Is the hangul *Cervus hanglu hanglu* in Kashmir drifting towards extinction? Evidence from 19 years of monitoring

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Abstract The Tarim red deer *Cervus hanglu* has been recently recognized as a separate deer species with populations in China, Central Asia and Kashmir. These populations are few, isolated and at risk of extinction. The documented range of the Kashmir population of the hangul, now recognized as *Cervus hanglu hanglu*, is restricted to c. 808 km^2 and comprises < 200 individuals, confined mainly to the 141 km^2 Dachigam National Park. A few relict herds inhabit the surrounding landscape. Here we analyse the results of almost 20 years of population monitoring (January 2001–March 2020). We found that this population is unable to increase despite full protection within Dachigam National Park. We performed a population viability analysis using both deterministic and stochastic simulations and found that further population decrease is likely. We recommend the use of improved monitoring methods to investigate the population dynamics of the hangul and the implementation of measures to reduce the risk of extinction faced by this small population. Science-based conservation policies, including ex situ conservation and reintroduction programmes, will be required to increase the hangul population size and range.

Keywords *Cervus hanglu hanglu*, hangul, Himalayas, Kashmir, population trend, population viability analysis, Tarim deer

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Introduction

The Kashmir deer *Cervus hanglu hanglu*, or hangul, was previously assumed to be one of the easternmost subspecies of red deer *Cervus elaphus*, but has now been recognized as a subspecies of the Tarim red deer *Cervus hanglu*, together with the Yarkand or Tarim deer *Cervus hanglu yarkandensis* (north-western China) and the Bactrian or Bukhara deer *Cervus hanglu bactrianus* (western Central Asia; Ahmad et al., in press). The *C. hanglu* subspecies are characterized by a complex biogeography as their populations are small and highly fragmented, and the ranges of the three subspecies are distant from each other, separated by the Himalayas and the Takla Desert (Wilson & Mittermeier, 2009). Such fragmentation is probably the result of both environmental conditions and human actions. At the species level, *C. hanglu* is categorized as Least Concern on the IUCN Red List (Brook et al., 2017a), but the Kashmir subspecies *C. hanglu hanglu* is categorized as Critically Endangered (Brook et al., 2017b) and listed as a Schedule 1 species under the Indian Wild Life (Protection) Act 1972. It is one of the conservation priority species in the National Wildlife Action Plan (2017–2031) of India (Ahmad et al., 2021).

The hangul is endemic to the mountains of the Kashmir Valley (Prater, 1980; Grzimek, 1990; Geist, 1998; Nowak, 1999). It was once widely distributed along the Greater Himalayan mountain range in Kashmir (Gee, 1966; Holloway & Wani, 1970) but the viable hangul population is now restricted to Dachigam National Park (Fig. 1), with a few relict herds in nearby areas (Ahmad et al., 2009, 2013, 2015, 2021; Qureshi et al., 2009). The hangul is characterized by a female-biased population structure and a low calf-to-hind ratio, probably because of predation by leopards *Panthera pardus*, meso-carnivores (foxes *Vulpes vulpes*, jackals *Canis aureus*) and domestic dogs belonging to local security forces and nomadic livestock graziers (Ahmad et al., 2009, 2015, 2021; Qureshi et al., 2009). Poaching has been a significant limiting factor that has been exacerbated because patrolling by rangers is made difficult by the presence of insurgents and armed forces (Ahmad et al., 2009; Qureshi et al., 2009). As a consequence there has been a decrease in genetic heterozygosity (Ahmad et al., 2009; Mukesh et al., 2013; Ahmad & Nigam, 2014; Lorenzini & Garofalo, 2015; Kumar et al., 2016).

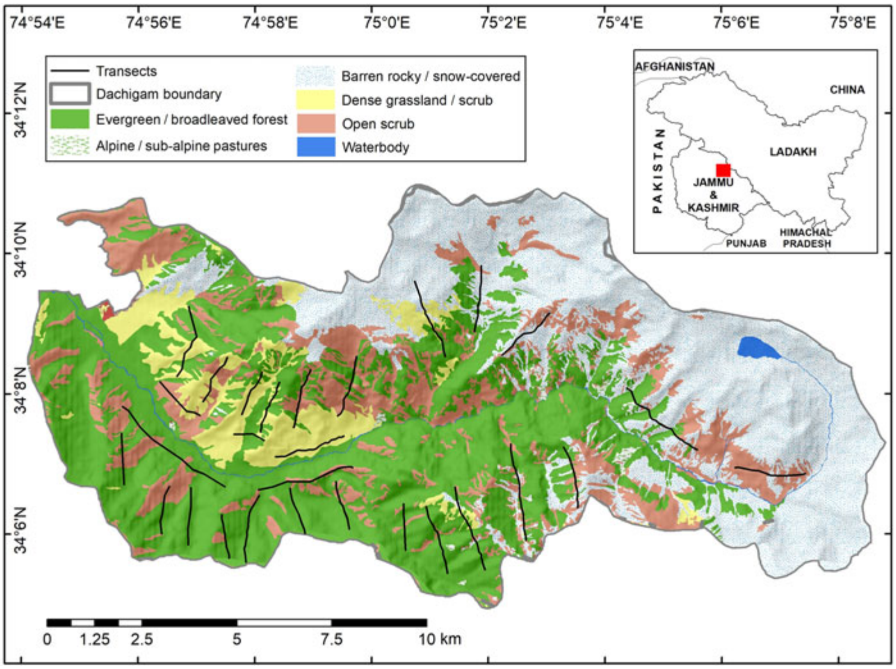

FIG. 1 Dachigam National Park, India, indicating the locations of the transects used for surveying the hangul *Cervus hanglu hanglu*. (Readers of the printed journal are referred to the online article for a colour version of this figure.)

Despite the lack of precise estimates it appears that the hangul population declined in the first half of the 20th century, from an estimated 5,000 in 1900 to 2,000 in 1947 (Gee, 1966; Schaller, 1969). This decline continued in the more recent past (Ahmad et al., 2009, 2013, 2015; Qureshi et al., 2009), and the latest estimates are a population of 175–190 (Ahmad et al., 2021; Charoo et al., 2021), suggesting this subspecies could be in terminal decline. We believe this population might be trapped in an extinction vortex because of its small population size, low genetic variability and fragmented range.

Here we present the findings from 19 years of monitoring the hangul, and updated demographic parameters. To assess the likelihood of the current population declining to extinction we performed a population viability analysis (Lacy et al., 2017). Our main aim was to generate realistic demographic projections that could reflect hangul population growth and dynamics. To address uncertainties associated with demographic processes in small populations we used both deterministic and stochastic formulations (Lacy et al., 2017) and developed multiple scenarios to assess the probability of extinction. These scenarios offer insights for conservation planning and will be of value for developing appropriate science-based management policies, prioritizing conservation actions, and ensuring the long-term survival of this highly threatened subspecies endemic to the Kashmir Himalayas.

Study area

We performed this study in the 141 km² Dachigam National Park (Fig. 1). The study area was described in detail by Ahmad et al. (2015). A large part of the area is forested, interspersed with large areas of grassland and scrubland and with pastures at high elevations.

Methods

We surveyed the study area using the methodology suggested by Holloway (1970) and modified by Routledge (1982) and Jhala et al. (2005). We designed a network of 30 transects of known length following trails and *nullahas* (streams) and used the strip count method to monitor the hangul. Where possible, we placed transects orthogonally to the ecological gradient to reduce between-transect variance. We conducted observations during 06.00–11.00 and 16.00–19.00 in spring and summer and during 08.00–11.00 and 15.00–17.00 in autumn and winter. Author KA, together with trained forest staff and researchers, performed the surveys and counts every year during January 2001–March 2020. At every sighting, observers noted the time and group composition, categorizing individuals into stags and hinds ($>$ 2–3 years of age), subadults (1–2 years of age, male/female including spiker males; i.e. a young male with one tine antler) and juveniles or calves ($<$ 1 year of age, readily distinguishable by their size and spotted body markings in summer).

To facilitate comparisons, we computed the kilometric index of abundance (number of individuals observed per km of transect). As the sampling was irregular during the 20-year period, for each analysis we selected a fixed number of months, to control for variations in detectability, which is affected by the status of vegetation, as follows: (1) For the analysis of the population trend we selected observations collected in February–May and October. This led to the exclusion of data from 2009, 2013 and 2020 when there were no surveys in some of these months. (2) For the analysis of the adult sex ratio we pooled data for adult and subadult males as they are often difficult to discriminate. We used observations collected in February and March, when the presence of antlers facilitates discrimination of males and females (detectability is facilitated in these months because of the congregation of deer in open areas of new grass growth). This led to the exclusion of data from 2007 and 2011. (3) We computed the calf-to-hind ratio using the data for September–October (cf. Bonenfant et al., 2005, for red deer). By this time calves are sufficiently grown to be visible and not concealed within vegetation, allowing their differentiation from hinds by their smaller size. This led to the exclusion of data from 2001, 2002, 2009, 2013, 2014, 2018 and 2020. Assuming that adult females give birth in late spring, it is possible to compute the neonatal mortality rate of calves. The results may be subject to bias if subadult hinds have been misclassified as adults, leading to a potential underestimation of the calf-to-hind ratio. (4) We computed the overwinter mortality of subadult males using the kilometric index of abundance of calves in year t as computed in (3) above divided by 2 (assuming a 50:50 sex ratio at birth and identical neonatal mortality in males and females) and the kilometric index of abundance of subadult males in year $t+1$, using the data for August–October when subadult males have recognizable, well-developed antlers. Mortality is hence

$$\frac{KIA_t - KIA_{t+1}}{KIA_t}$$

where KIA is the kilometric index of abundance. This value resulted in a bias in several years when the value of the kilometric index of abundance in year t was smaller than the kilometric index of abundance in year $t+1$. This might have occurred because of differing detectability of the adult and subadult males. Mortality is therefore apparent mortality because some animals might have moved outside the study area, where they may be exposed to greater threats.

For population viability analysis we used *VORTEX* (Lacy & Pollak, 2021). We performed deterministic simulations to assess hangul population growth rate using an age-structured model with three age classes. However, deterministic simulations serve as simplified models of an actual population, especially when dealing with a small population in a fluctuating environment. In population viability analysis one needs to separate the impacts of demographic and environmental variability. Environmental variability indicates the temporal variations in ecological conditions experienced by the studied population. Variations in vital rates represent interactions between environmental and demographic stochasticity. We separate these two components, following Lacy et al. (2017).

Accordingly,

$$\sigma_{EV} = \sqrt{\sigma_{EV}^2} = \sqrt{\sigma_{TOT}^2 - \sigma_{DS}^2}$$

where σ_{EV} represents the standard deviation of vital rates because of environmental factors and σ_{TOT}^2 and σ_{DS}^2 refer to total (observed) variance and demographic variance, respectively. The demographic component is computed by assuming a binomial distribution of the individual survival rate (p). Accordingly, $q = 1 - p$ is the probability of mortality, with variance $np(1-p)$, where n is the number of individuals in the sample. However, as we do not have individual samples but a mean value over the population, we assume $n = 1$, an assumption that probably increases the estimate of the variance. We derived the value for σ_{EV} using the mean demographic variance.

Results

Variation in the kilometric index of abundance, sex ratio, calf-to-hind ratio and subadult overwinter mortality during 2001–2020 are presented in Fig. 2. There is no evident trend in the kilometric index of abundance ($r = 0.003$, $F_{1,15} = 0.098$, P = 0.750), with an intercept of 0.55 ± SD 0.21 deer per km of transect. The mean adult sex ratio was 0.15, which suggests high mortality of adult males. The sex ratio remained stable ($r = 0.004$, $F_{1,16} = 1.250$, P = 0.270), with large annual fluctuations. The mean calf-to-hind ratio was 0.17 ± SD 0.090 and the regression coefficient was significantly negative ($r = -0.011$ ± SD 0.004, $t_{11} = -2.6$, P = 0.025), probably indicating an increase in calf mortality over time. The mean overwinter mortality of subadult males was 0.85 ± SD 0.87. The regression coefficient was −0.006 but not significantly negative ($F_{1,5} = 4.530$, P = 0.086).

The deterministic population viability analysis (Table 1) highlights the precarious state of the Dachigam population. Our parameter estimates consistently indicate that this population is in a critical state. Even the most favourable indicator (the trend) suggests that without intervention the population is likely to shift towards extinction.

To perform stochastic simulations, we report the mean calf and subadult mortality (Table 2). For subadults the total variance was 0.89 and the environmental variance was 0.77. For calves the total variance was 1.73 and the environmental variance was 1.59. The standard deviations of the environmental stochasticity used in *VORTEX* simulations were 1.26 for calves and 0.87 for subadults. A significant per cent of the simulations resulted in negative growth rates, as shown by the left tail of the probability density function being longer than the right tail (Fig. 3), indicating that large negative trends are more likely than large positive ones. The mean regression coefficient was just below zero. However, the predicted trends were

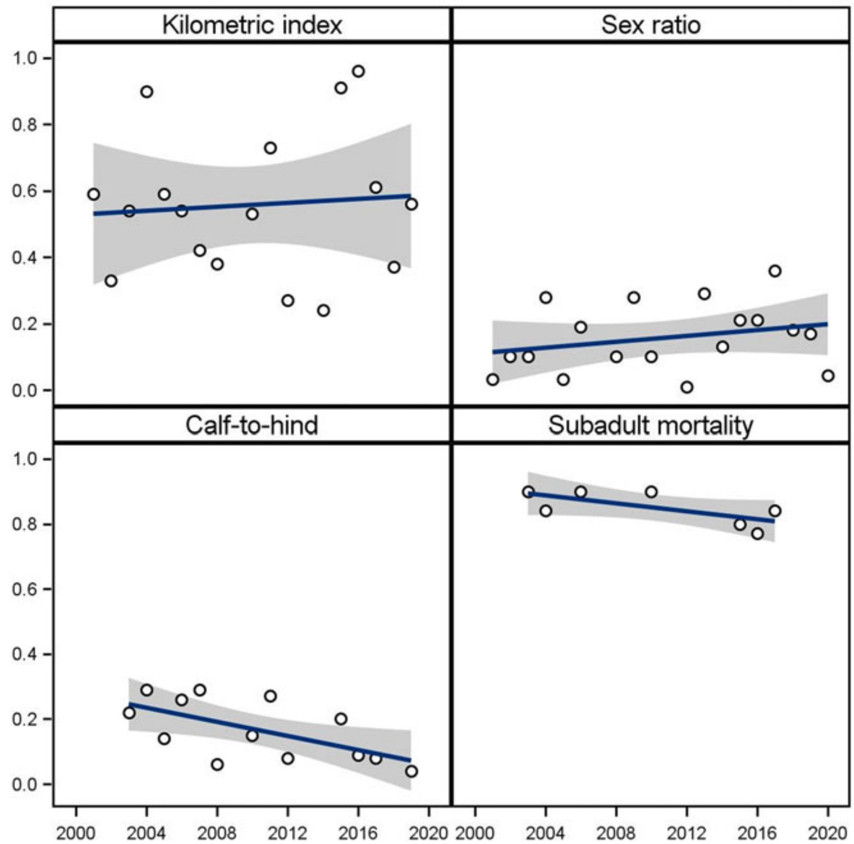

FIG. 2 The kilometric index of abundance (number per transect km), sex ratio (male : female), calf-to-hind ratio and subadult mortality of the hangul in Dachigam National Park (Fig. 1) over 2001–2020. The grey areas indicate the 95% confidence limits of the regression line.

usually small (either negative or positive), so we do not expect under present circumstances a catastrophic crash in this population.

Discussion

Although we did not find a negative trend in the kilometric index of abundance, our simulations and the population estimates, including the population trends and growth rates (Ahmad et al., 2013, 2014, 2021; Brook et al., 2017), strongly suggest that the hangul population in Kashmir may be in a terminal phase of decline and could become extinct if effective interventions are not implemented. The population could remain trapped in an extinction vortex because of its small population size, reduced genetic variability and small range.

We have identified certain concerns regarding the quality of data collected during the monitoring, particularly the significant inter-annual variability in the estimated variables. Despite our efforts to minimize bias in data collection,

TABLE 1 Deterministic population viability analysis of the hangul *Cervus hanglu hanglu* in Dachigam National Park, India (Fig. 1). The growth rate was computed for a range of subadult (columns) and calf mortality (rows). We obtained adult mortality data from Bonenfant et al. (2002), but we constrained them to the sex ratio observed in the study area. White cells indicate positive growth rates, dark grey cells indicate negative growth rates and light grey cells indicate the observed set of mortality values for calves and subadults.

	Subadult mortality								
Calf mortality	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.1	0.400	0.381	0.330	0.306	0.266	0.220	0.168	0.110	−0.014
0.2	0.375	0.345	0.317	0.303	0.247	0.203	0.152	0.081	−0.035
0.3	0.327	0.323	0.271	0.250	0.224	0.167	0.127	0.057	−0.055
0.4	0.302	0.281	0.241	0.219	0.186	0.135	0.105	0.039	−0.063
0.5	0.270	0.247	0.230	0.185	0.151	0.121	0.083	0.004	−0.070
0.6	0.218	0.208	0.173	0.153	0.104	0.081	0.041	−0.021	−0.071
0.7	0.170	0.156	0.124	0.095	0.086	0.031	**0.003**	−0.042	−0.085
0.8	0.097	0.086	0.067	0.051	0.013	−0.021	−0.043	−0.077	−0.088
0.9	0.004	−0.053	−0.055	−0.067	−0.085	−0.091	−0.092	−0.100	−0.110

TABLE 2 Mortality and survival probabilities and demographic variance for hangul calves and subadult males in Dachigam National Park for each seasonal period that we assessed. For calves we assessed the spring–summer period and we assumed that all adult females gave birth (which is likely for a population with low density and low competition for resources amongst hinds). For subadults we assessed the autumn–winter period.

Period	Mortality	Survival	Variance
Calves			
2003	0.78	0.22	0.17
2004	0.71	0.29	0.21
2005	0.86	0.14	0.12
2006	0.74	0.26	0.19
2007	0.71	0.29	0.21
2008	0.94	0.06	0.06
2010	0.85	0.15	0.13
2011	0.73	0.27	0.20
2012	0.92	0.08	0.07
2015	0.80	0.20	0.16
2016	0.91	0.09	0.08
2017	0.92	0.08	0.07
2019	0.96	0.04	0.04
Mean	0.83	0.17	0.13
Subadults			
2003–2004	0.90	0.10	0.09
2004–2005	0.84	0.16	0.13
2006–2007	0.90	0.10	0.09
2010–2011	0.90	0.10	0.09
2015–2016	0.80	0.20	0.16
2016–2017	0.77	0.23	0.18
2017–2018	0.84	0.16	0.13
Mean	0.85	0.15	0.13

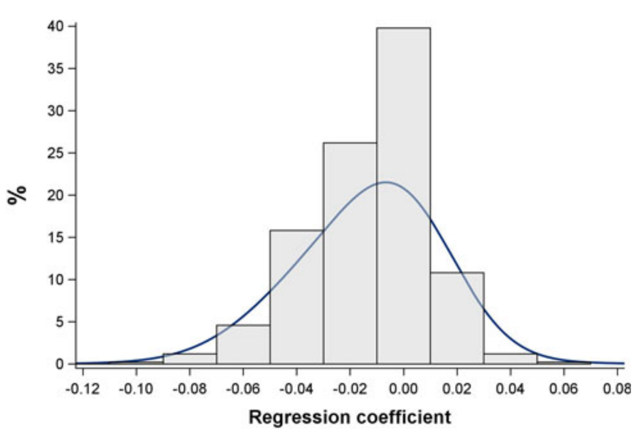

FIG. 3 The distribution of regression coefficients of the linear population trends of the hangul in Dachigam National Park. For each of 500 stochastic simulations (with a simulation horizon of 50 years) we computed the regression coefficient between the population size and years. We considered the environmental stochasticity for both calf and subadult mortality. A positive value of the regression coefficient indicates a growing population trend and a negative value a decreasing trend. The continuous line represents the kernel-based density of the observed distribution.

the variations in the data raise concerns about the reliability and accuracy of the estimates. However, we believe that our analysis has summarized the fundamental aspects of hangul population dynamics. To improve the quality of data to support conservation of this population, monitoring using advanced camera-trapping methods, such as distance sampling (Pal et al., 2021), is required. This has been used to take account of imperfect detectability in the Trans-Himalayas and Western Himalayan region of western India in estimating the density of blue sheep *Pseudois nayaur* and Himalayan musk deer *Moschus leucogaster*. Although implementing this method in Dachigam National Park will require significant time and resources, it is a crucial step towards improving conservation strategies. Camera-trap monitoring could also be used to estimate the hangul calf-to-hind ratio and develop occupancy models for the species. This information would be useful when planning more complex approaches to population assessment. Alternatively, observers could apply conventional distance sampling protocols (Buckland et al., 2015) using the existing network of transects.

During the study period we observed a female-biased sex ratio that we do not believe was a result of observation error (throughout the monitoring all observers utilized binoculars and consistently observed the biased sex ratio). The adult sex ratio averaged 0.15, suggesting high mortality of adult males. This is a marked decrease compared to historical reports for the hangul, which reported 25–30 males per 100 females (Schaller, 1969; Holloway, 1970; Inayatullah, 1987). In contrast, red deer typically exhibit a sex ratio of 50–70 stags per 100 females (Whitehead, 1972; Clutton-Brock et al., 1982, 1986). A female-biased sex ratio in red deer could result from selective abortion of male foetuses (Landete-Castillejo et al., 2004) or loss of male embryos before implantation (Flint et al., 1997) because of the susceptibility of red deer females to stress during gestation.

In red deer the calf-to-hind ratio is typically 16–54 fawns per 100 females (Clutton-Brock et al., 1982). Similar values were observed in a red deer population in France (range 0.2–0.6; Bonenfant et al., 2005). Hangul historically exhibited a calf-to-hind ratio of 45 fawns per 100 females (Schaller, 1969). We estimated the calf-to-hind ratio of 0.17 ± SD 0.09 based on all female age classes (because of difficulties in discriminating yearling and subadult hinds), which means that the figures we obtained might be biased low.

Our results suggest a progressive increase in calf mortality over 20 years. The recorded average subadult male mortality during the overwinter period in the hangul population (0.85 ± SD 0.87) significantly exceeded that of other red deer populations (0.2–0.3; Clutton-Brock et al., 1985). Predation on calves by domestic dogs and meso-carnivores, Asiatic black bears *Ursus thibetanus* and common leopards has been reported (Ahmad et al., 2009; Qureshi et al., 2009). Our population viability analysis suggests that any further reduction in calf survival could result in the extinction of the Kashmir population. It is therefore important to monitor calf survival and identify appropriate management actions (e.g. the removal of feral dogs).

Livestock presence in the upper reaches of Dachigam National Park, as well as in the unprotected areas adjacent to the Park that form corridors connecting Dachigam with the hangul relict range areas, poses a significant threat to the long-term survival of the hangul and its habitats (Ahmad et al., 2009; Qureshi et al., 2009). For example, elsewhere the presence of livestock during the summer displaces elk *Alces alces* and red deer, which disperse from the affected areas (Franklin, 1979; Clutton-Brock et al., 1982). The noticeable increase in livestock density reported by Ahmad et al. (2009, 2013, 2021) in the alpine pastures of the upper Dachigam National Park and its surrounding areas could have significantly affected the distribution and population size of the hangul. If the presence of livestock is not reduced, this could lead to further declines in the hangul population. Livestock removal would allow the highly productive summer habitats to recuperate, and could support the recovery of the hangul population.

The small population size and the large fluctuations in demographic parameters suggest that restocking the hangul in existing suitable habitats within the species' historical range is essential. This would require a breeding centre and the selection of appropriate restocking areas. Shikargah Conservation Reserve would be a good candidate for restocking, as it houses the only conservation breeding centre for the hangul and still hosts a wild population of 10–15 individuals, which range between the contiguous Shikargah and Overa-Aru Wildlife Sanctuaries. Overa-Aru Wildlife Sanctuary in the Lidder Valley is largely free from anthropogenic influences and its topography, climate and vegetation are similar to those of Dachigam National Park. In addition, there is a corridor connecting Overa-Aru Wildlife Sanctuary with Dachigam National Park, which would be beneficial for establishing a second viable hangul population.

To restock Shikargah Conservation Reserve and reintroduce the hangul to Overa-Aru Wildlife Sanctuary, a plan to initiate such a programme with 20 young hangul individuals (preferably 7 males and 13 females; Ahmad et al., unpubl. data) from the wild population in Dachigam National Park would be necessary. Efforts should also be made to attract wild hangul into the conservation breeding centre from areas adjoining Shikargah Conservation Reserve. Implementation of these recommendations would require the collective commitment of all stakeholders, the cooperation of administrative bodies and the provision of adequate technical support from the national and international scientific and conservation community.

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Author contributions Project conceptualization, data collection: KA, SC, RYN; study design: KA, PN, QQ, SF; data analysis and simulations: MM, SF; writing: KA, SF, with input from all other co-authors.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

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