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INVITED REVIEW

Lamellicorn beetles (Coleoptera: Scarabaeoidea) in Korea and Mongolia

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Abstract

This work was undertaken as an initial part of the collaborative effort between Korean and Mongolian researchers to study the terrestrial and aquatic insects in these countries. An analysis of data on faunal composition, taxonomic diversity and biogeographical structure of lamellicorn beetles in Korea and Mongolia was conducted in order to characterize the faunal relations between two countries. The Korean fauna of lamellicorn beetles is almost two fold greater in both generic diversity and species richness than that of Mongolia. The species compositions of lamellicorn beetles in two countries are substantially different from each other and the relative levels of faunal overlap are insignificant. Not only the faunal diversity and composition, but also the biogeographical structure of lamellicorn beetles in Korea and Mongolia display dissimilar patterns, except for their similar degree of endemism. Additional data on communities of dung beetles in the grasslands of central Mongolia, as well as a brief discussion on conservation issues of the endangered species in Korea, especially *Gymnopleurus mopsus*, are given.

Key words: biogeography, conservation, dung and scarab beetles, endangered species, fauna.

Introduction

The dung of herbivorous animals represents patchy and ephemeral habitats for many species of terrestrial invertebrates. Because of the high contents of nutritional components, herbivore droppings constitute an attractive habitat for many groups of arthropods, including insects, spiders, pseudoscorpions, centipedes, millipedes, mites, some mollusks, and worms, as well as their larvae and nymphs (Hanski 1980; Makarova 1992; Pérez-Bañón *et al*. 2003). The characteristic pattern of the coprophilous insect communities in temperate regions is the dominance of dung beetles, especially small- to medium-sized species belonging to genera *Aphodius*, *Onthophagus* with the addition of some large-bodied species of such genera as *Gynopleurus*, *Copris*, *Geotrupes* etc. (Hanski & Cambefort 1991; Liybechanskii & Smelyanskii 1999).

The superfamily of lamellicorn beetles (Scarabaeoidea or series Scarabaeiformia, according to Bouchard *et al*. 2009) currently consists of 12 families. Two major clades occur within Scarabaeoidea: the coprophagous dung beetle clade and the phytophagous scarab beetle clade (Smith *et al*. 2006). In much of the literature the term 'lamellicorn beetle' was often used to cover both of the groups which are presented in this paper. Dung beetles are known to be of ecological importance in terrestrial habitats that support populations of large vertebrates. By burying and eating dung, these beetles increase the rate of soil nutrient recycling, and decrease helminth and pest dipteran populations (Bornemissza 1960; Fincher 1973; Bang *et al*. 2005; Brown *et al*. 2010). Hundreds species of scarab beetles are nectar feeders and pollinators of a diverse assemblage of plant species. In addition, dead-wood feeding and detritivorous scarabs play a significant role in seed burial and germination

for some plant species (Vulinec 2002; Chapman & Chapman 2003). Many phytophagous species are considered pests of turf-grass, ornamental, and agricultural plants, and numerous invasive species can damage plants and ecosystems (Jackson & Klein 2006).

Dung beetles have been used in ecological and biodiversity studies (Jankielsohn *et al*. 2001; Spector 2006) to study diversity across landscapes and continents (Lobo & Davis 1999; Lobo *et al*. 2006) or as indicator taxa for ecosystem health (Halffter & Arellano, 2002; Scheffler 2005).

The study of lamellicorn beetles in Mongolia was initiated in the 19th century (e.g. Heyden 1889; Reitter 1893), but the main discoveries have been made by more recent researchers, such as Endrödi (1967, 1971), Medvedev (1976), Nikolajev (1976), and Puntsagdulam (1974). A review of previous studies can be seen in Nikolajev and Puntsagdulam (1984). Data on the previous studies of the Korean lamellicorn beetles are available in Kim (2000, 2001).

The main goal of this work is to summarize the data on faunistic composition of lamellicorn beetles in Korea and Mongolia, and perform a comparative analysis of their species richness, geographical distribution and faunal relations between two countries. Giving additional data on communities of dung beetles in grassland habitats of central Mongolia, and discussing the conservation issues of the endangered species in Korea are the other objectives of this paper. This is an initial part of results of the collaborative work by the Korean and Mongolian researchers on various groups of terrestrial and aquatic insects.

Materials and methods

Estimation of species composition, geographical distribution, faunal similarity of lamellicorn beetles in Korea and Mongolia is based on available literature data. The estimation of the recorded species and comparison of the scarabaeoid beetle faunas of Korea and Mongolia are based upon detailed and summarized data by Medvedev (1976), Paik (1976), Nikolajev (1982), Puntsagdulam (1979), Nikolajev and Puntsagdulam (1984), Maizlan and Peter (1988), Kim (1994, 2000, 2001, 2002a), Kim and Kim (2010). The Sørensen and Jaccard indexes of similarity were used to compare composition of dung beetles between studied countries.

Additionally, we studied the communities of dung beetles in the mountain steppe adjacent to birch forest, and lowland grassland pasture in Hustai National Park, Central Mongolia. The field study was carried out at pastures with different grazing regimes, in August of 2009 and 2010. Beetles were collected using pitfall traps baited with fresh dung of wild and domestic horses, red deer, sheep/goats and cows. We adopted pitfall traps made of plastic buckets (18 cm diameter, 21 cm depth), buried up to its upper margin in soil, with a small bait container suspended over the bucket by a wire loop. Two plots were studied with 625 m^2 area each, and in every plot 25 traps were placed in quadrangular configuration with interspaces of 5 m. Total number of exposed droppings of domestic and wild herbivores in each study site was counted to estimate the grazing intensity (see also Bayartogtokh & Otgonjargal 2009). The influence of grazing intensity on the diversity and abundance of dung beetles was analyzed by Spearman's rank of correlation coefficient, using the OpenStat (Iowa State University, Iowa, USA) package.

Results and discussion

Diversity of lamellicorn beetles in Korea and Mongolia

In both Korea and Mongolia, the countries with different geographical location, dissimilar ecological conditions as well as discrepant agricultural practices, the faunas of scarabaeoid beetles are well studied in terms of their taxonomic composition, but the knowledge on their ecology, biogeography and conservation is still largely incomplete. For these reasons, we consider it valuable to compile and summarize the data on lamellicorn beetle faunas of these two countries.

Currently, there are 236 known species (including subspecies) of scarabaeoid beetles belonging to 79 genera and 13 families in Korea. In the meantime, only 129 species from 42 genera and 11 families were recorded in Mongolia. Although the land area is much smaller and natural habitats are more heavily disturbed or altered in Korea, the overall diversity of its lamellicorn beetles is much higher than in Mongolia. The Korean fauna of lamellicorn beetles is almost two fold greater in both generic diversity and species richness than that of Mongolia (Table 1).

We suggest that the occurrence of suitable habitats, especially for phytophagous scarab beetles, as well as favorable climatic conditions in Korea benefit the maintenance of a high diversity of scarabaeoid beetles. Therefore, it is reasonable to explain that the species richness of scarabaeoid beetles is naturally higher in Korea than in Mongolia. The harsh continental climates, as well as arid or very dry conditions in most areas of Mongolia make the country unfavorable for the habitation of such species, which commonly occur in areas with humid, sub-continental mild climates. Generally, the diversity of local dung-beetle community is primarily influenced by vegetation cover, soil type, moisture, texture and food resource availability (Doube 1987; Davis 2002). On the other hand, it is known that beetles of this group are, to a large extent adapted to man-made habitats, such as pasture keeping a large herbivore population, agricultural fields with cultivated plants etc.

As mentioned above, the diversity of families belonging to the phytophagous scarab beetle clade, such as

Table 1 Taxonomic diversity of scarabaeoid beetles of Korea and Mongolia

No	Families	Korea		Mongolia	
		Genera (subgenera)	Species	Genera (subgenera)	Species
1	Aegialiidae	1 (2)	3	1	2
2	Aphodiidae	7 (25)	53	5 (20)	55
3	Cetoniidae	13 (6)	18	4	9
4	Dynastidae	3	3	1	1
5	Geotrupidae	4	4	4	4
6	Hybosoridae	1	2	0	0
7	Lucanidae	8	17	1	1
8	Melolonthidae	19 (2)	55	10 (5)	22
9	Ochodaeidae	2	2	1	2
10	Passalidae	1	1	0	0
11	Rutelidae	11 (3)	35	8	9
12	Scarabaeidae	7 (6)	33	5	19
13	Trogidae	2	10	2	5
	Total	79 (44)	236	42 (25)	129

Table 2 Common species of lamellicorn beetles in Korea and Mongolia, and their geographical range

Species name	Species	Known distribution
Aphodius haemorrhoidalis (Linnaeus, 1758), *A. putridus* (Herbst, 1789), *A. subterraneus* (Linnaeus, 1758), *Maladera castanea* (Arrow, 1913)	4	Holarctic
Aphodius pusillus (Herbst, 1789), *A. scrofa* (Faricius, 1787), *A. sordidus* (Faricius, 1775), *A. sturmi* Harold, 1870, *Cadocera ferruginea* (Eschscholtz, 1818), *Gymnopleurus mopsus* (Pallas, 1781), *Onthophagus gibbulus* (Pallas, 1781), *O. marginalis* Gebler, 1817, *Phylloperta horticola* (Linnaeus, 1758), *Scarabaeus typhoon* (Fischer-Waldheim, 1923), *Serica brunnea* (Linnaeus, 1758)	11	Transpalaearctic
Anomalia luculenta Erichson, 1847, *A. mongolica* (Faldermann, 1835), *Aphodius indagator* Mannerheim, 1849, *A. rectus* Motschulsky, 1866, *Copris ochus* (Motschulsky, 1860), *Holotrihia diomphalia* (Bates, 1888), *Hoplia aureolia* (Pallas, 1781), *Lasiopsis sahlbergi* (Mannerheim, 1849), *Trichius succinctus* Faricius, 1787, *Maladera orientalis* (Motschulsky, 1857), *M. renardi* (Ballion, 1870), *Onthophagus clitellifer* Reiter, 1894, *O. olsoufieffi* Boucomont, 1924, *O. punctuator* Reiter, 1893, *Mimela holosericea* (Faricius, 1787), *Serica polita* (Gebler, 1832)	16	Eastern Palaearctic

Melolonthidae, Rutelidae, Cetoniidae, Lucanidae etc., is much higher in Korea than in Mongolia. It is already known that the regional diversity may increase with increasing local diversities, but also with increasing difference in species composition between neighboring areas (Hanski 1989). In the meantime, the diversity of such families as Aphodiidae, Geotrupidae, Scarabaeidae etc. belonging to coprophagous dung beetle clade is similar in these two countries.

In the fauna of Mongolia, only three families, Aphodiidae, Melolonthidae, and Scarabaeidae, comprise almost three quarters (74%) of total recorded species. In Korea, however, these three families, with the addition of Rutelidae, also compose 74% of total fauna in terms of species number. There are two families, Hybosoridae and Passalidae, which are found in Korea with one or two species, but are lacking from the Mongolian fauna. Several other families, such as Aegialiidae, Dynastidae, Ochodaeidae, and Trogidae are poorly represented in both countries with not more than 10 species.

The species compositions of lamellicorn beetle faunas in the two countries differ substantially from each other, and therefore, the relative level of faunal overlap is insignificant. Thus, the faunal similarity of lamellicorn beetles in Korea and Mongolia is very low (Sørensen index, 0.17; Jaccard index, 0.11), as only 31 species are common to both countries. Nearly half of such common species are distributed in various areas or countries in the Eastern Palaearctic region, such as Siberia, Russian Far East, the eastern part of China, Japan, Korea, and Mongolia. The other species seem to be widespread in the whole Palaearctic region, but only few of them have Holarctic distributions (Table 2).

Thus, the majority of commonly occurring species in Korea and Mongolia have broad dispersal areas in the various types of forests, mountains, grasslands, and meadow

habitats of the Palaearctic region, especially in its eastern part. There is no species that is distributed exclusively in Korea and Mongolia, but several more common species may be revealed in the future, when remote or unexplored areas have been surveyed.

Biogeographical analysis

All known species of lamellicorn beetles of Korea and Mongolia were compiled for the biogeographic regions, and were divided into groups based upon their dispersal areas. Figure 1 shows the general data for each region and an overview of the results.

As for the biogeographic structure of the Korean fauna, the majority of species (around 55%) has East Asian distribution, followed by those of the Oriental region (19%). The East Asian species are known mainly from East Siberia, Russian Far East, China, Japan, and Mongolia, while the majority of Oriental species are known to be distributed in Taiwan, Myanmar, India, Tibet, Malaysia, Thailand, and rarely in Australia. The endemic species (32 spp.) comprise about 10% of the total lamellicorn beetles in Korea (see also Kim 2002b), while the species with broad geographical distributions show much less diversity. Thus, species with cosmopolite, Holarctic, Transpalaearctic, and Eastern Palaearctic distributions together comprise less than 10% of the total fauna of lamellicorn beetles in Korea (Fig. 1).

Contrarily, the species with wide distributions comprise a large proportion of the fauna of lamellicorn beetles in Mongolia. Thus, the species which are distributed in the whole area, or the eastern part of the Palaearctic as well as Holarctic regions, compose almost half of the total species (47%). The species, which occur mainly in the arid areas (steppe, semidesert, and desert) of Central Asia or relatively humid areas in East Asia, represent about one quarter of the fauna. The Mongolian endemic species comprise a similar portion (12%) of its lamellicorn beetles as in the case of Korea. Species with Europe-Siberian and Siberia-Mongolian geographical ranges have a lower percentage (15%), relatively, in the Mongolian fauna.

As Korea can be regarded a transitional zone between the Palaearctic and Oriental regions, it is reasonable to expect the Oriental elements being richly represented in this country, which do not occur in Mongolia. As suggested by Cabrero-Sañudo and Lobo (2009), the Oriental region can be considered as a macroevolutionary sink area for lamellicorn beetles. While the western elements, such as Europe-Siberian, Siberia-Mongolian, and Central Asian species, which comprise about one third of the Mongolian fauna, are not represented in Korea. Thus, in spite of an almost identical degree of endemism, not only diversity and faunal composition, but also the biogeographical structure of lamellicorn beetles in Korea and Mongolia display dissimilar patterns.

Communities of dung beetles in grasslands of Mongolia

We studied the communities of dung beetles in the mountain steppe adjacent to birch forest, and lowland grassland pasture in Central Mongolia, that are grazed by sheep, goats, domestic horses, cattle, and two wild herbivores, red deer and reintroduced wild horses (Przewalski's horses). A total of eight species of dung beetles, *Aphodius erraticus* (Linnaeus, 1758), *A. cf. fimetarius* (Linnaeus, 1758), *A. gregarius* Harold, 1871, *A. haemorrhoidalis* (Linnaeus, 1758), *A. subterraneus* (Linnaeus, 1758), *Geotrupes amoenus*, *Gymnopleurus mopsus* (Pallas, 1781) and *Onthophagus gibbulus* (Pallas, 1781) were found. A tunneller species, *O. gibbulus* was most abundant in all samples, which

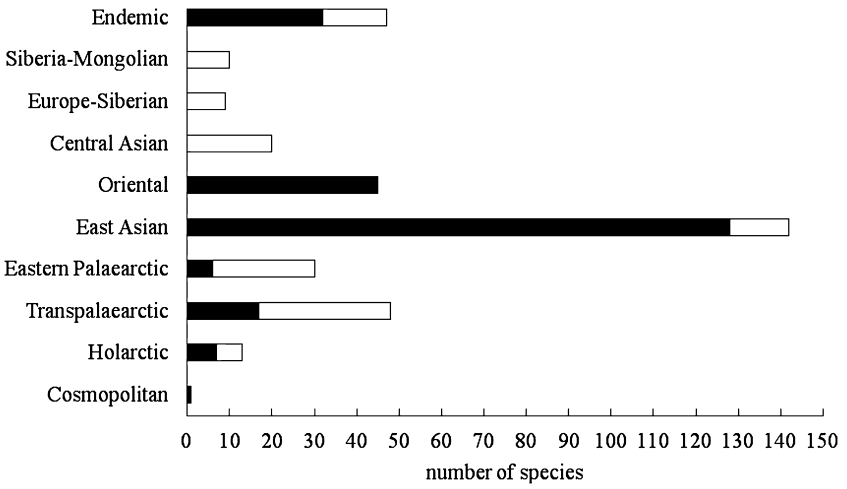

Figure 1 Biogeographical composition of lamellicorn beetles in Korea and Mongolia. ■, Korea; □, Mongolia.

comprised 26.9–92.9% of total entrapped beetles in different herbivore dung. The next common species were the members of the dweller genus *Aphodius*, which were found in different numbers, but their occurrence and abundance were not even in different herbivore dung. For instance, *A. gregarius* was abundantly represented in the dung of wild and domestic horses, while *A. haemorrhoidalis* was abundant in cow dung and sheep/goat droppings. Relative abundances of two large-bodied roller species, *G. amoenus* and *G. mopsus* were less numerous than other species. The first species was found commonly in the mountain steppe habitats, exclusively in wild and domestic horses' dung, while the second species occurred only in cow dung in the lowland grassland (Table 3).

The expectation was to find the highest diversity and greatest abundance of beetles in the heavily grazed areas where a large number of herbivore droppings were counted. This prediction was based upon the availability of sufficient provision of the herbivore droppings in the intensively grazed pastures which serve as favorable habitats for coprophilous beetles. However, the study results did not meet this expectation, on the contrary, more diverse and abundant communities of beetles were found to occur in the less grazed sites. As evaluated by the grazing intensity of each pasture using number of exposed droppings of herbivores, the more heavily grazed pastures seem to support a considerably lower diversity of dung beetles with relatively little abundances. Significant negative correlations were found in the relationships between species richness, abundance of coprophilous beetles, and number of herbivore droppings (Fig. 2).

Some other studies also demonstrated that the pasturelands with different grazing management were dissimilar in dung beetle assemblages, and the main differences were observed in both species composition and abundance of beetles. Additionally, the influence of grazing management in grasslands was observed on species richness and abundance of functional groups. Thus, both species richness and abundance of telecoprid dung beetles was greater at the park site than in the pasture, whereas those parameters of endocoprid dung beetles were similar in both park and pasture sites (Numa *et al*. 2010). A similar pattern of the coprophagous beetle assemblages were revealed not only in the temperate regions, but also in the tropics (Krell & Linsenmair 1998; Roslin & Koivunen 2001).

On the other hand, the patterns of occurrence of a high diversity of beetles in the dung baited traps of the less extensively grazed pastures might be explained by the lack of sufficient droppings, and the demonstration of competition between the species for their browsing, sheltering or breeding microhabitats as related species utilize similar ecological resources. In contrast, the low diversity of entrapped beetles in the heavily grazed pastures would give rise to the hypothesis that the availability of sufficient number of droppings could influence the behavior of beetles that were able to choose fresh dung with less competition.

Endangered species in Korea and their conservation

The changes in livestock and pasture management, as well as widespread usage of pesticides or anti-parasitic veterinary treatments, during the past a few decades are thought to have contributed to the decline of diversity and abundance of dung beetles in Korea, especially in its mainland (Kim 1994, 1998; Bang *et al*. 2000, 2007). Dung beetles are threatened

Table 3 Mean number of beetles in dung baited traps placed at mountain steppe adjacent to birch forest and in lowland grassland (ind./trap)

Species	Sheep/goat	Cattle	Domestic horse	Wild horse	Red deer
	Mountain steppe adjacent to birch forest				
Aphodius erraticus	6.5	3.4	0	0	0
A. cf. fimetarius	7	0	1	3	0.5
A. haemorrhoides	2.5	6.8	0	4	0
A. gregarius	0	0	9.3	11.2	1.4
A. subterraneus	0	0	6	0.5	0
Geotrupes amoenus	0	0	2.5	3.3	0
Gymnopleurus mopsus	0	0	0	0	0
Onthophagus gibbulus	9.5	8	86.5	92.5	3.5
	Lowland grassland				
Aphodius erraticus	0.5	2.7	1.6	6	0
A. fimetarius	1.5	0.5	1.5	6	0
A. haemorrhoides	0.5	8.6	1.5	6	0
A. gregarius	11.3	5.5	14.2	10	1.5
A. subterraneus	0.5	0	1.5	6	0
Geotrupes amoenus	0.5	0	1.5	6.5	0
Gymnopleurus mopsus	0	2.4	0	0	0
Onthophagus gibbulus	7.5	11.5	76	205	8.5

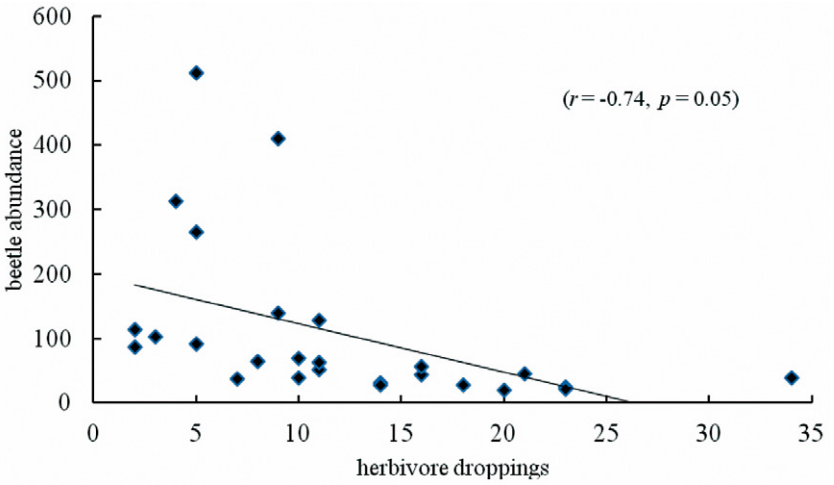

Figure 2 Relationship between abundance of dung beetles (total number of individuals per one plot) and grazing intensity of herbivores (droppings per 10 × 10 m area).

by habitat loss and conversion, and the reduction in livestock pasture associated with a more intensive agricultural system, bring declines in dung beetle numbers.

Several species of scarabaeoid beetles, such as *Polyphylla laticollis manchurica* Semenov, 1882 (Melolonthidae), *Gymnopleurus mopsus* (Pallas, 1781), *Copris tripartitus* Waterhouse, 1875 (Scarabaeidae), *Osmoderma opicum* Lewis, 1887 (Cetoniidae), and *Prosopocoilus blanchardi* (Parry, 1873) (Lucanidae) were included in the Red Data Book of Korea (Ministry of Environment 2009) as I and II class endangered species, but their main threat and status are still unknown. Korean scientists are, therefore, interested in understanding the biology and ecology of certain species of dung beetles in order to reverse their declining trend (Bang *et al*. 2001, 2003, 2004, 2008; Huerta & Bang 2004), and this could be achieved by the development of mass rearing and reintroduction programs similar to those used successfully in Australia and USA (Waterhouse, 1974; Fincher, 1990).

Most of the endangered species mentioned above are known to have restricted distribution in northeastern or southeastern Asia. Thus, besides Korea, *Polyphylla laticollis manchurica* is known from China and Japan, *Copris tripartitus* is reported from Japan and Hong Kong, *Osmoderma opicum* is recorded in the Russian Far East, *Prosopocoilus blanchardi* is found in China, Nepal, and Taiwan, and *Gymnopleurus mopsus* is distributed in the Ukraine, South Siberia, Kazakhstan, Turkmenistan, Uzbekistan, and Mongolia.

The telecoprid species, *G. mopsus* was recorded as being widespread in Korea until the mid 1960s (Paik 1976), but its population has decreased significantly during the last a few decades, and now it is nearly extinct in Korea (Kim 1998). However, this species is common in Mongolia, and is a typical inhabitant of lowland grasslands grazed mainly by cattle, sheep, and goats. This species is also widely distributed in the steppe, semidesert, and desert habitats of central, southern, and eastern areas of Mongolia. Therefore, in spite of the mass rearing or habitat restoration programs, the reintroduction effort of this species into Korea may be reasonable.

Of course, detailed investigations on the favored habitats with appropriate ecological niches for this species, including grassland with permanent grazing of large herbivores, especially cows, is required. Paik (1976) indicated the decrease of reproductive potentiality and low emergence rate of *G. mopsus* in midsummer caused by heavy rain. He also noted high mortality of immature stages during laboratory rearing, as well as death of newly emerged adults after releasing them in the field. Therefore, the thorough study on developmental biology and habitat ecology of this species is necessary. It is worth mentioning that Bang *et al*. (2003, 2004) reared two Korean paracoprid species, *Copris ochus* (Motschulsky, 1860) and *C. tripatitus* Waterhouse, 1875 in different rearing media.

Although the herders in Mongolia still keep their traditional nomadic animal husbandry, which is solely based on pastoral vegetation production, the development of industry, especially mining, has grown rapidly during the last 10 years disturbing vast areas of wildlife habitats. Despite the importance of dung beetles to ecosystem services via the removal of animal dung and the recycling of nutrients, their conservation status has never been systematically assessed in Mongolia. Therefore, in the future, the development of conservation strategies for maintaining dung beetle diversity, as well as an indicator system for assessment of biodiversity, and an estimation of the degree of its endangerment are required for both countries.

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