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## EFFECTS OF FIRE ON SMALL MAMMALS OF THE KOANAKA HILLS, NORTHWESTERN BOTSWANA

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### ABSTRACT

In June 2008, a series of 230 small mammals were collected from the Koanaka Hills of northwestern Botswana as a reference collection to aid in defining changes in the regional climate over the past ~2 million years. Just two months after this collection was made, large expanses of northwestern Botswana were consumed by wildfire, including the study site. Efforts to evaluate the effects of catastrophic fire on wildlife diversity and post-fire genetic composition in southern Africa are uncommon. The occurrence of this fire immediately after a comprehensive trapping effort allowed unanticipated research questions to be addressed. To evaluate the effect of large-scale fire on small mammal species abundance and diversity, we returned to the Koanaka Hills in July 2009 and replicated the collecting efforts of 2008, which yielded 510 small mammals. Analyses of the trapping data indicate only minor differences in species abundance and diversity among areas sampled.

Key words: Botswana, fire, rodents, species diversity

### INTRODUCTION

A relatively recent discovery of microvertebrate fossils, attributed to barn owls as the accumulating agent, in a Pleistocene cave system in the Koanaka Hills of northwestern Botswana (Pickford and Mein 1988; Williams et al. 2012) and a relatively poor understanding of the region's modern fauna prompted a collecting trip in 2008 to document the area's small mammal, amphibian, and reptile diversity. The primary purpose of this effort was to obtain a comparative reference collection for the interpretation of fossil fauna collected by Williams et al. (2012). In June 2008, a series of 230 small mammals, 38 reptiles, over 80 owl pellets, and hundreds of Plio-Pleistocene vertebrate fossils were collected from the Koanaka Hills.

Within three months of the initial collecting trip to the Koanaka Hills, the region was consumed by a concentrated bush-fire (M. Gabadirwe, Botswana National Museum, pers. com.). Opportunities to evaluate the effects of large-scale catastrophic fire on species diversity and genetic diversity and changes within populations are unfortunately not very common, and the fortuitous occurrence of these fires so soon after a comprehensive trapping effort allowed unanticipated research questions to be addressed.

Small mammal communities are influenced directly by fire and indirectly by burn effects on plant community structure. Research into the effects of

fire on small mammals in the tallgrass prairies of the United States has shown that direct effects may include burns, heat stress, asphyxiation, physiological stress, trampling, and predation during escape from fire (Kaufman et al. 1990). Species with aboveground nests may perish directly during the fire (Simons 1989, 1991); however, burrowing rodents are more likely to survive if burrow depth is adequate (Howard et al. 1959). Small mammals also may flee from their burrow or nest during a fire and establish a new burrow or nest site away from the burned area. Physiological stress induced by fire can impact small mammal populations through abortion of litters or abandonment of young. The primary influences of fire on small mammal communities, however, are often indirect effects through changes in vegetation composition and structure that alters the quantity or quality of food, availability of nest sites, predator/prey interactions, and rates of parasitism and disease (Kaufman et al. 1990).

One of the earliest publications on the devastating effect of wildfire on wildlife reported 43 carcasses comprised predominantly of rodents and rabbits on a

1.7 acre plot of chaparral scrub in Malibu, California, within days of major canyon fires in 1957 (Chew et al. 1959). In a study comparing rodent survivability in burned versus unburned areas of South Africa, species adapted to more open environments actually preferred burned areas whereas species preferring overhead cover appeared to leave the area, which was presumed to be a defense against increased risk of aerial predation (Christian 1977). Breeding percentages, survivorship, and movement distances of *Desmodillus auricularis* and *Gerbillurus paebea* were similar on burned and unburned areas, suggesting that survival of these species on burned areas is an adaptation to desert existence rather than to fire altered habitat (Christian 1977). Other studies (e.g., Ojeda 1989; Simons 1989, 1991; Kirkland et al. 1996; Monroe et al. 2004) demonstrate species composition and demographic shifts as a result of fire, but usually report effects of small controlled fires rather than fires of a scale comparable to the Koanaka Hills fire of 2008 that was reported to consume an estimated 650+ km<sup>2</sup> [Mmegi Online: www.mmegi.bw, 8 Oct. 2008, Vol. 25 (147); 30 Oct. 2008 Vol. 25 (160); 17 Nov. 2008 Vol. 25 (169)].

## STUDY AREA

Together with the Aha and Gcwihaba Hills, the remote Koanaka Hills (20° S, 21° E) form part of a series of dolomite uplifts in northwestern Ngamiland, Botswana (Fig. 1; Cooke 1975). Located 100 km due west of Tsau on the southwestern margin of the Okavango River Delta and 22 km southwest of the Gcwihaba Hills, the Koanaka Hills are comprised of three separate hills. Two hills, Koanaka North and Koanaka South (Fig. 2), are separated by ca. 0.5 km and the third hill is 12 km to the west. Composed primarily of dolomitic rocks and breccia infills (Cooke 1975) with maximum elevations of ca. 50 m above the surrounding plains, they represent the only topographic relief for over 20 km.

The habitat around the hills is a semi-arid, dense, shrub savanna, referred to as the Kalahari Thirstland (Smithers 1971; Pickford and Mein 1988). Annual rainfall of 400-450 mm occurs primarily during the austral summer months (van Regenmortel 1995). Two pans (ephemeral ponds) are located approximately 200 m west of Koanaka South, although neither the

frequency with which these pans contain water, nor the duration for which they hold water, is known. No signs of water in the pans were obvious during the months of June–August in 2007, 2008, or 2009. The pans are comprised of calcareous clays overlying calcrete and are separated from the rocky outcrops of the hills by dense scrub brush. Annual temperature variation near the Koanaka Hills varies from -8.5°C to 42.2°C (Botswana Department of Meteorological Services 2009). During the 2008 collection period daytime temperatures averaged 26°C, nighttime temperatures averaged 2°C, and there was no precipitation. During the 2009 collection period daytime temperatures averaged 28°C, nighttime temperatures averaged 5°C, and light precipitation occurred for less than 10 minutes on one day. Small, regularly occurring ground fires are known to occur in the area; however, duration, frequency, and intensity are not well documented.

In 2008, a baseline vertebrate inventory for the area around Koanaka South was completed (Bauer et al. 2009; Ferguson et al. 2010) to create a comparative

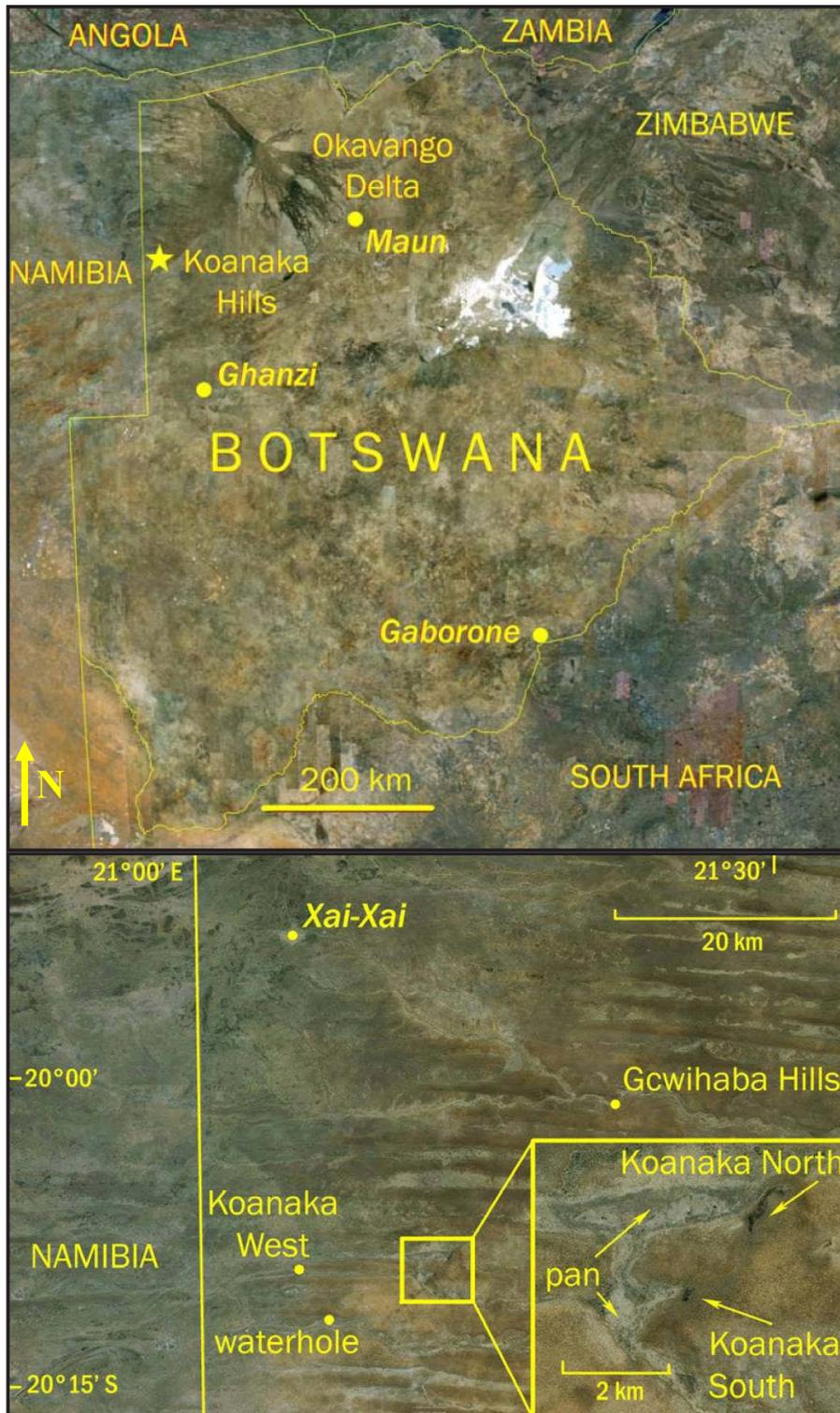


Figure 1. Map of the Koanaka Hills, Ngamiland, Botswana (modified from Bauer et al. 2009) showing the location of the Koanaka Hills (starred). The inset shows the locations of Koanaka North, Koanaka South, and primary pan in association with the waterhole.

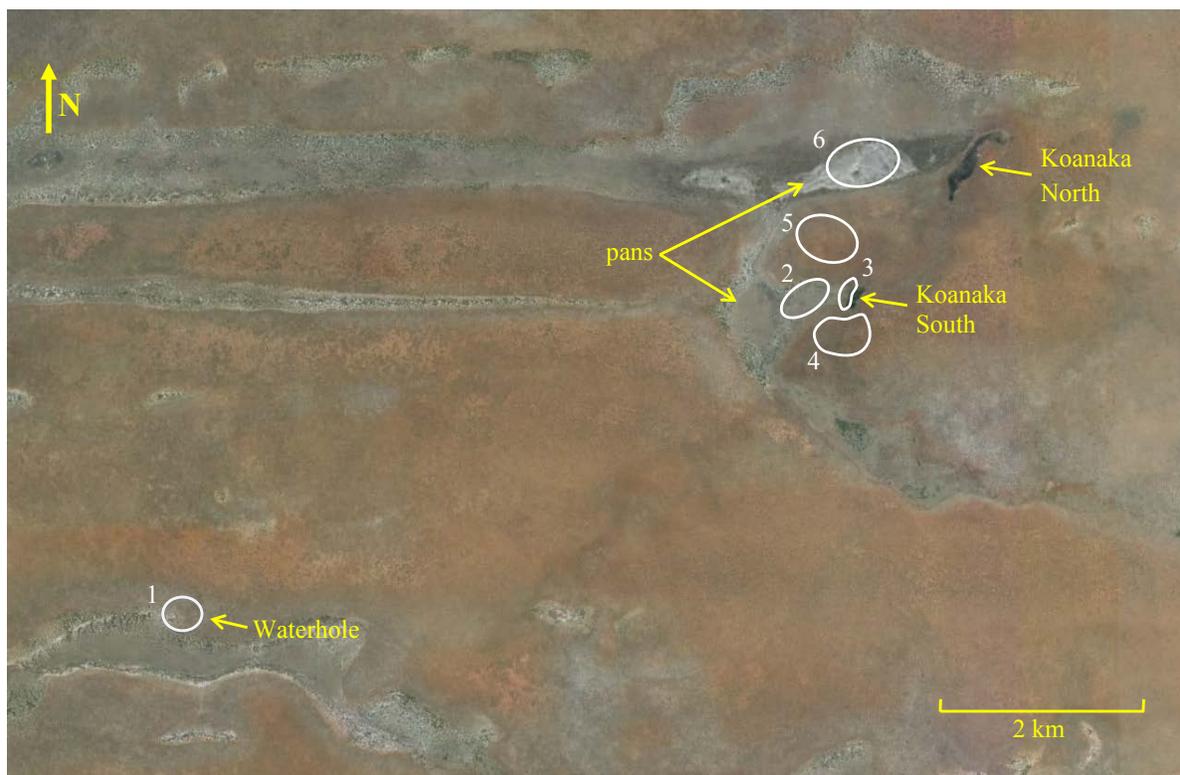


Figure 2. Magnified inset of Figure 1 with locations of the six Koanaka Hills study areas. Polygons indicate limits to trapping areas within each study area.

collection of modern skeletal material for interpretation of fossil fauna collected by Williams et al. (2012), and to aid in paleoclimatic reconstruction for the region. At that time, due largely to time constraints and the primary focus being development of a reference skeletal collection, no efforts were made to conduct quantitative habitat characterizations of the sampling localities.

Following fires in the area in late 2008, the objectives of the original project expanded to assess changes in small vertebrate species diversity and abundance within and around Bone Cave and the Koanaka Hills. Results from the effects of fire on the herpetofauna were reported in Kennedy et al. (2012) and the effects on small mammals are reported herein.

## METHODS

As part of an ongoing investigation of the past and present fauna of the region, small mammals were surveyed within the vicinity of the Koanaka Hills, Ngamiland, Botswana, from 17 June to 2 July 2008 (Bauer et al. 2009; Ferguson et al. 2012; Kennedy et al. 2012). Secondary efforts to document changes in small mammal species diversity and abundance of the Koanaka Hills stemming from reports of expansive fires of 2008 (after our initial trapping efforts) resulted in a resampling effort conducted 7–13 July 2009. Protocols

for the 2009 resampling effort duplicated field methods used in 2008, with three of the four original members of the 2008 mammal trapping team returning for the replicated efforts. Trapping efforts utilized similar numbers and styles of traps set in lines radiating out from GPS points recorded in 2008, similar baits, and were placed along similar transects whenever possible.

Six trapping areas were established in 2008 (Fig. 2) to represent primary habitat variability on and around

Koanaka South in an effort to sample the diversity of small mammals in the area as fully as possible. A general checklist of possible species in the proximity of the Koanaka Hills was compiled from works published by Smithers (1971), de Graaff (1981), and Skinner and Chimimba (2005) along with a review of available information on habitat preference and generalist/specialist behavior of those species expected. Areas were selected based on degree and type of general ground cover (e.g., bare ground and/or rocky outcrops, sparse scrubby vegetation, heavy grasses, and presence of larger shrubs and trees; Fig. 3). Area 1 and areas 2-6 were restricted to within a 2 km radius of a primary waterhole and Koanaka South, respectively, based on ranging behavior of barn owls (*Tyto alba*) in North American and European telemetry studies (Taberlet 1983; Colvin 1984; Taylor 1994).

Sampling for small mammals in both years consisted primarily of line transects of Sherman live traps, establishing pitfall arrays, and mist nets that were set in representative habitats. Museum special snap traps also were used to selectively sample for arboreal species in select habitats; however, they yielded no species in addition to those also being taken with Sherman traps. Specific trapping localities were selected in 2008 in an effort to maximize potential species diversity in building the reference collection within the limited time period available for field work. Collection protocols followed standard methods for conducting biological inventories for small mammals, and trapping efforts between years utilized similar numbers of traps set in lines radiating out from GPS points recorded in 2008.

Data collected for each trap line included GPS positions of line starting and ending points, number and type of traps set, and capture success. All field work was conducted under Sam Houston State University IACUC permit #08-04-03-1005-3-01 issued to M. L. Thies and guidelines of the American Society of Mammalogists for the use of wild mammals in research (Sikes et al. 2011). Each small mammal collected was sacrificed by thoracic compression or over-anesthetized with halothane, evaluated for general body condition, and standard museum specimen data recorded that included species, sex, weight, body measurements, and general condition. A series of specimens were prepared as standard museum skins and skeletons, with the remaining specimens preserved in formalin, and deposited in the The Museum of Texas Tech Uni-

versity (Lubbock, TX). Tissues were collected and preserved in either 95% ethanol. A list of unprocessed animals was made prior to any release; however, the inaccuracy of species identification without adequate DNA samples for verification forced us to remove the released specimens from any inclusion in subsequent data analyses. With the assistance of a larger field team in 2009, all specimens in the resampling effort were processed and none were released.

The vast majority of specimens were collected with Sherman traps; however, *Crocidura hirta* and *Mus* spp. also were captured using pitfall arrays and drift fences set near the base of Koanaka South. One pitfall array was Y-shaped with a pitfall trap on the end of each arm and one in the center. Two arrays were established with straight fences and three pitfall traps; traps within each array were placed approximately 3m apart. Each array was built with 0.5 m tall drift fence made of black plastic sheeting with wooden stakes, and 5-liter buckets were used for the pitfall traps. Arrays were checked twice daily, once just after sunrise and once just before sunset.

Bats were collected using standard 1.8 x 9.1 m mist nests set adjacent to the Bone Cave opening in area 3 and over water at the pond in area 1, or captured directly with butterfly nets as the bats emerged from Bone Cave. Due to time constraints and a lack of acoustic signals indicating the presence of low-level foraging bats, the other four areas were not sampled.

Trapping for carnivores consisted of setting Conabear #220 body grip traps (Oneida Victor, Cleveland, OH) and 18 x 18 x 76 cm Tomahawk live traps (Hazelhurst, WI) in suitable habitats. Unbaited Conabear traps were set directly in burrow openings of springhares (*Pedetes capensis*) in efforts to capture them entering or leaving their burrow system, or to capture associated predators such as honey badgers (*Melivora capensis*). Tomahawk traps were baited with canned cat food and sardines and placed in areas with deadfall and extensive ground cover for small carnivores. Traps generally were set in the evening and checked in the morning and evening of subsequent days until a capture was made. Bait was replaced as necessary and the traps relocated to different habitats once a capture at a site was made. All captures were processed in the same manner as specimens captured with Sherman traps.

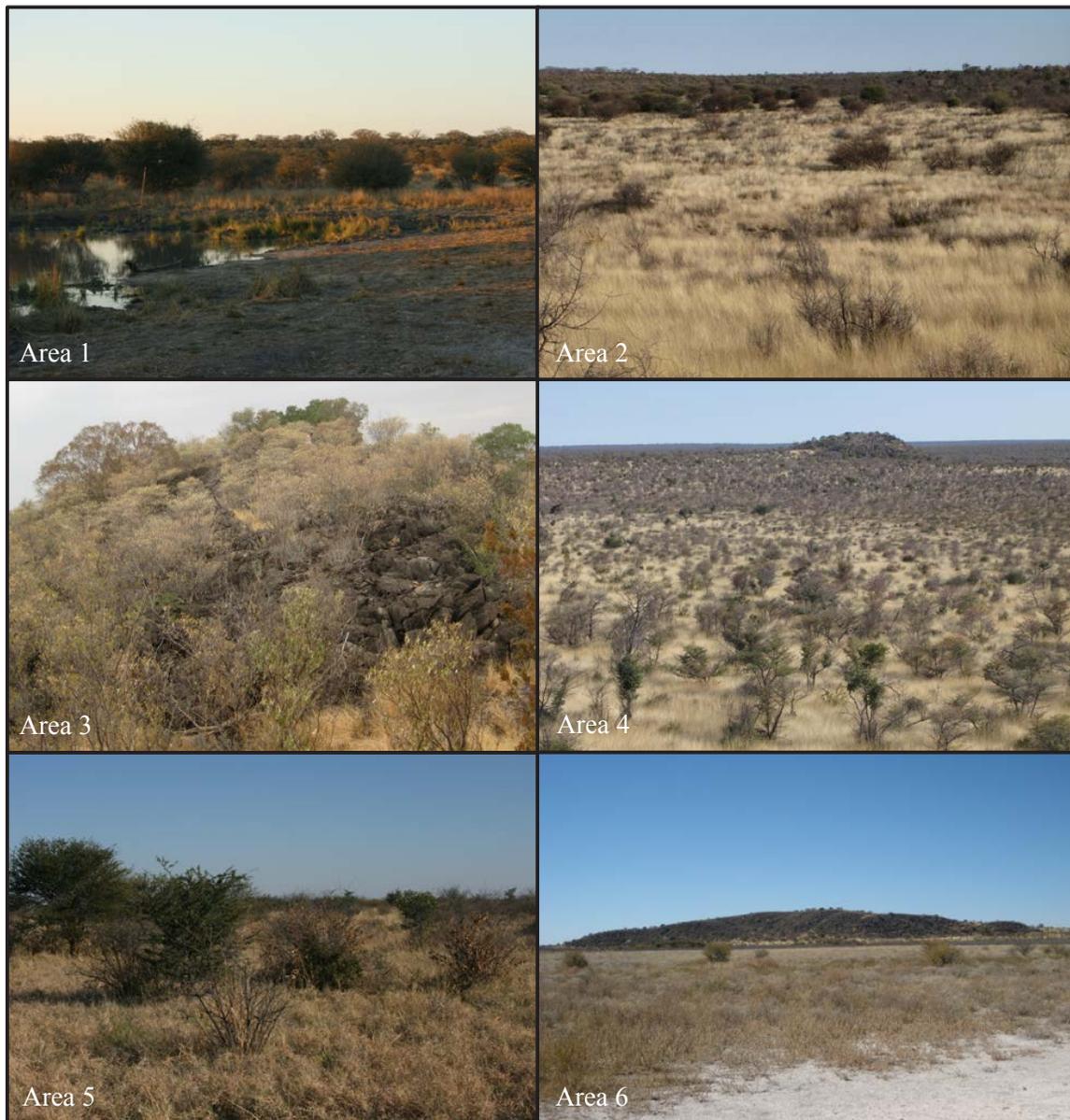


Figure 3. Photographs of representative habitats within the six Koanaka Hills trapping localities.

To aid in accurate species determination, all retained specimens were definitively identified using 400 bp cytochrome-b sequences following protocols outlined in McDonough et al. (2011). Collection data were used to determine species richness, diversity, relative abundance, and distribution patterns for all species collected within the areas surrounding Bone Cave and the Koanaka Hills. Because bats and carnivores were

not sampled consistently and effectively between years, those data were removed and species richness, diversity, abundance, and distributional patterns reexamined using both abundance and incidence based methods.

The date and source of ignition for the fire are not known, nor are other parameters such as fuel load, rate of spread, extinguishing method, and total area burned.

However, it is known that this was one of a number of fires that typically occur during the months of August through November that represent the peak of the dry season, many of which are ignited by lightning.

Data were analyzed for abundance-based differences using the program PAST and for incidence-based differences using EstimateS v. 9 (Colwell 2013). Shannon and Simpson indices were calculated using abundance data, with significance of results of the Simpson Indices compared within sites across years using a t-test. Diversities in abundance data also were compared between years for each area by plotting diversity against an index of sensitivity (Fig. 4). The left-hand end of the diversity profile gives information about species richness and rare species: when alpha is small, diversity is affected almost as much by rare

species as common ones. The right-hand tail gives information about dominance and common species: when alpha is large, diversity is only slightly affected by rare species (Leinster and Cobbold 2012). Due to our relatively small sample sizes and probable trapping biases, incidence-based comparisons were made using the non-parametric Incidence-based Coverage Estimator (ICE) and Chao-2 richness estimator values. Chazdon et al. (1998) reported that the ICE estimator, calculated using both rare and common species, best satisfies the requirements for an ideal species richness estimator and that Chao 2 also was relatively insensitive to sample size. Colwell and Coddington (1994) also showed that Chao 2 provided the least biased estimates for small numbers of samples and takes into account rare species and the total number of species observed in the sample to calculate its richness.

## RESULTS

Trapping results and observational records were compared for the six primary collection areas established from initial visual inspection of general floral components and soil structure (see Fig. 3 for representative habitat images). A total of 25 small mammal species representing five orders (one Soricomorpha, five Chiroptera, 14 Rodentia, one Macroscelidea, and four Carnivora) were collected in the course of this study (Table 1). A single shrew species was caught in both years (*C. hirta*: 2008 N = 6, 2009 N = 4), as was a single species of elephant shrew (*Elephantulus intufi*: 2008 N = 12, 2009 N = 17). Five species of Chiroptera (*Chaerephon nigeriae*: N = 1; *Hipposideros commersoni*: N = 8; *Neoromyscapensis*: N = 10; *Nycteris thebaica*: N = 12; *Rhyncholophus denti*: N = 7) were captured in 2008; however, only three species (*Hipposideros commersoni*: N = 1; *Nycteris thebaica*: N = 13; *Rhyncholophus denti*: N = 13) were captured again in 2009, all obtained from either inside Bone Cave or immediately outside its entrance in area 3. Only one species of small carnivore was trapped in 2008 (*Galerella sanguinea*: N=3), primarily as a result of a reduced effort for these taxa in 2008, whereas four species were captured in 2009 (*Cynictis penicillata*: N = 1; *G. sanguinea*: N = 6; *Genetta genetta*: N = 1; *M. capensis*: N = 2) when significantly more effort was applied to catching the smaller carnivores. The majority

of rodent species were represented in both sampling years (*Aethomys chrysophilus*: 2008 N = 19, 2009 N = 112; *Gerbilliscus brantsii*: 2008 N = 21, 2009 N = 41; *G. leucogaster*: 2008 N = 23, 2009 N = 43; *Gerbillurus paeba*: 2008 N = 9, 2009 N = 22; *Lemniscomys rosalia*: 2008 N = 1, 2009 N = 5; *Mastomys natalensis*: 2008 N = 57, 2009 N = 72; *Micaelamys namaquensis*: 2008 N = 24, 2009 N = 18; *Mus minutoides*: 2008 N = 1, 2009 N = 4; *Saccostomus campestris*: 2008 N = 6, 2009 N = 2; *Zelotomys woosnami*: 2008 N = 1, 2009 N = 1). However, three species (*Cryptomys damarensis*: N = 2, *Dendromus melanotis*: N = 2, and *Xerus inauris*: N = 2) were only captured in 2008 and two species (*Mus indutus*: N = 6, and *Steotomys parvus*: N = 1) were only captured in 2009 (Table 1).

Due to a lack of sufficient processing time and resources, and because the focus of our work in 2008 was to build a set of voucher specimens for fossil identification and a series of 10–12 members of a species was thought to be sufficient, a small number of captures were released during the 2008 field efforts. Adequate records were not kept regarding species, numbers of individuals released, or areas where those released specimens were captured, but we do know that only *A. chrysophilus*, *M. natalensis*, and *M. namaquensis* were released: all other captures were retained and processed

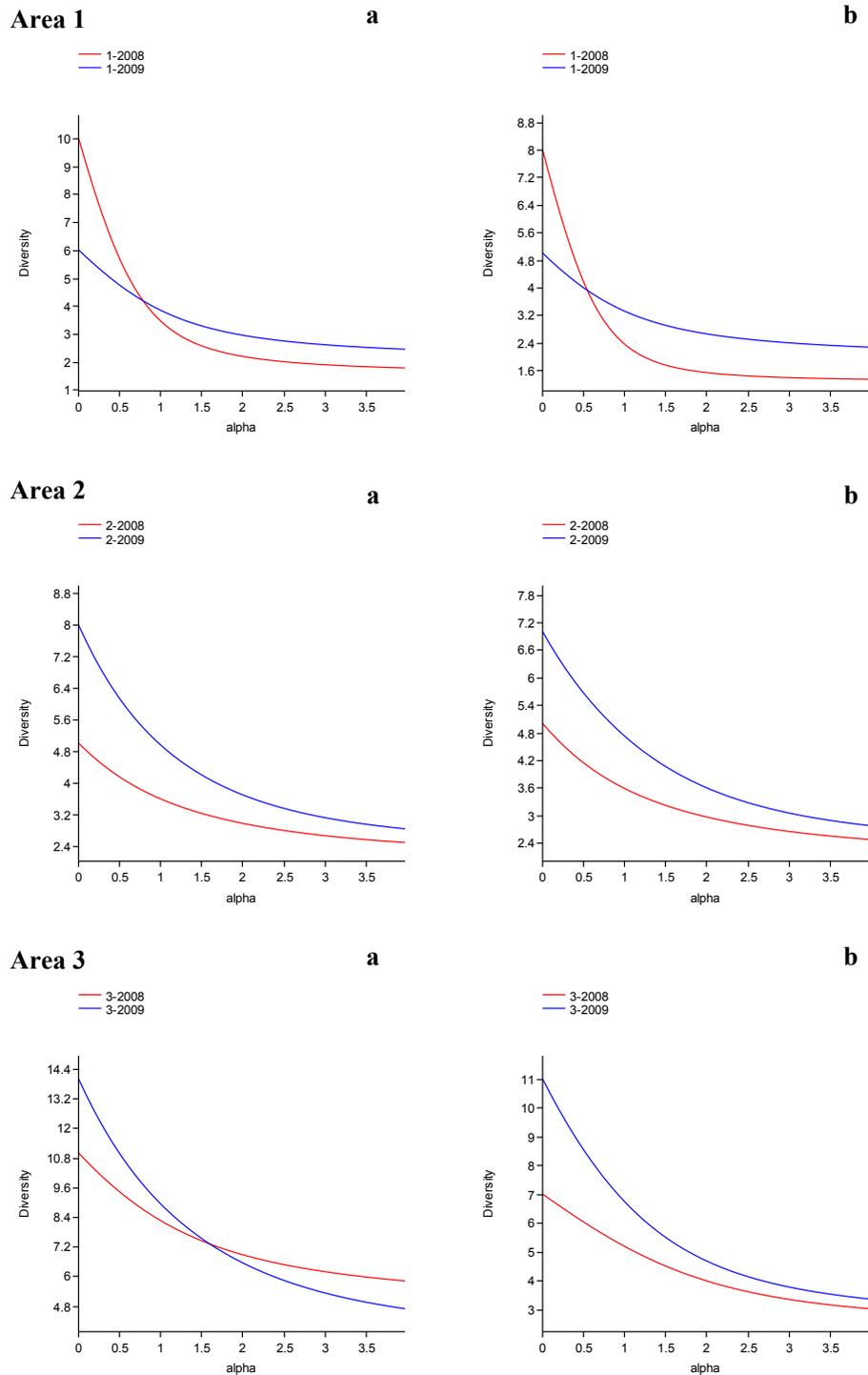


Figure 4. Diversity plots for the six Koanaka Hills study areas: a) plots with all data included; and b) plots with bats and small carnivores excluded. The left side of each plot provides comparative information on species richness and numbers of rare species and the right side provides information on species dominance and common species.

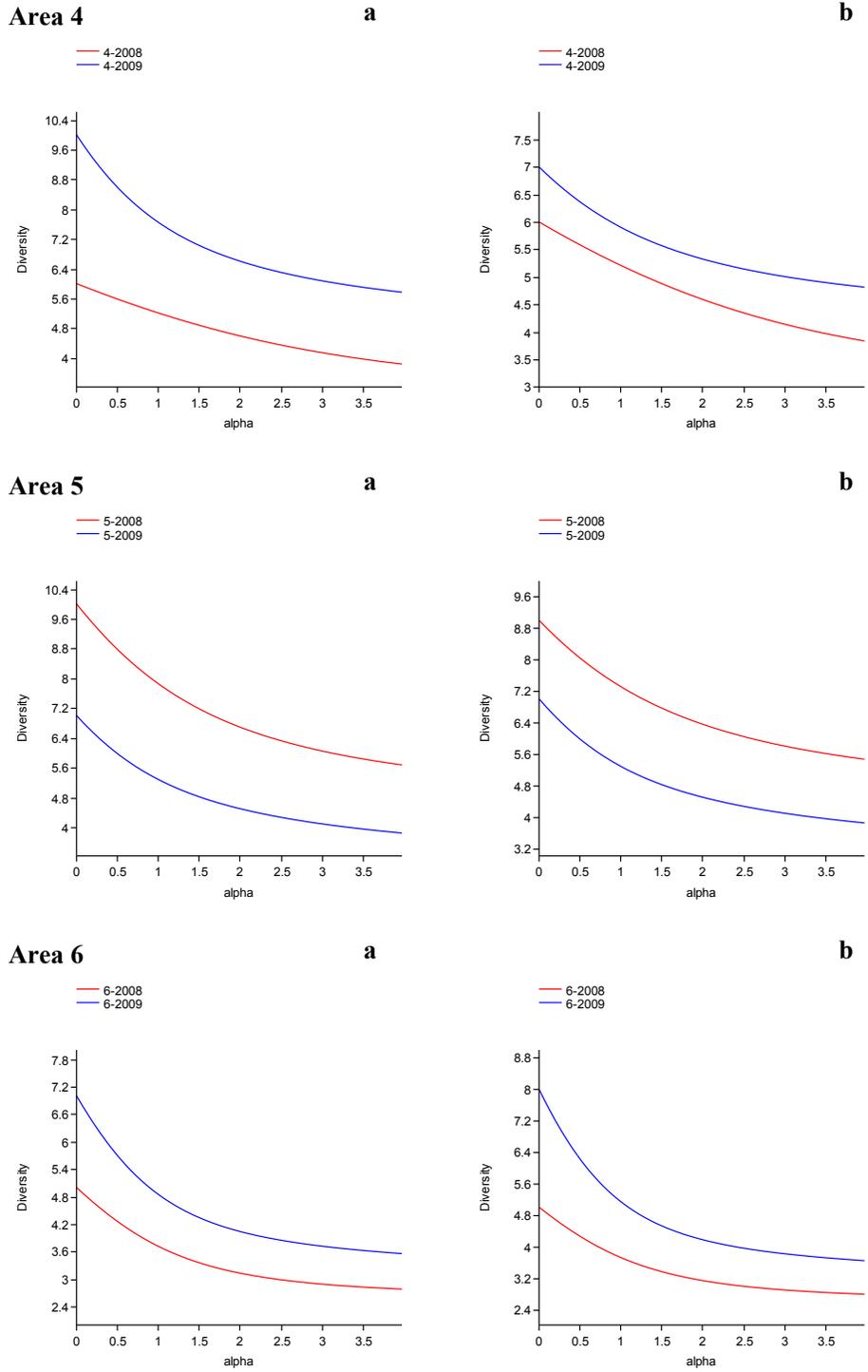


Figure 4. (cont.)

Table 1. Small mammal taxa and capture totals for the six Koanaka Hills localities in 2008 and 2009.

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Soricomorpha (shrews)												
<i>Crocidura hirta</i>	1				2	2	2	2	3			
Chiroptera (bats)												
<i>Chaerephon nigeriae</i>	1											
<i>Hipposideros commersoni</i>					8	1						
<i>Neoromicia capensis</i>	10											
<i>Nycteris thebaica</i>					12	19						
<i>Rhinolophus denti</i>					7	13						
Rodentia (rodents)												
<i>Aethomys chrysophilus</i>	1	1	9	37	3	45	3	9	3	4	3	16
<i>Cryptomys damarensis</i>					1				1			
<i>Dendromus melanotis</i>								2				
<i>Gerbilliscus brantsi</i>	1		2	13	3	13	6	5	8	7	3	3
<i>Gerbilliscus leucogaster</i>	3	5	6	12	10	6	11	11	2	6	2	3
<i>Gerbillurus paebe</i>	1			7		7	6	6	8	2		
<i>Lemniscomys rosalia</i>	1	1				3				1		
<i>Mastomys coucha</i>	37	9	1	5	1	14	3	12	4	11	11	21
<i>Micaelamys namaquensis</i>			19	5	3	13					2	
<i>Mus indutus</i>					4	4	2	2				
<i>Mus minutooides</i>		1			1	1	1	1				2
<i>Saccostomus campestris</i>	1								5			2
<i>Steatomys parvus</i>				1								
<i>Xerus inauris</i>											2	
<i>Zelotomys woosnami</i>									1	1		
Macroscelidea (elephant shrews)												
<i>Elephantulus intufi</i>					2	4					10	13

Table 1. (cont.)

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Camivora (carnivores)												
<i>Cynictis penicillata</i>			1									1
<i>Galerella sanguinea</i>				2				5		1		
<i>Genetta genetta</i>								1				
<i>Mellivora capensis</i>		1						1				

as voucher specimens for comparative purposes and have been deposited in the TTU Collections (Appendix). All individuals captured in 2009 were retained and processed as voucher specimens (Appendix).

Initial comparisons across areas (Table 2) incorporated all data for the specimens collected, and both abundance- and incidence-based diversity measures were determined. However, due to inconsistencies in data collection between years that resulted in unequal sampling of bats and small carnivores between years (e.g., the waterhole was dry and not attracting bats in 2009), those taxa were excluded and the analyses repeated. Three areas (2, 3, and 5) showed significant differences in species diversity between years based on comparisons utilizing abundance values with all data included (Table 2). When the carnivore and bat data were excluded, only area 2 showed a significant difference in species diversity between years using abundance data (Table 2).

A visual comparison of diversity plots (Fig. 4) showed that all of the areas sampled, with the exception of area 5, had a general increase in species diversity estimates using both the entire data set and the dataset with bats and small carnivores removed. Both diversity plots for area 5 indicate a decrease in comparable diversity values from 2008 to 2009. However, neither plot for area 1 nor the plot for area 2 with bats and small carnivores included should be considered as comparable because the two curves overlapped, indicating that there are at least two diversity indices that order the communities differently (Tóthmérész 1995).

An evaluation of the capture data using incidence-based analyses yielded increased ICE and Chao-2 richness estimator values from 2008 to 2009 that are reported in Table 2, which are visually but not statistically comparable. Both are based on presence/absence data and tend to be relatively insensitive to patchy distributions in spite of relatively small sample sizes (Chazdon et al. 1998).

## DISCUSSION

Species adapted for more open environments prefer burned areas whereas those species preferring overhead cover appeared to be no longer present in the area (Christian 1977). Data obtained during this study appear to support these conclusions, demonstrating both a change in species composition and number across our study areas. However, additional analyses are necessary to accurately identify all taxa sampled in this study, as the basic morphological characters described by Skinner and Chimimba (2005) and de Graaff (1981) proved grossly inadequate. Cytochrome b screening that was used to verify morphological species determination indicates potential cryptic species, especially within the genera *Aethomys*, *Mastomys*, and *Mus* (McDonough et al. 2013 and unpublished data).

Superficially, our data measuring changes in diversity and abundance in small mammals of the Koanaka Hills following fire appear inconclusive. Comparisons of species composition and diversity between years suggest that the faunas were similar and that fire in the Koanaka Hills had only minimal impact, particularly on the herpetofauna (Kennedy et al. 2012): differences in species richness for amphibians and reptiles were attributed in part to the increased trapping effort in 2009 that included seven additional trapping days (Kennedy et al. 2012). Weather in 2009 also was slightly warmer, supporting higher activity levels than during the 2008 sampling period.

Although the frequency and intensity of fire in the Koanaka Hills currently is unknown, given the prevailing weather conditions in the region it would be expected that such events are common and the flora and fauna are well adapted to a fire-managed ecosystem. Differences among areas appeared to be driven largely by an increased number of grassland adapted foragers (*A. chrysophilus*, *M. natalensis*, *M. namaquensis*, *G. brantsii*, and *G. leucogaster*) and the addition of small carnivores (*C. penicillata*) that were not effectively sampled in 2008. Two additional rodent species were captured in 2009 (*S. parvus* and *G. paeba*) that were not captured in 2008 although they were expected to occur in the general area and their addition may be an artifact of the increased sampling effort in the second year.

Fires in ungrazed grassland have negative impacts on small mammal species that are folivorous, frequently or usually use surface nests of plant debris, and forage in the litter layer for invertebrates; however, such fires have positive impacts on small species that forage for seeds and/or insects in habitats with little litter cover (Blaum et al 2007). These responses to fire are apparently related to changes in the litter and standing dead vegetation layers that occur with fire. Fire could potentially cause the death of small mammals, especially species that nest aboveground; however, most of the decreases in numbers of individuals of fire-negative species after a fire are undoubtedly due to the emigration of individuals shortly after fire as a result of the loss of litter and live and dead vegetation. The initial increase in numbers of individuals of fire-positive species is also due to movements of individuals, but in this case the burned area offers more suitable habitat conditions than nearby unburned sites. Clark and Kaufmann (1990) documented immediate changes following a fire and the subsequent recovery by deer mice (*Peromyscus maniculatus*), western harvest mice (*Reithrodontomys megalotis*), and Elliot's short-tailed shrews (*Blarina hylophaga*), with differing habitat requirements, suggesting that recovery or return to "unburned" densities would occur by the end of the second or third year after fire for most, if not all, species in burned, ungrazed grassland. As a result, recurring fires with frequencies of two or more years should create cycles in population density of both fire-negative and fire-positive species; however, it is uncertain how much average density for different species will vary through time due to the frequency of recurring fire.

Other factors, such as intensity of fire, seasonality of fire, general climate, weather conditions, and topographic conditions, undoubtedly affect the impact of fire. However, so little work has been done on these issues that the general and specific effects are unknown or unconfirmed. There was clear evidence through burrow and track identification that *Pedetes capensis* was active in area 4 in 2008 (although no individuals were captured) but no evidence was found that the species was present in 2009. Given our limited data we are uncertain whether the species was extirpated as a direct result of the fire or whether the species driven from the

area due to a lack of available food resources following the fire. Blaum et al. (2007) clearly demonstrated that an increase of shrub cover, although as a result of reduced grazing rather than fire, affected *Gerbillurus paeba* and *Gerbilliscus leucogaster* negatively. They attributed the negative response to an encroachment of shrubs reducing grass and herbaceous vegetation cover and arthropod abundance, which is the preferred diet (Skinner and Chimimba 2005). Other species such as *Gerbilliscus brantsii* might, however, benefit from the increased shrub cover for protection from predation during foraging bouts (Skinner and Chimimba 2005). Our data were far less conclusive, but we speculate that the Koanaka Hills does provide something of a refuge from fire events, and that species recolonize burned areas surrounding these refuges as the habitat recovers.

Small mammals commonly survive the initial passage of fire by sheltering in refugia (Cheeseman and Delany 1979; Yarnell et al. 2008), but populations of small mammals often have been observed to decline in numbers following a fire (Kern 1981; Fuller and Perrin

2001). This is thought to be a result of fire-induced changes in vegetation structure (Kern 1981; Monadjem and Perrin 2003), either causing the animals to migrate from the area (Clark and Kaufman 1990) or facilitating increased predation due to reduced protective cover. The duration of the post-fire population trough depends on the vegetation recovery period, often determined by the interval between fire occurrence and the following wet season's re-growth (Cheeseman and Delany 1979). They further suggest that grassland communities adapted to fire contain a large number of specialists, some of which are better adapted for pre-burn and others for post-burn conditions. An increase in the number of *A. chrysophilus* captured in five of the six areas from 2008 to 2009 was observed; however, our data neither supports nor refutes their suggestion. It is unfortunate that even basic species diversity and population data are unavailable for large geographic expanses such as the Koanaka Hills of northern Botswana, and far more study is necessary to both document the area's biodiversity and to evaluate effects of periodic fire on the ecosystem and its inhabitants.

#### ACKNOWLEDGMENTS

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under permits CHA 1/17/2 IX (64) and CYSC 1/17/21 (81) issued by the Botswana Ministry of Youth, Sport and Culture to Patrick J. Lewis and SHSU IACUC Permit #08-04-03-1005-3-01 issued to Monte L. Thies. All material was imported into the United States under permits from the U.S. Centers for Disease Control and Prevention, U.S. Fish and Wildlife Service, and U.S. Department of Agriculture APHIS Permit 105705 issued to Monte L. Thies.

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## APPENDIX

Specimens collected and deposited in the Museum of Texas Tech University (TTU) from the six trapping localities of the Koanaka Hills, Ngamiland Province, Botswana.

Area 1: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): waterhole on road to Namibian border (UTM 34K 51139.96 m E, 7767049.18 m S).

Area 2: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): grassland W of Koanaka South (UTM 34K 520032.48 m E, 7771048.51 m S).

Area 3: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): W slopes of Koanaka South (UTM 34K 520300.44 m E, 7770990.57 m S).

Area 4: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): grassy woodlands S of Koanaka South (UTM 34K 520246.37 m E, 7770802.44 m S).

Area 5: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): grassland N of Koanaka South (UTM 34K 520704.38 m E, 7772061.33 m S).

Area 6: BOTSWANA: Ngamiland Province: Koanaka Hills (Ncqumtsa Hills): 150 km W Tsao (Tsau): dry pan N of Koanaka South (UTM 34K 520421.30 m E, 7772677.52 m S).

## SORICOMORPHA

*C. hirta* (N = 10).—Area 1 (TTU 114166); Area 3 (TTU 114787-8); Area 4 (TTU 114161, 114165, 114785-6); Area 5 (TTU 114162-4).

## CHIROPTERA

*C. nigeriae* (N = 1).—Area 1 (TTU 114160). *H. commersoni* (N = 9).—Area 3 (TTU 114239-46, 114934). *N. capensis* (N = 10).—Area 1 (TTU 114334-43). *N. thebaica* (N = 31).—Area 3 (TTU 114344-55, 115179-97). *R. denti* (N = 20).—Area 3 (TTU 114356-62, 115224-36).

## RODENTIA

*A. chrysophilus* (N = 131).—Area 1 (TTU 114784, 114159); Area 2 (TTU 114142-50, 114152, 114770-2, 115064-7, 115069, 115071-78, 115092-7, 115099-111, 115221-2); Area 3 (TTU 114141, 114145, 114151, 114751, 114753-68, 115027-8, 115031, 115033-5, 115038-41, 115045-50, 115052-63); Area 4 (TTU 114156-8, 114776-81, 115089-90, 115219); Area 5 (TTU 114153-5, 114782-3, 115009, 115220); Area 6 (TTU 114773-5, 114986-7, 115079-88, 115217). *C. damarensis* (N = 2).—Area 3 (TTU 114167); Area 5 (TTU 114168). *D. melanotis* (N = 2).—Area 4 (TTU 114169-70). *G. brantsii* (N = 62).—Area 1 (TTU 114206); Area 2 (TTU 114190-1, 114836-43, 114845-6, 114848-40); Area 3 (TTU 114186-8, 114826-31, 114873, 114875-9, 114900); Area 4 (TTU 114200-5, 114858, 114861-2, 114865, 114872); Area 5 (TTU 114192-9, 114852-6, 114868, 115215); Area 6 (TTU 114890, 114894-5). *G. leucogaster* (N = 66).—Area 1 (TTU 114227-9, 114870, 114904-7); Area 2 (TTU 114208-9, 114220-3, 114834-5, 114844, 114847, 114882-8, 115214); Area 3 (TTU 114207, 114210-8, 114752, 114832-3, 114880-1, 114899); Area 4 (TTU 114857, 114859-60, 114863-4, 114866-7, 114896-8, 115218); Area 5 (TTU 114225-6, 114851, 114869, 114889, 114891-3); Area 6 (TTU 114219, 114224, 114891-3). *G. paeba* (N = 31).—Area 1 (TTU 114238); Area 2 (TTU 114918-24); Area 3 (TTU 114912-7, 114930); Area 4 (TTU 114926-114929,

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114931-2); Area 5 (TTU 114230-7, 114925, 114933). *L. rosalia* (N = 6).—Area 1 (TTU 114249, 114946); Area 3 (TTU 114942-4); Area 5 (TTU 114945). *M. natalensis* (N = 129).—Area 1 (TTU 114271-307, 115010-8); Area 2 (TTU 114251, 114958-62); Area 3 (TTU 114250, 114874, 114948-57, 114998, 115006, 115213); Area 4 (TTU 114268-70, 114947, 114994-4, 114999-5005); Area 5 (TTU 114262, 114265-7, 114963-70, 115007-8, 115216); Area 6 (TTU 114252-61, 114263, 114971-85, 114988-93). *M. namaquensis* (N = 42).—Area 2 (TTU 114308-21, 114325-6, 114328-30, 114769, 115068, 115070, 115091, 115098); Area 3 (TTU 114322-3, 114327, 114824, 114871, 115029-30, 115032, 115036-7, 115042-4, 115051, 115153-4); Area 6 (TTU 114324, 114331). *M. indutus* (N = 6).—Area 3 (TTU 115112, 115155, 115159, 115161); Area 4 (TTU 115156-7). *M. minutoides* (N = 5).—Area 1 (TTU 115158); Area 3 (TTU 115160); Area 4 (TTU 114333); Area 6 (TTU 115162-3). *S. campestris* (N = 8).—Area 1 (TTU 114367); Area 5 (114264, 114363-6); Area 6 (TTU 115257-8). *S. parvus* (N = 1).—Area 2 (TTU 114796). *X. inauris* (N = 2).—Area 6 (TTU 114368-9). *Z. woosnami* (N = 2).—Area 5 (TTU 114370, 115260).

## CARNIVORA

*C. penicillata* (N = 1).—Area 2 (TTU 114797). *G. sanguinea* (N = 9).—Area 3 (TTU 114183, 114185); Area 4 (TTU 114816-7, 114819-21); Area 5 (TTU 114184); Area 6 (TTU 114818). *G. genetta* (N = 1).—Area 4 (TTU 114823). *M. capensis* (N = 2).—Area 1 (TTU 115026); Area 4 (TTU 115025).

## MACROSCELIDEA

*E. intufi* (N = 29).—Site 3 (TTU 114171-2, 114798-801); Area 6 (TTU 114173-82, 114802-14).



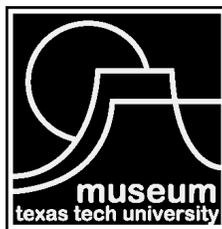


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