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Melanism in scorpions, reptiles and rodents inhabiting the volcanic fields of north-western Saudi Arabia

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ABSTRACT

Body colouration is involved in multiple aspects of species ecology and behaviour. Melanism, a common colour polymorphism, has been associated with camouflage and thermoregulation, particularly in diverse, high-altitude habitats of arid regions. This study reports the first case of melanism in the lacertid *Acanthodactylus boskianus*, two scorpions, *Leiurus haenggii* and *Compsobuthus manzonii*, and the first records of brown-black melanistic colouration in three rodent species, *Acomys dimidiatus*, *Meriones crassus*, and *Sekeetamys calurus*, in the dark lava fields (*harrat*) of north-western Saudi Arabia. Additionally, it expands observations of melanism in the endemic colubrid *Rhynchocalamus hejazicus* and provides the first documented records of brown-black melanistic *Acomys russatus* for the region, consistent with earlier predictions. These observations suggest that colour polymorphism may serve a cryptic function through background matching in both diurnal and nocturnal species, but other roles of melanism should be further investigated. Despite their extent, lava fields in arid regions remain poorly studied due to their remoteness and limited accessibility, yet they offer unique opportunities to investigate phenotypic evolution in arid ecosystems.

Body colouration has an important role in communication, predator-prey interactions, camouflage and maintaining physiological homeostasis (e.g., Caro, 2005). Melanism is a common form of colour polymorphism in animals, arising from variation in melanin production and resulting in different degrees of melanisation (Sahlean et al., 2025). Melanism has been related to diverse ecological and physiological functions, including camouflage, thermoregulation, protection against UV damage, and increased immunity to parasites (see Goldenberg et al., 2024, and references therein). The interplay of these functions likely shapes the emergence and maintenance of dark pigmentation. In species living on dark substrates, melanism is likely favoured for its cryptic role (Cloudsley-Thompson, 1979), reducing detectability by visual predators

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or facilitating ambush predation (Eizirik and Trindade, 2021). Beyond biotic interactions, abiotic environmental fluctuations have been repeatedly associated to increased melanin production in ectotherms, particularly in regions characterised by higher precipitation (Sahlean et al., 2025; Sreelatha et al., 2025) and, in some cases, with colder environments (Clusella-Trullas et al., 2007; Martínez-Freiría et al., 2020). In endotherms, melanism has likewise been associated with crypsis, thermoregulation, and behavioural roles, although these linkages remain poorly understood (Eizirik and Trindade, 2021).

In desert ecosystems, background matching is a strong selective pressure due to vast open spaces and limited vegetation cover, resulting in pale, sandy colour morphs blending into bright, sandy habitats, while melanistic morphs are associated with lava fields and dark volcanic sands (Cloudsley-Thompson, 1979). The Arabian Peninsula is characterised by approximately 180,000 km^2 of volcanic fields, locally known as *harrat*, with about half of the area located in Saudi Arabia (Alohali et al., 2022). These volcanic systems are under the influence of an arid climate, characterised by prolonged, hot summers with minimal rainfall, where frequent strong winds increase erosion and reduce vegetation development, resulting in predominantly rocky, dark terrain with sparse vegetation and gravel plains (Schulz and Whitney, 1986). The Harrat Lunayyir in Tabuk Province covers cc. 3575 km^2 and is a relatively recent (~600 kya) volcanic field primarily consisting of basaltic lava flows, while Harrat Khaybar in Ha'il Province extends over 14,000 km^2, formed roughly 5 mya, and is characterised by a compositionally diverse landscape that includes dark volcanic rock, light-coloured cones, and sandy areas (Alohali et al., 2022). Such volcanic landscapes, composed of dark lava fields in contact with lighter sandy areas, provide natural laboratories for testing the ecological and evolutionary roles of melanism. However, despite its richness in dark volcanic substrates, cases of this colour polymorphism have rarely been documented in the Arabian Peninsula (but see Licata et al., 2024).

This work reports different levels of melanism in two scorpion species, *Leiurus haenggii* (Buthidae) and *Compsobuthus manzonii* (Buthidae), two reptile species, *Acanthodactylus boskianus* (Lacertidae) and *Rhynchocalamus hejazicus* (Colubridae), and four rodent species, *Acomys dimidiatus*, *Acomys russatus*, *Meriones crassus*, and *Sekeetamys calurus* (all Muridae).

During a faunal assessment in north-western Saudi Arabia, field surveys were conducted in the Harrat Lunayyir between March and September 2024, and in the Harrat Khaybar between May and October 2023 (Fig. 1), at elevations from 367 m above sea level (a.s.l.) up to 1781 m a.s.l. Sampling methodologies differed by taxonomic group. For reptiles, visual encounter surveys along transects were conducted in the early morning, afternoon, and night, with each transect lasting approximately 1 h. Scorpion sampling mostly took place at night, using UV lights, while daylight search included flipping rocks and checking burrows and holes. Rodents were sampled using live traps (Sherman traps, wire-mesh cage traps, and Longworth traps) set before sunset and checked at sunrise. Additionally, visual encounter surveys were conducted at night to detect and capture individuals with hand nets, either on foot or by vehicle, where terrain permitted. Opportunistic records were also collected for all taxonomic groups. Geographic coordinates were recorded in the WGS84 system (Table S1), and captured specimens were photographed. Reptile and scorpion individuals were categorised as fully melanistic when entirely black, or as partially melanistic when the typical colour pattern was still visible despite the increased black pigmentation. In mammals, a standardised phenotypic categorisation of melanism is lacking (Eizirik and Trindade, 2021). To account for the melanism sub-categorisation recognised in rodents, individuals were visually categorised as: melanistic if the entire coat consisted of solid black hairs; partial melanistic if 75–90 % of the coat had solid black hairs, and brown-black melanistic if the coat was darkened, but individual hairs still showed the typical banded (alternating light/dark) pigmentation pattern (following McRobie et al., 2019). A DNA barcode assessment, using cytochrome *c* oxidase 1 (COI) for scorpions and reptiles, and 12S for rodents, was conducted to confirm species identification. The protocol outlined in Liz et al. (2025) was followed, with primers and PCR conditions adjusted by group (Table S1).

For scorpions, eight partially melanistic *Leiurus haenggii* and three melanistic *Compsobuthus manzonii* were found in Harrat Lunayyr, while two partially melanistic *L. haenggii* and five melanistic *C. manzonii* were

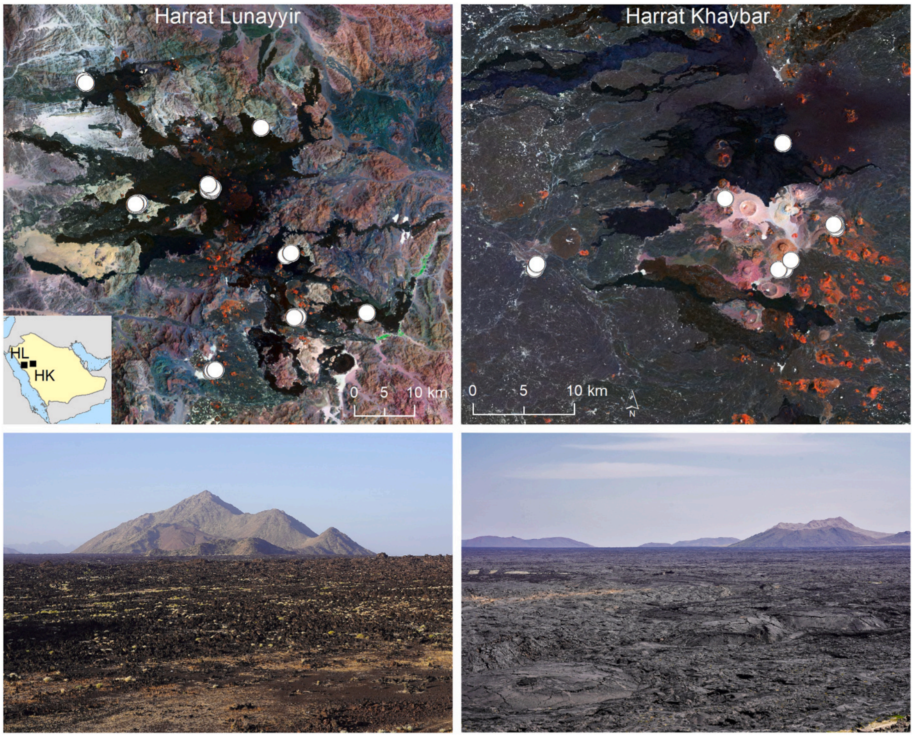

Fig. 1. Distribution of melanistic individuals in the harrats of north-western Saudi Arabia (top) and their microhabitats (bottom).

observed in Harrat Khaybar (Fig. 2A–C, S1). In reptiles, five partially melanistic *Acanthodactylus boskianus* and two fully melanistic *Rhynchocalamus hejazicus* were found in Harrat Lunayyir (Fig. 2E–G, S2). None of the fully or partially melanistic reptiles reported in this work were found in Harrat Khaybar; however, a melanistic individual from this *harrat* was included in the recent species description (Licata et al., 2024). Regarding brown-black melanistic rodents, 11 *Acomys dimidiatus*, six *Acomys russatus*, one *Meriones crassus* and two *Sekeetamys calurus* were found in Harrat Lunayyir, while only one individual of *A. dimidiatus*, *A. russatus* and *S. calurus* was observed in Harrat Khaybar (Fig. 3, S3). DNA barcoding confirmed the assignment of all darker individuals to their respective species.

All observed darker individuals of scorpions, reptiles, and rodents were encountered on dark volcanic substrate or within transition zones between light-coloured substrates and dark lava flows, in sympatry with their non-melanistic counterparts. In *Leiurus haenggii* and *Compsobuthus manzonii*, melanism likely facilitates crypsis through background matching, as shown in the single study reporting melanism in scorpions, in the genera *Centruroides* and *Hadrurus* occurring in volcanic areas of Baja California (Williams, 1980). Still, the ecological and evolutionary interpretations of this finding require additional studies on melanism in this taxon. As for diurnal reptiles at high-elevation, such as *A. boskianus* found between 1034 and 1068 m a.s.l., both thermoregulatory and predation pressures could synergistically drive different levels of melanism. However, since non-melanistic individuals were observed from 471 m to 1734 m a.s.l., thermoregulation in both morphotypes is likely achieved through behavioural strategies, such as shifting between warmer and cooler areas, adapting body posture and orientation, and shifting activity windows, rather than physiological fluctuations in melanin production alone (Clusella-Trullas et al., 2007). In the *harrats*, melanistic *A. boskianus* were often observed in open habitats lacking bushy vegetation, which are typically used as refuges from predators (Roobas and Feulner, 2013). Under these conditions, cryptic colouration may aid camouflage against a dark background, thereby increasing

Fig. 2. Melanistic and non-melanistic scorpion and reptile species from north-western Saudi Arabia. A) Partially melanistic *Leiurus haenggii*, B) Non-melanistic *L. haenggii*, C) Fully melanistic *Compsobuthus manzonii*, D) Non-melanistic *C. manzonii*, E) Partially melanistic *Acanthodactylus boskianus*, F) Non-melanistic *A. boskianus*, G) Fully melanistic *Rhynchocalamus hejazicus*, and H) Non-melanistic *R. hejazicus*.

Fig. 3. Brown-black melanistic and non-melanistic rodent species from north-western Saudi Arabia. A) Brown-black melanistic *Acomys dimidiatus*, B) Non-melanistic *A. dimidiatus*, C) Brown-black melanistic *Acomys russatus*, D) Non-melanistic *A. russatus*, E) Brown-black melanistic *Meriones crassus*, F) Non-melanistic *M. crassus*, G) Brown-black melanistic *Sekeetamys calurus*, and H) Non-melanistic *S. calurus*.

survival and reproductive success. A similar pattern has been reported in melanistic *Acanthodactylus erythrurus* inhabiting dark substrates, where melanism is likely related to enhanced crypsis and reduced predation risk, with no support for thermal melanism (Cuervo et al., 2024). In nocturnal species, such as *R. hejazicus*, colour polymorphism features both a conspicuous orange morph and a fully melanistic one. These morphs may suggest an adaptation for predator avoidance through crypsis on different soil colours, enabling them to inhabit diverse environments (Corl et al., 2018). In rodent species, the brown-black phenotype observed in *A. russatus* appears to match the melanism previously reported in Azraq (Jordan) and possibly in Harrat Al Harrah (northern Saudi Arabia) (Al Malki et al., 2024). Dark hair colouration likely serves a cryptic function primarily, in line with inferences from desert-adapted rodents outside the Arabian Peninsula (Cloudsley-Thompson, 1979), as in the case of *Chaetodipus intermedius* inhabiting basaltic lava flows in North American deserts (Eizirik and Trindade, 2021). The observation of brown-black melanism in nocturnal species (*A. dimidiatus*, *M. crassus*, *S. calurus*) might indicate that crypsis is adaptive regardless of ambient illumination levels (Cloudsley-Thompson, 1979). In this context, melanism might aid antipredator camouflage by increasing background matching under moonlight, similarly to diurnal species under sunlight. However, empirical studies are needed to quantify predation pressure on different colour morphotypes across distinct substrates. Furthermore, conducting studies on the ecology, ethology, and population demographics of all colour morphs is needed to test these proposed adaptive roles and to understand the adaptive significance of melanism in the lava fields of Saudi Arabia.

The findings reported here, although based on opportunistic observations during faunal assessments, raise important questions and highlight the need for systematic research. For instance, long-term monitoring of *Papilio glaucus* revealed a decline in the frequency of melanistic females over two decades (Scriber, 2020), underscoring the value of systematic approaches. Additionally, molecular approaches investigating known pigmentation pathways may provide insights into the evolutionary mechanisms underlying convergent melanism in Arabian desert fauna. Key candidates include mutations in the melanocortin-1 receptor (*MC1R*) gene, and Agouti signalling protein (*ASIP*) gene in rodents (see Eizirik and Trindade, 2021, and references therein); and mutations in the *TYRP1* gene, recently shown to promote dark colouration in agamid lizards inhabiting high altitudes (Sun et al., 2024). Overall, phenotypic variation in body colouration offers an excellent opportunity to combine ecological, physiological, and molecular approaches to understand how extreme desert environments influence adaptive traits (e.g., Eizirik and Trindade, 2021; Cuervo et al., 2024).

This work represents the first multi-taxon report of melanism in the volcanic fields of north-western Saudi Arabia. The repeated association of melanistic individuals with dark volcanic substrates suggests a role for melanism in background matching, likely reducing predation risk (Cloudsley-Thompson, 1979). Still, other potential benefits of melanism remain to be explored, especially when it occurs in both crepuscular and nocturnal species. In this context, the extreme conditions of these biotopes may favour context-dependent phenotypes, making them natural laboratories for testing ecogeographic hypotheses proposed to underlie the distribution of a colour polymorphism across diverse environments (Sreelatha et al., 2025, and references therein). Finally, despite their vastness, lava fields in arid regions remain understudied due to their remoteness and limited accessibility, yet they hold great potential for advancing knowledge of phenotypic evolution in arid ecosystems.

CRediT authorship contribution statement

Margareta Lakušić: Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Myrto Roumelioti:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Fulvio Licata:** Writing – review & editing, Visualization, Investigation, Conceptualization. **Marcello Bilancioni:** Writing – review & editing, Visualization, Investigation. **Diogo F. Ferreira:** Writing – review & editing, Project administration, Funding acquisition. **Leili Khalatbari:** Writing – review & editing, Project administration, Funding acquisition. **Vidak Lakušić:** Writing – review & editing, Investigation. **André Vicente Liz:** Writing – review & editing, Investigation. **Raquel N. de Oliveira:** Writing – review & editing, Visualization, Investigation. **Bárbara Santos:** Writing – review & editing, Project administration, Investigation, Funding acquisition. **Yuri Simone:** Writing – review & editing, Visualization, Investigation. **László Patkó:** Writing – review & editing, Project administration. **Ayman Abdulkarem:** Writing – review & editing, Project administration. **Benjamin P.Y-H. Lee:** Writing – review & editing, Project administration. **Magdy El-Bana:** Writing – review & editing, Project administration. **Ahmed Al-Ansari:** Writing – review & editing, Project administration. **Omar Al-Attas:** Writing – review & editing, Project administration. **José Carlos Brito:** Writing – review & editing, Visualization, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2025.105548.

Data availability

No data was used for the research described in the article.

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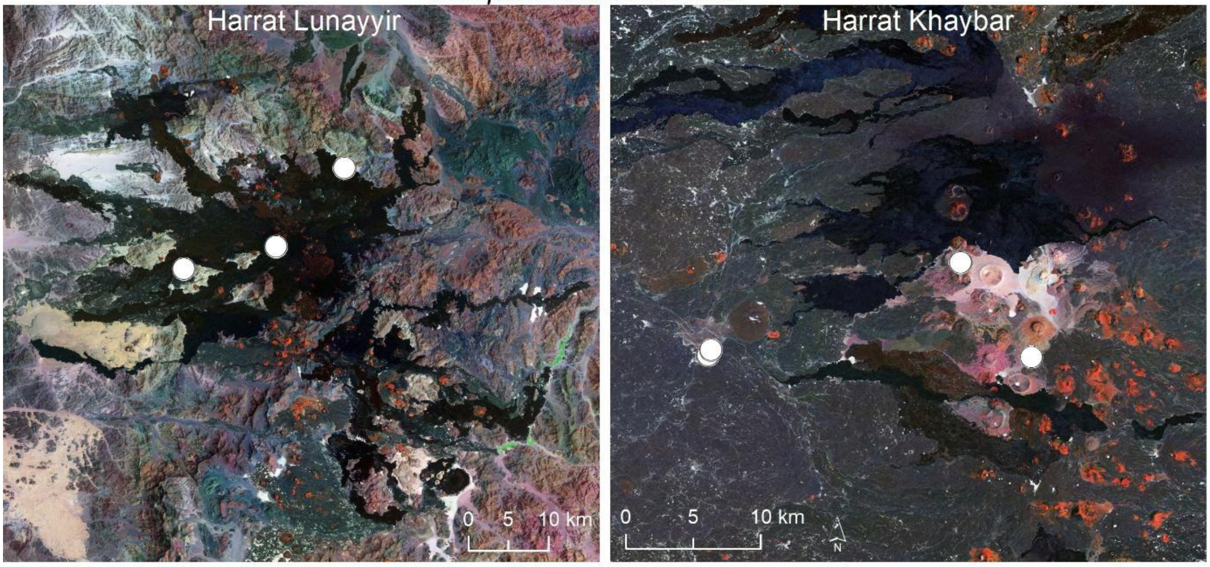
Supplementary material

Table 1. List of partially and fully melanistic scorpions and reptiles, and brown-black rodents observed in Harrat Lunayyir and Harrat Khaybar.

Sample ID	Species	Date	Harrat	Latitude	Longitude	Elevation	COI	12S
			Partially melanistic					
YSI_1095	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035		
YSI_1096	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035		
YSI_1097	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035		
YSI_1098	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035		
YSI_1099	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035	PX769403	PX775906
YSI_1101	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1096		
YSI_1102	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1035		
YSI_1103	*Leiurus haenggii*	20/04/24	Lunayyir	25.19	37.79	1106		
YSI_0045	*Leiurus haenggii*	05/10/23	Khaybar	25.61	39.97	1614		
YSI_0470	*Leiurus haenggii*	10/03/23	Khaybar	25.64	40.01	1690	PX769405	PX775905
			Fully melanistic					
YSI_0039	*Compsobuthus manzonii*	05/08/23	Khaybar	25.61	39.75	1141		
YSI_0056	*Compsobuthus manzonii*	05/10/23	Khaybar	25.61	39.96	1606		
YSI_0057	*Compsobuthus manzonii*	05/10/23	Khaybar	25.61	39.96	1606		
YSI_0067	*Compsobuthus manzonii*	05/11/23	Khaybar	25.67	39.91	1623		
YSI_0462	*Compsobuthus manzonii*	30/09/23	Khaybar	25.61	39.75	1143	PX769402	
YSI_1100	*Compsobuthus manzonii*	20/04/24	Lunayyir	25.19	37.79	1096	PX769404	PX775907
YSI_1243	*Compsobuthus manzonii*	19/06/24	Lunayyir	25.17	37.68	681		PX775908
YSI_1339	*Compsobuthus manzonii*	28/06/24	Lunayyir	25.28	37.87	882		PX775909
			Partially melanistic					
MLA_0282	*Acanthodactylus boskianus*	21/04/24	Lunayyir	25.19	37.79	1035		
MLA_0284	*Acanthodactylus boskianus*	21/04/24	Lunayyir	25.19	37.79	1035	PX769401	
MLA_0285	*Acanthodactylus boskianus*	21/04/24	Lunayyir	25.19	37.79	1035		

MLA_0276	*Acanthodactylus boskianus*	20/04/24	Lunayyir	25.19	37.79	1096	PX769399	
MLA_0277	*Acanthodactylus boskianus*	20/04/24	Lunayyir	25.19	37.79	1096	PX769400	
			Fully melanistic					
FLI_1449	*Rhynchocalamus hejazicus*	19/04/24	Lunayyir	25.09	37.90	1093		
FLI_1879	*Rhynchocalamus hejazicus*	21/06/24	Lunayyir	25.00	37.92	966	PX769398	
FLI_0330	*Rhynchocalamus hejazicus*	11/05/23	Khaybar	25.61	39.97	1610	PV255263	PP588465
			Brown-black melanistic					
ROL_0441	*Acomys dimidiatus*	22/06/24	Lunayyir	25.00	37.92	977		PX775900
ROL_0445	*Acomys dimidiatus*	22/06/24	Lunayyir	25.00	37.91	977		PX775901
ROL_0495	*Acomys dimidiatus*	29/06/24	Lunayyir	25.28	37.87	882		
MBI_0399	*Acomys dimidiatus*	20/04/24	Lunayyir	25.09	37.91	1090		PX775895
ROL_0448	*Acomys dimidiatus*	23/06/24	Lunayyir	25.00	38.02	788		PX775902
ROL_0426	*Acomys dimidiatus*	21/06/24	Lunayyir	24.92	37.79	1106		
ROL_0429	*Acomys dimidiatus*	21/06/24	Lunayyir	24.92	37.79	1093		
ROL_0430	*Acomys dimidiatus*	21/06/24	Lunayyir	24.92	37.79	1106		
ROL_0431	*Acomys dimidiatus*	21/06/24	Lunayyir	24.92	37.80	1106		
ROL_0418	*Acomys dimidiatus*	20/06/24	Lunayyir	25.17	37.68	636		PX775898
ROL_0419	*Acomys dimidiatus*	20/06/24	Lunayyir	25.17	37.68	639		
MBI_0029	*Acomys dimidiatus*	03/10/23	Khaybar	25.65	40.01	1690		PX775894
ROL_0576	*Acomys russatus*	21/06/24	Lunayyir	25.00	37.92	966		
ROL_0442	*Acomys russatus*	22/06/24	Lunayyir	25.00	37.92	977		
MBI_0408	*Acomys russatus*	21/04/24	Lunayyir	25.20	37.79	1096		PX775896
ROL_0421	*Acomys russatus*	20/06/24	Lunayyir	25.17	37.68	639		PX775899
ROL_0424	*Acomys russatus*	20/06/24	Lunayyir	25.17	37.68	636		
ROL_0417	*Acomys russatus*	20/06/24	Lunayyir	25.17	37.68	636		PX775897
MBI_0023	*Acomys russatus*	03/10/23	Khaybar	25.65	40.01	1690		PX775893
ROL_0480	*Meriones crassus*	28/06/24	Lunayyir	25.35	37.60	498		PX775903
ROL_0482	*Sekeetamys calurus*	28/06/24	Lunayyir	25.35	37.60	471		PX775904
ROL_0423	*Sekeetamys calurus*	20/06/24	Lunayyir	25.17	37.68	636		
MBI_0021	*Sekeetamys calurus*	02/10/23	Khaybar	25.72	39.97	1781		PX775892

Compsobuthus manzonii



Leirus haenggii

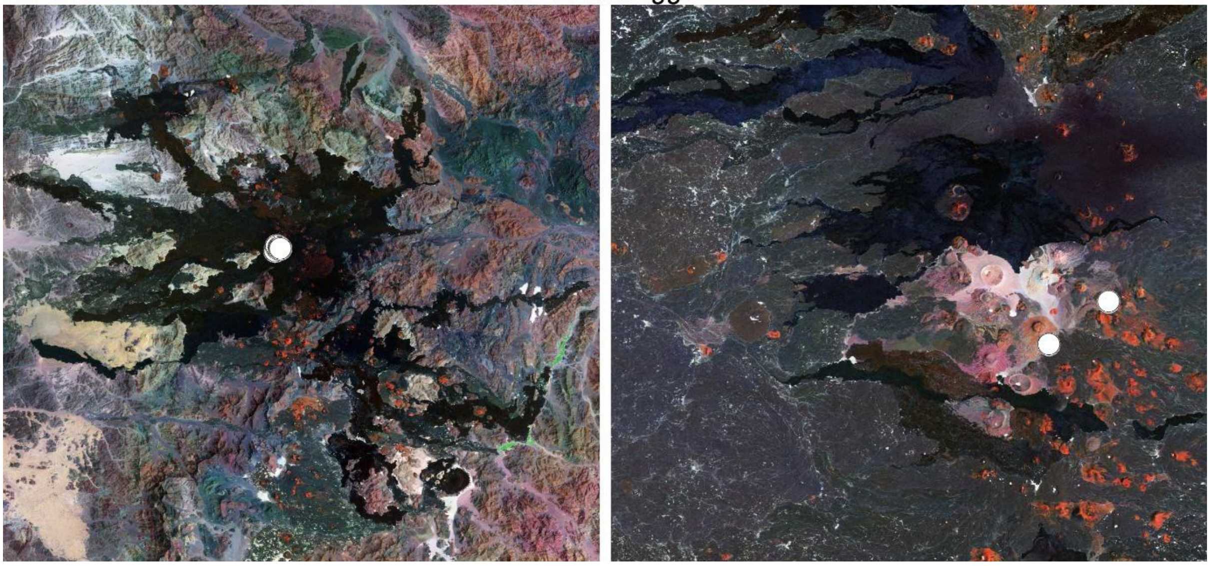
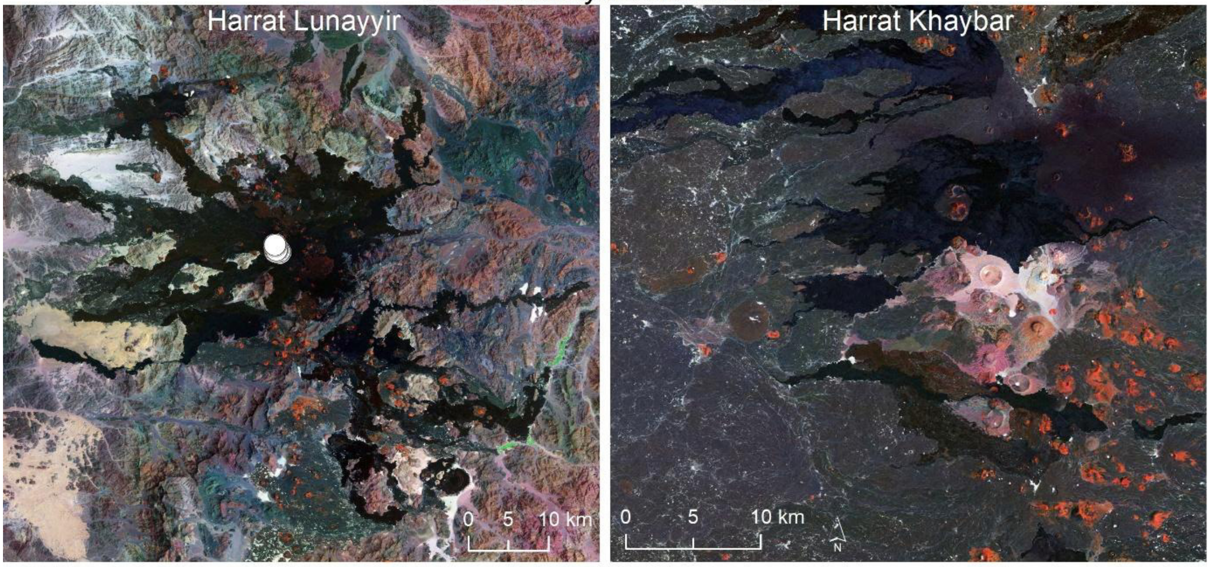
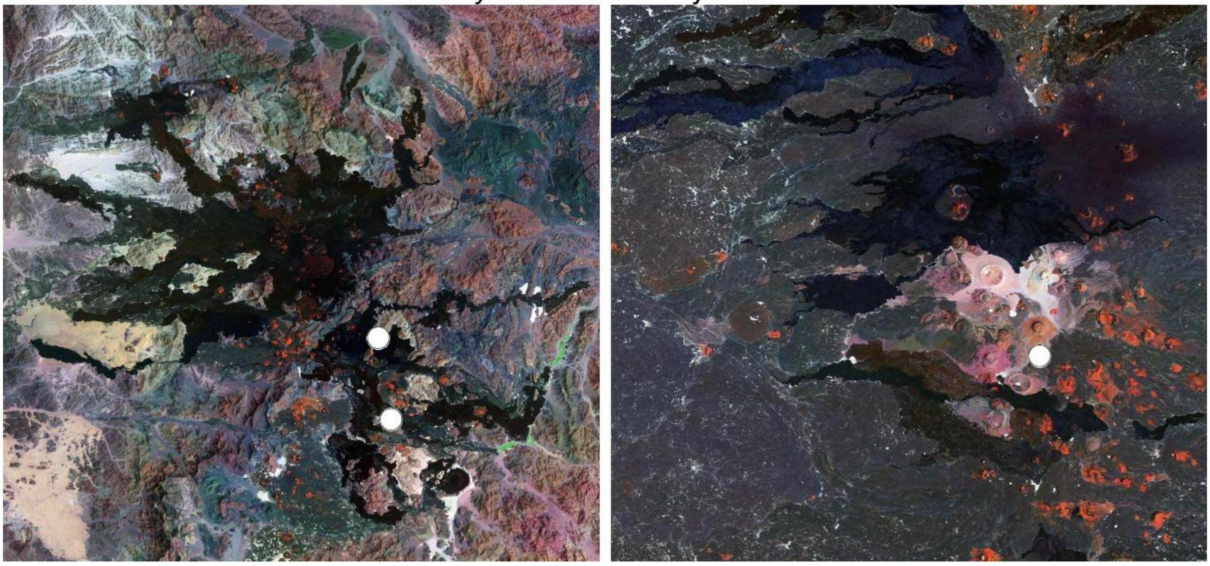


Fig. S1. Distribution of fully and partially melanistic scorpions in north-western Saudi Arabia.



Acanthodactylus boskianus



Rhynchocalamus hejazicus

Fig. S2. Distribution of partially and fully melanistic reptiles in north-western Saudi Arabia. The observation of *R. hejazicus* in Harrat Khaybar was published in Licata et al. (2024).

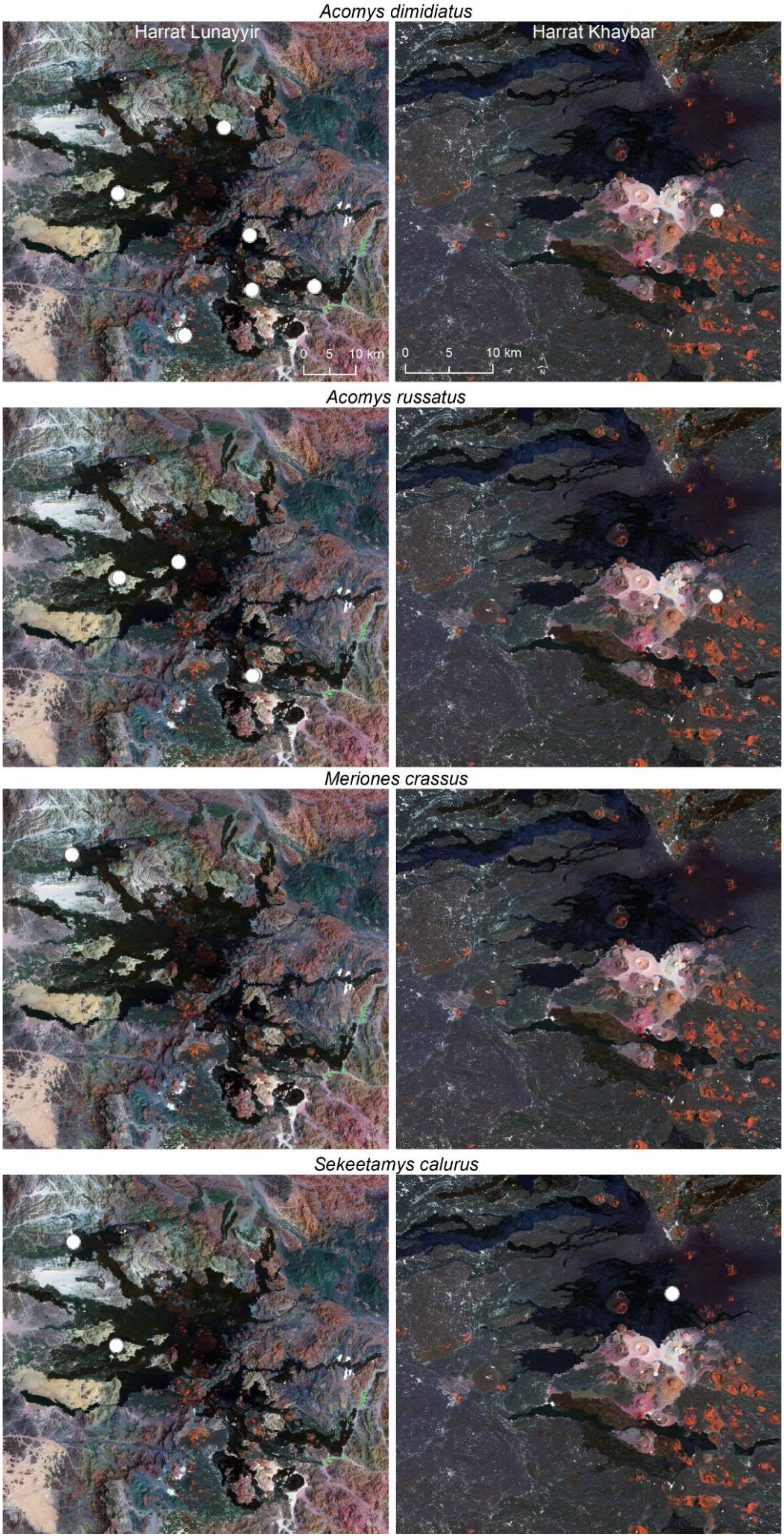


Fig. S3. Distribution of brown-black melanistic rodents in north-western Saudi Arabia.