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Research Article

Use of drone technology to monitor and map endangered marmot populations in Mongolian grasslands

Enkhmaa Enkhbat[1,*], Ulam-Urnukh Bayanmunkh[1], Altanbagana Yunden[1], Sukhchuluun Gansukh[1], Adiya Yansanjav[1], John L. Koprowski[2], Maria Vittoria Mazzamuto[2]

[1] *Institute of Biology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia*
[2] *Haub School of Environment and Natural Resources, University of Wyoming, Laramie, WY, USA*

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Abstract

Burrowing mammals impact the physical characteristics of the environment with their activity and, as a result, increase plant and animal biodiversity. The Siberian marmot (*Marmota sibirica*) is a globally endangered species inhabiting piedmont, mountain steppes, and alpine meadows in Mongolia and neighboring countries. Identifying a standardized national survey protocol in Mongolia is the first important step to developing a science-based management program and specific conservation measures for this endangered species. We used drones to collect aerial images of high-elevation Mongolian steppe grasslands to assess the efficacy of the application of this technology to count and monitor Siberian marmot population trends in a UNESCO Biosphere Reserve, Bogd Khan Mt. Based on the appearance of their entrance, we identified burrows on the ground on images and classified them as active (summer-living, hibernacula) and non-active. The drone survey was more effective in detecting and classifying burrows than ground survey and the detectability of burrows on aerial images taken at 150 m above ground was higher than 0.9. We counted burrows in images acquired by the drone in spring and early summer. Burrows in spring were more easily detectable compared to summer because of the absence of vegetation which made the differences in the color of the ground more pronounced. However, the summer counts were similar to spring. We suggest that seasonal counts might provide different ecological information about the marmot's habitat and population in space and time. Drone images also allowed the detection of differences in marmot populations between sites. This study represents a first step towards the development of a survey protocol to assess the status of this endangered mammal and for conservation planning aimed at restoring its key functional role in the grassland ecosystem.

Introduction

Accurate and precise population data are critical to the status assessment of keystone and endangered species and necessary for data-informed conservation decisions (Botsford et al., 2019; Lande et al., 2003). Keystone species by definition have profound and disproportionate impacts on their ecosystems because, through modification of their environment, they positively affect biodiversity (Coggan et al., 2018; Mills et al., 1993). One of the most common categories of engineers are burrowing mammals that excavate tunnels and nest chambers that have an array of impacts from physical characteristics (nutrient concentration, soil moisture, temperature, forage quality) to increased plant and animal biodiversity (Davidson et al., 2012; Fleming et al., 2014; Hale and Koprowski, 2018; James and Eldridge, 2007; Lacher et al., 2019; Van Staalduinen and Werger, 2007). Pocket gophers (Reichman and Seabloom, 2002), zokors (Zhang et al., 2003), pikas (Smith and Foggin, 1999), kangaroo rats (Prugh and Brashares, 2012), ground squirrels (Ewacha et al., 2016), prairie dogs (Davidson et al., 2012) and marmots (Suuri et al., 2021) are among the fossorial and semi-fossorial mammals that have been suggested as keystone species and ecosystem engineers.

For burrowing mammals, a number of techniques have been applied to document population trends including visual counts/distance sampling (Koshkina et al., 2022; Pelliccioli and Ferrari, 2014), camera trapping (Corlatti et al., 2020; Millar and Hickman, 2021), mark-recapture methods (Corlatti et al., 2017; Facka et al., 2008; Forti et al., 2022) of individuals and various counts of sign, such as burrows and mounds (Bean et al., 2012; Townsend, 2009). These methods are typically labor and time intensive and so other methods that use available satellite- or drone-collected imagery are being explored on species from moles to wombats (Burrows et al., 2006; Koshkina et al., 2020; Kotschwar Logan, 2016; Łopucki et al., 2022; Munteanu et al., 2020; Semerdjian et al., 2021; Swinbourne et al., 2018). The technique shows great promise for grassland/steppe dwelling burrowing mammals such as black-tailed prairie dogs (*Cynomys ludovicianus*: McDonald et al., 2011) and steppe marmots (*Marmota bobak*: Koshkina et al., 2020), but has not generally been applied to imperiled species (but see Bean et al., 2012; Kotschwar Logan, 2016).

One of the most endangered species in Mongolia is the Siberian marmot (*Marmota sibirica*), a burrowing social rodent that lives in steppe and grasslands at an altitude of 570-3200 m a.s.l. (Yansanjav, 2007). Marmot families live in colonies, but each family has its own burrow that might be enlarged over successive generations until it becomes a complicated warren (Budsuren, 1993). Based on their structure, organization, and use, marmot holes are classified as active hibernation and summer-living burrows, and non-active burrows (see Materials and Methods for a detailed description). Because of their fossorial habits and the disproportioned effect that they have on the habitat, marmots are considered ecosystem engineers and keystone species in open dry

*Corresponding author
Email address: enkhmaae@mas.ac.mn (Enkhmaa Enkhbat)

real-steppe (Todgerel et al., 2021; Yansanjav and Enkhbat, 2016; Yoshihara et al., 2010).

Aerial surveys are commonly used to detect species that are widely dispersed and/or occur in difficult to access areas (Wang et al., 2019). However, the use of manned aircraft is extremely expensive, and expertise is necessary to operate them safely. Moreover, while flying manned aircraft, species detection might be low or inaccurate especially when the environment is heterogeneous and/or there is a lack of contrast between the animals and their background (Hollings et al., 2018; Terletzky and Koons, 2016). Over the last decade, there has been an increase in the use of remote sensing through high resolution satellite images and drones to detect wildlife or environmental features associated to their presence in the landscape (Corcoran et al., 2021; Wang et al., 2019). Satellite imagery has been successfully used to specifically survey populations of burrowing mammals (e.g., Koshkina et al., 2020; Łopucki et al., 2022; Munteanu et al., 2020; Swinbourne et al., 2018); however, Mongolia lacks high resolution satellite imagery freely accessible on internet platforms such as Google Earth and Microsoft Bing Maps (Lesiv et al., 2018). In fact, much of the globe is only covered by Landsat resolution imagery (15 m) and images acquired by Sentinel-2 of the European Space Agency (10 m resolution), and their resolutions might not be sufficient for visual interpretation of many landscape features (Lesiv et al., 2018). Hence, herein, we used drones to collect aerial images of high-elevation Mongolian steppe grasslands to assess the efficacy of the application of this technology to monitor Siberian marmot population trends in a UNESCO Biosphere Reserve. The Siberian marmot is globally endangered (Batsaikhan et al., 2022) and is conserved under Mongolian Protected Area Laws and Animal Laws, but there are no standardized management and conservation measures established to date specifically aimed at this species. The aim of this study is to evaluate a survey method that could lead to the identification of a standardized national survey protocol to develop in the future a science-based management programme and specific conservation measures for this endangered species.

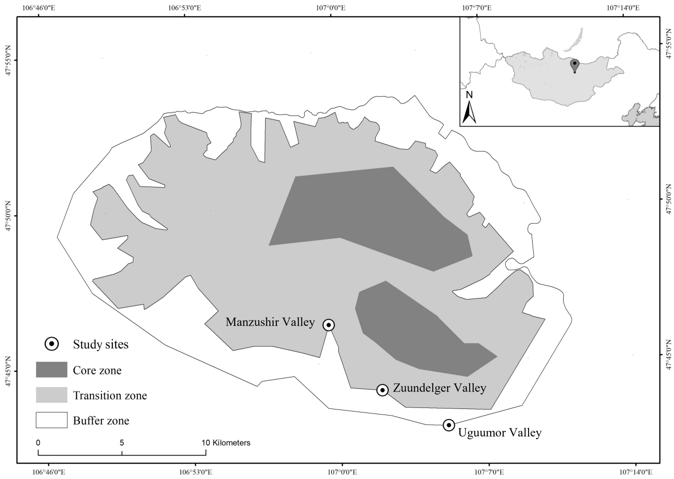

Figure 1 – Location of the study sites in Bogd Khan Mt., Mongolia and the different protection levels of its territory.

Material and Methods

Study area

Bogd Khan Mountain is a sky island south of the capital of Mongolia, Ulaanbaatar. The mountain has been protected since the 12th century, making it one of the oldest protected areas in the world and a UNESCO Biosphere Reserve since 1996. As a special protected area of 41,560 ha, the mountain is divided in a core zone, a transition zone and a buffer zone with different levels of protection. The mountain is surrounded by grasslands, except for the northern part where it is surrounded by Ulaanbaatar with a population of about 1,500,000, and a smaller town in the south, Zuunmond, with a population of 17,420. Bogd Khan Mt. is covered in conifer and mixed forests dominated by *Larix sibirica*, *Pinus sibirica*, *Picea obovata*, *P. silvestris*, *Betula platyphylla* and *B. rotundifolia.* It has an extreme continental climate with alternating cold winters and cooler summers. The average annual air temperature in the mountain is −1.5 °C to −3.1 °C, average temperature in the coldest month (January) is −10 °C to −24 °C, and the warmest month (July) will reach 14 °C-17.6 °C. At lower elevation, the forest transitions into steppe-grassland that characterizes the three valleys located at the southeast edge of the mountain where the study was conducted (Fig. 1). The valleys of Manzushir and Zuundelger are dominated by the following shrubs and grasses: *Stipa* sp., *Carex pediformis, Potentilla acaulis, Stellera chamaejasme*, and *Artemisia laciniata*. The dry steppe of Ogoomor Valley includes *Cleeistogeneas*p., *Elymuschinensis* sp., *Veronica incana, A. polgidae, Dontostemon integrifolius, Poa attenuate* and *A. frigida*. Each is located at the edge between the protected and transition zone (Manzushir and Zuundelger) or in the transition zones (Uguumor Valley) (Fig 1).

Study design

In this study we used the unmanned aerial vehicle DJI™ MAVIC™ Air 2 (SZ DJI Technology Co. Ltd., Shenzhen, China) to collect still images of the ground. This quadcopter drone with vertical takeoff and landing weights 570 gr, and, when unfolded, it is 183×253×77 mm. It has a battery capacity of 3500 mAh and energy of up to 40.42 Wh, providing a maximum flight time of 34 minutes and distance of 18.5 km. The drone captured georeferenced 48MP photos with a 1/2-inch CMOS sensor camera (focal length: 24 mm, aperture: f/2.8, focus range: 1 m to ∞, ISO: 100-1600) with fixed zoom and orientation and automated camera triggering. After an initial site inspection, we created the flight plan and route using the DroneDeploy software (DroneDeploy, Inc., California, USA). At 150 m above ground level (Duporge et al., 2021), we flew the drone on linear transects spaced 300 m from each other and photos had a 70 % and 60 % forward and lateral overlap, respectively. The drone was flown in each valley on May 20, 2022 and June 23, 2022 to collect photos at two different stages of the vegetation greening. In May 2022, the average daily temperature around Ulaanbaatar city was 10.3 °C, the total precipitation was 21.7 mm, and in June 16.6 °C, the total precipitation was 47.2 mm. The size of the planned flight area in each of the three valleys object of this study was on average 37 ha, for a total duration of each flight of 18-23 minutes depending on the wind speed and air pressure of the day. Georeferenced imagery was stored on board of the drone and later downloaded. We did not need any specific license or permit to fly the drone in the study sites because the drone was < 15 kg and the area was not covered by any restricted air space. However, we did follow the Mongolian Civil Aviation Rule 101.

In one valley, Manzushir, we also carried out a survey on foot in May to locate all the burrows present in the area and assess their status (active, non-active). Two people (EE, expert of the species and MVM) walked two separate sections of the area on foot along linear transects spaced 4 m apart and, using a Garmin GPSMAP® 64sx (Garmin Ltd., Kansas, USA), located and classified all burrows encountered. We then used the data collected on foot to identify the features on aerial photos from the drone that would allow the identification and classification of the burrows. Based on the appearance of their entrance, all burrows can be classified as active or non-active. Active burrows are identified by dark holes in the ground with fresh tracks or feces, with little to no vegetation in the immediate surroundings of the entrance. Non-active burrows are often filled with sand and dirt, no fresh feces can be seen, and the mound of soil is completely or partially covered with plants. Based on their usage and structure, burrows can also be classified as hibernating and summer-living burrows. Hibernating burrows have 1-2 entrances and consist of dozens of tunnels with several sleeping chambers 1 to 3 m below ground where heat can be kept constant. Before hibernation, marmots close the entrance to the hibernation burrow with soil mixed with stones, gravel, dead grass, and other organic materials to create a “wintering plug” 2.5 to 9.5 cm deep. Summer living burrows are structurally simpler than hibernation burrows, and the heat retention is poor. These seasonal burrows have up to ten entrances, suitable for a full use of the territory, grazing, and protection from enemies. At the edge of the colonies, burrows generally consist of short dead-end holes no more than 1 m deep where marmots can find refuge in case of sudden danger (Yansanjav, 2007).

Burrow classifications

From aerial images, we could identify the presence of burrows on the ground and classify them as active and non-active burrows. In spring, non-active burrows looked like dark spots (the entrance of the burrow) but the color between the soil at the entrance of the burrow and the surroundings did not differ. Active hibernacula or summer-living burrows looked like dark spots (the entrance of the burrow) on a mound of soil that had a typical yellowish/orange coloration different than the brownish color of the surrounding ground (Fig. 2). In the summer non-active burrow entrances were not as visible as in the spring because of the green grass covering them. Moreover, the color of the grass around non-active burrows and the surroundings did not differ. The amount of bare soil around active burrows in summer was smaller than in spring because of the growth of the vegetation. Grasses around active burrows looked brighter than the vegetation away from them, but visually reduced the difference in size between hibernacula and summer-living burrows.

Data analysis

After downloading the data from the drone, with the use of the DroneDeploy software (DroneDeploy, Inc., California, USA), we carried out the photogrammetric processing to produce orthomosaics. The average pixel value of an orthoimage taken by the drone was 2.5 - 3 cm. In each valley we randomly selected a sample area of 200 x 400 m to identify and count the burrows. We first used only the photos from Manzushir Valley to identify the features on aerial photos from the drone that would allow the identification and classification of the burrows. We used the approach of the independent double observer on photos from each valley to assess the detection probability of each type of burrow in each season per valley. In ArcGIS v. 10.8, in a given time of 1.5 h, two people (EE, expert of the species and UB) separately assessed the same photos and marked each visible burrow classifying them as hibernation vs summer-living burrows and active vs non-active. We analyzed data using the software DOBSERV (Nichols et al., 2000). Based on the results of the detection probability by DOBSERV, we used the photos processed by just one of the researchers for the following analyses. We fitted a negative binomial regression model to compare the number of each type of burrow (hibernacula, summer-living and non-active burrows) counted in spring and summer and assess their visibility. We performed pairwise comparisons using a post hoc analysis based on estimated marginal means with Tukey adjustment of p-values. We then compared the number of the active burrows (hibernacula and summer-living) between the three valleys using the same analytical approach.

Results

In Manzushir Valley, during the ground survey in spring, we detected 7 hibernating burrows, 25 summer living and 59 non-active burrows. All the burrows recorded by GPS were also detected in the drone photo. However, during the ground survey 7 burrows that we classified as non-active where then seen as active in the drone picture. In the drone picture we detected a total of 17 hibernating burrows, 33 summer-living and 189 non-active burrows, 59 %, 24 % and 69 % more than in the field survey, respectively. The burrows that we did not detect during the field survey, but that we detected on the drone images, were spread throughout the area indicating that the experience of the field observer was not determinant.

The software DOBSERV returned a detection probability between 0.90 and 1 for all types of burrows in all seasons and in all valleys, indicating a high probability of identifying a marmot burrow if present on the aerial photos taken by the drone (Tab. S1 in supplementary material). Number of burrows counted in spring per type and density reported in Tab. 1.

Comparing the two seasons, we did not find a difference in the number of burrows detected in spring or summer (spring-summer: hibernacula -0.02 ± 0.41, $z=-0.06$, $p=1$; summer living 0.008 ± 0.37, $z=0.02$, $p=1$; non-active 0.32 ± 0.36, $z=0.89$, $p=0.95$). The number of hibernacula we counted in spring was similar in all valleys (all $p > 0.5$). Zuundelger Valley was associated with more summer-living burrows compared to Manzushir (0.71 ± 0.21, $z = 3.33$, $p = 0.02$) and Uguumur (1.21 ± 0.25, $z=4.74$, $p=0.0001$) valleys. Moreover, Manzushir Valley had the highest number of non-active burrows and Uguumur the lowest (all $p\leq0.0001$).

Table 1 – Number and density of marmot burrows in Uguumur, Manzushir and Zuundelger valleys, Mongolia.

Valley	Season	Burrow	Count	Burrow density
Manzushir	Spring	Summer-living	41	5.13
Zuundelger	Spring	Summer-living	82	10.25
Uguumur	Spring	Summer-living	25	3.13
All valleys	**Spring**	**Summer-living**	**148**	**6.17**
Manzushir	Spring	Hibernacula	18	2.25
Zuundelger	Spring	Hibernacula	7	0.88
Uguumur	Spring	Hibernacula	15	1.88
All valleys	**Spring**	**Hibernacula**	**40**	**1.67**
Manzushir	Spring	Non-active	207	25.88
Zuundelger	Spring	Non-active	146	18.25
Uguumur	Spring	Non-active	43	5.38
All valleys	**Spring**	**Non-active**	**396**	**16.50**

Discussion

Grasslands cover one-quarter of the Earth's land area and are in part shaped by burrowing mammals that are keystone species for this biome (Hale and Koprowski, 2018; Suttie et al., 2005). Eighty percent of Mongolia is covered by grasslands and are the preferred habitat of the endangered Siberian marmot, as well as several other semi-fossorial species (Yansanjav, 2007). This study showed that, while the burrowing marmots can be difficult and time demanding to survey on the ground over large areas, the use of drone imagery can be used to reliably assess their distribution and relative population size identifying the soil mounds created by this large burrowing rodent. Despite the rare use of remote sensing in ecology in Mongolia (but see Kolesnikov et al., 2011; Sawamukai et al., 2012), researchers have tried to use this technology to assess the populations of other marmots in the world. Satellite images were shown to be effective in the identification of soil mounds created by the burrowing activity of bobak marmot (*Marmota bobak*) in Kazakhstan and southern Russia (Koshkina et al., 2020; Munteanu et al., 2020). Researchers used satellite imagery freely accessible on internet platforms and from historical Cold War spy satellites and described the occupied burrows as bright spots (turned soil) with sharp contours surrounded by dirt of a paler color because of the extracted soil and permanent removal of vegetation. On the other hand, abandoned burrows appeared as darker spots compared to the surrounding vegetation due to the overgrowing on mounds of the vegetation usually different from the surrounding communities (Koshkina et al., 2020; Munteanu et al., 2020). This is similar to what we found from the images collected by our drone, where burrows were clearly visible and distinguishable between active and non-active. In the future we aim to implement the acquisition of drone pictures with an effective and efficient automated system of deep machine learning and computer vision for the recognition of burrows on images [e.g., Roboflow, (Dwyer et al., 2022)]. However, attention needs to be paid because a study conducted in Hustai National Park, Mongolia using Quickbird imagery to map the

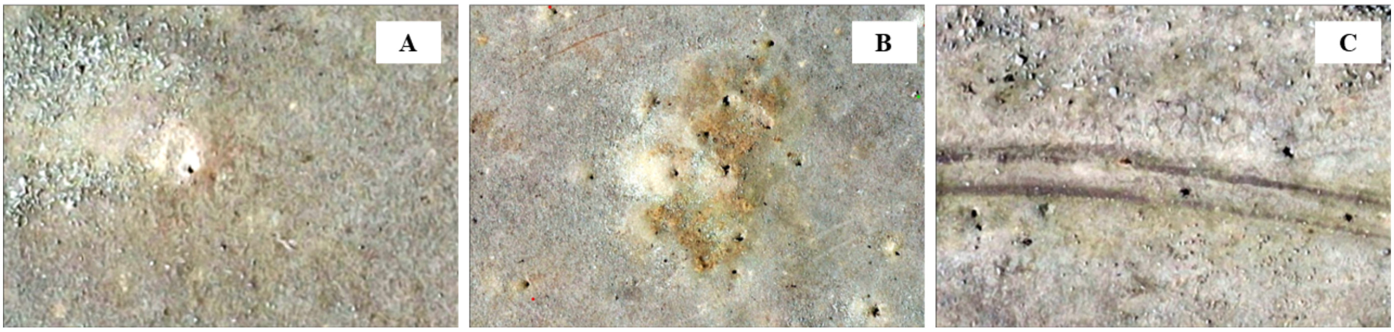

Figure 2 – Appearance of the marmot burrows in spring. A. Hibernaculum, B. Summer-living burrows, C. Non-active burrows.

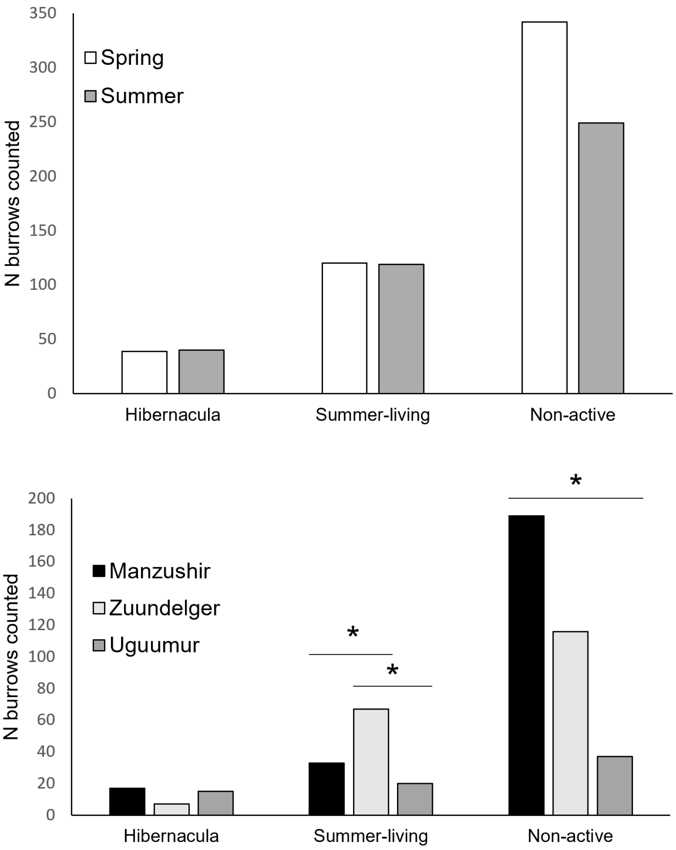

Figure 3 – Burrows of *Marmota sibirica* counted using the aerial photos taken by the drone in Uguumur, Manzushir and Zuundelger valleys, Mongolia. In the top panel number of burrows per type and season, in the panel below number of burrows per type per valley. Asterisks are reported for statistical significance (see methods and results for details).

mounds of marmot burrows, highlighted that the object-oriented classification rule that was built to detect active mounds produced a high number of false positives in desert areas, dry valleys and on gravel roads and tracks, because these objects have a reflectance similar to that of active mounds (Velasco, 2009).

Despite reported use of publicly available high-resolution images in the region of the Altai to identify marmot burrows (Kolesnikov et al., 2011), we were not able to collect high-resolution images from free internet platforms (e.g., Google Earth, Microsoft Bing Maps) for our study area, confirming instead the study that reported a lack of very-high-resolution images for most of the country of Mongolia (Lesiv et al., 2018). The lack of free and easy to access satellite images represents a limitation to the potential of remote sensing for the survey of marmots in the country in space and time, as drones are devices considered expensive in Mongolia. Nevertheless, as the main governmental institution responsible for wildlife conservation and management, the Mongolian Academy of Sciences, owns some drones (pers. comm.), opportunity exists for future monitoring projects in Mongolia on the endangered marmot, as well as other species detectable by remote sensing. Periodic surveys using images acquired by drones can provide information about marmot distribution, as well as colony expansion or reduction, in relation to several ecological factors over time.

Traditional field-based counts of marmot burrows can be affected by the observers' experience and visual ability. Drone images captured at constant elevation and on programmed routes reduce observer-related biases and are much more time efficient covering large areas in few minutes and with minimal effort from the operator. We showed that the detectability of burrows on drone images captured at 150 m above ground is extremely high (0.9-1.00) and allows the correct classification of the burrow in terms of activity, independently from the experience of the observer. In the future, because of the high detectability, only one digitizer might be employed to make the survey more efficient. All burrows recorded in the field were detected on satellite images. This is in contrast with the 39 % and 40 % of burrows detected on satellite images compared to ground surveys for bobak marmot in Kazakhstan and southern Russia (Koshkina et al., 2020; Munteanu et al., 2020). In these studies researchers hypothesized that the lower percentage of burrows detectable with remote sensing was because temporary summer burrows were small, and they were overlooked on satellite images. A limitation on the visual identification of burrows on images could be related to the terrain configuration: slopes steeper than 20° might alter the shape of the burrow and burrows might not be visible on screes (Kolesnikov et al., 2011). Moreover, marmot burrows also provide shelter for many native species (e.g., fox *Vulpes vulpes*, Pallas's cat *Otocolobus manul*, badgers *Meles leucurus;* Suuri et al., 2021) and, while burrows dug by other mammals, such as pikas, ground squirrels or voles, are easily distinguishable from marmot's (e.g., size), when other species use abandoned marmot burrows it might not be possible to distinguish between occupying species (Kolesnikov et al., 2011).

We counted burrows in spring and early summer. Burrows in spring were more easily detectable compared to summer because of the absence of vegetation that made the differences in color of the ground more pronounced. However, the summer counts were similar to spring. Despite it being not statistically significant, in Manzushir Valley we counted a higher number of summer-living burrows in summer than spring. When comparing images in the two seasons we saw that the higher number of burrows detected in the summer was due to new dug burrows that were not present in spring. Marmot family groups in the summer, after the breeding period, expand their distribution to the periphery of the colony where they often dig some protective temporary holes (Yansanjav, 2007). The differences in number and distribution of burrows between seasons can be used to gain information on the dynamics of the colony and more in general the population of marmots. The amount of newly dug burrow at the end of the summer compared to early spring could be an indication of the expansion of the family group in the colony, whereas a comparative analysis on burrow before (closed in fall) and after hibernation (open in spring) can give us information about relative survival rate of marmot families. As a consequence, each seasonal count might provide us with different ecological information about marmot's habitat and population in space and time.

We found differences in the number of burrows present among the valleys. The number of hibernacula can be used as proxy for the number of family groups in the colony while the number of active summer-living burrows can be an indicator of the size of the family group (Mashkin, 1997; Suntsov, 1981; Yansanjav, 2007). Zuundelger Valley is located at edge between the transition zone of the protected area (medium level of protection) and the buffer zone (low level of protection). In this valley we recorded the highest number of summer-living burrows. Despite Manzushir Valley is in the buffer zone and the nearest to the core area (high level of protection) of the protected area, we recorded the highest number of non-active burrows and a medium number of summer-living burrows. This could be explained by the level of human disturbance that the valley experiences. In fact, the valley is highly trafficked especially in the warmer seasons because of the presence of a religious and historical monastery daily visited by several touristic buses, schools, and locals. Surprisingly, despite its location at the periphery of protected area, Uguumur Valley had the lowest number of non-active burrows. Our aim was not to assess what affects the presence and distribution of marmots on the landscape, and our explanations of the differences recorded among valleys are speculative. Further studies should endeavor to understand to what extent habitat quality, human disturbance, and level of protection of the area affect local populations of marmots (Velasco, 2009). With the population of the region surpassing 1.5 million, the impact of human disturbance is only likely to increase.

Our analyses highlight how drone images can help in providing important baseline data for understanding the ecology and conservation status of semi-fossorial rodents in grasslands. The conversion of grasslands into heavily livestock grazed lands in Mongolia is one of the principal causes of the degradation of this habitat, exacerbated by climate change that causes widespread and frequent droughts and warming (Nandintsetseg et al., 2021). Mongolia grasslands support $\sim$70 million livestock and livelihoods of 29% of the country's population (Nandintsetseg et al., 2021) and how these land-use changes have affected the distribution and abundance of burrowing mammals, however, remains poorly understood. This study represents a first step towards the development of a much-needed national protocol to assess the status of this endangered mammal and for conservation planning aimed at restoring its key functional role in the grassland ecosystem.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Output of the software DOBSERV.