POPULATION, NESTING CHARACTERISTICS, AND BREEDING ECOLOGY OF THE CRITICALLY ENDANGERED *GYPS INDICUS* IN MUDUMALAI TIGER RESERVE, SOUTH INDIA

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The species extinction rate has recently accelerated worldwide and is a thousand times higher than through natural processes alone. Small, isolated populations are especially vulnerable to extinction due to deterministic and stochastic threats. Hence, the conservation of such populations is challenging. The present study from 2015 to 2021 aimed to understand the population, nesting characteristics, and breeding ecology of the country's southernmost population of *Gyps indicus* in Mudumalai Tiger Reserve, South India. The population estimation was performed on the roosting and nesting sites of *Gyps indicus* in the Mudumalai Tiger Reserve. To study the nesting characteristics and breeding ecology, each nesting colony was systematically visited four times per month during the breeding season (October to May). Assessments of threats were estimated during the field visits. In 2015–2021, four breeding sites were identified. Two nesting sites were identified in 2016 and two more in 2017 and 2020. The mean altitude of the nesting sites was 1122.25 ± 170.06 m a.s.l., ranging from 821 m a.s.l. to 1600 m a.s.l. In the Protected Area, two nests were located on east-facing exposure, one nest on southeast-facing exposure, and one nest on south-facing exposure. In terms of population composition, the mean number of adult individuals steadily increased from 9.5 ± 0.46 in 2016 to 14.08 ± 0.67 in 2021. Consequently, the mean total number of individuals per colony increased from 13.66 ± 0.56 in 2016 to 27.83 ± 0.62 in 2021. A total of 40 (in average, 6.66 ± 0.49 pairs/year) territorial pairs with occupied nests were observed in 2015–2021. Of them, 31 (in average, 5.16 ± 0.30 pairs/year) breeding pairs had laid eggs. Successful incubation was recorded, and the mean incubation period was 63.64 ± 1.74 days. Out of 31 incubated nests, 23 fledglings (3.83 ± 0.47 individuals/year) successfully came out with 74% breeding success. The entire nesting period was 128.43 ± 1.16 days. In total, out of 17 failed breeding attempts nine (53%) were detected before egg laying, and eight (47%) were found during incubation. There were no significant differences between nests abandoned before and after egg laying ($t = 0.4152$, $p > 0.05$). During the breeding seasons of 2015–2017, a human-made forest fire posed a serious threat to nesting colonies of *Gyps indicus*, resulting in no observed nesting. A species-specific conservation-oriented action programme is necessary to secure this last southernmost wild viable *Gyps indicus* population in the Mudumalai Tiger Reserve. At this juncture, we highly recommend declaring the buffer zone of the Mudumalai Tiger Reserve as a «Vulture Sanctuary» to provide a legal protection of the *Gyps indicus* population living in the studied area.

Key words: cliffs, colony, egg, fledgling, incubation, roosting, vulture

Introduction

In recent years, the extinction rate of species has increased worldwide and is a thousand times higher than through natural processes alone. Small, isolated populations are especially vulnerable to extinction (Sæther & Bakke, 2000) due to various threats (Boyce, 1992). The conservation of these populations is challenging (Young, 2000). Vultures are obligate scavengers and belong to the most threatened avian guild worldwide (Buechley & Şekercioğlu, 2016; McClure et al., 2021). A variety of factors, including contamination with veterinary pharmaceuticals (Oaks et al., 2004; Hernández & Margalida, 2008; Margalida et al., 2014), poisoning (Hernández & Margalida, 2008, 2009; Oro et al., 2008), habitat destruction (Thiollay, 2006), and low food availability (Thiollay, 2006; Margalida et al., 2010; Margalida & Colomer, 2012), combined with regulations and enactments (Camiña & Yosef, 2012), human persecution (Thiollay, 2006), collisions with wind turbines (Carrete et al., 2012), electrocution and collisions with power lines (Boshoff et al., 2011), and anthropogenic disturbance (Morán-López et al., 2006), have contributed to the decline of vultures worldwide. During the late 1990s – early 2000s, populations of three *Gyps* species across southern Asia declined by more than 95% (Prakash, 1999; Gilbert et al., 2006; Prakash et al., 2003, 2012; Oaks et al., 2004). These populations were decimated by veterinary use of non-steroidal anti-inflammatory drugs, particularly diclofenac (Oaks et al., 2004; Pain et al., 2008; Ogada et al., 2012; Margalida & Ogada, 2018). These drugs are nephrotoxic to birds and cause renal failure in vultures (Oaks et al., 2004). Six out of nine species of vultures found in India, have been facing the problem of existence and are, therefore, declared as threatened (Prakash et al., 2007). Of these, three species endemic to South Asia (*Gyps bengalensis* (Gmelin, 1788), *Gyps indicus* (Scopoli, 1786), and *Gyps tenuirostris* Gray, 1844) are at high

risk of global extinction and are listed as Critically Endangered because of rapid population declines within the last decade in the Indian subcontinent (Prakash et al., 2007).

Gyps indicus is one of the three native, resident *Gyps* species in India. It breeds in southeast Pakistan and peninsular India, south of the Gangetic plain, north to Delhi city, east through Madhya Pradesh state, south to the Nilgiris district, and occasionally further south (Collar et al., 2001). The species is classified as Critically Endangered (BirdLife International, 2021) because of a catastrophic decline of 90–98% in the population of *Gyps* species (Prakash et al., 2007) due to diclofenac poisoning (Gilbert et al., 2006; Green et al., 2004). Prakash et al. (2019) estimated the population to be c.12 000 individuals based on road transactions carried out in 2015. This roughly equates to 8000 mature individuals. It is placed in a band of 5000–15 000 mature individuals. It nests almost exclusively in colonies on cliffs and ruins (Naoroji, 2007), although in the deserts and grasslands of the Thar region (western India) they have been recorded as nesting on trees (Kulshreshtha, 2001). The breeding season of *G. indicus* is from October to May – June (Naoroji, 2007). Despite being a priority species for conservation, relatively little is known about their breeding and nesting ecology (Naoroji, 2007). In the southern Indian region, a small population of *G. indicus* in the Ramanagaram Hills of Karnataka and Nilgiri Forest Division in Tamil Nadu is known to remain in inland southern India, and it is rare elsewhere within its former range (Prakash et al., 2007; Venkitachalam & Senthilnathan, 2015, 2016). Regular monitoring breeding populations of threatened vultures is widely recognised as a priority to enable the effective implementation of targeted conservation actions in key areas across their ranges (Buechley et al., 2019; Santangeli et al., 2019).

This study was aimed to assess the population of *G. indicus* in the Mudumalai Tiger Reserve, Tamil Nadu, South India. To achieve this goal, the following objectives were outlined: to examine the nesting habitat characteristics of *G. indicus*, estimate the population structure within nesting colonies, analyse breeding ecology, identify conservation threats, and provide scientific management recommendations for long-term species conservation.

Material and Methods

Study area

Mudumalai Tiger Reserve (11.527828° – 11.716657° N, 76.367281° – 76.750001° E) is situated in the Western Ghats of South India (Fig. 1). Its area is 688.58 km^2. Mudumalai Tiger Reserve is bounded by Wayanad Wildlife Sanctuary on the west, Bandipur Tiger Reserve on the north, Nilgiris Forest Division on the south, and Sathiyamangalam Tiger Reserve on the east with an average altitude of 900–1000 m a.s.l. The perennial River Moyar flows eastwards in the Mudumalai Tiger Reserve. The climate has three marked seasons, namely a dry season (January – April), southwest monsoon (May – August), and northeast monsoon (September – December). The annual rainfall varies from 600 mm in the east to 2000 mm in the west. According to Champion & Seth (1968), the vegetation types in Mudumalai are classified into southern tropical dry thorn forest, southern tropical dry deciduous forest, southern tropical moist deciduous forest, southern tropical semi-evergreen forest, moist bamboo brakes, and riparian forest. Threats to this area include enormous biotic pressure (cattle grazing, cultivations, settlements, collection of fuel wood, non-timber forest products) exerted by the ever-expanding human population.

Breeding sites investigations

In 2015–2021, we found *Gyps indicus* nests by carrying out systematic searches in all areas taking into consideration appropriate for nesting individuals (cliffs, ravines, or large rocky outcrops). These territories were defined priorly based on topography and river systems within the study area (Fig. 1). The same areas were investigated each year, although some sites within the study area were added over the first few years of the study. Nests had remained observed with the use of 10 × 52 binoculars and a 25–75× 70 S3 spotting scope. Nests were identified by the presence of fresh nesting materials and whitewash (excreta) on the cliffs. Each nest was positioned using a GPS-receiver, and numerous photos of the nests and surrounding environment were taken to facilitate recognition of the exact location in subsequent years. A few environmental variables were collected to understand the selection of the nesting site. We categorised each nest as accessible or inaccessible to predators. Nest orientation, exposure, ledge type, and altitude were recorded because of their potential influence on the microclimatic conditions of the nest. We measured nest orientation with a compass. We extracted the information on the slope altitude, distances from neighbouring nesting sites as well as the nearest rivers, roads, and human habitation using Google Earth Pro 7.3.6 1.9345.

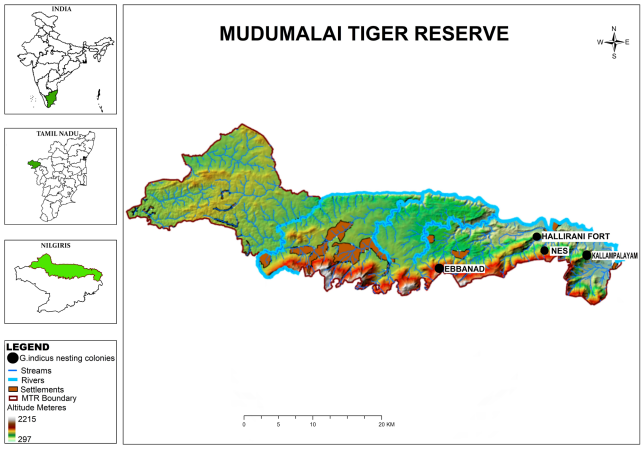

Fig 1. Study area with breeding sites of *Gyps indicus* in Mudumalai Tiger Reserve, South India.

Population estimation

The population estimation (72 visits) was done on the roosting and nesting sites of *G. indicus* in the Mudumalai Tiger Reserve in 2016–2021. The roosting and nesting locations were confirmed. Population estimation was done once a month. We divided the age class of *G. indicus* individuals into three categories based on plumage characteristics, namely adults (> 5 years), sub-adults (2–4 years), and juveniles (< 2 years) (Naoroji, 2007). The population size of *G. indicus* was estimated by counting the individuals in the roosting and nesting sites during the early morning (from 06:30 h to 09:30 h) and late evening (from 17.30 h to 19.30 h) (Dobrev et al., 2020). We assumed fidelity of nesting sites, fixed time of roosting and geographic closure, and no movement into (immigration) or out of (emigration) sites to estimate population size (Samson & Ramakrishnan, 2020).

Breeding ecology and threats

To study the breeding ecology of *G. indicus*, each colony was visited once a week during the breeding season (October to May) to check the status and number of individuals present in each nest. All observations of nesting colonies were made from a distance of 300–600 m from the breeding cliffs. The focal animal sampling method (Altmann, 1974) was used to monitor the status and behaviour of *G. indicus* in nesting colonies (Postupalsky, 1974; Acharya et al., 2009). An active breeding pair (breeding pair) was defined as one that laid an egg, and a non-breeding pair (territorial pair) was confirmed that occupied the nest at least for three weeks but did not lay any eggs (Fernández et al., 1998). Breeding success was calculated based on the number of fledglings divided by the number of breeding pairs, which had laid eggs. During each visit, active nests were considered occupied by a pair only when a single or two adult vultures were observed in the nest, i.e. one standing and one incubating or one incubating adult was present or one adult with a chick or a young chick alone was presented in the nest. A colony was considered active, only if it contained at least one active nest with an egg (Xirouchakis & Mylonas, 2005; Xirouchakis, 2010). Threat assessments, such as human pressure, predator threat, and man-made threats, were estimated during the field visits.

Results

In 2015–2021, four breeding colonies of *G. indicus* were identified in the Mudumalai Tiger Reserve. Two of these four nesting sites were identified in 2016, and two more were recorded in 2017 and 2020, respectively. Notably, all nesting sites located on rock cliffs were entirely inaccessible to both humans and wild animals, whether from the ground or the cliff top. The mean altitude of the nesting sites was 1122.25 ± 170.06 m a.s.l, ranging from 821 m a.s.l to 1600 m a.s.l. On nesting sites, the average slope exposure was 37.78° ± 0.50°, ranging from 28.37° to 41.99°. On the east exposure, 50% of the nests were located, 25% on the south east-facing exposure and 25% on the south-facing exposure. The nesting habitat ledges comprised an equal distribution between open and closed types, with 50% classified as open-type ledges and 50% as closed-type ledges.

On average, nest sites were located at 2.59 ± 0.30 km from water sources. 75% of the observed nest sites were situated within 2.5 ± 0.45 km of water bodies, and one nest site was located at 3.58 km from the nearest water body. The average distance between a given nest site and its closest neighbour was 11.40 ± 2.15 km. A half of the observed nest sites were within 6.58 ± 1.21 km of a neighbouring site, while all sites were within 18 km from each other. On average, nest sites were located at 3.76 ± 0.32 km away from human settlements; all sites were situated within 3.25 ± 0.49 km. 81% of the nest sites were located less than 4 km from human settlements. 66% of the recorded nest sites within 2.40 ± 0.37 km away of the road network. Furthermore, nest sites were less than 30.25 ± 1.24 km from major towns, while all sites being at least 20.59 ± 1.19 km away from large urban areas.

Table 1 summarises data on the number of colonies, visits, and the mean number of adult,

sub-adult, and juvenile individuals of *Gyps indicus* observed in the Mudumalai Tiger Reserve in 2016–2021. Over the study period, the number of colonies increased from two to four, by reflecting the expansion of nesting sites. The total number of visits remained constant at 12 per year throughout the study duration.

Regarding the population composition, the mean number of adults increased steadily from 9.5 ± 0.46 individuals in 2016 to 14.08 ± 0.67 individuals in 2021. Similarly, the mean number of sub-adults showed a consistent increase, reaching 7.25 ± 0.17 individuals by 2021. The t-test results comparing sub-adult and adult populations revealed a statistically significant difference ($t = 7.546$, $p < 0.001$). This indicates a notable distinction between the sub-adult and adult populations within the nesting colonies. Juvenile individuals also displayed an increasing trend, with their mean number escalating from 2.16 ± 0.27 individuals in 2016 to 6.5 ± 0.15 individuals in 2021. Consequently, the total mean number of individuals per colony increased from 13.66 ± 0.56 individuals in 2016 to 27.83 ± 0.62 individuals in 2021. The ANOVA test resulted for the nesting colony population across study years showed a statistical significance ($F = 34.08$, $p < 0.001$). This indicates that there is a significant variation in the population trends within nesting colonies across the study years. During the breeding season, breeding populations exhibited a significant increase, highlighting a notable disparity between breeding and non-breeding populations within nesting colonies ($t = 8.246$, $p < 0.001$).

A total of 40 territorial pairs, averaging 6.66 ± 0.49 pairs per year, with occupied nests were observed between 2015 and 2021 (Table 2). Among these, 31 breeding pairs, averaging 5.16 ± 0.30 pairs per year, successfully laid eggs, with a noted incubation period of 63.6 ± 1.7 days. Out of the 31 incubated nests, 23 fledglings (in average, 3.83 ± 0.47 individuals per year) successfully fledged from the nest, resulting in a breeding success rate of 74%. The total nestling period was calculated as 128.4 ± 1.16 days. The highest breeding success rate (83%) was observed in the breeding seasons of 2019–2020 and 2020–2021, indicating a considerable progress in *Gyps indicus* breeding success in the Mudumalai Tiger Reserve over the study years.

Significant differences were noted in the increase of the number of nests 2015 to 2021 between the occupied and incubated nests ($t = 6.70$, $p < 0.01$), as well as between an incubated and hatched nests ($t = 6.325$, $p < 0.001$). Fledging success was found to be significantly correlated with hatching success ($r = 1.00$, $p < 0.001$), and the incubation was significantly correlated with hatching success ($r = 0.95$, $p < 0.01$). No significant variability was recorded in breeding success and productivity over the study years ($F = 2.012$, $p > 0.05$).

Table 1. The characteristics of *Gyps indicus* population in 2016–2021 in the Mudumalai Tiger Reserve, South India

Number of colonies	Years	Number of visits	Adult individuals	M ± SE	Sub-adult individuals	M ± SE	Juvenile individuals	M ± SE	Total number of individuals	M ± SE
2	2016	12	114	9.50 ± 0.46	24	2.00 ± 0.27	26	2.16 ± 0.27	164	13.66 ± 0.56
3	2017	12	133	11.08 ± 0.39	34	2.83 ± 0.11	46	3.83 ± 0.24	213	17.75 ± 0.41
3	2018	12	132	11.00 ± 0.40	46	3.83 ± 0.35	61	5.08 ± 0.22	239	19.91 ± 0.57
3	2019	12	139	11.58 ± 0.45	58	4.83 ± 0.11	69	5.75 ± 0.13	266	22.16 ± 0.44
4	2020	12	158	13.16 ± 0.62	70	5.83 ± 0.29	72	5.91 ± 0.11	298	24.83 ± 0.66
4	2021	12	169	14.08 ± 0.67	87	7.25 ± 0.17	78	6.50 ± 0.15	334	27.83 ± 0.62

Note: M – average value, SE – standard error.

Table 2. Reproductive performance of *Gyps indicus* in the Mudumalai Tiger Reserve (South India) in 2015–2021

Number of colonies	Years	Territorial pairs	Breeding pairs (clutches)	Successful pairs (fledglings)	Nesting rate, %	Breeding success	Productivity	Abandoned nests
2	2015–2016	5	4	2	80	0.50	0.40	3
3	2016–2017	6	5	3	83	0.60	0.50	3
3	2017–2018	6	5	4	83	0.80	0.67	2
3	2018–2019	7	5	4	71	0.80	0.57	3
4	2019–2020	8	6	5	75	0.83	0.63	3
4	2020–2021	8	6	5	75	0.83	0.63	3
In total:		40	31	23	78	0.74	0.58	17
M ± SE		6.66 ± 0.49	5.16 ± 0.30	3.83 ± 0.47	77.83 ± 2.00	0.72 ± 0.05	0.56 ± 0.04	2.83 ± 0.16

Note: M – average value, SE – standard error.

Breeding failures occurred at various stages of the breeding cycle, with the highest proportion of nest failures occurring before the egg-laying stage. Out of a total of 17 failed breeding attempts, nine (53%) attempts were detected before egg laying, and eight (47%) during the incubation period. There was no significant difference observed between nests abandoned before and after egg laying ($t = 0.415$, $p > 0.05$). The analysis of nest abandonment across the studied years revealed a significant difference in month-wise distribution ($H = 5.84$, $p < 0.05$). The abandoned nests were observed in November (ten nests; 59%) and December (seven nests; 41%). Additionally, a significant difference was observed between the number of occupied and abandoned nests ($t = 8.032$, $p < 0.001$).

Discussion

Raptor populations are limited by the availability of breeding habitats at microscale level (Bevers & Flather, 1999). However, macrohabitat characteristics, such as vegetation cover type, topography, human pressure, availability and accessibility of prey are important components in nesting habitat selection (Sergio et al., 2004; Kudo et al., 2005; Rodriguez-Lado & Tapia, 2012). The present study highlights the suitability of the eastern side of the rocky mountainous structures in the Mudumalai Tiger Reserve as an optimal breeding habitat for *Gyps indicus*. The nesting colonies in the Mudumalai Tiger Reserve were inaccessible to humans as well as terrestrial predators, contributing to their protection and breeding success. The physical characteristics of nesting sites play a crucial role in determining the breeding success by influencing predation risk (Martin, 1993; Verlando & Márquez, 2002; Mainwaring et al., 2014). Specifically, hidden nests or those situated on locations inaccessible to terrestrial predators tend to have higher breeding success rates (Mallory & Forbes, 2011; Haynes et al., 2014; Anderson et al., 2015).

Sunshine and slope orientation appeared to be of low importance in the case of *Aegypius monachus* (Linnaeus, 1766) (Mihoub et al., 2013), but aspects of the cliff location play a role in nest site selection. For example, *Gyps fulvus* (Hablizl, 1783) generally prefers western and southern exposures of slopes due to a larger amount of sunshine (Marinković et al., 2012). Although the present study revealed the use of almost all aspects for nest building, the west and north slopes were the least preferred aspects. As expected, 50% of the nests were located on eastern exposure, 25% on southeast exposure, and 25% on southern exposure. This orientation provides more sunshine for chicks in a colder climate and typically maintains congenial atmospheric temperatures compared to western- and northern-facing locations. A similar observation was made in the *Gyps indicus* population in Protected Areas of Madhya Pradesh, Central India (Jha et al., 2021). Venkitachalam & Senthilnathan (2015) found that 50% of the nests were located on north-facing exposures, 16% on east-facing exposures, and 17% on south and southeast-facing exposures in the Moyar Valley, Tamil Nadu, India. In some other studies (e.g. Vlachos et al., 1998; Liberatori & Penteriani, 2001; Şen et al., 2017), the southern aspect was preferred, possibly, due to the sunlight availability (Carlon, 1992). The present study also revealed that the preferred nesting site altitude was between 821 m a.s.l. and 1600 m a.s.l. Jha et al. (2021) found that *Gyps indicus* and *Neophron percnopterus* (Linnaeus, 1758) showed preferences for nesting sites ranging from 56 m a.s.l. to 169 m a.s.l. in Protected Areas of Madhya Pradesh, Central India. This indicates that altitude is linked to local topography rather than a species-specific requirement (Mihoub et al., 2013). Notably, the same nests were consistently utilised by *Gyps indicus* throughout the study period in the Mudumalai Tiger Reserve. Some studies have observed that constructed nests are re-used for years or even decades by the same birds, gradually increasing in size with each breeding season (Rasmussen & Anderton, 2005; Kushwaha & Kanaujia, 2009; Vergara et al., 2010).

In the Mudumalai Tiger Reserve, factors contributing to disturbance, such as the average distance to roads and villages (2 km and 4 km, respectively), were notably far away from the nesting habitats. Most road networks have a very low traffic intensity due to the Protected Area status, although the State Highway passing through the Mudumalai Tiger Reserve exhibited a high traffic intensity. Consequently, their impact on vultures remains minimal. However, nesting vultures are highly sensitive to disturbance, to the extent that increased activity along roads may lead to nest site desertion (Bridgeford & Bridgeford, 2003; Monadjem & Garcelon, 2005). In contrast, *Gyps bengalensis*, *G. indicus*, *Sarcogyps calvus* (Scopoli, 1786) and *Neophron percnopterus* have been observed foraging around human settlements (Thakur & Narang, 2012; Samson & Ramakrishnan, 2016, 2020). Similar associations have been documented for other species, such as *Gyps bengalensis*, *Necrosyrtes monachus* (Temminck, 1823), and *Neophron percnopterus* in various parts of the world (Henriques et al., 2018).

Despite the crucial role of water in a vulture survival (Fergusons-Lees & Christie, 2001; Naoroji,

2007), information regarding the vulture nest proximity to water bodies is scarce. In the present study, the distance of *Gyps indicus* nests to water bodies is a few kilometres, indicating that vegetation suitability is prioritised over the water proximity. Jha et al. (2021) observed larger vulture congregations near water bodies and smaller populations at a higher distance from them in Protected Areas of Madhya Pradesh, Central India. Wagley et al. (2020) found that river banks are favourable areas for wild animal carcasses, providing enough food for vultures and increasing the food availability. Moreover, the presence of active and occupied nests near water sources allows the species and their offspring convenient access to water after feeding on carrion. Thakur & Narang (2012) also noted that most nest sites were located near water sources, while Ghimire (2016) observed nests on forest edges in a close proximity to water sources. Ramakrishnan et al. (2014) confirmed the importance of water for vulture nesting, emphasising its significance for all living organisms. Samson et al. (2014) highlighted the importance of waterholes as decisive factors for vulture conservation within their habitat range, a finding supported by similar observations elsewhere. *Gyps africanus* Salvadori, 1865 are known to prefer riparian vegetation for nesting (Monadjem, 2001; Monadjem & Garcelon, 2005), although this preference may vary in the absence of such vegetation (Tarboton & Allan, 1984; Monadjem & Garcelon, 2005).

In the Mudumalai Tiger Reserve, the population trend of *Gyps indicus* exhibited significant growth over the study years. Particularly, the number of adult and sub-adult individuals showed a notable association, indicating a promising trend in the survival and transition of sub-adults to adults within the *Gyps indicus* population in the Protected Area. Population variations were observed between breeding and non-breeding seasons, a pattern also noted in studies of Baral et al. (2005) and Samson & Ramakrishnan (2020), investigated *Gyps bengalensis* populations in Nepal and India. This observed variation could be attributed to the behaviour of adult birds during non-breeding seasons, as they tend to fly far away in search for food and may not return to nesting colonies at the same day (Rabenold, 1987). Consequently, the maximum number of vultures was observed in and around nesting colonies only during breeding period in contrast with non-breeding seasons. It was noted that the number of *Gyps indicus* individuals in the population slightly increased during the breeding season compared to the non-breeding season. This phenomenon may suggest a high survival rate among the birds and/or an influx of non-breeding birds from other areas. However, further investigations are needed to confirm this.

The timing of the breeding and nesting season of *Gyps indicus*, observed in this study from October to May, is consistent with earlier studies (Naoroji, 2007; Misher et al., 2017). *Gyps indicus* lay their eggs in November, i.e at the beginning of the winter season in the Mudumalai Tiger Reserve, which is at the end of the rainy season. The incubation takes place in November and December and eggs are being hatched in January. These findings strongly support the suggestion that the egg-laying in *Gyps* genus is generally triggered at the end of the rainy season, irrespective of the latitude (Mundy et al., 1992). Newton (1979) observed that normally the breeding chronology in raptors varies according to the geographic area and is largely defined by food availability and weather conditions. In the Mudumalai Tiger Reserve, nesting colonies of *Gyps indicus* are relatively small in number compared to the whole population, and breeding success varies depending on the colony. Some studies suggest that breeding success in group-living birds may be influenced by the colony size (Hunt et al., 1986; Barbosa et al., 1997; Brunton, 1997, 1999; Weaver & Brown, 2005). Furthermore, the optimal group size depends on the definition of fitness (Sibly, 1983; Giraldeau & Gillis, 1985; Kramer, 1985).

During the breeding seasons, spanning from 2016 to 2021, a total of 40 occupied nests, including 31 active nests and 23 chicks, were observed in the Mudumalai Tiger Reserve, resulting in a breeding success rate of 74%. The average incubation period was recorded at 63.6 ± 1.7 days, while the nestling period was observed to be 128.4 ± 1.16 days in the Protected Area. These findings are consistent with those reported by Misher et al. (2017), observed an incubation period at 62.5 ± 1.5 days and a nestling period of 129.4 ± 1.0 days along the River Chambal in Rajasthan, India. However, the study of Ravikanth & Baskaran (2023) showed that the incubation period ranged at 53–55 days with a mean of 54 ± 1 days, while the observed nestling period was 103 ± 2 days in the Kaghaznagar Forest Division and its adjoining areas on the Deccan Plateau, India.

In the southern Indian states of Tamil Nadu, Karnataka, Andhra Pradesh, and Telangana, there are only a few number of *Gyps indicus* populations. Venkitachalam & Senthilnathan (2015) reported four breeding pairs and nesting site characteristics of *Gyps indicus* in the Moyar Valley ecosystem, Tamil Nadu, India. Additionally, Samson & Ramakrishnan (2018) recorded an additional nesting site of *G. indicus* in

the Moyar Valley ecosystem with successful breeding. Subramanya & Naveein (2006) documented ten adults of *Gyps indicus* with three occupied nests, resulting in a 75% breeding success rate in the Ramanagaram hills, Karnataka state, India. A recent study of Padma (2018) reported 253 sightings of *Gyps indicus* in 76 visits, with an average of 3.3 vultures per visit in the Ramadevarabetta Vulture Sanctuary over 2015–2017. However, all three nests observed during the breeding seasons of 2015–2017 were unsuccessful. Srinivasulu et al. (2009) observed a total of 17 *Gyps indicus* emerging from nearby rocky outcrops in the Adoni area of the Nagarjunasagar-Srisailam Tiger Reserve, Andhra Pradesh state, India. Stotrabhashyam et al. (2015) documented nesting sites of *Gyps indicus* in the Southern Indian region, with a particular focus on Palarapu Cliffs, Bijjur Reserve Forest, Telangana state, India. Ravikanth & Ram Mohan (2016) reported 19 adults and ten occupied nests with eight chicks, resulting at 80% breeding success rate in Palarapu Cliff, Telangana state, India. Considering the northern part of India, Chhangani (2004) observed that 92 nests of *Gyps indicus* with eggs had chicks from October 1999 to April 2000 at various nesting sites. The nesting success, determined from egg laying to fledging was 90%. Gurjar & Gawande (2011) found eight nests accounting for eight chicks with 100% breeding success on *Gyps indicus* in the Panna Tiger Reserve, Madhya Pradesh state, India. Misher et al. (2017) recorded 22 nests with 17 active ones, of which 16 were successfully hatched (94%) and 14 chicks were successfully fledged (82.25%) out from the nest of *Gyps indicus* in Gapernath, River Chambal, Rajasthan state, India. Chishty & Choudhary (2020) recorded that in the first observation year (July 2017 – June 2018), a successful breeding rate of 60% was recorded. Of the five nests, in three nests successfully developed the chicks and were able to fly while two nests were a failure. In the second year (July 2018 – August 2019), the successful breeding rate was 20% only. In one nest the chick developed successfully and it was able to fly, while the other four nests failed (Chishty & Choudhary, 2020). McClure et al. (2021) observed that *Gyps indicus* had 2397 potential nesting ledges, of which 1183 (49.4%) were in the Rajasthan state and 1214 (50.6%) in Madhya Pradesh state. Of them, 686 (58%) and 723 (60%) ones were occupied at least once in Rajasthan state and Madhya Pradesh state, respectively. Ravikanth & Baskaran (2023) studied the breeding ecology of *Gyps indicus* at Palarapu Cliffs in Kaghaznagar and Sironcha Forest Divisions in 2010–2021. The study documented 84 nests with 58 successfully hatched chicks, resulting in a breeding success rate of 65%.

In the Mudumalai Tiger Reserve, all nesting colonies were located quite far away from human habitation on top of cliffs. Thus, both human pressure and terrestrial predators did not pose a threatening factor to the *Gyps indicus* population. Only the largest eagles and vultures were relatively free from predation pressure, although their nests may occasionally be assaulted by carnivores (Tapia & Zuberogoitia, 2018). Forest fires, particularly those caused by humans, posed a serious threat to one of the nesting colonies of *G. indicus* during the years of 2015–2016 and 2016–2017, resulting in no nesting being observed during the breeding seasons. Forest fires, especially those of human origin, represent a significant threat to the *Gyps indicus* population in the Mudumalai Tiger Reserve. Andalus (1993) observed that forest fires destroyed nests of *Coragyps atratus* (Bechstein, 1793) with chicks in Spain, indicating a potential threat to the only Balkan colony located in Greece.

Conclusions

The present study indicates an increase in the population of *Gyps indicus* in the Mudumalai Tiger Reserve, India, during 2015–2021. Forest fires posed a serious threat to the nesting colonies of this species. Based on these findings, we suggest continuous monitoring of the population and breeding status of *Gyps indicus* in the Mudumalai Tiger Reserve as it is crucial for understanding the population trend of the species. A species-specific conservation-oriented action programme is necessary to secure this last southernmost wild viable *Gyps indicus* population in the Mudumalai Tiger Reserve. At this juncture, we highly recommend declaring the buffer zone of the Mudumalai Tiger Reserve as a «Vulture Sanctuary» to provide legal protection to the *Gyps indicus* population living in this area.

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ПОПУЛЯЦИЯ, ОСОБЕННОСТИ ГНЕЗДОВАНИЯ И ЭКОЛОГИЯ РАЗМНОЖЕНИЯ НАХОДЯЩЕГОСЯ ПОД УГРОЗОЙ ИСЧЕЗНОВЕНИЯ *GYPS INDICUS* В ТИГРОВОМ ЗАПОВЕДНИКЕ МУДУМАЛАЙ, ЮЖНАЯ ИНДИЯ

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В последнее время скорость вымирания видов увеличилась во всем мире и во много раз выше, чем в результате воздействия только естественных процессов. Небольшие изолированные популяции наиболее уязвимы перед процессом вымирания ввиду обусловленных и случайных угроз. Поэтому сохранение таких популяций является сложной задачей. Настоящее исследование, проведенное с 2015 по 2021 гг. в Тигровом заповеднике Мудумалай (юг Индии), было направлено на изучение популяции, особенностей гнездования и экологии размножения самой южной в стране популяции *Gyps indicus*. Оценка численности особей проводилась на местах ночевок и гнездования *Gyps indicus* в Тигровом заповеднике Мудумалай. Для изучения особенностей гнездования и экологии размножения каждую гнездовую колонию систематически посещали четыре раза в месяц в течение сезона размножения (октябрь – май). Оценки угроз оценивались в ходе выездов на места обитания вида. За период 2015–2021 гг. было выявлено четыре гнездовых участка. Два из них были выявлены в 2016 г. и еще по одному в 2017 г. и 2020 г. Гнездовья располагались в среднем на высоте 1122.25 ± 170.06 м н.у.м., в пределах от 821 м н.у.м. до 1600 м н.у.м. На территории исследования два гнезда располагались на склонах восточной экспозиции, одно – на склоне юго-восточной экспозиции и одно – на склоне южной экспозиции. В отношении состава популяции средняя численность взрослых особей возросла с 9.5 ± 0.46 в 2016 г. до 14.08 ± 0.67 в 2021 г. Следовательно, среднее значение общей численности особей в колонии увеличилось с 13.66 ± 0.56 в 2016 г. до 27.83 ± 0.62 в 2021 г. В общей сложности в 2015–2021 гг. наблюдалось 40 (в среднем 6.66 ± 0.49 пар/год) территориальных пар с занятыми гнездами. Из них 31 (в среднем 5.16 ± 0.30 пар/год) гнездящаяся пара отложила яйца. Было отмечено успешное высиживание яиц со средним инкубационным периодом в 63.64 ± 1.74 дня. Из 31 гнезда с кладками 23 птенца (3.83 ± 0.47 особей/год) успешно вышли из гнезда; успех размножения составил 74%. Полный период гнездования составил 128.43 ± 1.16 суток. Из 17 неудачных попыток гнездования девять (53%) были обнаружены до откладки яиц, а восемь (47%) – во время периода высиживания яиц. Статистически значимых различий между количеством гнезд, покинутыми до и после откладки яиц, не было выявлено ($t = 0.4152$, $p > 0.05$). В сезоны размножения в 2015–2017 гг. серьезную угрозу нескольким гнездовым колониям *Gyps indicus* представляли лесные пожары антропогенного происхождения, в результате чего гнездования там не наблюдалось. Для сохранения изученной единственной сохранившейся и самой южной жизнеспособной популяции *Gyps indicus* в Тигровом заповеднике Мудумалай необходима программа действий, ориентированная на сохранение данного вида. В этой связи рекомендуется представить охранную зону Тигрового заповедника Мудумалай в качестве «Заказника грифов» («Vulture Sanctuary») для обеспечения легальной охраны популяции *Gyps indicus*, обитающей на территории исследования.

Ключевые слова: высиживание, гнездование, гриф, колония, птенец, скалы, яйцо