete their moult generally in the non-breeding grounds. In adults, it is timed after breeding. Exceptions occur: A complete moult during the breeding season observed in live birds and museum skins is associated with non-breeding adults and with individuals who lost their broods (Kramer 1950). This process is well documented for migratory shrikes. Heinroth & Heinroth (1924-1926) observed it in captive Red-backed Shrikes, Marc Galvéz in captive Lesser Grey Shrikes (*Lanius minor*) in Spain (2020, pers. comm.).

6.2.2 Moult in the southern hemisphere

Young Red-backed Shrikes hatched in June or July arrive in their non-breeding grounds when they are four or five months old as indicated by the first average arrival date of 24 October for Zambia between 1971 and 2000; one exceptionally early observation is from 25 September 1976 in the far north-east, in Mwinilunga (Bowen 1983, in Dowsett 2009, p. 87).

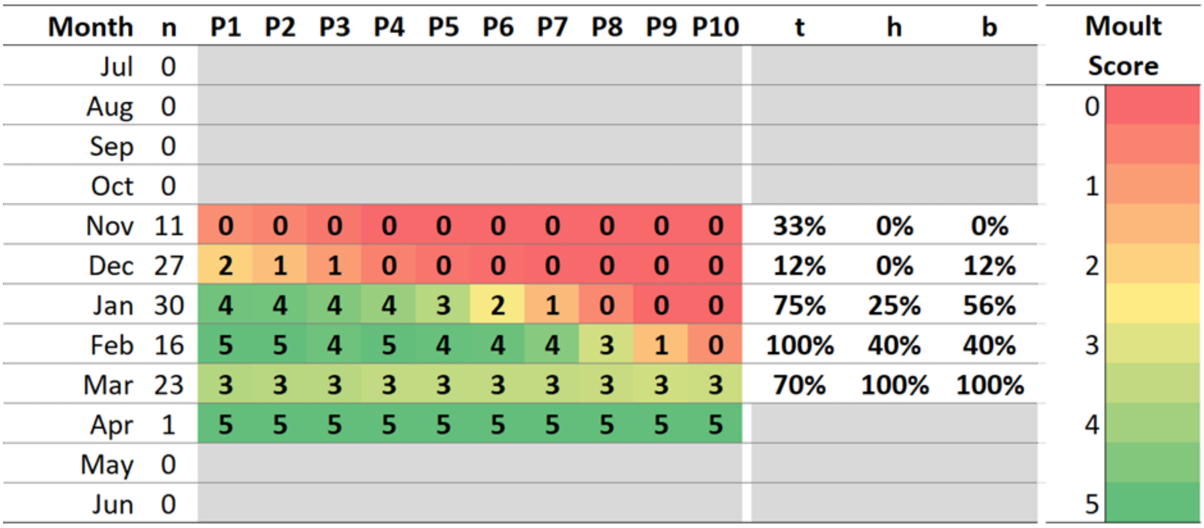
The time for the moult of the flight feathers has been estimated to cover about 80-90 days (Ginn & Melville 1983, p. 77). In southern Africa, the complete moult of all individuals has been recorded to start between late December or January to March (Cramp & Perrins 1993, p. 476), in Zambia between late November and April (Snow 1965, p. 140; Fig. 3, ibid., shows 108 records mainly from Dowsett from then Northern Rhodesia, now Zambia), with adults starting the primary moult before the first-year birds. This corresponds with our findings. In adults, the first three primaries showed signs of moult as early as November while the first-year birds were displaying similar values only in December. The results of our sample, collected over more than 15 years, are presented in Tables 2 and 3.

The primary moult is descending, as is typical for almost all passerines. The state and progress of moult is expressed by the moult score. The moult score is the sum of the feather codes, with 0 for old to 5 for fully grown, newly moulted primaries. The numbers in between show the stage of growth. A fresh, completed wing thus has a moult score of 50.

Our data suggest that tail moult starts earlier in adults than in first-year birds, while both age groups complete tail moult after four months.

In northern Botswana, between October and early November, Traylor (1965, p. 372) found the same pattern in two adults "in mixed fresh and worn contour plumage, but no active moult". Four immatures in January showed various stages of (complete) pre-breeding moult, while one adult was just finishing its "annual moult", which appears to be very early. We found fully moulted adults in Namibia only in April and in Botswana from mid-March on, in time for the migration northwards.

Table 2: *Extent of primary feather moult (P1 to P10) of* ***adult*** *Red-backed Shrikes in the non-breeding grounds in Namibia, Botswana and Zambia. The average moult scores between 0 and 1 result from a few individuals with two sprouting primaries (moult score 2). Values are average moult scores of each primary for the n birds per month sampled. The colour gradient is shown at the side. The tail (t), head (h), and body (b) are expressed as a percentage of birds assessed showing signs of moult. No data were collected for the cells marked in grey.*



Month	n	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	t	h	b
Jul	0													
Aug	0													
Sep	0													
Oct	0													
Nov	11	0	0	0	0	0	0	0	0	0	0	33%	0%	0%
Dec	27	2	1	1	0	0	0	0	0	0	0	12%	0%	12%
Jan	30	4	4	4	4	3	2	1	0	0	0	75%	25%	56%
Feb	16	5	5	4	5	4	4	4	3	1	0	100%	40%	40%
Mar	23	3	3	3	3	3	3	3	3	3	3	70%	100%	100%
Apr	1	5	5	5	5	5	5	5	5	5	5			
May	0													
Jun	0													

Moult Score

0
1
2
3
4
5

Table 3: *Extent of primary feather moult (P1 to P10) of Red-backed Shrikes in their* ***first year*** *of life in the non-breeding grounds in Namibia, Botswana and Zambia. The average moult scores between 0 and 1 result from a few individuals with two sprouting primaries (moult score 2). Values are average moult scores of each primary for the n birds per month sampled. The colour gradient is shown at the side. The tail (t), head (h), and body (b) are expressed as a percentage of birds assessed showing signs of active moult. No data were collected during the months marked in grey.*

Month	n	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	t	h	b
Jul	0													
Aug	0													
Sep	0													
Oct	0													
Nov	6	0	0	0	0	0	0	0	0	0	0	0%	0%	0%
Dec	44	1	1	0	0	0	0	0	0	0	0	10%	0%	3%
Jan	79	4	4	3	2	1	1	0	0	0	0	67%	16%	29%
Feb	32	4	4	4	4	4	3	2	0	0	0	95%	37%	50%
Mar	44	4	4	4	4	4	4	4	4	3	2	83%	91%	82%
Apr	0													
May	0													
Jun	0													

Moult Score	
0	🟥
1	🟧
2	🟨
3	🟨
4	🟩
5	🟩

Maybe not all Red-backed Shrikes complete their moult in mid-April before the northern migration (as stated in Harris & Franklin 2000, p. 198; Hidalgo 2022, pers. comm.) but the majority do, as shown in Tables 2 and 3. Still, some have been recorded to depart with inner secondaries still growing (Herremans, unpubl. data, cit. in Herremans 2005).

7. PLUMAGE OF ADULT FEMALES AND MALES

Age and sex can be determined by plumage. Red-backed Shrikes are dimorphic i.e. adult females and males have differing plumages. They are, however, highly variable, mainly in females. While males are mostly well recognisable by their plumage, the differentiation of females and young birds often requires closer inspection.

Figure 6: *Adult female with uniform coverts, mantle and cheek, arrow-marked underparts, plain brown tail, slightly grey nape, brown ear coverts and horn-coloured beak with darker culmen and tip. Aragón, Spain, mid-July. Photo courtesy of Javier Blasco-Zumeta.*

A reliable criterion, at least for the identification of the sex of adults, is the colour and the pattern of the tail. Females can be identified by their entirely brown tail (Bub 1981, p. 111; Figures 6 and 7). See also Ringers DigiGuide (2022).

Females in general have chevrons (arrow-like markings) on the underparts which are absent in adult males. Further, although quite variable, criteria for the distinction of females and males are the brown vs. grey top of the head and the brown vs. grey rump.

7.1 Described colour variations of female and male plumage

Most field guides depict Red-backed Shrikes in their full adult plumage with clearly distinguishable female and male features of head, nape and underparts which unfortunately do not match our observations.

Figure 7: *Freshly moulted male arriving in Italy in mid-May, with plain, unbarred mantle and rump, distinctive black and white tail, uniformly grey cap and neck, well defined black mask and all black beak as depicted in most field guides. Ventotene Island, Italy, mid-May.*

An extensive plumage variation between individuals during the same season comprises all ages and both sexes in colour, gender features and moult progress (Stresemann 1920; Bub 1981).

This plumage variation arises from multiple elements. It reflects individual factors like annual wear and bleach, different timing of onset and end of moult and/or different proveniences. The geographical variation must be taken into consideration, too, with different speed of moult for different geographic regions (Gwinner & Biebach 1977), introgression by hybrids in adjacent zones (Panow 1983, pp. 83-88, with Isabelline Shrike *L. isabellinus* and Brown Shrike *L. cristatus* [Cramp & Perrins 1993, p. 477] and with Turkestan Shrike *L. phoenicuroides* [Shirihai & Svensson 2018, p. 185]), and differing expressions of colour (and size) throughout the distribution area. In their vast breeding range from western Europe to 85 degrees east in Siberia, birds are described as getting paler from west to east, and being smaller in the south east (Bub 1981, p. 102).

7.2 Observed variations of plumage and bill colouration

Table 4 presents a summary of plumage and bill colouration through the different age groups, gathered from literature and in the field. Due to a wide timespan of breeding, the time categories can fluctuate.

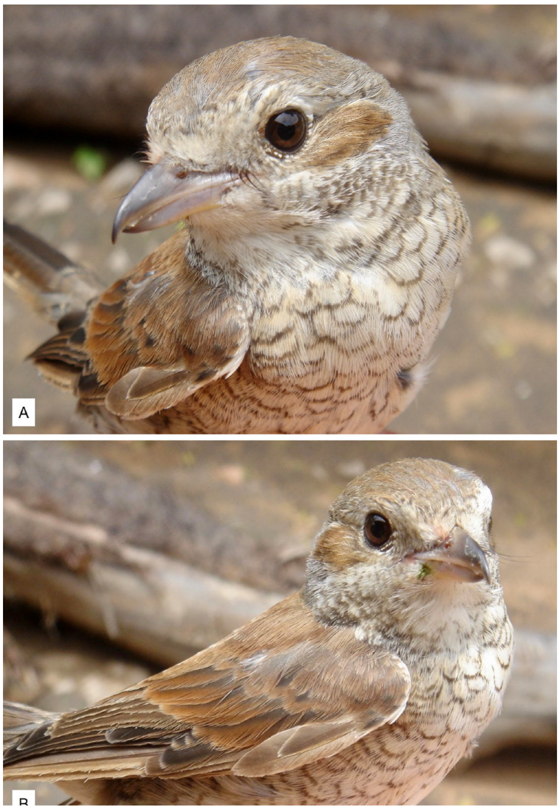


Figure 8: *Adult female in pale plumage with female rufous ear coverts, markings on the cheeks and grey tinge on the head. The tail is uniformly dark brown. Primary moult score 27 (5555430000). Waterberg, 15 January 2006.*

8. ADULT FEMALE RED-BACKED SHRIKES

In females, the colour variation concerns mainly the upperparts, often the whole body. Furthermore, several females show male features (see Table 4). This frequently creates confusion especially when age but also sex is being determined.

8.1 Variable plumage of adult females

Figures 8, 9 and 10 depict three different colour types of adult females. The adult age was determined by the plain mantle and wing coverts without any barring which still would be seen in birds in their first year of life in January (as discussed in Section 10).

8.2 Barring of the upperparts in females

Even after more than a hundred years of intensive research, there are quite frequently females in both hemispheres that escape precise age determination; they show plumage features of different age groups that do not allow a conclusive determination of age.

Barring on the upperparts is usually one of the signs of first-year individuals, and birds with more than one year of life are considered as adults.

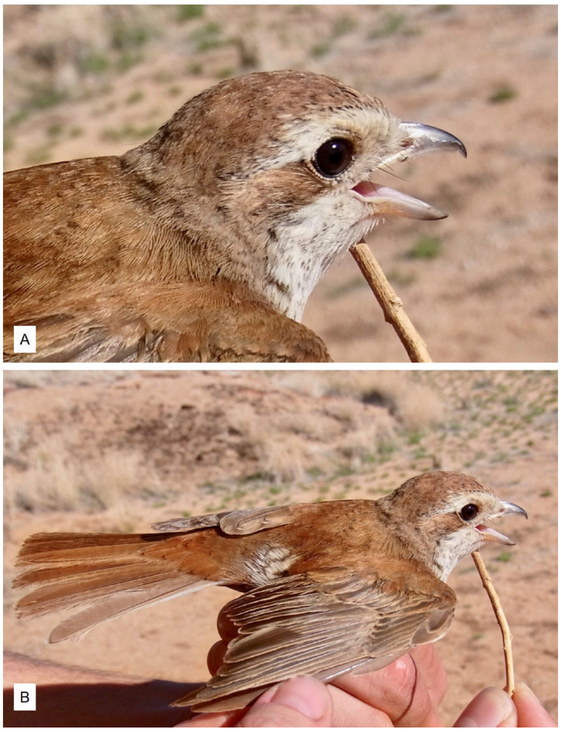


Figure 9: *Rufous adult female with plain rufous rump and tail, plain head and cheeks and broad white supercilium. Primary moult score 11 (4430000000). Farm Sphinxblick, Erongo region, 6 January 2011.*

It has been discussed in the literature that there might be a plumage phase between first-year birds and adults, represented in second-year birds. In the northern hemisphere, some plumage patterns of Red-backed Shrikes have left researchers in doubt, mainly about features of two age groups: It "is unknown" whether "...females with many barred feathers on upperparts and retained, heavily worn tertials with dark subterminal bars (juvenile pattern) are invariable first-summer" birds (Shirihai & Svensson 2018, p. 187); likewise it is unknown if "all females with juvenile-like pattern are invariably 2nd year birds" which makes aging impossible "after pre-breeding moult ... using plumage pattern" (Blasco-Zumeta & Heinze 2019).

Blasco-Zumeta & Heinze (2019) describe in detail the two phenotypes as adult-like and juvenile-like females, juvenile here being used in the wider sense for the first year. The adult-like female can be "recognized by tertials with pale brown tips without dark subterminal bars (often with just a dark mark)". The upperparts show no bars "except very slight barred on uppertail coverts", while the juvenile-like female has "tertials with pale tips and blackish subterminal bars and bars on upperparts from crown to uppertail coverts". First-year birds have upperpart feathers with a dark subterminal bar, an overall fresh plumage and wing coverts with a dark subterminal line (Figure 11).

Figure 10: *Dark adult female, almost no supercilium. Despite white tips on the freshly moulted feathers on the head, the plain scapulars and ear coverts and the markings of the underparts define it as an adult. It had finished its primary moult. Moult score 50 (5555555555). Near Witvlei, March 2015.*

Currently, the question of whether this plumage is a variation of adult plumage or a separable intermediate plumage in the development of the females is being studied by Hidalgo *et al.* in Spain (pers. comm., 2022). The results to date show, through retraps, a constant pattern in the plumage: the barred "juvenile-like" females keep their markings throughout the (known) years. Interestingly, no similar feature for males has been described.

The significance of these results is that Red-backed Shrikes with barred upperparts are not necessarily first- or second-year individuals, but more criteria have to be applied to allow a correct determination of sex and age.

In our research area in southern Africa we recorded a low number of adult females with all plain upperparts. Almost all had markings on the rump, the mantle or coverts and scapulars. The variations are inconsistent and complex, possibly due to different breeding grounds, resulting in different times of hatching and subsequent start of partial

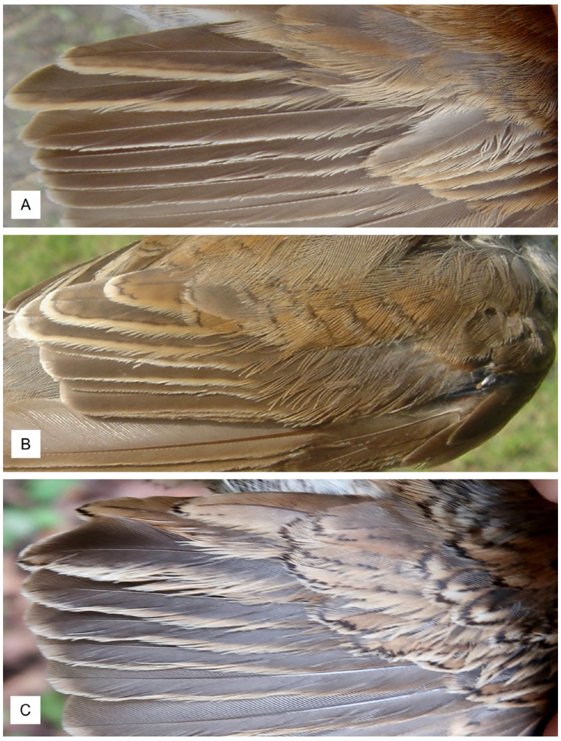


Figure 11: *Pattern of tertials and scapulars of female and first-year Red-backed Shrikes. All pictures were taken in Namibia in December. (A) adult female with plain scapulars and tertials, light edges and only a faint subterminal band; 30 December 2021; (B) "juvenile-like" female with faintly barred tertials with broader, light edge and a distinct, dark subterminal band and a vermiculated bar with paler fringe on the scapulars; 13 December 2007; (C) unsexed juvenile/first-year bird with prominent black subterminal band on the tertials, scapulars and coverts; 4 December 2005. (Compare with Blasco-Zumeta and Heinze 2019.)*

Table 4: *Summary of basic phenotypical differences of Red-backed Shrikes in the different age groups. The poorly researched second plumage of the first year (Jenni & Winkler 2020b, p. 102) is not taken into consideration.*

Feature	**Adult**		**Juvenile (until post-juvenile moult, mostly up to 2 - 3 months).**	**Immature (1st calendar year, after post-juvenile moult).**	**Immature (2nd calendar year)**
	Male	**Female**			
Crown	Plain grey, sometimes white above the black of the frontal mask.	Rufous, brown, sometimes slightly or all grey like male; sometimes barred.	Greyish brown with undefined, faint markings.	Pale brown, rufous or dark brown with or without strong black bars. When already in transition, males are mottled grey and brown.	While in transition: mottled and/or still barred.
Hind-neck	Medium-grey.	Brown to grey; greyer than crown and body; sometimes grey like males and/or barred.	Greyish brown with faint barring.	In transition: pale to rufous-brown or grey, sometimes still with barring.	While in transition: mottled and/or still barred.
Ear-coverts	Black.	Brown in varying shades, rarely black like males.	Pale brown to dark brown.	Pale-brown (fresh or old), rufous- or dark-brown, sometimes with black markings. Males in transition with first black specks in varying degrees.	Intensifying black in males, reducing over time old brown or pale feathers.
Bill	Non-breeding with brown-grey, blue-slate or dark horn-brown bill from base outwards, becoming uniformly black at the end of the pre-breeding moult.	Horn-, deep- or slate-brown or pink, some all black while breeding, in average paler than males. Horn-coloured upper mandible, pink lower mandible, small black tip, both becoming darker to blackish with pink base and black tip towards the breeding season.	Yellow when very young, also pale or dark horn or pink, always with yellow gape flange; bill becoming horn-coloured with yellow or pink tinge and darker upper mandible and tip.	Pale horn with pink, flesh, whitish or yellow tinge, culmen and tip darker.	In transition to colouration of breeding adults.
Mantle	Rufous-brown in varying darkness.	Plain brown (pale, rufous or dark) with or without barring.	Similar to females, but mostly close, black barring.	Brown with mostly dark bars and/or light fringes; moult starting.	In transition: often mottled, without or with dark bars and light fringes.
Rump	Grey.	Mostly brown, in male-coloured birds mostly grey.	Mostly rufous with strong black bars.	Often mottled old and fresh brown in females, with grey in males with or without light fringes and with or without faint or black bars.	Mottled old and fresh brown in females, with grey in males, with or without light fringes and with or without faint or black bars.
Underparts	Plain with often pink.	Light with distinct vermiculations.	Buff grey with faint bars.	Light with dark irregular vermiculations.	Transition to adult.
Tail	Black and white with white terminal fringes.	Plain, mostly uniformly rufous, brown or dark brown with white edge on outer rectrix, sometimes with dark subterminal band, black bar or/and slim light tips.	Brown with white edge on outer rectrix, slim white tips, often variable dusky sub-terminal mark.	By moulting, some start to differentiate into female and male plumage.	By moulting differentiating into female and male plumage.

moult. We discerned in the same months various stages from freshly moulted vs. heavily worn tail, and a diversity of plain back and barred rump or barred mantle and plain rump or barred mantle and barred rump.

Figures 12 and 13 show a varying number of these barred feathers on the mantle, the scapulars and/or on the rump. The adult age of these females was determined first by the plain areas on the upperparts, then confirmed by markings or lack thereof of the tertials, the coverts and the head and signs of primary moult.

9. TAIL

The quality of the first tail feathers is poor and thus the white tips of the rectrices are easily abraded. To distinguish adult females and first-year young the earlier onset of tail moult in adults might be a helpful criterion. For timing see Table 2 and 3.

In females the tail is plain rufous or brown, or dark brown (with a rufous tinge in "normally" coloured birds), sometimes almost black towards the tips, and shows a white outer fringe on the outermost tail feather (see Figures 15 and 19). The colour is mostly corresponding with the overall plumage colouration (Figure 19) but varying in darkness and shade.

Our male-coloured females always had a plain tail (see Figures 22 and 27) although Harris & Franklin (2000, p. 197) mention for females occasional male-like tails (see Section 12. Male-like plumage features in females and vice versa).

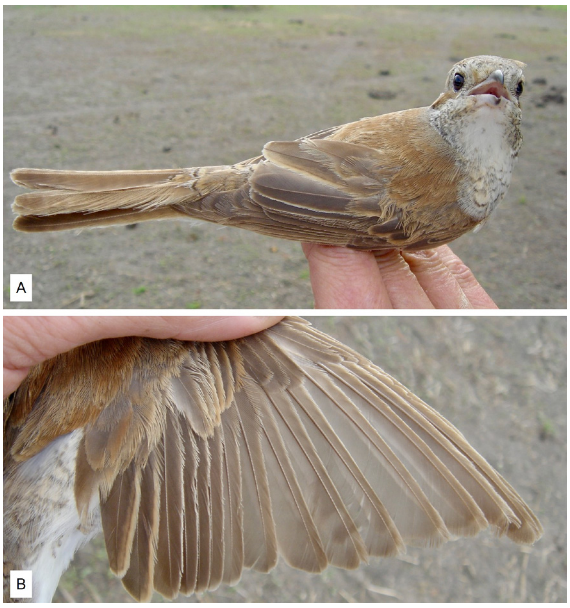


***Figure 12**: Adult female with plain back and wing coverts and barred rump. Only the middle tertial shows a faint dark subterminal band while all the primaries are heavily worn. Lake Ngami, Botswana, 4 December 2005.*

***Figure 13:** Adult female, possibly second year of life, with barred mantle and mainly plain rump, and male-like features: grey rump, grey on head and neck and the outer tail feather showing white marking. The tail moult has, quite early, been almost completed while the wing was still in moult: moult score of primaries 26 (5555420000) and of secondaries 405555. Otavi, 26 January 2007.*

***Figure 14**: Tail of a first-year bird: thin, worn uppertail coverts, and almost transparent rectrices; white edge of the left outer rectrix with white tip and faint black subterminal bar. Witvlei, 31 December 2021.*

***Figure 15:** Tail of an adult female. The feathers are of thicker quality and stronger colour. Witvlei, 20 December 2021.*

***Figure 16:** Tail of a male Red-backed Shrike with typical black and white pattern. Witvlei, 17 December 2020.*

Figure 17: *First-year male growing its first adult tail, starting, as is common, with the central rectrices. Witvlei, 13 January 2020.*

Figure 18: *First-year male growing its first adult tail, presumably a replacement of lost rectrices. Witvlei, 31 December 2021.*

Figures 14, 15 and 16 show the tails and uppertail coverts of an unsexed first-year bird, an adult female and an adult male.

At least in first-year birds, the moult process of the tail does not seem to follow a fixed sequence. It can start by growing the middle or also non-sequential rectrices (Figures 17 and 18).

10. COLOUR VARIATIONS IN FEMALE AND YOUNG RED-BACKED SHRIKES

As in many bird species, the young birds wear a “female-coloured”, brown and barred plumage which provides better camouflage than the often more eye-catching adult male plumage and protects young males from adult male aggression.

Already in immatures, different colouration types (Färbungstypen) are found which continue into adulthood after the complete moult. Siblings in one nest can belong to different types (Stauber in litt. in Bub 1981, p. 113). Stauber describes distinctly red and grey young and “normal” birds in shades in between. The colour variation is not related to the sex of the birds.

We found three colour types during our studies (Figure 19).

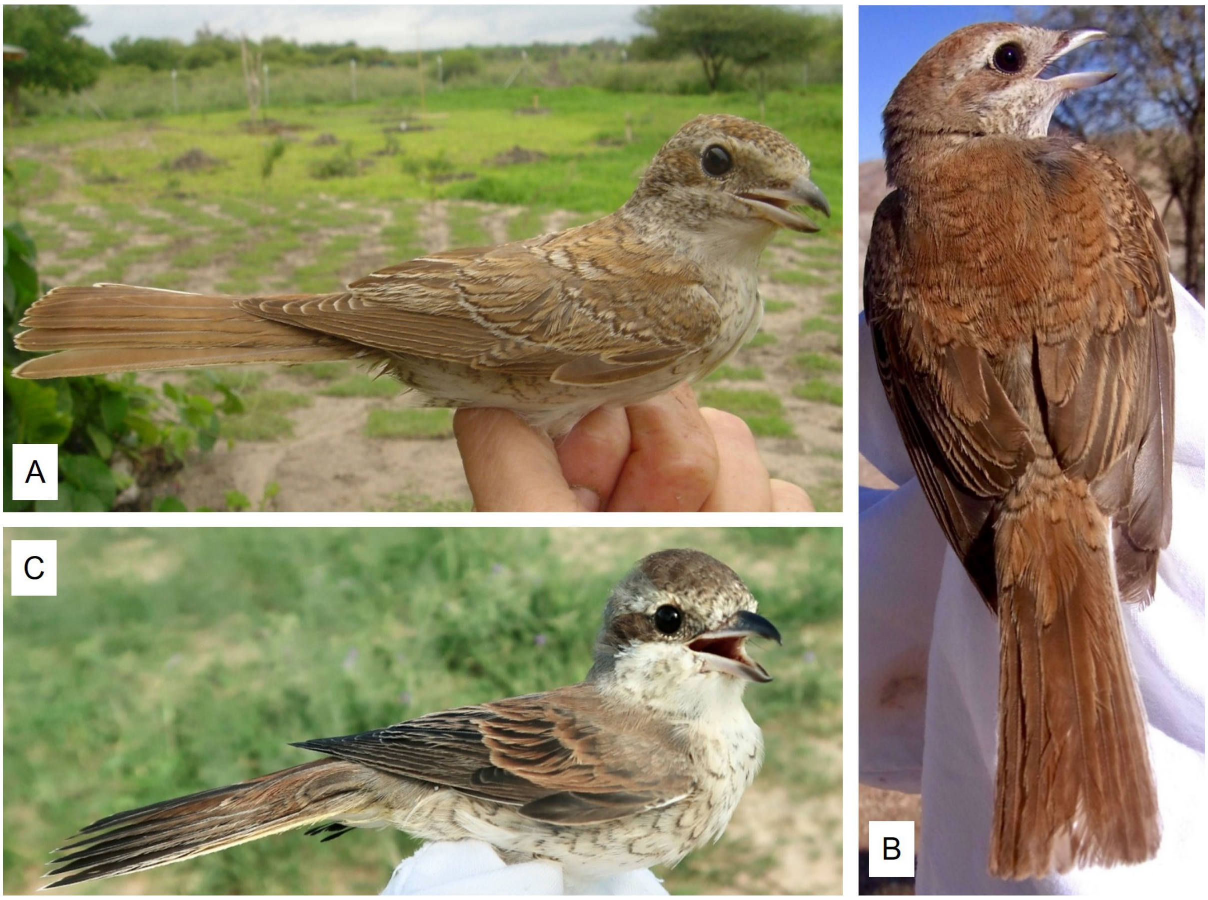


Figure 19*: Colouration types: (A) Pale first-year individual, unsexed, still showing buff tips and a blackish subterminal band on tail and coverts. Maun, Botswana, 9 December 2005; (B) Rufous adult female in "juvenile-like" plumage. Erongo region, 1 January 2011. (C) Dark grey-brown adult female with blackish flight feathers and end of tail. Farm Hamakari, 25 February 2022.*

11. ADULT MALE RED-BACKED SHRIKES

Males are recognisable by their grey head and nape, black mask, rufous mantle and the typical black and white tail pattern. The rectrices show much white with long black tips, except for the entirely black central feathers (Cramp & Perrins 1993, p. 475).

We found considerable variation in mainly the plumage colour of adult males, which not yet have been described in the southern literature.

11.1 Neck and mantle

While some males have a clearly confined grey neck (Figure 20), in others the grey area extends into the mantle, ending diffusely (Figure 21). Intermediate features occur.

11.2 White primary patch (Spiegel)

Stresemann (1920) described the white primary patch as the white base at the inner web on P4 or P5 to P9, found in "many males from Macedonia". Other authors report this feature from different European countries, in males as well as in a few females (in Bub 1981, p. 115).

Information about a white primary patch (Spiegel) is not conclusive. It is claimed generally not to be visible. While some individuals have little hidden white patches, visible patches are reported especially from British, French and Finnish birds, although localised more in the eastern parts of the range (Shirihai & Svensson 2018, p. 185). In the field, in the Czech Republic, Kauzal claims that about a quarter of the trapped males show small signs of white on the coverts (pers. comm. 2022). In our sample, an aggregation of possibly highly diverse origins (compare Figure 3), several individuals (at least 15% of 164 males) showed a primary patch of varying size.

Figure 20: *Adult male. The grey of head and neck ends in a distinct line. Lake Ngami, Botswana, 10 December 2005.*

Figure 21: *Adult male. The grey of head and neck disperses downwards into the mantle. Witvlei, Namibia, 4 March 2019.*

With one exception (Figure 22), we found primary patches only in males. It could be seen in some individuals from P1 onwards, and in some it was

Figure 22: *Adult female with small white wing patch. Near Witvlei, 9 December 2022.*

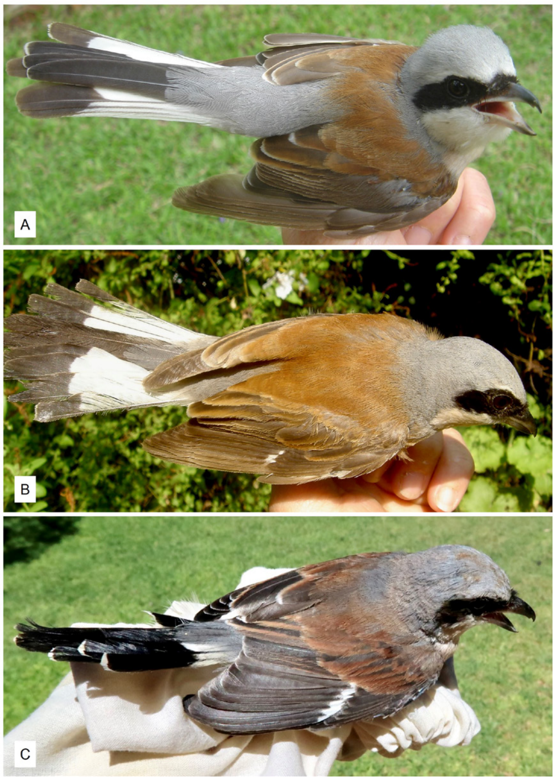


Figure 23: *Variation of wing patch, general plumage wear and moult status of two males, ringed on the same day. (A) "Normal" adult male without white primary patch. Head, body, tail and primary moult have progressed already in mid-December. See the striking difference of colouration compared to (B). Moult score 16 (5533000000). (B) Adult male with fine primary patch below coverts. Moult score 0. Both Gaborone, Botswana, 13 December 2007. It is not clear if these two individuals belonged to different populations with different origins with different onset of moult, if there is an age difference with older birds starting moult earlier than younger ones or if there are other reasons. (C) Adult male with primary patch forming a white wing bar; tail growing after almost completed wing moult. Moult score 47 (5555555435). Near Witvlei, 4 March 2019.*

extending over the inner and outer web (Figure 23). This feature, as far as we can determine, has not yet been described for southern Africa.

***Figure 24**: Adult female with grey head, greyish rump and uncommon dark, plain tail with faint marks. The second outer rectrix shows a light, buff window which reminds of the tail pattern of a male. Otavi, 26 January 2007.*

***Figure 25:** Adult female with plain back and greyish rump. Near Maun, Botswana, 24 February 2006.*

***Figure 26:** Adult female with unmarked male-like grey nape and crown (compare Shirihai & Svensson 2018, p. 186) and dark mantle, but female-coloured, uniformly brown tail and ear coverts and typical female vermiculation of the underparts. Botswana, 1 December 2007.*

12. MALE-LIKE PLUMAGE FEATURES IN FEMALES AND VICE VERSA

Females can show varying amounts of male features, from pronounced grey on the head or a grey rump (Figures 24, 25 and 26) to even a black-brown mask through the eye. Studies by Stegmann (1930, cit. in Bub 1981, p. 115) on living and dead specimens showed that male features in females were not related to age or the "extinction of the reproductive instinct".

***Figure 27**: Tail of adult female with one single male-like rectrix (T3 left). Witvlei, 27 March 2016.*

***Figure 28:** Undertail of adult female with one single male-like rectrix (T6 right, above). Witvlei, 19 December 2021.*

***Figure 29:** Adult male with female-like features: (A) Upperparts with typical adult male black and white tail pattern, but mostly brown ear coverts and brown top of the head. The mask is not fully formed black, while the rump was slaty-grey. (B) Mantle and underparts showed few faint markings that are strongly expressed in young birds. Otavi, 26 January 2007.*

Males can show features of typical female plumage also, but this occurs infrequently. The crucial criterion to determine the sexes is tail colour: the tail is plain and predominantly brown in the female and black and white in the male.

Although Harris & Franklin (2000) mention occasional male-like tails in females, in the literature and in the extensive photo data base of the Macaulay Library (https://search.macaulaylibrary.org/catalog?taxonCode=rebshr1&mediaType=photo&sort=rating_rank_desc) we could find only one single depiction of a single male-coloured rectrix (T5) in a tail of a female (Bub 1981, p. 111, picture on p. 112 by Stauber, who ibid. claimed, though, to find this feature multiple times [vielfach]).

In our sample we photographed two females with one male-like rectrix (Figures 27 and 28).

Only occasionally we came across males with deviant features (Figure 29) as mentioned in the literature (Stauber in litt. in Bub 1981, p. 115).

13. COLOURATION OF THE BILL

The colouration of the bill provides information about age, sex and breeding status. The bill colouration differs between young and adults and females and males and also during the breeding and non-breeding season.

In first-year individuals the gape flange is yellow, as is the base of the lower mandible of the indistinctly pale-grey coloured bill (Figure 30).

In the African literature, the bill of the male is always depicted in black, sometimes also the bill of the female. Though, in July/August the bills of adults start getting pale, beginning at the base, and only after the complete moult in the non-breeding area does it turn fully black again, starting from the tip (Figures 31 and 32) (Harris & Franklin 2000; Jenni & Winkler 2012). The colour change is more evident in males (Figure 33), while the bill of the female “never becomes as dark black as in males” (Kramer 1950, pp. 21-22). Also, during the non-

***Figure 30**: First-year Red-backed Shrike with yellow gape flange, still yellow on the lower mandible and indistinct bill colouration. Head and ear coverts are darker than in the adult female of Figure 31. Near Witvlei, 28 December 2019.*

***Figure 31:** Adult female in December with pale upper and pink lower mandible and small black tip. Botswana, 4 December 2005.*

***Figure 32**: Adult female in February with blackish upper mandible and lower mandible with pink base and black tip. Waterberg, 25 February 2022.*

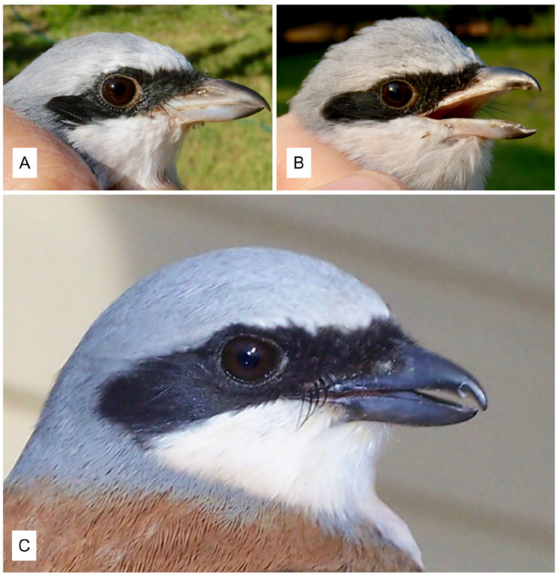


***Figure 33:** Bill colouration of adult males. In the non-breeding grounds the bill is bluish or pinkish pale with black on the upper mandible and the tip. (A) Botswana, 9 March 2011 and (B) 12 March 2011. (C) shows a male after the arrival in Europe with fully black bill. Ventotene Island, Italy, 15 May 2012.*

breeding season, the bill of the adult never turns as pale as in young birds (ibid.).

Adult males in the non-breeding grounds show pale bills with black on the upper mandible and the tip of the lower mandible and acquire the black bill of a breeding male shortly before or during migration.

14. EARLIEST DISTINCTION OF SEXES BY HEAD, BILL, RUMP AND TAIL

The first distinction between sexes in juvenile birds is claimed to be generally possible by February (Harris & Franklin 2000; Shirihai & Svensson 2018, p. 186); of 50% of 302 mainly South African birds, mostly specimens, "towards the end of January and for most birds before mid-February" (Bruderer 2007, p. 557).

In our Namibian sample we generally could determine the sex from the end of December and early January onwards, when the head moult started progressing. With the birds in the hand, we could see females intensifying the rufous on crown and cheeks, with the bill typically lighter than in males (Figure 34). Males in early January showed prominent black feathers in the mask, especially in front of the eyes, first fresh blackish primaries and tail, and blackish upper mandible and tip of the lower mandible. Still, huge variability is possible due to different populations and age differences in first year birds.

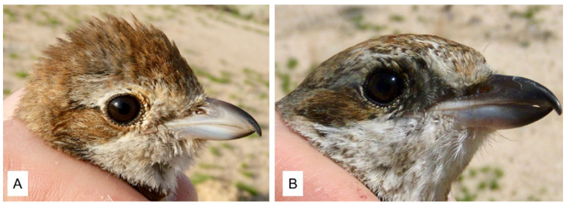


***Figure 34**: Earliest possible distinction of sexes of first-year Red-backed Shrikes by plumage features on the head and the colouration of the bill: (A) Female with rufous ear coverts and crown, (B) male with first black feathers showing on ear coverts and mask, and first grey ones on the forehead. From the Erongo region, 9 January 2011.*

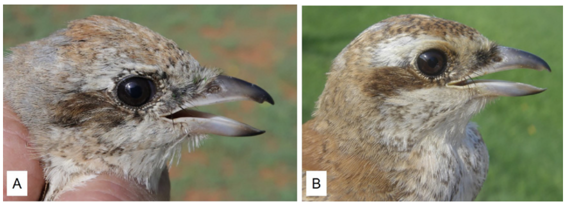


***Figure 35:** Two first-year males at the end of the year of hatching show black feathers between bill and eye indicating the sex: (A) showing grey on the back of his head. Near Witvlei, Namibia, 22 December 2019. (B) with mask clearly starting from the bill. Gaborone, Botswana, 5 December 2007.*

Some males could be recognised as such at close quarters even earlier, when the first black feathers appeared between the bill and eye and the grey of the head expanded (Figure 35). Females at this time did not show any black feathers in this area.

15. NOTES AND OBSERVATIONS

15.1 Sex ratio

Our sample comprised similar numbers of female and male birds (136 and 131 respectively). However, more males have been reported on the non-breeding grounds in other studies, with Bruderer & Bruderer (1994) quoting Becker's (1974) male-female ratio of 30:1 and Ludwig (in litt.) of 5:1, both for Namibia, and Mundy (in litt.) for Zimbabwe of 10:1.

15.2 Age ratio

In our sample, the age ratio of adults to young (first and second calendar year) Red-backed Shrikes was about 1:3 (82:249 individuals, not all of them were measured fully). These numbers correspond to the relation of age groups in the post-breeding/post-fledging period when naturally the numbers of young birds are about twice as high as those of adults (Ondrej Kauzal, pers. comm. 2022). Also, adult birds are more experienced and possibly less prone to take a bait as used in the flap traps.

15.3 Retraps and site fidelity

Red-backed Shrikes show high site fidelity in the non-breeding grounds (Harris & Franklin 2000, p. 199). The records of the SAFRING data base from September 2021 show that in their non-breeding grounds 169 out of 2604 Red-backed Shrikes were retrapped, which corresponds to a remarkable 6.49%. In comparison, for the resident White-crowned Shrike (*Eurocephalus anguitimens*), the SAFRING data base holds data on 460 individuals (ringed prior to 2020) and 19 retraps of which 16 (3.48%) were found at the very same location of the first capture (Bryson & Paijmans 2022).

A few earlier individual records of retraps in Africa are published: Ludwig (1978, p. 4) mentioned that one Red-backed Shrike in Namibia was retrapped at the same location after one year and again after three years. Skead (1973, p. 81) reported two retraps out of eight Red-backed Shrikes ringed during 40 months at one trapping site in the Transvaal. Two intercontinental recaptures from and to Africa are recorded in Harris and Arnott (1988, p. 50).

Over more than 15 years we retrapped seven out of 248 individuals: one each after one, two and seven days, one after 42 days, but only two birds after almost exactly one year (365 days and 368 days) and one after two years (730 days). These latter three were ringed in January and February as second calendar year birds and retrapped in adult plumage after one and two migrations respectively to the breeding grounds. One individual was recaptured in an adjacent pentad, all others at the original location.

15.4 Reported numbers

The South African Bird Atlas Project 2 (SABAP2) hosts statistical data about the birds of southern Africa. In the database, the average reporting rate of Red-backed Shrike has declined over the years. In Namibia since SABAP1 (1981-1998), there is a decline in reporting rate to SABAP2 (2007-present) of over 10% (SABAP2 2022).

It is not known if this decrease reflects real change of Red-backed Shrike numbers or if it is related to a change in observation. Although there are differences in methodology between SABAP1 and SABAP2 (i.e. survey protocol, spatial unit and no measure of effort), this is still a notable decrease in reporting rate for the Red-backed Shrike in Namibia and Botswana.

15.5 Precipitation and shrike numbers

We found a strong positive relationship between rainfall in the pre-Namib and numbers of Southern Fiscal (*Lanius collaris*) and Lesser Grey Shrike (*Lanius minor*). The numbers of Red-backed Shrikes did not follow this curve, but did rise noticeably in 2011 following exceptional precipitation (see graph in Bryson & Paijmans 2021, p. 15).

15.6 Parasites

Out of more than 250 individuals ringed, a tick was detected in only one bird ringed in mid-March. No other ecto-parasites like feather flies, mites or pox were observed.

15.7 Does the Red-backed Shrike breed in Namibia?

Migratory Palaearctic bird species have been found breeding in southern Africa, including the White Stork (*Ciconia ciconia*) and the European Bee-eater (*Merops apiaster*). During the past 150 years, there have been notes that claim breeding of the Red-backed Shrike in the southern hemisphere. Andersson (1872, p. 136) thought that it bred in Okavango, Roberts (1940, p. 299) mentions that "it has been reported to [breed] once in Rhodesia". Macdonald (1957, p. 143) (erroneously) deduced a post-breeding status from the finishing of the (complete) moult in mid-March.

For Namibia, we found two reports of Red-backed Shrike behaviour that resembled breeding behaviour in Europe:

Sauer and Sauer (1960a), who in 1958 first had documented that birds navigate by stars during nocturnal migration, described in their report on migratory birds in Namibia that a pair of Red-backed Shrikes alarmed each other (and other conspecifics) when the researchers intruded into their territory. Furthermore: "The territorial behaviour of some pairs and males was sometimes so pronounced that we were gladly tempted - but in vain - to look for nest sites or 'play nests'" (1960b, p. 73).

Figure 36: *Red-backed Shrike in plumage that looks like that of a juvenile, ringed in May in Europe. It was aged as second-year. It is unclear if a major part of the plumage was retained from the year before or if this shows a bird bred in Africa. Czech Republic, 10 July 2022. Photo courtesy of Ondrej Kauzal.*

Becker (1974) reported: "On 26.1.65 I observed a pair near Windhoek who became very excited at my approach and warned violently. The pair was fully coloured (ausgefärbt), kept close together, and could be observed in the same place for several days at a time. The behaviour was the same as that of a breeding pair." From this observation and familiar with the description of Sauer and Sauer, he considers breeding of this European species in Namibia as possible.

Potentially, the occurrence of breeding in Africa goes undetected because it is not considered an option by field workers and does not match the knowledge we have about this species. One individual was trapped in the Czech Republic in May 2020 by Ondrej Kauzal (Figure 36). It "looked like a bird in juvenile plumage. But considering the date of capture (beginning of May, actually it was at the time Shrikes began to appear that year), a bird in juvenile plumage is very unlikely" (2022, http://ondrejkauzal.org/gallery/_spec173-lan_col.html, individual CZEP20-149). The bird was aged "as a second year because of that much retained juvenile contour feathers" (ibid.). More research is needed to answer this question.

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Mountain Wheatear *Myrmecocichla monticola*: comparative biometrics, moult and breeding data, and criteria for the determination of age and sex

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CONTENTS

ABSTRACT

In this article we present measurement and moult data from over 160 Mountain Wheatear (*Myrmecocichla monticola*) of the subspecies *atmorii* (Tristram, 1869) ringed in Namibia, as well as two individuals of the adjacent northerly subspecies *M. m. albipileata* (Bocage, 1867) from Angola, and discuss our findings from these subspecies. We gathered nesting, breeding and moulting records for Namibia from published literature and photographic records, and compared our observations of the moult process and our records of active brood patches with breeding records, gathered by Brown *et al*. (2017), to gain insight into the timeline of physical processes. On the basis of photographs, we describe the nestling and compare juvenile and immature plumage and other features which help to distinguish these age groups. We add notes on the overall numbers observed in the last fifteen years and notes on recaptures, site fidelity and parasites. We discuss the white covert-patch as an indicator of age and document undescribed plumage details such as signs of a second-year plumage, spots on the coverts of first-year birds, white supercilium in grey males, the occurrence of grey or black greater coverts in grey males and features from both sexes in one plumage. This article is intended to supplement published data and encourage further research and discussion.

Keywords: age; Angola; biometrics; bird-ringing; breeding; immature; juvenile; misidentification; *Muscicapidae;* moult; Namibia; plumage; sex; territory

1. INTRODUCTION

For many bird species and subspecies of southern Africa and especially Namibia there remain gaps in biometrics, moult data and the description of different plumages in research and literature. We have been ringing birds in Namibia and southern Africa for more than twenty years and are evaluating our data to expand the knowledge about less researched species and subspecies (Bryson & Paijmans 2021, 2022, 2023; Paijmans & Bryson 2023).

In this article we present our observations of the Mountain Wheatear *Myrmecocichla monticola* (Vieillot, 1818) and our results of measurement and moult data from more than 160 individuals of the ssp. *atmorii* from Namibia (Figure 1). We also include the data of two Mountain Wheatear (*M. m. albipileata* Bocage, 1867) from Angola and discuss our findings from these subspecies.

Published measurements for the Mountain Wheatear are scarce. Moult data are mostly absent (Dean in Hockey *et al.* 2005); only one unspecific record can be found in Friedmann & Northern (1975, p. 28).

2. DISTRIBUTION AND SITES

Mountain Wheatears are almost endemic to southern Africa (Figure 2) and occur mainly in South Africa and Namibia, with some records from southwest Botswana and close to the border with South Africa (Southern African Bird Atlas Project, SABAP 2022). In Angola they are found in the southwest up to Benguela inland from the coast. An isolated population lives on Mount Moco and on inselbergs of the central-west Angolan highlands (Dean 2000, p. 215).

Distribution maps from different sources differ considerably. This seems to be due to methodological issues, such as which research opportunities were available (Traylor 1963, p. 137), which methods were used to collect data, which routes were frequented by bird watchers and which data were reported in which data base. The changes in distribution might also be due to changes in range

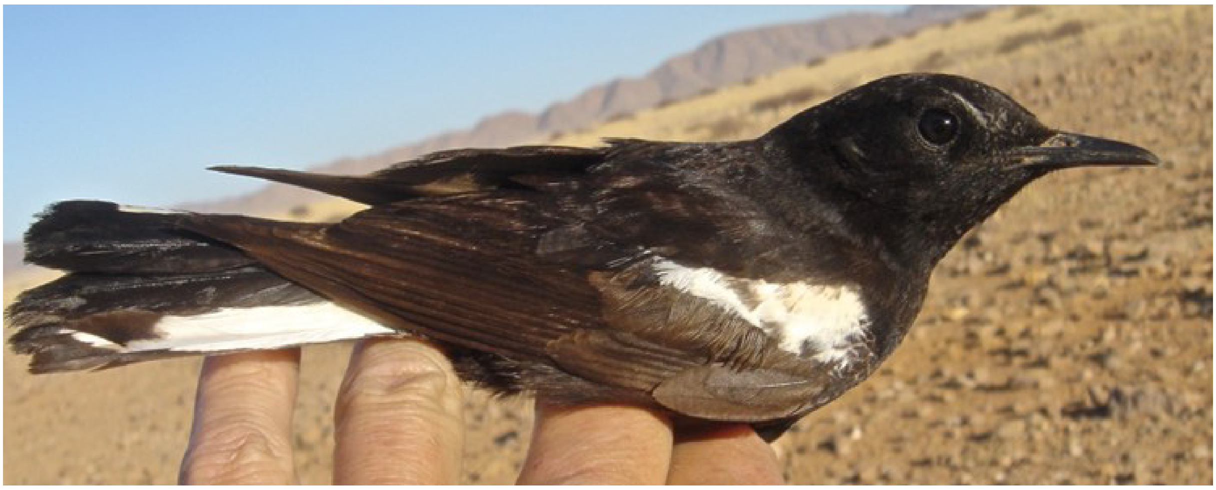


Figure 1*: Adult male Mountain Wheatear, presumably second-year; age determined by strongly bleached primaries and rectrices and slightly mottled covert-patch. Some all-black individuals of the subspecies* M. m. atmorii *show a more or less prominent white line over the eye, here only faintly expressed. SAFRING FH34712. Farm Sphinxblick, Erongo region, Namibia, January 2007.*

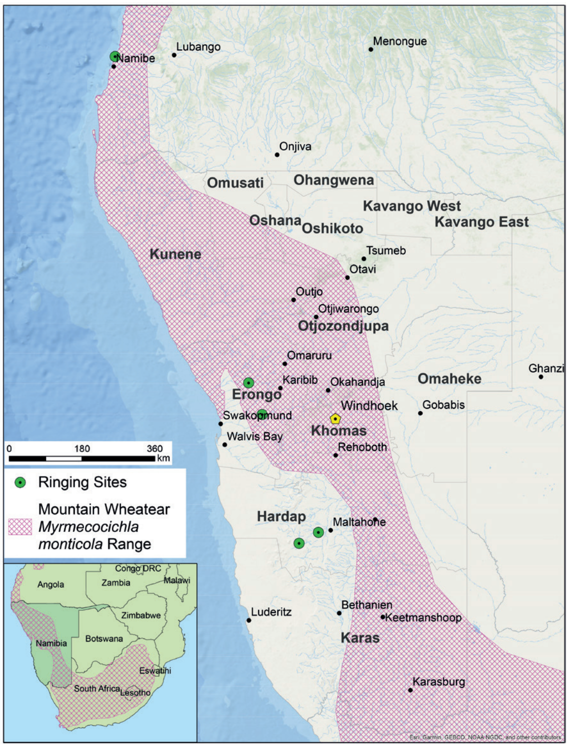


Figure 2: *Distribution map for the Mountain Wheatear (*Myrmecocichla monticola*) downloaded from www.iucnredlist.org on 19 August 2022. The green dots designate sites where the main data for the current study were gathered.*

over the last decades, or even to short-term changes in adaptation to drought and rainfall. For a detailed map of recorded sightings in southern Africa see the map of SABAP (https://sabap2.birdmap.africa/species/564).

Our data from Mountain Wheatears were collected mainly in the arid savanna around the farmhouses at the eastern edge of the Namib-Naukluft Park (Farm Sphinxblick, 22°29'S, 15°27'E), with a few at Spitzkoppe (21°50'S, 15°09'E) and various locations along the Swakop River valley. Records from two ringing sites in the NamibRand Nature Reserve (25°06'S, 16°16'E and 24°53'S, 16°04'E) from 2020/2021 are well outside the range of IUCN and the *Birds of the World* (Collar & Boesman 2021, https://birdsoftheworld.org/bow/species/mouwhe1/cur/introduction). We presume that large areas in the region have not yet been assessed by observers and that our findings are not isolated populations, since the habitat serves the species well. However, one must also consider that these years had a good rainy season which facilitates a range extension. It is unknown how swiftly the species can adapt to habitat changes and expand its range.

In Angola, one female and one male were ringed at the beach in Namibe Province (14°57'S, 12°11'E). See the distribution map in Figure 2 and habitat depictions of our research area in Figures 3, 4 and 5.

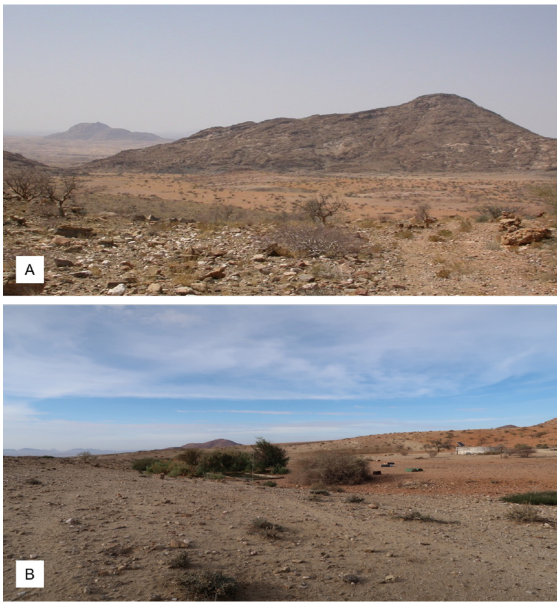


Figure 3: *(A) Typical arid habitat of Mountain Wheatear with rocky hills and plains. Erongo region, August 2004. (B) In arid areas Mountain Wheatear favour plains with waterholes and salt licks for game, whose droppings attract insect prey, and with trees or fences. Erongo region, January 2021.*

Figure 4: *A more mountainous terrain is suitable for Mountain Wheatears as it provides opportunities for perching and nesting. Erongo region, January 2013.*

Figure 5: *Our research area with high grass cover after good rainfall. Erongo region, 30 May 2006.*

3. TAXONOMY AND SUBSPECIES

3.1 Taxonomy

When Vieillot (1818, p. 434) first classified the Mountain Chat after Levaillant's description and depiction in the "Histoire naturelle des oiseaux d'Afrique" (1805, p. 105), he placed it in the genus *Oenanthe.* Later it was moved into the genus *Saxicola* (see Hoesch & Niethammer 1940, p. 242), but based on genetic results it was finally grouped with *Myrmecocichla* (Collar & Boesman 2021; del Hoyo & Collar 2016, p. 658).

3.2 Subspecies

Of the four recognised subspecies, two occur in Namibia and two in Angola. We predominantly researched subspecies *M. m. atmorii* (Tristram, 1869) (Figures 6 and 7) which is smaller than the nominate subspecies. It lives in western Namibia northwards to the Kunene River, the border with Angola, that seems to separate it strictly from the more northern subspecies *M. m. albipileata* (Bocage, 1867).

Southern Namibia and South Africa is the home of the nominate subspecies *M. m. monticola* Vieillot, 1818*,* and central Angola of the subspecies *M. m. nigricauda* Traylor, 1961 (Dean 2005, p. 949).

In Angola we ringed *M. m. albipileata* which can be found in the coastal area of the Namibe Province south of Benguela in southwest Angola. Both female and male show plumage variations which seem to be unstudied. We depict two females: one with a brown, the second with a white covert-patch (see also Sections 8.5 and 11.7) and two black males: one with a fully black head and a faint white supercilium, the second with a light grey cap (Figures 8 and 9).

Figure 6: *Adult female of the subspecies* atmorii *in dark brown plumage and plain wing. SAFRING FB22180, 20 December 2013.*

Figure 7: *Adult black male of the subspecies* atmorii *with silver-grey cap. SAFRING FH31538, 28 May 2006.*

4. METHODS

4.1 Bird ringing

Birds were ringed and measured and moult scores were taken in accordance with the guidelines of the South African Bird Ringing Unit's (SAFRING) Bird Ringing Manual (de Beer *et al.* 2001, based on Svensson 1984). Sex was determined by plumage.

Figure 8: *Adults of the subspecies* albipileata. *(A) Female in graduated, lighter brown plumage with extensive white vent. SAFRING FH39110. (B) Male with a fine white line above the eye which also can be found in some individuals of the southern subspecies* M. m. atmorii. *SAFRING FH39109. Praia das Pipas, Namibe, Angola, 26 July 2010.*

Figure 9: *A pair of adults of the subspecies* albipileata. *The male has a white crown and the female has a small white covert-patch. Namibe, Angola, 5 July 2018. Photo courtesy of Dubi Shapiro.*

Table 1: *Measurement data from this study. Average adult measurement data (including standard deviation, minimum and maximum measurements) of adult Mountain Wheatear (*Myrmecocichla monticola atmorii*) from Namibia and of adult Mountain Wheatear (*M. m. albipileata*) from Angola. Measurements are grouped by sex.*

Grouping	**Parameter**	**Wing (mm)**	**Tail (mm)**	**Tarsus (mm)**	**Culmen (mm)**	**Head (mm)**	**Mass (g)**
***M. m. atmorii* Namibia**							
All Adults SAFRING Code Age 4	Mean ± SD	105.5 ± 4.3	69.8 ± 3.6	29.9 ± 1.1	22.3 ± 1.6	43.4 ± 1.1	29.1 ± 2.4
	Min–max	89–117	60–86	25.4–34	18.2–29.8	40.7–48.1	24.5–39.5
	n	164	159	149	150	152	153
Adult Unknown Sex	Mean ± SD	106 ± 3.2	69.5 ± 2.7	30.3 ± 1	22.7 ± 1	43.7 ± 0.9	30.4 ± 1.9
	Min–max	103–111	68–76	29–31.8	21.5–24.2	42.4–44.9	28.5–33.4
	n	8	8	8	8	8	7
Adult Females	Mean ± SD	103.1 ± 2.9	68.5 ± 3.8	29.7 ± 1	21.9 ± 1.9	42.9 ± 0.9	28.5 ± 2.2
	Min–max	94–117	61–76	27.4–34	18.2–29.8	40.7–45.4	24.5–35
	n	79	75	71	72	72	75
Adult Males	Mean ± SD	108 ± 4.3	71 ± 2.9	30.2 ± 1.2	22.6 ± 1.3	44 ± 1	29.7 ± 2.5
	Min–max	89–117	60–78	25.4–32.9	18.9–26.5	42.2–48.1	25.5–39.5
	n	77	76	70	70	72	71
***M. m. albipileata* Angola**							
All Adults SAFRING Code Age 4	Mean ± SD	107 ± 4.2	70.5 ± 0.7	31.3 ± 0.7	22.8 ± 0.1	44.2 ± 0.1	34.6 ± 2.1
	Min–max	104–110	70–71	30.8–31.8	22.7–22.9	44.1–44.2	33.1–36
	n	2	2	2	2	2	2
Adult Female	Value	104	70	30.8	22.7	44.2	33.1
	n	1	1	1	1	1	1
Adult Male	Value	110	71	31.8	22.9	44.1	36
	n	1	1	1	1	1	1

All photographs were taken by the authors on Farm Sphinxblick in the Erongo region if not given otherwise. See photographs of ringing sites in Bryson & Paijmans (2021, 2022).

4.2 Measurements

Table 1 presents the measurements of our samples of the Mountain Wheatear from Namibia (ssp. *atmorii*) and from Angola (ssp. *albipileata*), Table 2 those of *M. m. atmorii* and *M. m. albipileata* in the literature. At a subspecies level we tried to compare the data from our sample and from literature.

A comparison of our restricted sample with published general data (for example Rose *et al.* 2020) proves almost impossible, as sets of measurements are lacking, subspecies and even sex are not always defined, some samples are too small, or the methods are not declared or not consistent. On comparing the results, it became clear that the methods must have differed between the researchers (see Paijmans & Bryson 2023).

The measurement of the culmen was taken to the indentation on the front of the skull following the convention for the measuring of passerines (Demongin 2016, p. IX).

The measurements for the ssp. *M. m. atmorii* in Keith *et al.* (1992, p. 507) correspond with our findings (Table 2).

Our results show that all measurement averages of females are smaller than those of males, especially those of wing and tail as in Maclean (1993, p. 508), Keith *et al.* (1992, p. 507) and Rose *et al.* (2020). The measurements of females have a greater range (minimum to maximum) than the males for wing, tail, tarsus and culmen (including a greater maximum value), while the males have a larger head and mass average and maximum.

Like in all desert birds, the mass is highly variable. Friedmann & Northern (1975, p. 28) collected of *M. m. atmorii* one male weighing 38 g, and five females from 30–38 g (33.2 g), both sexes being in the high range of our sample with a range between 24.5 g and 39.5 g and a median value of 29.1 g.

M. m. albipileata is claimed to be smaller than the nominate (Keith *et al.* 1992, p. 507). However, all measurements (excluding mass) of the two Angolan birds we ringed are greater than those published (ibid.) and even greater than the average Namibian values in our sample (excluding head). Also, the first description of *albipileata* by Bocage has all measurements bigger than the averages of

Table 2: *Measurement data from the literature: Average measurement data (including minimum and maximum measurements) of adult Mountain Wheatear* M. m. atmorii *(Dean 2005, p. 949; Keith* et al. *1992, p. 507; mass from Friedmann & Northern 1975, p. 28) and of* M. m. albipileata *(Keith* et al. *1992, p. 507). Measurements are grouped by sex.*

Grouping	**Parameter**	**Wing (mm)**	**Tail (mm)**	**Tarsus (mm)**	**Culmen (mm)**	**Mass (g)**
***M. m. atmorii* Namibia**						
Adult Females	Mean	103	67.5	28.8	21.5	33.2
	Min–max	99–107	62–73	28–30	20–24	30–38
	n	11	11	11	11	4
Adult Males	Mean	108	70.2	29.9	21.6	38.0
	Min–max	105–111	65–76	28–32	20 –23	
	n	15	15	14	14	1
***M. m. albipileata* Angola**						
Adult Females	Mean	101	67	28.8	20	30
	Min–max	100–106	65–70	28–29	20–20	
	n	6	6	6	6	1
Adult Males	Mean	102	67.7	29.6	20	30.7
	Min–max	99–107	66–69	29–30	19–21	28–35
	n	7	7	7	7	4

monticola: bill 23 mm, wing 107 mm, tail 80 mm, tarsus 30 mm (Bocage 1867, p. 429).

5. BREEDING: EGG-LAYING, INCUBATION AND FLEDGING

The observed and published egg-laying dates of the Mountain Wheatear vary widely between September and March, depending on the area. Furthermore, in arid areas eggs are laid opportunistically after rain (Dean unpubl., in Dean 2005; Keith *et al.* 1992, p. 508).

In South Africa, a winter-rainfall area, breeding activity peaks in September to November (range from June to March) (Keith *et al.* 1992, p. 508) or mainly in October (range from September to November) (Winterbottom 1968, quoted in Harrison 1997, pp. 172–173; Tarboton 2014, p. 294).

In Namibia, a summer-rainfall area, egg-laying takes place later, usually between January and early March (ibid.). Besides the moult process, Figure 10 shows Namibia's nesting data for the Mountain Wheatear (Brown *et al.* 2017). The peak of the curve is December and January, but nests have been recorded in all months of the year, excluding June.

Matching these data, Hoesch and Niethammer found two complete clutches in Namibia with two and three eggs on 21 January and 10 February 1939, respectively (Hoesch & Niethammer 1940, p. 243).

The young fledge about 21 days after egg-laying (after 13 days of incubation and 14–16 days of nestling period) (Tarboton 2014, p. 294) and are kept under parental care for about one month after leaving the nest (Dean, unpubl. data, in Dean 2005).

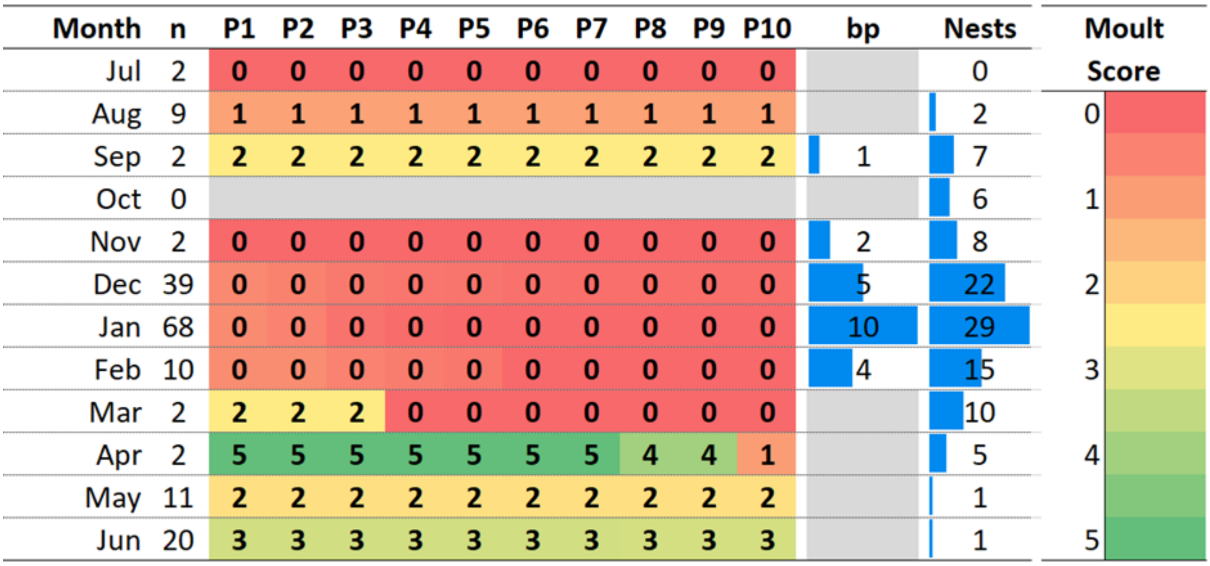
In 2009, we ringed two chicks in the nest on 13 February and two on 22 December. Throughout 2006 to 2020 we ringed visibly young birds (within their first six months of age: SAFRING code 5) from early January to mid-March, and one at the end of May.

6. BREEDING AND MOULT

The available energy of a bird is typically used sequentially for establishing a territory, mating, egg-laying, breeding and feeding the young, and migration, when applicable. The quite costly complete moult begins in most songbirds immediately after completing the breeding process (Svensson & Hedenström 1999, p. 264) and mostly indicates the actual status of the bird in its annual cycle (Perrins 1970; see also the discussion in Jenni & Winkler 2020, pp. 178–179).

7. MOULT OF THE MOUNTAIN WHEATEAR

The Mountain Wheatear follows the general passerine pattern of a complete post-breeding moult. The order of the primary moult is descendent, and the secondary moult starts with the outermost S1 (Figure 11). The code 0 designates an old primary, the code 1 a sprouting or missing feather, code 2 a growing feather of less than 1/3 of its final length, and code 3 2 a growing feather of less than 2/3 of its final length (see de Beer *et al.* 2001). For a detailed description of the moult sequence of passerines see Kasparek (1981, p. 6f.).



Month	n	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	bp	Nests
Jul	2	0	0	0	0	0	0	0	0	0	0		0
Aug	9	1	1	1	1	1	1	1	1	1	1		2
Sep	2	2	2	2	2	2	2	2	2	2	2	1	7
Oct	0												6
Nov	2	0	0	0	0	0	0	0	0	0	0	2	8
Dec	39	0	0	0	0	0	0	0	0	0	0	5	22
Jan	68	0	0	0	0	0	0	0	0	0	0	10	29
Feb	10	0	0	0	0	0	0	0	0	0	0	4	15
Mar	2	2	2	2	0	0	0	0	0	0	0		10
Apr	2	5	5	5	5	5	5	5	4	4	1		5
May	11	2	2	2	2	2	2	2	2	2	2		1
Jun	20	3	3	3	3	3	3	3	3	3	3		1

Figure 10: *Extent of primary feather moult (P1 to P10) of adult Mountain Wheatear (*M. m. atmorii*). Values are average moult scores of each primary for the number (n) of birds per month sampled. The colour gradient is shown on the side. Counts of birds displaying a full brood patch (bp) are given, as well as nest count values for Namibia from Brown* et al. *(2017). No data were collected for the cells marked in grey.*

7.1 Moult data for the Mountain Wheatear in the literature

In the literature "no data" is recorded for the moult of the Mountain Wheatear (Dean 2005; Clement & Rose 2015) although the latter mention "several females of the race *atmorii* in active moult in October in Namibia". In the original source we found that only "one of the females still had some of the outer primaries basally enclosed in sheaths" (Friedmann & Northern 1975, p. 28), thus she was finishing the primary moult in October.

7.2 Moult data of the Mountain Wheatear ssp. *atmorii* in Namibia

Our moult data of the primaries gathered from more than 160 Mountain Wheatears of the ssp. *atmorii* are presented in Figure 10. We also compare our recorded brood patch data per month with the numbers of active nests from Brown *et al.* (2017).

Figure 11: *Descendent primary moult of an adult male Mountain Wheatear. Primary moult score 17 (5543000000). The innermost secondary, the first to moult, has already been shed. Secondary moult 100000. SAFRING FH63920, 6 February 2012.*

The data in Figure 10 reflect that moult was recorded in Mountain Wheatears almost throughout the year. The constant low scores do not indicate short feathers, but result from the mean being calculated from few moulting feathers and numerous feathers which were not moulting. This fact also leads to the lighter red fields marked with "0" in the months December, January and February.

Of 17 examined immature Mountain Wheatears, three underwent their first primary moult, extending from January (4300000000, 5554410000) to March (5432000000) (Figure 12).

Figure 12: *Black male after the pre-breeding partial moult at the end of his first year of life. The fresh black upperparts contrast with the juvenile brown wing and the tail. Both are well abraded and will be moulted only a few months later in a complete moult after the adult breeding season. SAFRING FH33993, 7 January 2007.*

7.3 Record of brood patches

Brood patches indicate the timing of breeding. In birds that start incubating with the first egg, they usually develop at the beginning of the laying period and in birds that start incubating with the last egg they develop towards the end of the laying period (Brown & Franke-Bryson 2016). Mountain Wheatears, like most passerines, start incubating when the clutch is (almost) completed (Stanford 2022; R Bijlsma, pers. comm. 2022).

Not all of our captured birds were checked for brood patches. Even so, we found a total of 16 brood patches in females, all of them during the southern summer months and the favourable rainy season between the end of November and early February (see Figure 10).

7.4 Overlap of breeding and moult

During the year's cycle, only a certain amount of energy is available for development. Both breeding and moulting are energetically demanding, and thus rarely overlap in their timing. We did not observe any overlap of active brood patch and moult in the Mountain Wheatear. This feature is regularly found in other bird species, like Southern Fiscal (*Lanius collaris*), White-crowned Shrike (*Lanius anguitimens*) (Bryson & Paijmans 2021, 2022) or Namaqua and Burchell's Sandgrouse (*Pterocles namaqua* and *P. burchelli*) (Bryson unpubl. data**).**

7.5 Interrupted and irregular primary moult

The term "**interrupted** moult" encompasses **suspended** and **arrested** moult. Both occur in the same sequence as a regular wing moult but may temporarily be discontinued during breeding (or migration). If the moult is **suspended** it will later resume at the same location where it stopped. With **arrested** moult, in contrast, moulting does not continue but will restart from the normal site of initiation, usually P1 (Harper 1984, p. 101; Shirihai & Svensson 2018, p. 24; Jenni & Winkler 2020, p. 63).

Interrupted moult is a common feature of birds in arid habitats. Although there is a general breeding season and thereafter the period for moulting, the features of the annual cycle are adapted to the circumstances. Without precipitation, and the subsequent adverse conditions for raising chicks, the birds tend to start moulting instead of breeding. But as soon as rain falls, breeding begins. The shedding of feathers stops. Those feathers in active moult will continue to grow to their full length and the fully grown wing will then show new flight feathers next to old ones.

Not much is known yet about **suspended** and **arrested** moult in Namibian species. During our study period of 20 years, we observed **interrupted** moult in numerous species we examined in our research area of arid habitat in the west of Namibia. Examples are Common Fiscal (Bryson & Paijmans 2021); Tractrac Chat *Emarginata tractrac*, Karoo Chat *Emarginata schlegelii,* Namaqua and Burchell's Sandgrouse *Pterocles namaqua and P. burchelli*, Temminck´s Courser *Cursorius temminckii* and others (Bryson & Paijmans, unpubl. data). Also, in Red-billed Spurfowl *Pternistis adspersus*, Cape Turtle Dove *Streptopelia capicola*, Laughing Dove *Spilopelia senegalensis*, Namaqua Dove *Oena capensis*, Dusky Sunbird *Cinnyris fuscus*, Bokmakiri *Telophorus zeylonus*, White-throated Canary *Serinus albogularis*, Sabota Lark *Mirafra sabota*, Karoo Long-billed Lark *Certhilauda subcoronata* and in other species we found this feature, as we did in other ringing areas in Namibia. For both Tractrac Chat and Karoo Chat, we could ascertain **suspended** moult (ibid.), a feature not yet recorded.

In the Mountain Wheatears we checked for moult, we did not observe any irregular primary moult. However, we recorded 11 individuals with **interrupted** primary moult, all of them between December and March.

We did retrap one of those individuals four months later when moult was completed (SAFRING FH31312: ringed on 19 January 2006 with 5000000000, retrapped on 30 May 2006 with all new wing 5555555555). The subtle colour difference between P1 and the following primaries served as an indicator of **suspended** moult. Thus, the replacement of nine primaries (P2 to P10) occurred in less than 130 days.

We recorded one individual (SAFRING FH21245) on 27 August 2004 also with **suspended** and then completed primary moult. The four inner primaries were older and six outer primaries new (0000555555) (Figure 13).

Figure 13: *Remiges with perfectly shaped tips and edges after the completion of the moult. The four inner primaries are lighter, since they were grown before the moult suspension. The primary coverts of P1 to P4 and the greater coverts are of the same age while the outer primary coverts are fresh. SAFRING FH21245, 27 August 2004.*

8. AGE DEVELOPMENT IN THE FIRST YEAR

For age terms see the Glossary for Ageing in Bryson & Paijmans (2021, pp. 21-22).

First-year birds comprise individuals from nestling and fledgling to juvenile birds, and, after the post-juvenile moult, immature birds. Passerines reach adulthood and maturity when entering their second year of life (Bub & Dorsch 1988, p. 7), and then adopt the breeding cycle of adults.

8.1 Nestling

In the beginning of 2009, we found a nest on an empty shelf inside an abandoned farmhouse. On the shelf below was an old nest from former breeding activity (see also Plowes 1948, p. 80). At the end of January the new nest contained two eggs, and on 13 February, when we checked next, the young had hatched. In the meantime, the nest had been reinforced and re-upholstered (Figure 14).

Figure 15 shows one of the nestlings, which must have been less than a week old: according to Plowes, who followed the development of the breeding and

Figure 14: *A Mountain Wheatear nest on a shelf in an abandoned farmhouse. (A) and (B) With two eggs. (C) With the hatched young two weeks later. The nest by then had been refurbished with dry grass stalks and finer, soft material inside the nest. 28 January and 13 February 2009.*

Figure 15: *Nestling a few days after hatching with very first downs on head, back and, to a lesser extent, on the lateral vane. 13 February 2009.*

hatching minutely (1948, p. 84), the first primaries become visible at about one week old – at this stage we could not see any traces of these. At a few days old, the nestling's body is almost naked, with brown downs growing only on the crown and along the vane on the spine, and starting to appear on the lateral vane. The gape flange is bright, but pale yellow, as is the beak. The eyes are still closed.

8.2 Juvenile

In an astoundingly short period of two weeks the young passerines reach full size and the first feathering covers the whole body. The quality of the feathers, though, is poor and the density low due to the restriction in food supply during this fast-paced development.

Young Mountain Wheatears can be discerned by a prominent, now dark yellow gape flange (Figure 16) and a drab, loose plumage with low numbers of barbs.

Figure 16: *Juvenile Mountain Wheatear. (A) Close up of the head with yellow gape flange and (B) body with loose drab plumage of mantle and coverts and almost translucent primaries and secondaries. See also on the rectrices the juvenile pale rufous tinge above the terminal black band. SAFRING FB22183, 20 December 2013.*

8.3 Spots on the wing of juveniles and immatures

In some juvenile males of the black morph we observed white dots on the marginal and lesser coverts (Figure 17) and in the grey morph white terminal spots along the marginal coverts (Figure 18). This feature seems not have to been described before, but "the uniform head and upperparts [of juveniles are claimed to be] lacking any pale spots" (Clement & Rose 2015, p. 646).

In the grey morph, the transition of males from the uniform juvenile dark brown to the grey plumage results in a mottled appearance, as can be seen in Figure 18 on the sides of the head and on the chest.

8.4 Post-juvenile moult and distinction of the sexes in early age

Within the first two months of life (Dean 2005, p. 948) the juvenile plumage is replaced during the

Figure 17: *Juvenile male Mountain Wheatear with dark black plumage. (A) Close-up of the head with the prominent yellow gape flange and yellowish edges on the beak. (B) Marginal coverts with white spots. The second outer primary is still in the sheath which indicates a very young bird still growing the primaries and corresponding secondaries. SAFRING FH63208, 22 January 2010.*

partial post-juvenile moult by an immature first-year plumage. In most chat species this is still distinct from the adult plumage (Clement & Rose 2015, p. 15, but no further description given for Mountain Wheatear).

The colouration of the juvenile plumage is said to resemble that of the female (Taylor 1946, p. 248; Dean 2005, p. 948).

We found that the sexes are distinguishable at an early age and can be determined by the overall colouration of the plumage (Figure 19). There is a distinct colour difference between the brownish or slate colouration of the female and the shiny pitch-black males. Females show a plain wing, males a blurry white patch of the marginal and lesser coverts (Figure 20) as described in Davies (1910, p. 36) who "shot a young male, hardly fledged, with white shoulders, this skin is now in the Transvaal Museum".

8.5 White covert-patch as indicator of age

The covert-patch of adult males, formed by the marginal and lesser coverts, is considered to be all white (Keith *et al.* 1992, p. 506; Dean 2005, p. 948) (Figure 21). It is sometimes called "shoulder-patch" for convenience, but it is located around the joint between ulna and metacarpus.

Figure 18: *Juvenile grey male, two months old at most, with decreasing yellow gape flange at the beginning of his post-juvenile (partial) moult. The primary and secondary coverts and the alula still show fine pale fringes, the dark marginal and lesser coverts show white spots. SAFRING BH17854, 27 November 2003.*

We have observed that an all-white patch is a sign of a fully adult bird only. Younger birds show dark markings on white. The markings consist of several dark brown or black feathers of the distal marginal coverts in both morphs and dark streaks in the grey morph. It is unknown how long it takes for a Mountain Wheatear to accomplish its full adult plumage and at what exact age the coverts turn all-white.

In juveniles, the covert-patch is faint and only slightly expressed (Figures 19B and 20B). It develops fully during the first pre-breeding moult around the end of the first year of life. In the black morph, black markings on the distal marginal coverts (Figure 22) seem to be a quite common feature from an early age onwards. Reviewing our photographs, from 34 males we recorded 16 with substantial and 10 with minor markings, while on eight individuals, the marginal and lesser coverts

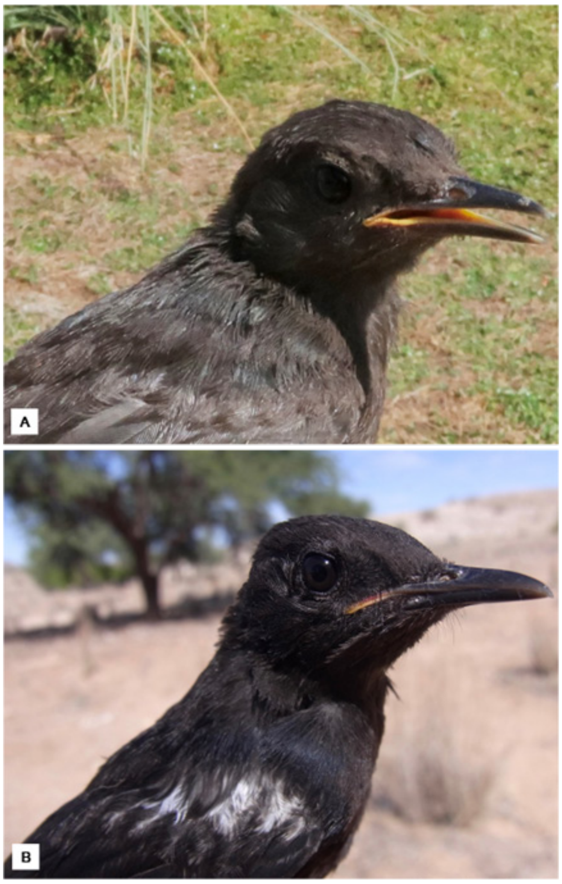


Figure 19: *Juvenile Mountain Wheatears (*M. m. atmorii*) within their first two months of age and during their post-juvenile (partial) moult. Note the prominent yellow gape flange. (A) Female in dark brown-grey plumage of light quality. The mantle shows first single darker feathers, the coverts are still paler, and the wing is plain without white patch. The yellow inner mouth can be seen. SAFRING FH79579, 27 February 2020. (B) Male in soft black plumage. The white covert-patch is already well visible, as is a dark shine of the new generation of feathers. SAFRING FB22182, 20 December 2013.*

Figure 20: *First-year birds in fresh plumage. (A) Juvenile dark-brown female. SAFRING FH79579, 27 February 2020. (B) Pitch-black young male after its post-juvenile moult. The white, faint covert-patch is almost hidden, the mantle and head feathers are opulent and uniform. SAFRING FB22296, 7 January 2014.*

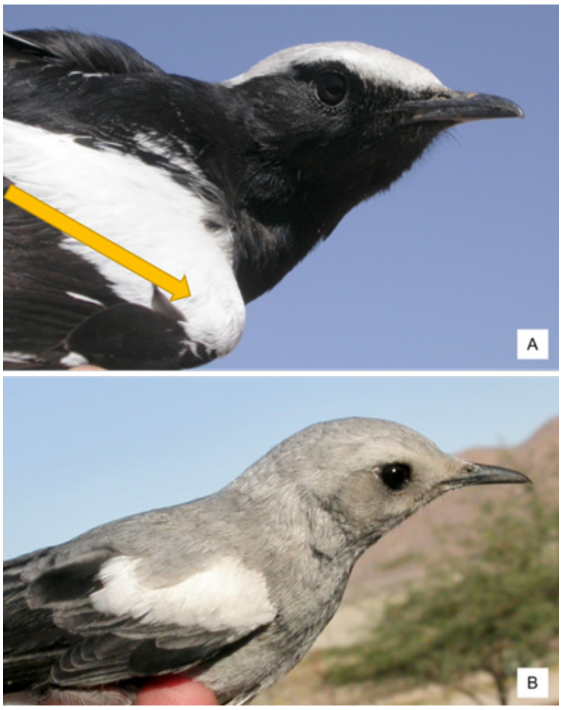


Figure 21: *Adult males with plain white marginal and lesser coverts. (A) Black morph, SAFRING FH21245, 27 August 2004. (B) Grey morph, SAFRING FH13705, 21 June 2003.*

were all white. Since the birds otherwise were recognisable as adults by plumage abrasion and bleaching and dark gape flange, it must be a feature continuing from the first year into the second or even third year.

In the grey morph, we found first-year birds that had prominent dark shafts on the white covert-patch (Figures 23 and 24A) and faint grey shafts after the first complete moult (Figure 24B). Also, the bill changes colour with age, from horn-coloured to black.

The plumage differences between first-year males and older ones are depicted in Figure 25: The brown tinges of all parts changes to grey and black colours.

Figure 22: *Black markings on the distal marginal coverts on a sub-adult male. No gape flange is visible anymore, the feathers with dark markings are fresh. SAFRING FH33993, 9 January 2007.*

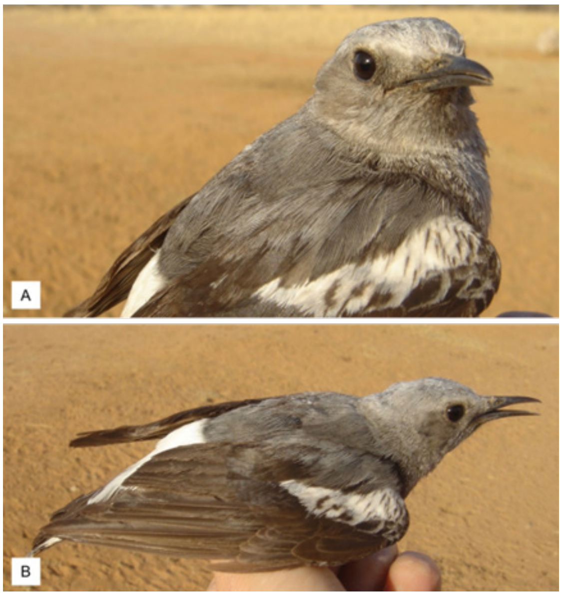


Figure 23: *Signs of a first-year male Mountain Wheatear: horn-coloured bill, strong dark shafts on the covert-patch and dark markings on its distal edge. (A) Close-up and (B) mainly grey mantle compared to the brown wings of the first plumage. SAFRING FH33709, 6 January 2007.*

8.6 Colouration of the inside of the mouth and colouration of the beak of female and male

The colouration of the inside of the mouth undergoes a change during ageing, corresponding to the gape flange and outer bill. Juveniles have light yellow inner mandibles that get darker yellow in immatures and finally turn dark, greyish and blackish, in adults (Figures 26 and 27).

Figure 24: *With age, the bill and the gape flange become black and the dark shafts and markings become paler. (A) First-year male, still with brown wing and dark distal marginal coverts. SAFRING FH38192, 19 January 2009. (B) Presumed second-year (of life) male with cold-grey plumage and blackish wings. SAFRING FH44463, 22 January 2008.*

Figure 25: *A comparison of the males from Figure 24. (A) First-year male, the brown wing and the tail are worn. SAFRING FH38192, 19 January 2009. (B) Presumed second-year (of life) male with fresh, blackish wings, coverts and tail. SAFRING FH44463, 22 January 2008.*

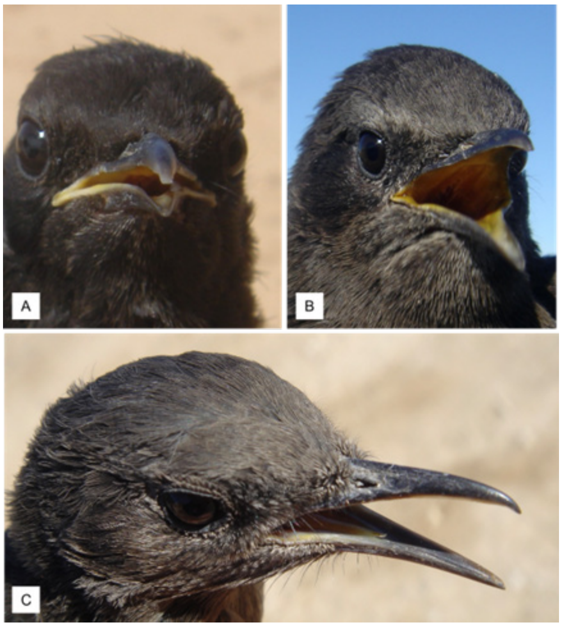


Figure 26: *Comparison of gape flange and inner mouth of (A) juvenile, (B) immature and (C) sub-adult Mountain Wheatear. The juvenile (A) shows an extensive, light gape flange which colour extends to the inside of the mouth, in the immature (B) the gape flange has receded and has become darker and in the sub-adult (C) the gape flange and inside of the mouth are greyish-yellow. SAFRING FH39430, February 2009; SAFRING FH33530, May 2006; SAFRING FH33538, May 2006.*

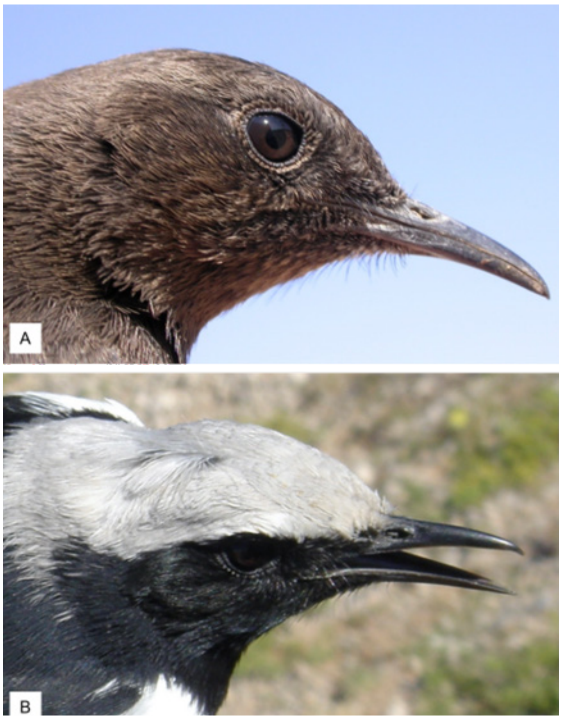


Figure 27: *(A) Dark horn-coloured beak of an adult female. SAFRING FH31538, August 2004. (B) Black gape flange and beak of an adult male. SAFRING FH31538, May 2006.*

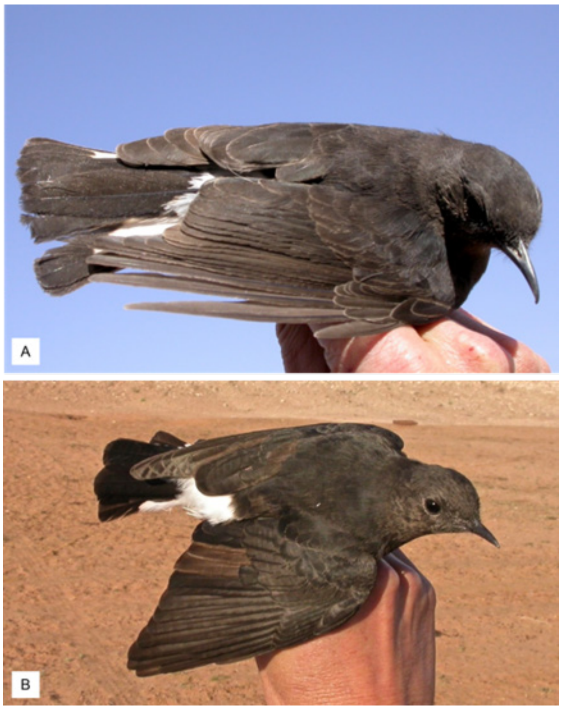


Figure 28: *(A) Uniform dark brown plumage of an adult female, with signs of the partial moult on the marginal coverts. SAFRING FH21054, August 2004. (B) Adult female, presumed second-year, with freshly moulted primaries and tertials. Of the secondaries, the three lighter ones are still old. SAFRING BD07552, 21 April 2003.*

9. ADULT FEMALES

Adult females have a dark horn-coloured beak and a slaty-grey to blackish-brown plumage. The beak never seems to become as dark as in males. During the year the dark plumage turns lighter brown which creates a notable contrast during the following active moult (Figure 28).

Some individuals show feathers of the previous plumage, for example the adult female in Figure 29B. The lighter area in the tail is not white as in fully mature birds, but buff, as the upper-tail cover peeking out from under the wing (B). It is unexplored if these are residual feathers or consistent, overlooked signs of second-year birds.

Older females can show some white on marginal and lesser coverts (as mentioned in Clement & Rose 2015, p. 646). Unfortunately, there is no original reference or a further description of this feature in males. On one of the females we ringed, though, a light white hue was visible at the covert-patch and above the eye (Figure 30). It is undetermined if these features result from hormonal changes in advanced age, which we can regularly observe in other species: older females of the Southern Masked Weaver (*Ploceus velatus*), for example, are likely to display marbled orange, not brown eyes, while older males of the Southern Red Bishop (*Euplectes orix*)

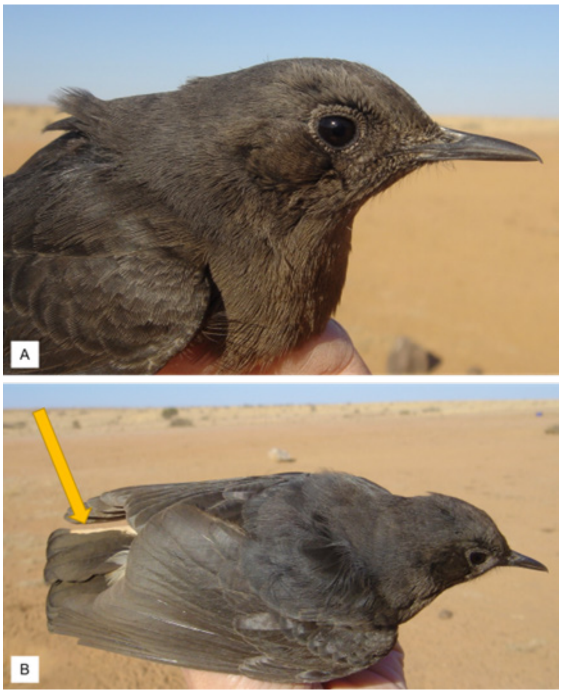


Figure 29: *This adult female has finished her yearly complete moult. (A) Close-up of the head with dark gape flange and marginal coverts with fine lighter fringes. (B) The tips of the freshly moulted primaries and secondaries are in perfect shape. The residual light rufous, not white, tail areas indicate a second-year bird. SAFRING FH34959, 17 June 2007.*

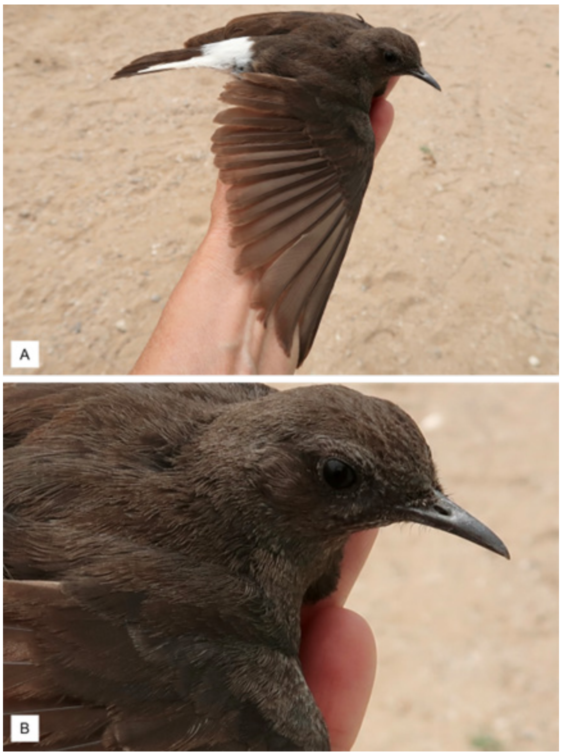


Figure 30: *Adult female Mountain Wheatear with slight male features. (A) Full view and (B) Close-up showing a hint of white on the supercilium and on the marginal and lesser coverts. SAFRING FH84811, 11 January 2021.*

lose the brightness of their red plumage, which turns more pale and orange.

10. ADULT MALES

The black and the grey colour morphs of adult males show a great variability of colouration of the upper- and underparts. Males can mostly be recognised by the white marginal and lesser coverts.

Describing the species, Levaillant erroneously considered the grey morph as “jeune age... avec son plumage au sortir du nid”, “of young age ... with its plumage when leaving the nest” (1805, p. 106; see Plate 185 in Fig. 6) (Figure 31) which was repeated by Vieillot when he described the species (1818, p. 434-435).

This discussion how to categorise the colour variations went on for many years until Davies (1910) proposed two different morphs with extensive variability in the amount of black, white and grey.

10.1 Black morph

A great array of variation occurs even in small areas of distribution. In our study area, the grey morph occurs beside the dominant black morph sometimes

Figure 31: *Levaillant´s depiction of the Mountain Wheatear (1805, Plate 185), taking the grey morph for a young bird, and a black male for “middle age” for his grey cap. https://www.biodiversitylibrary.org/page/41414789#page/182/mode/1up.*

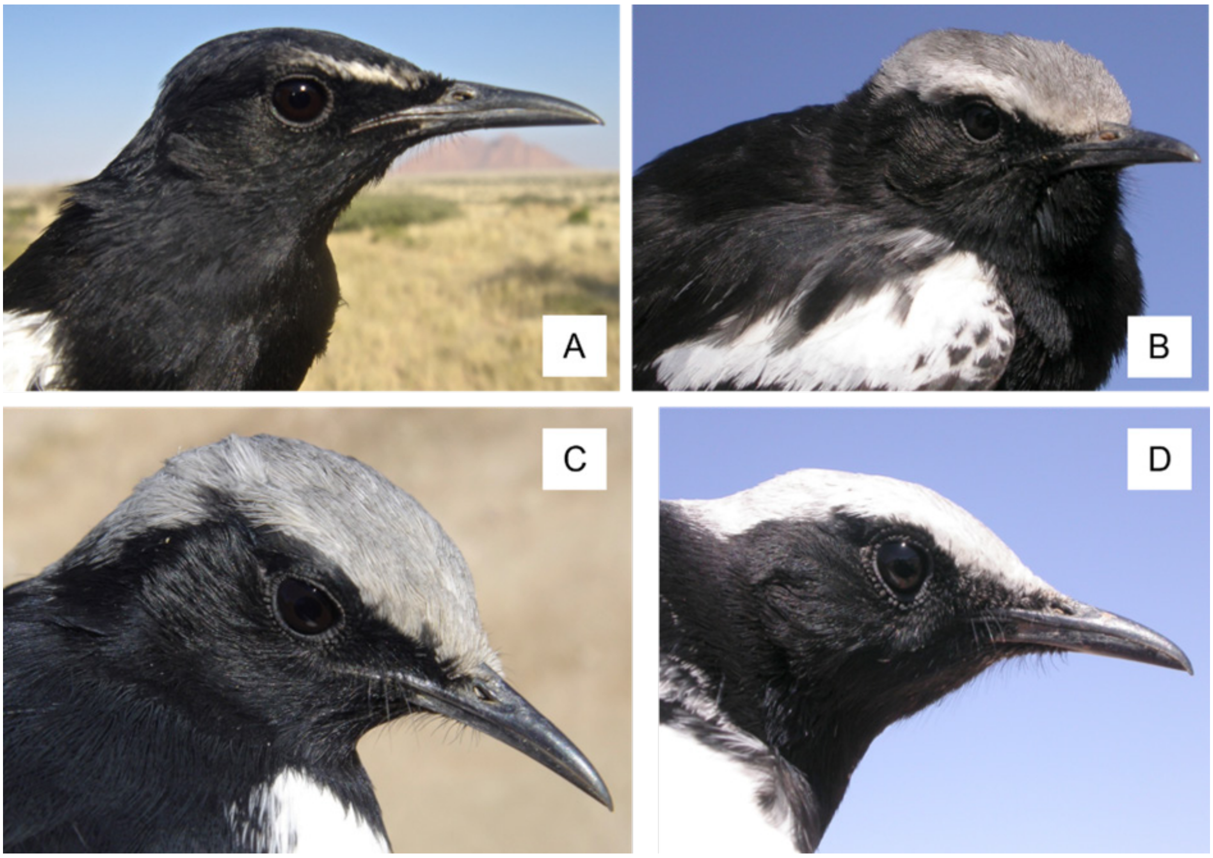


Figure 32: *The variety of head phenology of the black morph is well described. (A) Black head with white supercilium; (B) grey crown with white supercilium; (C) plain grey crown; (D) silver, almost white crown. 16 June 2006, 28 August 2004, 30 May 2006, 27 August 2004.*

in adjacent territories but always in fewer numbers (confirming the observations in Namibia of Hoesch & Niethammer 1940, p. 243). One group of our observation sample yielded 68 black and 17 grey individuals.

The variations of plumage features comprise head, crown, neck in various combinations, darkish grey, bluish-grey or white crown, at times a narrow white supercilium (Figure 32), white or white-mottled belly to vent, and a very variable tail pattern. This also seems to be the case in the subspecies *albipileata* from Angola where the plumage features are hardly described. (For further studies on plumage variations see the photographic records in the Macaulay Library of the Cornell Lab of Ornithology, Macaulay Library 2022a).

Figure 33: *Adult male Mountain Wheatears of the grey morph with (A) white and (B) grey marginal and lesser coverts. (B) The brown remiges and overall brownish colouration suggest that this is a second-year bird. SAFRING FB22190, 20 December 2013 and SAFRING FH30724, 18 June 2005.*

Figure 34: *A grey adult male with faint white supercilium and exceptional grey greater coverts. SAFRING FH13719, 22 June 2003.*

10.2 Grey morph

The grey morph, too, shows a number of individual variations of the plumage. In our sample it concerns mainly the amount of white in the tail and especially on the wing (Figure 33), and a fine white supercilium, which has not yet been described (Figure 34). Presumably, cold grey plumage is the sign for full adults, while the warmer and browner plumage of some individuals illustrates a second-year feature. We also found grey males with white and with grey marginal and lesser coverts (Figure 34). The variation of grey or black greater coverts has to our knowledge also not been described yet (Figures 35 and 36B).

In Summary: Colour differences in our sample originated mainly from age differences. Until the first complete moult, young grey individuals have brown (female-like) remiges and rectrices, a warm grey mantle and dark streaked and marked marginal and lesser coverts (Figure 35A). There is possibly a second-year plumage with transitional features: the upper body becomes greyer, but the covert-patch is still not fully white. Full adults are bluish-grey with black wings and tail and plain snow-white marginal and lesser coverts (Figure 35B).

Figure 35: *(A) First-year grey male before his first complete moult with dark horn-coloured beak, brown wing and tail and warm grey mantle. The white covert-patch shows streaked shafts and dark distal markings, one tail covert with a dark centre. SAFRING FH33709, 6 January 2007. (B) Fully adult male with black wing and tail, blue-grey mantle and (almost) plain white covert-patch. The greater coverts are black. SAFRING FH30737, 19 June 2005.*

11. NOTES AND OBSERVATIONS

11.1 Variation in the tail pattern

Clement & Rose (2015, p. 647) incorrectly attributed different tail patterns to different subspecies: beyond the three almost fully black inner tail feathers in all subspecies, *M. m. monticola* is claimed to have two fully white outer tail feathers, *M. m. atimorii* to have the three outer white with black tips, and *M. m. albipileata* to show transitional features. Unfortunately, no sources are given for this claim.

In "our" subspecies (*M. m. atimorii*), we found a great variety of tail markings. No change in the tail markings seems to occur during ageing, nor could a specific pattern be found for females or males. It appears that the amount of white on the outer rectrices as well as the breadth of the black tips are individual expressions that cannot be categorised.

We found variations of the tail pattern in females and males showing a wide array of markings on the outer tail feathers and the subterminal spots (Figures 36 and 37). All pictures show *M. m. atimorii.* Compare also the depictions of the tails in Figure 31 by Levaillant (1805, plate 185).

Figure 36: *Variation of tail markings of* ***female*** M. m. atimorii. *(A) and (B) with variant extent of brown along the edge of the outer rectrix, and (C) and (D) with varying width of the subterminal bar.*

11.2 Overall numbers of Mountain Wheatear

The South African Bird Atlas Project 2 (SABAP2) hosts statistical data about the birds of southern Africa (SABAP2 2022). In the database, the average reporting rate of Mountain Wheatear has declined over the years. In Namibia, since SABAP1 (1981–1998), there is a decline of over 10% in the reporting rate compared to SABAP2 (2007–present) (ibid.), with similar reports for the Northern and Western Cape. In Botswana, the species was recorded during SABAP1 in 12 Quarter Degree Grid Cells, and not reported during SABAP2 for the last 10 years.

It is not known if this decrease reflects real change of Mountain Wheatear numbers or if it is related to changes in observation patterns. Although there are differences in methodology between SABAP1 and SABAP2 (i.e. survey protocol, spatial unit and no measure of effort), this is still a notable decrease in reporting rate for the Mountain Wheatear in Namibia and Botswana.

11.3 Sex ratio

The ratio between the sexes in our sample was quite balanced, with 93 males and 90 females.

11.4 Retraps, site fidelity and longevity

Of the Mountain Wheatears that were trapped in the field and around buildings and waterholes, twelve were retrapped once, and six were retrapped twice, all in the same pentad of their original ringing.

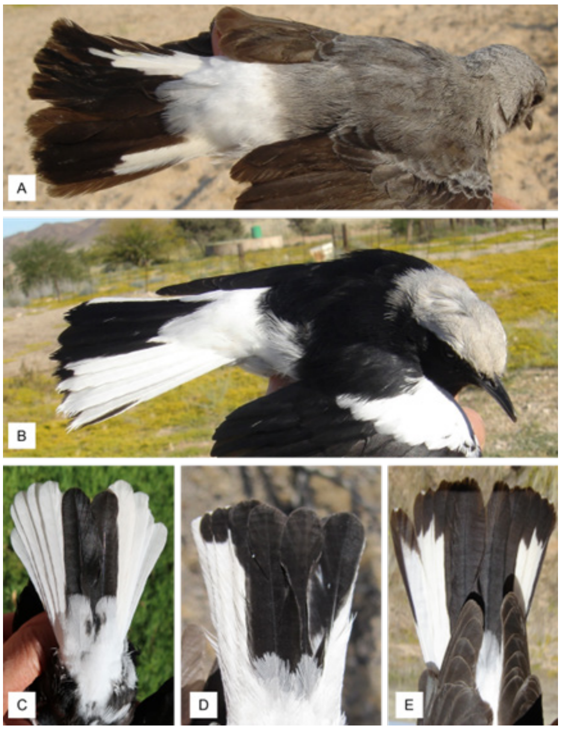


Figure 37: *Variation of tail markings of* ***male*** M. m. atimorii. *(A) Grey morph with dark outer vane, (B) male with the four outer rectrices full white except for a black streak on T6, (C) all white T2 to T6, (D) and (E) with small white spots on tip of the black markings.*

One male (SAFRING FH33533) living around a house and garden was ringed as an adult on 30 May 2006. It was retrapped and resighted at least 35 times over the next 12 years. The last sighting was on 25 February 2018. One year later, the territory had been abandoned. During these 11y 9m 4d, a longevity record for this species, we observed him being involved in breeding several times in an old building (see nest from Figure 14). The first female mate of several years (SAFRING FH34817) disappeared from the area from unknown causes, and we recorded another mate in the following season.

11.5 Behaviour

Our observations suggest that Mountain Wheatears can act quite insightfully. While the Tractrac Chats we observed in our research area are consistently trap-shy, i.e. we did not retrap any of more than 60 individuals ringed (Bryson *et al.* unpubl. data), we found that the Mountain Wheatears learn quickly. One became quite confident and used to us, especially as a food source. When it saw us arriving, after weeks or even months, or when we clinked a glass bowl with a few mealworms, the bird would come flying, even from far away. In another incident, we observed a Mountain Wheatear just released after ringing, going for the next trap nearby. After eight minutes of what looked like a thinking and decision-making process in front and around the trap, the male grabbed the worm with speed and escaped the closing trap (Franke-Bryson 2016).

11.6 Parasites

Out of 200 individuals ringed, 12 were hosts of ticks. Mostly, we counted one or two ticks, but young birds in February and March were more infested (with 17, 8 and 6 ticks). We found that young birds are more prone to be targeted by ticks than adults. In adult birds (SAFRING code 4) we found ticks in three of 226 birds, in juveniles (SAFRING code 5) in four individuals out of nine.

Despite uncertainties in identification, we presume after research and discussions that the tick species is the "cattle tick" *Rhipicephalus (Boophilus) microplus* of the family of *Ixodidae*, the so called 'hard ticks' since they display a hard shield on the front of their body. *Ixodidae* feed on the blood of reptiles, mammals and birds (Madder *et al.* 2023; Turner *et al.* 2017*,* see also Wikipedia 2022) (Figure 38). This species is clearly distinguishable from *Hyalomma* species which have striped legs and which we also found in birds in Namibia.

Figure 38: *Ticks found on Mountain Wheatears. We presume them to be common cattle ticks (*Rhipicephalus [Boophilus] microplus*). See the black shield on front of the body which gave them the name "hard ticks". Erongo region, 24 November 2017.*

Occasionally we find feather parasites in birds we ring. Figure 39 shows a wing infested with mites or feather lice. In the inset, the colony can be seen on the outer vane and feeding marks on the inner vane.

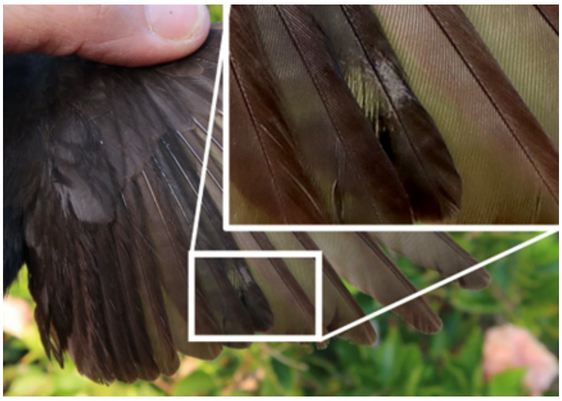


Figure 39: *Feather parasites on the wing of a Mountain Wheatear. Inset: the colony on the outer vane can be seen and feeding marks on the inner vane. 21 February 2021.*

11.7 Females with male features

We caught one Mountain Wheatear with features of both sexes (Figure 40). It was an adult bird, as visible by the wear of the plumage, and the lack of any signs of juvenile or immature age, like yellow gape flange or rufous tinge in the white areas of on the rectrices.

The overall colour was brown like a female, however with a thinly white covert-patch like found in males. Furthermore, the head, neck and chest showed tones of grey similar to the grey morph, while the ear-coverts were mildly brown like in females. The beak was dark horn-coloured like in females, not fully black like in males.

Females with male features have been described in other passerines species such as Red-backed Shrikes *Lanius collurio* and others (see Bryson & Paijmans 2023). This appearance might go undetected in Namibian (and southern African) birds since the features are not documented and thus not recognisable to the public or even researchers.

It is unclear how frequently this feature occurs. One female from the Angolan ssp. *albipileata* with similar features (Figure 41) is depicted in the Macaulay Library (2022b).

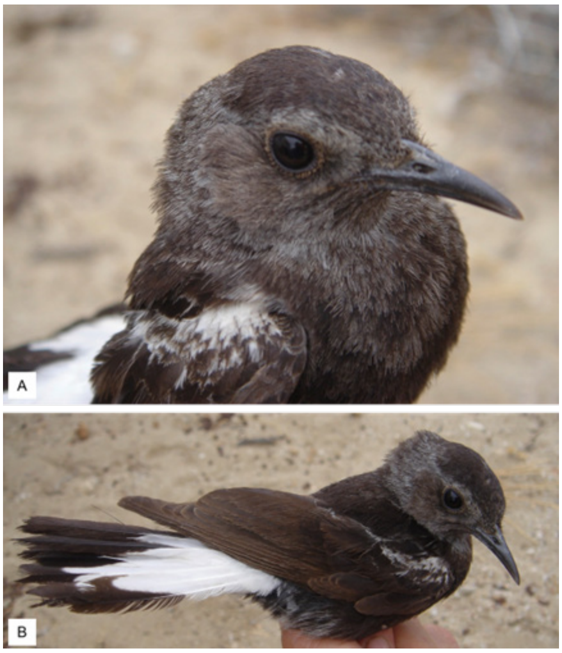


Figure 40: *Female Mountain Wheatear: overall brown, female plumage with traces of the male white covert-patch, and head, neck and chest in tones of grey, reminiscent of the grey morph of males. SAFRING FH31272, 8 January 2006.*

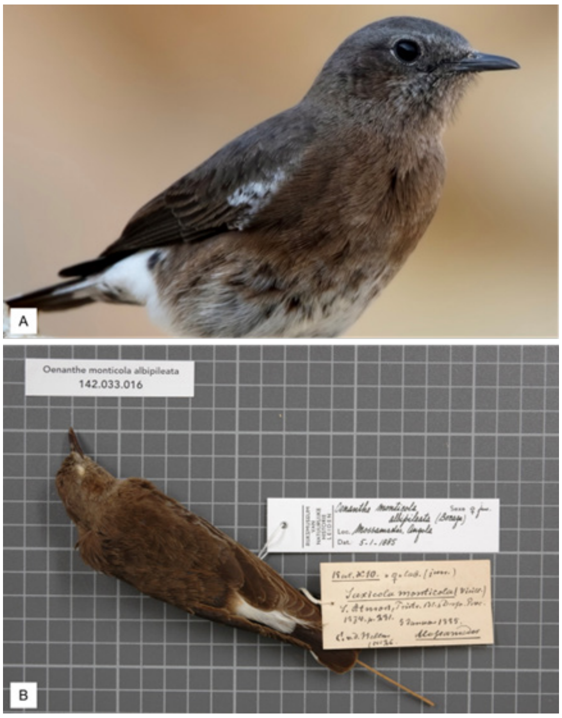


Figure 41: *A comparison of female Mountain Wheatears of the ssp.* albipileata. *(A) Adult female forming a pair (Figure 9) with grey crown and mantle, slight white supercilium and small white covert-patch. Namibe, Angola, 5 July 2018. Photo courtesy of Dubi Shapiro. (B) First-year, plain female. Collected in Moçamedes on 5 January 1885. Naturalis Biodiversity Center, Leiden, The Netherlands. [*Oenanthe monticola albipileata*; RMNH.AVES.145735], https://bioportal.naturalis.nl/ multimedia/RMNH.AVES.145735_1/term=albipileata &from=0 [Accessed 26 September 2022].*

12. FURTHER RESEARCH

The Mountain Wheatear is considered to be a locally common to fairly common species (Maclean 1993, p. 509). Yet many aspects of basic information are missing. Extensive research is needed across the different subspecies to obtain sufficient samples for a sound validation of measurements.

In terms of plumage, research is required:

- to describe the plumage after the post-juvenile moult in first-year females and males;
- to describe the development through the first (three?) years until full adult plumage with focus on the development of the covert-patch;
- to describe the undertail coverts of female and male first-year birds, i.e. of juvenile and immature birds as possible indicators for more exact age determination;
- to document residual feathers from former plumages and plumage features from the other sex;
- to describe plumage variations of the Angolan subspecies, both for females and males.

Regarding moult, basic and detailed research is needed to gain sufficient data:

- to describe moult features and moult progress in the first and second year to allow a continuous moult and age description;
- to include the moult sequences of the different feather groups, both in first-year and adult birds, for both partial and complete moult.

For further research we recommend:

- examination and description of the colour of bill and inner mouth across all ages, in both the black and grey morph;
- recording possible changes of the beak colouration in the breeding and non-breeding season;
- exploration of possible hybridisation with other species;
- a thorough examination and determination of tick species as well as other parasite species hosted by southern African bird species.

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1240 and all birds were captured and handled under a ringing license issued by the Namibian Ministry of Environment, Forestry and Tourism (Enquiries: Holger Kolberg holgerk@afol.com.na).

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Tractrac Chat *Emarginata tractrac*: comparative biometrics, moult data and criteria for the determination of age and sex

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CONTENTS

ABSTRACT

Data on the Tractrac Chat (*Emarginata tractrac*) (Wilkes), 1817 are scarce and widely scattered in the literature. We present measurement and moult data from 97 Tractrac Chats of the subspecies *E. t. albicans* ringed in Namibia over 20 years. We gathered published data of nesting, breeding and moulting, and compare our observations of the moult process and our records of active brood patches with breeding records compiled by Brown *et al*. (2017). On the basis of photographs, we describe the nestling of the ssp. *E. t. albicans* and its development to immature and then adult. We compare young and adult plumage and other features which help to distinguish these age groups. We also document several cases of irregular primary moult. We add observations on site fidelity; on changes in habitat and subsequent changes in numbers of territories; on the development of overall numbers of the species in our research area; on behaviour and on parasites and injuries. We also point out errata in the literature from Levaillant that remain in use, as well as discuss the elevation of the distribution range.

Keywords: age; behaviour; biometrics; bird ringing; breeding; Levaillant; moult; misidentification; *Muscicapidae;* Namibia; SABAP; SAFRING; sex; subspecies; territory

1. INTRODUCTION

Data on the Tractrac Chat (*Emarginata tractrac)* are scarce and widely scattered in the literature. Between 2004 and 2013 we ringed and collected data from 100 Tractrac Chats (*E. t. albicans*) (Figures 1 and 2), including 33 data sets mostly from the coast at Swakopmund and data of one roadkill from that area. In this paper we present our observations, our results of measurement and our moult data from these specimens. During our study we recorded eight individuals with active brood patches which are considered to be a reliable indication for breeding. Our moult data for the species, substantiated by photographs, give insights into the moult strategies of *E. t. albicans*. Furthermore, we discuss the misidentification of a Karoo Chat (*Emarginata schlegelii*) as a Tractrac Chat by Levaillant in his first description as well as other errata in the literature.

Figure 1: *Typical pale and bleached adult Tractrac Chat standing on its perch, a small rock, overviewing the surrounding plains. Erongo region, 11 September 2019. Photo courtesy of Mhairi McFarlane.*

Figure 2: *Adult Tractrac Chat during its annual complete moult in its typical habitat on the edge of the Namib desert. SAFRING FH43100, 3 January 2007.*

2. DISTRIBUTION AND SITES

As near-endemic residents of southern Africa, Tractrac Chats occur throughout the west of Namibia northwards into the arid southwest of Angola and southwards into the west of South Africa (Figure 3). For a detailed map of recorded sightings see the map of the Southern African Bird Atlas Project (SABAP 2022c). For unvetted sightings see the map from eBird (https://birdsoftheworld.org/bow/species/tracha1/cur/introduction).

We collected our data in the arid, almost treeless plains of central Namibia in the pre-Namib (Farm Sphinxblick 22°29'S 15°26'E, Figure 4) and westwards along the Swakopmund-Usakos road around 22°24'S 15°25'E. We also ringed and processed Tractrac Chats in the even more sparsely vegetated Namib desert (Figure 5) around Swakopmund 22°34'S 14°32'E, as well as further south towards Gobabeb 23°27'S 15°02'E and 23°32'S 14°60'E.

3. TAXONOMY AND SUBSPECIES

The southern African Tractrac Chat is split into five subspecies which show considerable differences in colouration and, to a certain extent, in size. All of them occur in Namibia. Three of them were first described in the 20th century. (See Bryson & Paijmans [in prep.] A review of the species complex *Emarginata tractrac*.)

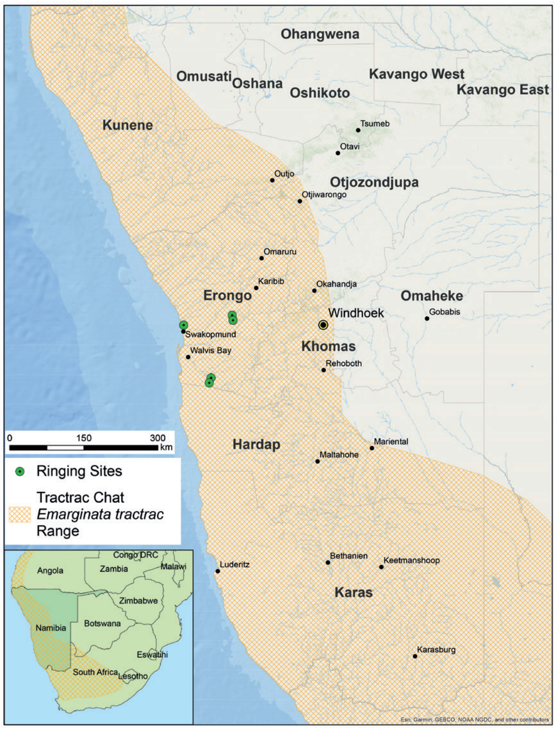


Figure 3: *Distribution map for the Tractrac Chat, downloaded from www.iucnredlist.org on 18 July 2022. The green dots designate sites where the data were gathered.*

4. METHODS

For a general description of the methods and measurements see de Beer *et al.* (2001) and Bryson & Paijmans (2021, 2022). All photographs were taken by the authors on Farm Sphinxblick in the Erongo region if not given otherwise.

4.1 Bird ringing

Birds were ringed and measured and moult scores were taken in accordance with the guidelines of the South African Bird Ringing Unit's (SAFRING) Bird Ringing Manual (de Beer *et al.* 2001, based on Svensson 1984).

Figure 4: *Typical habitat of the Tractrac Chat (*E. t. albicans*) in the pre-Namib, with a few rocks and blocks of salt lick in the foreground being used as perches. The photo was taken during the rainy season. On average there is 45 mm or rain per year. Territories here were abandoned after several years of extraordinary precipitation resulted in high grass. 14 January 2005.*

4.2 Measurements

Published measurements of the Tractrac Chat are restricted to four individuals of each sex of the subspecies *E. t. tractrac* in Dean (in Hockey *et al.* 2005, p. 954) and to three females and three males of the subspecies *E. t. albicans* in Keith *et al.* (1992, p. 536).

Table 1 presents our measurements of the Tractrac Chat subspecies *E. t. albicans* taken in Namibia. The measurement of the bill was taken to the indentation on the front of the skull following the convention for the measuring of passerines (Demongin 2016, P. IX). The table also includes the data of *E. t. albicans* from Keith *et al.* (1992) and of mixed subspecies from Rose *et al.* (2020). Our measurements were not included in the latter paper, since we are publishing them separately for Namibia only here.

As is typical for desert birds, mass is highly variable. In a good feeding season, the mass can be more than double the lowest record. Our values of *E. t. albicans* vary between the extremes of 18.6 g and 41.5 g.

A comparison with published data proves almost impossible, since in different sources sets of the different measurements are lacking, subspecies and even sex are not defined, sample sizes are too small or the methods are not declared. When comparing results between researchers these differences become evident (see Paijmans & Bryson 2023).

The measurements of *E. T. albicans* taken during our research show that males are larger than females in wing, tail, tarsus and mass, as documented in Maclean (1993, p. 512) and Keith *et al.* (1992, p. 536). Maclean (1993) does not specify the subspecies, while Keith *et al.* (1992) give the measurements of just three females and three males of *E. t. albicans* which fall within our measurement ranges (see Table 1).

Figure 5: *Typical habitat of the Tractrac Chat in the Namib desert, almost bare of vegetation. See the plumage adaptation to the soil colouration of the ssp.* E. t. albicans*, especially of the adult in the foreground. The juvenile in the background remains darker. Welwitschia Drive, Swakopmund, Namibia. December 2003. Photo courtesy of Christoph Moning.*

Table 1: *Average measurement data of adult Tractrac Chats (*E. t. albicans*) from our sample (including standard deviation, minimum and maximum measurements) and from Keith* et al. *(1992) and of mixed subspecies from Rose* et al. *(2020). Measurements are grouped by sex.*

Grouping	**Parameter**	**Wing (mm)**	**Tail (mm)**	**Tarsus (mm)**	**Culmen (mm)**	**Head (mm)**	**Mass (g)**
Bryson & Paijmans - ssp. *albicans*							
All Adults SAFRING Code Age 4	Mean ± SD	90.9 ± 3.4	52.9 ± 2.9	30.8 ± 1.1	20.4 ± 1.3	41.4 ± 1	26.2 ± 3.3
	Min–max	83–98	47–65	28.1–34.3	17.9–24.1	37.6–43.5	18.6–41.5
	n	90	86	90	73	95	96
Adult Unknown Sex	Mean ± SD	90.3 ± 1.3	52 ± 2.4	30.9 ± 0.8	19.8 ± 0.9	41.1 ± 0.9	26.5 ± 2.5
	Min–max	88–93	47–60	29.6–32.6	18.3–20.9	39–42.7	23–33.5
	n	27	26	28	17	32	33
Adult Females	Mean ± SD	88 ± 2.4	51.6 ± 2.4	30.4 ± 1	20.4 ± 1.5	41.6 ± 1.1	26.1 ± 2.8
	Min–max	83–93	48–57	28.1–32.8	17.9–24.1	38.1–43.3	18.8–35
	n	31	30	31	25	31	31
Adult Males	Mean ± SD	94.2 ± 2.4	54.9 ± 2.8	31.1 ± 1.2	20.8 ± 1.1	41.5 ± 1.1	25.9 ± 4.5
	Min–max	90–98	50–65	28.4–34.3	18.6–23.2	37.6–43.5	18.6–41.5
	n	32	30	31	31	31	31
Keith *et al*. (1992) – ssp. *albicans*							
Adult Females	Mean ± SD	91.3	48.1	29	15.5		
	Min–max	88–96	47–49		tip to feathers		
	n	3	3	3	3		
Adult Males	Mean ± SD	92.7	49.4	29.7	17		
	Min–max	92–94	47–51		tip to feathers		
	n	4	4	4	4		
Rose *et al*. (2020) - mixed ssp.							
Adult	Mean ± SD	89.5 ± 4.6	53.1 ± 2.5	30.6 ± 11.1	20.4 ± 1.5		26.1 ± 2.7
	Min–max	80–96	50–58	28–33	17–23		22–32
	n	118	65	45	64		127

Comparing our data with the most recent publication on measurements of southern African birds (Rose *et al.* 2020), we must take into account that in their paper neither the subspecies nor the sex has been considered and that retraps were included.

Although *E. t. albicans* is claimed to be larger (Keith *et al.* 1992, p. 536), the average measurements of unknown, but presumably mixed subspecies in Rose *et al.* (2020) match our findings.

4.3 Determination of sex

The sex of the birds was determined, when possible, by the colouration of the plumage and the bill, the shape of the two pelvis bones and their distance from each other, the existence and size of a brood patch and by the shape and placement of the cloaca.

When the brood patch was scored, it was determined as absent or, during its development, as starting, full and post-breeding (Brown & Franke-Bryson 2016). For our records we used only the data from a fully developed, active brood patch.

The brood patch is likely to develop shortly before incubation starts, always in females, but also in males to an extent that seems to correspond with their active participation in breeding. The skin of the area with which the bird has contact with the eggs, becomes naked and looks swollen, and, as the blood vessels increase in size and number, the skin turns dark red. When the young have hatched, the area starts returning to normal conditions. The naked patch shrinks, the skin becomes paler and finely wrinkled; then dry scales appear. Shortly after fledging of the young, the skin returns to normal, while the new feathering on the belly will occur only during the next complete, post-breeding moult, which might start soon after breeding (Svensson 1984, pp. 38–39; Brown & Franke-Bryson 2016).

Figure 6: *The plumage of the female and male Tractrac Chats* E. t. albicans *shows a slight, but perceptible colour difference. The female (above) is sandy brown while the male is paler and a colder grey. From the collection of the Natural History Museum, Berlin.*

Figure 7: *Colour difference of* E. t. albicans *in the field. (A) Slightly browner female. SAFRING FH31336, 20 January 2006. (B) More grey male. SAFRING FH34966, 18 June 2007.*

4.31 Colour differences between the sexes

Dean (in Hockey *et al.* 2005, p. 954) and Keith *et al.* (1992, p. 536) call the sexes of the Tractrac Chat "alike", while Collar (2020) notes that sexes are similar. For the subspecies *albicans*, Niethammer and Hoesch first described a slight colour difference between female and male: "The females have on the upperparts a sand-coloured hue, thus are less purely grey" (Hoesch & Niethammer 1940, p. 241). This can best be discerned when both sexes are compared next to each other. Figures 6, 7 and 8 show the difference between the browner female and the paler, greyer male.

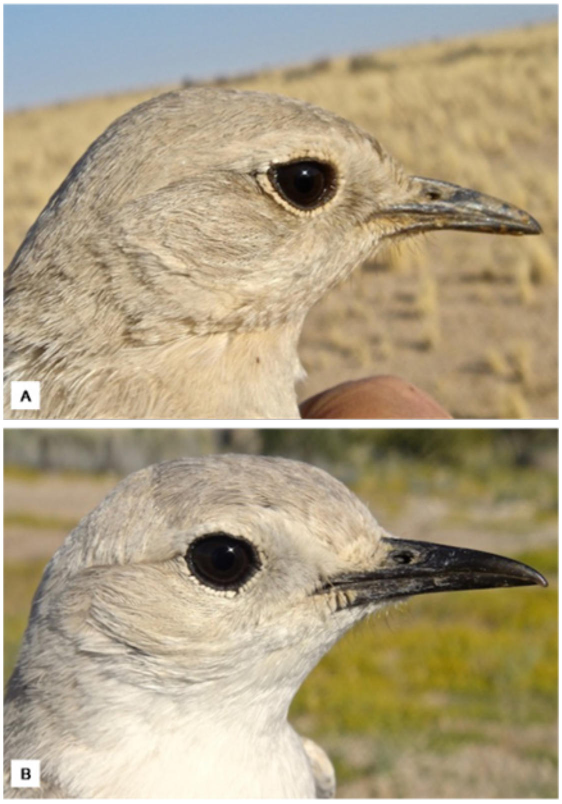


Figure 8: *Head colouration. (A) Adult female, warm-sandy brown. SAFRING FH31182, 13 September 2005. (B) Adult male, lighter and cooler grey with jet-black beak. SAFRING FH31537, 26 May 2006.*

5. BREEDING

5.1 Breeding season

The main criterion that triggers breeding in desert species and thus in the Tractrac Chat is rainfall and the subsequent availability of food for raising the brood. "A long season with opportunistic breeding linked to rainfall is probably the norm" (Harrison *et al.* 1997). The few breeding records (9 in total) obtained in the whole distribution range during data gathering for the Atlas of southern African Birds showed a bias for breeding in spring, i.e. August to October (ibid., p. 179), while in Namibia nesting was recorded in almost every month, except March, July and December (Brown *et al.* 2017).

Our main primary moult records from between November and February follow the (small) peak of these nesting observations in Namibia (as shown in Table 2). With the low number of observations, many breeding events clearly go undetected. It is possible that breeding takes place all year round.

5.2 Records of brood patches

With variable precipitation across years, breeding takes place at different times in different years. For the ssp. *albicans* we recorded seven brood patches out of 64 females spread over the months of the year:

Figure 9: *Descendent primary moult of a Tractrac Chat. While the primary moult score counted 29 (5555540000), the first secondary S1 has almost reached its full length. SAFRING FH34686, January 2007.*

three from January (2004, 2008 and 2012), one from May (2006), two from June (2004 and 2006) and one from September (2005). Beyond that, one nest record with young chicks from 17 August (Demasius 2021) indicates nesting and breeding in July.

6. NESTING AND FLEDGING

Tractrac Chats fledge about 32 days after egg-laying (after 14 days of incubation and 18 days of nestling period) (Tarboton 2014, p. 296) and have been observed to remain with parents for at least one month after fledging (Collar 2020). According to Paterson they are fed for at least nine weeks (unpublished data quoted in Dean 2005).

7. BREEDING AND MOULT

The relationship between breeding and moult is well researched and applicable to the Tractrac Chat. (See Perrins 1970, Svensson & Hedenström 1999, Jenni & Winkler 2020b, pp. 178–179).

8. MOULT

Passerines generally go through two quite distinct moult events every year, a complete and a partial moult. The annual complete post-breeding moult encompasses the whole plumage including the great feathers of wing and tail, while the partial moult is typically restricted to areas of the body plumage (Leisler & Schulze-Hagen 2011, p. 221).

Kasparek (1981, p. 6f.) summarises the progress of the complete moult: all passerines follow a uniform sequence, which is highly consistent through all species, with some minor modifications and very few exceptions. The moult starts with the wing: It begins with the inner primary and progresses towards the outer wing. During this process, which occurs symmetrically on both sides, the secondaries start to be replaced, in such a way that the capacity to fly is not compromised. The moult of the tertials starts shortly after the begin of primary moult and is completed when the growing secondaries reach the tertials. Variations and exceptions occur.

The moult of the Tractrac Chat follows this pattern. The order of the primary moult is descendent, and the secondary moult starts with the outermost S1 (Figure 9).

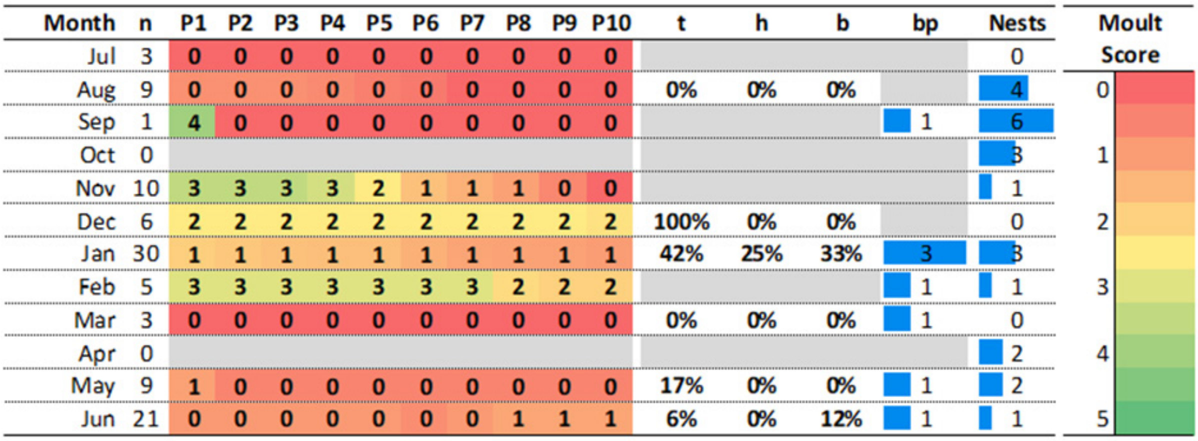
8.1 Moult of the Tractrac Chat

In the literature “no data” for the moult of Tractrac Chats is recorded (Dean 2005; Clement & Rose 2015).

8.2 Moult records of the Tractrac Chat in Namibia

Notwithstanding, Hoesch & Niethammer (1940) report three moulting individuals. One male of the ssp. *albicans* in post-juvenile moult (Jugendmauser)

Table 2: *Extent of primary feather moult (P1 to P10) of adult Tractrac Chat (*E. t. albicans*). Values are average moult scores of each primary for the number (n) of birds per month sampled. The colour gradient is shown at the side. The tail (t), head (h) and body (b) are expressed as a percentage of birds assessed as showing signs of moult. Counts of birds displaying a full brood patch (bp) are given, as well as nest count values for Namibia from Brown* et al. *(2017). No data were collected for the cells marked in grey.*



Month	n	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	t	h	b	bp	Nests
Jul	3	0	0	0	0	0	0	0	0	0	0					0
Aug	9	0	0	0	0	0	0	0	0	0	0	0%	0%	0%		4
Sep	1	4	0	0	0	0	0	0	0	0	0				1	6
Oct	0															3
Nov	10	3	3	3	3	2	1	1	1	0	0					1
Dec	6	2	2	2	2	2	2	2	2	2	2	100%	0%	0%		0
Jan	30	1	1	1	1	1	1	1	1	1	1	42%	25%	33%	3	3
Feb	5	3	3	3	3	3	3	3	2	2	2				1	1
Mar	3	0	0	0	0	0	0	0	0	0	0	0%	0%	0%	1	0
Apr	0															2
May	9	1	0	0	0	0	0	0	0	0	0	17%	0%	0%	1	2
Jun	21	0	0	0	0	0	0	0	1	1	1	6%	0%	12%	1	1

Figure 10: *Adult moulting its tail and primaries, secondaries and coverts of the wing. Both sides were moulting symmetrically. SAFRING FH21182, 26 August 2004.*

Figure 11: *This adult is in the process of its complete post-breeding moult with wing (primaries, secondaries, tertials and coverts), tail, head and mantle visibly involved. Both wings were moulting symmetrically. Edge of Namib-Naukluft Park. SAFRING FH43100, 3 January 2007.*

was collected as one of nine individuals from Cape Cross, about 110 km north of Swakopmund on 25 November 1938 (p. 241). One male in post-juvenile moult and one female in complete moult of the now ssp. *barlowi* were collected as two of five individuals in Kubub and the Namib desert near Lüderitz (p. 245).

8.3 Moult and breeding records of the Tractrac Chat throughout the year

In Table 2 we present moult data of 97 Tractrac Chats, including primary, head, tail and body moult, and compare our brood patches data per month with the numbers of active nests from *Brown et al.* (2015) that might include other subspecies than *E. t. albicans.*

Our data on primary moult peak in the months after the main breeding months gathered by Brown *et al.* (2017), although active brood patches and primary moult activity are spread throughout the year. More extensive monthly data for nests, active brood patches and ongoing moult are needed for a more complete overview of the annual life cycle of this species.

Figure 12: *Adult in all fresh plumage. Farm Sphinxblick. SAFRING FH39403, 3 February 2009.*

8.4 Complete moult of the Tractrac Chat throughout the year

The complete moult, which includes the major feathers of wing and tail, follows the breeding events. We found moulting (and non-moulting) adults throughout the year.

Figures 10 and 11 show adults moulting in August and January while the individual in Figure 12 showed a completed moult in the first days of February.

The primary coverts are lost shortly after their corresponding primaries, while the secondary coverts generally fall out all together at the same time (Kasparek 1981, p. 6f.) (Figure 10).

The tail moult starts shortly after the start of the secondary moult. First, the central pair are replaced, with the movement towards the outer side. Body moult starts on the upper part of the body, being followed by the underparts and finally by the head (Kasparek 1981, p. 6f.).

8.5 Irregular primary moult

Out of 97 Tractrac Chats we found four individuals with an irregular primary moult. The code 0 designates an old feather, the code 4 a growing feather of at least 2/3 of its final length and the code 5 a feather that has completed its growth. An x indicates a missing feather.

- FH20658 from 1 June 2006: 0000000555,
- FH20661 from 1 June 2006: 5555505555,
- FH20591 from 26 May 2004: 5000000000 and
- FH31182 from 13 September 2005: 4000000000.

A roadkill from 27 August 2003 had primary moult left 55xx000500 and right 5000000000.

All others had a normal descendant primary moult.

The combination of feathers with code 0 and 5, i.e. old and fresh full-length feathers, points to an interruption of the continuous growth of the wing feathers. This occurs when the primary moult has started and rain sets in, thus triggering breeding activity. In this case no further feathers are shed and replaced, but the ones in development finish their growth.

9. AGE DEVELOPMENT OF TRACTRAC CHATS

There is a lack of published knowledge about the development of African chats. For a first basic ageing structure to be further developed in future studies, we refer to European species for which more extensive research has been done.

For age terms see the Glossary for Ageing in Bryson & Paijmans (2021, pp. 21–22).

9.1 First-year birds

First-year birds comprise individuals from nestling and fledgling to juvenile birds, and, after the post-juvenile moult, also the immature birds. At about one year of age the young birds are thought to become mature and start the adult breeding cycle. Description of fledglings differ and the development during the first year of this species including the juveniles and post-juveniles is almost undescribed.

As far as we can determine, this is the first published description of a nestling of a Tractrac Chat (*E. t. albicans*) (documented by photographs in Demasius 2021).

9.1.1 Nestling

The nest shown in Figure 13 was raided and destroyed presumably by a domestic dog (*Canis lupus familiaris*) or a black-backed Jackal (*Lupulella mesomelas*). The young did not survive the following days.

Like chats in general (Clement & Rose 2015, p. 15), the nestlings of the Tractrac Chat “usually hatch with a fine or rather fluffy textured down” which are whitish in this species (Figure 14). Dean (2005, p. 954) describes long, dark grey down on dark feather tracts in newly hatched Tractrac Chats. It is unclear if this is a question of subspecies differences. Within days, structured feathers are sprouting on the body along the vanes, on the head and on the wing. Out of the sheaths, dark due to the blood supply, grow the wing feathers with a light sandy tinge. The beak is light yellow, as are the legs, the gape flange a pale yellow (Figures 14 and 15).

9.1.2 Juvenile

9.1.2.1 Juvenile plumage of Tractrac Chats

The first plumage is followed within the first two months of life by a partial post-juvenile moult into a second first-year plumage. This development is comparable to the Mountain Wheatear (*Oenanthe oenanthe*) that starts its post-juvenile moult at the age of 5 to 8 weeks (Ginn & Melville 1983) to completion by the third month of life (Heinroth & Heinroth 1924).

Bill colour is also an indicator for the young age. It turns from a yellowish flesh colour to blackish.

Figure 13: *Nest of a Tractrac Chat (*E. t. albicans*), destroyed by a predator. Swakopmund, Namibia, August 2017. Photo courtesy of Eckart Demasius.*

Figure 14: *Nestling of a Tractrac Chat (*E. t. albicans*), outside of its nest. Swakopmund, August 2017. Photo courtesy of Eckart Demasius.*

Figure 15: *Nestling of a Tractrac Chat (*E. t. albicans*) outside of its nest, killed by a predator. Swakopmund, August 2017. Photo courtesy of Eckart Demasius.*

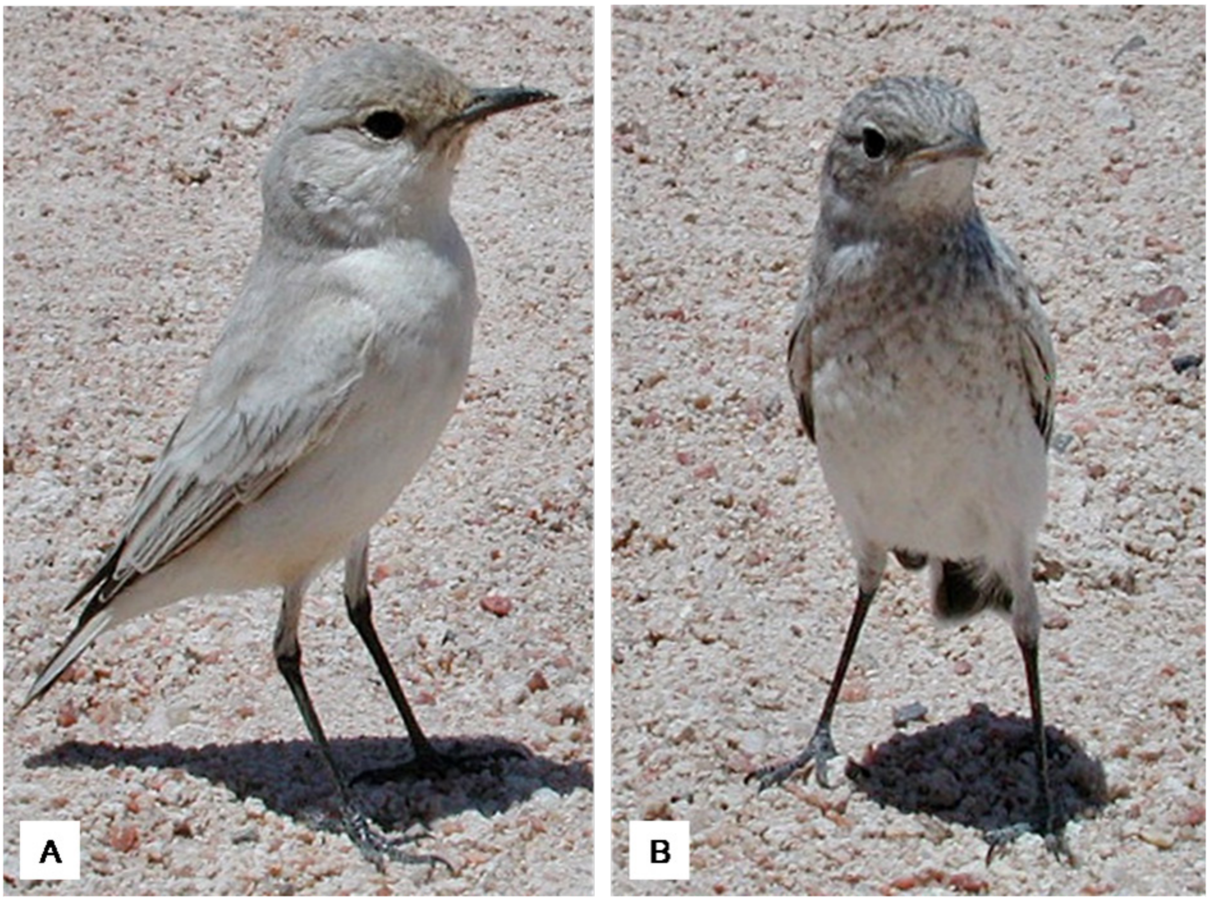


Figure 16: *Comparison of (A) an adult, with white chest, uniform head and dark bill, with (B) the accompanying juvenile with dark, mottled chest, streaked head and lighter coloured bill. See also the dark ear coverts and cheeks of the young. Welwitschia Drive, Swakopmund, Namibia; December 2003. Photo courtesy of Christoph Moning.*

9.1.2.2 Juvenile plumage of Tractrac Chat subspecies *E. t. albicans*

The plumage of the juvenile Tractrac Chat of the subspecies *albicans* is “speckled with buff and black above and below” (Dean 2005) (Figure 16) and lacks most of the brown colouration described (p. 623) and depicted (p. 150) by Clement & Rose (2015) which therefore must refer to the more southern subspecies.

9.1.3 Post-juvenile plumage of Tractrac Chat *E. t. albicans*

The post-juvenile plumage, acquired within the first two months of life, can easily distinguished from the adult plumage by, among other factors, the quality and density of the plumage, although the differences are quite subtle on first sight (Figures 17, 18 and 19). As is well documented in most European passerines, it is looser in structure and lesser in mass when compared to the adult plumage (see discussion and references in Jenni and Winkler 2020a, p. 62). This is the case also in southern African juvenile passerines as well as in first-year birds after the post-juvenile moult (pers. obs.).

The gape flange of a young bird and the edge of the lower mandible, though, show a yellowish tinge for some months which, with other features, allows the determination of age. It is not known if the inner upper mandible is not yellowish and thus diagnostic for a first-year bird, like in *Oenanthe oenanthe*, where it is black in adults (Jenni & Winkler 2012, p. 104).

The bird in Figure 17A was still in company of the adult (17B) which points to quite a young age of several weeks after fledging, as does the yellowish edge along the lower mandible and a yellowish gape flange. The juvenile plumage, though, had already been replaced.

When comparing the plumage of the adult parent and its young, the darker colouration of the adult wing and tail and the stronger contrast between centres and edges of the remiges are visible, while the young show broader fringes of the tertials and longer white tips of the primaries and secondaries (Figure 18). See also the plumage on head and mantle which is plain in the adult and uneven and patchy due to the ongoing moult in the young (Figure 19).

Figure 17: *(A) Close up of the plain head of a first year Tractrac Chat (*E. t. albicans*) after its post-juvenile moult, with yellowish edge of the lower mandible and still scanty feathering. Near Swakopmund, November 2006. (B) Fully grown adult with dense feathering and all-black bill. SAFRING FH30311, 11 February 2005.*

9.2 Adults

When birds become sexually mature, they are considered to be adults. In passerines this occurs at about one year of age. Around this time, the first-year birds generally undergo their first complete moult and acquire a first fully adult plumage. Remiges may moult slightly later in Palearctic passerines (Jenni & Winkler 2020a, p. 61), but detailed knowledge about the moult strategies of chats are still to be explored. In Tractrac Chats, this plumage is similar to that of the first-year. Adults, however, show a plain and abundant plumage which gives the head and the body a smooth round shape (Figure 20).

We observed differences in moult pattern and subtle colour differences in the plumage of adults, which raises the question of whether a second-year plumage will be recognisable as such.

We ringed two individuals on two subsequent days in the same area (Figure 21). One showed a uniform plumage and no signs of primary moult (A) but fresh scapulars and lower mantle, while the other (B) had started the primary and secondary moult and was moulting head, mantle and body with well discernible old lighter and fresh darker feathers.

Figure 18: *Comparison of adult and first-year Tractrac Chat (*E. t. albicans*). (A) Adult with uniform back, dark primaries and tail, and contrasting rectrices. SAFRING FH18950. (B) First-year bird with yellow edge of the lower mandible, broad white edges on tertials, longer white tips of primaries and mottled back, due to post-juvenile moult. Near Swakopmund, November 2006.*

Figure 19: *Close up of head and back of an adult (left) and a first-year (right) Tractrac Chat (*E. t. albicans*). See also the yellow in the lower mandible of the first-year bird. The beak is all black in adults. Near Swakopmund, November 2006.*

Figure 20: *Full adult with well developed "thick" plumage. SAFRING FH34966, 18 June 2007.*

Figure 21: *Difference in moult pattern in two adult Tractrac Chats ringed on two subsequent days in the same area. (A) In plain, almost uniform plumage with fresh scapulars and lower mantle, a pale tail compared to (B), but without signs of primary moult. (B) Moulting head, mantle, primaries and secondaries, with fresh, darker grey feathers. SAFRING FH34966 and FH34962 respectively, 18 and 17 June 2007 respectively.*

We propose as a hypothesis to be explored that the Tractrac Chat passes through a second-year plumage before acquiring a consistent adult plumage.

One challenge for the precise determination of age (of second-year and older) is the wide range of timing for breeding which triggers a subsequent complete moult. Thus, the moult process cannot be attributed to certain months, but occurs variably during all the year.

To date, it has not been possible for us to collect enough data to compare the stage of moult in one population throughout all the months of the year.

10. NOTES AND OBSERVATIONS

10.1 Movements

Tractrac Chats are considered to be sedentary (Collar 2020) but locally nomadic (Dean 2005) with nomadic short-distance movement in non-breeding season (Clement & Rose 2015) associated with unpredictable rainfall (Harrison *et al.* 1997, p. 178). No regular movements are known or discernible from scientific models (ibid.)

10.2 Site fidelity and retraps

Despite ringing for 12 years in the very same locations during the same season, none of 66 birds were retrapped. A single uncounted retrap in our records was a persistent individual that was caught again in the same trap five minutes after being first ringed.

The site fidelity, though, was high. Ringed birds were resighted in the known territories. Even after one and two years we saw a ringed bird on the same bush in the same territory of a previous trapping.

At one of our standard ringing sites (Figure 4) we observed ringed Tractrac Chats inspecting the traps, but they never attempted to get the worm. This behaviour is quite different from other chats like Mountain Wheatear (*Myrmecocichla monticola*) (Bryson & Paijmans 2023), Capped Wheatear (*Oenanthe pileata*) (both Franke-Bryson 2016) and Karoo Chats (ibid., unpubl. data). Unfortunately, we could not identify specific individuals.

North of Swakopmund, we ringed 33 Tractrac Chats and resighted or retrapped four of them up to two years and four months later at the same location or in an adjacent pentad.

10.3 Changing habitat, and changing numbers of observed territories and ringed Tractrac Chats

10.3.1 Changing habitat

Since 2002 we have been ringing in the Erongo region, at the guest and hunting farm Sphinxblick (22°29'S, 15°27'E). In the years following our first visit in 1995, the area was extremely dry. From 1999 on, though, for about 15 years the rainfall was constantly above the average 45 mm. The years 2006, 2010 and 2011 brought exceptional precipitation, with peaks of overall 90, 60 and 85 mm per year respectively, in localised places up to 165 mm and flooding. What used to be quite barren land, carried more and more vegetation. The grass grew high and interfered with the hunting habits of the Tractrac Chats. The area depicted in Figure 22A had hosted several Tractrac Chats in their long-term territories. After the massive rains in 2011, they disappeared from the area and have not returned (Figure 22B).

10.3.2 Changing numbers of observed territories and ringed Tractrac Chats

The drought of 2014 to 2021 was so severe that the game populations almost completely died. Only small patches received rain of 10 to 15 mm. In the field, no Tractrac Chats were found or observed and most of the birds, even the sandgrouse, left the area. The only four remaining territories of Tractrac Chats were around waterholes and human constructions. One constantly occupied throughout all the years was located near the farmhouse, where the sheep and the horses provided dung and attracted insects. Two territories were entirely deserted in 2017 after 30 months of drought. One was deserted in 2018 and occupied again five years later, in 2023 (pers. obs.).

Figure 23 shows the rainfall over a larger area covering Usakos and Karibib. Our research area is on the edge of the Namib-Naukluft Park and receives just a fraction of the precipitation for areas only 10 or 20 km further inland (or 65 km like Usakos, or 95 km like Karibib). After years with high precipitation, the numbers of Tractrac Chats were low.

Due to the secluded nature of our sites, accurate long term weather station measurements were not easily available, so as an alternative Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data was sourced (Funk *et al.* 2015) to estimate average precipitation levels of the area (0.05° resolution, gridded precipitation time series between [-21.91874, -22.65359] latitude, [15.00748, 15.84465] longitude. Although CHIRPS has been assessed to be an adequate dataset for long term precipitation trends, limited suitability studies have been done in Namibia (Liu & Zhou 2021, Robertson 2023), and over/underestimation of the seasonal precipitation may be present at small scales and closer to the Namibian coastline (Robertson 2023).

Figure 22: *Typical habitat of the Tractrac Chat (*E. t. albicans*) in the pre-Namib. (A) The few low dry bushes in the foreground are being used as perch. Farm Sphinxblick, Erongo region; 25 January 2008. (B) Former area of the Tractrac Chat after extraordinary rain that changed the vegetation to a degree that the habitat became unsuitable. 24 February 2011.*

10.4 Overall numbers of the Tractrac Chat

The South African Bird Atlas Project 2 hosts continually updated statistical data about the birds of southern Africa (SABAP 2022a).

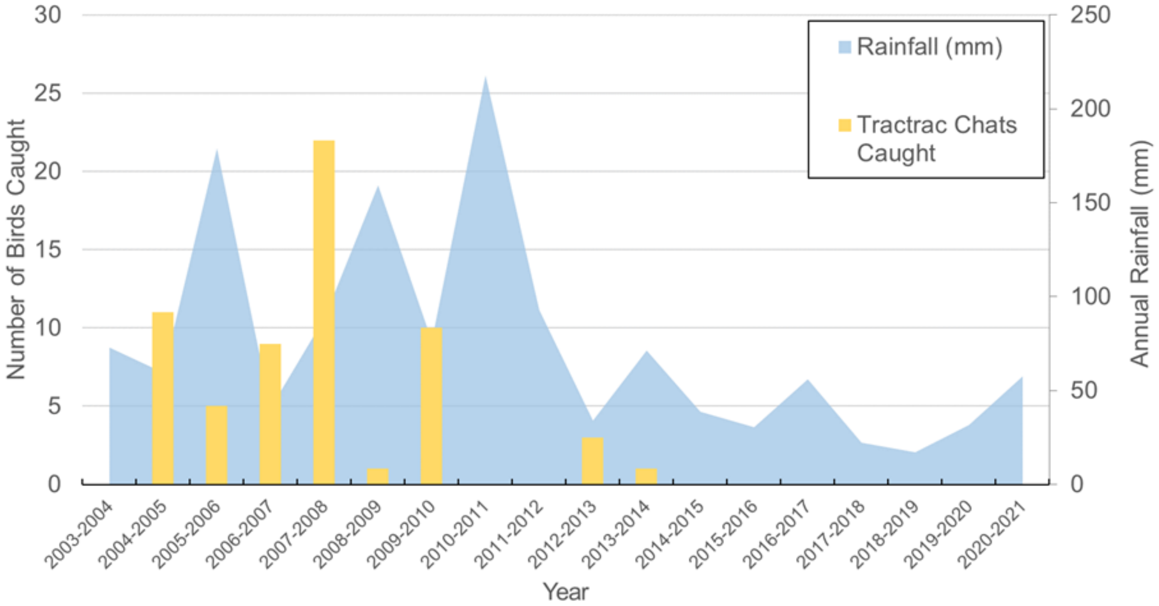


Figure 23*: Annual rainfall fluctuations in the pre-Namib savanna in relation to the numbers of Tractrac Chats (*E. t. albicans*) ringed per year. The low record for individuals caught for 2008/2009 is due to reduced ringing activity. Precipitation estimates retrieved from the CHIRPS dataset between [-21.91874, -22.65359] latitude, [15.00748, 15.84465] longitude).*

In the database, the average reporting rate of Tractrac Chats has declined over the years (SABAP 2022c). In Namibia since SABAP1 (1981–1998), there has been a decline in reporting rate compared to SABAP2 (2007–present) of over 20% in 2022 (SABAP 2022b), with similar pictures for the Northern and Western Cape.

It is not known if this decrease reflects real change of chat numbers or if it is related to a change in observation intensity or protocols. Although there are differences in methodology between SABAP1 and SABAP2 (i.e. survey protocol, spatial unit and no measure of effort), this is still a notable decrease in reporting rate for the Tractrac Chat in Namibia.

10.5 Behaviour

Notes on behaviour of the Tractrac Chat are scarce and general, restricted to perching, running fast after prey, short hovering for inspection when alarmed or when hunting, wing flicking and jerking the tail (Maclean 1993, p. 513) while for *Oenanthe* species a wide variety of behaviour elements have been described in detail: song flights as behaviour against intruders of the territory or during pair formation; mating; nest defence; roosting behaviour; body posture; bobbing and many more patterns and single observations (Cramp 1988, p. 755 ff.).

During our studies, we repeatedly observed Tractrac Chats hovering when they were inspecting prey (or our traps) as described in Macdonald (1957, p. 125) and Maclean (1985, p. 513). See also the photographic report of Demasius (2021) and Figure 24.

We observed an interaction between one Tractrac Chat repeatedly swooping down on another individual (Franke-Bryson 2017) which left us in doubt about the causes (mating behaviour or territorial defence). We suggest that more complex behavioural actions are still undetected or undescribed.

10.6 Parasites and injuries

Out of 66 ringed individuals only two birds from mid-June were parasitised by ticks: one hosted one, the other three ticks. One adult was missing one foot (Figure 25), which did not seem to affect his physical condition. It had a freshly moulted plumage and weighed 23.9 g, compared to an average mass of 27.3 g (out of seven) (collected by Hoesch & Niethammer 1940, p. 241) and our median mass of 26.2 g (range 18.6–41.5 g).

11. ERRATA IN THE LITERATURE

In the literature we found some incorrect descriptions and information that are being passed on unnoticed in further publications. In the reference to "Motacilla tractrac Wilkes, 1817, Encyclopaedia Londinensis 14:89" (Dean in Hockey *et al.* 2005, p. 954) the volume number should be 16, not 14 (Wilkes 1817).

Figure 24: *(A) A Tractrac Chat overviewing the disturbance and (B) hovering in front of the windscreen when inspecting an intruder close to its nest. Swakopmund. August 2017. Photos courtesy of Eckart Demasius.*

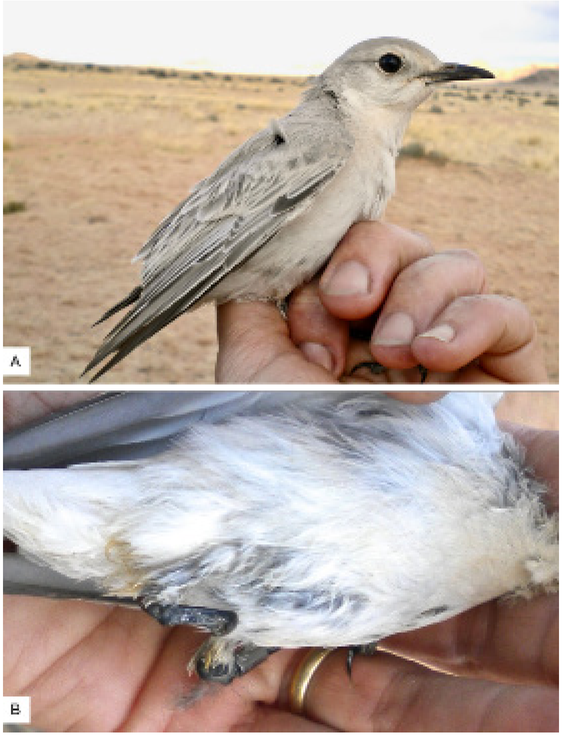


Figure 25: *This Tractrac Chat (*E. t. albicans*) had lost its right foot, which did not seem to present a handicap for normal mass and moult. SAFRING FH39762, 15 December 2009.*

11.1 Depiction of the Tractrac Chat

In the first description of a Tractrac Chat in Levaillant's "Histoire naturelle des oiseaux d´Afrique (1805)" the drawing shows a Karoo Chat (*E. schlegelii*), with the middle tail feathers dark up to the rump and white upper-tail coverts (Figure 26).

The description of the plumage in the text is also that of a Karoo Chat*:* "The twelve feathers of the tail are generally black ending in white and all equal in length: the first four on each side are edged in white on the outside, but the fourth and the third are not of this white until near their beginning..." (ibid. p. 104, compare with Figure 27B.)

In the text Levaillant describes the behaviour: "... it frequents the bushes, at the top of which it is always seen to perch, ... fleeing ... from bush to bush" (ibid. p. 103). Tractrac Chats prefer open arid plains with few scrubs, or perennial grasslands in deserts, or, when on dunes, those are vegetated sparsely with shrubland (Macdonald 1957, p. 124; Dean 2005, p. 954).

Figure 27 shows a Tractrac Chat (A) and a Karoo Chat (B) from Namibia for comparison.

The "Auteniquois" country where Levaillant first observed and collected the as such described Tractrac Chat is the "high country lying behind Knysna, southern Cape province" (Macdonald 1957, p. 125). The fact that the species is recorded there in only five quite isolated pentads and in very low numbers (https://sabap2.birdmap.africa/species/571) while the Karoo Chat in the area is observed in high numbers and high frequency (https://sabap2.birdmap.africa/species/566) raises the question of identification and range. See also Macdonald (1957, pp. 125–126) where he discusses the possible confusion between Tractrac and Karoo Chat).

Figure 26: *Levaillant's depiction of a Tractrac Chat shows a Karoo Chat (see text). Histoire naturelle des oiseaux d´Afrique by Levaillant (1805).*

Without detailed descriptions, photographs or genetic samples, it is difficult to define the taxonomy. Further studies would improve our understanding of this species and its range.

11.2 Elevation of the distribution range

The occurrence of the Tractrac Chat in Clement and Rose (2015, Habitat, p. 622) is specified as "from sea-level to c. 350 m" which is in contrast to Hoesch who collected five specimens in Kubub (26°43'60" S and 16°16'60" E), south west of Lüderitz, about 30 km south of Aus, 1552 m above sea level (Hoesch & Niethammer 1940, p. 61, map on page 15). Tecklenburg, "the most eastern location" where the then called *Oenanthe albicans* was found (Hoesch & Niethammer 1940, p. 241), is situated north of Uis near the Brandberg at an elevation of about 800 m at 21°19' S and 14°81' E, while our main ringing site for the species, Farm Sphinxblick, is at about 1,000 m above sea level.

12. FURTHER RESEARCH

Much is still unknown or unrecorded about the Tractrac Chat and many questions are unanswered. More continuous monthly data of nests, active brood

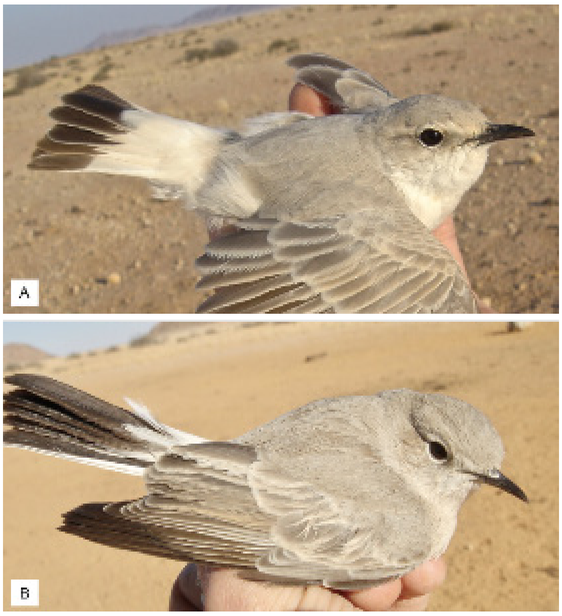


Figure 27: *(A) Tractrac Chat with white tail and black tips. SAFRING FH34975, 18 June 2007. (B) Karoo Chat with dark tail and whiter outer tail feathers as described and depicted by Levaillant. SAFRING FH34958, 17 June 2007.*

patches and ongoing moult are needed for a more complete overview of the annual life cycle of this species.

Concerning the breeding period and the first-year development detailed research is needed to gain sufficient data:

- to observe the nesting activity to define the still unknown incubation period and the also unknown breeding success (Dean 2005).

Concerning the plumage description and the age development basic research is needed:

- to document the appearance of hatchlings and young birds and the development into adult age;
- to identify and describe a possible second phase of the juvenile plumage, the adaptation of the adult moult cycle by first-year birds, and a possible second-year plumage;
- to investigate the inner mouth colour in first- and second-year birds and adults to determine the age more precisely.

For further research we recommend:

- gathering more data on the size of territories and relating nest data to precipitation data;
- studying and describing the behaviour all year round, from song flight and mating behaviour to territorial defence, against intruders or during pair formation, behaviour at the nest and nest defence, roosting behaviour, body posture, etc.
- monitoring the area where the species was first described (Auteniquois country) to learn about the species´ actual distribution and abundance and the possible misidentification of Karoo Chats.

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