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Endemic plants and animals are susceptible to extinction in an imperilled alpine hotspot in southern Africa

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Background: As global temperatures rise, alpine species at the upper limit of their distribution are at risk of decline and extinction due to shrinking habitats downslope. The alpine (> 2 800 m a.s.l.) biodiversity of the Maloti-Drakensberg is poorly known but may be threatened by climate change.

Objectives: Using expert BioBlitzes, we documented species richness and elevational patterns of distribution in 14 plant and animal higher taxa from alpine and upper-montane zones in an unexplored corner of the Maloti-Drakensberg.

Methods: Using standardised methods such as Sherman traps, acoustic monitoring, bird timed counts, pitfall traps, sweep nets, aquatic SASS5 kick-nets, timed searches and herbarium collections, we assessed elevational zonation of flowering plant and selected invertebrate and vertebrate diversity in the Witsieshoek Community Conservation Area (WCCA).

Results: GBIF records complemented expert BioBlitz data, together enumerating 1 216 plant, vertebrate and invertebrate species along an elevation gradient from 1 760 m to 3 145 m at WCCA. Birds, insects and plants showed concordant beta diversity patterns from BioBlitz and GBIF data: high turnover compared to nestedness in more sedentary insects and plants, and the opposite in more mobile birds (GBIF data not available for bats). Although identifications are ongoing, 17% of species or morphospecies were exclusively recorded in the alpine zone, including 82 species of plants and 92 of animals.

Conclusion: Alpine endemics are vulnerable to the 'escalator to extinction' process due to climate change. Surveys of under-explored alpine hotspots should be prioritised, drawing on mountain tourism-based citizen science. We advocate an ecotourism- and community-centred, restoration and rewilding approach for this strategic and biodiverse community conservation area.

Keywords: Drakensberg Mountains; climate change; ecology; escalator to extinction; GBIF.

Introduction

As global temperatures rise, alpine species at the upper edge of their distribution are at risk of decline and extinction due to shrinking habitats downslope, a phenomenon known as the 'escalator to extinction' (Freeman et al. al. 2018; Urban 2018; Watts et al. 2022; Environments [GLORIA] 2024).

Temperate grasslands, globally and in the Maloti-Drakensberg (MD) of southern Africa, are rapidly transforming, and are currently poorly protected (Carbutt et al. 2017; Bengtsson et al. 2019; Scholtz & Twidwell 2022). Comprising both montane (1 800–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) elements, the

MD is a key area of endemism and diversity for plants (Carbutt & Edwards 2015; Brand et al. 2019; Carbutt 2019), vertebrates (Van As et al. 2014a,b; Kopij 2015), terrestrial invertebrates (Armstrong & Brand 2012; Van der Merwe et al. 2020; Modise 2023) and aquatic invertebrates (Hamer & Brendonck 1997; Martens et al. 1998; Van Damme et al. 2013; Deacon et al. 2020), with ongoing species discoveries of both plants (Clark et al. 2011; 2015; 2016a,b) and animals (Hamer & Martens 1998; Hamer & Slotow 2009; Conradie 2014; Conradie et al. 2018; Taylor et al. 2020; Haddad et al. 2021; Mdidimba et al. 2021; Cornette et al. 2022).

Alpine grasslands and shrublands in Africa are predominantly found in two regions: the tropical Afroalpine 'sky islands' of northeast Africa (3 400–4 600 m) and the higher slopes and plateaux of the MD (2 800–3 482 m). The latter is located within Lesotho (90%) and adjacent areas of South Africa (10%) (Carbutt 2020). Reflecting a biome in crisis, these alpine areas are mostly unprotected and vulnerable to anthropogenic and climate change (Dinerstein et al. 2017; Carbutt 2019, 2020). The Qwaqwa Mountains form a northern outpost of the MD spanning both montane and alpine elevations (Figure 1). Within South Africa, along its Free State province's border with Lesotho, these mountains fall within the Witsieshoek Community Conservation Area (WCCA), which is valuable for ecotourism and biodiversity, but poorly researched with few biological studies (Delves et al. 2021; Shezi et al. 2021; Praeg et al. 2023). The WCCA is an important conservation buffer bordering two protected areas, Royal Natal National Park (RNNP) and Golden Gate Highlands National Park (GGHNP). However, it is being transformed by conversion into settlements, bush encroachment and livestock overgrazing, leading to reduced plant diversity (Shezi et al. 2021), while hunting and competition with people and livestock has reduced populations of larger mammals (Morake 2010). Rewilding of the WCCA from adjacent protected areas is therefore viable in conjunction with community-based sustainable rangeland management. However, conservation efforts in the WCCA require engaged scholarship to understand the multidimensional social, environmental and biodiversity challenges of the area (Delves et al. 2021). This should be underpinned by robust assessments of grassland and rangeland biodiversity, particularly alpine biodiversity potentially at risk from the escalator to extinction.

In 2023, the Witsieshoek Mountain Lodge and the Afromontane Research Unit of the University of the Free State (ARU) established a joint Alpine Research Station, facilitating surveys of hitherto poorly explored alpine biota. Leveraging improved access and conducting five expert BioBlitzes (i.e., surveys by specialist taxonomists; Parker et al. 2018) between October 2021 and November 2023, we documented elevational patterns across 14 animal and plant higher taxa at WCCA. We identified the extent of alpine endemism among these taxa within the scope of our study, and consequently, assessed the risk of extinction for these species. At the time of our study, tourist and scientist visitors to the Witsieshoek Mountain Lodge contributed 3 438 georeferenced biodiversity records to public platforms such as the Global Biodiversity Information Facility (GBIF), mostly concentrated along the hiking trail leading from the lodge to the alpine summit (Figure 1). We compared our BioBlitz data with records from the GBIF database (which were validated by experts in our study), thereby demonstrating the complementarity of the two approaches.

Methods

Study area

The geographical context of the WCCA is described above (Figure 1). Surveys were conducted from our bases of the Witsieshoek Lodge (at 2 200 m; GPS: 28.6860°S, 28.9014°E) and the ARU Alpine Research Station (at 3 145 m; GPS: 28.7536°S, 28.8672°E). The vegetation of the lower sites is classified as uKhahlamba Basalt Grassland while sites above 2 800 m are classified as Drakensberg Afroalpine Heathland (Table 1). A total of 17 sites (ten terrestrial and seven aquatic) were surveyed within the study area, classified into lower-montane (< 2 400 m a.s.l.), upper-montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) zones (Table 1, Figure 1).

The area receives between 1 200 and 1 500 mm annual rainfall, and falls within a cool, wet, summer rainfall region, with cold winters. Precise data were not available for the WCCA, but the mean annual temperature for the adjacent Lesotho Highlands is about 7°C, with a summer mean of 20°C and a winter minimum of -6.3°C (Lesotho Meteorological Services). Five distinct plant communities have been recognised in the study area (Shezi 2014), the Cheche Open Shrubland, the Ledile–*Eragrostis plana*, the Lodi, the Lekgapu and the Red Grass communities. Generally, the lower-lying Cheche Open Scrub and Ledile-*Eragrostis plana* communities are dominated by encroaching shrubs (*Leucosidea sericea* Eckl. & Zeyh; Rosaceae) and grasses (*Eragrostis plana* Nees; Poaceae) respectively, indicating the effects of over-grazing. The Lodi and Red Grass communities are both characterised by a grass species (*Themeda triandra* Forssk.; Poaceae) that indicates good rangeland quality. The Lekgapu community is characterised by dwarf shrubs dominated by *Erica dominans* Killick (Ericaceae), characteristically occurring on the high plateau. In general, lower and gentler slopes showed evidence of overgrazing by livestock from local communities while the summit plateau showed evidence of overgrazing in summer by livestock of Basotho herders from Lesotho (Table 1; Kotzé et al. 2023). The soils of the alpine zone in the Amphitheatre summit area are characterised by exceptionally high soil organic carbon (SOC) (Kotzé et al. 2023).

GBIF records

A search of the GBIF database was conducted on 18 February 2023 for all records within a polygon that defined the study area, using the search term ‘Geometry POLYGON((28.867 -28.755, 28.902 -28.755, 28.902 -28.677, 28.867 -28.677, 28.867 -28.755))’. The DOI citation is ‘GBIF.org (18 February 2023) GBIF Occurrence Download 10.15468/dl.ykm4r7’. The search yielded 3 438 records. After excluding chromista, fungi and uncertain records, a final list of 3 366 flowering plant and animal records was obtained for

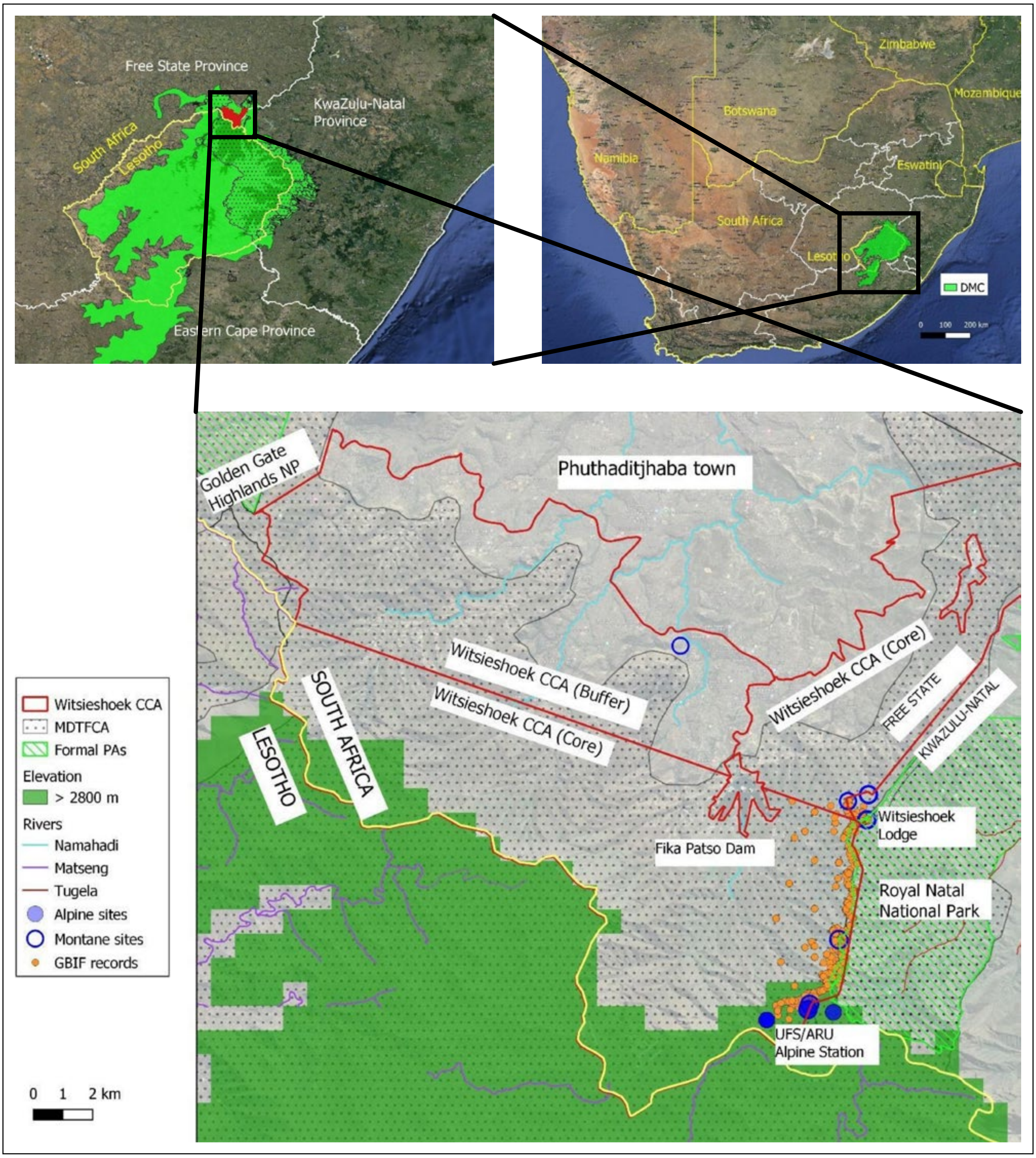

Figure 1. Maps showing (top panels) the location of Witsieshoek Community Conservation Area (WCCA; red shading) in relation to the Drakensberg Mountain Centre of southern Africa (green shading; Carbutt 2019, with elevations > 2 800 m a.s.l. shown in darker green in the top left panel), including the Maloti Drakensberg Transfrontier Conservation Area (stippled; MDTFCA), and (bottom panel) detailed map of WCCA showing aquatic invertebrate and terrestrial plant and animal sampling sites and GBIF records from montane (≤ 2 800 m) and alpine (> 2 800 m) zones within the WCCA, which connects the Golden Gate Highlands (west) and Royal Natal (east) National Parks. The study area is a watershed for three major drainage systems draining east (Tugela R), west (Matseng R) and north (Namahadi R). Maps for MDTFCA © Peace Parks Foundation Open Data. Maps for WCCA © MDTFCA.

Table 1. Details of terrestrial (TER) and aquatic (AQS) sites for five expert BioBlitzes conducted between October 2021 and November 2023. For this study, sites were grouped in three elevational zones as lower montane (< 2 400 m a.s.l.), upper montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.)

Site ID	Longitude	Latitude	Site name	Elevation (m a.s.l.)	Elevation zone	Vegetation type (Mucina & Rutherford 2006)	Site description (where available)	Grazing pressure
TER 1	28.9019	-28.6773	Witsieshoek Dam	2 058	Lower Montane	Ukhahlamba Basalt Grassland		Mod–High
TER 2	28.90138	-28.686	Witsieshoek Lodge (=Pollinator ‘lower montane’ Site 1)	2 200	Lower Montane	Ukhahlamba Basalt Grassland	Gentle southerly facing slope, short grassland with low flowering forbs and relatively few bushes; some low rocks and bare stoney areas; signs of grazing by cattle.	Mod–High
TER 2a	28.90138	-28.686	Witsieshoek Lodge (=Pollinator ‘lower montane’ Site 2)	2 197	Lower Montane	Ukhahlamba Basalt Grassland	Gentle slope; short grassland with forbs; signs of grazing by livestock.	Mod–High
TER 3	28.8917	-28.7273	Sentinel Car Park (=Pollinator ‘upper montane’ Site 2)	2 590	Upper Montane	Ukhahlamba Basalt Grassland	Westerly facing slope, short grassland; many flowering forbs; some bare stoney areas; some low rocks.	Low
TER 3a	28.89249	-28.72574	Sentinel Car Park (=Pollinator ‘upper montane’ Site 1)	2 567	Upper Montane	Ukhahlamba Basalt Grassland	Variable (gentle to moderately steep) slope; short grassland with forbs.	Low
TER 4	28.88101	-28.7514	Top of chain ladder	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
TER 5	28.86723	-28.75359	ARU Alpine Station (=Pollinator Alpine Site 1 & MIREN upper site)	3 145	Alpine	Drakensberg Afroalpine Heathland	Gentle easterly facing hillside; low bushes, forbs and grass; with stoney bare areas and low rocks.	Mod–High (summer)
TER 6	28.8693	-28.75279	Near ARU Alpine Station (=Pollinator Alpine Site 2)	3 124	Alpine	Drakensberg Afroalpine Heathland	Flattish area; some standing water; many rocks, some bare areas with stoney soil; low bushes, many flowering forbs and tall grasses.	Mod–High (summer)
TER 7	28.88274	-28.75136	Royal Natal NP, top of Amphitheatre (=Pollinator Alpine Site 3)	3 037	Alpine	Drakensberg Afroalpine Heathland	Flattish area; slightly marshy, some standing water; many sedges, grasses and *Helichrysum* flowers.	Mod–High (summer)

Table 1. Details of terrestrial (TER) and aquatic (AQS) sites for five expert BioBlitzes conducted between October 2021 and November 2023. For this study, sites were grouped in three elevational zones as lower montane (< 2 400 m a.s.l.), upper montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) (continued)

Site ID	Longitude	Latitude	Site name	Elevation (m a.s.l.)	Elevation zone	Vegetation type (Mucina & Rutherford 2006)	Site description (where available)	Grazing pressure
TER 8	28.88468	-28.75246	Royal Natal NP, top of Amphitheatre (=Pollinator Alpine Site 4)	3 038	Alpine	Drakensberg Afroalpine Heathland	Easterly facing slope; fairly rocky; some small bushes and tallish grass clumps; sparse short grass and many flowering forbs including *Helichrysum*.	Mod–High (summer)
AQS 1 (~TER 1)	28.9019	-28.6773	River feeding Witsieshoek Dam	2 060	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 2	28.837	-28.626	Namahadi River near Phuthaditjhaba	1 710	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 3 (~TER 2)	28.90138	-28.686	Temporary wetland near Witsieshoek Lodge	2 200	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 4 (~TER 4)	28.88101	-28.7514	Tugela River, just above the chain ladders	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 5 (~TER 4)	28.88101	-28.7514	Pool on summit, just above the chain ladders	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 6	28.88993	-28.75229	Pool near Tugela Falls	3 019	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 7	28.88968	-28.75237	Tugela River, just upstream of Tugela Falls	3 019	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)

599 species. The geographical and taxonomic accuracy of these records was checked by specialists for mammals, amphibians, reptiles, birds, insects and plants, resulting in 434 fully validated species used for this study.

Sampling

During five expert BioBlitzes between November 2021 and November 2023 (Table 2), we sampled 10 terrestrial (TER 1, 2, 2a, 3, 3a, 4–8) and seven aquatic sites (AQS 1–7), divided into lower-montane (< 2 400 m a.s.l.), upper-montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) elevation zones (Table 1). For taxa that lacked data for upper-montane or alpine sites, we further subdivided the lower-montane zone into lower (TER 1; Witsieshoek Dam; 2 058 m a.s.l.) and upper (TER 2; Witsieshoek Mountain Lodge; 2 200 m a.s.l.) sub-zones. This allowed us to maintain three elevational intervals for standardised plotting of Venn diagrams.

Using standard methods, we compiled site and elevation zone checklists of 14 higher taxa: i) small mammals (Sherman traps) and ii) their ectoparasites; iii) bats (acoustic methods); iv) birds (timed counts); v) ants (pitfall traps); vi) insect flower-visitors (timed collections); vii) leafhoppers (sweep nets); viii) dung beetles (baited pitfall traps); ix) grasshoppers (sweep nets and timed counts); x) bugs (sweep nets); xi) flies (sweep nets), xii) spiders (pitfall traps), xiii) aquatic macroinvertebrates (kick-nets) and xiv) flowering plants (herbarium specimens collected during transects or searches). Identification was provided by relevant specialists to species level in plants, vertebrates, dung beetles, insect pollinators and flower visitors, grasshoppers and leafhoppers; to genus level in ants; and to family level in aquatic macroinvertebrates, flies and bugs. Samples identified to genus or family level were further sorted into morphospecies, and all collected specimens were deposited in relevant institutional repositories (Table 2). We conducted sample replication within a site where possible, e.g. two bat detectors, rodent trap grids or arthropod pitfall arrays placed 300–500 m apart at a site. Some invertebrate taxa not mentioned here are still being processed and identified for future publications.

Taxon-specific methods

Small mammals and their ectoparasites

Paired grids of Sherman traps were set at Sites TER 1, TER 2 (lower montane), and TER 3 (upper montane) (Table 1). Each grid was configured in a 3 × 7 layout, with traps 10 m apart (totalling 42 traps per night at each site). Trapping was conducted for three nights per session, repeated three times at Sites TER 1–3 in October 2021, March 2022 and February 2023. Additionally, alpine sites (Site TER 4 and TER 5) were sampled opportunistically in October 2022 and February 2023 for two nights each using 20 Sherman traps and two modified 'Hickman' mole-traps (Hickman 1979). Sherman traps were baited with a mixture of peanut butter and oats and checked every morning and evening. Individual rodents and shrews were identified using Monadjem et al. (2015). Sex and reproductive status were determined, and standard external measurements were taken following McCleery et al. (2021). For all rodents, shrews and bats captured, their fur was inspected and lightly brushed for ectoparasites, collecting mites, fleas and ticks into 95% ethanol for later identification by N.I. Nyembe and L. Mofokeng.

Bats

Pairs of Song Meter Mini-4 (SM4+) bat detectors (Wildlife Acoustics), set at least 300 m apart, were deployed at Sites TER 1, TER 2, TER 3 and TER 4, recording passively from dusk until dawn for 2–4 nights. Sampling was repeated in October 2021, March 2022, October 2022 and February 2023. Echolocation calls were saved in '.wav' format and identified manually by V.M. Mdluli using Kaleidoscope Pro (Wildlife Acoustics) and available call reference libraries (P.J. Taylor unpublished; A. Monadjem unpublished; Taylor et al. 2013, Monadjem et al. 2020).

Birds

Bird counts were conducted from 11 to 14 October 2021 across all elevation zones, from Sites TER 1 and TER 2 (lower montane), TER 3 (upper montane) and TER 4 (alpine) recording all species seen (with binoculars) or heard. Each site was visited for at least an hour. To increase species numbers, birds seen or heard while walking between sites were also recorded, creating a preliminary checklist for the area. All bird species were logged on the BirdLasser app, with a new list for each of the four days of sampling. Standardised timed counts of 10 min duration were conducted on three further occasions: 8–12 March 2022 (all sites), 3–6 November 2022 (Sites TER 2 and TER 4) and 6–8 February 2023 (all sites), with between 6 and 12 counts per site per occasion.

Invertebrate sampling method 1 (Focus: Ants)

During the first BioBlitz, following Munyai and Foord (2015), pitfall grid arrays were set at Sites TER 1 (Witsieshoek Dam), TER 2 (Witsieshoek Lodge) and TER 3 (Sentinel Car Park). Each grid consisted of 20 pitfall traps in a 4 × 5 grid. Test-tube shaped plastic containers (30 mm diameter) were half-filled with propylene glycol and left open for 48 hours before collection.

Table 2. Total and alpine observed and asymptotic species richness, sampling methods, institutional repositories and collection effort of taxa sampled during five expert BioBlitzes (2021–2023) at WCCA compared with GBIF point records and ADU Virtual Museum (VM) records from the locus 2828D and a previous herpetological survey of WCCA (Van As 2014a). Shaded rows represent taxa surveyed in this study, while unshaded rows represent taxa only incidentally recorded. Abbreviation of institutional museum collections as follows: ANSP = Academy of Natural Sciences, Philadelphia; DMSA = Durban Natural Science Museum; NMB = National Museum, Bloemfontein, South Africa; NMSA = Natal Museum, South Africa; SANC = South African National Collection of Insects, South Africa; TMSA = Ditsong National Museum of Natural History [previously Transvaal Museum], South Africa. Other abbreviations: SC = sample coverage (%); SR = species richness; UKZN = University of KwaZulu-Natal; UFS Zoo & Ento = University of the Free State, Department of Zoology and Entomology, Qwaqwa Campus

Taxon	ADU VM locus 2828D	GBIF + BB	GBIF	Herps (Van As 2014a)	Witsieshoek BioBlitz (BB) results, covering five field sessions of 3–6 days each. Session 1: Oct 2021; Session 2: Mar 2022; Session 3: Nov 2022; Session 4: Feb 2023; Session 5: Nov 2023										
					Sampling method	Institution	Sessions	No. records	SR	SC(%)	Asymptotic SR	95% limits	No. alpine spp.	% alpine spp.	No. new spp.
Domestic mammals	1	8	0	–	Field observations, records of Witsieshoek Lodge	NA	Incidental	NA	8	NA	NA	NA	NA	NA	0
Larger indigenous mammals	30	6	5	–	Field observations, records of Witsieshoek Lodge	NA	Incidental	NA	4	NA	NA	NA	NA	NA	0
Small mammals	–	9	0	–	Sherman traps, pitfalls	NMB	1, 2, 4	59	9	0.98	9	9.0–17.3	3	30	0
Bats	–	8	0	–	Acoustic bat detectors	NMB	1, 2, 3, 4, 5	16 442	8	1	8	8.0–9.38	0	0	1
Birds	–	120	110	–	Timed bird counts	NA	1, 2, 3, 4	411	60	0.94	97	72.0–172.0	10	16.7	0
Frogs	28	24	5	21	Collections/photos	NMB	Incidental	3	1	NA	NA	NA	1	4.8	0
Reptiles	48	33	5	32	Collections/photos	NMB	Incidental	4	2	NA	NA	NA	2	6.2	0
Ants (Formicidae)		20	0	–	Pitfalls, collection	UKZN	1	1 214	20	0.99	20.2	20.0–23.5		NA	0

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Taxon	ADU VM locus 2828D	GBIF + BB	GBIF	Herps (Van As 2014a)	Witsieshoek BioBlitz (BB) results, covering five field sessions of 3–6 days each. Session 1: Oct 2021; Session 2: Mar 2022; Session 3: Nov 2022; Session 4: Feb 2023; Session 5: Nov 2023										
					Sampling method	Institution	Sessions	No. records	SR	SC(%)	Asymptotic SR	95% limits	No. alpine spp.	% alpine spp.	No. new spp.
Pollinators, other flower visitors & grasshoppers	145	151	43	–	Timed collection of flower visitors	DMSA, NMSA, TMSA, SANC	4, 5	649	115	0.91	265	186–431	38	33.0	12
Leafhoppers	–	35	0	–	Sweep nets, collection		5 only	532	35	0.99	43	36.5–77.4	13	37.1	3
Dung beetles	–	29	0	–	Pitfalls, collection	UFS Zoo & Ento; ARC-SG	2, 4	512	29	0.98	36	30.5–58.4	2	6.9	1
Grasshoppers	–	65	2	–	Pitfalls, sweep nets, collection	UFS Zoo & Ento	1, 2	506	65	0.94	106	81.2–167.8		NA	0
Bugs	–	69	–	–	Pitfalls, sweep nets, collection	UFS Zoo & Ento	1, 2	352	69	0.91	112	86.5–177.6		NA	0
Flies	–	91	3	–	Sweep nets, collection	UFS Zoo & Ento	1, 2	919	91	0.96	148	115.3–224.8		NA	0
Aquatic macro-invertebrates	–	60	1	–	Kick-net, SAS Net, collections	Albany Museum	1, 2	647	60	0.97	120	78.3–259.1	23	33.3	0
Mammalian ectoparasites	–	5	0	–	Collection from small mammal hosts	UFS Zoo & Ento	1, 2, 4	78	5	1	5	5.0–6.5	0	0	0
Spiders & harvestmen	7	47	0	–	Pitfalls, collection	UFS Zoo & Ento	1, 2	200	47	0.92	60	51–88		NA	0

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					Sampling method	Institution	Sessions	No. records	SR	SC(%)	Asymptotic SR	95% limits	No. alpine spp.	% alpine spp.	No. new spp.
Flowering plants	–	466	260	–	Herbarium specimens	UFS Qwaqwa Herbarium	1, 4 + additional collecting (see Methods)	2120	322	0.96	420	380–490	82	25.4	0
Totals or Means	**259**	**1 215**	**434**	53				**23 624**	**950**		**1 449**		**174**	**17.6**	17

Invertebrate sampling method 2 (Focus: Ground-dwelling insects)

In March 2022 (second BioBlitz) and February 2023 (fourth BioBlitz), pitfall sizes were increased to 250 ml plastic containers (60 mm diameter), half-filled with a 2:1 mixture of 70% ethanol and propylene glycol. Sites TER 1, TER 2 and TER 3 were sampled with 20 pitfalls per site in a random grid to cover surrounding vegetation diversity. Pitfalls were left out for 48 hours. The alpine sites were excluded due to equipment transport difficulties.

Invertebrate sampling method 3 (Focus: Dung beetles)

Dung beetles were collected at Sites TER 1–3 in March 2022, and at Sites TER 1–4 in February 2023, using pitfall traps baited with pig dung. Pitfall traps were made from 2-litre cold drink bottles, cut to form a funnel system. Three plots per site, spaced 50 m apart, each contained four traps, spaced 5 m apart. Traps were left for 48 hours. Samples from the four traps in each plot were pooled. Identification was conducted using published keys and morphological comparison with specimens at the National Museum Bloemfontein (BMSA). Some voucher specimens were deposited at BMSA.

Invertebrate sampling method 4 (Focus: Flying insects)

During pitfall sampling (Sampling method 2 above), Sites TER 1–3 were also sampled using a sweep-net method along 10 × 100 m transects per site. Additional time was spent actively searching for large insects and observing secondary signs of insect activity.

Invertebrate sampling method 5 (Focus: Insect flower visitors and orthopteran herbivores)

Eight 1-ha sampling sites were set up: four in the alpine zone (TER 5–8), two in the upper-montane zone (TER 3, 3a), and two in the lower-montane zone (TER 2, 2a). Sampling was conducted on specific dates in February and March 2023 (fourth BioBlitz) and November 2023 (fifth BioBlitz), with weather conditions noted. Each site was sampled by two people for one hour, one focusing on flower visitors and the other on herbivorous Orthoptera, switching roles at the next site. Specimens were deposited in several museum collections (Table 2). Samples were frozen and later identified using published keys, reference to determined specimens in state collections, and expert consultation (A.J. Armstrong).

Invertebrate sampling method 6 (Focus: Leafhoppers)

Intensive searches for leafhoppers were conducted at lower-montane (TER 2, 2a), upper-montane (TER 3, 3a) and alpine (TER 4–8) sites in November 2023 (fifth BioBlitz). Males provided the best and convenient features for identification, with associated females or nymphs often more difficult to identify. Specimens were deposited in the South African National Insect Collection (SANC). Sweep netting was the common collection method, with some plants vacuumed for leafhoppers.

Invertebrate sampling method 7 (Focus: Aquatic macroinvertebrates)

Aquatic macroinvertebrates were collected from freshwater systems (temporary pools and rivers) in March 2022 and February 2023. Samples were collected using a SASS net (square frame size: 300 × 300 mm, mesh size 1 mm; Dickens & Graham [2002]) and preserved in 80% ethanol. Identification was conducted using published keys (Day et al. 2002; Day & De Moor 2002; De Moor et al. 2003a; b) and the collection will form a preliminary checklist for the Maloti-Drakensberg mountains, accessioned at the Albany Museum, Makhanda.

Flowering plants

Specimens of flowering plants were collected during transect searches at Sites TER 1 and TER 3 in October 2021, and at Sites TER 1 and TER 2 in February 2023. Additional specimens were collected in the alpine zone (TER 5) by MSc and PhD students. An independent dataset was collected using the Mountain Invasion Research Network (MIREN) sampling protocols (Liedtke et al. 2020; Haider et al. 2022) between October 2021 and February 2022, with coordinates recorded for future reference. All vascular plant species were identified and assigned their status as native or alien, and their endemism status. A total of 2 120 specimens were identified and vouchers stored in the Qwaqwa, UFS Herbarium (QWA).

Data analysis

To evaluate the sample coverage of our surveys, we conducted abundance-based rarefaction-extrapolation analyses for each taxon using the R-package, 'iNEXT' (Chao et al. 2014; Hsieh et al. 2022). Venn diagrams were produced using the R-package, 'VennDiagram' v1.7.3 (Chen 2022). After classifying both GBIF and BioBlitz records for birds, flying insects and plants into alpine, upper-montane and lower-montane zones (Table 1), we used a beta-partitioning approach to estimate nestedness, turnover and total taxonomic beta diversity from both sampling approaches using the R-package 'betapart' (Baselga & Oreme 2012). All analyses were performed under RStudio using R Statistical Software (v4.4.0; R Core Team 2024).

Results

Based on 16 442 bat acoustic calls, 411 bird counts, 5 663 animal and 2 120 plant specimens, and incidental observations of herpetofauna and large mammals, the expert BioBlitzes in WCCA recorded 950 species, including 322 plants, 92 vertebrates, and 536 invertebrates (Table 2). Rarefaction-extrapolation analysis estimated 1 449 species for those taxa here surveyed, with significant increases expected in plants, vertebrates and invertebrates (Figure 2), hence true species richness is likely to be higher. From these analyses, the sample coverage for different taxa was high (Table 2: mean 0.96; range 0.91–1; n=14). Combined BioBlitz and GBIF data revealed 1 216 species, which is closer to the estimated diversity, and highlights the complementarity of these two approaches (Figure 3; Table 2).

High species turnover between elevational zones was observed for more sedentary taxa such as invertebrates, plants and small mammals, whereas more mobile taxa such as birds and bats showed a more nested pattern (Figures 4, 5). In other respects, for easily identifiable taxa such as birds and flowering plants, based on the congruence in beta diversity patterns between approaches (Figure 5), GBIF data independently and accurately retrieved fine scale patterns of elevation turnover validated by expert BioBlitz data.

In the study, 174 species were found only in the alpine zone, 17.6% of all taxa sampled. This included 3 small mammals, 2 reptiles, 1 amphibian, 10 birds, 38 insect flower-visitors and Orthoptera, 13 leafhoppers, 2 dung beetles, 20 aquatic macroinvertebrates and 82 plants (Table 2). Beta diversity analyses of both BioBlitz and GBIF datasets for birds, flying insects and plants showed that mobile birds had more nested elevational patterns, while low-dispersal insects and plants were influenced by turnover between zones (Figure 5).

Taxonomic considerations

Although taxonomic identifications and reviews are still ongoing and more new species are likely to be recognised in time, specialists identified two new insect genera and 16 new or probably new bat and insect species. This included 11 species exclusive to the alpine zone: 1 leaf beetle (Coleoptera: Chrysomelidae: *Odontionopa* sp. nov.), 1 dung beetle (Coleoptera: Scarabaeinae: *Epirinus* sp. nov.), 1 flightless keratin

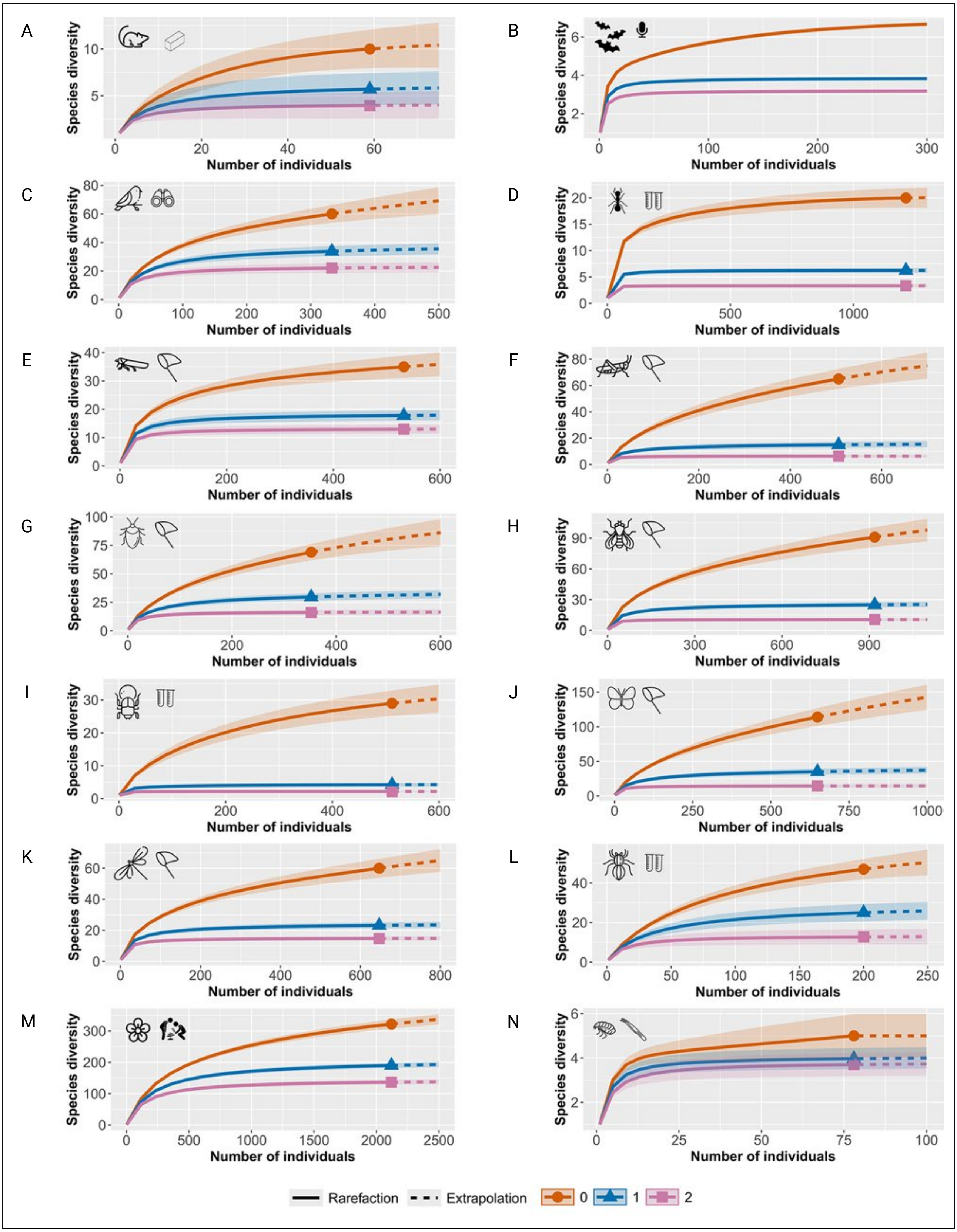

Figure 2. Rarefaction-extrapolation curves for Hill's numbers: 0 (richness), 1 (effective number of rare species, exponent of Shannon entropy) and 2 (effective number of abundant species, inverse Simpson index) for 14 plant, vertebrate and invertebrate taxa surveyed at Witsieshoek Community Conservation Area using different techniques as indicated (symbols on right in each panel): A, small mammals (Sherman traps); B, bats (SM4 mini bat detectors); C, birds (timed counts); D, ants (pitfall traps); E, leafhoppers (nets and searches); F, grasshoppers (pitfall traps and nets); G, bugs (pitfall traps, nets); H, flies (nets); I, dung beetles (baited pitfall traps); J, insect flower-visitors and grasshoppers (timed counts); K, aquatic macroinvertebrates (kick-net, SASS net); L, spiders (pitfall traps); M, flowering plants (specimen collection); N, small mammal ectoparasites. Refer to Table 2 for asymptotic values for species richness and sample coverage percentages for each taxon and method.

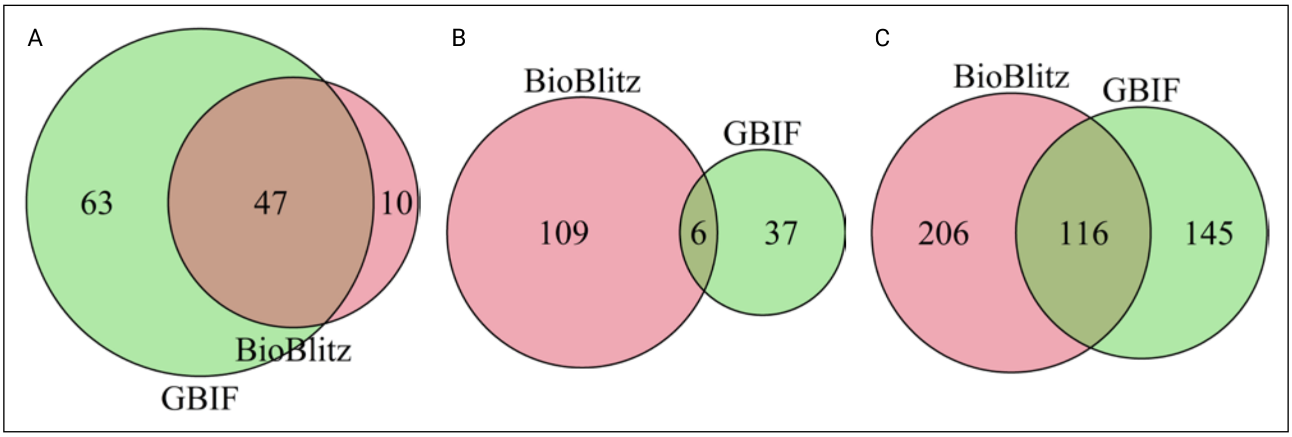

Figure 3. Venn diagrams summarising complementarity of species lists of A, birds; B, flying insects and C, flowering plants based on GBIF records and the current expert BioBlitz study from the Witsieshoek Community Conservation Area.

beetle (Coleoptera: Trogidae: *Phoberus* sp. nov. (Werner Strumpher, Ditsong Museum of Natural History, Pretoria, personal communication), 3 leafhoppers (Hemiptera: Cicadellidae: gen. and sp. nov.: *Bloemia* sp. nov.; *Henchunia* sp. nov.), 1 ambush bug (Hemiptera: Phymatidae: Phymatinae: gen. et sp. nov.), 2 hymenopterans (Hymenoptera: Colletidae: *Scrapter nitidus* (Friese) group sp. nov.; Hymenoptera: Eucharitidae: Eucharitinae: *Hydrorhoa* sp. nov.) and 1 grasshopper (Orthoptera: Caelifera: Acrididae: *Euloryma* sp. nov.). At least 6 additional new-to-science species were sampled either in the montane zone or both in the montane and alpine zones: 1 newly described horseshoe bat (Chiroptera: Rhinolophidae: *Rhinolophus cervenyi* Benda et al. 2024), 1 grasshopper (Orthoptera: Acrididae: Gomphocerinae: *Leva* sp. nov.), 1 wasp (Hymenoptera: Braconidae: Charmontinae: *Charmon* sp. nov.), 2 or more weevils [Coleoptera: Curculionidae: Entiminae: *Holcolaccus* sp. nov. (alpine and montane), Coleoptera: Curculionidae: *Bronchus* sp. nov. (montane)], and 1 leaf beetle (Coleoptera: Chrysomelidae: *Estcourtiana* sp. nov.), amongst others. Photographs of a few of the new species are featured in Figure 6.

Discussion

Discussion of taxon-specific results

Mammals

We incidentally recorded five species of native large and medium-sized mammals: baboon [*Papio ursinus* (Kerr)], klipspringer [*Oreotragus oreotragus* (Zimmerman)], grey rhebuck [*Pelea capreolus* (Forster)], rock hyrax [*Procavia capensis* (Pallas)] and Hewitt's red rock hare (*Pronolagus saundersiae* Hewitt) and eight domestic species including dogs, cats, rats, sheep, goats, cattle and horses. The WCCA, lacking formal protection or fencing, supported fewer large native mammals compared to the neighbouring Royal Natal National Park (RNNP) and Golden Gate Highlands National Park (GGHNP). These protected areas host 30 large to medium mammal species, as recorded by the MammalMap database for the 0.5 × 0.5° locus 2828D (which includes both protected areas). This includes 13 antelope species, plains zebra, two suids, three mustelids, two genets, three mongooses, two felids, two canids, rock hyrax and baboon. Many of these species are either extinct or very rare in neighbouring areas of Lesotho (Morake 2010) but would be potential candidates for a rewilding programme in the WCCA.

Out of 10 terrestrial small mammal species recorded, three were alpine endemics in our study area, Sclater's golden mole [*Chlorotalpa sclateri* (Broom)], the white-tailed rat [*Mystromys albicaudatus* (A.Smith)] and the ice rat (*Otomys sloggetti* Thomas). Although not previously recorded from the alpine zone (Lynch 1994; Taylor 1998; Taylor et al. 2020), the vlei rat (*Otomys auratus* Wroughton) was recorded from both montane and alpine zones in our study. Alpine-collected individuals were considerably smaller in body and skull size than montane-collected individuals, although their identity was confirmed by cytochrome-b sequences (Taylor; unpublished data). None of the three alpine endemics in our study have been recorded at either montane or alpine elevations in adjacent GGHNP (Avenant 1997) or RNNP (Taylor 1998), but *M. albicaudatus* has also been recorded in montane grasslands (ca. 1 500 m a.s.l.) elsewhere in the foothills of the Drakensberg in South Africa and Eswatini (Lynch 1983; Armstrong & Van Hensbergen 1996; Taylor 1998; Simelane et al. 2018) and in both montane and alpine habitats in Lesotho, ca. 1 600–3 000 m a.s.l. (Lynch 1994). Due to its rarity and patchy distribution, *M. albicaudatus* is listed as Vulnerable on the IUCN Red List (Avenant et al. 2019). Ice rats, *O. sloggetti* have been widely recorded in alpine habitats in Lesotho and the KwaZulu-Natal Drakensberg (Lynch & Watson 1992; Lynch 1994; Taylor 1998), while Sclater's golden mole, *C. sclateri* has been recorded from montane elevations in the KZN

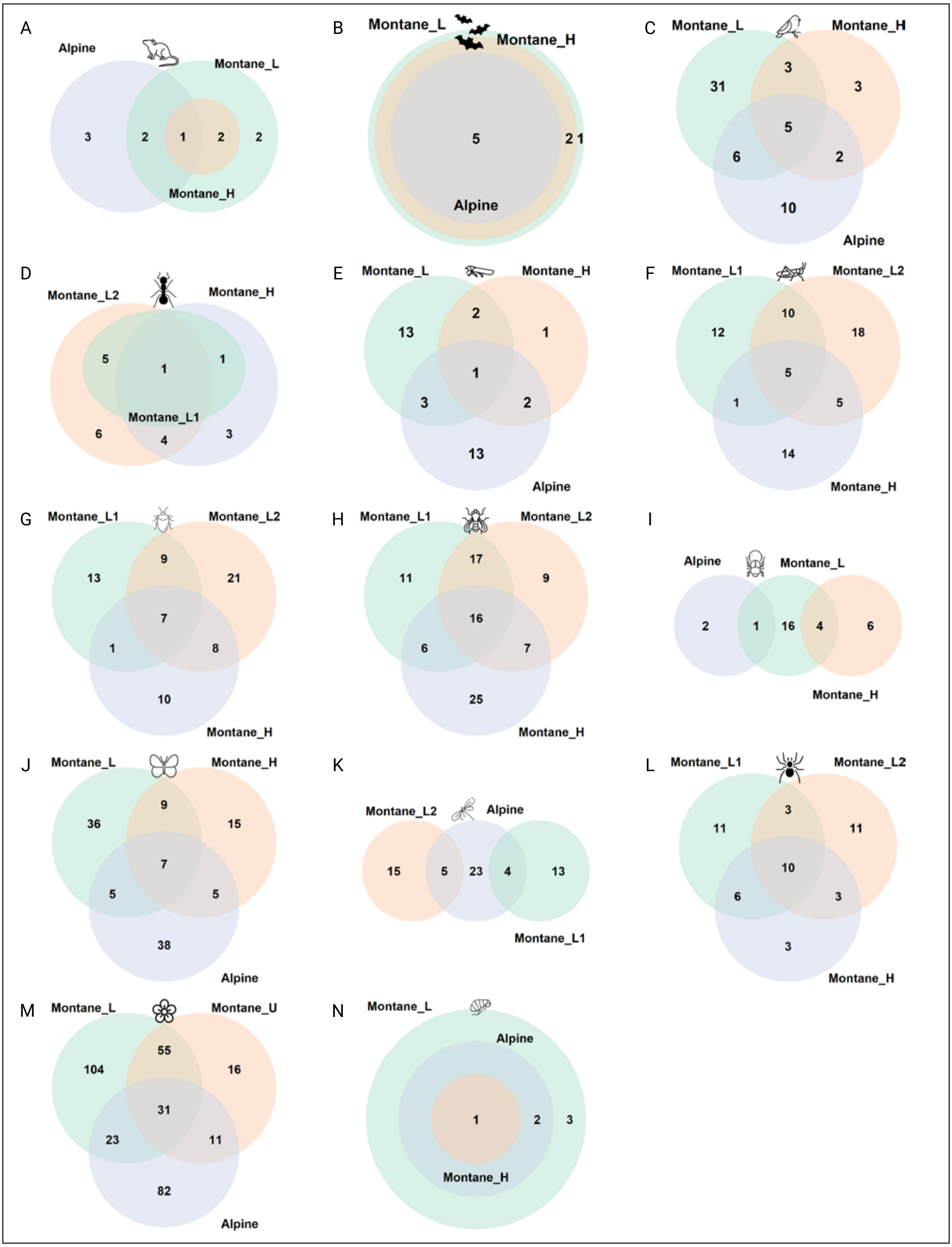

Figure 4. Venn Diagrams for 14 animal and plant taxa, illustrating the number of species shared between different elevational zones at WCCA, lower montane (Montane_L; sites TER 1, 2, 2a & AQS 1-3 in Table 1), upper montane (Montane_H; TER 3, 3a in Table 1) and alpine (TER 4–8 & AQS 4–7 in Table 1). In some taxa where data were not available for alpine or upper-montane sites, the lower-montane zone was further divided into lower (Montane_L1; TER 1 & AQS 1-2) and upper (Montane_L2; TER2 & AQS 3) zones. Venn diagrams represent 14 different taxa sampled: A, small mammals; B, bats; C, birds; D, ants; E, leafhoppers; F, grasshoppers; G, flies (nets); H, bugs; I, dung beetles; J, insect flower-visitors and herbivorous Orthoptera (plots); K, aquatic macroinvertebrates; L, spiders; M, flowering plants; N, small mammal ectoparasites.

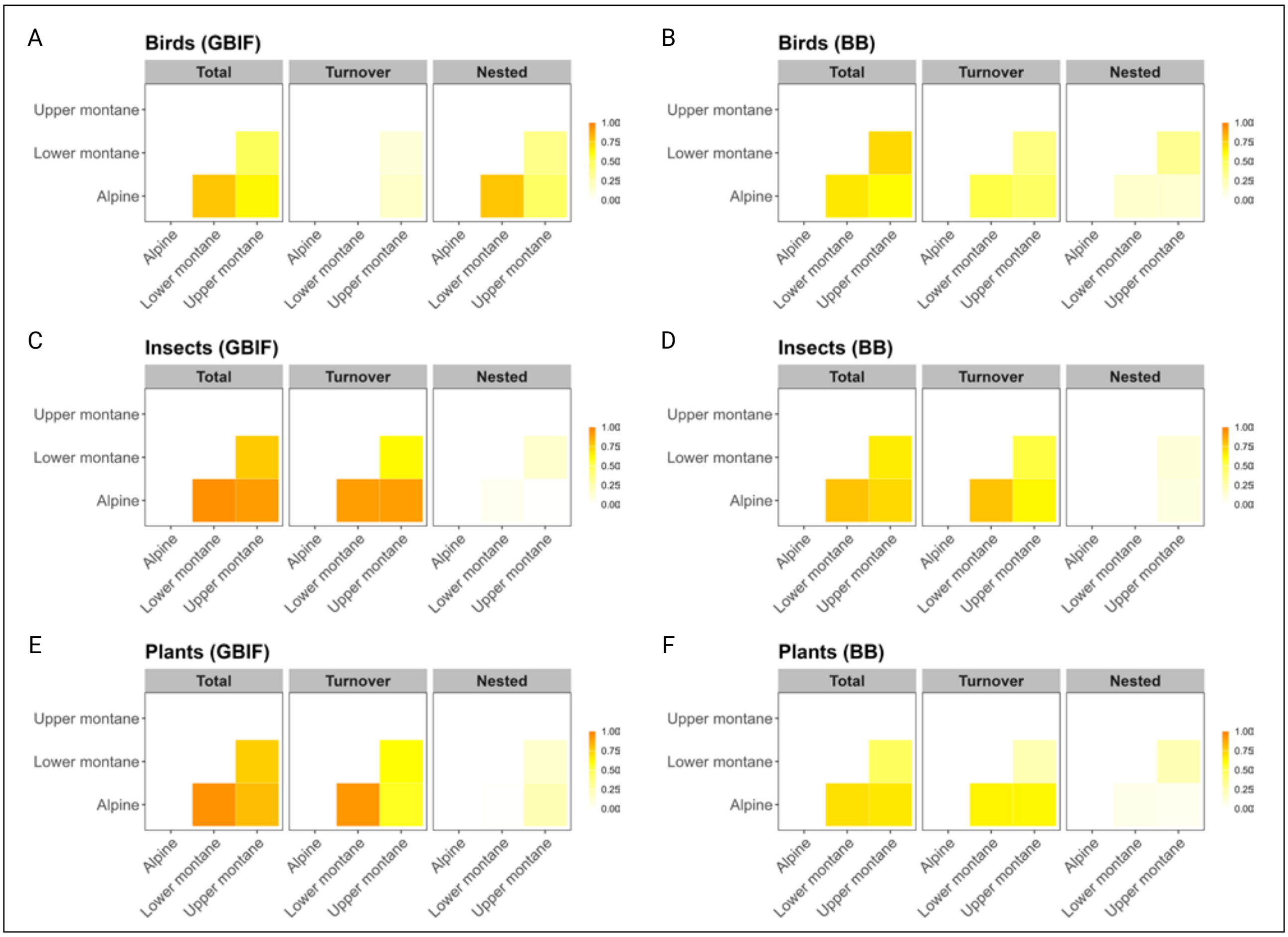

Figure 5. Heat maps representing total beta diversity and its components of turnover and nestedness in birds, insects and plants between grouped alpine, upper-montane and lower-montane sites in the Witsieshoek Community Conservation Area bordering South Africa and Lesotho, based on (left panel) GBIF records and (right panel) data acquired from recent field BioBlitz surveys. See text for methods of data collection, grouping and analysis.

Drakensberg (Taylor 1998) and montane to alpine elevations (1 750–3 000 m a.s.l.) in Lesotho (Lynch 1994). Elsewhere it is known patchily from montane habitats along the Great Escarpment from Sutherland and Beaufort West to the Sneeuberg Mountains to the Eastern Cape Drakensberg and from the northern Drakensberg in the vicinity of Wakkerstroom (Bronner 2013).

The terrestrial small mammal composition recorded at WCCA was distinctly different from that recorded in the neighbouring protected areas to the west (GGHNP; Avenant 1997) and east (RNNP; Taylor et al. 1998), possibly due to its intermediate geographic position, straddling three major watersheds between drier western and moister eastern slopes of the Drakensberg (Figure 1). Supporting this idea, the more arid-associated rodent, *Mastomys coucha* (A.Smith) was recorded at WCCA (identified from cytochrome-b sequence, unpublished data), while the more mesic-associated *M. natalensis* (A.Smith) was recorded at RNNP (Taylor et al. 1998). Taylor et al. (1998) recorded three of the species found in our study (two rodents and one shrew) and an additional two shrews and five rodent species, two of which [Mozambique thicket rat, *Grammomys cometes* (Thomas & Wroughton) and woodland dormouse, *Graphiurus murinus* (Desmarest)] were forest-associated. A small forest patch in WCCA was not sampled for small mammals in this study for logistic reasons and could be shown by future sampling to harbour these two rodents. Avenant (1997) recorded six of the small mammals (two shrews and four rodents) recorded by our study and an additional golden mole, hedgehog, two shrews and seven rodents.

Bat activity and species richness declined at the alpine sites compared with the upper- and lower-montane sites. Eight species were recorded at the lower-montane site, seven at the upper-montane site and five at the alpine site (Figure 4B). The eight species recorded in total are all known to occur in the area, except for one species of horseshoe bat, which is a newly described high elevation Drakensberg-endemic species, *Rhinolophus cervenyi* (Benda et al. 2024), having a distinctive echolocation peak frequency of 81 kHz (Taylor et al. 2024). This species was found at all sites in our study from 2 000 to 3 100 m a.s.l., whereas the congeneric *R. acrotis* Heuglin was only recorded at the lower-montane site (2 000 m a.s.l).

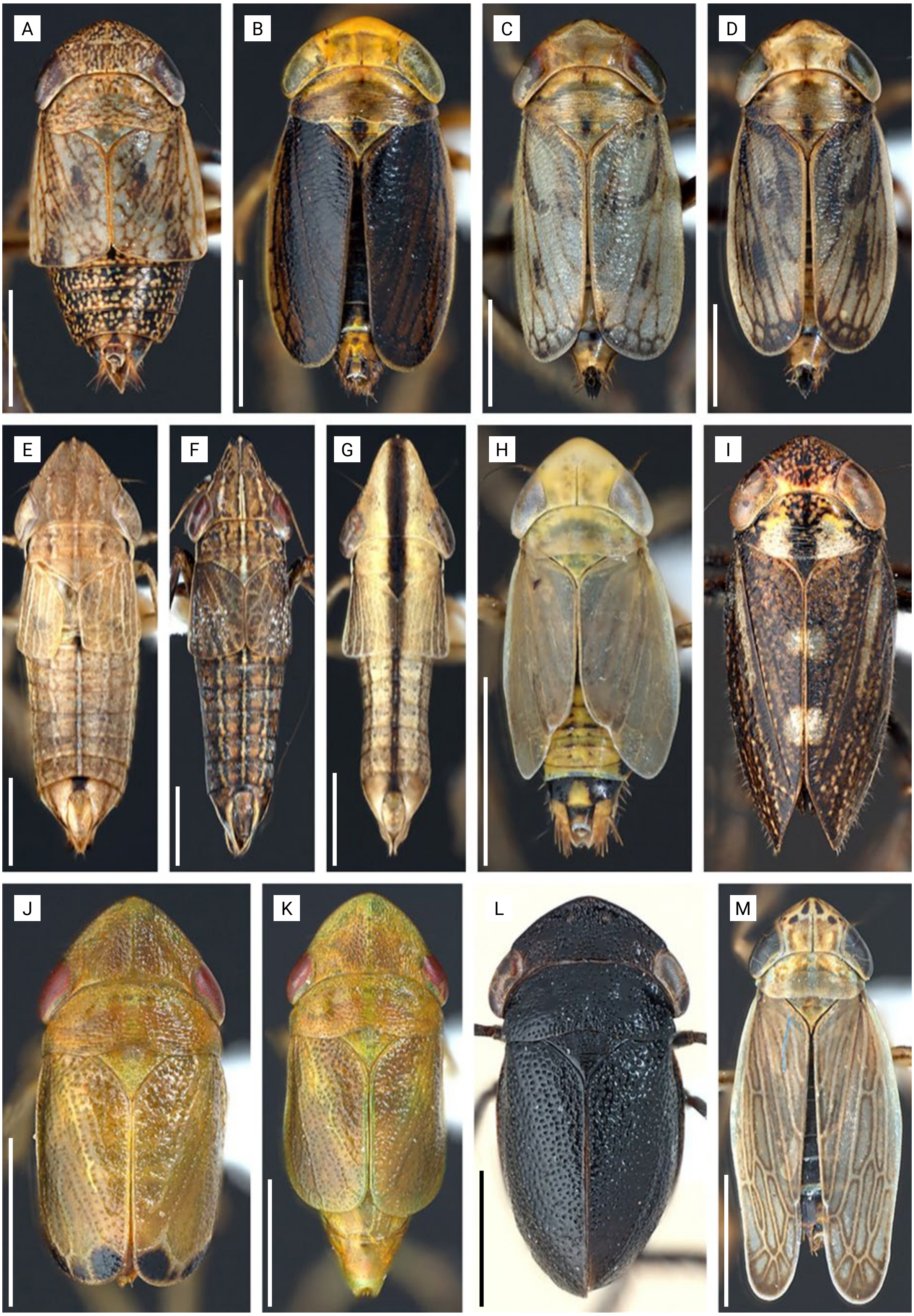

Figure 6. Different leafhopper species identified at WCCA: A, *Bloemia* sp. nov., records from Sani Pass, Rockeries Pass, Witsieshoek; B, Bonaspeiini gen. nov. and sp. nov., Witsieshoek, male; C, Bonaspeiini gen. nov. & sp. nov., Witsieshoek, female colour variant; D, Bonaspeiini gen. nov. and sp. nov. Witsieshoek, female colour variant; E, *Drakensbergena labeona*; F, *Drakensbergena ochracea*; G, *Drakensbergena simulata*; H, *Henchunia* sp. nov. male, only known from Namahadi Valley; I, *Mamates drakensi*; J, *Sichaea coriaria* male; K, *Sichaea coriaria* female; L, *Chiasmus* male; M, *Tetramelasma nodosatha*, new record, widespread grass-feeding, Drakensberg.

Birds

Of the 246 bird species known to occur in the KwaZulu-Natal Drakensberg (Little & Bainbridge 1992), some 130 bird species (39 of them endemic) are expected to occur in the Qwaqwa Maloti (Van As 2014b). Based on our time counts at the four sites, we recorded 60 species, which, when combined with GBIF data (110 species), resulted in the detection of all six Maloti-Drakensberg strict endemic or near-endemic bird species (see below). Birds commonly recorded at the lower elevations included widespread and abundant species such as Cape Longclaw [*Macronyx capensis* (Linnaeus)], Dark-capped Bulbul [*Pycnonotus barbatus* (Desfontaines)] and Cape Robin-chat [*Cossypha caffra* (Linnaeus)]. In contrast, birds seen at higher elevations included species endemic (or near endemic) to the Drakensberg such as Drakensberg Rockjumper (*Chaetops aurantius* E.L.Layard) and Sentinel Rock Thrush [*Monticola explorator* (Vieillot)]. The number of bird species recorded on GBIF for the study area was almost double the number recorded during our surveys.

Near Sani Top in Lesotho, Kopij (2015) recorded 30 bird species in alpine grassland and 69 in upper-montane grassland. The alpine habitat was considered to be much more important from a conservation standpoint since it supported high breeding densities of Maloti-Drakensberg endemics, e.g., Mountain Pipit (*Anthus hoeschi* Stresemann), Drakensberg Rockjumper and Drakensberg Siskin [*Crithagra symonsi* (Roberts)], and near endemics i.e. the Southern Bald Ibis [*Geronticus calvus* (Boddaert)], Sickle-winged Chat [*Emarginata sinuata* (Sundevall)] and Sentinel Rock Thrush, compared with non-alpine habitats. Our BioBlitzes recorded two of the three alpine endemics (all but the Drakensberg Siskin), and two of the three near-endemics (all but the Southern Bald Ibis), while the GBIF list included all six endemics and near-endemics. Kopij (2015) found endemic and near-endemic species to be more abundant/dominant in alpine versus upper-montane grasslands. Our BioBlitz data showed Mountain Pipit and Sickle-winged Chats to be present only at alpine but not upper montane sites, while the Drakensberg Rockjumper was recorded only at upper-montane sites. The Sentinel Rock Thrush was recorded in both sites but was far more common in alpine sites. None of these four species occurred in any of the lower sites.

Herpetofauna (reptiles and amphibians)

Although not comprehensively surveyed, Van As (2014a) recorded 32 reptile and 21 amphibian species in the study area. Two reptile species from the study area, Lang's Crag Lizard (*Pseudocordylus langi* Loveridge) and Essex's Mountain Lizard (*Tropidosaura essexi* Hewitt) can be considered alpine endemics or near-endemics, and both are listed as Least Concern (Tolley et al. 2023). Breyer's Long-tailed Seps (*Tetradactylus breyeri* Roux) occurs across a broader elevational range in montane grasslands of the Drakensberg but is listed as Near Threatened due to ongoing degradation and loss of grasslands (Tolley et al. 2023). The ice frog [(*Amietia vertebralis* (Hewitt)] is an alpine endemic and is expected to have been impacted by river impoundment, road construction and wetland degradation. All these alpine or montane endemics are therefore critical sentinels of climate change and should be monitored regularly.

Ants

A total of 20 ant morphospecies from 13 genera, and five subfamilies were sampled during a single sampling of two lower (TER 1, TER 2) and one upper (TER 3) montane sites in October 2021. Myrmicinae was the most dominant subfamily, representing 82% of the total ant abundance. Ponerinae and Formicinae subfamilies had 11% and 7% of the total abundance, respectively. Over half of the abundance was made up of one unidentified species, *Pheidole* UKZN_04. Six species were exclusively recorded in the vicinity of the Lodge (TER 2) while three were exclusively recorded from the Sentinel Car Park (TER 3). Other species were shared between two or three sites.

Dung beetles (Scarabaeidae)

A total of 29 dung beetle species from 10 genera were collected across montane and alpine elevation zones. Two species were recorded exclusively in the alpine zone, *Epirinus pygidialus* Scholtz & Howden and *Labarrus pseudolividus* Balthasar. The species collected in total represented six of the seven functional groups in a dung beetle assemblage (all except large, fast-burying paracoprids – Functional Group III), indicating a relatively intact ecosystem (Doube 1990). The functional groups were diverse and well represented over the elevational change. Ball-rolling dung beetles were present at WCCA but are largely absent from intensive mixed maize and livestock agricultural areas surrounding the WCCA (Astrid Jankielsohn, unpublished data).

Flower-visiting insects and orthopteran herbivores

We recorded 21 species of pollinator insects, 18 species of herbivorous orthopterans and 76 species of other flower-visiting insects at eight sites covering three elevation zones, lower and upper montane and alpine (Table 2; Figure 4). There was little overlap of species between the montane and alpine sites: 38 species were only recorded at alpine sites, 60 only at montane sites (upper and/or lower) and 17 species in both montane and alpine zones. Of the undescribed and probably undescribed species, four were collected at alpine sites, six at montane sites and two at both alpine and montane sites. The montane sites thus had a different fauna compared to the alpine sites, reflecting the montane and alpine sub-centres of floristic endemism in the Drakensberg Mountain Centre (Carbutt 2019). However, the exact number of species recorded that are alpine endemics has still to be established. The expert and public datasets were highly complementary, with little overlap between the species sampled and those in the citizen science dataset (Figure 3). Overlapping species represented those easily identifiable by citizen scientists. Field guides to less easily identified insect taxa should be published to assist citizen scientists with their identification, leading to more complete public databases of insects.

Leafhoppers

Several new species of leafhoppers have been described in the last 15 years (e.g., Stiller 2009, 2010, 2011, 2012). The first extensive examination of leafhoppers on the Drakensberg alpine summit and adjacent higher slopes identified 35 species, 13 of which were only found in the alpine zone (Figure 4, Table 2). Three new, undescribed species were collected from the alpine summit: *Henchunia* Vilbaste from grass (Figure 6H), a new species of *Bloemia* Theron (Figure 6A) and a new genus and species from the tribe Bonaspeiini from shrubs (Figure 6B–D). The latter was recorded from two locations on the alpine summit in this study and has also been recorded at Sehlabathebe National Park in Lesotho and Monks Cowl and possibly the summit of Organ Pipes Pass in the KwaZulu-Natal Drakensberg. Leafhoppers associated with small black-stick lily plants (*Xerophyta* spp., Velloziaceae) were not collected in this study, but are expected to occur, based on a single record of *Xerophytavorus rastrullus* Stiller from the summit of the KwaZulu-Natal Drakensberg (2 880 m a.s.l.) near the Orange River source (Stiller 2012).

We sampled shrubs, moribund grass and grass and sedge regrowth after fire. Species could be classified into functional groups based on feeding on grass (20 species), shrubs (11 species) or both (one species), and in the case of grass-feeding species, into Savanna Biome (6 species), Grassland Biome (10, including two wetland species) or both biomes (4 species). Grass-feeding Savanna Biome leafhoppers included *Aconurella* Ribault, *Balclutha* Kirkaldy, *Chiasmus hyalinus* (Evan) (short-winged), *Exitianus turneri* Ross, *Nicolaus* Lindberg and *Pravistylus exquadratus* (Naudé), while wetland-associated species included *Afrosteles distans* (Linnavuori) and *Teyasteles divisifrons* (Naudé). Grassland Biome-associated grass-feeders included three species of *Drakensbergena*, *D. labeona* Stiller (Figure 6E), *D. ochracea* Linnavuori (Figure 6F), *D. simulata* Stiller (short winged) (Figure 6G), as well as *Elginus falcatus* Stiller, *Henchunia* sp. nov. (short-winged) (Figure 6H), *Naudeus bivittatus* (Naudé), *Pravistylus interdiscus* Stiller (short winged), *Tetramelasma nodosatha* Stiller (Figure 6M) and *Sandia brevis* Theron (short-winged). Shrub-associated species included *Basutoia brachyptera* Linnavuori, 1961 (short-winged), *Bloemia* sp. nov. (short winged) (Figure 6A), *Chiasmus* Mulsant & Rey (short winged) (Figure 6L), *Mamates drakensi* Theron (short winged) (Figure 6I), *Molopopterus* Jacobi, Bonaspeiini gen. nov. & sp. nov. (short-winged) (Figure 6B–D), *Sichaea coriaria* Stål (short winged) (Figure 6J, K), *Typhlocybinae* (tree and shrub feeding) and *Tzitzikamaia irrorata* Linnavuori (short-winged, shrub or forb-feeding). Although considered to be grass-feeding (Stiller 2009), in this study *Drakensbergena* spp. were collected on shrubs and grass, in regrowth after fire and in moribund grass, but with nymphs only on grass.

Overgrazing and regular burning may be causing a decline in grass-feeding leafhoppers and an increase in shrub-associated ones (Michael Stiller, unpublished observations).

Other arthropods from pitfall traps and associated sweep nets

For logistical reasons, the alpine zone was not sampled for these groups in this study. General collections of spiders and insects from standardised pitfall arrays and sweep netting from lower (TER 1–2) and upper (TER 3–3a) montane sites resulted in 200 spiders (17 families; 47 morphospecies), 352 bugs (Hemiptera: 15 families; 69 morphospecies), 919 flies (Diptera: 30 families; 91 morphospecies) and 506 grasshoppers and other orthopterans (Orthoptera: 9 families; 65 morphospecies). Since most specimens were identified only to family and morphospecies for this study, species numbers are likely to change as specialist identifications are completed. Nevertheless, for all four groups mentioned above, there was low overlap (i.e., high turnover) in species composition of spider and insect assemblages among elevation zones (Figure 4F, G, H, L).

Aquatic macroinvertebrates

The Maloti-Drakensberg region including the WCCA is host to a diverse range of freshwater invertebrates, found in both river systems and temporary water bodies such as rockpools. Many of these species are endemic to the MD (Hamer & Brendonck 1997; Martens et al. 1998; Van Damme et al. 2013; Deacon et al. 2020). Those found in temporary water bodies often exhibit extraordinary eco-physiological adaptations to survive marked wet-dry seasons, harsh cold temperatures and nutrient-limited systems (Mdidimba et al. 2021).

We collected 647 aquatic macroinvertebrates (60 morphospecies from 33 families and 13 orders) from 2 montane (AQS 1–3) and 4 alpine (AQS 4–7) sites.

While 23 species were only recorded in alpine sites, 28 were only recorded in montane sites, and 9 species occurred in both montane and alpine sites (Figure 4K). Montane sites showed higher abundance and richness, but lower evenness and diversity scores, compared to alpine sites (Table 3). Assemblage composition differed, with Ephemeroptera, Plecoptera and Trichoptera (EPT) being most abundant at alpine (36%) compared with montane (26%) sites, and Plecoptera and Mollusca only found in montane sites. As identifications were generally made only to family and morphospecies, these numbers may change as specialist identifications are completed, and potential novel species are described. There were nevertheless clear differences in the insect communities between elevations, with 13 and 9 families only found in montane and alpine sites, respectively.

Aquatic beetles were well represented in these samples. This group has a high diversity in the Drakensberg (Perkins 2005a,b, 2008; Bilton 2017) but are still poorly known from WCCA, where cryptic diversity has been uncovered (Englund et al. 2020). Rockpools and ephemeral wetlands support a surprising diversity of large branchiopods (i.e., Anostraca, Notostraca, Spinicaudata and Laevicaudata) including the tadpole shrimp [*Triops granaries* (Lucas)] recorded from the Drakensberg summit and 4 out of 5 known *Branchipodopsis* species that are endemic to Maloti-Drakensberg rockpools (Hamer & Martens 1998). Although no specimens were collected in this study, the desiccation-tolerant chironomid, *Polypedilum cranstoni* Cornette, Motitsoe & Mlambo, 2022, was originally described from WCCA, near Fika-Patso Dam and seems to be endemic

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution

Phylum or Order	Family	Subfamily	Genus	Elevation (m a.s.l.)	
				Montane (1 700–2 100)	Alpine (>2 900)
Decapoda	Potamonautidae			2	
Hydrachnidia					1
Hirudinea					6
Ephemeroptera	Baetidae			74	6
	Baetidae		*Acanthiops* sp. 1	4	
	Baetidae		*Acanthiops* sp. 2	4	
	Baetidae		*Afroptilum* sp.		3
	Baetidae		*Cloeon* sp.	34	
	Baetidae		*Demoulinia* sp.		1
	Caenidae			5	
	Leptophlebiidae		*Adenophlebia* sp.	53	17
	Tricorythidae		*Tricorythus* sp.	11	
Odonata	Aeshnidae			3	
	Aeshnidae		*Anax* sp.	1	
	Coenagrionidae			17	
	Coenagrionidae		*Pseudagrion* sp.	36	
	Libellulidae				1
	Libellulidae		*Orthetrum* sp.	8	
Lepidoptera	Crambidae			6	2
Trichoptera	Barbarochthonidae		1		
	Leptoceridae			3	
	Leptoceridae		*Athripsodes* sp.		1

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution (continued)

Phylum or Order	Family	Subfamily	Genus	Elevation (m a.s.l.)	
				Montane (1 700–2 100)	Alpine (>2 900)
Plecoptera	Perlidae		*Neoperla* sp.	4	
Coleoptera	Aspidytidae				1
	Dytiscidae				1
	Dytiscidae	Colymbetinae larva		1	
	Dytiscidae	Hydroporinae larvae		2	
	Dytiscidae		*Africophilus* sp.		1
	Dytiscidae		*Copelatus* sp.	6	
	Dytiscidae		*Laccophilus* sp.	24	
	Dytiscidae		*Philodytes* sp.		1
	Elmidae			2	3
	Gyrinidae			1	
	Hydrophilidae		*Helochares* sp.	5	
	Ptilodactylidae				1
	Scirtidae		*Cyphon* sp.		3
	Scirtidae		*Scirtes* sp.		1
Hemiptera	Belostomatidae		*Appasus* sp.	1	
	Corixidae		*Sigara* sp.	27	1
	Gerridae		*Gerris swakopensis*	14	10
	Notonectidae		*Anisops* sp.	1	
	Nepidae		*Borborophilus* sp.	1	
	Nepidae		*Ranatra* sp.	2	
	Pleidae		*Plea* sp.	6	1
	Veliidae				2
	Veliidae		*Microvelia* sp.		1
Diptera					1
	Athericidae			4	
	Athericidae		*Suragina* sp.		5
	Chironomidae			24	
	Chironomidae				2
	Chironomidae			77	7
	Chironomidae	Tanypodinae			8
	Culicidae			3	
	Culicidae		*Culex* sp.	10	8
	Simuliidae		*Simulium* sp.		5

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution (continued)

Phylum or Order	**Family**	**Subfamily**	**Genus**	**Elevation (m a.s.l.)**	
				Montane (1 700–2 100)	**Alpine (>2 900)**
	Tipulidae				1
Basommatophora	Planorbidae		*Bulinus* sp.	61	
Unidentified Nematoda					7
			Taxa relative abundance	538	109
			Taxa richness	37	31
			Pielou's Evenness	0.797	0.876
			Shannon Diversity	2.88	3.01
			Composition:		
			Ephemeroptera	185	27
			Odonata	65	1
			Coleoptera	41	12
			Hemiptera	52	15
			Diptera	118	37
			Mollusca	61	0
			Trichoptera	4	1
			Plecoptera	4	0
			EPT%	35.87	25.69
			EPTO%	47.96	26.60

to montane rock pools in the MD (Cornette et al. 2022). Three other related species of desiccation-tolerant chironomid species from the same genus are known from similar elevations in Namibia, Malawi and Nigeria (Cornette et al. 2017).

Preliminary results indicate that freshwater resources in WCCA are largely natural, with a high diversity of sensitive taxa like EPT (Dickens & Graham 2002; Odume et al. 2012). Nevertheless, the absence of some expected genera, such as the endemic Plecopteran genus, *Balinskycercella* Stevens & Picker, 1995, may point to increased disturbance in the region. Given the importance of these freshwater invertebrates as ecological indicators of ecosystem health, the above examples highlight the rich diversity of aquatic macroinvertebrates from WCCA and the urgent need for future studies to further unravel the hidden diversity that will inform evidence-based conservation and rewilding of the WCCA.

Plants

Combining various local projects, MSc (Lesego Malekana) and PhD (Mosiuoa Bereng) research, and BioBlitz records, 2 120 plant specimens were collected, representing 322 vascular flowering plant species in 59 families and 189 genera. The MIREN transect contributed 86% of the collection, with additional contributions from the PhD collection (6%), MSc project (4%), and general BioBlitz records (4%). Twelve non-native species were recorded. The GBIF database for the WCCA provided 549 records, with 260 plant species, 116 of which overlapped with the BioBlitz surveys.

The combined data from local projects and GBIF include 466 species from 66 families and 215 genera. This current checklist covers about 30% of the potential flora for the 7 000 ha Witsieshoek precinct, with notable gaps in woody habitats below 2 000 m a.s.l., comprehensive fern flora, and C_3 grasses above 2 600 m. Additional data sources yet to be incorporated include historical collections, extensive grass work in 2020 (e.g. Sylvester et al. 2020), SANBI's *Plants of the Free State* (Retief & Meyer 2017), published literature (e.g. Shezi et al. 2021), and data from the 7th Plant Functional Traits Course, which took place in the WCCA in December 2023 (https://plantfunctionaltraitscourses.w.uib.no/). As such, the current data are incomplete and preliminary and do not lend themselves to in-depth analyses at this point. Nevertheless, analyses of elevational patterns of the independently obtained species lists (GBIF and current study) indicate a high turnover between elevation zones in both datasets (Figure 5), with 82 species recorded as alpine-endemic at the scale of the current study (Figure 4).

The most diverse family in our study was Asteraceae (29%), followed by Poaceae (10%), Scrophulariaceae (6%), Iridaceae (6%) and Orchidaceae (4%). This dominance pattern is largely reflected in the total flora of the Drakensberg Mountain Centre (e.g., Carbutt & Edwards 2004). *Helichrysum* is the most diverse genus with 37 taxa, followed by *Senecio* with 16 taxa. Other significant genera include *Moraea*, *Erica* and *Disa*.

General discussion

The escalator to extinction

While most studies of climate change impacts on alpine biodiversity are situated in the northern hemisphere and focus on a single taxon (Freeman et al. 2018; Urban 2018; Watts et al. 2022), our study showed correlated responses across various plant and animal taxa to a montane–alpine gradient in southern Africa. Of 11 taxa for which data existed from both montane and alpine sites in this study, nine had alpine endemics (range 0–37%; mean 17.5%). This highlights the systematic biodiversity extinction risk for alpine endemics under climate change, especially small and flightless species. Species that are currently trapped within a narrow range of alpine habitat face a high extinction risk from further climate warming, especially for species that lack phenotypic plasticity or behavioural or physiological flexibility.

Predominantly in northern hemisphere mountain ranges like the European Alps and Himalayas, 227 000 km^2 of new lands will emerge by 2100 due to shrinking ice under the high emissions RCP8.5 scenario (Zimmer et al. 2022). Although this can be perceived as a benefit, there are many adverse effects of increased snow melt (Xu et al. 2009). This is not an issue in the Drakensberg Mountain Centre, which lacks current glaciers. Nevertheless, warming conditions may result in non-alpine plant and animal species from lower elevations being able to colonise higher elevation alpine habitats, possibly out-competing more specialised alpine congeners. For example, we were surprised to trap vlei rats *Otomys auratus* at 3 145 m a.s.l. in our study, occurring sympatrically with ice rats, *O. sloggetti*. No historical records for *O. auratus* exist from such a high elevation, and the animals captured were markedly smaller than individuals from lower elevations (Peter John Taylor, unpublished data), suggesting the possibility of phenotypic plasticity towards smaller size to save energy in a demanding cold environment that regularly experiences snow.

As expected and found also by Monadjem et al. (2023), we found that smaller and less mobile organisms such as insects and small mammals showed higher turnover and lower nestedness, than more mobile organisms like birds and bats. We can thus predict that the former are more vulnerable to global warming.

We demonstrated remarkable congruency between citizen science (GBIF, including iNaturalist, eBirds and the Southern African Bird Atlas 2 project) and our expert BioBlitz datasets (Figures 3, 5), validating the importance of mountain tourism-based citizen science in documenting species checklists and elevational patterns in the fauna and flora of imperilled alpine hotspots. Since mountain tourism is an important feature in alpine zones globally such as the Alps, Himalayas, Rockies and Andes, we advocate renewed exploration of citizen science datasets from these regions to document biodiversity at risk from the escalator to extinction.

Climate models may predict varying vulnerability of ecosystems to climate change. For example, the environmentally defined grassland floristic domains of the study area are considered mainly susceptible to climate-induced change according to the down-scaled HadCM2 climate model but robust to climate-induced change according to the downscaled GFDL2.1 climate model (Jewitt et al. 2015). Adaptation strategies vary based on climate model predictions (Mawdsley et al. 2009). For susceptible scenarios, conservationists should focus on expanding protected areas, managing ecosystem functions and land-cover change impacts, and designing climate-resilient protected areas. For robust scenarios, conservationists should focus on improving management of existing protected areas, regularly reviewing conservation policies, and increasing biodiversity representation and replication in protected areas (Jewitt et al. 2015). Future monitoring of our baseline data will help test climate models' predictive powers regarding the susceptibility of different assemblages, guiding appropriate conservation strategies.

Ecological indicators of ecosystem health and the potential for rewilding in WCCA

As they are highly sensitive to environmental conditions and disturbance, taxa such as aquatic invertebrates

(Mdidimba et al. 2021) and dung beetles (Botes et al. 2006) are excellent indicators of ecosystem health and biodiversity intactness. The functional and taxonomic diversity of aquatic invertebrates and dung beetles (and plants and animals generally) suggest that montane and alpine grassland ecosystems are largely intact. The almost complete absence of large mammalian herbivores and carnivores in the study area that occur in adjacent protected areas is therefore not due to habitat availability but rather mostly to hunting (Morake 2010) and/or competition with domestic grazers such as cattle, goats, donkeys and sheep. Although grassland ecosystems are currently largely intact, they are threatened by increasing alien invasion and bush encroachment (RangeX project; Mountain Invasion Research Network – RangeX, available online at https://www.mountaininvasions.org/rangex, accessed on 14 February 2024), as well as increasing grazing pressure by livestock of both South African and Basotho herders in the montane and alpine zones respectively (personal observation; Carbutt 2020; Kotzé et al. 2023). As they are dependent on specific shrub or grass plant species, leafhoppers are useful indicators of vegetation changes including shrub (bush) encroachment. In our study, leafhopper assemblages included both shrub and grass-dependent species, providing a good baseline for future assessments of rangeland condition.

Since these threats will impact the experience of, and revenues from, ecotourists, we advocate a mountain tourism and community-centred rewilding approach. Reintroduction of iconic species such as the common eland (*Tragelaphus oryx*), which has a strong cultural and spiritual connection with local communities (the municipality of '*Maluti-A-Phofung*' means 'The Place of the Eland' in the local Sesotho language), can considerably boost tourism revenue. Rewilding has been shown to be an effective strategy for protecting both charismatic large mammalian 'umbrella species' and entire ecosystems, but this requires mitigating conflicts between conservation stakeholders and livestock farmers (Freese et al. 2014). At present, rewilding is focused on large mammals because of the lack of data on what other taxa may be missing from the WCCA that might not be able to recolonise it naturally. In the WCCA, rewilding and reintroduction of large mammals can be achieved either by fencing and/or a community-based conservation plan, but these options need to be explored in partnership with local communities. Since the WCCA borders two countries, the Maloti-Drakensberg Transfrontier Conservation Authority (MDTFCA) is a critical player in conserving this area. Equally important is engaging with local communities and NGOs such as Meat Naturally Africa (https://www.meatnaturallyafrica.com/), to improve communal rangeland quality and sustainability, which directly benefits biodiversity and ecosystem services, as well as revenues from both livestock farming and biodiversity carbon credits (intact rangelands sequester more carbon than degraded rangelands; Preger et al. 2019). Since community conservation areas are critical to conserving alpine grasslands (Carbutt 2020), we propose that the WCCA is a test case that can provide solutions that are applicable to alpine grassland ecosystems globally.

Conclusions

Several groups, such as lepidopterans, were not comprehensively sampled during our expert BioBlitzes, suggesting that our species list will increase considerably as sampling gaps are filled. For example, the LepiMAP project database (Underhill & Navarro 2023) yielded 145 species of Lepidoptera from the 0.5 × 0.5° locus 2828D, which includes WCCA plus the two adjacent protected areas of RNNP and GGHNP, yet our study only recorded a few species, mainly incidentally, and GBIF yielded 29 species for the WCCA.

Area-based conservation requires a detailed understanding of local species, as well as ecosystem processes and should be underpinned by robust biodiversity inventories. Such inventories should be compiled from multiple sources, including field surveys by specialists, citizen science observations, public datasets and published studies. Each approach has its own limitations, and no single approach is comprehensive. There is no substitute for field-based surveys, but due to their costly and time intensive nature, these are often limited to rapid assessments (snapshots in time and space) such as BioBlitzes, carrying an inherent risk of limited data representation. To address this bias, we advocate multiple expert BioBlitzes that draw on a wide range of taxonomic expertise. In this study, we engaged a range of experts from such diverse fields as mammalogy, ornithology, herpetology, arachnology, entomology and botany, resulting in checklists for 14 diverse taxa. These experts also provided an understanding of local species, and corroborated local species lists obtained from public databases.

Data parity and data complementarity between approaches are essential to ensuring an accurate and comprehensive dataset to guide conservation management actions. In this study, we show that inventories obtained from the GBIF and from expert BioBlitzes were highly complementary; the combined species sums were considerably greater than those of either approach alone. Combining datasets resulted in a list of over 1 200 species.

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Declaration of competing interest

The authors declare that they have no known competing financial interests that could have appeared to influence the work reported in this paper.

Ethical considerations

Permission for scientific collecting was provided by Permit No. 202106000007056 of the Free State Province Department of Economic, Small Business Development, Tourism and Environmental Affairs (DESTEA) and from the landowners, the Batlokoa Royal House through a MOU between the ARU/UFS and Transfrontier Parks Destinations (TFD), who manage the Witsieshoek Mountain Lodge on behalf of the Royal Council. Ethical clearance was provided by the UFS Animal Research Ethics Committee (Project numbers: UFS-AED2021/0029/21 and UFS-AED2023/0037), UFS Environment and Biosafety Research Ethics Committee (Clearance no. FS-ESD2021/0233/22), and Section 20 permit from the Department of Agriculture, Land Reform and Rural Development (DALLRD) to conduct research in terms of Section 20 of the Animal Diseases Act, 1984 (Act No. 35 of 1984) [Reference no. 12/11/1/4 (2038 RJ)].

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Year-to-year changes in population density and site fidelity of psittaciform, coraciiform and piciform species in an acacia savanna, north-central Namibia

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Background: Bird species belonging to the orders of Coraciiformes, Psittaciformes and Piciformes may be regarded as good indicators of environmental quality. Since most species are fairly large and have distinctive plumage colouration, they attract human attention. Most of them are also strongly territorial and vocally conspicuous. However, not much is known about their population densities and virtually nothing about interannual population changes.

Objectives: The aims of this study were to: 1) estimate population densities; 2) assess interannual variations in population densities; 3) study site fidelity; 4) find preferences (or their lack) for natural or man-modified savanna of all coraciiform, piciform and psittaciform species breeding in a mosaic of natural and man-modified savanna; and 5) compare population densities of all these species recorded in the study area with those obtained in other regions of southern Africa.

Methods: Population densities of coraciiform, psittaciform and piciform species were assessed by means of the territory mapping method in an acacia savanna in the Cuvelai Drainage System, north-central Namibia. Studies were carried out in three separate years: 2012, 2017 and 2020.

Results: In total, 15 species representing these orders were recorded as breeding in the study plot (400 ha). In 2020, all three parrot species, namely Meyer's Parrot (*Poicephalus meyeri*), Rüppell's Parrot (*P. rueppellii*), and Rosy-faced Lovebird (*Agapornis roseicollis*), nested in a similar density of 0.50–0.75 pairs per 100 ha. The African Hoopoe (*Upupa epops*) was the most abundant coraciiform species reaching a density of 3.3 pairs per 100 ha in 2017. The second most abundant coraciiform species was the Lilac-breasted Roller (*Coracias caudatus*), which population increased from 0.5 pairs per 100 ha in 2012 to 1.4 pairs per 100 ha in 2020. Among the other coraciiform species, only the Common Scimitar-bill (*Rhinopomastus cyanomelas*) reached a density higher than one pair per 100 ha, in 2017. Among piciform species the most abundant was the Acacia Pied Barbet (*Tricholaema leucomelas*; up to 2.5 pairs per 100 ha).

Conclusion: Contrary to expectation, for most species and species groups studied, their population densities were negatively related to the precipitation. No other species of this order reached a density higher than 1 pair per 100 ha in any year. These population densities are compared with those obtained in 10 sites in Namibia and the South African Highveld. Lilac-breasted Roller, Common Scimitarbill, parrots and hornbills showed high, while barbets showed low site fidelity.

Keywords: *Agapornis roseicollis*, *Coracias caudatus*, *Upupa epops*, *Rhinopomastus cyanomelas*, *Poicephalus meyeri*, *Poicephalus rueppellii*, *Tricholaema leucomelas* population density, philopatry, population trends, urban ecology, acacia savanna.