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Current status and future challenges for khulan (*Equus hemionus*) conservation in China

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ABSTRACT

Understanding the changes in population size, distribution and threats, is essential for assessing the status of threatened species. Northern China is believed to be an important stronghold for the *Near Threatened* Asiatic wild ass or khulan (*Equus hemionus*), but a recent assessment of the species has been lacking. To document change and updated the current status of khulan in China, we conducted a literature review targeting peer-reviewed and grey literature, newspaper articles, and summarized the results own field surveys and interviews from part of the species range. For a better understanding of the threats to khulan in China, we summarized the results of studies on environmental habitat factors and human disturbances for khulan, most of which are only available in Chinese language. Our results suggest that khulan in China have experienced a dramatic decline and fragmentation of their distribution range caused by excessive anthropogenic interferences. The remaining khulan range in China covers probably less than 40,000 km^2 and is scattered over several nature reserves and the border areas in northern Xinjiang, northwestern Gansu, and western Inner Mongolia. We estimate the remaining population at about 4000 individuals, with ~80% found in Kalamaili Mountain Ungulate National Nature Reserve in Xinjiang. The occurrences along the border with Mongolia are small and dependent on cross-border movements, which are currently severely hindered by border fences. Over the past 15 years, Kalamaili Mountain Ungulate National Nature Reserve was exposed to various human pressures and experienced dramatic population fluctuation in the khulan population size. Key factors which negatively influenced khulan were habitat loss, fragmentation, and disturbance due to mining

Abbreviations: ANR, Anxi Extreme-arid Desert National Nature Reserve; CMS, Convention on Migratory Species; IUCN, International Union for Conservation of Nature; KNR, Kalamaili Mountain Ungulate National Nature Reserve; QNR, Qitai Desert Grassland Nature Reserve; UNR, Urad National Nature Reserve.

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exploration and infrastructure development. No systematic monitoring of khulan is done in the rest of the khulan range, but whereas illegal hunting seems no longer a serious threat, infrastructure development and land use changes (including increasing livestock numbers) are happening throughout the remaining range of khulan in China. Hence there is an urgent need to develop a national khulan conservation strategy and initiate cross-border cooperation with Mongolia to safeguard the long-term survival of the species in the Gobi region.

1. Introduction

Khulan or Mongolian wild ass (*Equus hemionus hemionus*) is the most numerous surviving subspecies or ecotype of the Asiatic wild ass (*E. hemionus*) found throughout the Gobi area of southern Mongolia and northern China (Kaczensky et al., 2015). The population and distribution status of khulan in Mongolia is well studied, and current estimates suggest a total of 64,000 individuals which constitutes > 80% of the global population (Buuveibaatar et al., 2016a; Kaczensky et al., 2020). Although the global population is still relatively large, khulan are listed as Near Threatened by the IUCN Red List, as rapid infrastructure development and socio-economic changes in combination with climate change may quickly and negatively affect this highly mobile species which needs access to large tracts of land (Kaczensky et al., 2015, 2020; Kauffman et al., 2021a, 2021b). Historically, the population in Mongolia was continuous with khulan in the three northern provinces of China, namely Xinjiang Uygur Autonomous Region (hereafter referred to as "Xinjiang"), Gansu Province ("Gansu"), and Inner Mongolia Autonomous Region ("Inner Mongolia"). However, this situation has changed with the construction of the border fence along the international border in the 1990 s and its subsequent reinforcement (Yang, 2007; Kaczensky et al., 2011a, 2011b; Linnell et al., 2016).

A critical review and assessment of the current situation in China is lacking (Lin et al., 2011). The 2015 Red List assessment assumed a population of ~5000 khulan based on regional studies from Inner Mongolia and Xinjiang, China from the early 2000 s (Li et al., 2002; Gao et al., 2002; Ge et al., 2003; Bi, 2007; Chu, 2009). Hence, this last assessment is based on data going back at least 15 years, which is well before the rapid construction of transport infrastructure and excessive exploitation of mineral and fossil resource started, which in northern Xinjiang resulted in a dramatic decline of the khulan population (Peng, 2012, 2015; Zhang et al., 2020).

Kalamaili Mountain Ungulate National Nature Reserve (hereafter "KNR") in northern Xinjiang is the most important reserve for desert ungulates in China, estimated to host the largest khulan population, China's largest reintroduced population of Przewalski's horse (*Equus ferus przewalskii*), and a large population of Goitered gazelle (*Gazella subgutturosa*) and Argali sheep (*Ovis ammon*) (Chu et al., 2009; Xu, 2012; Zhang et al., 2020). In 2005, exploitation of mineral and fossil resources started which resulted in a dramatic increase in anthropogenic activities. From 2015–2019, the massive exploitation was shut down completely and ecological restoration work begun. However, in 2017, the construction of an expressway and a railroad parallel to the existing highway (G216) created new

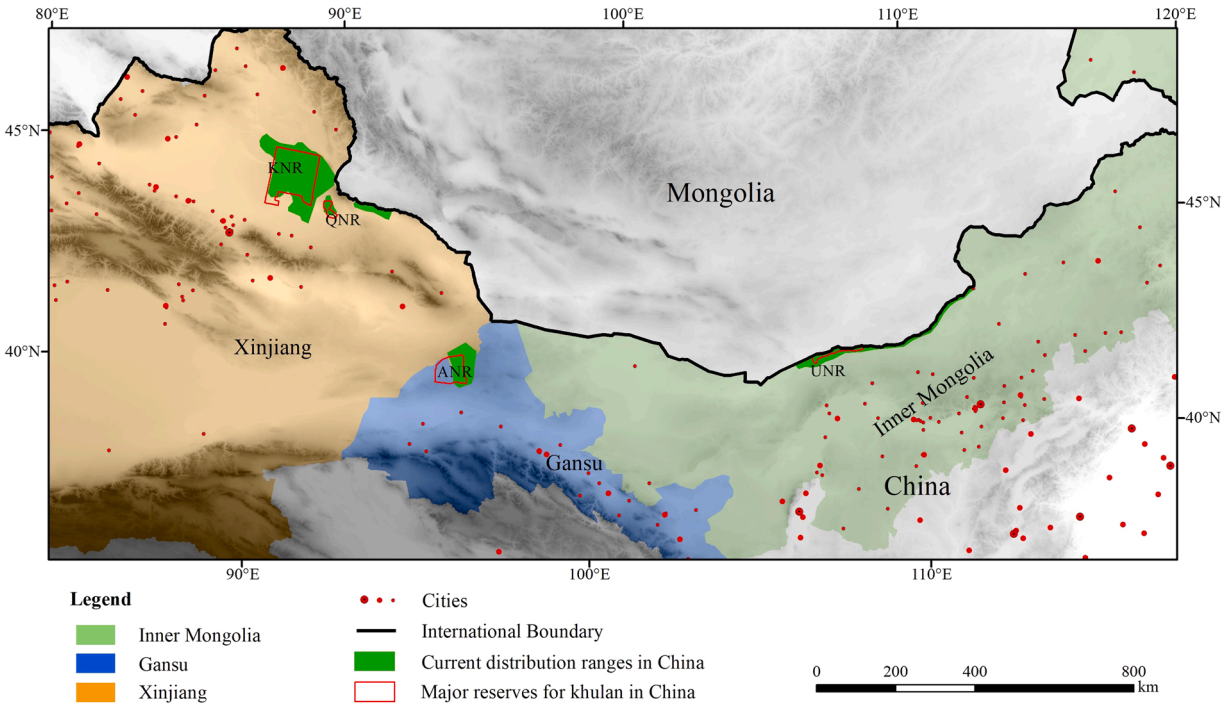

Fig. 1. Study area and major reserves for khulan in China. Sketch map of the GS (2016) 1600.

impacts to the reserve. Since then, several studies have looked at the effect of these new anthropogenic disturbances on khulan but were largely published in Chinese only (Lin et al., 2012; Xu et al., 2012; Wang et al., 2016).

While there has been a focus on KNR, systematic studies from the other regions, believed to have or have had khulan, are missing and the little existing information is highly fragmented. Given the anthropogenic impacts on khulan documented in KNR, it is likely that remaining khulan populations remaining in other parts of northern China are experiencing similar pressures. We therefore believe it is very important to compile and update the current status of khulan in China and distribution and communicate the threats the species faces KNR as a basis for a national conservation strategy for the species.

For the status update we reviewed the peer-reviewed and grey literature on the status and distribution of khulan in China in the past, updated the current status based on field studies and interviews in Xinjiang province and based on the most recent literature, and newspaper reports from the reminder of the range. For a better understanding of the threats, we reviewed the studies on environmental habitat factors and human disturbances for khulan in KNR.

2. Materials and methods

2.1. Study area

We divided the known and potential khulan range in northern China into three regions: northern Xinjiang, northwestern Gansu, central and western Inner Mongolia (Fig. 1). The entire area is the part of the Mongolian plateau with an average elevation of ~1000 m above sea level, dominated by the plains and pluvial fan with eroded gullies, hummocks, rocky outcrops, and rolling hills. Surface water sources are rare in the area. The vegetation is sparse, and dominates by desert shrubs and dwarf shrubs, e.g. *Haloxylon ammodendron*, *Ceratoides latens*, *Reaumuria soongorica*, *Anabasis* spp., *Calligonum* spp., *Nitraria* spp., etc. Dense vegetation is only found near water (i.e. oasis and intermittent rivers) and is dominated by *Phragmites communis*, *Juncus* spp., and *Achnatherum splendens*. The

Table 1
Characterization of the three major reserves of khulan range in northwestern China.

Habitat parameter	KNR	ANR (Northern part)	UNR	References
Regions	Northern Xinjiang	Northwestern Gansu	Western Inner Mongolia	Fig. 4
Coordinates	44°36′ - 46°00′N, 88°30′ - 90°03′E	41°12′26″ - 41°47′33″N, 94°43′35″ - 95°47′52″E	41°50′ - 42°27′N, 106°15′ - 108°00′E	Chen et al. (2021); Bao et al. (2020); Zhao and Jin (2019).
Terrestrial Ecoregions of the World (TEOW)	Junggar basin semi-desert	Alashan plateau semi-desert	Alashan plateau semi-desert	Olson et al. (2001)
Size of the reserve	14,856 km^2	3995 km^2	1318 km^2	Chen et al. (2021);
Landscape type	Plains in the north and south, sand dunes in the west, and rolling hills of Kalamaili Mountains in the center.	Large pluvial plains in the west, and mountains in the east.	Plains and small fault basins alternate with low hills.	Bao et al. (2020); Zhao and Jin (2019).
Range in elevation	600–1464 m	1300–2335 m	840–960 m	
Average annual temperature	2.4 ℃	5 ℃	4.4 ℃	Zhang et al. (2020); Bao et al. (2020);
Range in monthly temperature averages	-24.3–20.5 ℃	-16.9–32.4 ℃	-14–34.3 ℃	Zhao and Jin (2019).
Average rainfall	186.8 mm	50.9 mm	138.5 mm	
Average snow cover	ca. 100 days	Irregular	Irregular	
Dominate plant families	Chenopodiaceae, Asteraceae, Brassicaceae, Fabaceae and Poaceae	Asteraceae, Chenopodiaceae, Poaceae, Fabaceae and Brassicaceae	Chenopodiaceae, Zygophyllaceae, Polygonaceae, Fabaceae and Convolvulaceae	Xu et al. (2012); Bao et al. (2020); Bi (2007).
Dominate plant communities	*Haloxylon ammodendron*, *Seriphidium terrae-albae*, *Anabasis salsa, Ceratoides latens*, *Stipa glarosa*	*Haloxylon ammodendron*, *Nitraria sphaerocarpa*, *Reaumuria soongorica*, *Sympegma Regelii*, *Stipa glareosa*	*Haloxylon ammodendron*, *Nitraria tangutorum*, *Artemisia arenaria*, *Caragana korshinskii* and *Stipa glareosa*	
Herder presence / year	ca. 4 months	No livestock	12 months	Zhang et al. (2020); Bao et al. (2020);
Seasonality of herder presence	Winter	–	Year-round	Zhao and Jin (2019).
Herder camp density	0.015/km^2	–	0.02/km^2	
Average livestock density (all species)	6.55/km^2	–	2.73/km^2	
Human infrastructure	Railway, expressway and highway	Railway, expressway and highway	Railway and fence	Bao et al. (2020); Zhang et al. (2020); Bi (2007)

key protected areas in these three regions are KNR in northern Xinjiang, northern part of Anxi Extreme-arid Desert National Nature Reserve (hereafter ANR) in northwestern Gansu, and Urad National Nature Reserve (hereafter UNR) in Inner Mongolia (Fig. 1). All these reserves have the similar continental arid climate characterized by long cold winters and short hot summers, but vary somewhat in respect to topography, vegetation, and human impact such as lands use and infrastructure (Table 1).

2.2. Methods

2.2.1. Literature review for khulan occurrence in China

To assess the status of khulan throughout China, we searched through (1) all publicly reported news from http://www.chinaso.com/, (2) scientific reports and peer-reviewed publications in Chinese available at Chinese academic search engines via https://xueshu.baidu.com/, or English accessed via Web of Science. We used the search terms "野驴", "蒙古野驴" and "亚洲野驴" in Chinese, "Asiatic wild ass", "Mongolian wild ass", "Khulan" and "*Equus hemionus*" in English.

We divided the information on population size and area of occurrence into three time periods: $<$ 1980, 1980–2009, and $\geq$ 2010. The year 1980 marks the beginning of the "reform and opening up" of China, while $\geq$ 2010 was used to describe the present status of khulan. We based the current distribution range of khulan in China on the most recent publications from Gansu, Inner Mongolia, and our own surveys in Xinjiang. The shrinking of the khulan range from 1950 to 1980–1980–2010 is based on Gao and Gu (1989), Zheng and Gao (2000), and other regional studies before 2010.

2.2.2. Field and interview surveys for khulan occurrence in Xinjiang

Xinjiang has been the core of the khulan distribution since the 1980 s and so we had restricted our systematic field surveys to this region only. The areas surveyed included the Baytik Mountains (or Baitag Bogd) and Haftik Mountains (or Takhin Shar Naruu Mountains) in 2008–2010 (Xu, 2012; Yang et al., 2016), KNR in 2018–2019 (Zhang et al., 2020), and other area along China-Mongolia border in northeastern Xinjiang in 2020 (Fig. 2). The presence of khulan was confirmed by any sign, including carcasses and body remains (Fig. 3). Fresh feces and footprints were also used to identify the existence of khulan near the border (where there was no livestock present, or in areas where livestock is only seasonally present but was not in the area during the survey).

As a complementary approach, we also carried out interview during the field survey in 2008, 2010 and 2020 (Fig. 2). Totally, 5 local forestry rangers (n = 5) and 8 herders (n = 8) were interviewed during the field survey in the border area. Forestry rangers tend to have the experience and knowledge about the area and khulan, for these people are well trained by the local forestry departments of the government. And local herders often hold substantial ecological knowledge, which can be used to inform species management and

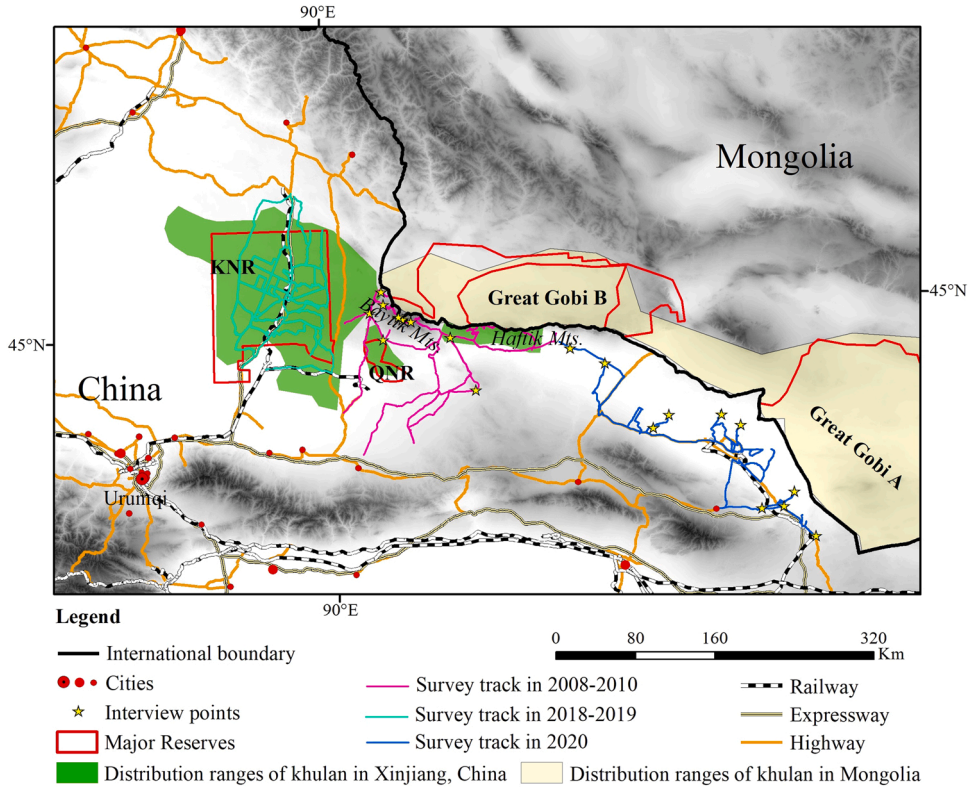

Fig. 2. Field survey in northeastern Xinjiang, China. Sketch map of the GS (2016) 1600.

Fig. 3. Khulan and signs (entire carcass, and body remains) found in the Haftik Mountains of northern Xinjiang, China.

policy-making (Cui et al., 2017). Due to the large body size and similarity to horses, khulan are well-known by local herders and are unlikely to be confused with any other wild ungulate species. When talking with rangers and herders, we asked open questions on whether, when, and where they had ever seen or heard khulan, the location of their livestock pastures in different seasons, and their attitude towards wildlife. The possible current stressors affecting the khulan population were also asked. Furthermore, totally 6 border soldiers we met during the survey were also interviewed. When we met soldiers on patrol near the border, we show them the wildlife photos, and ask what, when and how many wildlife they have seen in the area during their service.

2.2.3. Population estimation in Xinjiang

During the survey in Xinjiang, the weather was sunny and calm, all transects were traversed by an off-road vehicle at 20–30 km h^{-1}, and checked by 2–4 observers. On detection of khulan, with the aid of binocular and monocular (CarlZeiss Terra ED 10 ×42 and DiaScope 85 T * FL), laser rangefinder (Bosma LA-1500), hand-held GPS receiver (Garmin 631sc) and compass, the group size, coordinates, distance and the angle (°) between the direction of transect and the khulan group were recorded.

In 2008 and 2010, terrestrial line transect surveys were conducted in Baytik Mountains and Haftik Mountains (Fig. 2). Given the ruggedness topography in this region (mountains) (Fig. 3), strip transect method was used to estimate the khulan population in this region (Xu, 2012). The density of khulan on each strip transect (D_i) was obtained by dividing the recorded number of khulan (N_i) by the area of the strip (A_i). The ridge on either side of each transect is the boundary of the strip transect, and the area of each strip transect (A_i) was calculated by the ArcGIS, and the density of the survey area (D) was the arithmetic mean of the density in each transect (Gong and Zhang, 2010). The khulan population in this region (N) was estimated by multiplying the average density (D) and the total area (A) of the survey area.

In 2018–2019 and 2020, with relatively flat topography, distance sampling line transect surveys were conducted in KNR and the border area to the east of Haftik Mountains (Fig. 2). The surveys in KNR get enough number of replicated lines to ensure that variation in encounter rate could be estimated with adequate precision, and ensured sufficient observations to fit the detection function (Table 2) (Buckland et al., 2001). Therefore, the software Distance 7.0 was used to estimate khulan densities from line transects (Thomas et al., 2010).

3. Results

3.1. Status of khulan in northern China

Besides the field survey conducted in northwestern Gansu and western Inner Mongolia in 1976 (Zheng and Gao, 2000), we did not find any other studies that estimated population size of khulan in China before 1980. However, descriptions of khulan presence in the literature (Gao, 1987; Zheng and Gao, 2000; Si, 2004), suggest that the species used to be widespread and abundant in northwest China in the past. Early guestimates from the 1980 s suggested that there may have been less than 2000 animals distributed over 140,

Table 2
Summary of own field surveys for khulan in Xinjiang, China.

Date	Area	No. of Transects	Total length (km)	No. of group	No. of khulan	No. of signs	Population estimation
06/30–07/12 2008	Baytik Mt.	4	256.6	0	0	0	0
	Haftik Mt.	6	414.2	10	37	5	251 ± 53
08/15–08/24 2010	Baytik Mt.	6	653.8	0	0	0	0
10/31–11/07 2010	Haftik Mt.	6	610.2	6	54	3	144 ± 84
06–08 2018	KNR	16	1841.9	356	2731	18	3246 ± 575
06–07 2019	KNR	11	1340	363	2051	14	
10/10–10/22 2020	Border area east of Haftik Mt.	9	1251.8	0	0	0	0

000 km^2 of Gobi area in Xinjiang, Gansu and Inner Mongolia adjacent to Mongolia (Gao and Gu, 1989; Zheng and Shao, 1994; Zheng and Gao, 2000). Numbers had apparently sharply decreased due to hunting (Gao, 1987), and the rapid expansion of oasis during 1950–1970 s (Cheng et al., 2002).

3.1.1. Xinjiang

In Xinjiang, khulan were often seen in the western and southwestern Junggar Basin in the 1950 s (Gao, 1987). Within the next 20 years, the species became increasingly restricted to the eastern part of the Junggar basin, and by the 1980 s was primarily found from the Kalamaili Mountain north to the Ulungur River (Chu et al., 1985; Gao and Gu, 1989). As a consequence, KNR was established in 1982 in this region aiming to conserve khulan and other rare ungulates (Liang, 1982).

3.1.1.1. KNR. Based on an aerial survey, the population of khulan in the reserve numbered only 358 animals in 1982 (Chu et al., 1985). Subsequently, the khulan population was continuously monitored using terrestrial line transect sampling which documented a steady increase of the khulan population in KNR. In 2006, the population reached its peak at 5318 ± 1102 (Table 4, Fig. 4) (Wang, 1993; Xu et al., 1997; Ge et al., 2003; Chu et al., 2009). However, thereafter the population within the reserve decline sharply (Chu et al., 2009; Peng et al., 2012), reaching a low of only 1358 ± 749 animals in 2012 (Peng et al., 2015). An investigation in 2016 confirmed that the khulan population had begun to recover (Investigation report of KNR, 2016). In 2018 and 2019, the field surveys were conducted in KNR, the total survey effort were 27 transects with 3181.9 km, and the estimated population of khulan in KNR is 3246 ± 575 (Fig. 4) (Zhang et al., 2020). Although the sampling intensity varies year to year (Appendix A), and make the results not so precise, these results can roughly explain the change of khulan population in KNR.

3.1.1.2. Outside KNR. South to KNR, Qitai forestry administration confirmed that there are about 300–400 khulan distributed in the rangeland close to the sand dunes of the Gurbantunggut Desert, which are isolated from the reserve by railway and highway. Although no systematic monitoring has been conducted, photos by the journalist from Xinhua News Agency clearly confirmed the presence of the species (Appendix B). In addition, khulan also occur in Qitai Desert Grassland Nature Reserve (QNR, 493 km^2, Fig. 2) to the east of KNR (Zhang et al., 2021), but there has been no systematic population assessment so far (QNR pers. comm. 2021).

The area along the international border with Mongolia is another important distribution range for khulan in Xinjiang (Shaw and Chao, 1957; Wang et al., 1983; Gao and Gu, 1989; Zheng and Gao, 2000; Gao et al., 2002). Therefore, the field surveys were conducted in 2008, 2010 and 2020 in this region (Table 2). By transects in 2008 and 2010, we failed to find any khulan and their signs in Baytik Mountains, and confirmed the distribution of khulan in Haftik Mountains that adjacent to Great Gobi B Strictly Protected Area (SPA) in Mongolia (Fig. 2). The population is unstable in Haftik Mountains with only 251 ± 53 in 2008 and 144 ± 84 in 2010 (Xu, 2012).

In the past, khulan were also distributed in the border area to the east of Haftik Mountains that adjacent to the Great Gobi A SPA in Mongolia (Gao and Gu, 1989; Zheng, 1998; Zheng and Gao, 2000). However, our investigations and interviews (Fig. 2) with local forestry rangers (n = 3), herders (n = 2) and border soldiers (n = 5) revealed that no khulan have been seen in this region since 2010.

3.1.2. Gansu

In Gansu, khulan were common in northwestern part of the province in the 1950 s and 1960 s, khulan were found in the

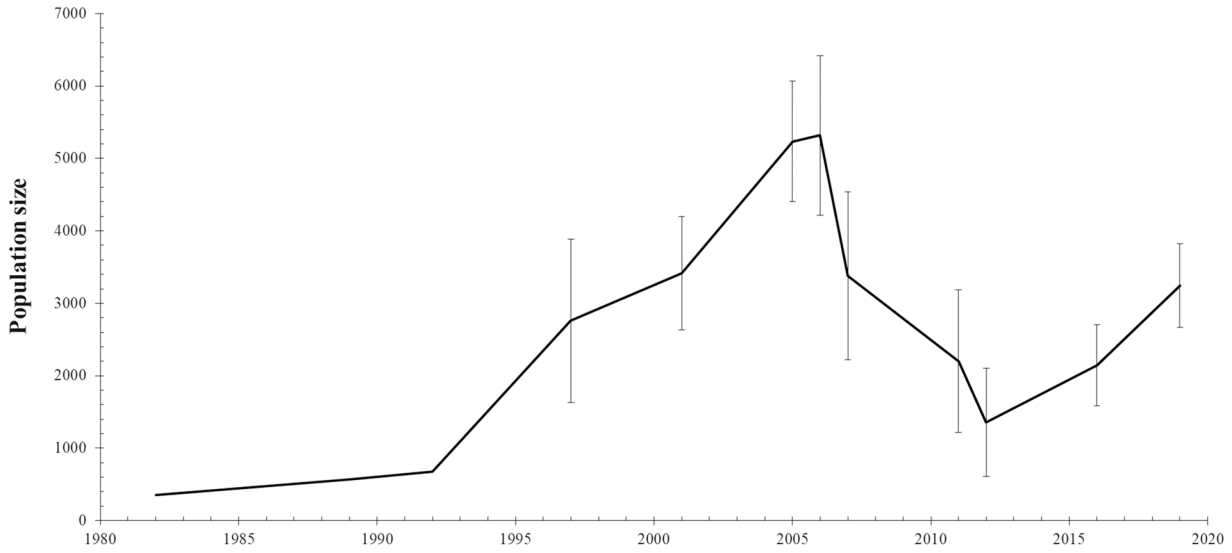

Fig. 4. Population fluctuation of khulan in KNR, China. Note: Data of khulan population in KNR comes from Chu et al. (1985); Wang (1993); Hu et al. (1998); Xu et al. (1997); Ge et al. (2003); Bi (2007); Yue et al. (2008); Chu (2008); Chu et al. (2009); Peng (2012); Peng (2015); KNR Investigation Report, 2016 and Zhang et al. (2020) (Table 4). And 2005–2015 is the period of the massive exploitation in KNR (Chen et al., 2021).

surrounding area of the Mazongshan Mountain (or Beishan Mountain) (Gao and Gu, 1989; Chen and Luo, 1991; Zheng and Gao, 2000; Si, 2004), herds of khulan from this region sometimes came into the Transaltai Gobi within Mongolia. Khulan receded to the border area with their population declined dramatically in 1970 s, and only 16 animals were recorded by a field investigation conducted in 1976 (Zheng and Gao, 2000). West to Mazongshan Mountain, ANR was established in 1988, and the following three scientific investigations conducted in 1988, 2002 and 2012 have confirmed the occurrence of khulan in this reserve but did not attempt to estimate population size (Zhang et al., 2008; Bao et al., 2014). Recent studies suggested that, except for the northern part of ANR and its surrounding areas, there have been no khulan in the border areas or other areas (including the Mazongshan Mountains) in northwestern Gansu since 2009 (Zhao et al., 2011; Zhao, 2016; Liu et al., 2017).

In 1993, 30–40 khulan in 2 groups were encountered in ANR during a field investigation (Chen and Luo, 1997). After that, khulan were spotted only occasionally during forestry rangers' routine patrols and scientific investigations (Zhang et al., 2008; Bao et al., 2014). According to the information provided by ANR Administration, in 2015, a group of 13 khulan was photographed by an infrared camera trap (Appendix C), which was the first time that such a large group was seen since 1993. In 2018, according to the information by the Gansu Provincial Environmental Protection Department, a group of 16 khulan was captured by an infrared camera trap (http://www.gs.chinanews.com/news/2018/08–16/307424.shtml). Further camera trapping efforts suggest that the khulan population has increased greatly in 2019 (Bao et al., 2020), and we speculate that there may be up to 100 khulan in ANR (Table 4).

3.1.3. Inner Mongolia

In Inner Mongolia, khulan were common in the vast rangeland from the Alashan prefecture eastward to Xilingol during the 1950–1970 s (Xing and Yang, 1982; Zheng and Gao, 2000). After 1980, the distribution range receded to the border area close to Mongolia (Liang, 1989; Gerelt et al., 2007). According to Wang and Schaller (1996), the khulan range in Inner Mongolia was limited to a narrow strip about 15 km wide along the border, and the population size was estimated at 250 animals at the most, sustained by immigration from Mongolia.

According to a field investigation conducted in 1976, 85 khulan were recorded in Ejin, Alashan prefecture (Zheng and Gao, 2000). In June 1987, on the other hand, only 2 khulan and 4 khulan carcasses were encountered in the 800 km^2 of border area in Alashan prefecture (Liang, 1989); and in 1990 s, only a few animals were spotted occasionally near the border area (Gerelt et al., 2007). A field investigation conducted in 2006 failed to detect any khulan or their signs such as feces and footprints. Furthermore, border soldiers also had not seen any animals during their patrols in recent years (Bi, 2007). If there are still any surviving khulan in this region, it is unlikely that the population exceeds 50 animals (Bi, 2007). Furthermore, no khulan were recorded using the wildlife crossings of the G7 expressway (from Beijing to Urumqi) in the Alashan prefecture (Li et al., 2018, 2019; Zhang et al., 2019).

Nowadays, khulan only range from Urad (or Wulate) Houqi in Bayannur to Erenhot in Xilingol along the border in Inner Mongolia, and are mainly concentrated in UNR. In summer 2000, about 11,400 khulan breached the border fence and migrated from Mongolia to the border area of Urad Houqi and Urad Zhongqi in Bayannur as a result of drought (Li et al., 2002). To better protect this rare equid species, UNR was upgraded to a national nature reserve in 2001. However, most individuals returned to Mongolia, and the total number of khulan within UNR was estimated at no more than 100 in 2005 (Bi, 2007). According to the estimation of Bi (2007), the khulan population likely numbers 180–250 in the border area from Bayannur to Erenhot in Xilingol. Considering there have been persistent news reports on khulan roaming on the border areas in recent years (Table 3), this estimation is still valid now (Table 4).

3.1.4. Current range and population estimation in China

Combining all areas and sources of information, we estimate that the remaining khulan range in China covers probably less than 40,000 km^2 and is scattered over several nature reserves and the border areas in northern Xinjiang, northwestern Gansu, and western Inner Mongolia in northern China (Fig. 1). Although the presence of khulan these three provinces was confirmed as before, the distribution range has shrunk dramatically in the past decades (Fig. 5).

Our synthesis highlights that monitor efforts on khulan populations are not homogeneous among different distribution ranges of

Table 3
News reports about khulan found in Inner Mongolia 2013–2021.

Date	Sources	Place
12/11 2021	https://xw.qq.com/cmsid/20211211V06HU700	Border area in Urad Zhongqi
03/12 2021	http://inews.nmgnews.com.cn/system/2021/03/12/013087599.shtml	Border area near inland port of Mandula in Baotou
02/19 2021	https://www.chinanews.com/shipin/2021/02–18/news880780.shtml	Border area in Sonid Youqi
02/01 2021	http://inews.nmgnews.com.cn/system/2021/02/01/013065078.shtml	Border area near inland port of Erenhot
01/14 2021	https://news.cctv.com/2021/01/14/ARTIt6uh4ePnlHxsV9t5qjl8210114.shtml	Border area near inland port of Ganqimaodu in Urad Zhongqi
12/26 2020	https://tv.cctv.com/2020/12/26/VIDEFYoZevuqZeU1DBZE4pQM201226.shtml	Border area in Sonid Youqi
08/31 2020	http://xhpfmapi.zhongguowangshi.com/vh512/share/9365381	Border area in Urad Zhongqi
04/21 2020	https://xw.qq.com/cmsid/20200421A0D17700	Border area in Urad Zhongqi
04/17 2020	http://www.xinhuanet.com/video/2020–04/17/c_1210561565.htm	Border area in Urad Zhongqi
11/18 2019	https://www.chinanews.com/sh/shipin/cns/2019/11–18/news838667.shtml	Border area near inland port of Erenhot
06/11 2019	https://www.sohu.com/a/319898077_206722	Border area in Urad Zhongqi
01/16 2018	http://news.cnr.cn/native/city/20180116/t20180116_524101357.shtml	Border area in Sonid Youqi
12/04 2014	https://www.chinanews.com/sh/2014/12–04/6846465.shtml	Border area in Sonid Youqi
07/09 2013	https://news.sina.com.cn/o/2013–07–09/210827621844.shtml	Urad Nature Reserve in Urad Zhongqi

Table 4
Khulan population estimates in China based on literature review and own field surveys.

Province	Prefecture	Region	Year	Population Estimation	Investigation method	Reference
Xinjiang	Altay and Changji	KNR	1982	358	Aerial strip transect	Chu et al. (1985)
			1989	568	Terrestrial line transect	Wang (1993)
			1992	680	Terrestrial line transect	Hu et al. (1998)
			1997	2760 ± 1127	Terrestrial line transect	Xu et al. (1997)
			2001	3416 ± 784	Terrestrial line transect	Ge et al. (2003)
			2005	5234 ± 834	Terrestrial line transect	Bi (2007); Yue et al. (2008)
			2006	5318 ± 1102	Terrestrial line transect	Chu (2008); Chu et al. (2009)
			2007	3379 ± 1160	Terrestrial line transect	
			2011	2201 ± 983	Terrestrial line transect	Peng (2012)
			2012	1358 ± 749	Terrestrial line transect	Peng (2015)
			2016	2144 ± 562	Terrestrial line transect	KNR Investigation Report, 2016
			2018–2019*	**3246 ± 575**	Terrestrial line transect	Zhang et al. (2020)
		Qitai county	2018	**300–400**	Direct counting	Qitai forestry administration, 2018
	Changji and Hami	Haftik Mountains	2008*	251 ± 53	Terrestrial line transect	Xu (2012)
			2010*	**144 ± 84**	Terrestrial line transect	
Gansu	Jiuquan	ANR and Mazongshan	2021	**< 100**	Infrared camera traps	*Estimation in This study*
Inner Mongolia	Alashan	Border area	2006	< 50	Terrestrial line transect	Bi (2007)
	Bayannur, Baotou, Ulanqab and Xilingol	Border area (including UNR)	2000	11,400	Terrestrial line transect	Li et al. (2002)
			2005	**180–250**	Terrestrial line transect	Bi (2007)
Estimated total population size for China			1989	< 2000		Gao and Gu (1989)
			1994	< 2000		Zheng and Shao (1994)
			2015	~5000		Kaczensky et al. (2015)
			2021	~4000		*This study*

Note: the bold number is used to estimate the total number of khulan in China in this paper, and the year with * is our own field survey.

China (Table 4), resulting in high levels of uncertainty around population size estimates in different regions. And just by adding our most recent estimation in Xinjiang (Xu, 2012; Zhang et al., 2020), the direct counting in Qitai county, our speculation in ANR in Gansu (Table 4), and the still valid estimation in Inner Mongolia (2007); we estimate the total population in China at ~4000 khulan (Table 4), with the vast majority occurring in protected areas, primarily in KNR (~80%). And this estimation of khulan in China may be underestimated as the population in QNR and the area around KNR were not investigated (Fig. 2).

3.2. Factors influencing khulan habitat use in KNR

Earlier studies indicated that over-hunting and extensive agricultural activities were the major threats to khulan in China before 1980 (Gao, 1987; Gao and Gu, 1989). Since 1980, the economy of China has developed rapidly, which exposed khulan to new anthropogenic interferences (Zheng, 1998; Zheng and Gao, 2000). However, no studies on how these new anthropogenic activities affected khulan were conducted anywhere, except for KNR, and even here most studies to date have been primarily descriptive.

Chu et al. (1985) found that khulan were concentrated in the northeastern part of KNR, and concluded that water, terrain condition, and anthropogenic impacts were the three major factors influencing habitat use of khulan. Recent quantitative analysis, identified food and water as the key factors affecting small-scale habitat selection of khulan in KNR (Chu, 2008; Xu, 2012), while anthropogenic factors, such as the highway, mine exploitation, and grazing livestock, are the key factors affecting the larger-scale habitat selection of khulan in KNR (Lin et al., 2012). MaxEnt modeling, determining the suitable habitat – before mining development (2005), at the peak of mining development (2011), and after ecological restoration and road construction (2019) – confirmed the overarching importance of water during all time periods, but also documented a 13% reduction in suitable habitat during peak exploitation (Chen et al., 2021). Ecological restoration recovered the total suitable habitat but resulted in a lower proportion of highly suitable versus moderately suitable habitat (Chen et al., 2021; also see Appendix D). Furthermore, the new, fenced expressway and fenced railway which run parallel to the old highway have severely fragmented the protected area into a western and an eastern part (Zhang et al., 2020; Chen et al., 2021).

4. Discussion

4.1. Status of khulan in China

Our assessments based on a literature research for all of China and own field assessments in Xinjiang confirmed the presence of khulan in Xinjiang, Gansu and Inner Mongolia. Although there were no systematic population estimates of khulan available from

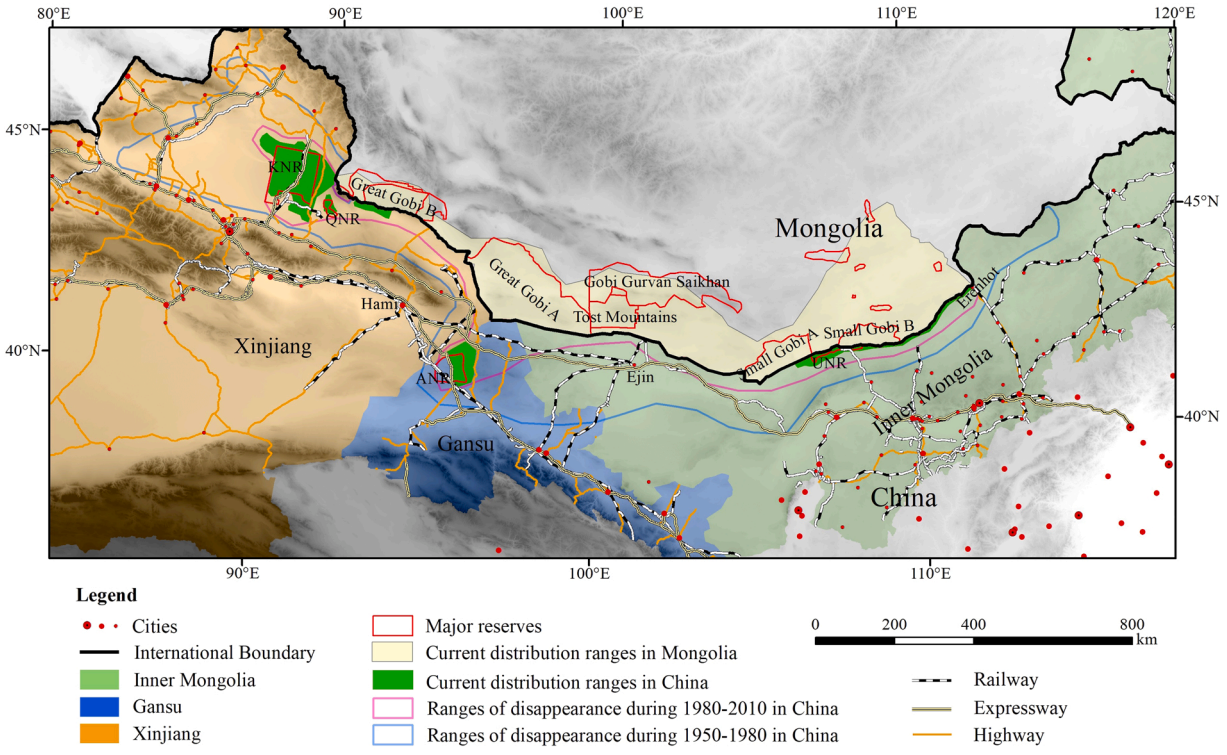

Fig. 5. Past and present distribution range of khulan in China. Note: Distribution ranges of khulan in Mongolia download from IUCN that assessed by Kaczensky et al. (2015). Sketch map of the GS (2016) 1600.

before 1980, it is clear that the distribution range and population size of khulan in China decreased dramatically since the 1950 s, which resulted in the classification of the species as a first-class protected animal according to the relevant provisions of "the Wildlife Protection Law of China" enacted in 1989. Compared with the national assessments from 1989, 1994 and 2000, the current khulan range has been reduced from an estimated 140,000 km^2 in 1989 to less than 40,000 km^2 (Fig. 1). Furthermore, the khulan range in China was separated into several populations that scattered in some reserves and remote areas of Xinjiang, Gansu, and Inner Mongolia (Fig. 5).

Our population estimate, on the other hand, is about twice as high as those from 1989 and 1994 (Table 4). These early population assessments likely underestimated the true population sizes due to the lack of adequate field data, and we do not assume that the population has in fact doubled. Rather, the dramatic shrinkage and fragmentation of the distribution range suggests that the future of the species in China is far from secure. With about 80% of the total population currently living in KNR, which was the most important area defining the status of the species in China, conservation efforts in this reserve will be instrumental for the future fate of khulan in China. And results of long-term systematic studies from KNR and adjacent Mongolia are most relevant for khulan conservation in the reminder of the range in China.

4.2. Threats

4.2.1. Over-hunting

Before "the Wildlife Protection Law of China" was enacted in 1989, all wildlife hunting was legal. Hunting of khulan likely happened throughout their range but was only rarely documented (i.e., in Mosuowan in the southwestern Junggar Basin, 84 khulan were documented to have been shot in 1958–1965; Zheng and Gao, 2000). After 1989, illegal hunting remained a problem, but with efforts by the national and regional governments and increased public awareness of wildlife protection in recent years (Huang et al., 2021; Wei et al., 2021; Yang et al., 2021), illegal hunting on khulan does not seem to constitute a major problem as the firearms are tightly controlled (Linnell et al., 2016).

4.2.2. Habitat fragmentation

Fences constitute absolute barriers for khulan, as the animals seem unwilling to jump and unable to crawl underneath them (Kaczensky et al., 2020). Fences alongside international borders, expressways, and railways are the most pervasive barrier that have unintended, but significant impacts on far ranging wildlife (Fahrig and Merriam, 1994; Ito et al., 2010; Trouwborst et al., 2016; CMS, 2019). The large population in the Mongolian Gobi is an important source of animals for the small and highly fragmented khulan populations in the border areas in Xinjiang, Gansu and Inner Mongolia, but the international border fence currently severely hinders khulan movements (Kaczensky et al., 2011b; Linnell et al., 2016). In recognition of this importance, four openings in the border fence within UNR in Inner Mongolia were created on September 10, 2009 to allow for transboundary khulan movements (Chen, 2009; Appendix E). However, this action has not been coordinated with the Mongolian side and lack of professional scientific report.

But in China fences have also increased on rangelands since the introduction of the "Rangeland Contract Responsibility System" in the mid-1980 s (basically introducing a system of grazing prohibition and grazing rest often implemented through fencing; Greenfield et al., 2021). These fences pose a serious threat to wildlife by splitting populations, impeding migrations, restricting access to resources, and killing animals attempting to cross (Forman and Alexander, 1998; You et al., 2013; Greenfield et al., 2021).

Roads and railways also have been identified as significant barriers for migratory ungulates such as khulan, particularly if the traffic volume is high or if they are fenced (CMS, 2019; Kauffman et al., 2021b). For example, the linkage between ANR and Great Gobi A was completely blocked by expressway, railway and border fence (Fig. 5). China has one of the most developed road networks in the world. In Xinjiang alone, the highway and railway network exceed 200,000 km (including 5500 km of expressway) and 7700 km, respectively as of 2020 (http://xj.people.com.cn/n2/2021/0609/c186332–34768643.html). By law, all expressways and railways must be fenced in China, with the exception of specific wildlife overpasses or bridges. The new expressway and railway that run parallel to the old highway G216 constitute a major barrier to the seasonal movement of khulan, making them more vulnerable to local catastrophic events (i.e., droughts or severe winters, Kaczensky et al., 2011a) thereby reducing the perspective for long term survival of the species in KNR (Chen et al., 2021; Appendix D).

4.2.3. Habitat loss

Mineral and fossil resource exploitation and associated constructions have been recognized as a key factor leading to habitat loss of wildlife globally (i.e., Edwards et al., 2014; Sonter et al., 2020). The distribution range of khulan in northern China and southern Mongolia overlaps in large parts with areas rich in mineral and fossil fuel deposits. The area is currently experiencing a rapidly developing mining industry, which if not carefully mitigated, poses a serious threat to the long-term survival of khulan due to habitat fragmentation, habitat loss, disturbance, and impact on water resources (Wang et al., 2016; Buuveibaatar et al., 2016b; Kaczensky et al., 2015, 2020).

KNR houses the largest populations of khulan in China. However, due to the large-scale coal exploitation, thermal power plant and coal chemical industry construction during 2005–2015, the local government successively reduced the size of KNR from originally 18,000 km^2 to 12,800 km^2 (Wang et al., 2016). During the peak of mining development in 2011, a lot of suitable khulan habitat was negatively impacted; the core habitat (highly suitable area) decreased by 30%, the habitat became fragmented (Chen et al., 2021; Appendix D), and the khulan population decreased dramatically (Peng, 2012, 2015; Fig. 4). This negative development in KNR aroused wide concern from the public in China which resulted in a stop of mineral exploitation followed by ecological restoration and an area increase to 14,856.48 km^2. Recent population estimates confirmed that the khulan population has responded positively to these

measures and increased again (KNR Investigation Report, 2016; Zhang et al., 2020; Fig. 4).

4.2.4. Competition with livestock

Historically, khulan were distributed beyond the Gobi (Reading et al., 2001). And now, the ranges of khulan in China and Mongolia are restricted to the Gobi Desert which is characterized by long, cold winters and low pasture productivity (Pfeiffer et al., 2018; Kempf, 2021). In Xinjiang, the rangelands used by the khulan are usually the traditional winter pasture of local herders which have historically coexisted with khulan for millennia. However, with the rapid economic development in the 1980 s, livestock have been rapidly increasing. For example, KNR is currently inhabited by ~2000 nomadic Kazakh herders with ~200,000 livestock from November to March (Chu et al., 2008; Xia et al., 2014; Ji et al., 2017). Livestock tends to occupy the pastures with the best productivity, thereby reducing habitat quality for khulan in winter (Lin et al., 2012). The dietary overlap between khulan and domestic sheep in KNR was 48.3% during winter, with khulan consuming more woody plants potentially as a consequence of avoiding people and livestock as also suggested for Great Gobi B SPA in adjacent Mongolia (Xu et al., 2012; Burnik Šturm et al., 2017). Avoidance of people and livestock is also seen at water points, which khulan in KNR do not visit if they are occupied by the horses, cattle, and camels (Wang et al., 2016; Zhang et al., 2020). To address concerns over competition and disturbance by livestock, some herders and their livestock have recently been moved out of KNR, and the reserve was successfully upgraded to a national nature reserve in 2020, and was shortlisted as a national park this year (KNR pers. comm. 2022).

4.3. Management recommendations

Key factors which negatively influenced khulan were habitat loss, fragmentation, and disturbance due to mining exploration and infrastructure development. No systematic monitoring of khulan is done in the rest of the khulan range, but whereas illegal hunting seems no longer a serious threat, infrastructure development and land use changes (including increasing livestock numbers) are happening throughout the remaining range of khulan in China. Furthermore, on top of this comes climate change with expected higher temperatures, which will impact pasture and water availability, and an increase in the frequency of extreme events (Joy et al., 2020).

Khulan in China are now primarily restricted to protected areas or border regions with limited access. However, experiences from KNR showed that anthropogenic pressures do not necessarily stop at reserve boundaries. Even if ecological restoration can reverse negative effects, it is extremely costly, often does not reverse all negative effects (i.e., the fragmentation effect of the upgraded transportation corridor in KNR), and initially puts the population at risk during the impact phase. The small number and highly fragmented range of the remaining khulan population in China is cause of concern. Small population size makes the species vulnerable to localized chance events (i.e., extreme weather, disease outbreaks) and fragmentations hinders recolonization, reduces the flexibility to respond to changes in pasture and water availability, and threatens genetic variability (Kauffman et al., 2021a, 2021b).

The khulan population in northern China was once continuous with khulan in Mongolia and in the highly fragmented areas along the Mongolian border, long-term survival will depend on immigration of khulan from Mongolia. In Xinjiang, connecting KNR with the Great Gobi protected areas on the Mongolian side, would benefit the species in the Junggar basin by increasing the range and allowing for higher movement flexibility and genetic exchange over a large transboundary protected area network (Kaczensky et al., 2011a, 2011b; CMS, 2019). Hence there is an urgent need to develop a national khulan conservation strategy and action plan which initiates cross-border cooperation with Mongolia to safeguard the long-term survival of the species in the Gobi region. This status update is an important first step for such a national strategy and will contribute to the global khulan action plan aimed to be developed under the Convention of Migratory Species Central Mammals Initiative in spring 2023.

Declaration of Competing Interest

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02156.

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