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Assessing the accuracy of population estimation methods for vulture populations: a case study from the Mudumalai Tiger Reserve, Tamil Nadu, India

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Abstract

Two resident and two local migratory vulture species are reported in the Mudumalai Tiger Reserve of the Nilgiri Biosphere Reserve. The early population estimates from the region are either scanty or crude. Vulture population estimation was performed using three different methods based on their breeding seasons and regional movements between 2019 and 2021. Road transect counts, nest counts, and carcass monitoring counts were used for population assessments. The road transect survey and nest site counting during the breeding season were conducted in all three years, while carcass monitoring was done in 2019 – 2020. For population estimation, three nest site colony counts were conducted for the resident *Gyps bengalensis* and for *Gyps indicus*. The other two methods, carcass monitoring and the road transect survey, were used for all four focal vulture species of the Mudumalai Tiger Reserve – *Gyps bengalensis, Gyps indicus, Neophron percnopterus* and *Sarcogyps calvus*. Significant variation in vulture population count was observed with different assessment methods.

Key words: carcass monitoring, critically endangered, Moyar Valley, nest count, Nilgiri Biosphere Reserve, road transect survey, vultures.
Abbreviations: MTR, Mudumalai Tiger Reserve; NBR, Nilgiri Biosphere Reserve; NSAIDs, non-steroidal anti-inflammatory drugs.

Introduction

Vultures, as keystone scavengers (Green et al. 2004), play an important role in the terrestrial ecosystems (Naoroji 2006), environmental health (Ogada et al. 2011), and the prevention of the spread of dangerous diseases such as anthrax and rabies (Prakash et al. 2003). Nine species of vultures are recorded in India. Seven of them are documented in the Nilgiri Biosphere Reserve (NBR) in southern India. Of these, two critically endangered species are resident in the Mudumalai Tiger Reserve (MTR): *Gyps bengalensis* (Davidar, Davidar 2002; Ramakrishnan et al. 2014; Venkitachalam, Senthilnathan 2016; Samson et al. 2018) and *Gyps indicus* (Venkitachalam, Senthilnathan 2015). The critically endangered *Sarcogyps calvus* (Ramakrishnan et al. 2012) and near-threatened *Neophron percnopterus* (Subramanya, Naveen 2006; Samson et al. 2014) are local migrants. *Aegypius monachus* (Samson et al. 2019), *Gyps himalayensis* (Praveen et al. 2014), and *Gyps fulvus* (Gajamohanraj 2020) are vagrants in the MTR.

The decline of vulture populations in many parts of their former distribution ranges has been attributed to food shortage, habitat loss (Pain et al. 2003), and non-steroidal anti-inflammatory drugs (Virani et al. 2001; Green et al. 2004; Gilbert et al. 2004). Without the threat of non-steroidal anti-inflammatory drugs like diclofenac, reasonable numbers of vultures are present on the MTR's Segur plateau (Ramakrishnan et al. 2010). *Gyps* vulture populations have declined dramatically in the Indian subcontinent over the last few decades, with the population estimated to be less than 5% of their previous size (Prakash et al. 2007; MoEFCC 2020).

Estimating population distribution and abundance is critical for any conservation action. The "bird count" method is the most commonly used estimation method (Bibby et al. 2000). Vultures, regardless of size, generally move in and out of any area. During the non-breeding season, vultures will roam widely (and sometimes during the breeding season). Each landscape requires different estimation methods, as vultures are tree nesters and rock cliff nesters. These estimation methods include road transect surveys (Pomeroy et al. 2015; Subedi et al. 2018;

Praksh et al. 2019), nest site count methods (Ramakrishnan et al. 2014; Venkidachalam, Senthilnathan 2015; Bhusal et al. 2019; Rana et al. 2019), and carcass count methods (Fielding et al. 2014; Manigandan et al. 2021a).

In NBR, the previous population estimates were made using road transects (Samson et al. 2016; Venkitachalam, Senthilnathan 2016; Manigadan et al. 2021a), carcass monitoring methods (Samson, Ramakrishnan 2020), and vulture breeding ecology (Ramakrishnan et al. 2014) performed for a single year. The limitations of the earlier studies were that only one estimation method was used in each year. NBR, being a biological hotspot, is one of the unique landscapes in southern India, and holds a small breeding and viable wild population of these critically endangered vultures (Samson, Ramakrishna 2020). A comparative population estimation method evaluation was selected due to the following limitations: (1) the MTR parts of the Western Ghats have limited access for assessing breeding populations because they are located mostly in inhospitable and undulating terrain that is difficult to cover by the road transect method; (2) nest counts can be performed only for breeding populations; *G. bengalensis* nests in trees, whereas *G. indicus* nests on cliffs, hence, any one method for population estimation will not provide a comprehensive scientific count; (3) carcass monitoring solely depends on wild kills of cattle, and it can affect population estimation if the sample size is small. A literature review revealed no previous record of assessing the reliability of various estimation techniques for vulture populations in any vulture landscape in the world. There are no studies that have tested the accuracy of the various methods used in population estimation for vultures. Therefore, the present study was aimed to assess the accuracy of various methods used in population estimation of vultures in the MTR. The objectives of the present investigation were to assess the current vulture population using different sampling methods, and to select the most accurate vulture population estimation method for each species and mixed nesting species in this unique landscape.

Materials and methods

Study area

Mudumalai Tiger Reserve (MTR) (11°35'0" N, 76°33'0" E) is located in the Nilgiri Biosphere Reserve (NBR) and is bordered by the Bandipur Tiger Reserve to the north and Wayanad Wildlife Sanctuary to the west. It is situated on the northern flank of the Nilgiri Mountain Range in the Western Ghats. The area is renowned for its rich ecological diversity of flora and fauna. The MTR has a total area of 688.5 km^2 (the core area alone is 321 km^2, and the buffer zone is 367.5 km^2). According to Champion and Seth (1968), the vegetation in MTR consists of moist bamboo brakes, riparian forest, southern tropical dry thorn forest, southern tropical dry deciduous forest, southern tropical moist deciduous forest, and southern tropical semi-evergreen forest. MTR is also home to the Asian elephant *Elephas maximus*, tiger *Panthera tigris*, leopard *Panthera pardus*, Indian gaur *Bos gaurus*, chital *Axis axis*, sambar deer *Rusa unicolor*, and many other species. The five major flowing water bodies in the MTR are the Moyar River, the Sigur River, the Avarahalla River, the Kedarhalla River, and the Gundathalla River, which crisscross the Moyar Valley and finally end up in the Bhavanisagar reservoir. In the tribal villages of MTR, the livestock population is estimated to be around 3000.

Sampling methods

As there are several species of vultures recorded in MTR, three different methods were used to evaluate the vulture population: road transect survey, total number of counts from nesting sites, and camera trap carcass monitoring.

For the road transect survey, four transects in the study area were chosen (Fig. 1). From January 2019 to December 2021, two teams, each with one observer and one driver, conducted surveys twice a month. In these protected areas, transects were driven by four-wheel vehicles at 10 to 20 km h^{-1} during 7:00 – 11:00 and 15:00 – 19:00 local time. A total of 1704 km were surveyed for a length of 85 km in each survey, which was replicated 74 times in the area with a good road network (Venkitachalam, Senthilnathan 2016; Prakash et al. 2017). Vultures were observed from vehicles; when they were spotted, the vehicle stopped for recording. Binoculars (8 × 42) and digital single-lens reflex cameras with telephoto lenses were used to observe and record them. Field guides were used as an aid for identifying doubtful records in the field, especially for young individuals (Grimmet et al. 2016). Vultures that were observed on the ground, in trees, and on cliffs, flying and soaring within 500 m on either side of the transect, were documented (Prakash et al. 2017).

For the nesting colony count, a preliminary survey performed in 2018 by tribal members and forest staff helped to determine both nesting and roosting locations of the *G. bengalensis* and the *G. indicus* in MTR. The vultures were counted during the breeding season (October to March). Population estimation by direct counting was done for three breeding seasons (2018 – 2019, 2019 – 2020, and 2020 – 2021) in each nesting colony twice a month. To monitor the *G. bengalensis* population, the rivers and nullas (streams) where nesting trees are present were thoroughly searched for nesting sites. The population size of *G. bengalensis* was estimated by counting individuals at roosting and nesting sites during 6:30 – 9:30 and 17:00 – 19:00. The emigration and immigration of vultures to the nesting colonies were also considered for population estimation (Baral et al. 2005). As *G. indicus* are cliff-nesters; the only difference compared to *G. bengalensis* is that old and existing breeding colonies were counted (Venkitachalam, Senthilnathan 2015), in addition to new colonies. The rest of the methods regarding timing, equipment, and identification, remain the same. All observations were recorded with telescopes

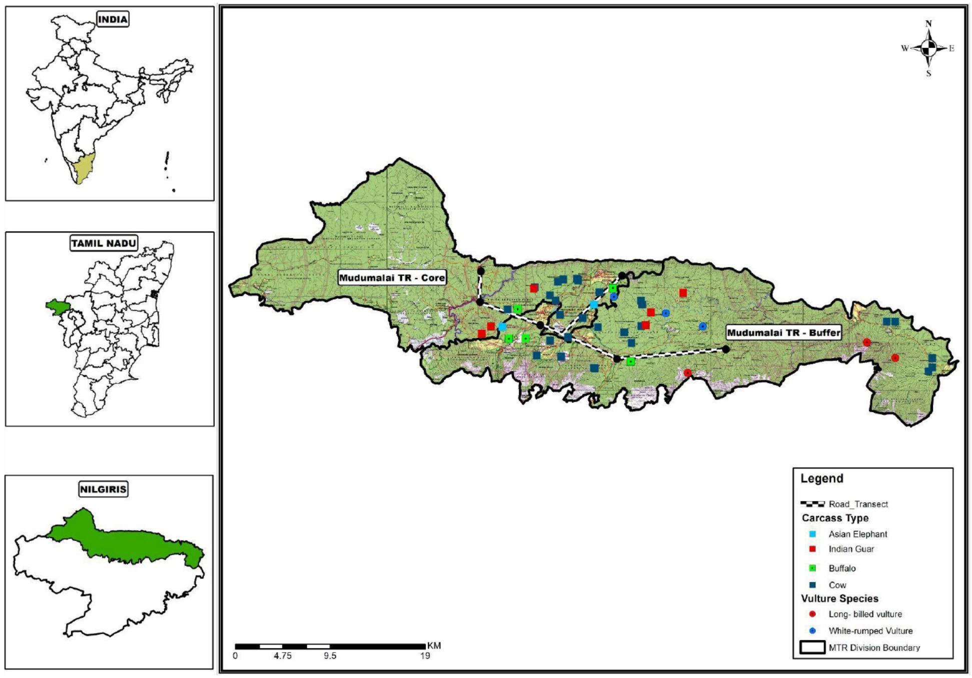

Fig. 1. Map of the study area with road transects, nesting colonies of *Gyps bengalensis* and *Gyps indicus*, and depredation of livestock spots (for carcass monitoring) in the vulture habitat.

and binoculars. To avoid disturbing the birds, we kept a minimum distance of 30 m from the nests.

For carcass monitoring using the camera trap method, depredation data from January 2020 to December 2021 were collected. Both domestic and wild animals killed due to carnivore conflict were mapped (Fig. 1). Carcasses were monitored by automatic, motion-activated cameras using a non-intrusive camera trapping method. In order to get better pictures, the area around the carcasses was cleared of grass and bushes, and cameras were hidden at 5 – 10 m distance. The cameras were programmed to take a single picture every two minutes if there was any movement and operated 24 h a day (Blazquez et al. 2009; Moleon, Sanchez-Zapata 2015). The carcass was assumed to have been fully eaten when only the head and large skeleton bones were left, or if a vulture had snatched it from the camera's field of view. Scavengers meticulously mounted the carcasses until they were reduced to skeletal remains. The identification of each vulture species was done from camera trap images. These images were then used to determine attendance by focus species. Similar protocols for all 42 wild kill carcasses were followed (33 livestock and nine wild animals) during the study period for vulture population monitoring and assessment.

Statistical analysis

Statistical analyses were performed using the PAST 3 statistical software package for the Kruskal-Wallis test, and nest locations were mapped using Quantum GIS 1.7.1, the Walcrow version, with the help of GPS field data.

Results

Four vulture species (*G. bengalensis, G. indicus, S. calvus* and *N. percnopterus*) were recorded during the three years of road transect surveys, which covered 1704 km (Table 1). In 2019, an average of 87.8 vultures were recorded per transect, followed by 80.3 in 2020 and 68.7 in 2021. The encounter rate of 1.23 individuals per km decreased from 2019 to 1.12 individuals per km in 2020, and then to 0.96 individuals per km by 2021. *G. bengalensis* populations were the largest in all three-year road transect surveys, while *N. percnopterus* populations were the smallest. Both *G. indicus* and *N. percnopterus* showed a stable count throughout the survey period.

G. bengalensis nesting colonies were recorded in the study area for all three years during the breeding season in 24 visits (Table 2). Three breeding colonies of *G. bengalensis* were identified. Two colonies had nesting colonies throughout the study period – Anaikatty and Jagalikadavu. The other breeding colony, Gudalpatti, had a new nesting colony recorded in the third year of the study. During 2018 – 2019, 1159 Gyps bengalensis individuals were sighted in 24 visits at the Anaikatty nesting colony, with the mean declining during 2020 – 2021. In the breeding season of 2020 – 2021, a total of 1189 *G. bengalensis* were sighted in 24 visits with a mean of 49.5 individuals per visit at the new Gudal Patti nesting colony that was not presents in previous years (Table 2).

From 2018 to 2021, three *G. indicus* nesting colonies – Ebbanad, North Eastern Slopes, and Kallamapalayam –

Table 1. Vulture population (all species) estimation by road transect method (2019 – 2021). Data are means from four transects ± SE

Year	Total vulture count	*Gyps bengalensis*	*Gyps indicus*	*Sarcogyps calvus*	*Neophron percnopterus*
2019	87.8 ± 3.0	75.1 ± 2.0	6.8 ± 0.37	5.4 ± 0.3	0.50 ± 0.13
2020	80.3 ± 2.6	68.7 ± 2.3	6.3 ± 0.34	4.9 ± 0.3	0.29 ± 0.09
2021	68.7 ± 2.2	57.5 ± 2.0	6.0 ± 0.26	4.8 ± 0.2	0.29 ± 0.09

Table 2. Population estimation of *Gyps bengalensis* at tree nesting colonies (2018 – 2021

Nesting colony sites	2018 – 2019		2019 – 2020		2020 – 2021	
	Total number of sightings	Mean	Total number of sightings	Mean	Total number of sightings	Mean
Jagalikadavu	1604	66.8 ± 1.8	1588	66.1 ± 1.7	1013	50.6 ± 1.7
Anaikatty	1159	48.2 ± 1.9	747	37.3 ± 0.7	126	5.3 ± 0.3
Gudalpatti	0	0	0	0	1189	49.5 ± 2.0

were observed during the breeding season in the study area (Table 3). The number of *G. indicus* recorded at the Ebbanad nesting colony in the breeding season of 2020 – 2021 was 92, with a mean of 4.4 per visit. During the 2019 – 2020 study period, 142 *G. indicus* were recorded in the Nilgiri Eastern Slopes nesting colony, with a mean 4.5 per visit. During the 2019 – 2020 observation period, 144 *G. indicus* were encountered in 24 visits at the Kallampalayam nesting colony, with a mean 5.9 per visit (Table 3). Throughout the three years, the population in all of the colonies remained relatively stable.

Camera trap monitoring of wild kill carcasses was performed on 42 carcasses, including 33 from domestic and nine from wild animals. The wild kill carcasses reported were either within five kilometres of human settlements (n = 22), from the nearest vulture nesting colony or from forest areas (n = 20). There were 34 tiger kills of 42 carcasses, followed by leopard attacks (n = 6) and two wild dog kills. A summary of the attendance of all focal vulture species in MTR using the camera trap method for carcass monitoring is given in Table 4.

Only two vulture species were recorded in the study area using the nest site count method. *G. bengalensis* and *G. indicus* are examples. The local migratory species *S. calvus* was mostly observed during road transect surveys, and *N. percnopterus* was predominantly recorded during carcass attendance counts.

A significant difference was occurred between the three vulture population estimation methods (Kruskal-Wallis test – *chi-square* = 185.258, df = 2, P < 0.0001). Maximum counts of vultures were recorded in the road transect survey (83.7 ± 2.4), compared to carcass attendance counts (63.8 ± 2.65) and nesting site counts (45.5 ± 1.4) (Fig. 2).

Discussion

The crisis of vulture population decline in the Indian subcontinent is well documented (Samant et al. 1995; Prakash et al. 2003; Gilbert et al. 2004; Green et al. 2004; Gilbert et al. 2006; Oaks et al. 2006; AVPP 2007; Prakash

Table 3. Population estimation of *Gyps indicus* at rock cliff nesting colonies (2018 – 2021)

Nesting colony sites	2018 – 2019		2019 – 2020		2020 – 2021	
	Total number of sightings	Mean	Total number of sightings	Mean	Total number of sightings	Mean
Ebbanad	60	2.5 ± 0.2	67	2.7 ± 0.1	92	4.4 ± 0.1
Nilgiri Eastern Slopes	110	4.3 ± 0.2	142	4.5 ± 0.2	105	3.9 ± 0.1
Kallampalayam	95	3.8 ± 0.2	104	5.9 ± 0.2	86	3.5 ± 0.1

Table 4. Estimation of vulture population by carcass monitoring during the study period

Animal species of carcasses	Number of individuals	Average days observed	*Gyps bengalensis*	*Gyps indicus*	*Sarcogyps calvus*	*Neophron percnopterus*	Total
Cow	28	3.5	49.6 ± 3.0	5.6 ± 0.2	4.0 ± 0.2	0.3 ± 0.1	59.7 ± 3.0
Buffalo	5	4	57.1 ± 2.2	6.0 ± 0.2	3.7 ± 0.2	0.7 ± 0.2	67.6 ± 3.5
Indian Guar	6	4.5	53.7 ± 1.4	4.6 ± 0.1	3.6 ± 0.1	0.4 ± 0.1	62.4 ± 1.4
Elephant	3	6.5	61.5 ± 2.4	4.8 ± 0.3	3.7 ± 0.2	0.4 ± 0.1	70.4 ± 2.5

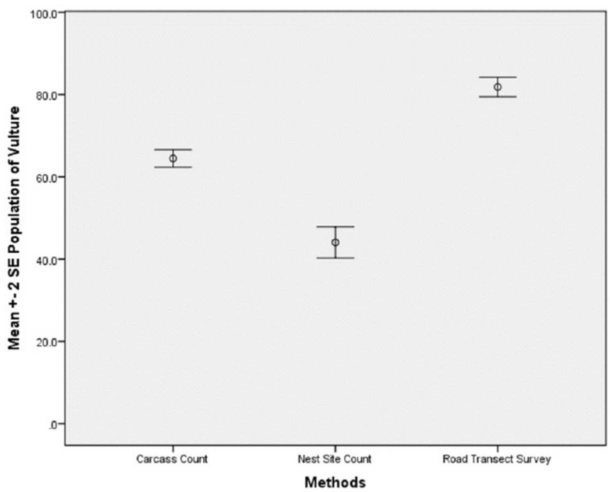

Fig. 2. Comparative vulture population status using different estimation methods in the study area.

et al. 2007; Pain et al. 2008). The rate of population decline of *G. bengalensis*, the dominant species in India, was estimated at around 96% between the years 1991 and 2000 (Prakash et al. 2003; Prakash et al. 2005; Pain et al. 2008). The major threat causing the huge decline is the poisoning of vultures by diclofenac in carcasses, which is included in livestock feed (Oaks et al. 2004; Green et al. 2004; Green et al. 2007). Given that 90% of the vulture population typically feeds on wild carcasses (Ramakrishnan et al. 2010), MTR in the NBR is a home to a reasonable number of vulture populations that are not at risk from diclofenac, even though the remaining 10% could still be endangered. Any accurate population estimation of vultures in this critical habitat of the MTR requires considering various factors like logistics, the cost-effectiveness of the surveys, accessibility to breeding colonies, the elephant migration and tiger habitats. Taking these limitations into consideration for population assessment, our study examined three different estimation techniques for vulture populations over a three-year period.

Road transect surveys showed the presence of all four vulture species present in the area: *G. bengalensis, G. indicus, S. calvus* and *N. percnopterus*. However, it was not possible to record any vagrant species during the entire 36 months of survey, even though there were reports of a possible electrocution death of the Himalayan griffon vulture (Manigandan et al. 2021b). Even though the encounter rate decreased from 2019 to 2021 (from 1.23 to 0.96 individuals per km) in the study area, *G. bengalensis* maintained the largest population throughout the study. The presence of suitable nesting trees like *T. arjuna* in the riverine area of the tiger reserve is one of the major contributory reasons for the stability of the *G. bengalensis* population during the three years, as they are able to construct nests every year, and produce offspring. Prakash et al. (2017) reported fluctuations in the *G. bengalensis* population during road transect surveys. Earlier, a single year assessment of *G. bengalensis* in MTR following the road transect method (Venkitachalam, Senthilnathan 2016) recorded the group size as 30 to 48. However, in the current three-year study, the *Gyps bengalensis* maximum group size was 47 to 82. Thus, regular monitoring helps to understand population estimation in a better manner.

A nest survey helps in counting adults, juveniles, and young chicks, which will provide an estimate of the current population and can also be used to assess change over time. According to our observations, there were three *G. bengalensis* tree nesting colonies in *Terminalia arjuna* trees and three *G. indicus* rock cliff nesting colonies in MTR. In the third year of the study, the Gudalpatti nesting colony of *G. indicus* was established. We observed many *T. arjuna* trees drying up over the last few years in the regular *G. bengalensis* nesting areas of Anaikatty and Jagalikadavu, and more healthy and taller trees were available in the newly established breeding colony of Gudalpatti. The reason for greater mortality of nesting tree deaths was attributed to a lack of perennial water flow in the streams. Most of these nesting trees grow on the banks of streams. This relationship between the establishment of nesting colonies of *G. bengalensis* based on the availability of *T. arjuna* nesting trees requires further study. The location of *G. bengalensis* breeding colonies near human habitations was observed. These findings are similar to those from other *G. bengalensis* breeding areas in Nepal, Gujarat, and the NBR (Baral et al. 2005; Baral, Gautam 2007; Dave 2011; Harris 2013; Samson, Ramakrishnan 2020). The population range of *G. bengalensis* in our nesting colony study was 49 to 104. Similar patterns were reported in other *Gyps bengalensis* breeding sites (Baral et al. 2005; Samson, Ramakrishnan 2020). We also recorded 32 sighting records of the *N. percnopterus* over three years. Prakash et al. (2007; 2017) reported that *N. percnopterus* was recorded at the lowest levels in all road transect surveys, and this is a general trend throughout the NBR and the state of Tamil Nadu (Byju, Raveendran 2022).

According to Subramanya and Naveen (2006), Gyps indicus are cliff-nesting birds that typically build their nests 25 – 35 m above the ground, making accessibility challenging from the ground or clifftop (Misher et al. 2017). As an exception, *G. indicus* nesting was recorded also on *Dalbergia lanceolaria* trees (Ramesh et al. 2011). In the current assessments, *G. indicus* nesting was observed in rock cliffs, and three nesting colonies – Ebbanad, North Eastern Slopes, and Kallamapalayam – were recorded during the breeding season in the study area. Locations near cliffs allowed for better visibility of predators, easier access to nests, and a decrease in human disturbances (Donazar et al. 1993; Yamac 2007). In the present study, during the three years *G. indicus* had a stable population size.

When carnivores in the tiger reserve prey on livestock, vulture populations benefit from the carcasses that are frequently left outside in open areas by livestock owners. Several reasons force the livestock owners to dump their dead cattle out in the open in the reserves. These factors include the lack of equipment to lift a carcass, the higher cost involved in transporting the dead cattle out of the reserve to the nearest village by the poor villagers, and the statutory paperwork to be completed with the forest department for removal from the tiger reserves. Camera traps employed on these carcasses monitored vulture attendance to assess the population size of all focal species. *S. calvus* and *N. percnopterus* were recorded only during road transect surveys and carcass monitoring methods, indicating the local migration of these two species. To support this, in the present study, six *S. calvus* were found on a single carcass. More vultures were observed around the carcasses of elephants (70.4) than Indian guars (59.7). This could be due to the carcass size and the vultures' ability to find it while soaring and foraging. Surprisingly, more vultures were found on buffalo (67.6) and cow (62.4) carcasses, because livestock carcasses were mostly found within a one-kilometre radius of the vulture nesting area, and this domestic carcass is left out in the open. On average, vultures in groups fed on individual carcasses for almost a week, including *N. percnopterus* pecking toward the final stage of consumption. Food availability, along with healthy nesting trees, are the reasons for a stable vulture population in MTR.

Nest site counts to determine breeding population size of *G. bengalensis*, and *G. indicus* was conducted earlier in MTR (Subramanya, Naveen 2006; Ramakrishnan et al. 2014; Venkitachalam, Senthilnathan 2015; Samson et al. 2020). Other studies (Umapathy et al. 2009; Samson et al. 2016; Venkitachalam, Senthilnathan 2016; Prakash et al. 2017) estimated vulture populations using road transect surveys and carcass counts separately. These studies were either limited to a single year or a breeding season, and hence there was a need for a comparative assessment. Evaluation of the three different methods – road transect method, nest site count method, and carcass count method for vulture population estimation showed that vulture species estimates were significantly higher in the road transect survey when compared to the carcass count and nest site count methods. As vultures in general, move in and out of a territory, the road transect method is very effective in determining population change over time. Its estimates generally provide an index of abundance. This is because, apart from the resident vultures, the migratory vultures can also be found in road transect surveys rather than in other methods. The road transect survey method can be considered to be a reliable estimation method in the MTR. Even though nest counting and carcass monitoring methods do have their limitations, all four focal vulture species were reported using these methods. To sum up, we believe that any accurate assessment of vulture population estimation should consider landscape limitations and other restraining factors.

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