Recent studies on Indian primates show declining population trends, even in protected areas

Shahid Hameed, Tawqir Bashir, Mohammad Niamat Ali
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Abstract Population size and geographical range are the key quantitative criteria used by the IUCN to assess the conservation status of a species. However, such information is often incomplete and inconsistent, even for seemingly abundant species. To assess the population and conservation status of Indian primates, we conducted a systematic review of recent research using the searching, appraisal, synthesis and analysis (SALSA) approach. We reviewed a total of 41 studies on Indian primates conducted during the last 2 decades (2000–2021) for information on various parameters that influence their conservation. We found that 20 out of a total of 26 primate species were evaluated for their population status, and the majority of these studies (71%) showed an overall declining population trend. Remarkably, all but one of the studies conducted exclusively within protected areas revealed declining population trends, whereas trends were more variable for primate populations in non-protected areas. Our data indicate that only 27% (n = 7) of Indian primate species have been surveyed or re-surveyed to assess their population status within the last 5 years. Although threats vary in time and space from species to species, 78% of the studies recorded natural system modifications including habitat loss and fragmentation among the main threats to the survival of Indian primates. Most studies on the population status of Indian primates have either been spatially limited or used outdated methods. We recommend that future studies adopt robust techniques to estimate populations and work across larger geographical scales to develop effective management strategies for the conservation of primates in India.

Keywords Conservation, habitat loss, India, literature review, population trend, primates

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Introduction

Continuing, large-scale biodiversity loss is a global conservation concern and represents a major challenge for the 21st century (Butchart et al., 2010). Despite international conventions to overcome this challenge (Thomsen & Willerslev, 2015), the dearth of information on the status and distribution of species impedes effective conservation and prioritization. Over the past few decades, anthropogenic land-cover changes have resulted in declining populations of many species (Butchart et al., 2010), with the current rate of species extinction estimated to be nearly 1,000 times the background rate (Pimm et al., 1995, 2014). Furthermore, species conservation efforts both regionally and globally are often impeded by the lack of fine-scale range maps and accurate information on species distribution (Singh et al., 2020).

Primates are at risk of extinction globally, with 60% of species categorized as threatened on the IUCN Red List and c. 30% of non-human primate species listed as Critically Endangered (Estrada et al., 2017). Nearly 75% of primate species are experiencing global population declines and the situation is particularly alarming for Asian primates, with 95% of species declining (Estrada et al., 2017). Globally, populations and geographical ranges of most primate species are decreasing because of habitat loss and fragmentation caused primarily by anthropogenic activities (Rabanal et al., 2010; Wich et al., 2014; Cotton et al., 2016). Increasing human populations (Campbell et al., 2008), hunting of primates for consumption and the pet trade (Rosen & Smith, 2010), political instability (Kalpers et al., 2003) and diseases (Bermejo et al., 2006; Williams et al., 2008) are additional threats affecting primate populations. These threats often act synergistically and are not mutually exclusive. Collecting baseline data on primate distribution, population sizes and trends is a key step towards effective conservation, as population monitoring enables researchers to quantify the impact of local threats and evaluate the success of any conservation measures implemented (Campbell et al., 2016). In addition, population monitoring can help to identify priority areas for primate conservation, develop conservation management strategies and eliminate threats.

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Taxonomic accuracy plays a crucial role in understanding species distribution ranges, population trends, threats and conservation efforts (Mace, 2004; Lewis & Maslin, 2015). The ambiguity in the taxonomic status of some Indian primate species arises from the fact that the majority of existing classification schemes rely on plastic morphological traits, a situation that is further complicated by incompatibility between various classification systems (Nag et al., 2011). Given these taxonomic uncertainties, the exact number of Indian primate species at risk of extinction remains unknown (Ashalakshmi et al., 2015). There have, however, been studies employing molecular techniques in an effort to resolve this issue (Karanth et al., 2008, 2010a; Osterholz et al., 2008; Wangchuk et al., 2008; Ashalakshmi et al., 2015). For example, studies based on molecular phylogeny and biogeography have led to the assignment of the purple-faced langur *Semnopithecus vetulus* and Nilgiri langur *Semnopithecus johnii* to the genus *Semnopithecus*, rather than *Trachypithecus* (Karanth et al., 2008; Osterholz et al., 2008), and maintaining the species status of the tufted gray langur *Semnopithecus priam* (Blyth, 1844) and black-footed gray langur *Semnopithecus hypoleucos* (Blyth, 1841). A study using an integrative taxonomic approach confirmed species status for the Himalayan langur *Semnopithecus schistaceus* (also referred to as Nepal gray langur) but did not support dividing this taxon into multiple species or subspecies (Arekar et al., 2021). Similarly, a recent study ascertained the hoolock gibbon *Hoolock hoolock* as the only gibbon species in India (Trivedi et al., 2021), contrary to an earlier report of there being two species, the eastern *Hoolock leuconedys* and western *Hoolock hoolock* hoolock gibbons (Das et al., 2006).

Taking these ambiguities into account, a recent study reported 24 species of non-human primates in India, including two species of lorises, 10 species of langurs, 10 species of macaques and two species of small apes (Singh et al., 2020), of which 18 species are categorized as threatened on the IUCN Red List (IUCN, 2021). For many primate species in India, information on their current distribution is lacking, which impedes the assessment of their conservation status (Karanth et al., 2010b). Furthermore, with the exception of a few recent studies, most surveys on Indian primates have been methodologically outdated and geographically limited (Singh et al., 2020).

To improve our understanding of the conservation status of Indian primates, we carried out a comprehensive review of the published literature, seeking to answer the following questions: (1) What do the data from recent studies indicate about population trends of Indian primates and the reasons for any observed changes? (2) How has the conservation status of Indian primates changed over time? (3) What are the reasons for such changes? (4) How do these changes vary amongst different species with respect to their habitats and the level of anthropogenic disturbance?

Methods

We undertook a systematic review using the search, appraisal, synthesis and analysis (SALSA) approach (Grant & Booth, 2009). We followed methods described by Shrestha et al. (2022) and included research articles dedicated either fully or in part to the study of the population status of non-human primates in India (Fig. 1). To keep our findings relevant to current species conservation efforts, we limited our search to studies published during the past 2 decades (2000–2021). We conducted a Boolean search across the Web of Science (Clarivate, Philidelphia, USA), Research Gate (ResearchGate, 2023), and Google Scholar (Google, 2023) platforms, using a combination of keywords related to the population and conservation status of Indian primates. To retrieve the relevant results, we used search operators such as AND, OR and NEAR in combination with species names and different keywords related to population status (Supplementary Table 1). We retrieved a total of 105 research publications related to Indian primates, which we examined for the presence of search query terms in the title, abstract and keywords. After this initial selection process, 41 publications accounting for 62 status reports, including multi-species studies, were retained for further analysis. For each research article in this sample (Supplementary Table 2), we recorded information on the population trend, year of survey, main threats reported, study area location, protection status of the study area and survey methods used. In the case of species for which repeated surveys had been conducted in a given area, we considered only the results from the most recent study. Although various studies have attempted to resolve the taxonomic ambiguity among Indian primates, here we considered the species taxonomy as reported by the authors in the research articles. We retrieved information on all primate species present in India, irrespective of whether or not they are threatened. We conducted all data analyses in *R 4.2.2* (R Core Team, 2013) and used *ArcGIS Desktop 10.8* (Esri, Redlands, USA) to map the geographical areas covered by the analysed publications.

Results

Population status

We included all primate species in India, along with their conservation status and the number of studies that we found for each species, in our review. We found the highest number of studies on the rhesus macaque *Macaca mulatta*, but there were no reports on the population status of some species, including several langurs (Table 1). We identified five population status categories (Fig. 2) based on author inference in the reviewed articles: declining, increasing, stable, small and recovering populations. Studies that were the first

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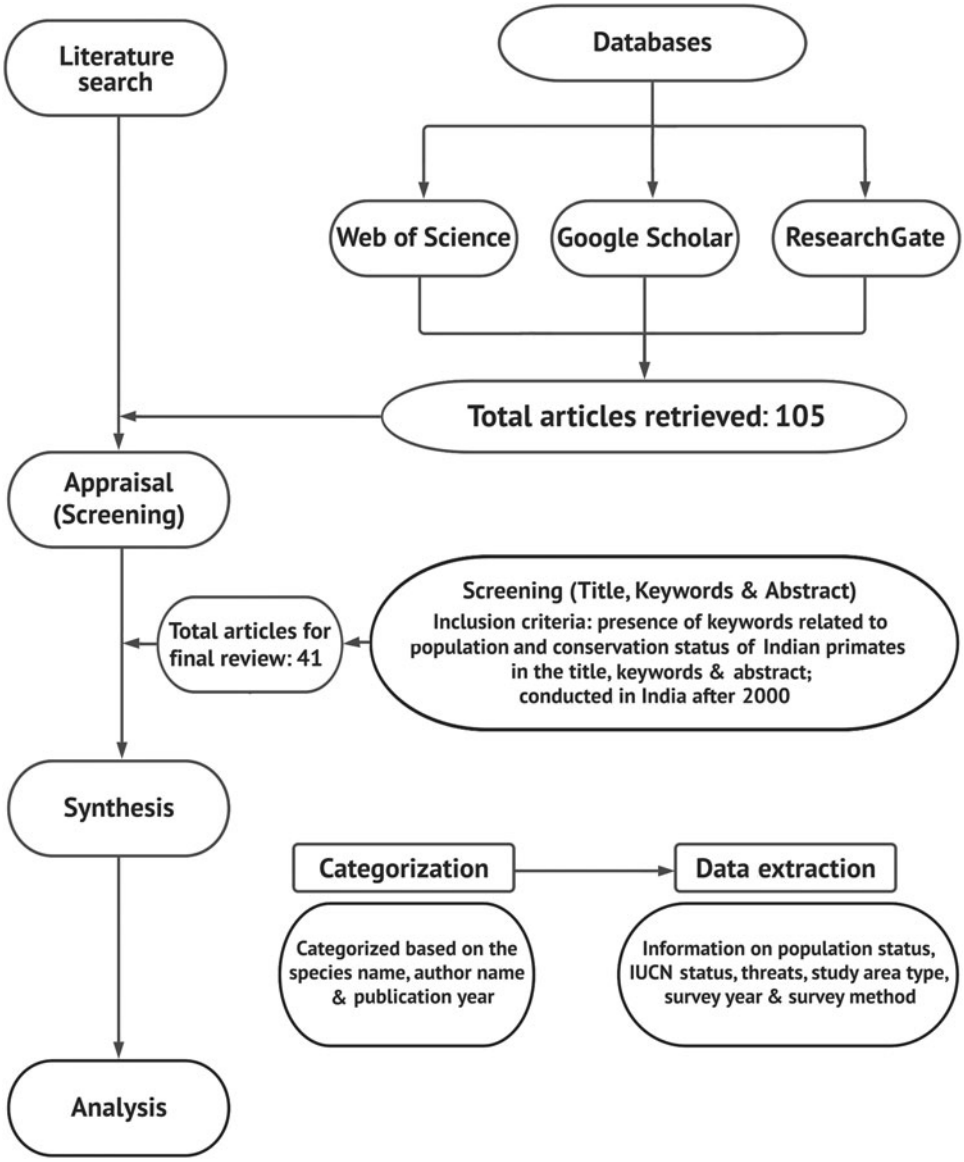

FIG. 1 Flow diagram of the searching, appraisal, synthesis and analysis (SALSA) method used in the literature review. The left-hand side of the diagram shows the four main processes of the review, with the components of these processes shown on the right-hand side (following Shrestha et al., 2022).

to report on primate populations in a given area (and thus could not compare observed populations to previous studies) categorized populations as either small or stable/good. The majority of publications (71%) reported a declining population trend of the target species, followed by increasing (16%) and stable (13%) population trends. Declining population trends were attributed mostly to modifications of natural systems, such as habitat loss and fragmentation. Amongst the studies indicating declining population trends, 67% reported on only six primate species. For example, all nine reports on western (n = 5) and eastern (n = 4) hoolock gibbons showed declining population trends across the surveyed areas. Recovering population trends were reported for the Nicobar long-tailed macaque *Macaca fascicularis umbrosus* populations in coastal areas, which had been affected by a tsunami. A number of factors could affect the population dynamics of this species; for example, groups of crop-using macaques that had come into conflict with people may have moved from forest interiors to coastal areas. However, the observed population recovery is generally regarded as having been caused by the regeneration of native vegetation in coastal areas following the evacuation of people after the tsunami, which created space and suitable habitat for the species to thrive (Narasimmarajan & Raghunathan, 2012; Velankar et al., 2016). The increasing population trend reported by 16% of the analysed studies was, however, mainly attributed to improved knowledge (i.e. increased spatial coverage compared to previous studies; Kumar et al., 2018) or to the effective protection offered to species by religious customs or cultural norms (Chaudhuri et al., 2007). For example, the increasing population trend of the lion-tailed macaque *Macaca silenus*

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TABLE 1 Data on primate species in India, including the conservation status according to the IUCN Red List (IUCN, 2021) and the Wild Life (Protection) Act (WLPA; numerals denote schedule types under the WLPA, with lower values representing a higher protection status), the number of population studies published during 2000–2021, study site protection (PA, protected areas; NPA, non-protected areas), survey methods used, study location, main direct threats faced, local population trend (as reported in the studies) and the global population trend (according to the IUCN Red List). The numbers in parentheses indicate the number of reports. Species for which we did not find any studies are marked with asterisks (*); data on the direct threats and global population trend for these species were taken from the IUCN Red List.

Species	Conservation status		No. of studies	Study location (State)	Protection status of the study site(s)	Methods used	Main direct threats [IUCN threat code]	Local population trend	Global population trend
	IUCN	WLPA							
Lorises									
Grey slender loris* *Loris lydekkerianus grandis*	EN	I	0	n/a	n/a	n/a	Residential & commercial development [1]; agriculture & aquaculture [2]	n/a	Declining
Bengal slow loris *Nycticebus bengalensis*	EN	I	1	Assam	PA (1)	All count (1)	Natural system modifications [7]	Declining (1)	Declining
Langurs									
Kashmir gray langur *Semnopithecus ajax*	EN	II	2	Himachal Pradesh (1); Jammu and Kashmir (1)	PA (1); both PA & NPA (1)	Line transects (1); distance sampling (1)	Natural system modifications [7]	Stable (2)	Declining
Northern plains gray langur *Semnopithecus entellus*	LC	II	4	Maharashtra (1); Odisha (1); Rajasthan (1); Karnataka (1)	PA (1); NPA (2); both PA & NPA (1)	All count (1); line transects (3)	Natural system modifications [7]; biological resource use [5]	Stable (2); declining (1); increasing (1)	Declining
Tarai gray langur* *Semnopithecus hector*	NT	II	0	n/a	n/a	n/a	Residential & commercial development [1]; agriculture & aquaculture [2]	n/a	Declining
Black-footed gray langur *Semnopithecus hypoleucos*	LC	II	1	Karnataka (1)	PA (1)	Line transects (1)	Natural system modifications [7]	Increasing (1)	Declining
Tufted gray langur *Semnopithecus priam*	NT	II	1	Tamil Nadu (1)	PA (1)	All count (1)	Natural system modifications [7]	Stable (1)	Declining
Nepal gray langur* *Semnopithecus schistaceus*	LC	II	0	n/a	n/a	n/a	Residential & commercial development [1]; agriculture & aquaculture [2]	n/a	Declining
Nilgiri langur* *Semnopithecus johnii*	VU	I	0	n/a	n/a	n/a	Residential & commercial development [1]; agriculture & aquaculture [2]	n/a	Stable
Capped langur *Trachypithecus pileatus*	VU	I	5	Arunachal Pradesh (1); Assam (3); Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland & Tripura (1)	PA (4); NPA (1)	Line transects & all count (1); all count (1); line transects (1); random sampling (1); various (1)	Natural system modifications [7]; biological resource use [5]	Declining (5)	Declining

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Table 1 (*Cont.*)

Species	Conservation status		No. of studies	Study location (State)	Protection status of the study site(s)	Methods used	Main direct threats [IUCN threat code]	Local population trend	Global population trend
	IUCN	WLPA							
Gee's golden langur *Trachypithecus geei*	EN	I	2	Assam (2)	PA (2)	Line transects (1); all count (1)	Natural system modifications [7]	Increasing (1); decreasing (1)	Declining
Phayre's leaf monkey *Trachypithecus phayrei*	EN	I	1	Tripura (1)	PA (1)	Line transects (1)	Human intrusions & disturbance [6]	Decreasing (1)	Declining
Macaques									
Rhesus macaque *Macaca mulatta*	LC	II	7	Uttar Pradesh (1); Karnataka (1); Assam (3); Maharashtra, Andhra Pradesh, Gujarat, Goa & Karnataka (1); Odisha (1)	PA (2); NPA (3); both PA & NPA (2)	Line transects (4); all count (2); random sampling (1)	Natural system modifications [7]; biological resource use [5]	Increasing (2); decreasing (5)	Unknown
Assamese macaque *Macaca assamensis*	NT	II	4	Arunachal Pradesh (1); Assam (3)	PA (2); NPA (2)	Line transects (2); all count (1); random sampling (1)	Natural system modifications [7]	Declining (3); small (1)	Declining
Stump-tailed macaque *Macaca arctoides*	VU	II	3	Assam (3)	PA (2); NPA (1)	All count (2); random sampling (1)	Natural system modifications [7]	Declining (2); stable (1)	Stable
Dark-bellied bonnet macaque *Macaca radiata radiata*	VU	II	2	Karnataka (2)	NPA (1); both PA & NPA (1)	Line transects (2)	Natural system modifications [7]; human intrusions & disturbance [6]	Declining (2)	Declining
Southern pig-tailed macaque *Macaca nemestrina*	EN	II	1	Assam (1)	PA (1)	Line transects (1)	Natural system modifications [7]	Declining (1)	Declining
Northern pig-tailed macaque *Macaca leonina*	VU	II	2	Assam (2)	PA (1); NPA (1)	Random sampling (1); all count (1)	Natural system modifications [7]	Declining (2)	Declining
Arunachal macaque *Macaca munzala*	EN	Not listed	4	Arunachal Pradesh (4)	NPA (4)	Random sampling & direct sighting (4)	Natural system modifications [7]; biological resource use [5]	Increasing (1); small (3)	Declining
White-cheeked macaque* *Macaca leucogenys*	EN	Not listed	0	n/a	n/a	n/a	Agriculture & aquaculture [2]; biological resource use [5]	n/a	Declining
Tibetan macaque* *Macaca thibetana*	NT	Not listed	0	n/a	n/a	n/a	Residential & commercial development [1]; agriculture & aquaculture [2]	n/a	Declining

Table 1 (*Cont.*)

Species	Conservation status: IUCN	Conservation status: WLPA	No. of studies	Study location (State)	Protection status of the study site(s)	Methods used	Main direct threats [IUCN threat code]	Local population trend	Global population trend
Lion-tailed macaque *Macaca silenus*	EN	I	4	Tamil Nadu (1); Karnataka (2); Kerala (1)	PA (3); both PA & NPA (1)	All count (3); line transects (1)	Natural system modifications [7]; biological resource use [5]	Declining (2); increasing (1); stable (1)	Declining
Bonnet macaque *Macaca radiata*	VU	II	5	Maharashtra, Andhra Pradesh, Gujarat, Goa & Karnataka (1); Karnataka, Tamil Nadu & Kerala (1); Goa (1); Karnataka (2)	PA (1); NPA (1); both PA & NPA (3)	Line transects (3) All count (1); random sampling & direct sighting (1)	Natural system modifications [7]; biological resource use [5]	Declining (4); increasing (1)	Declining
Nicobar long-tailed macaque *Macaca fascicularis umbrosus*	VU	I	4	Great Nicobar Island (3); Andaman & Nicobar Islands (1)	NPA (3); both PA & NPA (1)	Distance sampling (1); line transects (3)	Natural system modifications [7]; human intrusions & disturbance [6]	Increasing (1); recovering (3)	Declining
Gibbons									
Eastern hoolock gibbon *Hoolock leuconedys*	VU	I	4	Assam (2); Arunachal Pradesh (2)	PA (3); NPA (1)	Line transects (2); line transects & call count (2)	Natural system modifications [7]; human intrusions & disturbance [6]	Declining (4)	Declining
Western hoolock gibbon *Hoolock hoolock*	EN	I	5	Assam (4); Meghalaya (1)	PA (2); NPA (1); both PA & NPA (2)	Line transects (2); all count (1); random sampling (1); call count and all count (1)	Natural system modifications [7]; human intrusions & disturbance [6]	Declining (5)	Declining

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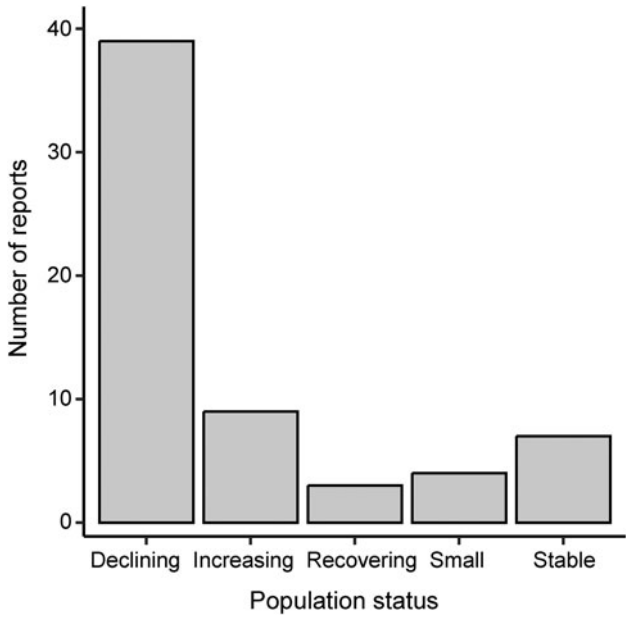

FIG. 2 The population status of Indian primates as indicated by recent studies (2000–2021).

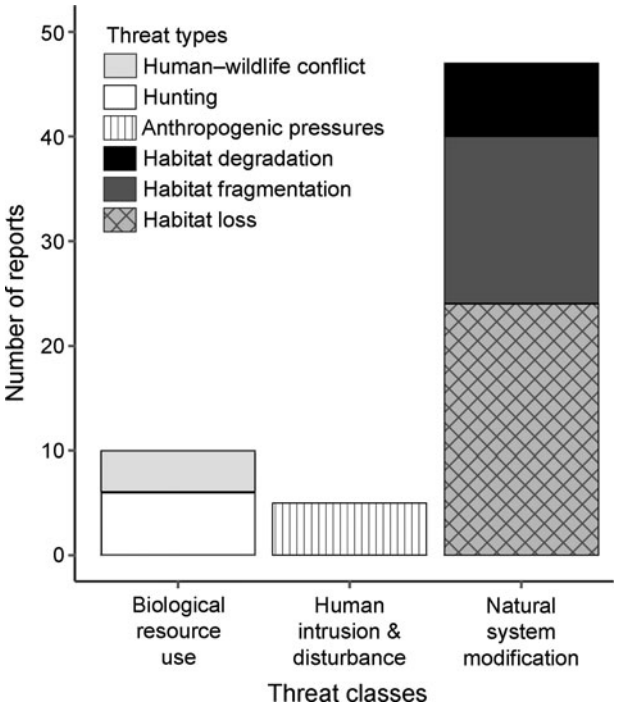

FIG. 3 Number of reports indicating various threats faced by primates in India. Threats are categorized according to the IUCN–Conservation Measures Partnership threat classification scheme (IUCN, 2023).

was attributed to better spatial coverage and improved enumeration techniques compared to previous studies (Kumar et al., 2018). For the Arunachal macaque *Macaca munzala*, which primarily inhabits the Tawang district of Arunachal Pradesh, the increasing population trend could be the result of enhanced spatial coverage and the absence of hunting attributed to the religious/cultural beliefs of the Monpa people (Kumar et al., 2008). Elsewhere, the species has been reported to be at risk of extirpation because of prevalent hunting practices (Sarania et al., 2017). In the absence of hunting, the population would be expected to fluctuate, with ups and downs over the years. However, studies reported a nearly 1.5% growth per year in the number of groups recorded during 2008–2017 (from 35 to 41 groups; Kumar et al., 2008; Biswas et al., 2011; Sarania et al., 2017), which we assume to be a combined effect of absence of hunting and greater spatial coverage of surveys.

Main threats

We assigned the various threats reported to three categories: (1) modification of natural systems, (2) human intrusions and disturbance, and (3) biological resource use according to the IUCN–CMP Unified Classification of Direct Threats (IUCN, 2023). Modification of natural systems (78%) such as habitat loss, fragmentation, modification and degradation was the main threat faced by Indian primates, forcing them to occupy isolated forest patches, including within protected areas. Other threats (Fig. 3) included biological resource use such as hunting for bushmeat and retaliatory killing because of human–wildlife conflict, and human intrusions and disturbance such as dam and road construction. The χ^2 test indicated no significant association between the types of threats and population status categories ($\chi^2 = 9.575$, P = 0.653). Based on a comprehensive review of these studies, we found that major threats faced by Indian primates are not species-specific, but area-specific, and vary both spatially and temporally from species to species. For example, Hanuman langurs face the threat of habitat degradation within protected areas (Narasimmarajan & Raghunathan, 2012), whereas habitat loss and hunting constitute a prevalent threat to species outside protected areas (Kumara et al., 2010; Mishra et al., 2020). Similarly, trapping and deforestation have been considered major threats to rhesus macaques in the past (Southwick & Siddiqi, 1994); however, the species is currently believed to be affected primarily by habitat loss and fragmentation (Sharma et al., 2012; Imam & Ahmad, 2013).

Survey methods and duration

Most studies (83%) in our sample focused on population estimations of a single primate species. Distance sampling based on lines transects was the most commonly used method (48%) followed by the total count method (25%). Other methods used (Fig. 4) included direct sighting/random sampling (18%) and call counts (2%). Of the studies included in our analysis, only 22% were conducted during the 5 years

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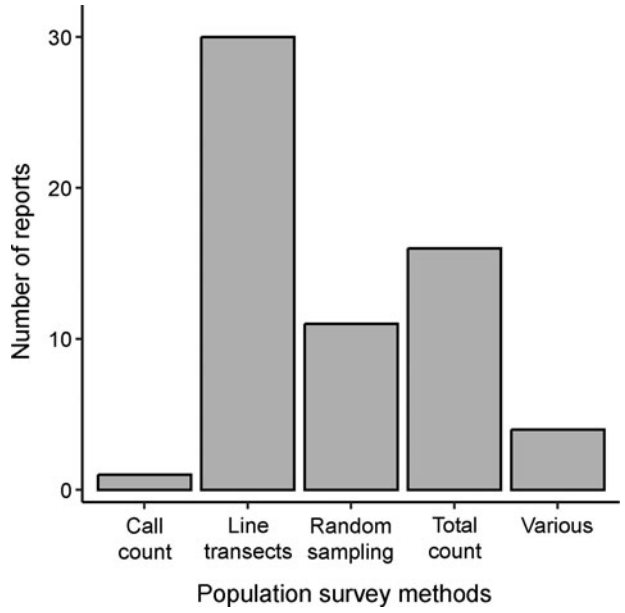

FIG. 4 Different primate survey methods used in the studies included in our analysis.

prior to our review (2016–2021), targeting only 27% (n = 7) of the 26 Indian primate species. There has been great disparity in the distribution of population status studies across Indian primate species over the years. A few species, including rhesus macaques, bonnet macaques *Macaca radiata* and eastern hoolock gibbons, have received more attention from researchers than others, with the tufted gray langur, black-footed gray langur and southern pig-tailed macaque *Macaca nemestrina* being studied the least.

Species coverage, temporal and spatial distribution of the studies

The population status studies on Indian primates conducted since 2010 have diversified in terms of species coverage (Fig. 5). In terms of geographical coverage, > 60% of the reports represent surveys conducted in the Western Ghats and north-eastern Himalayas (Fig. 6), and 34% of studies were conducted in non-protected areas. Unlike the studies conducted in non-protected areas, which showed stable, increasing or declining population trends, all reports (66%) conducted exclusively in protected areas reported declining population trends, except in the Chakrashila Wildlife Sanctuary, Assam (Chetry et al., 2020). In contrast, one study conducted in the upper Brahmaputra Valley of north-eastern India reported increasing population trends within and decreasing trends outside protected areas. Focused on the overall population abundance of six primate species, this study reported a 251% increase of the population within protected areas for all six species, but a dramatic decline outside protected areas caused by rapid, severe habitat loss resulting in small habitat fragments and disruption of canopy continuity (Sharma et al., 2012).

Discussion

The overall trend in the population status of Indian primates mirrors the global pattern, with a population decline in 75% of primate species worldwide (Estrada et al., 2017). This declining trend in the population of Indian primates has persisted for decades, with 70% of species categorized as

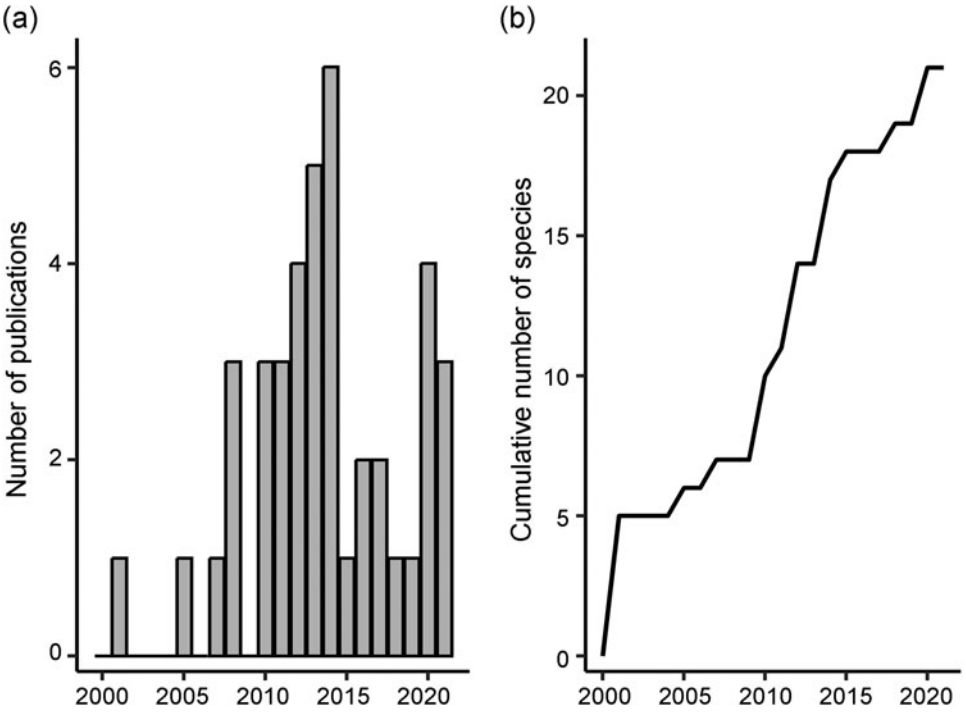

FIG. 5 (a) Temporal distribution of the number of publications on the population status of Indian primates and (b) total number of primate species surveyed for their population over time.

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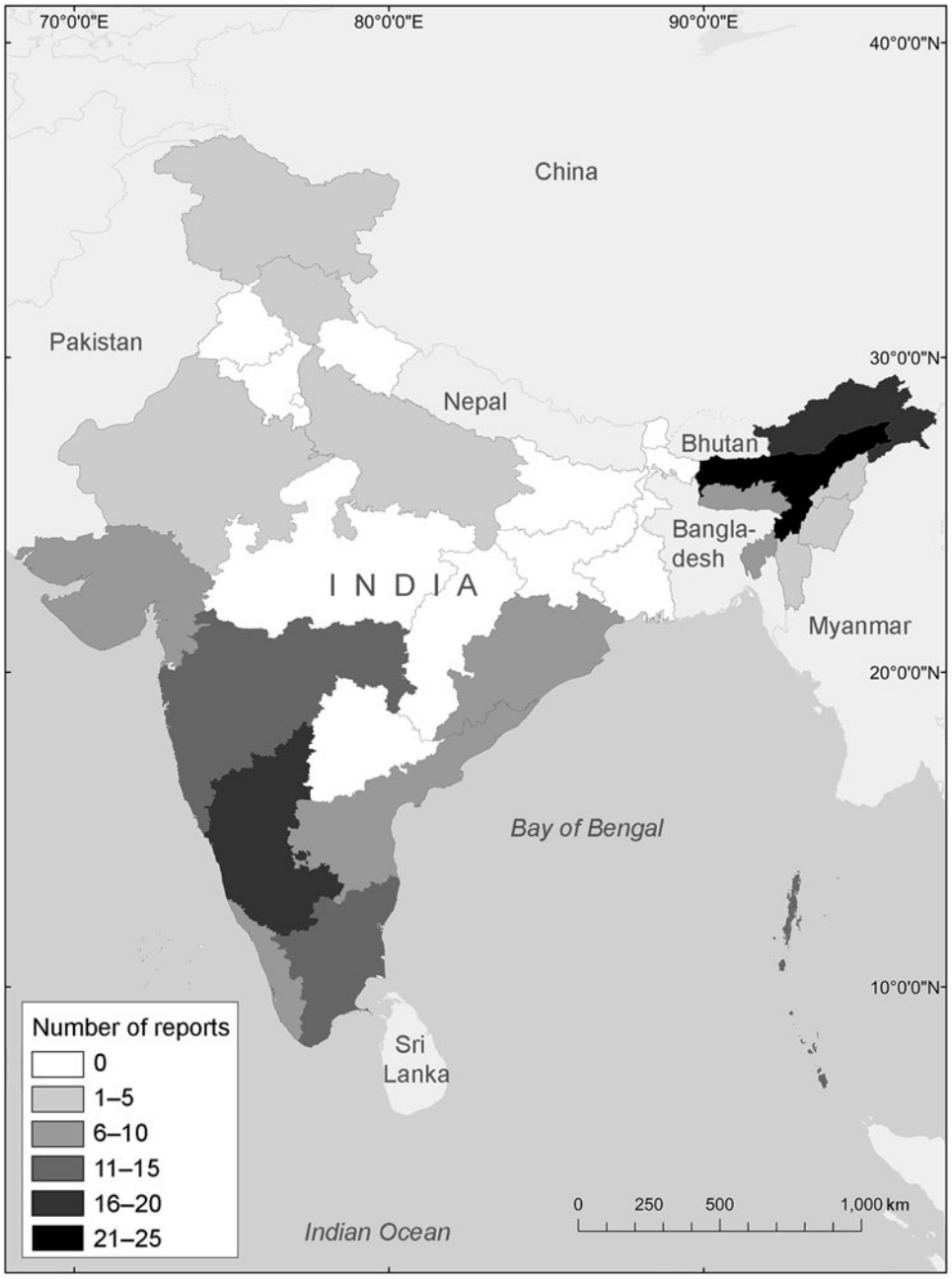

FIG. 6 Spatial distribution of the population status studies conducted on Indian primates during 2000–2021.

threatened (including 35% Vulnerable and 35% Endangered) on the IUCN Red List (IUCN, 2021). Establishing reliable baseline data on species distribution and population status using appropriate methods would offer insights into population trends across a temporal scale as well as species' responses to changing habitats (Lyons et al., 2008; Jones et al., 2019).

Routine wildlife population monitoring (Nichols & Williams, 2006), in addition to serving as a foundation for evaluating ecosystem functioning, conservation success and intensity of threats faced by wildlife (Stokes et al., 2010), also offers a comparative view of the effectiveness of different conservation strategies (Ferraro & Pattanayak, 2006). For example, population monitoring of bonnet macaques over the past 3 decades has shown a sharp decline, with a 70% reduction in population size, which has been attributed mainly to habitat loss (decreased vegetation cover and canopy connectivity) because of urbanization (Erinjery et al., 2017). Population monitoring of rhesus macaques over 6 decades has shown varying trends, with population size decreasing by 90% during the 1960s and 1970s, followed by a partial recovery during the 1980s (Southwick & Siddiqi, 1994) and a substantial population growth of 203% during 1995–2010 (Imam & Ahmad, 2013). To evaluate population trends, a representative population of the target primate species must be identified and monitored in each habitat at least once every 3 years (Singh et al., 2020). To better

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understand the drivers of changing wild populations, we recommend population monitoring for all Indian primate species, with priority given to species that are threatened and/or for which we have limited or no data on their population status (e.g. the grey slender loris *Loris lydekkerianus grandis* and Nilgiri langur; Table 1).

Seventy-three per cent of Asian primate species are considered threatened (Estrada et al., 2017). Threats to their survival are dynamic, in terms of both scope and severity, and interact with each other at various spatial and temporal scales. We found that most threats to the long-term survival of populations of Indian primates were anthropogenic in origin, with modification of natural systems, such as habitat loss and fragmentation, being of particular concern. The conversion of natural habitats to agricultural lands appears to be the main cause of habitat loss and fragmentation (Gibbs et al., 2010). Destruction of habitat patches often results in the loss of all individuals in the affected area (Wich & Marshall, 2016). The consequences of habitat fragmentation on primate survival are determined by several factors, including the matrix embedding the habitat fragments, fragment size and inter-patch distance, and the species' home range and diet (Michalski & Peres, 2005; Boyle & Smith, 2010; Meijaard et al., 2010). Some primates exhibit behavioural and ecological resilience in the face of habitat loss, fragmentation and degradation, but population decline is a common and immediate result of habitat loss (Estrada et al., 2017). To limit the threats faced by Indian primates, conservation activities must be initiated where they are absent and continued where they already exist. One encouraging example of population recovery is provided by population trend studies of rhesus macaques in northern India. Deforestation, excessive trapping and export of juvenile rhesus macaques for biomedical research reduced the population by 90% in the 1970s. However, the subsequent ban on trapping and export, coupled with a stabilizing economy and increased agricultural production, helped the population to recover and thrive in a short period of time (Southwick & Siddiqi, 1994; Imam & Ahmad, 2013).

Our results indicate that $>60\%$ of studies concerning the population status of Indian primates were concentrated in the north-eastern Himalayas and southern Western Ghats, areas that harbour a rich diversity of primates (Srivastava, 2006; Karanth et al., 2010b). This spatial bias could be attributed to the fact that $>70\%$ of Indian primates are supported by moist deciduous, evergreen, and semi-evergreen forests in these two regions, with a total of 13 species inhabiting the north-eastern Himalayas and 10 species inhabiting the Western Ghats (Choudhury, 2001; Kumara & Singh, 2004). Although declining population trends were observed even within protected areas, these declines may have been more pronounced had these areas not been protected. Protected areas thus continue to play a crucial role for primate conservation.

Efforts have been made to modify and improve traditional monitoring methods and to devise new methods for generating robust estimates of wildlife populations. No population survey method is entirely free of bias, and some methods can be more suitable than others in a given situation, depending on variables such as species behaviour and landscape characteristics. To utilize methodological advancements and obtain scientifically robust and reliable population estimates, given the ecological diversity of Indian primates, we suggest employing methods tailored to the target species and population to minimize bias. This includes methods not yet tested on Indian primates, for example the genetic capture–recapture method for elusive species, the double observer method for diurnal primates, cue or point count methods for species with distinctive vocalizations, lure count methods for species that respond to playback calls, and occupancy-based methods for rare species. Further studies are needed to evaluate the appropriateness and statistical soundness of such methods for the study of various primate species.

The dearth of recent population data and limited spatial coverage of most studies on Indian primate populations highlights the urgent need for a comprehensive, nationwide primate distribution and population status study as a priority for effective conservation. The threatened status and declining population trends of several Indian primates warrant immediate attention and efficient management to prevent a major extinction event in the region.

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Conflicts of interest None.

Ethical standards Our analysis is based on data collected from published studies. No ethical approval was required for this research, and it otherwise abides by the *Oryx* guidelines on ethical standards.

Data availability The evidence supporting our findings is available on request from the corresponding author.

References

Arekar, K., Sathyakumar, S. & Karanth, K.P. (2021) Integrative taxonomy confirms the species status of the Himalayan langurs, *Semnopithecus schistaceus* Hodgson, 1840. *Journal of Zoological Systematics and Evolutionary Research*, 59, 543–556.

Ashalakshmi, N.C., Nag, K.S.C. & Karanth, K.P. (2015) Molecules support morphology: species status of south Indian populations of

https://doi.org/10.1017/S0030605323000716 Published online by Cambridge University Press

the widely distributed Hanuman langur. *Conservation Genetics*, 16, 43–58.

Bermejo, M., Rodríguez-Teijeiro, J.D., Illera, G., Barroso, A., Vilà, C. & Walsh, P.D. (2006) Ebola outbreak killed 5000 gorillas. *Science*, 314, 1564.

Biswas, J., Borah, D.K., Das, A., Das, J., Bhattacharjee, P.C., Mohnot, S.M. & Horwich, R.H. (2011) The enigmatic Arunachal macaque: its biogeography, biology and taxonomy in Northeastern India. *American Journal of Primatology*, 73, 458–473.

Boyle, S.A. & Smith, A.T. (2010) Can landscape and species characteristics predict primate presence in forest fragments in the Brazilian Amazon? *Biological Conservation*, 143, 1134–1143.

Butchart, S.H.M., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J.P.W., Almond, R.E.A. et al. (2010) Global biodiversity: indicators of recent declines. *Science*, 328, 1164–1168.

Campbell, G., Head, J., Junker, J. & Nekaris, K.A.I. (2016) Primate abundance and distribution: background concepts and methods. In *An Introduction to Primate Conservation* (eds S.A. Wich & A.J. Marshall), pp. 79–110. Oxford University Press, Oxford, UK.

Campbell, G., Kuehl, H., N'Goran Kouamé, P. & Boesch, C. (2008) Alarming decline of West African chimpanzees in Côte d'Ivoire. *Current Biology*, 18, R903–R904.

Chaudhuri, S., Murmu, A. & Mazumdar, P.C. (2007) Survey of non-human primates of Nayagarh District of Orissa, India. *Records of the Zoological Survey of India*, 107, 35–43.

Chetry, D., Das, A.K., Phukan, M., Chetry, R., Boro, R.N. & Bhattacharjee, P.C. (2020) Conservation status of the golden langur *Trachypithecus geei* in Chakrashila Wildlife Sanctuary, Assam, India. *Primate Conservation*, 34, 167–173.

Choudhury, A.U. (2001) Primates in northeast India: an overview of their distribution and conservation status. In *ENVIS Bulletin: Wildlife and Protected Areas* (ed. A.K. Gupta), pp. 92–101. Wildlife Institute of India, Dehradun, India.

Cotton, A., Clark, F., Boubli, J.P. & Schwitzer, C. (2016) IUCN Red List of Threatened Primate Species. In *An Introduction to Primate Conservation* (eds S.A. Wich & A.J. Marshall), pp. 31–38. Oxford University Press, Oxford, UK.

Das, J., Biswas, J., Bhattacharjee, P.C. & Mohnot, S.M. (2006) First distribution records of the eastern hoolock gibbon *Hoolock leuconedys* from India. *Zoos' Print Journal*, 21, 2316–2320.

Erinjery, J.J., Kumar, S., Kumara, H.N., Mohan, K., Dhananjaya, T., Sundararaj, P. et al. (2017) Losing its ground: a case study of fast declining populations of a 'least-concern' species, the bonnet macaque (*Macaca radiata*). *PLOS One*, 12, 1–19.

Estrada, A., Garber, P.A., Rylands, A.B., Roos, C., Fernandez-Duque, E., di Fiore, A. et al. (2017) Impending extinction crisis of the world's primates: why primates matter. *Science Advances*, 3, e1600946.

Ferraro, P.J. & Pattanayak, S.K. (2006) Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLOS Biology*, 4, e105.

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N. & Foley, J.A. (2010) Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 16732–16737.

Google Scholar (2023) *Google Scholar*. Google, Mountain View, USA. scholar.google.com [accessed August 2023].

Grant, M.J. & Booth, A. (2009) A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26, 91–108.

Imam, E. & Ahmad, A. (2013) Population status of rhesus monkey (*Macaca mulatta*) and their menace: a threat for future conservation. *International Journal of Environmental Sciences*, 3, 1279–1289.

IUCN (2021) *The IUCN Red List of Threatened Species 2021-3*. iucnredlist.org [accessed 20 January 2022].

IUCN (2023) *Threats Classification Scheme (Version 3.3)*. IUCN, Gland, Switzerland. iucnredlist.org/resources/threat-classification-scheme [accessed 20 March 2023].

Jones, T., Hawes, J.E., Norton, G.W. & Hawkins, D.M. (2019) Effect of protection status on mammal richness and abundance in Afromontane forests of the Udzungwa Mountains, Tanzania. *Biological Conservation*, 229, 78–84.

Kalpers, J., Williamson, E.A., Robbins, M.M., McNeilage, A., Nzamurambaho, A., Lola, N. & Mugiri, G. (2003) Gorillas in the crossfire: population dynamics of the Virunga mountain gorillas over the past three decades. *Oryx*, 37, 326–337.

Karanth, K.P., Singh, L. & Stewart, C.B. (2010a) Mitochondrial and nuclear markers suggest Hanuman langur (Primates: Colobinae) polyphyly: implications for their species status. *Molecular Phylogenetics and Evolution*, 54, 627–633.

Karanth, K.K., Nichols, J.D. & Hines, J.E. (2010b) Occurrence and distribution of Indian primates. *Biological Conservation*, 143, 2891–2899.

Karanth, K.P., Singh, L., Collura, R.V. & Stewart, C.B. (2008) Molecular phylogeny and biogeography of langurs and leaf monkeys of South Asia (Primates: Colobinae). *Molecular Phylogenetics and Evolution*, 46, 683–694.

Kumar, R.S., Gama, N., Raghunath, R., Sinha, A. & Mishra, C. (2008) In search of the munzala: distribution and conservation status of the newly-discovered Arunachal macaque *Macaca munzala*. *Oryx*, 42, 360–366.

Kumar, P.R., Kumara, H.N., Priya, M.M., Sushma, H.S., Meharabi, K.M. & Udayraj, S. (2018) Conservation status of primates in the central Western Ghats, Karnataka, India. *Primate Conservation*, 32, 175–183.

Kumara, H.N., Kumar, S. & Singh, M. (2010) Of how much concern are the 'least concern' species? Distribution and conservation status of bonnet macaques, rhesus macaques and Hanuman langurs in Karnataka, India. *Primates*, 51, 37–42.

Kumara, H.N. & Singh, M. (2004) Distribution and abundance of primates in rain forests of the Western Ghats, Karnataka, India and the conservation of *Macaca silenus*. *International Journal of Primatology*, 25, 1001–1018.

Lewis, S.L. & Maslin, M.A. (2015) Defining the Anthropocene. *Nature*, 519, 171–180.

Lyons, J.E., Runge, M.C., Laskowski, H.P. & Kendall, W.L. (2008) Monitoring in the context of structured decision-making and adaptive management. *Journal of Wildlife Management*, 72, 1683–1692.

Mace, G.M. (2004) The role of taxonomy in species conservation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 359, 711.

Meijaard, E., Albar, G., Nardiyono, R.Y., Ancrenaz, M. & Spehar, S. (2010) Unexpected ecological resilience in Bornean orangutans and implications for pulp and paper plantation management. *PLOS One*, 5, e12813.

Michalski, F. & Peres, C.A. (2005) Anthropogenic determinants of primate and carnivore local extinctions in a fragmented forest landscape of southern Amazonia. *Biological Conservation*, 124, 383–396.

Mishra, P.K., Sharma, A., Khan, F. & Maurya, I.B. (2020) A study on Hanuman langur (*Semnopithecus entellus*) for distribution and demography south-eastern Rajasthan. *International Journal of Current Microbiology and Applied Sciences*, 9, 1291–1301.

Nag, K.S.C., Pramod, P. & Karanth, K.P. (2011) Taxonomic implications of a field study of morphotypes of Hanuman langurs (*Semnopithecus entellus*) in peninsular India. *International Journal of Primatology*, 32, 830–848.

Narasimmarajan, K. & Raghunathan, C. (2012) Status of long tailed macaque (*Macaca fascicularis umbrosa*) and conservation of

https://doi.org/10.1017/S0030605323000716 Published online by Cambridge University Press

the recovery population in Great Nicobar Island, India. *Wildlife Biology in Practice*, 8, 1–8.

Nichols, J.D. & Williams, B.K. (2006) Monitoring for conservation. *Trends in Ecology & Evolution*, 21, 668–673.

Osterholz, M., Walter, L. & Roos, C. (2008) Phylogenetic position of the langur genera *Semnopithecus* and *Trachypithecus* among Asian colobines, and genus affiliations of their species groups. *BMC Evolutionary Biology*, 8, 1–12.

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N. et al. (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, 344, 1246752.

Pimm, S.L., Russell, G.J., Gittleman, J.L. & Brooks, T.M. (1995) The future of biodiversity. *Science*, 269, 347–350.

Rabanal, L.I., Kuehl, H.S., Mundry, R., Robbins, M.M. & Boesch, C. (2010) Oil prospecting and its impact on large rainforest mammals in Loango National Park, Gabon. *Biological Conservation*, 143, 1017–1024.

R Core Team (2013) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. r-project.org [accessed August 2023].

ResearchGate (2023) *ResearchGate*. ResearchGate GmbH, Berlin, Germany. researchgate.net [accessed August 2023].

Rosen, G.E. & Smith, K.F. (2010) Summarizing the evidence on the international trade in illegal wildlife. *EcoHealth*, 7, 24–32.

Sarania, B., Devi, A., Kumar, A., Sarma, K. & Gupta, A.K. (2017) Predictive distribution modeling and population status of the Endangered *Macaca munzala* in Arunachal Pradesh, India. *American Journal of Primatology*, 79, 1–10.

Sharma, N., Madhusudan, M.D., Sarkar, P., Bawri, M. & Sinha, A. (2012) Trends in extinction and persistence of diurnal primates in the fragmented lowland rainforests of the Upper Brahmaputra Valley, north-eastern India. *Oryx*, 46, 308–311.

Shrestha, L., Sarkar, M.S., Shrestha, K., Aung, P.S., Wen, X., Yongping, Y. et al. (2022) Mammalian research, diversity and conservation in the Far Eastern Himalaya Landscape: a review. *Global Ecology and Conservation*, 34, e02003.

Singh, M., Singh, M., Kumara, H.N., Chetry, D. & Mahato, S. (2020) A history of primatology in India (in memory of professor Sheo Dan Singh). *Journal of Threatened Taxa*, 12, 16715–16735.

Southwick, C.H. & Siddiqi, M.F. (1994) Population status of nonhuman primates in Asia, with emphasis on rhesus macaques in India. *American Journal of Primatology*, 34, 51–59.

Srivastava, A. (2006) Conservation of threatened primates of northeast India. *Primate Conservation*, 20, 107–113..

Stokes, E.J., Strindberg, S., Bakabana, P.C., Elkan, P.W., Iyenguet, F.C., Madzoké, B. et al. (2010) Monitoring great ape and elephant abundance at large spatial scales: measuring effectiveness of a conservation landscape. *PLOS One*, 5, e10294.

Thomsen, P.F. & Willerslev, E. (2015) Environmental DNA – an emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation*, 183, 4–18.

Trivedi, M., Manu, S., Balakrishnan, S., Biswas, J., Asharaf, N.V.K. & Umapathy, G. (2021) Understanding the phylogenetics of Indian hoolock gibbons: *Hoolock hoolock* and *H. leuconedys*. *International Journal of Primatology*, 42, 463–477.

Velankar, A.D., Kumara, H.N., Pal, A., Mishra, P.S. & Singh, M. (2016) Population recovery of Nicobar long-tailed macaque *Macaca fascicularis umbrosus* following a Tsunami in the Nicobar Islands, India. *PLOS One*, 11.

Wangchuk, T., Inouye, D.W. & Hare, M.P. (2008) The emergence of an Endangered species: evolution and phylogeny of the *Trachypithecus geei* of Bhutan. *International Journal of Primatology*, 29, 565–582.

Wich, S.A., Garcia-Ulloa, J., Kühl, H.S., Humle, T., Lee, J.S.H. & Koh, L.P. (2014) Will oil palm's homecoming spell doom for Africa's great apes? *Current Biology*, 24, 1659–1663.

Wich, S.A. & Marshall, A.J. (2016) An introduction to primate conservation. In *An Introduction to Primate Conservation* (eds S.A. Wich & A.J. Marshall), pp. 1–12. Oxford University Press, Oxford, UK.

Williams, J.M., Lonsdorf, E.V., Wilson, M.L., Schumacher-Stankey, J., Goodall, J. & Pusey, A.E. (2008) Causes of death in the Kasekela chimpanzees of Gombe National Park, Tanzania. *American Journal of Primatology*, 70, 766–777.

https://doi.org/10.1017/S0030605323000716 Published online by Cambridge University Press