Population assessment of the Endangered Nilgiri tahr *Nilgiritragus hylocrius* in the Anamalai Tiger Reserve, using the double-observer survey method

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Abstract The Nilgiri tahr *Nilgiritragus hylocrius* is an Endangered species of mountain ungulate endemic to the Western Ghats of India, a biodiversity hotspot. Habitat fragmentation, hunting and a restricted range are the major threats to this species. Although several surveys have assessed the species' status, a population estimate based on a scientifically robust method is needed. We used the double-observer method to estimate the population of the Nilgiri tahr in the Anamalai Tiger Reserve, a protected area in the Western Ghats. We walked 257 km of transects across the Reserve, covering 36 grassland blocks (i.e. clusters of montane grasslands that were relatively separate from each other). We counted a minimum of 422 individuals in 28 groups, and estimated the tahr population in the study area to be 510 individuals (95% CI 300–858) in 35 groups. The male:female ratio was 0.71 and the young:female ratio was 0.56. Comparing our estimate with previous surveys suggests that the Nilgiri tahr population in Anamalai Tiger Reserve is stable. We found the double-observer survey method to be appropriate for population estimation and long-term monitoring of this species, and make recommendations for improved field protocols to facilitate the implementation of the method in the tropical mountains of the Western Ghats. Our findings suggest that the Reserve harbours 20–25% of the global population of the Nilgiri tahr, highlighting the area's importance for the conservation of this species.

Keywords Capture–recapture, double observer method, endemic, Nilgiri tahr, *Nilgiritragus hylocrius*, mountain ungulate, population estimation, Western Ghats

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Introduction

Wild ungulates play an important role in maintaining ecosystems by influencing vegetation structure, plant species composition and nutrient cycling (Augustine & McNaughton, 1998; Bagchi & Ritchie, 2010). They are also critical determinants of predator population density (Carbone & Gittleman, 2002). Conservation of any species requires effective population monitoring (Yoccoz et al., 2001); understanding populations trends is thus crucial for implementing or assessing the impact of conservation actions. National and global assessments of species' extinction risk, such as the IUCN Red List of Threatened Species, rely on robust assessments of population sizes and trends.

The Nilgiri tahr *Nilgiritragus hylocrius* is a mountain ungulate endemic to the Western Ghats in India. It is categorized as Endangered on the IUCN Red List, based on criterion C2a(i) (Alempath & Rice, 2008), and is listed in Schedule I of the Indian Wildlife (Protection) Act 1972 (Parliament of India, 1992). The global population is estimated to be 2,000–3,000 individuals (Daniels et al., 2008; Predit et al., 2015). However, population estimates based on robust methods are scanty and our knowledge of the species' status and distribution remains limited. The Nilgiri tahr is restricted to montane grasslands and has a patchy distribution in the states of Tamil Nadu and Kerala. The species' range covers < 5% of the Western Ghats (Grubb, 2005). The Nilgiri tahr is primarily threatened by habitat loss and disturbance caused by invasive species, and in some sites by livestock grazing, poaching and fragmentation of the landscape (Daniels et al., 2008). Being a montane grassland specialist, the species is also particularly vulnerable to climate change as its habitat is highly climate-dependent (Sony et al., 2018). Surveys of the Nilgiri tahr in the Anamalai Hills have been conducted by Davidar (1971, 1978), Rice (1984), Mishra & Johnsingh (1998), Kumar et al. (2002) and Predit et al. (2015), with estimates of 500–600 individuals. The Anamalai Hills are one of the strongholds of the species and the Anamalai Tiger Reserve in Tamil Nadu is estimated to have the second highest number of Nilgiri tahrs after Eravikulam National Park in Kerala. Most previous surveys have estimated the tahr population using a total count method. Although it may be possible to conduct a total count of a population across a small area, it is difficult to accurately count all individuals when

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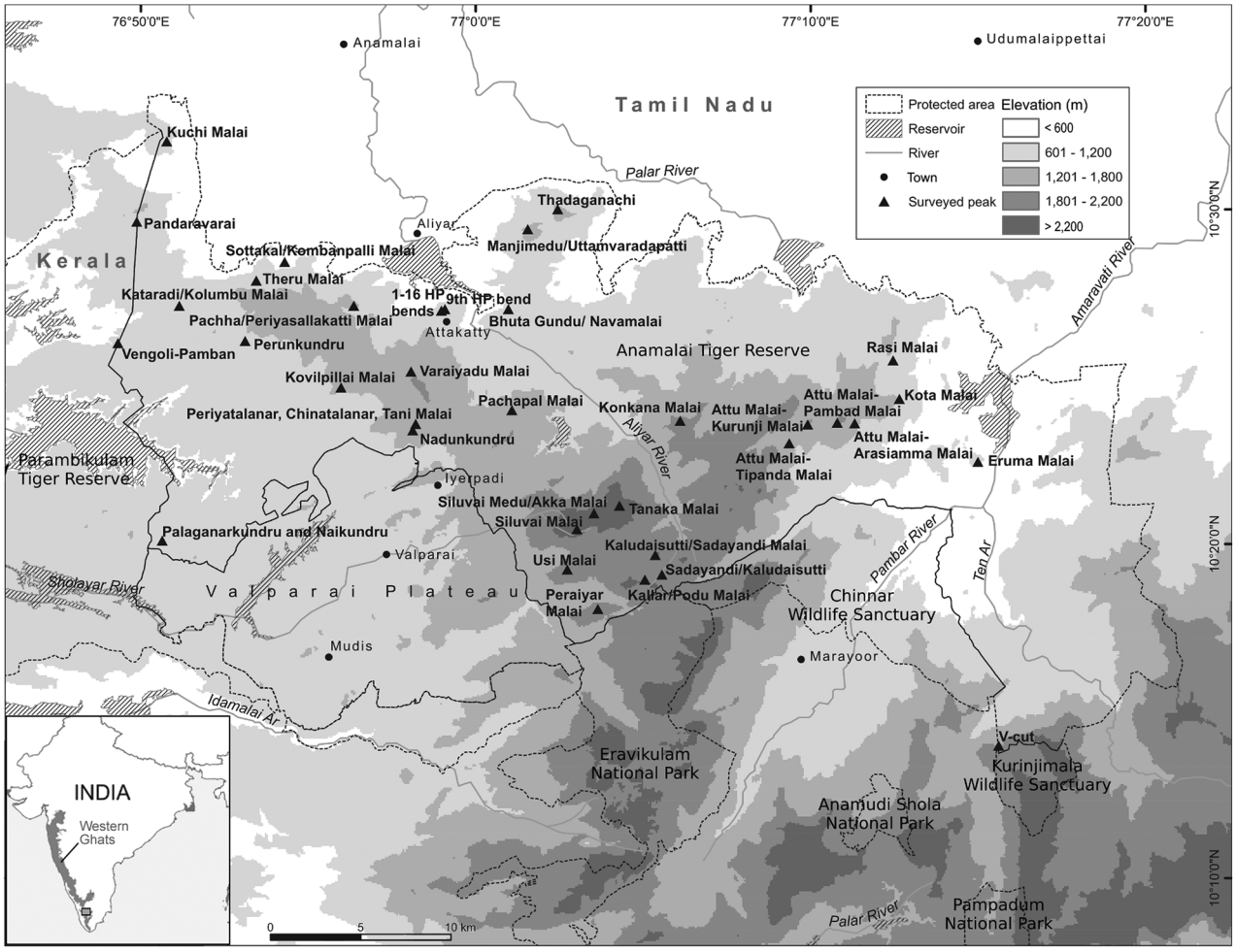

FIG. 1 The study area in India, showing the peaks in the Anamalai Tiger Reserve surveyed for the Nilgiri tahr *Nilgiritragus hylocrius*.

surveying large areas. In addition, total counts do not allow for an estimation of errors that enables statistical comparisons over time (Yoccoz et al., 2001). Standard methods used for monitoring ungulates in tropical forests, such as distance sampling and dung counts, are not suitable for estimating the Nilgiri tahr population as surveyors often cannot walk straight lines because of the complex terrain, and sighting distances can be long and difficult to estimate accurately in the species' mountainous habitat (Singh & Milner-Gulland, 2011; Suryawanshi et al., 2012). A recent study identified a panel of genetic microsatellite markers that can be used to identify individual tahrs, enabling population estimates based on a capture–recapture framework (Luis et al., 2017). However, genetic methods are too expensive and time-consuming for regular monitoring of animal populations.

Suryawanshi et al. (2012) standardized the double-observer survey method (Forsyth & Hickling, 1997) to estimate populations of mountain ungulates in the Himalayas. Since then, the method has been applied successfully to estimate the populations of the blue sheep *Pseudois nayaur*, ibex *Capra ibex*, argali *Ovis ammon*, urial *Ovis vignei* and markhor *Capra falconeri* (Michel et al., 2015; Tumursukh et al., 2016; Suryawanshi et al., 2017). The need to use a statically robust method to estimate the population of the Nilgiri tahr has been recognized in previous surveys (Predit et al., 2015). The primary goal of our study was to assess the suitability of the double-observer survey method for estimating the population in the Anamalai Tiger Reserve.

Study area

Anamalai Tiger Reserve is located in Coimbatore and Tiruppur districts of Tamil Nadu state, India, and covers 1,480 km², including the core and buffer area (Fig. 1). Tanaka Malai is the highest peak in the Reserve, at 2,513 m. The Reserve has six ranges: Pollachi, Valparai, Ulandy, Amaravathy, Udumalpet and Manamboli. Part of the Reserve has been gazetted as a National Park, including Grass Hills (3,123 ha) in Valparai Range and Manjampatty (7,202 ha) in Amaravathy Range, which contain much of the montane grasslands within the Reserve. The Reserve is bordered by Eravikulam National Park, Chinnar Wildlife

Sanctuary and Kurinjimala Wildlife Sanctuary in the south and Parambikulam Tiger Reserve in the west (Fig. 1). The altitude varies from 275 m in the Amaravathy and Udumalpet forest ranges to 2,400 m in the Grass Hills National Park region in Valparai Range. Annual rainfall is c. 800 mm in the eastern dry rain shadow region and c. 3,500 mm in the Reserve's wetter western ranges. The Reserve receives both south-west and north-east monsoons, with the former predominant in the western, and the latter in the eastern part. The terrain is rugged, with diverse vegetation types ranging from tropical dry thorn forest in the foothills (< 500 m), tropical dry and moist deciduous forests and tropical wet evergreen rainforests in mid-elevation areas (500–1,600), to montane grasslands interspersed with montane evergreen forests (*sholas*) at higher altitudes (> 1,600 m). There are c. 32 settlements with a total population of c. 6,000 people across the Reserve. There is a long history of forestry operations in the Reserve, and established tea and coffee plantations in the adjoining 220 km² Valparai Plateau. Montane grasslands above 1,600 m are the main habitat of the Nilgiri tahr, although some grasslands along cliffs in the drier, lower slopes are also used by the species.

Methods

Training and field survey

On 14 February 2018 a training workshop was held by DM, MK, TRSR and DR at the Attakatti Forest Training Centre in Anamalai Tiger Reserve for 45 officers and field staff of the Reserve, to familiarize staff with the double-observer method for estimating mountain ungulate populations. We conducted training sessions to discuss the assumptions of the double-observer survey method (Suryawanshi et al., 2012) and planned the fieldwork for the survey during the workshop. The double-observer survey method is based on the principle of capture–mark–recapture, but applied to groups rather than individuals. Most mountain ungulates cannot be identified individually, but groups can be identified by characteristics such as group size, age-sex structure and location. The unit being marked and recaptured in the double-observer technique is thus a group of animals rather than an individual. The method involves two observers locating and counting animals simultaneously or separated by a short time interval, ensuring they do not cue each other on the locations of the animals counted. After the training, nine researchers and 18 Forest Department staff (in teams of one researcher and two staff each) conducted field trials in Grass Hills National Park to assess the feasibility of the double-observer survey method. We found that the surveys conducted using this method yielded sufficient data for analysis. We conducted surveys to estimate tahr populations during 15 February–12 March 2018.

We identified potential sites of Nilgiri tahr occurrence from published studies (Kumar et al., 2002) and reports by knowledgeable forest staff and researchers. For practical reasons, we divided each of the Reserve's ranges into blocks; i.e. clusters of montane grasslands that were relatively separate from each other. The shape and size of these blocks depended on the terrain and the logistics of accessing and surveying the area. Block size varied from 1–2 km² to c. 30 km², and we divided large contiguous habitats such as the Grass Hills National Park (Fig. 1) into several blocks. We calculated the size of the total study area as the sum of all individual blocks, which we mapped using *QGIS 3.4.14* (QGIS Development Team, 2018). We mapped the blocks before carrying out fieldwork and used them to plan the surveys. In some cases a block's area was refined retrospectively, based on the area actually surveyed in the field, which did not always exactly match the planned survey block.

Each observer had a pair of binoculars (8 × 40) or spotting scope (20–40 × 60) to locate and characterize tahr groups. We covered 257 km along trails across 36 blocks during the surveys. Each block was surveyed by two teams following the recommendation of Suryawanshi et al. (2012), with the second team starting the survey c. 15–30 minutes after the first, depending on the estimated time needed to survey the block. For eight of the smaller survey sites, the same group acted as first observer on the outward survey and as second observer on the return survey. The observers ensured that they deployed a similar survey effort on both surveys. The total survey effort is summarized in Table 1.

We used a topographic map of the area and field experience of the local guards and our team to predetermine survey trails. Ridgelines or valleys were generally preferred as they provided the best views. Often, trails followed the topography of the landscape and were not straight lines. We started surveys just after sunrise as that is when tahrs are active, whereas they rest in potentially inaccessible sites (i.e. rocky outcrops) during the hot afternoon. We carried out surveys throughout the day, during 6.00–18.00. To ensure independence of observations we used only trained and/or experienced observers who had participated in the training workshop and/or had previously carried out double-observer surveys. Additionally, observers were instructed not to spend too much time at one spot regardless of whether or not they spotted a group of tahrs.

The assumptions underlying this survey method were that: (1) each block can be viewed in its entirety during the survey and any visibility gaps within the blocks are not so large that groups of tahrs could have spent an entire day in them and not be seen, (2) the survey by the second (or return) observer was independent of the first, and (3) the two observers recorded adequate information of the tahr sightings to be able to identify individual herds based on the age-sex composition of the herd, its location and any other specific details noted by observers. Both observers

TABLE 1 Total survey effort and number of Nilgiri tahrs *Nilgiritragus hylocrius* observed in various locations within each range of Anamalai Tiger Reserve, India.

Route (by range)	Date (2018)	Effort (km)	No. of tahrs observed
Valparai (Grass Hills)			
Kaludaisutti/Sadayandi Malai	16 Feb.	8	0
Usi Malai	16 Feb.	8	34
Peraiyar Malai	16 Feb.	11	0
Kallar/Podu Malai	16 Feb.	8.5	0
Siluvai Medu/Akka Malai	17 Feb.	8	43
Tanaka Malai	17 Feb.	10	137
Siluvai Malai	17 Feb.	8	10
Kallar/Sadayandi/Kaludaisutti	17 Feb.	10	0
Valparai			
Pachapal Malai	19 Feb.	7	38
Nadunkundru	19 Feb.	6	0
Konkana Malai	10 Mar.	13	0
Varaiyadu Malai	23 Feb.	4	9
Periya/ChinnaTalanar Malai, Tani Malai	24 Feb.	3	4
Konkana Malai	10 Mar.	13	0
Ulandy			
Perunkundru	20 Feb.	8	44
Vengoli–Pamban Malai	20 Feb.	7	0
Kovilpillai Malai	20 Feb.	4	18
Pandaravarai	20 Feb.	15	1
Kataradi/Kolumbu Malai	20 Feb.	10	0
Pollachi			
Aliyar road, 1st–16th hair-pin bends	23 Feb.	9	1
Kuchi Malai	21 Feb.	5	15
Sottakal/Kombanpalli Malai	21 Feb.	5	9
Theru Malai	21 Feb.	6	0
Pachha Malai, Periyasallakatti Malai	21 Feb.	13	16
Pollachi–Valparai road, 9th hair-pin bend	21 Feb.	3	12
Thadaganachi	22 Feb.	8	0
Manjimedhu/Uttamvaradapatti	22 Feb.	6.5	0
Bhuta Gundu/Navamalai	23 Feb.	3	0
Manamboli			
Palaganarkundru, Naikundru	24 Feb.	7	0
Amaravati			
Eruma Malai	06 Mar.	6	0
V-cut	07 Mar.	3	3
Udumalpet			
Attu Malai–Pambad Malai–Arasiamma Malai	09 Mar.	6.5	23
Attu Malai–Kurinji Malai–Tipanda Malai	09 Mar.	4	5
Kota Malai	09 Mar.	16	0
Rasi Malai	09 Mar.	7	0

noted whether or not tahr groups were detected, the number of groups observed, and number of individuals in each group. We recorded age-sex composition of tahr groups (with individuals categorized as saddleback male, young male, adult female, or young) wherever possible, using the guidelines of Rice (1988).

Data analysis

We estimated the total number of Nilgiri tahr groups using the two survey mark–recapture in the *BBRecapture* package, which uses the Bayesian framework, in *R 3.3.4* (Fegatelli & Tardella, 2013; R Core Team, 2018). We analysed the number of groups following Suryawanshi et al. (2012), and used group size, age-sex composition and location of sighting to assess whether a group was re-sighted by the second observer. A group was coded 1–1 if seen by both observers, 1–0 if only the first observer saw it, and 0–1 if only seen by the second observer. We modelled the detection for the two observer groups separately (mt model; i.e. detection probability varied across the two surveys). To estimate the number of groups ($\hat{G}$) of tahrs in our study area, we fit the mt

model using the function *BBRecap* with a uniform prior, i.e. all values of the estimate had an equal likelihood. We used the mt model because we expected detection probability to be different across the two surveys (Suryawanshi et al., 2012). We used uninformed uniform priors because this is the first time this method has been used for the tahr in this Reserve. We did 10,000 Markov chain Monte Carlo iterations with a burn-in of 1,000 (see Fegatelli, 2013 for further details on model fitting). The estimated detection probability by model mt for occasion 1 and 2 was interpreted as the detection probability for observer teams 1 and 2.

We estimated the total tahr population (N_{est}), as a product of the estimated number of groups ($\hat{G}$) and the estimated mean group size (μ). To estimate the confidence intervals (CI) of the tahr population using the variance in estimated number of groups and the mean group size, we generated a distribution of estimated group size by bootstrapping it 10,000 times with replacement (Fig. 2b). We generated a distribution of the estimated tahr population (N_{est}) by multiplying 10,000 random draws of the estimated number of groups ($\hat{G}$) weighted by the posterior probability (Fig. 2a) and draws of mean group size (μ; Fig. 2b). The median of the resulting distribution (Fig. 2c) was the estimated Nilgiri tahr population (N_{est}), and we used the 2.5 and 97.5 percentiles as the boundaries of the 95% CI.

Results

Across the 36 surveyed blocks, the total minimum count of the Nilgiri tahr was 422 individuals in 28 groups (Table 1). The first observer team detected a total of 334 individuals in 23 groups, and the second team detected a total of 293 individuals in 16 groups. Eleven groups were detected by both observer teams, and mean group size was 14 (range 1–83). Of the 422 animals observed, the age and sex of 134 (32%) could not be determined. Of the others, 71 (25%) were young and 217 (75%) were adults. Of the 217 adults that could be sexed, 90 (41%) were males and 127 (59%) were females. The male:female ratio was 0.71 and the young: female ratio was 0.56.

The mt model estimated the number of tahr groups to be 35 (95% CI 28–45; Fig. 2a). The mean of the bootstrapped group size distribution was 15 (Fig. 2b). The estimated Nilgiri tahr population (N_{est}) was 510 (95% CI 300–858; Fig. 2c). The detection probability was 0.66 and 0.47 for the first and second observer, respectively.

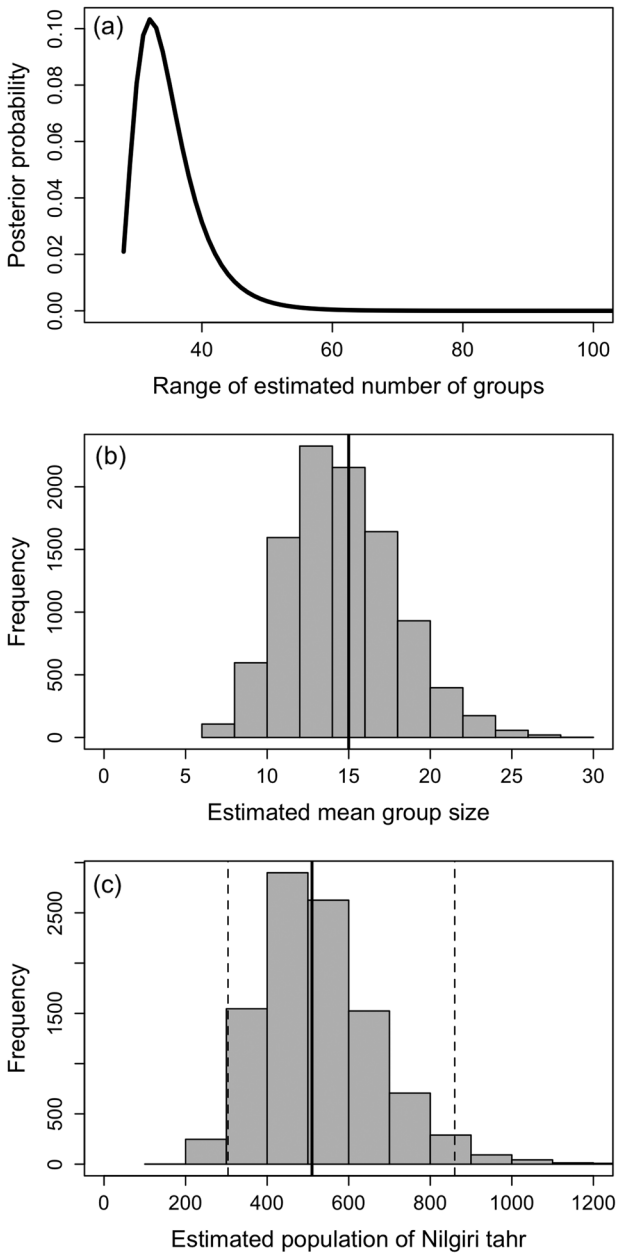

FIG. 2 (a) The posterior probability distribution estimated by the mt model for the range of number of Nilgiri tahr groups in the study area. (b) Histogram of 10,000 bootstrapped means of Nilgiri tahr group size. The vertical solid line indicates the median. (c) Histogram of the estimated Nilgiri tahr population. The solid line indicates the median (510) and the dotted lines indicate the 95% CI (300–858).

Discussion

The primary objective of this study was to assess the effectiveness of the double-observer survey method for estimating the Nilgiri tahr population in the Anamalai Tiger Reserve, India. Our findings suggest that the double-observer survey method is statistically robust and can be employed efficiently to estimate Nilgiri tahr populations. Despite its relatively low precision (95% CI 300–858), our population estimate of 510 is similar to previous estimates. Mishra & Johnsingh (1996) observed a total of 339 individuals in Anamalai Tiger Reserve and estimated the total population to be 540–645 tahrs (excluding tahrs recorded in Parambikulam Wildlife Sanctuary, Kerala). Their surveys did not, however,

include the Udumalpet and Amaravati Ranges. Davidar (1978) had estimated the total population to be c. 598 tahrs in this Reserve. Both earlier estimates are within the 95% CI of our estimate. We could not directly compare our results with Predit et al. (2015), because their survey included only six sites in the Reserve, where they observed a total of 107 tahrs. Another survey (Kumar et al., 2002), with a coverage similar to our study, reported 186 tahrs and proposed the existence of eight subpopulations, but the survey covered multiple years and did not have the primary aim of estimating tahr populations. Examination of topographical maps of the study area and observations during our survey suggest that there may be suitable tahr habitat around some of the isolated montane grassland areas between Grass Hills and Udumalpet. These areas are difficult to access and have not yet been surveyed for tahrs. These areas could be surveyed in an expedition mode (i.e. a logistically intensive effort, but of relatively short duration) in the future.

To improve the accuracy of the double-observer survey method, future investigators will need to adapt the protocol based on field conditions. We recommend that field surveys across Anamalai Tiger Reserve should be conducted during a short period of 2–3 weeks to minimize movement of tahrs across sites. The year in which we surveyed (2018) was particularly dry and there were several forest fires during March, which interrupted fieldwork. Based on our surveys and on experience of working and living in this landscape, we suggest February may be better suited for double-observer surveys as this is usually a dry period but without fires. In large, continuous, open habitats such as Grass Hills, we recommend that observers be separated in space. This can be achieved by (1) both observers starting the survey from opposite ends of the survey trail, covering the entire area; (2) for valleys, observers using different ridge lines, which both provide maximum visual coverage of the entire valley; or (3) both observers choosing different paths but ensuring that both paths facilitate visual coverage of the same area to be surveyed (Suryawanshi et al., 2012). Caution must be taken while surveying smaller habitat patches surrounded by forest, because the presence of an observer may displace tahrs into nearby forest, affecting recaptures by the second observer. To avoid this, the interval between the two observers could be reduced to 10–15 minutes. Reducing this interval means that if tahrs move away because they are disturbed by observer 1, they are more likely to still be within observable distance of observer 2 than they would be after a longer time interval. In addition, independent visual surveys of smaller patches by two observers from a stationary location are also possible (Forsyth & Hickling, 1997; Suryawanshi et al., 2012). Adaptation of the field protocol could improve the estimate's precision (narrowing the CI) and accuracy. However, the low precision of our estimate is also a result of the high variation in tahr group sizes.

In terms of logistics (effort) and financial (money) expenses, the double observer survey method is only marginally more costly than the total count method and yet provides a robust estimate of error. Both methods require the entire study area to be surveyed, by at least two people. With the study area being located in a protected area with rugged terrain and potentially dangerous animals such as tigers, elephants and bears, it is safer for two people to be together when doing the surveys. For the total count, both observers survey together, whereas the double observer method requires them to survey independently. Additional people are required only if the temporal separation between the two observers has to be longer than 30 minutes, as this would require additional survey teams. Although we did not use any other method such as distance sampling, we would expect them to be more costly and more difficult to implement in the rugged *shola* grassland of the Western Ghats.

We recommend that a scientifically rigorous method that can provide an estimate of error, such as the double observer survey method, be used for long-term monitoring of the Nilgiri tahr in the Anamalai Tiger Reserve. A survey to estimate the total population of the Reserve could be conducted every 3–5 years. A subset of sites representing 30–50% of the tahr habitat in the Reserve could be monitored annually, including key sites such as Grass Hills and Pachapal Malai, which support the largest numbers of tahrs and are critical for the population in the Reserve. Grass Hills had the largest continuous population of the tahr (Table 1), and Pachapal Malai is located in the central part of the Reserve, maintaining connectivity across the landscape (Fig. 1).

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Author contributions Study concept: KS, DM, TRSR; study design: KS, MAK, DM, TRSR; fieldwork: KS, MK, DR, JP; data analysis: KS, MK, DR; writing: all authors.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. All necessary research permits were obtained from the Tamil Nadu Forest Department.

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