Bat species (Mammalia: Chiroptera) occurring at Telperion Nature Reserve

T. C. Kearney[1,2,3]*, M. Keith[4], W. Markotter[5], M. Pretorius[3] and E. C. J. Seamark[3,4]

[1]Ditsong National Museum of Natural History, P.O. Box 413, Pretoria, 0001 South Africa

[2]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, WITS, 2050 South Africa

[3]AfricanBats, 357 Botha Ave, Kloofsig, 0157 South Africa

[4]Eugène Marais Research Chair for Wildlife Management, Mammal Research Institute, University of Pretoria, 0002 South Africa

[5]Centre for Viral Zoonoses, Department of Medical Virology, University of Pretoria, 0002 South Africa

KEARNEY, T. C., KEITH, M., MARKOTTER, W., PRETORIUS, M. and SEAMARK, E. C. J., 2019. Bat species (Mammalia: Chiroptera) occurring at Telperion Nature Reserve. *Annals of the Ditsong National Museum of Natural History* **8:** 30–42.

Mist nets, harp traps and roost searches resulted in the eight bat species being recorded in Telperion Nature Reserve, which is in a transition between the Savanna and Grassland biomes. The majority of these were species in the family Vespertilionidae. Anabat release calls were recorded from three species. Sexual dimorphism in external body size, and in two of the Anabat release call parameters (Fc and Sc), were observed in *Neoromicia capensis*. This species was roosting in larger numbers in buildings than previously recorded for vegetation roosts. The low capture rate and lack of certain bat families was most likely the result of capture bias, even though the Grassland biome is known to have fewer species than the Savanna biome.

Keywords: Telperion Nature Reserve, Bats, Chiroptera, Vespertilionidae, Echolocation, Sexual Dimorphism.

INTRODUCTION

In southern Africa Schoeman *et al*. (2013) and Cooper-Bohannon *et al*. (2016) identified the highest bat species richness in the dry Savanna of the northeastern part of the region. Investigating bat species richness in South Africa, Gelderblom *et al*. (1995), not surprisingly, also found a peak in the Savanna in the northeast of the country. Taking into account taxonomic changes since the work by Gelderblom *et al*. (1995), Seamark (2013) recorded 56 bat species in the Savanna biome, relative to 39 species in the Grassland biome. Accounting for this difference between the Savanna and Grassland biomes, various studies have identified habitat structure as an important predictor of species richness (Fahr and Kalko, 2011; Curran *et al*., 2012; Schoeman *et al*., 2013). Increased habitat structure in the Savanna biome is associated with a greater range of vegetation roosts, and probably greater food availability, relative to the Grassland biome. In the Grassland biome, caves, crevices and riverine vegetation provide natural, albeit more limited, roost sites for bats. However, certain bat species are able to roost in man-made structures (Monadjem *et al*., 2010). *Neoromicia capensis* is one of these species, which has resulted in its current, ubiquitous distribution across South Africa, especially in biomes with more limited natural bat roosts (ACR, 2016). Records also suggest the move by *N. capensis* from natural crevice and vegetation roosts to man-made structures has been accompanied by a change in roosting group size. Smithers (1983) reported vegetation roost sizes of *N. capensis* between two and three individuals. In comparison, anecdotal information about the number of *N. capensis* roosting in buildings indicates far larger roosting group sizes, in excess of 50 individuals. This information comes from two localities: as observed by one of the authors (E.C.J.S.) at Suikerbosrand Nature Reserve in Gauteng province (–26.4808° 28.2196°) in the Grassland biome, and from National Museum of Bloemfontein museum records for buildings at Jagersfontein Common in the Free State Province (–29.61° 25.36°), in the Nama-Karoo biome.

Relative to most other parts of Africa, information about bat species distributions and life history is relatively well understood in South Africa (ACR, 2016; Herkt *et al*., 2016). Yet, this fundamental information is still relatively patchy for species occurring in South Africa, and thus requires continued field efforts (Monadjem *et al*., 2010; ACR, 2016). In order to prioritize fieldwork to address the gaps, initial

---

*Author for correspondence. E-mail: kearney@ditsong.org.za

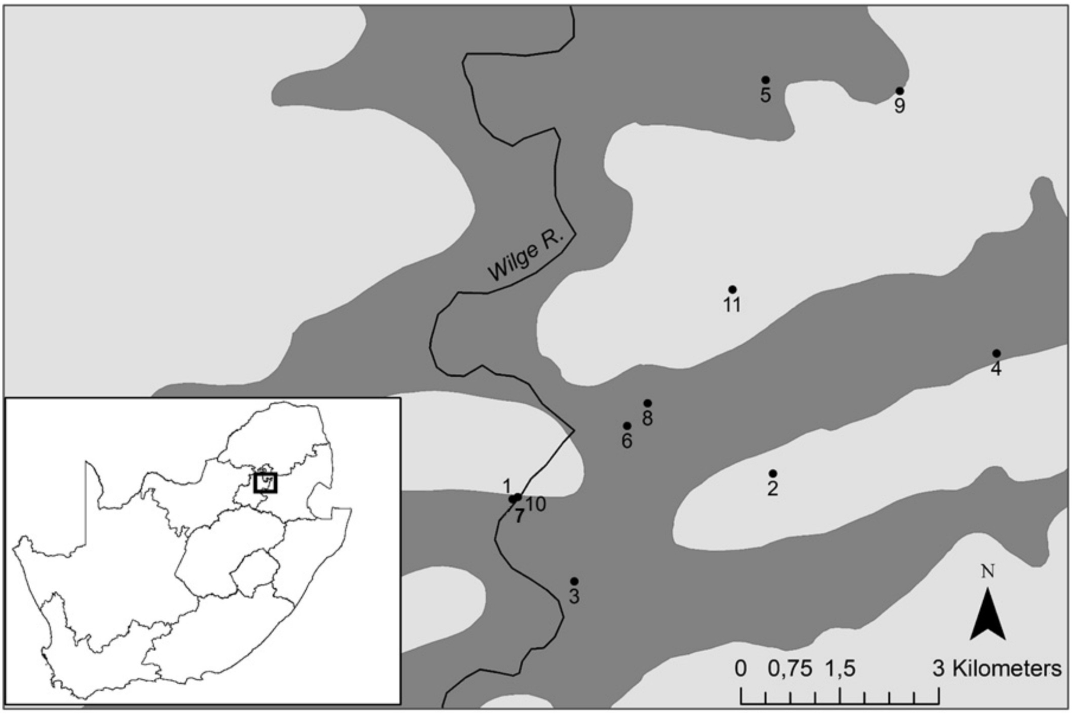

Fig. 1

Sample sites (numbered 1–11) in relation to the Grassland (light grey) and Savanna (dark grey) biome, within Telperion Nature Reserve, and location of the research site within South Africa (inset) (see Table 1 for more details).

focus should be on existing protected areas that have not yet been investigated. Telperion Nature Reserve (Mpumalanga Province, South Africa) is not currently part of the officially recognized protected areas in South Africa. However, its management largely aligns with the aims of protected areas. This reserve is in an ecotone between the Grassland (Rand Highveld Grassland) and Savanna (Loskop Mountain Bushveld) biomes (Mucina and Rutherford, 2006). As there were no known published records of the bat species occurring in Telperion, the aim of this study was to use roost searches and capture methods to verify the different bat species occurring in the reserve. Echolocation release calls were also recorded to start building a release call library for the area.

MATERIAL AND METHODS

Telperion Nature Reserve (Blaauwpoort 257-JS), is located northeast of Bronkhorstspruit, straddling the boundary of Mpumalanga and Gauteng provinces in South Africa, and across the Wilge River from Ezemvelo Nature Reserve. Following Coetzee (2012) the reserve is located between southern latitudes 25.6333° and 25.75° and eastern longitudes 28.9167° and 29.05°. Within the reserve, the Loskop Mountain Bushveld biome extends into flatter plains of Rand Highveld Grassland (Mucina and Rutherford, 2006). The Loskop Mountain Bushveld occurs along the Wilge River, which in parts cuts through steep, gorge-like areas, and along the steeper side of rocky ridges that are found within the grassland plains. Roost searches and active capture methods (mist nets and harp traps) were undertaken from 11 to 22 February 2014. Mist nets were set at nine different sites, which were chosen to cover different parts of the reserve, and different vegetation and landscape features (Table 1 and Fig. 1). Details of the different length and number of nets, how they were set, and for how long they were up at the various sites are shown in Table 1. Given the difficulties of catching free-flying bats in nets, none of the netting was within open grassland areas, although many were close to grasslands. Two harp traps were also used: a 1.58 m × 1.48 m custom made double bank trap, and a 1.28 m × 0.95 m double bank cave strainer (Bat Conservation and Management, Carlisle, Pennsylvania, U.S.A.). These were set in the grounds of the University of South Africa's Applied Behavioural Ecological and Ecosystem Research Unit (UNISA ABEERU) centre, and their positions were changed over the time deployed, including into position near roosts in a stone-clad wall.

Table 1

Sample site information, capture method, the number and length of the nets (net height 2.4 m), how they were set, how long they were open, and the bat species and number that were captured at Telperion Nature Reserve in 2014.

Site #	Y	X	Description	Capture method	Net details	Species caught and number of individuals
1	–25.7148	28.9821	Across a gully on western bank, southwest of causeway over Wilger River	Mist nets	2 × 6 m and 2 × 3 m, two stacked. double on poles, V-shape; 1.4 h	*P. hesperidus* ($n = 1$)
2	–25.7113	29.0176	Old school building	Hand net	–	*N. capensis* ($n = 1$)
3	–25.726	28.9905	Within rocky area above gorge	Mist nets	2 × 12 m and 2 × 15 m, stacked double on poles, V-shape; 1.7 h	*N. capensis* ($n = 3$), *P. rusticus* ($n = 1$)
4	–25.6949	29.0481	UNISA ABEERU centre	Mist nets, harp traps	2 × 6 m, stacked double on ropes in trees; 1.3 h	*N. capensis* ($n = 39$, all harp trapped)
5	–25.6576	29.0166	Within trees and shrubs on western side of a ridge	Mist nets	4 × 6 m and 2 × 12 m, two stacked on poles, Z-shape; 2 × 9 m, stacked double on ropes in trees; 2.1 h	*N. capensis* ($n = 7$), *N. zuluensis* ($n = 1$)
6	–25.7048	28.9977	Within stand of *Burkea africana* on a south facing slope	Mist nets	2 × 6 m and 2 × 12 m, stacked double on ropes in trees, V-shape; 1.4 h	*N. capensis* ($n = 2$), *N. zuluensis* ($n = 1$)
7	–25.7148	28.9821	Around pools on northern bank, west of causeway over Wilge River	Mist nets	2 × 9 m and 2 × 12 m, stacked double on poles, V-shape; 1.38 h	None
8	–25.7017	29.0005	Along a road and across a suspension bridge at a rondavel on a ridge	Mist nets	2 × 6 m, 2 × 12 m, 2 × 15 m, stacked double on poles, Z-shape; 1 h	None
9	–25.6591	29.0349	Across a road, within trees close to a boundary fence and close to a gorge	Mist nets	2 × 6 m and 2 × 12 m, stacked double on ropes in trees, V-shape; 2.45 h	*N. capensis* ($n = 3$)
10	–25.7145	28.9828	Across the Wilge River causeway	Mist nets	2 × 9 m and 2 × 15 m on poles, V-shape; 2.4 h	*N. capensis* ($n = 1$), *M. tricolor* ($n = 2$)
11	–25.6862	29.0121	Buildings	Hand net	–	*R. clivosus* ($n = 1$)

Captured bats were processed as described in Kearney *et al*. (2010, 2017). Voucher specimens, taken to record the presence of previously unrecorded species in the reserve, were lodged in the Small Mammal Collection at Ditsong National Museum of Natural History (formerly Transvaal Museum – TMSA). Baculum morphology of five of the vouchers was used to confirm species identification. Blood and tissue samples were also taken from these specimens by one of the co-authors (WM) to test for zoonoses. Calculations were made of capture effort and capture rate following Kearney *et al*. (2010). Mist net capture results were used to calculate two species richness estimates, Chao 1 and ACE, using SPADE software (Chao and Shen, 2010). Included in these calculations was a measure; the coefficient of variation for the rare species group (CV), which characterizes the detection probability of rare species in a community (Chao and Shen, 2010) and assists in identifying the most appropriate species richness estimator.

Acquiring reference calls and building call libraries has various challenges and trade-offs as identified by Parsons and Szewczak (2009). Many bat species in South Africa are not identifiable to species when on the wing, which makes it difficult to determine from free-flying calls the species that made the call. This means there needs to be certainty that the recorded call was from a previously identified individual. However, there is a potential bias in calls recorded from bats recently released from the hand in relation to the distance the bat is from the ground, which might still be near enough to result in short, steep calls associated with clutter. Such recordings may under-represent the full repertoire of a species, which would also include longer, shallower calls resulting from flight in more open areas. The use of captive flight, light tagging and zip lines has been suggested to try and improve the conditions that allow more routine flight and vocalization under natural conditions (Parsons and Szewczak, 2009). Two of the authors (T.K. and E.C.J.S.) have not previously had success with any of these methods. Thus, following Taylor *et al*. (2013), and bearing in mind the limitations of hand released recordings, echolocation calls were recorded after captured individuals were released in open areas. To try to obtain recordings representative of search phase calls, the bats were followed for as long as possible after release. While these recordings have the potential to underrepresent the full repertoire of the species recorded, having been recorded consistently between individuals they do provide evidence of at least part of the call repertoire of a species. Sandie Sowler (pers. comm.), however, cautions that acoustic parameters from released bats may be variable because of stress. Evidence of individual stress was not tested in this study, and pending evidence of this, we have assumed the calls were not variable because of stress.

Recordings were made using an Anabat SD2 linked to an HP iPAQ (model hx2490c). Calls were recorded in AnaPocket (version 3.0k, Chris Corben 2012). The same detector set-up was also used to make recordings of free-flying bats at the different mist-net capture sites, and when travelling between capture sites. When recording after dark at a capture site, a Zaptec high beam spot light was used to locate the bat when calls were heard. This allowed various observations on the appearance and behaviour of the bat to be linked to specific calls. Calls were analysed with AnalookW software (Version 4.2d 25, April 2016). An anti-noise filter, with smoothness set to 30, body $>$ 1000 ms, frequency constant (Fc) between 2 and 250 kHz, and duration (Dur) 3–70 ms. Steep calls of higher frequency at the start of a call sequence were removed. These are indicative of social calls if the bat was still in the hand (Middleton *et al*., 2014), or increased clutter as a result of flying too close to the ground just after release. Chris Corben (pers. comm.) suggested the use of the following four echolocation call parameters: duration of the call (Dur), time from the start of the call to Fc (Tc), characteristic frequency; the frequency at the end of flattest portion of the call (Fc), and slope at the start of the call (Sc). These parameters were extracted from files linked to released individuals or specific free-flying observations.

Sexual dimorphism in external measurements and release call parameters were assessed using one-way ANOVA and MANOVA using R (R Core team, 2014) in RStudio Desktop software Version 0.98.1091, for three different datasets: all *N. capensis* caught; only those caught at the UNISA ABEERU centre; and all *N. capensis* caught excluding one outlier. The fieldwork was conducted under permits from the Mpumalanga Tourism and Parks Agency (Permit No. MPB. 5385) and Gauteng Provincial Government, Department of Agricultural and Rural Development, Directorate of Conservation (CPF6 permit No 0109). All field procedures were done in accordance with guidelines of the American Society of Mammalogists (Sikes *et al*., 2011), with ethical permission from the University of Pretoria (EC054-14).

RESULTS

For a netting capture effort of 1557.50 nm^{2}hrs, the capture rate was 1.41%. Twenty-two adults, from a single family (Vespertilionidae), were netted at six of the nine mist net capture sites (Tables 1 and 2). These represented five species: *Myotis tricolor* (Temminck, 1832) (Temminck's Hairy

Table 2

Information about the adult bats captured at Telperion Nature Reserve in 2014. Mean, standard deviation and range for all individuals of each sex within a species, as well as the individual measurements for the voucher specimens. FA = forearm length, HL = head length, HF (cu) hind foot length including the claw. Mass was measured in grams, while the other measurements were in millimetres.

Species	Sex	Mass	FA	HL	Total	Tail	Ear	Hf (cu)	Catalogue #
Neoromicia capensis	M	5.76 ± 0.50	32.96 ± 1.18	16.59 ± 0.38					
		(4.60–6.60)	(30.50–35.20)	(15.90–17.30)					
		n = 33	*n* = 33	*n* = 33					
		6.60	32.15	16.60	78	32	12	6	TMSA 49170
		6.35	35.20	17.30	78	31	11	5	TMSA 49171
	F	6.85 ± 0.53	35.03 ± 0.91	17.01 ± 0.38					
		(5.85–7.80)	(32.50–36.20)	(16.10–17.60)					
		n = 23	*n* = 23	*n* = 23					
		7.30	35.20	17.40	91	34	12	6	TMSA 49169
Neoromicia zuluensis	M	3.90	29.40	13.70	77	32	11	6	TMSA 49173
	F	4.20	31.10	14.90					
Pipistrellus hesperidus	M	4.50	31.40	15.00	79	35	11	6	TMSA 49168
Pipistrellus rusticus	M	5.90	29.00	14.50	72	27	10	5	TMSA 49172
Myotis tricolor	F	14.75, ,	50.95	21.80					
		14.50–15.00	50.70–51.20	*n* = 2					
		n = 2	*n* = 2						
		15.00	51.20	21.80	109	49	16	11	TMSA 49175
Rhinolophus clivosus	F	16.00	53.60	23.70	96	31	22	12	TMSA 49174

Bat), *Neoromicia capensis* (A. Smith, 1829) (Cape Serotine), *Neoromicia zuluensis* (Roberts, 1924) (Aloe Serotine), *Pipistrellus hesperidus* (Temminck, 1840) (Dusk Pipistrelle), and *Pipistrellus rusticus* (Tomes, 1861) (Rust Pipistrelle). No mist net captures were made within trees at the UNISA ABEERU centre (site 4, Table 1), at pools adjacent to the Wilge River near the causeway (site 7, Table 1), and at a rondavel on the ridge (site 8, Table 1). Eight voucher specimens were taken (Table 2). The CV-rare was zero, meaning all rare species had an equal probability of detection in the community, and indicated the ACE species estimator was appropriate. Species richness estimates calculated that only one (Chao 1: species number estimate = 6; S.E. 1.8; 95% confidence interval 5, 16) and two (ACE: species number estimate = 7; S.E. 2.6; 95% confidence interval 5, 20) additional species remained undetected by mist netting.

Three additional species were found searching for roost sites. *Taphozous mauritianus* E. Geoffroy, 1818 (Mauritian Tomb Bat) were observed roosting in trees, and on an external wall under the eaves of a thatch roof at the UNISA ABEERU centre (site 4, Table 1). *Scotophilus dinganii* (A. Smith, 1833) (Yellow House Bat) were observed as they left their roost in the roof of one of the houses at the centre (site 4, Table 1). A single *Rhinolophus clivosus* (Cretzschmar, 1828) (Geoffroy's Horseshoe Bat) was hand netted at a day roost in a dark room (site 11, Tables 1 and 2).

Two harp traps, set in varying positions around the grounds of the UNISA ABEERU centre (site 4, Table 1), caught 39 individuals of a single species, *N. capensis*, which were observed to be roosting in large numbers in the buildings. Individuals were observed returning to roosts in gaps between a roof beam and a stone clad sidewall, and between stone cladding on exterior walls of another building. Our attention was first drawn to the latter roosts hearing audible calls that appeared to be between individuals already occupying a space, and another/others still flying and trying to approach the same space. *Neoromicia capensis* was also found roosting in light fittings at the old school building (site 2, Table 1). From the size of the droppings observed on the floor at the old school, a larger bat species, possible the Yellow House Bats (*S. dinganii*), was also roosting in the roof of the old school building.

Neoromicia capensis was the most dominant species, occurring at seven of the nine sites where bats were found. However, away from buildings and the roost at the UNISA ABEERU centre, the number of free-flying *N. capensis* caught relative to other species (Table 1) did not indicate a dominance of this species in the area. All bats caught were adults. In males, testes were descended onto the tail in all but one of the *N. capensis*, and both *N. zuluensis* and *P. rusticus*, but not the *P. hesperidus*. Testis measurements were not taken from the *N. zuluensis* (TMSA 49173), but in *P. rusticus* (TMSA 49172), testes length and width were 5.5 × 3.8 mm. In *N. capensis* the lengths and widths of testes that had descended onto the tail (TMSA 49170) and not descended onto the tail (TMSA 49171), were 4.2 × 3.4 mm and 4.7 × 2.8 mm, respectively. In the females, nipples were not found in the *N. zuluensis* and 61% of the *N. capensis*, which possibly indicates the nipples were still small and unkeratinized. Keratinized nipples were recorded for all the *M. tricolor*, the single *R. clivosus*, and 39% of the *N. capensis*. The sex ratio of males to females of the 39 *N. capensis* caught in the grounds of the UNISA ABEERU centre (site 4, Table 1) was 1.44:1.

Compared with *N. capensis* and the other *Pipistrellus* species, individuals of *N. zuluensis* had longer dorsal fur extending over the surface of the interfemoral membrane. In *N. zuluensis* the membrane under this fur was lighter than other parts of the interfemoral membrane, forming a relatively broad, pale band along the proximal edge of the interfemoral membrane where it joins the body. Although sample sizes were small for most of the species, *N. capensis*, separated from *N. zuluensis*, *P. hesperidus* and *P. rusticus* based on mass, forearm and head length measurements plotted together (Fig. 2). The larger size range of *N. capensis* males relative to females was also evident in Fig. 2, and in the standard deviations of external measurements of the different sexes (Table 2). Figure 2 also indicates sexual dimorphism in size within *N. capensis*. Forearm and head lengths, and mass of all *N. capensis* were uni-, as well as multivariably, significantly sexually dimorphic (forearm – SS 58.20, *F* 49.90, *P* 3.244e–09; head length – SS 2.33, *F* 16.02, *P* 0.0001922, mass – SS 15.96, *F* 60.58, *P* 2.208e–10; multivariate – Wilks 0.41, *F* 24.62, d.f. 3, error d.f. 52, *P* 4.735e–10). Forearm and head lengths, and mass of *N. capensis* caught at the UNISA ABEERU centre only (site 4, Table 1) were also uni-, as well as multivariably, significantly sexually dimorphic (forearm – SS 46.59, *F* 45.51, *P* 6.19e–08; head length – SS 2.26, *F* 20.65, *P* 5.719e–05, mass – SS 10.13, *F* 44.20, *P* 8.368e–08; multivariate – Wilks 0.40, *F* 17.51, d.f. 3, error d.f .35, *P* 4.112e–07).

Release calls were recorded from three species: *N. capensis* (37 individuals), *M. tricolor* (one individual), *N. zuluensis* (one individual) (see Table 3 and Fig. 3). Although the full echolocation and social call repertoire of these species has not been investigated, the recorded release calls that were analysed were not Type B Vespertilionidae social calls that are emitted when bats are caught,

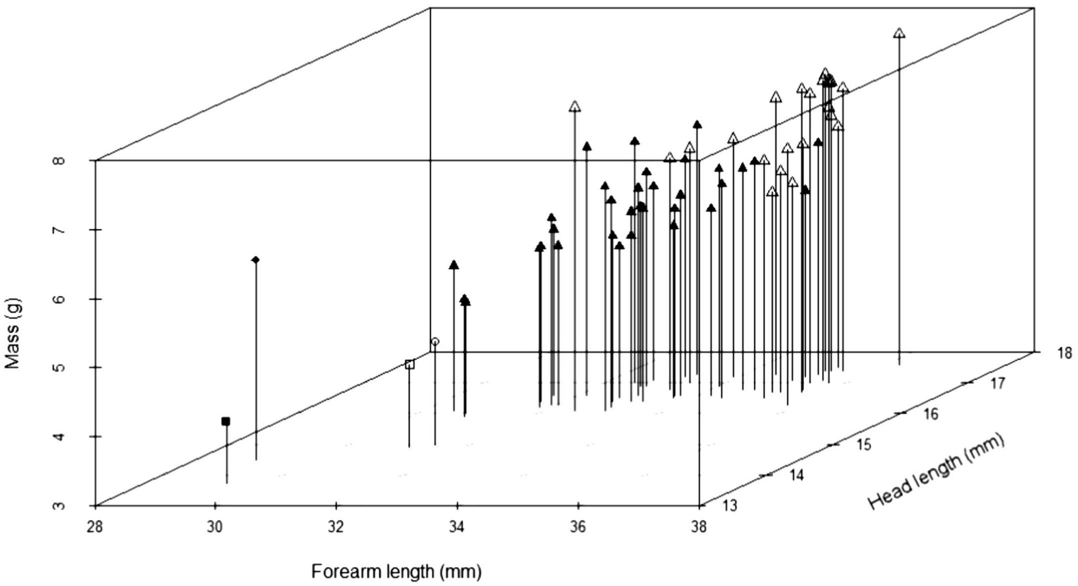

Fig. 2

Plot of mass, forearm length, and head length measurements of male (closed symbols) and female (open symbols) *Neoromicia capensis* (triangle), *N. zuluensis* (squares), *Pipistrellus rusticus* (diamonds) and *P. hesperidus* (circle) caught at Telperion Nature Reserve.

restricted or confined (Middleton *et al*., 2014). Sexual dimorphism was assessed, assuming the call parameters were not influenced by other factors, such as stress. The analysis of 559 call pulses from 37 *N. capensis* caught at six different sites across Telperion showed significant sexual dimorphism in call variable Fc (SS 14.81, *F* 7.39, *P* 0.006754) and Sc (SS 12863, *F* 7.30, *P* 0.007105), but not in duration (SS 0.19, *F* 0.15, *P* 0.6989), and Tc (SS 0.10, *F* 0.077, *P* 0.7817). A multivariate assessment of Fc, duration, Tc and Sc was also significant (Wilks 0.97, *F* 6.40, d.f. 4, error d.f. 554, *P* 4.887e–05). Analysing only those *N. capensis* caught at the UNISA ABEERU centre (site 4, Table 1), 406 call pulses from 36 individuals, there was significant sexual dimorphism in call variable Fc (SS 33.42, *F* 16.67, *P* 5.36e–05) and Sc (SS 10731, *F* 7.95, *P* 0.005054) but not in duration (SS 0.46, *F* 0.32, *P* 0.571), and Tc (SS 1.30, *F* 0.89, *P* 0.345). A multivariate assessment of Fc, duration, Tc and Sc was also significant (Wilks 0.93, *F* 7.82, d.f. 4, error d.f. 401, *P* 4.51e–06).

Compared to most other female *N. capensis* specimens, a female caught at site 9 (Table 1, Fig. 1), which was released after it had been measured, had a smaller forearm and head length but larger mass, and plotted as an outlier (Figure 2). It was noted that it had a longer, narrower muzzle than the males it was captured with. An analysis into the sexual dimorphism of the external body measurements of the *N. capensis* (excluding this outlier) still yielded significant results, both uni- and multivariably (forearm – SS 63.14, *F* 59.44, *P* 3.26e–10; head length – SS 2.75, *F* 20.81, *P* 3.044e–05, mass – SS 14.83, *F* 56.53, *P* 6.611e–10; multivariate – Wilks 0.42, *F* 23.97, d.f. 3, error d.f. 51, *P* 8.106e–10). Removing this outlier and analysing 536 call pulses from 36 *N. capensis* caught at six different sites across Telperion, also confirmed significant sexual dimorphism in call variables Fc (SS 21.02, *F* 10.41, *P* 0.001329) and Sc (SS 16920, *F* 9.61, *P* 0.00204), but not in duration (SS 0.15, *F* 0.12, *P* 0.734) and Tc (SS 1.23, *F* 0.94, *P* 0.334). The multivariate assessment of Fc, duration, Tc and Sc was also significant (Wilks 0.95, *F* 7.25, d.f. 4, error d.f. 531, *P* 1.082e–05). In a PCA (not shown) together with 36 other *N. capensis*, of mean release call pulse values (Fc, duration, Tc, and Sc), the release call of this individual was not an outlier.

Noteworthy observations of free-flying bats with associated echolocation call recordings were made at two sites. At site 9 (Table 1, Fig. 1) a *T. mauritianus* (identified by the white ventral body colour, and pale, long and narrow wings) was recorded flying high (*ca.* 30 m) above trees (Fig. 4). From the treed area, it moved into an 'open' area above grassland, where it flew toward another *T. mauritianus* individual, and having come close to each other, they flew off in different directions (Fig. 4). Bats flying along

Table 3

Summary statistics of four acoustic parameters (Dur = duration of the call, Tc = time from the start of the call to the Fc, Fc = characteristic frequency – frequency at the flattest portion of the call, and Sc = slope at the start of the call) from Anabat release calls of three species caught at Telperion in 2014. Separate information is also provided for males and females of *N. capensis*. # indiv. = the number of individuals recorded, # pulses = number of pulses from which information derived.

Species	# indiv.	# pulses	Dur	Tc	Fc	Sc
Myotis tricolor	1	1	3.13	2.62	37.04	372.62.
Neoromicia zuluensis	1	6	3.82 ± 0.58 (3.13–4.83)	3.43 ± 0.84 (2.26–4.83)	45.89 ± 0.43 (45.45–46.51)	52.41 ± 16.85 (31.71–68.40)
Neoromicia capensis	37	559	4.61 ± 1.12 (3.01–8.19)	4.25 ± 1.14 (1.66–7.64)	37.10 ± 1.42 (32.65–42.11)	53.67 ± 42.21 (–42.66–261.53)
N. capensis M	20	290	4.63 ± 1.07 (3.01–7.74	4.24 ± 1.09 (1.66–6.99)	37.26 ± 1.46 (32.65–42.11)	58.29 ± 46.30 (–18.07–261.53)
N. capensis F	17	269	4.59 ± 1.18 (3.02–8.19)	4.26 ± 1.19 (1.76–7.64)	36.93 ± 1.36 (33.20–40.20)	48.68 ± 36.75 (–42.66–205.01)

the Wilge River, high above the height of nets set along a causeway across the river (site 10; see Table 1 and Fig. 1) were thought to be *Miniopterus* sp. based on call (Fig. 3) and flight pattern.

Bedbugs (*Cimex* sp.) were observed, never more than one per bat, on 31% of *N. capensis* caught at the UNISA ABEERU centre (site 4, Table 1), but not on any *N. capensis* caught at other sites, or any of the other species that were caught.

DISCUSSION

Only adults of the following eight bat species, belonging to three different families, were recorded at Telperion Nature Reserve in February 2014:

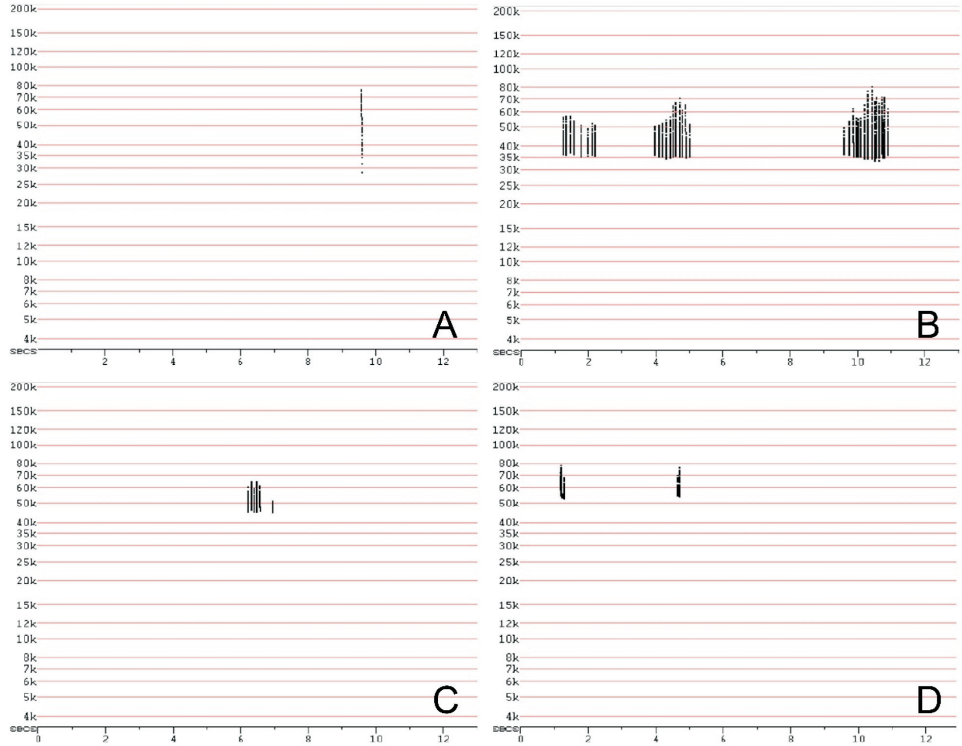

Fig. 3

Analook sonographs (call file name and field number in brackets) of released (**A**) *Myotis tricolor* (O2222123.04#, ECJS-3/22/02/2014), (**B**) *Neoromicia capensis* (O2131828.19#, ECJS-23/2014), (**C**) *Neoromicia zuluensis* (O2162050.14#, ECJS-2/16/02/2014), and (**D**) a free-flying individual assumed to be *Miniopterus natalensis* (O2221941.01#).

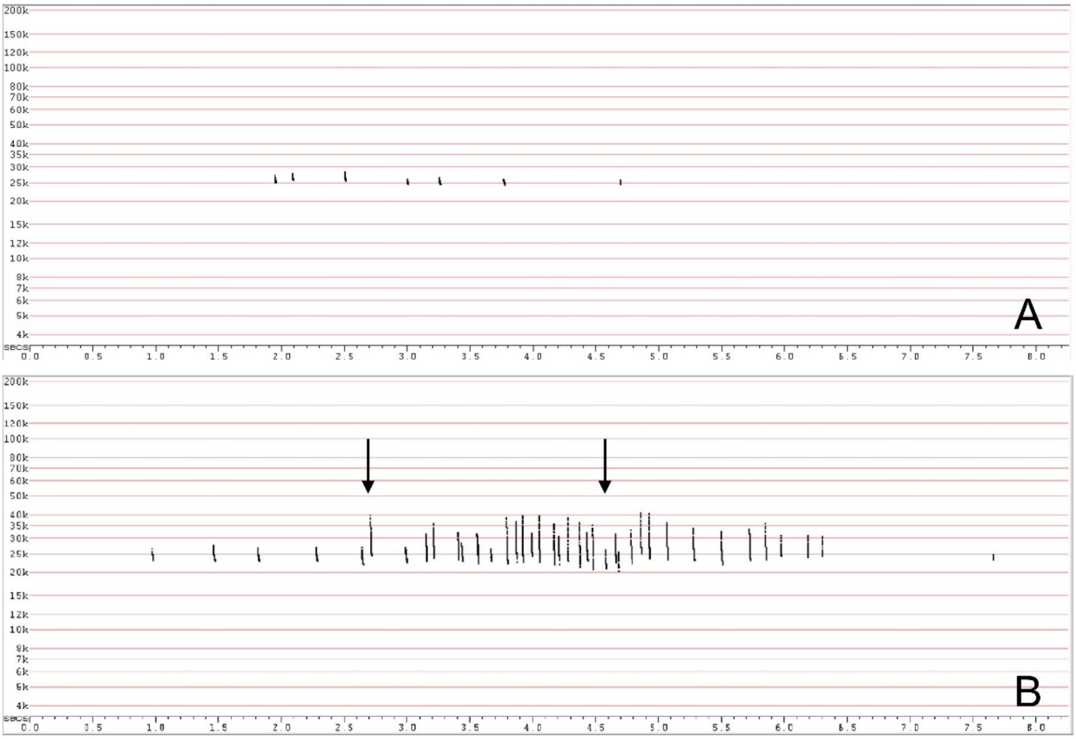

Fig. 4

Analook sonographs (call file name in brackets) of a *Taphozous mauritianus* observed (**A**) flying high (*ca.* 30 m) above trees (O2192105.53#), and (**B**) flying toward and then away (as marked by arrows) from another *T. mauritianus* individual in an 'open' area above grassland (O2192108.18#).

Rhinolophidae – Geoffroy's Horseshoe Bat (*Rhinolophus clivosus*); Emballonuridae – Mauritian Tomb Bat (*Taphozous mauritianus*); Vespertilionidae – Temminck's Hairy Bat (*Myotis tricolor*), Yellow House Bat (*Scotophilus dinganii*), Cape Serotine (*Neoromicia capensis*), Aloe Serotine (*Neoromicia zuluensis*), Dusk Pipistrelle (*Pipistrellus hesperidus*), and the Rusty Pipistrelle (*Pipistrellus rusticus*). The records reported in this study for *N. zuluensis* filled a gap in the previously mapped distribution of this species, while those for *P. hesperidus* and *P. rusticus* extended previously recorded distributions for these species (ACR, 2016). In relation to records in the ACR (2016), the distribution of *P. hesperidus* was extended further west, while that for *P. rusticus* was extended further east, closing a gap toward more easterly records from Legogot (now known as Logogotu,-25.216667 31.25) and Blyde River Canyon (–24.683333 31.833333) in Mpumalanga. *Myotis tricolor* at Telperion were flying along a river course close to the water surface, as was reported for *M. tricolor* in Ithala Game Reserve (Seamark and Kearney, 2004).

The species richness recorded at Telperion was only 14% and 20% of the possible Savanna and Grassland species, respectively, as indicated by Seamark (2013). Large upper ranges of the 95% probabilities of species estimates based on netting results indicated that even more species remained undetected (upper species estimate of Chao 1 = 16, and ACE = 20). Three additional species were identified searching for roosts. However, it is likely more species remained undetected. From observations of bats in flight, it seems probable that *Miniopterus* sp. was using the Wilge River as a flight path. No Molossidae were documented, although cliffs along the Wilge River and rocky ridges in the reserve, which could have provided suitable roost sites, were not exhaustively searched. It is also likely Rhinolophidae and Miniopteridae were undersampled. While the absence of any Pteropodidae, Nycteridae, and Hipposideridae may not have been a true reflection of actual absence, but merely an artefact of the sampling method. The echolocation calls of *T. mauritianus* and many Molossidae are very similar. When recorded with the Anabat zero-crossing system, it is difficult to differentiate calls of *T. mauritianus* from those of many Molossidae. This meant species of Molossidae could not be

Table 4

Comparison of bat capture rates for Telperion Nature Reserve and several other localities in South Africa, Botswana and Zambia. Vegetation classifications follow Sayre *et al.* (2013) subclasses, and Mucina and Rutherford (2006) biomes are included in brackets for South African localities.

Capture rate (%)	Locality	Date	Vegetation classification	Source
1.41	Telperion Nature Reserve, Mpumalanga, South Africa	February 2014	Tropical Grassland, Savanna Shrubland and Temperate Boreal Grassland Shrubland (Savanna and Grassland)	This study
5.54	Kliphuis, Western Cape, South Africa	February 1999 and February 2005 combined	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney *et al.* (2008) and Seamark and Kearney (2008) reported nm^{2}h results. Seamark and Kearney (2007) initially reported nmh results
0.17	Lapalala Wilderness Area, Limpopo, South Africa	April 2007	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney *et al.* (2008)
11.27	Messina Nature Reserve, Limpopo, South Africa	November 1996	Tropical Grassland,Savanna,Shrubland (Savanna)	Seamark and Kearney (2008)
19.33	Chitabe, Botswana	April 2009	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney and Seamark (2011)
25.75	Kaparota, Botswana	April 2009	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney and Seamark (2011)
27.29	Kwetsani, Botswana	April 2009	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney and Seamark (2011)
4.92	Lufupa Camp, Kafue National Park, Zambia	January 2008	Tropical Grassland,Savanna,Shrubland (Savanna)	Kearney *et al.* (2010)

identified based on echolocation calls only. The capture rate of 1.41% was the second lowest relative to other localities sampled by the authors in South Africa, Botswana, and Zambia (Table 4). Being a February sample, bats were still active, even though thunderstorms and rain did stop or interrupt several netting sessions. Therefore, the low capture rate may reflect an element of capture bias, as catching free-flying bats away from a roost has considerable limitations (Kunz *et al*., 2009). Free-flying bats may not be flying at the height of the nets, and in open areas bats have room to avoid the nets by flying over or around them. Even though net placements were chosen to maximize capture potential, i.e. within some clutter along movement corridors or in forage area, and/or close to water (Kunz *et al*., 2009), many of the netting sites were still in rather 'open' areas.

Comparing release calls with information provided in Taylor *et al*. (2013), the calls from *N. capensis* and *N. zuluensis* recorded at Telperion had longer duration and lower Fc values than Taylor *et al*. (2013) reported for *N. capensis* from Limpopo and the Western Cape, and *N. zuluensis* from Limpopo. In comparison with echolocation parameters provided by Monadjem *et al*. (2010) for bats caught in southern Africa, the calls from *N. capensis* and *N. zuluensis* recorded at Telperion also had longer duration and lower Fc values, as well as higher Tc values.

Buildings within Telperion, in particular those at the UNISA ABEERU centre, were providing roosts for *N. capensis*. Based on observations of bats in the roosts, and those caught in the bat trap, the number in these roosts was estimated to be around ten times more than previously recorded by Smithers (1983) for vegetation roosts. In view of the change in roost size with roost type, the large *N. capensis* population roosting in buildings at the UNISA ABEERU centre merits further investigation. Has the social structure and mating system of *N. capensis* roosting in larger numbers in man-made structures changed relative to individuals roosting in smaller numbers in vegetation roosts? And, if so, is this associated with increased reversed sexual size dimorphism in morphology, and sexual dimorphism in Fc and Sc of the echolocation calls, i.e. is there a functional reason for the differences? (Assuming the sexual dimorphism in the call parameters was not a function of some other untested variable such as stress.)

Reversed sexual dimorphism, where females are larger than males, is not uncommon in bats and has been relatively well documented in Vespertilionidae species (Ralls, 1976; Myers, 1978; Tidemann, 1986), and *Rhinolophus ferrumequinum* (Rossiter *et al*., 2006). In bats, this type of dimorphism has been attributed to increased fecundity in females, and the necessity to fly with their offspring attached. Investigating morphological variation in *N. capensis* across southern Africa, Kearney (2005) identified the greatest degree of sexual dimorphism in a large colony ($n = 57$) from Jagersfontein Common in the Free State. These individuals were collected over two days, at a similar time of year to this study (12 and 16 February 1990), from a single colony in a shaft next to water works at a disused mine. Captured males outnumbered females at both the UNISA ABEERU site and Jagersfontein Common, although the ratio of males to females was far higher at Jagersfontein Common (UNISA ABEERU 1.44:1; Jagersfontein Common – 3.38:1). In a study of several *Eptesicus* (Vespertilionidae) species in Australia, Carpenter *et al.* (1978) found sexual dimorphism varied with roost type, and that sexual dimorphism was greater for forest-roosting than cave-roosting individuals.

Only finding *Cimex* sp. on *N. capensis* caught at the ABEERU centre (site 4, Table 1) appeared to corroborate the large size of this roost. Zahn and Rupp (2004) proposed larger host densities and that continuous use of roosts may result in increased parasite populations. They also observed increases in the number of Cimicidae at a roost of *Myotis myotis* (Borkhausen, 1797) (Vespertilionidae) in a church in Bavaria before, during and after the nursing season. Observing *Pipistrellus pygmaeus* (Leach, 1825) (Vespertilionidae) in the Czech Republic, Bartonička and Gaisler (2007) suggested these bats switched roosts to limit the reproduction of *Cimex pipistrelli* Jenyns, 1839. Whether or not this happens with the roost of *N. capensis* at the ABEERU centre would be interesting to investigate.

In a laboratory test, Kazial and Masters (2004) showed female *Eptesicus fuscus* (Beauvois, 1796) (Vespertilionidae) could identify a caller's sex from echolocation information. Grilliot *et al*. (2009) found sexual dimorphism in calls of *E. fuscus* when roosting in the mating season, but not when roosting in the non-mating season, or while flying, which they suggest indicated an ability to change calls in relation to the functional context. They proposed sexual dimorphism in the call during the mating season had a social role in the reproductive context. Although the testes in all but one of the male *N. capensis* had descended into the tail membrane, they were still relatively small in comparison with those of the smaller *P. rusticus*. The testis size of *N. capensis* captured in February from Modderfontein in Gauteng (7.0 × 2.5 mm – TM 48667) and in April from Wakefield Farm in KwaZulu-Natal (5.0 × 3.5 mm – TM 49182) was larger than in the samples from Telperion. Thus, February was probably early in the mating season of *N. capensis*, and as with *E. fuscus* (Grilliot *et al*., 2009), the dimorphism in the call may have been playing a social role within this reproductive context. Based on a study of *N. capensis* in Limpopo, van der Merwe (1994) found spermatogenesis peaked from March to May, and copulation occurred from the end of March. Our observations, hearing audible calls of *N. capensis* that appeared to be between individuals already occupying a roost space in a stone clad wall, and seeing other individuals trying to approach the same space at the UNISA ABEERU centre, was not unlike the premating behaviour of *Myotis lucifugus* (Le Conte, 1831) (Vespertilionidae) observed by Thomas *et al*. (1979). Albeit a cave roosting scenario, Thomas *et al*. (1979) described how drill holes, small crevices and shelves were the foci of bat activity; bats approached these areas, and briefly hovering in front of them. Most bats flew away, but sometimes groups of 2–11, predominately males, congregated for periods of less than five minutes in these cavities. If what was observed at the UNISA ABEERU centre was also premating behaviour, this easily accessible roost would be ideal to study the social behaviour of *N. capensis* in more detail.

Although this work provided the first verified records of eight bat species occurring in Telperion Nature Reserve, further sampling should be undertaken that also includes passive acoustic echolocation recording. Even without a local reference call library, this would help establish whether the absence of Molossidae, Nycteridae, Miniopteridae, Hipposideridae, and presence of only one Rhinolophidae species in 2014 was the result of sampling bias. It would also help identify whether the capture rate was really indicative of low bat densities in the area, influenced by the more species depauperate Grassland biome meeting the Savanna biome in Telperion Nature Reserve, or not. Further investigation of the Wilge River as a commuting route, in particular for *Miniopterus*, would be valuable to understand spatial use patterns.

ACKNOWLEDGEMENTS

The authors wish to thank E. Oppenheimer and Son for funding the fieldwork; Duncan MacFadyen and Elsabe Bosch for facilitating access at Telperion Nature Reserve. Leon Labuschagne, Stewart McCulloch, and Terence Scott kindly provided assistance with the capture of bats. UNISA WIL Nature Conservation staff and students who were working at the ABEERU centre at the time, and provided assistance in the field, scribing, releasing bats, and net set-up, in particular Ishmael Mothemane, Kara Wickins, and Graeme Wilson. Two reviewers are thanked for comments on an earlier draft.

REFERENCES

ACR, 2016. *African Chiroptera Report 2016*. AfricanBats, Pretoria.

BARTONIČKA, T. and GAISLER, J., 2007. Seasonal dynamics in the numbers of parasitic bugs (Heteroptera, Cimicidae): a possible cause of roost switching in bats (Chiroptera, Vespertilionidae). *Parasitology Research* **100:** 1323–1330.

CARPENTER, S.M., McKEAN, J.L. and RICHARDS, G.C., 1978. Multivariate morphometric analysis of *Eptesicus* (Mammalia: Chiroptera) in Australia. *Australian Journal of Zoology* **26:** 629–638.

CHAO, A. and SHEN, T-J., 2010. Program SPADE (Species Prediction And Diversity Estimation). Program and User's Guide published at http://chao.stat.nthu.edu.tw/

COETZEE, C., 2012. The effect of vegetation on the behaviour and movements of Burchell's Zebra, *Equus burchelli* (Gray, 1824) in the Telperion Nature Reserve, Mpumalanga, South Africa. Master's thesis, University of Pretoria, 174 pp. (https://repository.up.ac.za/handle/2263/29301)

COOPER-BOHANNON, R., REBELO, H., JONES, G., COTTERILL, F., MONADJEM, A., SCHOEMAN, M. C., TAYLOR, P. and PARK, K., 2016. Predicting bat distributions and diversity hotspots in southern Africa. *Hystrix, the Italian Journal of Mammalogy* **27**(1): DOI:10.4404/hystrix-27.1-11722.

CURRAN, M., KOPP, M., BECK, J. and FAHR, J., 2012. Species diversity of bats along an altitudinal gradient on Mount Mulanje, southern Malawi. *Journal of Tropical Ecology* **28**(3): 243–253. DOI:10.1017/S0266467412000193

FAHR, J. and KALKO, E. K. V., 2011. Biome transitions as centres of diversity: habitat heterogeneity and diversity patterns of West African bat assemblages across spatial scales. *Ecography* **34**(2): 177–195. DOI: 10.1111/j.1600-0587.2010.05510.x

GELDERBLOM, C. M., BRONNER, G. N., LOMBARD, A. T. and TAYLOR, P. J., 1995. Patterns of distribution and current protection status of the Carnivora, Chiroptera and Insectivora in South Africa. *South African Journal of Zoology* **30**(3): 103–114.

GRILLIOT, M. E., BURNETT, S. C. and MENDONÇA, M. T., 2009. Sexual dimorphism in big brown bat (*Eptesicus fuscus*) ultrasonic vocalizations is context dependent. *Journal of Mammalogy* **90**(1): 203–209.

HERKT, K. M. B., BARNIKEL, G., SKIDMORE, A. K. and FAHR, J., 2016. A high resolution model of bat diversity and endemism for continental Africa. *Ecological Modelling* **320:** 9–28.

KAZIAL, K. A. and MASTERS, W. M., 2004. Female big brown bats, *Eptesicus fuscus*, recognize sex from a caller's echolocation signals. *Animal Behaviour* **67:** 855–863. DOI: 10.1016/j.anbehav.2003.04.016

KEARNEY, T. C., 2005. Systematic revision of southern African species in the genera *Eptesicus*, *Neoromicia*, *Hypsugo* and *Pipistrellus* (Chiroptera: Vespertilionidae). Ph.D. thesis, University of Kwa-Zulu Natal, Durban, South Africa.

KEARNEY, T., SEAMARK, E. C. J., BOGDANOWICZ, W., ROBERTS, E. and ROBERTS, A., 2008. Chiroptera of Lapalala Wilderness Area, Limpopo Province, South Africa. *African Bat Conservation News* **18:** 8–12.

KEARNEY, T., SEAMARK, E. C. J., MATEKE, C. and HOOD, D., 2010. Chiroptera of Lufupa Camp, Kafue National Park, Zambia; with taxonomic notes on *Epomophorus*, *Nycticeinops*, *Scotophilus* and *Scotoecus*. *African Bat Conservation News* **23:** 7–31.

KEARNEY, T. C. and SEAMARK, E. C. J., 2011. Bat fieldwork at three different areas in the Okavango Delta in 2009. *Africanbats.org Technical Report* 1/2011: i–iv + 1–66 pp.

KEARNEY, T. C., KEITH, M. and SEAMARK. E. C. J., 2017. New records of bat species using Gatkop Cave in the maternal season. *Mammalia* **81**(1): 41–48. DOI: 10.1515/mammalia-2015-0043

KUNZ, T. H., HODGKINSON, R. AND WEISE, C. D., 2009. Methods of capturing and handling bats. *In*: KUNZ, T. H. and PARSONS, S., eds, *Ecological and behavioural methods for the study of bats,* pp. 3–35. The Johns Hopkins University Press, Baltimore.

MIDDLETON, N., FROUD, A. and FRENCH, K., 2014. *Social calls of the bats of Britain and Ireland*. Pelagic Publishing Limited, Exeter.

MONADJEM, A., TAYLOR, P. J., COTTERILL, F. P. D. AND SCHOEMAN, M. C., 2010. *Bats of southern and central Africa: A biogeographic and taxonomic synthesis.* Wits University Press, Johannesburg.

MUCINA, L. and RUTHERFORD, M. C., eds, 2006. *The vegetation of South Africa, Lesotho and Swaziland*. Strelitzia **19:** viii + 807 pp. South African National Biodiversity Institute, Pretoria.

MYERS, P., 1978. Sexual dimorphism in size of Vespertilionid bats. *The American Naturalist* **112**(986): 701–711.

PARSONS, S. and SZEWCZAK, J. M., 2009. Detecting, Recording and Analyzing the Vocalizations of Bats. *In*: KUNZ, T. H. and PARSONS, S. , eds, *Ecological and behavioural methods for the study of bats,* pp. 91–111. The Johns Hopkins University Press, Baltimore.

RALLS, K., 1976. Mammals in which the females are larger than males. *The Quarterly Review of Biology* **51**(2): 245–276.

R CORE TEAM, 2014. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

ROSSITER, S. J., RANSOME, R. D., FAULKES, C. G., DAWSON, D. A. and JONES, G., 2006. Long-term paternity skew and the opportunity for selection in a mammal with reversed sexual size dimorphism. *Molecular Ecology* **15:** 3035–3043.

SAYRE, R.G., COMER, P., HAK, J., JOSSE, C., BOW, J., WARNER, H., LARWANOU, M , KELBESSA, E., BEKELE, T., KEHL, H., AMENA, R., ANDRIAMASIMANANA, R., BA, T., BENSON, L., BOUCHER, T., BROWN, M., CRESS, J.J., OUEDDO DASSERING, O., FRIESEN, B.A., GACHATHI, F., HOUCINE, S., KEITA, M., KHAMALA, E., MARANGU, D., MOKUA, F., MOROU, B., MUCINA, L., MUGISHA, S., MWAVU, E., RUTHERFORD, R., SANOU, P., SYAMPUNGANI, S., TOMOR, B., VALL, A.O.M., VANDE WEGHE, J-P., WANGUI, E., and WARUINGI, L., 2013. *A new map of standardized terrestrial ecosystems of Africa*. African Geographical Review. Washington, DC.

SCHOEMAN, M. C., COTTERILL, F. P. D., TAYLOR, P. J. and MONADJEM, A., 2013. Using potential distributions to explore environmental correlates of bat species richness in southern Africa: Effects of model selection and taxonomy. *Current Zoology* **59**(3): 279–293.

SEAMARK, E. C. J., 2013. The use of incidence data to estimate bat (Mammalia: Chiroptera) species richness and taxonomic diversity and distinctness within and between the biomes of South Africa, Lesotho and Swaziland. M.Sc. thesis, University of the Witwatersrand, Johannesburg, South Africa.

SEAMARK, E. C. J. and KEARNEY, T. C., 2004. Bats (Chiroptera) of Ithala Game Reserve, Northern KwaZulu-Natal. *Durban Museum Novitates* **29:** 1–4.

SEAMARK, E. C. J. and KEARNEY, T. C., 2007. Field notes (February 2005): Kliphuis Camp Site, Cederberg, Western Cape Province, South Africa. *African Bat Conservation News* **13:** 4–5.

SEAMARK, E. C. J. and KEARNEY, T., 2008. Bats of Messina Nature Reserve, Limpopo Province, South Africa. *African Bat Conservation News* **18:** 5–7.

SIKES, R. S., GANNON, W. L. and the Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy* **92**(1): 235–253. DOI: 10.1644/10-MAMM-F-355.1

SMITHERS, R. H. N., 1983. *The mammals of the southern African subregion*. University of Pretoria, Pretoria.

TAYLOR, P. J., SOWLER, S., SCHOEMAN, M. C. and MONADJEM, A., 2013. Diversity of bats in the Soutpansberg and Blouberg Mountains of northern South Africa: complementarity of acoustic and non-acoustic survey methods. *South African Journal of Wildlife Research* **43**(1): 12–26. DOI: 10.3957/056.043.0117

THOMAS, D. W., FENTON, M. B. and BARCLAY, R. M. R., 1979. Social behaviour of the little brown bat, *Myotis lucifugus*: I. Mating behaviour. *Behavioural Ecology and Sociobiology* **6**(2): 129–136. DOI: 10.1007/BF00292559

TIDEMANN, C. R., 1986. Morphological variation in Australian and Island populations of Gould's wattled bat *Chalinolobus gouldii* (Gray) (Chiroptera: Vespertilionidae). *Australian Journal of Zoology* **34**(4): 503–514. DOI: 10.1071/ZO9860503

VAN DER MERWE, M., 1994. Reproductive biology of the Cape serotine bat, *Eptesicus capensis*, in the Transvaal, South Africa. *South African Journal of Zoology* **29**(1): 36–39.

ZAHN, A. and RUPP, D., 2004. Ectoparasite load in European vespertilionid bats. *Journal of Zoology, London* **262**(4): 383–391.