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Unravelling the vertebrate scavenger assemblage in the Gobi Desert, Mongolia

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Abstract

Despite the essential role that vertebrate scavengers play in the ecosystem, most studies have been conducted in Europe and North America, exacerbating the lack of information on vertebrate scavengers in vast regions of the world. Our aim was to describe the functioning and composition of the unknown vertebrate scavenger assemblage in the Gobi Desert, Mongolia, and determine how carcass size and habitat type affect species composition and carrion use. We monitored carcasses with automatic cameras and we also conducted observation points to survey the raptor community and identify the proportion of raptor species making use of the carcasses. We recorded eight vertebrate scavenger species (five birds and three mammals) by camera trapping and seven raptors at observation points. Over half of the raptor species recorded at the observation points were also found feeding on carrion. We found differences in the composition of the avian assemblages between habitat types, where the two most threatened species were only recorded in the mountain habitat. Furthermore, scavenger abundance and consumption rates were higher in large carcasses. This study highlights the importance of scavenging for raptors, of mountains as wildlife refuges, and of vertebrate scavengers for carrion elimination in ecosystems with extreme climatic conditions.

Keywords: Arid ecosystem; Carrion; Consumption rate; Seminomadic herder; Species richness; Vulture

1. Introduction

Vertebrate scavengers play a key role in nutrient cycling, biodiversity maintenance, and disease control (Barton et al., 2013; Beasley et al., 2019), affecting 45% of trophic links worldwide (Wilson and Wolkovich, 2011). Thus, the disruption of scavenger assemblages may trigger major mismatches in ecosystems, which can severely affect humans (Markandya et al., 2008). For example, a decrease in the Indian vulture population by 97-99% in less than two decades, resulted in an increase in free-ranging dogs (*Canis lupus familiaris*) and rats (*Rattus sp.*), and consequently in human rabies infections, which costed the Indian government $34 billion (Markandya et al., 2008; Prakash et al., 2007). However, humans continue to undermine biodiversity. For example, Sebastián-González et al. (2019, 2020) showed that human activity is the main process reducing species richness and network structure of terrestrial vertebrate scavenger communities in a global scale, which may involve an invaluable social, economic and ecological cost.

Scavenging dynamics are affected by both biotic and abiotic factors (Barton et al., 2013; DeVault et al., 2004; Wilson and Wolkovich, 2011), being carrion features among the most important ones. Olson et al. (2016) showed that carcass type (i.e., the carrion species) affected the vertebrate scavenger assemblage more than habitat connectivity. Some vertebrate scavenger species (particularly mammalian carnivores) were also found to avoid feeding on conspecific carcasses, leading to carrion partitioning amongst vertebrate and invertebrate scavengers (Moleón et al., 2017). Besides, Moleón et al. (2015) concluded that larger carcasses had higher vertebrate scavenger species richness and consumption rates than the smaller ones. Habitat features can also influence detection times and the composition of the scavenger assemblage feeding on carrion (Pardo-Barquín et al., 2019; Selva et al., 2005). For example, Turner et al. (2017) found that carrion detection times were 50% larger in habitats with more vegetation cover, especially during the warm season. In addition, vegetation cover can influence species composition, with species with developed sense of smell appearing in areas with more cover rather than species more dependent on visual cues (Byrne et al., 2019). Also, birds are expected to occur more often in open than in dense forest areas, where mammals tend to be more abundant (Pardo-Barquín et al., 2019).

As happens with other vertebrate groups (Amano et al., 2016; Orihuela-Torres et al., 2020), there are spatial gaps in the knowledge about vertebrate scavenger assemblages worldwide. The vast majority of studies focused on North America and Europe, and to a lesser extent, on Australia and Southern Africa (Sebastián-González et al., 2019, 2020). However, there is a lack of surveys in South America and Asia, which are priority areas both for vultures (obligate scavengers) and raptors (facultative scavengers) due to the high number of species and their threat degree (Buechley et al., 2019). Asia, despite being the largest continent, is probably the least studied in terms of scavenger assemblages. There are only such studies in temperate forests in Japan (Inagaki et al., 2020; Sugiura et al., 2013; Sugiura and Hayashi, 2018) and China (Huang et al., 2014), tropical dry deciduous forests in India (Samson and Ramakrishnan, 2017), and tropical rainforests in Borneo (Lim, 2015). Furthermore, there is a noticeable gap in the study of biomes with extreme climatic conditions, such as deserts (Sebastián-González et al., 2019). Our study is located in the pristine great steppe of Mongolia, in the Gobi Desert, an understudied ecosystem which holds high biodiversity values. For instance, this is the one of the most important breeding and migratory area for some endangered raptors (Dixon et al., 2015; Gombobaatar et al., 2012). The great steppe of the Gobi Desert is not homogeneous, combining wide plain steppes scattered with mountains. These mountains act as "vertical islands" in the landscape, increasing microhabitat heterogeneity and providing refuge for wildlife as nesting places, areas to hide from predators or to shelter from the weather (Rixen and Rolando, 2013). Extensively managed livestock production by seminomadic herders is the major socioeconomic activity in Mongolia (Angerer et al., 2008) and these socio-ecological systems are highly relevant for the conservation of scavengers elsewhere (Morales-Reyes et al., 2018).

The main objective of our study was to identify the functioning and composition of the vertebrate scavenger assemblage in the Gobi Desert in Mongolia. We also studied whether this assemblage is affected by carcass features or habitat type. To do so, we compared the scavenger species composition and the scavenging efficiency of the vertebrate scavenger assemblage in the Gobi Desert between I) habitat types (steppe vs mountain) and II) carcass sizes (large vs small carcasses). We hypothesized that both habitat type and carcass size would affect the composition of the vertebrate scavenger assemblage and, therefore, its scavenging efficiency. Due to the greater heterogeneity of microhabitats in the mountains and the higher amount of carrion in larger carcasses, we predict that both mountain habitat type and large carcasses will have a higher richness and abundance of scavengers and higher carrion consumption rates. III) We also wanted to evaluate the relative use of carrion for the important Mongolian raptor guild. To do so, we compared the avian community (raptors and corvids) observed at fixed observation points with the avian scavenger community detected at carcasses using camera traps. IV) Finally, we compared the species richness and carrion use with that of other vertebrate scavenger assemblages worldwide. We expect low species richness and carrion use in our study area due to the extreme climatic conditions.

2. Material and methods

2.1 Study area

Our study area was located in the central Gobi Desert (southern Mongolia; 43° 56' N, 103° 44' E; Fig. 1), in the Ömnögovi aimag (province), close to the cities of Dalanzadgad and Bulgan.

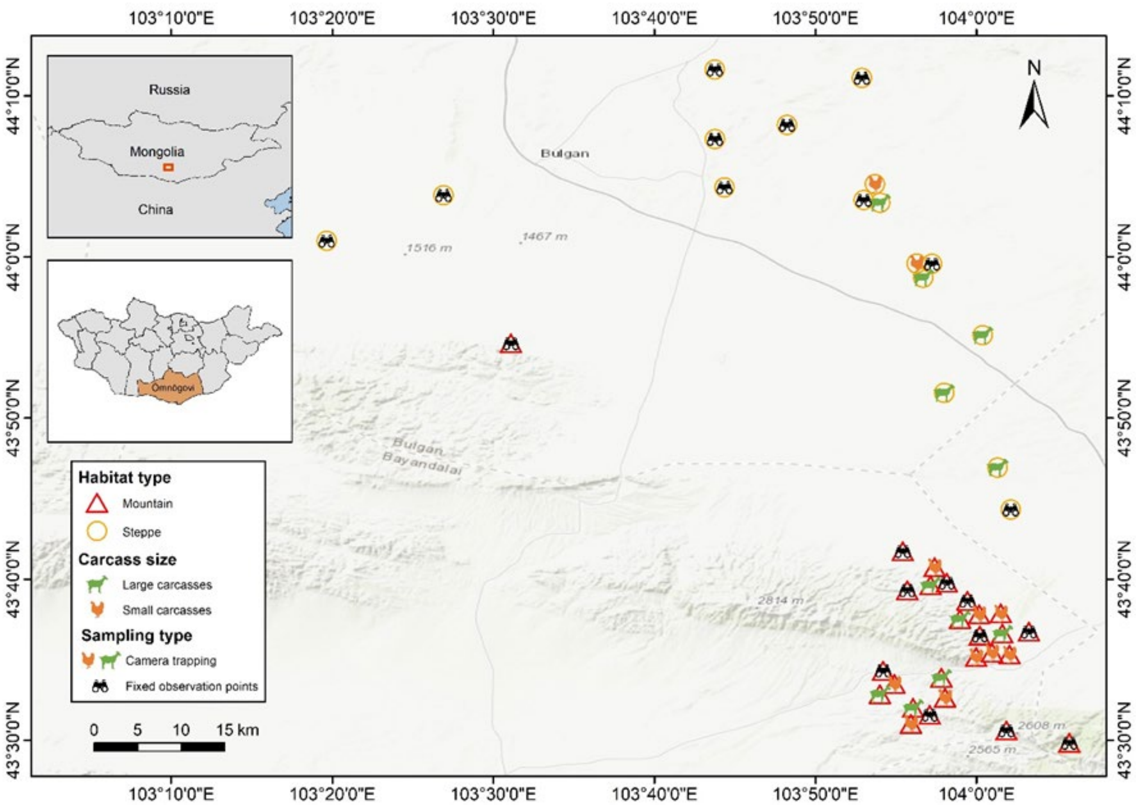

Fig. 1. (1.5 column fitting image). Map of the study area in the Ömnögovi aimag (province) in the Gobi Desert, Mongolia. We show the locations of 22 carcasses with different sizes (large vs small) to detect the vertebrate scavenger assemblage and 21 fixed observation points in two habitat types (mountain vs steppe).

The area has huge temperature contrasts reaching 40°C in summer and -49°C in winter. The mean annual temperature is 4.3°C and the mean annual rainfall is 125 mm (Pfeiffer et al., 2003) with 85–90% of the total annual precipitation falling from April through September. The Gobi Desert is not constant in terms of climate and vegetation, as it is more arid and dry in the center and increases in rainfall and vegetation towards its boundaries (Yu et al., 2004). Our study area was dominated by steppes with rolling topography and scattered mountain ranges with elevations ranging from 706 to 2,825 m a.s.l. (Begzsuren et al., 2004). The Gobi steppe is one of the largest steppes in the world, which has been exploited by nomadic shepherds for millennia, being one of the least populated and well preserved regions in the world.

2.2 Data sampling

In July 2019, we monitored 22 carcasses with automatic cameras activated by movement (model: Browning Strike Force pro HD) to study the vertebrate scavenger assemblage in the Gobi Desert. We used two sizes of fresh carcasses: 1) large, i.e., domestic goats (*Capra hircus*) weighing between 8.5 - 55 kg (n = 11), and 2) small, i.e., chickens (*Gallus gallus*) weighing between 0.1 - 0.4 kg (n = 11). Carcasses were placed in two types of habitat: 1) mountain (n = 15) and 2) steppe (n = 7). They were randomly placed at least 500 m apart (small carcasses minimum distance = 600 m; large carcasses minimum distance = 3,150 m) to consider each sample as independent. Carcasses came from local shepherds and were fixed to the ground by stakes to prevent them from being taken out of camera range by scavengers. They were placed equally in the morning and evening. We installed two automatic cameras per carcass. One camera was programmed to take two pictures every 30 seconds with a 30-second delay, while the other took one-minute long videos with a two-minute delay, when motion was detected. First, we checked the photos to identify all vertebrate scavengers (i.e., carrion-consuming) at each monitored carcass. Then, we visualized the videos to avoid possible failures in species detection or identification (see Appendix 1 for detailed information).

Moreover, we conducted 21 fixed observation points to determine the avian community (raptors and corvids) at the same time than the carcass monitoring. They were carried out by experienced observers using binoculars and a scope, following methods employed in similar surveys (Sánchez-Zapata et al., 2007). All raptor and corvid species were identified and counted. Fixed observation points were divided into: 1) mountain (n = 11) and 2) steppe (n = 10). They lasted 30 min each, and were carried out between 8:30h and 12:30h local time with a minimum distance of 1,500 m (minimum mean distance = 6,500 m) between them (Appendix 1).

2.3. Scavenging measures

We used four variables to characterize the scavenger assemblage and scavenging efficiency: 1- 'Richness' (i.e., total number of vertebrate scavenger species recorded consuming carrion in each carcass or observed in each fixed observation point). Richness was calculated for all vertebrates, and for birds and mammals separately; 2- 'abundance' (i.e., maximum number of unequivocally different individuals recorded in a sampling point, i.e., each carcass or fixed observation point). In the case of the carcasses, it was calculated by counting the highest number of individuals appearing simultaneously on a picture (Sebastián-González et al., 2019), as well as individuals who can be differentiated due to age, sex or body features; 3- 'detection time' (i.e., time elapsed since the carcass was placed until it is detected by a vertebrate scavenger); 4- 'consumption rate' (i.e., amount of carrion consumed at the end of the experiment (kg) divided by consumption time (h)). We also identified the conservation status of each recorded species according to the International Union for Conservation of Nature's red list of Threatened Species (IUCN, 2020).

Finally, we compiled the vertebrate scavenger species richness and carcass consumption rates from scavenger assemblages in the literature with small (ranging 0.2-2 kg) and large carcasses (10-55 kg) worldwide (Sebastián-González et al., 2020) to compare those values with those obtained in our study area (see Appendix 2 for information on these surveys).

2.4. Statistical analyses

To evaluate the differences in vertebrate scavenger assemblages, we used generalized linear models (GLMs) in R 3.6.0 (R Core Team, 2019). In GLMs, 'richness', 'abundance', 'detection time' and 'consumption rate' were the response variables, whereas 'habitat type' (steppe or mountain), 'carcass size' (large or small) and 'sampling type' (camera trapping or fixed observation point) were categorical predictors. We used one-predictor GLMs to compare the differences between categorical predictors. In 'habitat type' and 'sampling type', we only used the avian assemblage for 'richness' and 'abundance' since in fixed observation point only the avian community (raptors and corvids) was noted, whilst for 'carcass size' we compare the total scavenger assemblage (avian and mammals). We used Poisson error distribution for 'richness', negative binomial error distribution for 'abundance', and Gaussian error distribution for 'detection time' and 'consumption rate'. 'Detection time' and 'consumption rate' were log-transformed to meet normality. Moreover, we compared the vertebrate scavenger assemblages between 'habitat type', 'sampling type' and 'carcass size', separately, using the permutational multivariate analysis of variance (PERMANOVA). PERMANOVA is a non-parametric test to analyze differences in the composition and/or relative abundances of organisms of different species in samples from different groups (Anderson, 2001). We also evaluated the dispersion of the communities by means of a PERMADISP analysis. For both PERMANOVA and PERMADISP analyses we used the *vegan* (Oksanen et al., 2019) package in R. We compared avian assemblages between 'habitat type' and 'sampling type', and the vertebrate scavenger assemblage (birds and mammals) between 'carcass size'. In addition, we calculated the species accumulation curves to test whether the sampling effort has been sufficient to identify all vertebrate scavenger and raptor species.

3. Results

We recorded eight vertebrate scavenger species (Table 1; Fig. 2) at carcasses, including three obligate scavengers (i.e., vultures): Himalayan griffons (*Gyps himalayensis*), cinereous vultures (*Aegypius monachus*) and bearded vultures (*Gypaetus barbatus*), and five facultative scavengers (one raptor, one corvid and three mammalian carnivores; Fig. 3).

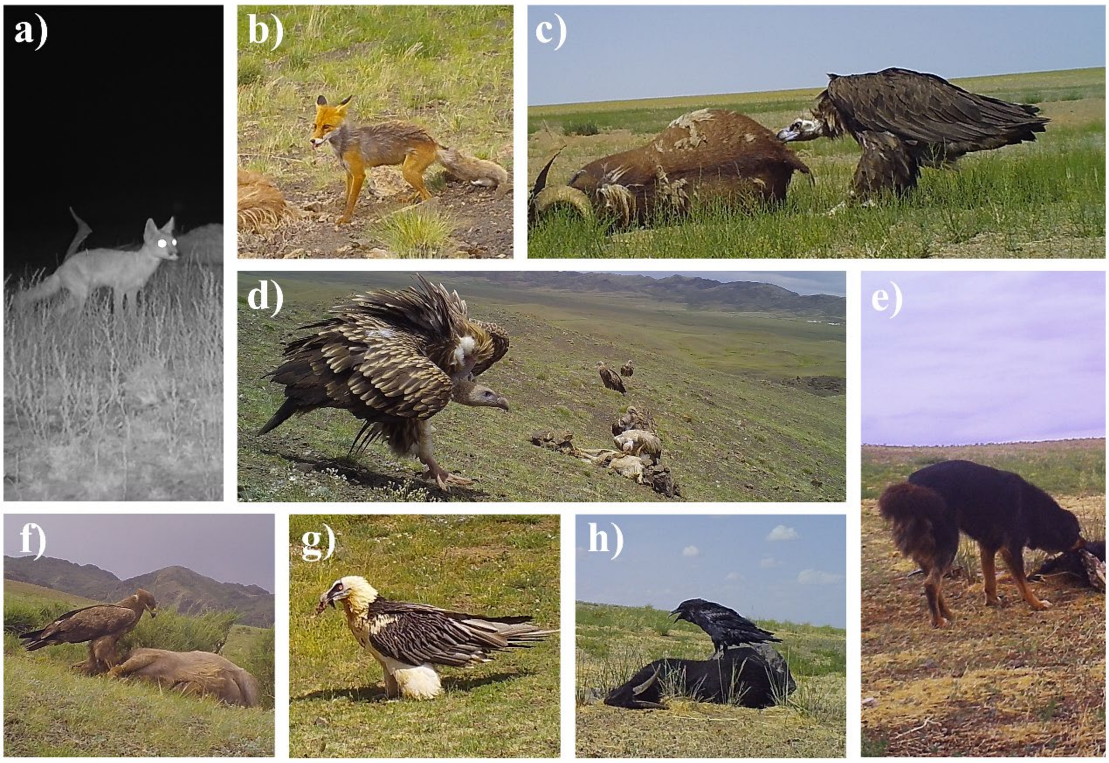

Fig. 2. (2 column fitting image). All recorded vertebrate scavenger species in our survey in the Gobi Desert, Mongolia. The pictures are organized from the species that appeared in more carcasses (a) to the one that appeared in less carcasses (h). a) corsac fox, b) red fox, c) cinereous vulture, d) Himalayan griffons, e) free-ranging dog, f) steppe eagle, g) bearded vulture and h) common raven.

In addition, we detected some additional mammalian carnivores with camera traps, but they did not consumed any carcass, such as the grey wolf (*Canis lupus*) or the marbled polecat (*Vormela peregusna*). Of the five avian scavenger species, 20% were classified as Endangered and 60% as Near Threatened, whereas the three mammalian species were classified as Least Concern (Table 1). The species accumulation curves showed that sampling effort was satisfactory to identify the vertebrate scavenger species of the study area (Appendix 3: Figure 1). Vertebrate scavenging activity was detected at 68% (n = 15) of the carcasses, 18% (n = 4) of the carcasses were only consumed by invertebrates and 14% (n = 3) remained unconsumed at the end of the experiment. Mammals scavenged on 55% (n = 12) of the carcasses, and birds on 41% (n = 9) of them. The species that appeared on more carcasses were the corsac fox (*Vulpes corsac*) and the red fox (*Vulpes vulpes*) (Fig. 3; Appendix 3: Table 1 for detailed values).

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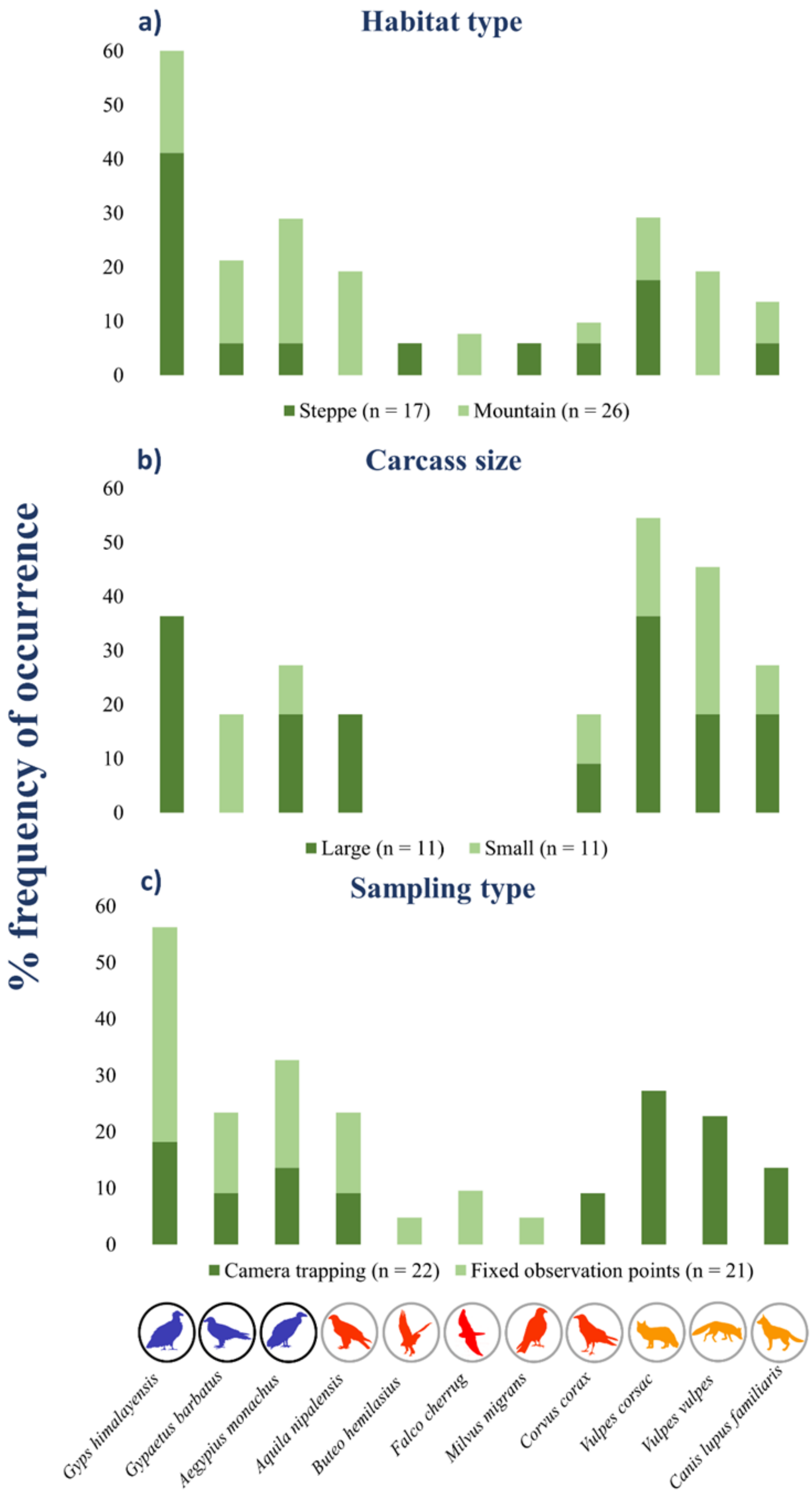

a)
Habitat type
Steppe (n = 17)
Mountain (n = 26)
b)
Carcass size
Large (n = 11)
Small (n = 11)
c)
Sampling type
Camera trapping (n = 22)
Fixed observation points (n = 21)
% frequency of occurrence
Gyps himalayensis
Gypaetus barbatus
Aegypius monachus
Aquila nipalensis
Buteo hemilasius
Falco cherrug
Milvus migrans
Corvus corax
Vulpes corsac
Vulpes vulpes
Canis lupus familiaris

Fig. 3. (1 column fitting image). Frequency of occurrence of the vertebrate scavenger assemblage in the Gobi Desert, Mongolia. We compared the frequency of occurrence of each recorded species between: a) habitat type (method: camera trapping and fixed observation point), b) carcass size (method: camera trapping) and c) sampling type (method: camera trapping and fixed observation point). At fixed observation points we only recorded the raptor community, not mammals. Obligate scavengers (black circle) are in blue, facultative scavengers (grey circle) including avian (in red) and mammal scavengers (in orange). See Appendix 3: Table 1 for detailed values.

However, the most abundant species was the Himalayan griffon followed by the cinereous vulture (Table 1). Mammals were the first to detect the carrion in most cases (73.3%). Species richness and consumption rate in the Gobi Desert were lower than those in most vertebrate scavenger studies from other regions (Fig. 4).

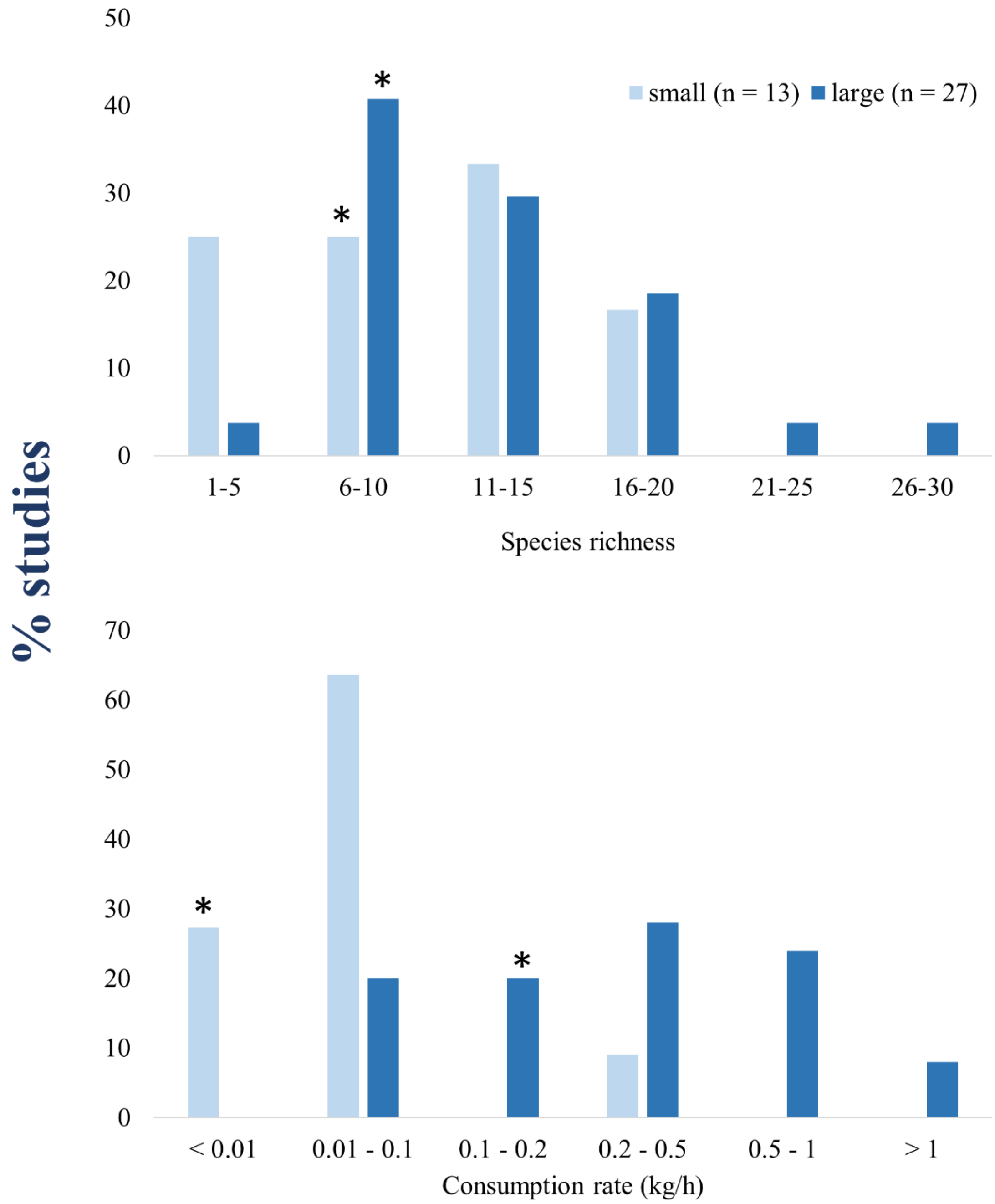

Fig. 4. (1 column fitting image). Species richness and consumption rate from vertebrate scavenger surveys worldwide. Bars show the percentage of studies belonging to the value where they are located. Asterisk represent observed values for small and large carcasses in our study area.

We recorded seven raptor species at fixed observation points, including three obligate scavengers (vultures) and four facultative scavengers (other raptors), but we did not record corvids (Table 1). The species accumulation curves showed that most raptor species had been recorded, although it did not reach the asymptote (Appendix 3: Figure 1).

3.1 Habitat type

The composition of the avian assemblages was different between steppe and mountain habitats (Appendix 3: Table 2). Total species number (at carcasses and fixed observation points) was slightly higher in the mountain habitat (n = 9) than in the steppe (n = 8), whereas the difference was greater when we compared only the species at the carcasses (n = 8 mountain, n = 4 steppe). In addition, the number of mammal species was higher in the mountain (Table 1). Although all obligate scavengers were recorded in the two habitats, several facultative scavengers only appeared in one (Table 1). We found no significant differences in richness or abundance per sampling point (carcasses and fixed observation points) between the two habitat types (Table 2). In the mountain, the species that appeared in more carcasses was the red fox (33.3%). At the steppe, the corsac fox was present in almost half of the carcasses (42.9%; Fig. 3). We also found no significant difference between detection time and consumption rate between habitat types (Table 2).

3.2 Carcass size

We found no differences in species composition of vertebrate scavenger assemblages between carcass sizes (Appendix 3: Table 2). Vertebrate scavenger species richness was similar in large (n = 7 species) and small carcasses (n = 6). All recorded mammals appeared in both carcass sizes. Cinereous vultures and steppe eagles (*Aquila nipalensis*) were only recorded in large carcasses, while bearded vultures only appeared in small carcasses (Table 1). There were no significant differences in species richness per carcass between carcass sizes. However, there were significant differences in abundance per carcass, being four times higher in large than in small carcasses (Table 2). Although we found no significant differences in detection time, the consumption rate was much higher in large than in small carcasses (Table 2). The species that were recorded in most of the large carcasses were corsac foxes (36.4%) and cinereous vultures (36.4%), whilst at small carcasses were red foxes (27.3%; Fig. 3). Nonetheless, the most abundant species at large carcasses was the Himalayan griffon whereas it was the red fox at small carcasses (Table 1).

3.3 Sampling type

We found no differences in composition of avian assemblages recorded at monitored carcasses by camera trapping and fixed observation points (Appendix 3: Table 2). The number of avian species recorded by fixed observation points was higher than at automatic cameras (Table 1). We identified 57% of the species recorded at fixed observation points, feeding on carcasses. Furthermore, we found no significant differences in avian species richness or abundance per sampling point (carcass or fixed observation point) between sampling types. All obligate scavengers (i.e., vultures) were recorded by both sampling methods, but we found different species of facultative avian scavengers (Table 1). The most abundant avian species were Himalayan griffons followed by cinereous vultures both at monitored carcasses and fixed observation points (Table 1).

4. Discussion

Some regions of the planet are much less studied than others from a community approach, biasing our understanding about how they affect large-scale processes involving the ecosystems and species that inhabit them (Sebastián-González et al., 2019). Our study presents the first description of the vertebrate scavenger assemblage in the Gobi Desert, Mongolia. This assemblage is mainly composed by avian species (62.5%), which were pervasive and also more abundant at the carcasses than mammals, unlike other arid ecosystems in Africa and Australia, where top carnivores were the main scavengers (Cunningham et al., 2018; Moleón et al., 2015). However, mammals discovered most carcasses and scavenged in a high number of them, revealing the key role they play in carrion removal. Top carnivores like grey wolves were detected in the study area, but were not found feeding on the carcasses, maybe because Eurasian top predators have a long history of persecution (Ordiz et al., 2013). Furthermore, we found differences in avian species composition (raptors and corvids) between mountain and steppe, but not between carcass size or habitat type. The two most threatened species, the steppe eagle and the saker falcon (*Falco cherrug*), were only recorded in the mountains, highlighting the importance of these "vertical islands" in landscapes such as steppes where there is a lack of wildlife refuge and nesting places.

Steppes are ecosystems with very extreme conditions that constrain the presence of many species (Currie et al., 2004), including scavengers. Consequently, we recorded a lower number of vertebrate scavenger species than in most study areas worldwide, further considering that our study area was located in a well-preserved ecosystem. However, other studies conducted in steppes of Argentina (Sebastián-González et al., 2013; Travaini et al., 1998) and Australia (Read and Wilson, 2004) showed between 5-9 vertebrate scavenger species, similar to our study. These results support the hypothesis that vertebrate scavenger diversity is lower in ecosystems with more extreme climatic conditions (Mateo-Tomás et al., 2015). Furthermore, the mean carcass consumption rate (0.0024 kg/h at small carcasses and 0.194 kg/h at large carcasses) is low compared to other sites. The Mongolian steppe is well known for its large number of livestock, which has doubled in the last decade (NSO, 2020). This livestock availability provides a large amount of carrion biomass, which added to the decrease in vulture populations in Asia (Prakash et al., 2007), may result in a low consumption rate and carrion removal by vertebrate scavengers in this area. These results indicate that invertebrate scavengers may have a relevant role, at least in the warm season (DeVault et al., 2004).

It has been shown that larger carcasses facilitate more organized, richer and more abundant vertebrate scavenger assemblages, removing carrion faster (Moleón et al., 2015; Stiegler et al., 2020; Turner et al., 2017). Our results show that carcass size strongly and positively affected the abundance of scavenging vertebrates and their consumption rate. Larger carcasses had a much higher abundance of avian species, especially vultures such as Himalayan griffons and cinereous vultures which were virtually absent at small carcasses, making the consumption rate much higher in larger carcasses (Moleón et al., 2015). Furthermore, although we found no significant differences in vertebrate scavenger species composition between carcass sizes, different species appeared at each of them. For example, the bearded vulture was only recorded at small carcasses, demonstrating a preference for smaller carcasses, as suggested by Moreno-Opo et al. (2015), and the steppe eagle or the cinereous vulture only appeared at large carcasses.

At fixed observation points, we recorded seven raptor species, some of them categorized as endangered, such as the saker falcon and the steppe eagle. In addition, some facultative scavenger raptors, such as the black kite (*Milvus migrans*) and upland buzzard (*Buteo hemilasius*), appeared at fixed observation points but were not recorded feeding on carcasses, as happened in Argentinean Patagonia (Travaini et al., 1998). This may be due to different dietary choices, season or competitive interactions (Pereira et al., 2014; Sebastián-González et al., 2016), as the Steppe of Mongolia is rich in micromammals (Dixon et al., 2017) and some species may prefer them to carrion. However, carrion consumption is a strategy used by a large number of raptor species in ecosystems worldwide (Sebastián-González et al., 2020, 2019). Our survey exposed that more than half of recorded raptor species consumed carrion, highlighting the relevance of this food resource in the Gobi Desert food web (Wilson and Wolkovich, 2011).

Our findings reveals the, hitherto, unknown vertebrate scavenger assemblage in the Gobi Desert. It also highlights the importance of carrion resource for raptors and the mountains as a wildlife refuge in our study area, which is a key breeding and migratory area for many endangered raptor species. Through this work we aid to fill spatial gaps in order to understand the large-scale processes that affect scavenger assemblages (Sebastián-González et al., 2019), which are especially unknown in desert regions. Finally, it is necessary to highlight the fundamental role of seminomadic extensive livestock systems, particularly in arid regions, in the conservation of vertebrate scavengers and the ecosystem services they provide (Morales-Reyes et al., 2018).

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Tables

Table 1. Vertebrate scavenger and raptor species richness and abundance for each habitat type (steppe or mountain), carcass size (large or small) and sampling type (camera trapping or fixed point) in the Gobi Desert, Mongolia. We also report for each species, the total abundance (Total), the percentage of scavenged carcasses (% carcasses), and the conservation status of each species according to the IUCN red list of threatened species (Endangered (EN), Least Concern (LC) and Near Threatened (NT)).

	Habitat type		**Carcass size**		**Sampling type**				
	Steppe (n = 17)	**Mountain (n = 26)**	**Large (n = 11)**	**Small (n = 11)**	**Camera trapping (n = 22)**	**Fixed point (n = 21)**	**Total**	**% carcasses**	**IUCN**
Aegypius monachus	16	14	9	0	9	21	30	18.18	NT
Gypaetus barbatus	1	4	0	2	2	3	5	9.09	NT
Gyps himalayensis	6	59	27	1	28	37	65	13.64	NT
Aquila nipalensis	0	7	3	0	3	4	7	9.09	EN
Buteo hemilasius	2	0	0	0	0	2	2	0	LC
Falco cherrug	0	3	0	0	0	3	3	0	EN
Milvus migrans	1	0	0	0	0	1	1	0	LC
Corvus corax	1	2	1	2	3	0	3	9.09	LC
Vulpes corsac	3	3	4	2	6	-	6	27.27	LC
Vulpes vulpes	0	9	5	4	9	-	9	22.73	LC
Canis lupus familiaris	2	3	4	1	5	-	5	13.64	
Total abundance	**32**	**104**	**53**	**12**	**65**	**71**	**156**		
Avian species richness	6	6	4	3	5	7	10		
Mammal species richness	2	3	3	3	3	-	3		
Total species richness	**8**	**9**	**7**	**6**	**8**	**7**	**13**		

Table 2. "Species richness", "abundance", "detection time" and "consumption rate" for each habitat type (mountain or steppe) and carcass size (large or small). Values represent mean ± standard deviation and sample size (n) of the vertebrate scavenger assemblage in the Gobi Desert, Mongolia. The results of univariate generalized linear models (GLMs) are shown, which tested for differences between habitat type and carcass size in terms of 'species richness', 'abundance', 'detection time' and 'consumption rate'. We show the estimate and the standard error (SE) of the univariate GLMs and the *p*-value. Significant *p*-values are in bold.

	Habitat type					**Carcass size**				
	Mountain	**Steppe**	**Estimate**	**SE**	***p-value***	**Large**	**Small**	**Estimate**	**SE**	***p*-value**
Species richness	1.27 ± 1.12 (26)	0.94 ± 0.83 (17)	-0.2257	0.3561	0.526	1.55 ± 1.12 (11)	0.91 ± 0.83 (11)	0.5306	0.3985	0.183
Abundance	4.00 ± 7.96 (26)	1.88 ± 2.69 (17)	-0.7679	0.5890	0.192	4.82 ± 10.02 (11)	1.09 ± 1.04 (11)	1.4854	0.5791	**0.010**
Detection time (h)	33.38 ± 25.84 (13)	31.13 ± 16.92 (6)	-0.0768	0.4237	0.858	29.07 ± 13.85 (10)	36.66 ± 29.21 (9)	-0.0689	0.3945	0.863
Consumption rate (kg/h)	0.076 ± 0.089 (11)	0.042 ± 0.027 (4)	0.7322	1.2388	0.565	0.12 ± 0.07(8)	0.004 ± 0.003(7)	3.7395	0.4031	**<0.001**

Appendices

Appendix 1. Database used for statistical analysis. For each fixed observation point and/or carcass point we show: start time and date, detection time (h), carcass weight (kg), consumption rate (kg/h), avian richness, avian abundance, mammal richness, mammal abundance, total richness, total abundance and recorded species. The description of each variable is explained in metadata.

Appendix 2. Database that compiles published vertebrate scavenger studies worldwide (Sebastián-González et al., 2020). For each study, we show: citation, country, number of scavenger species, habitat, carcass species, carcass size, carcass weight (kg), consumption rate (kg/h) and reference. The description of each variable is explained in metadata.

Appendix 3: Figure 1. Species accumulation curves and standard error (grey shadow) to measure the sampling effort in order to estimate the vertebrate scavenger (avian and mammals) species richness and raptor species richness of the Gobi Desert, Mongolia. a) Number of carcasses monitored by camera trapping, b) Number of fixed observation points, c) Number of fixed observation points and monitored carcasses.

Appendix 3: Table 1. Frequency of occurrence per species of the vertebrate scavenger assemblage in the Gobi Desert, Mongolia. Results are shown for each habitat type (steppe or mountain), carcass size (large or small) and sampling type (camera trapping or fixed observation point).

Appendix 3: Table 2. Comparison of vertebrate scavenger assemblages of the Gobi Desert, Mongolia, between habitat types (mountain vs steppe), carcass sizes (large vs small) and sampling types (carcass by camera trapping vs fixed observation point) by means of permutational multivariate analysis of variance (PERMANOVA), and permutational analysis of distance (PERMADIST). We show the Predictor (categorical predictor), Df (degrees of freedom), SS (sum of squares), R2 (pseudo R2), MS (mean of squares), F (pseudo F-statistic) and the p-value. Significant p-values are in bold.