




# Monitoring diversity and abundance of mammals with camera-traps: a case study of Manas National Park, Assam, India

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## Abstract

Information on the status and distribution of species within a geographical area is vital for developing effective conservation plans. We conducted camera-trapping ( $n = 473$ ) to determine diversity, species composition, relative abundance index, sampling effort, and conservation status of mammals in forested habitats of Manas National Park, Assam, India. Camera stations accumulated data over 11,388 trap nights over three sampling years: 2017–2019. Camera-traps recorded 34 mammalian species belonging to seven orders, 15 families, and 29 genera, with 22,738 independent records. Among them, 17 species are globally threatened or 50% of the recorded species. The species accumulation curve reached an asymptote, indicating an adequate sampling design for obtaining a robust inventory of the mammalian community. Despite a history of ethnopolitical conflict, almost all mammals expected to occur in the park were detected. Our study will enable future evaluations of the recovery process in terms of changes in mammal abundance over time.

## Keywords

Camera-trapping, conservation, Mammalia, minimum trapping effort, species composition, tropical forest

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## Introduction

Mammals have a crucial role in the maintenance and equilibrium of forest ecosystems (Miller et al. 2001; Magioli et al. 2015) with several ecological services: prey population control, plant pollination, and seed dispersal (Terborgh et al. 1999; Galetti et al. 2015; Derhé et al. 2017). Terrestrial mammals are a vital component of tropical forest communities, being ecosystem service providers and ecosystem health indicators, and are often

of particular concern for conservation and management (Kitamura et al. 2010). Currently, there are 6,399 extant mammal species (Burgin et al. 2018). Due to ever-increasing anthropogenic pressure, the geographic distribution of terrestrial mammals has been reduced to 83% (WWF 2020), and one in five species is clearly on the verge of extinction (The Extinction Crisis 2016). Therefore, it is crucial to document their diversity,



species richness patterns, and compositions under different forest conditions to facilitate sound decisions on their conservation (Bernard et al. 2013). However, monitoring these animals in tropical forests is incredibly challenging as they are elusive and mainly nocturnal, prefer dense vegetation, occur in low abundance, and avoid human presence (Datta et al. 2008; Mohd-Azlan 2009; Gonthier and Castañeda 2013). Monitoring these animals using camera-traps triggered by passing animals is an alternative and popular method (Ancorenaz et al. 2012).

Camera-traps detect the rare, secretive, or elusive wildlife species and are more often used worldwide to estimate the population density of naturally marked animals using well-established spatially explicit capture-recapture (SECR) models (Efford 2011; Laetitia et al. 2013; Efford and Fewster 2013). Unfortunately, for most tropical animals, such as ungulates, bears, and small mammals, it is impossible to distinguish individual animals from photographs, thus hindering the estimation of their population status and density at a larger spatial scale (Pollock et al. 2002). The photographic trapping rate has been widely used to estimate relative abundance, assuming that the photodetection rate is influenced by animal abundance (Rovero and Marshall 2009; Jenks et al. 2011). Furthermore, a significant correlation between trapping rates and independent density estimates supported its use as a relative abundance index (Carbone et al. 2001; O'Brien et al. 2003). Although the use of relative abundance index derived from camera-trap encounter rates is controversial, given its bias toward animal body mass and study design (Sollmann et al. 2013), there are plenty of examples of a linear relationship between RAI and abundance, which is estimated in more precise ways (Rovero and Marshall 2009; Jenks et al. 2011; Palei et al. 2015).

Manas National Park (MNP), encompassing 500 km<sup>2</sup>, is located in the eastern Himalayan biodiversity hotspot. The Bodoland Territorial Council (BTC) governs the region, which is divided into two administrative districts (Chirang and Baksa) in the state of Assam. This national park experienced an intense 15-year ethnic and political battle starting in the mid-1980s until fledgeling peace was restored in 2003 (Goswami and Ganesh 2014). During the conflict, this UNESCO World Heritage Site was listed as “in danger” following large-scale destruction to infrastructure, wildlife populations, and habitats (George 1994; Sarma et al. 2008; Goswami and Ganesh 2014). *Rhinoceros unicornis* Linnaeus, 1758 population was locally extirpated, and *Rucervus duvaucelii ranjitsinhi* (Groves, 1982) population was greatly reduced. Conservation measures such as population reintroduction, strengthening of law enforcement, community engagement, and transboundary initiatives with Bhutan have been ongoing to ensure species and habitat recovery since the end of the conflict (Barman et al. 2014; Borah et al. 2012b, 2013). Notably, 80% of worldwide armed conflicts between 1950 and 2000 have overlapped

with biodiversity hotspots (Hanson et al. 2009). Furthermore, a more recent analysis from Africa highlights that the population trajectories of large mammals fell significantly below replacement levels with an increase in conflict frequency (Daskin and Pringle 2018). Therefore, documenting species diversity, assemblages, and composition after the conflict is critical to informing subsequent conservation interventions.

Information on the diversity of mammals is needed to estimate the conservation status of ecosystems, particularly those that are protected. Moreover, certain species could be a preliminary indicator of the conservation success of the management measures applied in protected areas. For that reason, we conducted camera-trapping surveys across four administrative forest ranges (Panbari, Kahitema, Bansbari, and Bhuyanpara) of MNP from 2017 to 2019 with the aim to (a) document mammal diversity, and their assemblages and composition, (b) calculate the relative abundance index of mammals, and (c) discuss conservation needs of rare and threatened mammalian species in the park. We could not directly compare pre- and post-conflict effects on the mammalian assemblage because there was no comparable data on mammal distribution before the conflict.

## Study Area

The study was carried out in Manas National Park (MNP), a UNESCO Natural World Heritage Site, a tiger reserve, an elephant reserve, and a biosphere reserve, in the state of Assam, India. MNP lies on the borders of the Indo-Gangetic and Indo-Malayan biogeographical realms on a gentle alluvial slope in the foothills of the Himalayas, where wooded hills give way to grasslands and tropical forests. The climate is subtropical and is characterised by four seasons: (1) pre-monsoon: March–May, (2) monsoon: June–September, (3) retreating monsoon: October–November, and (4) winter: December–February (Borthakur 1986; Das et al. 2009). The humidity levels are high and can reach up to 76%. The mean annual rainfall is 3330 mm, and the mean temperature ranges from 5–37 °C. The elevation ranges from 40 m to 200 m a.s.l. (Bhattacharjya et al. 2015). The park is home to various important mammal species, including *Panthera tigris tigris* (Linnaeus, 1758), *Porcula salvania* (Hodgson, 1847), *Caprolagus hispidus* (Pearson, 1839), and *Elephas maximus indicus* Cuvier, 1798 (Wikramanayake et al. 2002). The park also supports 22 of India's most threatened mammal species, as listed in Schedule-I of the Wildlife (Protection) Act of India, 1972 (DebRoy 1991). Together with the Royal Manas National Park (RMNP) in Bhutan, the park forms one of the largest areas of conservation significance in South Asia, representing the full range of habitats from the subtropical plains to the alpine zone (Wang and Macdonald 2001). MNP is a vital conservation area due to its tropical forests, endemism, and long history of social and political conflict (Soud et al. 2013).



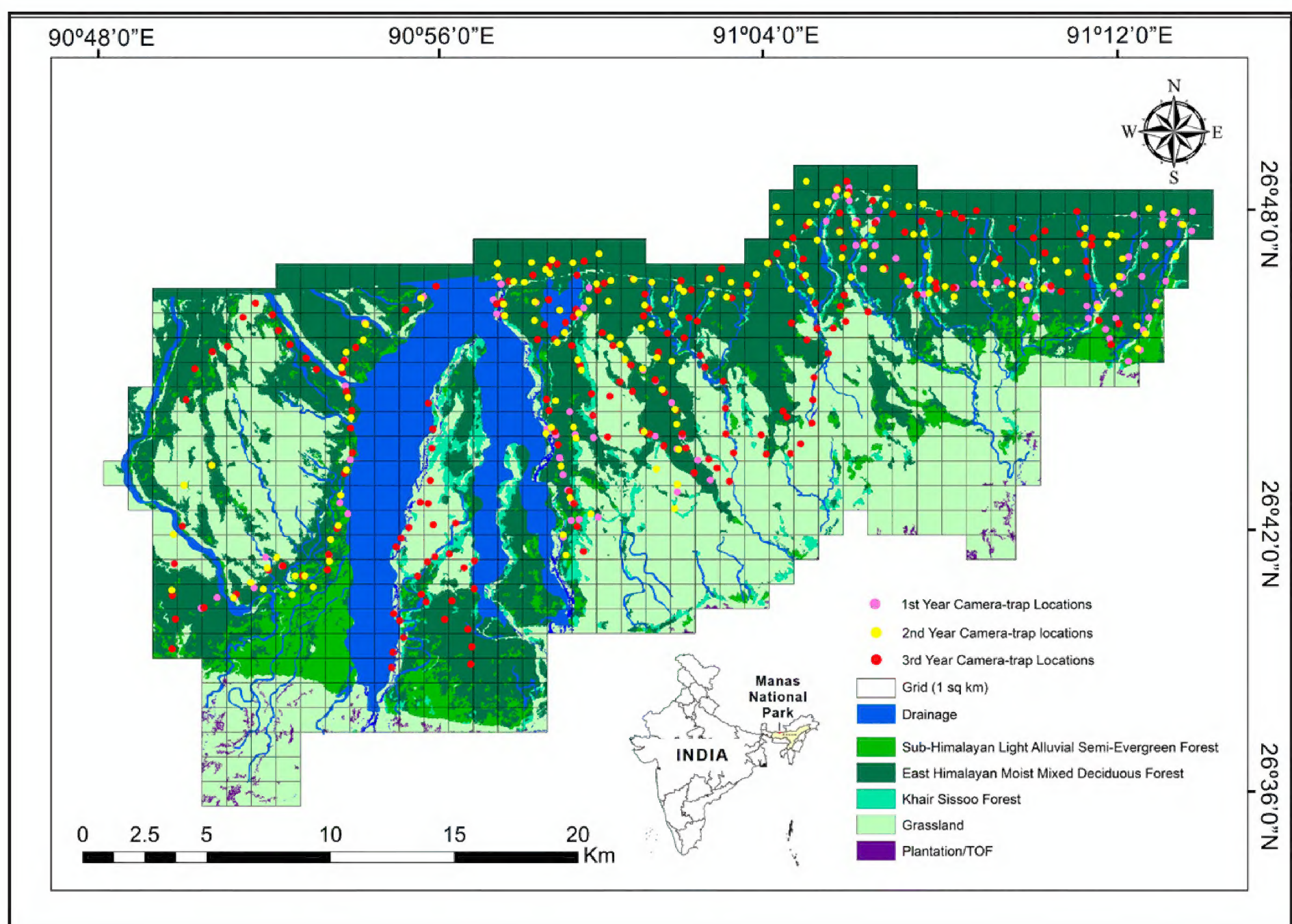
## Methods

**Data collection and preparation.** Mammals were photographed using camera-traps in an area of 270 km<sup>2</sup> within the strictly forested habitats of MNP. Camera-trap locations were unbaited and selected based on accessibility, terrain features, animal trails, and nallahs (seasonal drainages) with carnivore signs (Ramesh et al. 2015, Marinho et al. 2018). At each location, a single Cuddeback X-Change™ colour model (Cuddeback, Green Bay, WI, USA) with motion sensors was deployed, and a time lag of 1 s was set between animal detections. Cameras were fastened to trees at the height of approximately 30–45 cm above the ground for 24 days (Range: 16–45). We used 473 camera-trap locations in a grid-based approach (grid size: 1 km<sup>2</sup>) during three sampling periods: April–June 2017 ( $n = 101$ ), December 2017–May 2018 ( $n = 152$ ), and November 2018–May 2019 ( $n = 220$ ) (Fig. 1). These months were specifically chosen for greater accessibility and minimal variance in weather conditions. The average temperature and humidity during the entire sampling period were 24° C ( $\pm$  SE 0.29) and 79.4% ( $\pm$  SE 0.54), respectively (<http://timeanddate.com>). As the study area is home to many threatened and rare mammal species and is highly prone to illegal poaching and hunting, we do not provide geographic coordinates of camera locations or species occurrence.

Monitoring of camera-traps was done at least twice a month, including changing batteries and memory cards. After completing each camera-trapping session, the photographs were examined for images of animals. Mammals were identified with the help of literature (Jerdon 1874; Prater 1965; Jerdan 1984; Tritsch 2001; Menon 2014; Grewal and Chakravarty 2017). The data from all camera stations of each sampling period were merged before analysis. The amount of trapping effort required (unit: camera-days) was calculated for each camera from when the camera was mounted until the camera was retrieved, if the film had any remaining exposures, or until the time and date stamped on the final exposure. Total trapping effort in a sampling period was defined as the sum of the camera days of all cameras.

**Species composition.** Species composition was estimated as the total number of species detected during the study period. Species-specific body masses were obtained from the literature and calculated as the average male and female adult body masses. Mammals were classified into three body-size classes: large (>50 kg), medium-sized (>10–50 kg), and small (<10 kg) (Prater and Barruel 1971; Menon 2003; Wilson and Mittermeier 2011; Menon 2014).

**Relative abundance index (RAI<sub>i</sub>).** RAI<sub>i</sub> was calculated



**Figure 1.** The study area (MNP) map shows camera-trap locations ( $n = 473$ ), drainage, and forest cover. Camera-traps were deployed in a grid-based approach (grid size: 1 km<sup>2</sup>) during three sampling periods: April–June 2017 ( $n = 101$ ), December 2017–May 2018 ( $n = 152$ ), and November 2018–May 2019 ( $n = 220$ ).



as a total number of independent photographs for each species divided by total trap nights and multiplied by 100 (Carbone et al. 2001). The criteria to determine a photographic event (a species occurrence) were (1) consecutive photographs of the same species within 30 min were counted as one species occurrence, (2) the stamped time of the first photograph of these consecutive photographs was taken as the species-occurrence time. After 30 min, additional photos of the same species were considered another occurrence event, and (3) different identifiable individuals were treated as a separate occurrence even though they appeared in the same photograph, or the photographs were taken within 30 min (O’Brien et al. 2003). The analysis was carried out in a Windows-based MS Office Excel worksheet using the data analysis tool.

**Trap effort.** We calculated  $RAI_2$  (the number of trap nights required to get a single photograph of the species) to understand the time required to detect mammals if they are present at a sampling location (Jenks et al. 2011).  $RAI_2$  was calculated by dividing total trap nights by the number of independent photos of each species. The analysis was carried out in a windows-based MS office excel worksheet using the data analysis tool.

$$RAI_2 = \left(\frac{N}{A}\right)$$
 (Jenks et al. 2011)

where  $A$  is independent photo captures, and  $N$  is trap nights.

Furthermore, to quantify the optimal number of camera stations, that is, how many locations needed to be sampled to capture most of the mammalian species of MNP, we plotted mammal species detected against sample locations and fitted a hyperbola curve. We created this species accumulation curve (SAC) for all mammals pooled across camera stations to evaluate the sampling quality and survey effort needed for determining species richness. To eliminate the order in which data was recorded, we randomised the data 100 times using the vegan package (Jari Oksanen et al. 2018) with R v. 3.5.2 (R Core Team 2018).

**Conservation status.** We identified the conservation status of recorded mammals based on the IUCN (Inter-

national Union for the Conservation of Nature) Red List criteria: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT) and Least Concern (LC) (IUCN 2020), the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendices I, II, and III (CITES 2020), and the Indian Wildlife Protection Act (WPA), 1972 Schedules I, II, III, and IV (Anonymous 2006).

Results

**Species composition.** We followed Chakravarty and Ramachandran (2022) for mammalian systematics. We recorded 39 mammals (camera-trapping: 34, direct sightings: five, carnivores: 17, non-carnivores or herbivores: 22) with 22,738 independent records over the whole sampling period of 11,388 trap nights (Table 1). The richest order was Carnivora, with 16 species, followed by Artiodactyla with nine species, Rodentia with five, Primates with four, Lagomorpha with two, and Pholidota, Proboscidea, and Perissodactyla with one each (Fig. 2). Felidae and Cervidae were the most species-rich families, represented by five species each (Fig. 2).

**$RAI_1$ .** The independent records ( $n$ ) and  $RAI_1$  for the photo-captured species ranged from *Neofelis nebulosa macrosceloides* (Hodgson, 1853) ( $n = 21$ ,  $RAI_1 = 0.18$ ) to *Panthera tigris tigris* ( $n = 466$ ,  $RAI_1 = 4.09$ ) for medium-sized to large carnivores, from *Melogale moschata millsii* (Thomas, 1922) ( $n = 3$ ,  $RAI_1 = 0.03$ ) to *Viverricula indica indica* (É. Geoffroy Saint-Hilaire, 1803) ( $n = 402$ ,  $RAI_1 = 3.53$ ) for small carnivores, from *Axis axis* (Erxleben, 1777) ( $n = 1$ ,  $RAI_1 = 0.01$ ) to *Elephas maximus indicus* ( $n = 6386$ ,  $RAI_1 = 56.08$ ) for medium-sized to large herbivores, and from *Caprolagus hispidus* ( $n = 8$ ,  $RAI_1 = 0.07$ ) to *Lepus nigricollis sadiya* Kloss, 1918 ( $n = 92$ ,  $RAI_1 = 0.81$ ) for small herbivores (Table 1; Fig. 3).

**Trap effort.** One carnivore species, *Melogale moschata millsii* ( $RAI_2 = 3796$ ), and two herbivores, *Axis axis* ( $RAI_2 = 11388$ ) and *Naemorhedus goral goral* (Hardwicke,

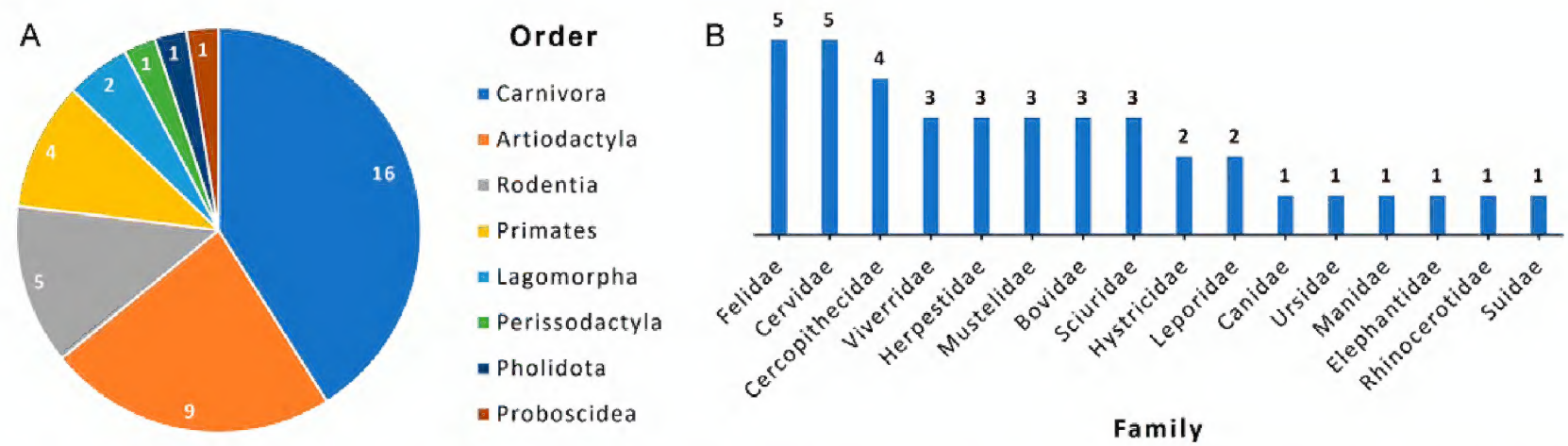
**Table 1.** Independent captures, relative abundance index, minimum trap nights required to detect a single photograph, body mass along with body-size class, and conservation status of recorded mammal species in Manas National Park, Assam, India.  $RAI_1$  = (independent photographs / trap nights)  $\times$  100. Estimated  $RAI_1$  for each mammalian species with associated standard errors were given in parenthesis.  $RAI_2$  (minimum time, i.e., trap nights required to detect single photograph) = Trap nights / independent photographs. Mammal species with an Asterisk (\*) indicate direct sightings. The mean average body mass of mammals was taken from the literature (Prater and Barruel 1971, Menon 2003, Wilson and Mittermeier 2011, Menon 2014). Mammals were classified into three body-size classes: large (>50 kg), medium (>10–50 kg), and small (<10 kg). Abbreviations:  $n$  = independent captures,  $RAI_1$  = Relative Abundance Index,  $RAI_2$  = minimum trap nights required to detect single photograph, L = large, M = medium, S = small, IUCN = International Union for Conservation of Nature, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora, I = species listed under CITES Appendix I, II = species listed under CITES Appendix II, III = species listed under CITES Appendix III, NL = not listed, NA = not available.

Scientific name	Vernacular name	<i>n</i>	RAI <sub>1</sub>	RAI <sub>2</sub>	Mean body mass (kg)	Body- size class	Conservation status		
							IUCN	CITES	WPA, 1972
ORDER CARNIVORA BOWDICH, 1821									
Family Felidae Fischer de Waldheim, 1817 (cats)									
<i>Panthera tigris tigris</i> (Linnaeus, 1758)	Tiger	466	4.09 (±0.33)	24	217.5	L	EN	I	Sch I (Part I)
<i>Panthera pardus fusca</i> (Meyer, 1794)	Leopard	452	3.97 (±0.34)	25	61	L	VU	I	Sch I (Part I)

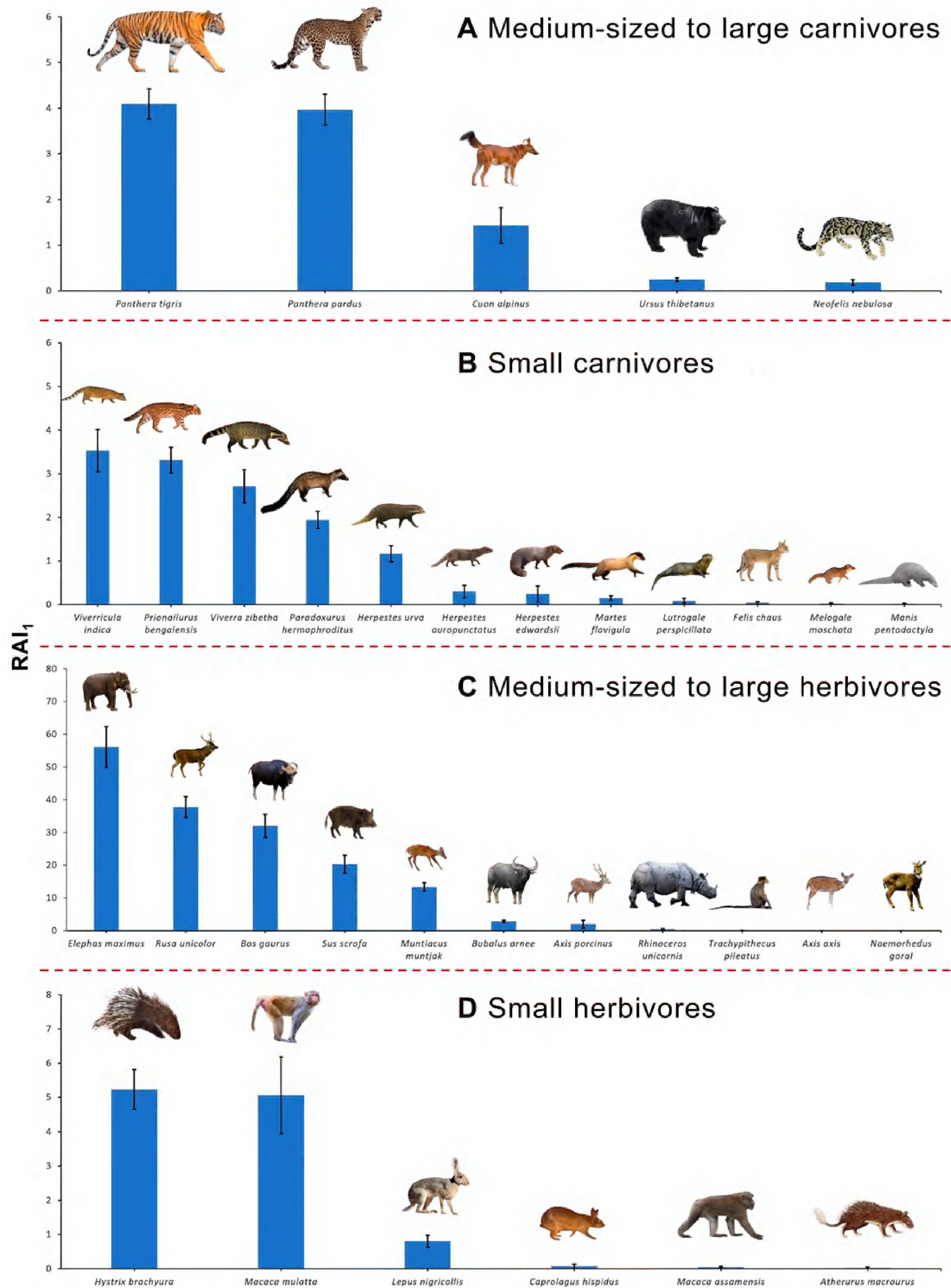


Scientific name	Vernacular name	n	RAI <sub>1</sub>	RAI <sub>2</sub>	Mean body mass (kg)	Body- size class	Conservation status		
							IUCN	CITES	WPA, 1972
<i>Neofelis nebulosa macrosceloides</i> (Hodgson, 1853)	Clouded Leopard	21	0.18 (±0.06)	542	17	M	VU	I	Sch I (Part I)
<i>Prionailurus bengalensis horsfieldii</i> (Gray, 1842)	Leopard Cat	377	3.31 (±0.30)	30	3.5	S	LC	I/II	Sch I (Part I)
<i>Felis chaus affinis</i> Gray, 1830	Jungle Cat	5	0.04 (±0.02)	2278	4	S	LC	II	Sch II (Part I)
Family Canidae Fischer, 1817 (dogs, wolves, jackals, and foxes)									
<i>Cuon alpinus adjustus</i> Pocock, 1941	Dhole	163	1.43 (±0.39)	70	17.5	M	EN	I/II	Sch II (Part I)
Family Ursidae Fischer de Waldheim, 1817 (bears)									
<i>Ursus thibetanus laniger</i> (Pocock, 1932)	Asiatic Black Bear	28	0.25 (±0.04)	407	155	L	VU	I	Sch II (Part I)
Family Viverridae Gray, 1821 (civets and palm civets)									
<i>Viverra zibetha zibetha</i> Linnaeus, 1758	Large Indian Civet	309	2.71 (±0.38)	37	8	S	LC	III	Sch II (Part I)
<i>Viverricula indica indica</i> (É. Geoffroy Saint-Hilaire, 1803)	Small Indian Civet	402	3.53 (±0.49)	28	3	S	LC	III	Sch II (Part I)
<i>Paradoxurus hermaphroditus pallasi</i> Gray, 1832	Asian Palm Civet	221	1.94 (±0.20)	52	3	S	LC	III	Sch II (Part I)
Family Herpestidae Bonaparte, 1845 (mongooses)									
<i>Herpestes auropunctatus</i> (Hodgson, 1836)	Small Indian Mongoose	34	0.30 (±0.14)	335	0.8	S	LC	III	Sch II (Part I)
<i>Herpestes edwardsii nyula</i> (Hodgson, 1836)	Indian Grey Mongoose	28	0.25 (±0.18)	407	1.4	S	LC	III	Sch II (Part I)
<i>Herpestes urva urva</i> (Hodgson, 1836)	Crab-eating Mongoose	133	1.17 (±0.18)	86	2.1	S	LC	III	Sch II (Part I)
Family Mustelidae Fischer de Waldheim, 1817 (badgers, otters, and weasels)									
<i>Martes flavigula flavigula</i> (Boddaert, 1785)	Yellow-throated Marten	17	0.15 (±0.05)	670	2.2	S	LC	III	Sch II (Part I)
<i>Melogale moschata millsii</i> (Thomas, 1922)	Chinese Ferret Badger	3	0.03 (±0.01)	3796	2	S	LC	NL	Sch II (Part I)
<i>Lutrogale perspicillata perspicillata</i> (I. Geoffroy Saint-Hilaire, 1826)	Smooth-coated Otter	10	0.09 (±0.06)	1139	9	S	VU	I	Sch II (Part I)
ORDER PHOLIDOTA WEBER, 1904									
Family Manidae Gray, 1821 (pangolins)									
<i>Manis pentadactyla pentadactyla</i> Linnaeus, 1758	Chinese Pangolin	2	0.02 (±0.01)	5694	7	S	CR	I	Sch I (Part I)
ORDER PROBOSCIDEA ILLIGER, 1811									
Family Elephantidae Gray, 1821 (elephants)									
<i>Elephas maximus indicus</i> Cuvier, 1798	Asiatic Elephant	6386	56.08 (±6.29)	2	4300	L	EN	I	Sch I (Part I)
ORDER PERISSODACTYLA OWEN, 1848									
Family Rhinocerotidae Gray, 1821 (rhinoceroses)									
<i>Rhinoceros unicornis</i> Linnaeus, 1758	Greater One-horned Rhinoceros	54	0.47 (±0.25)	211	2000	L	VU	I	Sch I (Part I)
ORDER ARTIODACTYLA OWEN, 1848									
Family Bovidae Gray, 1821 (cattle, antelopes, sheep, and goats)									
<i>Bos gaurus</i> C.H. Smith, 1827	Gaur	3643	31.99 (±3.54)	3	825	L	VU	I	Sch I (Part I)
<i>Bubalus arnee arnee</i> (Kerr, 1792)	Wild Water Buffalo	324	2.85 (±0.38)	35	1000	L	EN	III	Sch I (Part I)
<i>Naemorhedus goral goral</i> (Hardwicke, 1825)	Himalayan Goral	1	0.01 (±0.01)	11388	38.5	M	NT	I	Sch III
Family Cervidae Goldfuss, 1820 (deers)									
<i>Axis axis</i> (Erxleben, 1777)	Chital	1	0.01 (±0.02)	11388	77.5	L	LC	NL	Sch III
<i>Muntiacus muntjak vaginalis</i> (Boddaert 1785)	Barking Deer	1523	13.37 (±1.27)	7	24	M	LC	NL	Sch III
<i>Axis porcinus porcinus</i> (Zimmermann, 1780)	Hog Deer	229	2.01 (±1.19)	50	47.5	M	EN	III	Sch III
<i>Rusa unicolor unicolor</i> (Kerr, 1792)	Sambar	4302	37.78 (±3.16)	3	225	L	VU	NL	Sch III
<i>Rucervus duvaucelii ranjitsinhi</i> (Groves, 1982) *	Swamp Deer	—	—	—	185	L	VU	I	Sch I (Part I)
Family Suidae Gray, 1821 (pigs)									
<i>Sus scrofa cristatus</i> Wagner, 1839	Wild Boar	2310	20.28 (±2.71)	5	182.5	L	LC	NL	Sch III
ORDER RODENTIA BOWDICH, 1821									
Family Hystricidae G. Fischer, 1817 (Old World porcupines)									
<i>Hystrix brachyura hodgsoni</i> (Gray, 1847)	Himalayan Crestless Porcupine	596	5.23 (±0.58)	19	8	S	LC	NL	Sch II (Part I)
<i>Atherurus macrourus</i> (Linnaeus, 1758)	Asiatic Brush-tailed Porcupine	3	0.03 (±0.02)	3796	2.8	S	LC	NL	Sch II (Part I)
Family Sciuridae Hemprich, 1820 (squirrels)									
<i>Tamiops mcdellandii mcdellandii</i> (Horsfield, 1840) *	Himalayan Striped Squirrel	—	—	—	0.05	S	LC	NL	NA
<i>Ratufa bicolor gigantea</i> (McClelland, 1839) *	Malayan Giant Squirrel	—	—	—	1.1	S	NT	II	Sch II (Part I)
<i>Callosciurus pygerythrus lokroides</i> (Hodgson, 1836) *	Hoary-bellied Squirrel	—	—	—	0.5	S	LC	NL	NA
ORDER PRIMATES LINNAEUS, 1758									
Family Cercopithecidae Gray, 1821 (Old World monkeys)									
<i>Macaca mulatta</i> (Zimmermann, 1780)	Rhesus Macaque	577	5.07 (±1.12)	20	8.2	S	LC	II	Sch II (Part I)
<i>Macaca assamensis assamensis</i> (M'Clelland, 1840)	Assamese Macaque	6	0.05 (±0.02)	1898	8.3	S	NT	II	Sch II (Part I)
<i>Trachypithecus pileatus tenebricus</i> (Hinton, 1923)	Capped Langur	12	0.11 (±0.05)	949	12	M	VU	I	Sch I (Part I)
<i>Trachypithecus geei geei</i> Khajuria, 1956 *	Golden Langur	—	—	—	10.9	M	EN	I	Sch I (Part I)
ORDER LAGOMORPHA BRANDT, 1855									
Family Leporidae Fischer, 1817 (hares and rabbits)									
<i>Lepus nigricollis sadiya</i> Kloss, 1918	Indian Hare	92	0.81 (±0.17)	124	1.8	S	LC	NL	Sch I (Part I)
<i>Caprolagus hispidus</i> (Pearson, 1839)	Hispid Hare	8	0.07 (±0.06)	1424	2.2	S	EN	I	Sch IV
Total		22738							



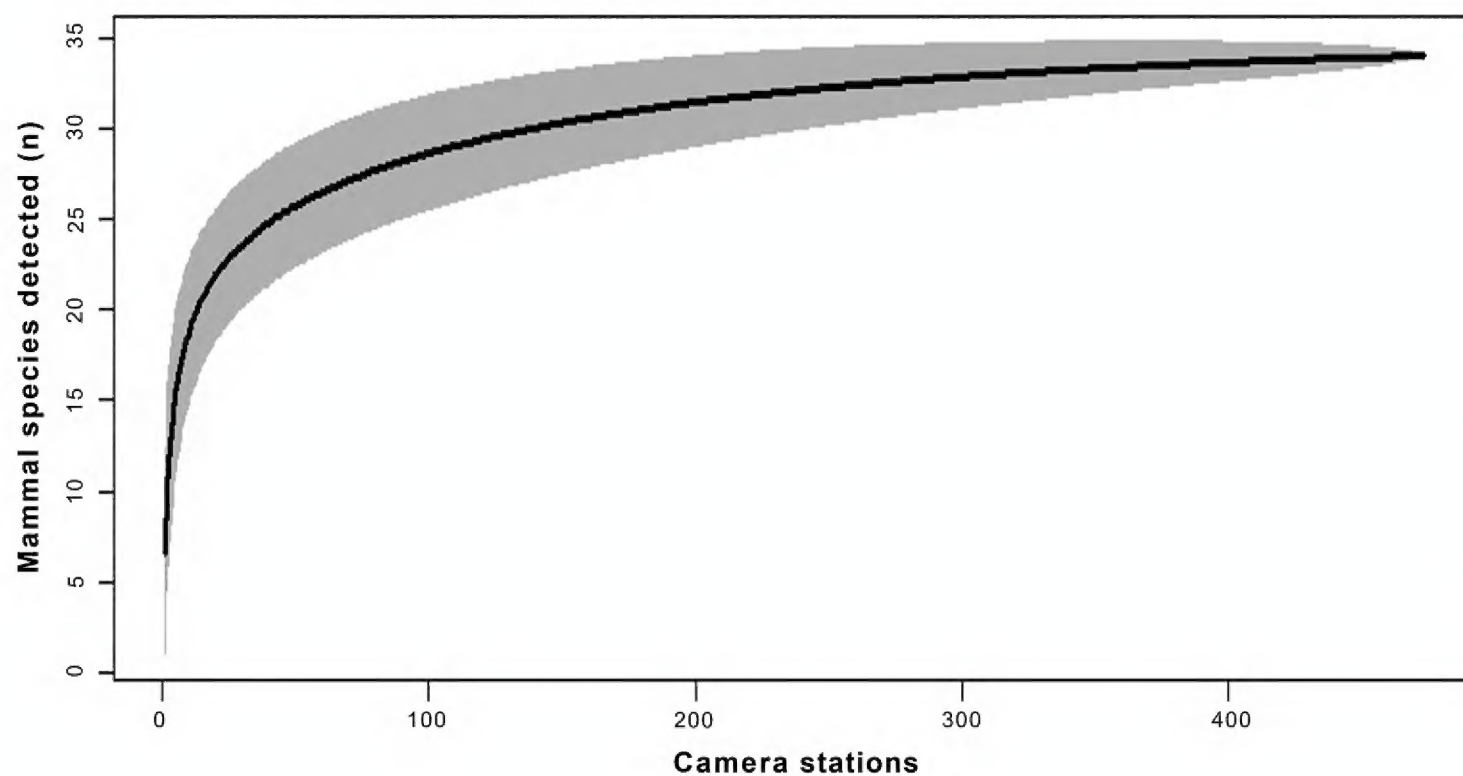


**Figure 2.** The number of mammalian species recorded in each order (A) and family (B) through camera-trapping and direct sightings in Manas National Park, Assam, India.



**Figure 3.** Relative abundance index (RAI<sub>1</sub>) of photo-captured mammal species through camera-trapping in Manas National Park, Assam, India. RAI<sub>1</sub> = (independent photographs / trap nights) × 100. **A.** Medium-sized to large carnivores. **B.** Small carnivores. **C.** Medium-sized to large herbivores. **D.** Small herbivores.





**Figure 4.** Species accumulation curve for mammals, depicting the relationship to the number of mammal species ( $n = 34$ ) detected in 473 camera stations. The black line indicates the modelled species accumulation curve, and the shaded area indicates 95% confidence interval.

1825) ( $RAI_2 = 11388$ ), required the most trap nights for a single detection. The SAC indicated that the mammal community was adequately sampled after deploying 300 camera stations (Fig. 4).

**Conservation status.** From the IUCN Red List of threatened species, the recorded species belong to Critically Endangered (one species), Endangered (seven species), Vulnerable (nine species), Near Threatened (three species), and Least Concern (19 species); see Table 1. All the recorded mammal species are protected under various Schedules of the Indian Wildlife Protection Act (WPA), 1972. We categorised 13 species in schedule I (part I), 17 in schedule II (part I), six in schedule III, and one in schedule IV under the WPA, 1972. Only 10 (26%) species are not included in the CITES Appendices.

#### Annotated list

Order Carnivora Bowdich, 1821

Family Felidae Fischer de Waldheim, 1817

#### *Panthera tigris tigris* (Linnaeus, 1758)

Tiger, Bengal Tiger

Figure 5A

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–6, 8, 11, 13, 16–18, 20–23, 26–35, 37, 40, 42–44, 46, 48, 49–50, 53–54, 60–61, 65–67, 70–71, 73, 76–80, 83, 85, 88, 93, 95–98, 101–103, 105, 113–115, 117, 119, 122, 125, 130, 132, 135–137, 139, 143–144, 147, 151, 156, 159, 161, 167, 178, 188, 196, 200, 203–205, 213, 217, 221, 230, 232, 237–241, 244–246, 249–251, 253, 263, 266–268, 275–278, 288, 293, 296–298, 302–303, 306–307, 309, 314, 319, 322, 324–325, 327, 329–335, 340, 342, 344–345, 348–349, 351, 353, 355–357, 360, 363, 368–371, 373, 375, 377–379, 382–385, 389, 391, 394, 397, 399, 402, 404–405, 407, 412–413, 415–416, 419, 425, 428, 431, 435–436, 440, 464; first capture on 10.IV.2017; Urjit Bhatt obs.; camera-trap photo;

moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Tigers have a yellowish-orange coat with vertical black stripes along the flanks and shoulders that vary in size, length, and spacing. The underside of the limbs and belly, chest, throat, and muzzle are white or light. White is found above the eyes and extends to the cheeks. A white spot is present on the back of each ear. The dark lines about the eyes tend to be symmetrical, but the marks on each side of the face are often asymmetrical. The tail is yellowish-orange and ringed with several dark bands.

#### *Panthera pardus fusca* (Meyer, 1794)

Leopard

Figure 5B, C

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 3, 7–8, 11–20, 23, 25, 27–28, 30–35, 38–40, 42–44, 46, 48–51, 54, 56, 58, 60–61, 65–66, 70, 74, 78–80, 82–83, 86, 88–89, 91–95, 99–101, 103–105, 108, 115, 118–119, 121–122, 127–128, 130–132, 134–135, 139, 142, 144, 147, 151–152, 155–156, 159–160, 162–163, 165, 168, 178–179, 183, 188, 192, 199–200, 202–203, 205, 210–211, 213–214, 219, 221, 223, 225, 228, 230, 232, 234, 238–241, 245, 249–251, 254, 266, 268, 272, 275–276, 281, 284–285, 287, 292, 294, 302, 306–307, 309–310, 313, 318–320, 322–324, 326, 329–331, 335, 337–338, 340, 342, 347–349, 351, 353, 363, 366–367, 370, 378, 383, 405, 407, 411–413, 416–417, 419, 423, 425, 428, 430–431, 433, 435–436, 438, 440–441, 443, 446, 449, 451, 454–455, 459, 461, 464–465, 468, 470; first capture on 06.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Leopard coats range from tawny or light yellow in warm, dry habitats to reddish-orange in dense forests. Leopards have solid black spots or rosettes on their chest, feet, and face and rings on their tail. They



have short legs relative to their long body. They have a broad head, and their massive skull allows for powerful jaw muscles. Their scapula has specialised attachment sites for climbing muscles. They have small round ears, long whiskers extending from dark spots on the upper lip, and long whiskers in their eyebrows. Cubs have a smoky grey coat, and their rosettes are not yet distinct. Melanism is common in Leopards, wherein the animal's entire skin is black, including its spots.

***Neofelis nebulosa macrosceloides* (Hodgson, 1853)**

Clouded Leopard

Figure 5D

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 33, 74, 85, 87, 90, 137, 176, 217, 220, 226, 249, 283, 314, 347, 351, 359–360; first capture on 21.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** The distinctive cloud-shaped markings of their coats make Clouded Leopards unmistakable. Their fur is marked with elliptical blotches of a darker colour than the background, and the posterior edge of each blotch is partially framed in black. The blotches sit on a background field ranging from yellowish-brown to dark grey. The muzzle is white, and solid black spots mark the forehead and cheeks. The ventral side and limbs are marked with large, black ovals. Two solid black bars run from behind the ears along the back of the neck down to the shoulder blades, and the bushy, thick tail is ringed in black. The legs are relatively short compared to other felids, with the hind limbs being longer than the forelimbs. The ankles have a wide range of motion, and the feet are large and padded with retractile claws. As in other members of the family Felidae, the radius and the ulna are not fused, allowing for greater motion independence. The skull is long and narrow compared to other felids. They have the longest canine teeth relative to any felids' head and body size, and canines can reach four centimetres or longer. The nose pad is pink, sometimes has small black spots, and the ears are short and round. The eye's iris is usually brownish yellow or greyish-green, and the pupils contract into vertical slits.

***Prionailurus bengalensis horsfieldii* (Gray, 1842)**

Leopard Cat

Figure 6A

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 2–6, 10–11, 18–19, 22, 24–25, 27, 29, 31, 33–35, 38, 43–44, 46–47, 67, 69–70, 74, 79–80, 84, 87, 89–90, 97, 99–100, 102–103, 105, 108, 110, 112, 118–119, 122–123, 125–126, 130–132, 135–137, 139, 141–144, 146–147, 149–152, 156, 158–160, 162–163, 178, 181, 186, 189, 194, 199–200, 205–206, 208–209, 211–213, 215–221, 223, 226, 229, 232–233, 240, 242, 245, 249–250, 252, 257, 262, 267–269, 273–274, 276, 280, 284, 296, 299, 301–306, 309–310, 313, 320, 322–326, 329, 331, 334, 336–337, 340, 342, 347, 351,

357, 360, 364–366, 373, 377–378, 385, 388–389, 391–392, 395–396, 399, 403, 405, 407, 412–413, 416, 419, 421, 425, 429, 432, 435, 438–439, 441, 448, 469, 471; first capture on 06.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Leopard Cats have pale, tawny pelage with a white belly. Their body and tail are covered with rosettes, and their tail is often ringed at the tip. Four longitudinal bands run from their foreheads to their necks. They have a small head with a short muzzle and round ears. There are differences in coat length and colour based on local environmental conditions. Their colouration varies with habitat, and their fur is longer and paler at more northern latitudes. For example, individuals in snowy habitats have lighter pelage than those in heavily forested habitats, with dark-tawny pelage.

***Felis chaus affinis* Gray, 1830**

Jungle Cat

Figure 6B

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 209, 215, 237, 405; first capture on 23.IV.2018; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Jungle Cats have long, slim faces with white lines above and below their bright yellow eyes, a dark spot just below each eye near the nose. They have long rounded ears, with a distinctive tuft of hair at the tips. They have relatively short tails, about 1/3 of their total body length, with several dark rings along their length and a black tip. Their coat colour varies from a reddish or sandy brown to tawny grey. Kittens may be stripped and spotted; however, these markings typically fade with age and are only retained on the fore and hindlimbs. The muzzle, throat, and belly are a pale cream colour, and their winter coat is darker and denser than their summer coat.

Family Canidae Fischer, 1817

***Cuon alpinus adjustus* Pocock, 1941**

Dhole, Asiatic Wild Dog, Indian Dhole, Red Dog

Figure 5E

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 30, 43, 58, 78, 86, 89, 91, 94, 96, 99, 105, 115, 140, 144, 147, 151, 156, 159, 161, 178, 181, 260–261, 266, 292, 303, 313, 314–315, 322, 324–325, 330–331, 370, 380, 382, 384, 388–389, 400–401, 405, 413, 415–416, 425, 427, 431, 449–450, 458–459, 463; first capture on 13.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Dholes are set apart from other canids in that it has an unusually thick muzzle and one less molar tooth on each side of their lower jaw. Other members of the family Canidae have a total of 42 teeth. A rusty red coat characterises the adult with a pale underside.





**Figure 5.** Mammal species recorded through camera-trapping in Manas National Park, Assam, India. **A.** *Panthera tigris tigris*. **B.** *Panthera pardus fusca*. **C.** *Panthera pardus fusca* (Melanistic form). **D.** *Neofelis nebulosa macrosceloides*. **E.** *Cuon alpinus adjutus*. **F.** *Ursus thibetanus laniger*.

The pelage may vary depending on the region, from light brownish-grey to a uniform red coat. The species is born with a sooty brown colour, acquiring an adult colour at three months. They also have dark, almost always black, bushy tails.

Family Ursidae Fischer de Waldheim, 1817

***Ursus thibetanus laniger* (Pocock, 1932)**

Asiatic Black Bear, Asian Black Bear, Himalayan Black Bear

Figure 5F

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 26, 35–36, 46–47, 49–51, 67–68, 74, 77, 106, 144, 181, 184, 187, 192–194, 411, 418, 420; first capture on 16.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** The head of Asiatic Black Bears is large and rounded, and the eyes are small. The ears are large and set farther apart than an American Black Bear *Ursus americanus* Pallas, 1780. The body is heavy, the legs are thick and strong, and the paws are broad. The stance is plantigrade. The tail is short and is barely visible under a long, coarse coat. The black pelage has a light beige to white “V” shape on the chest area, a small beige to white coloured crescent across the throat, and a small spot of white on the chin. The white fur on the muzzle seldom reaches the orbits of the bear.

Family Viverridae Gray, 1821

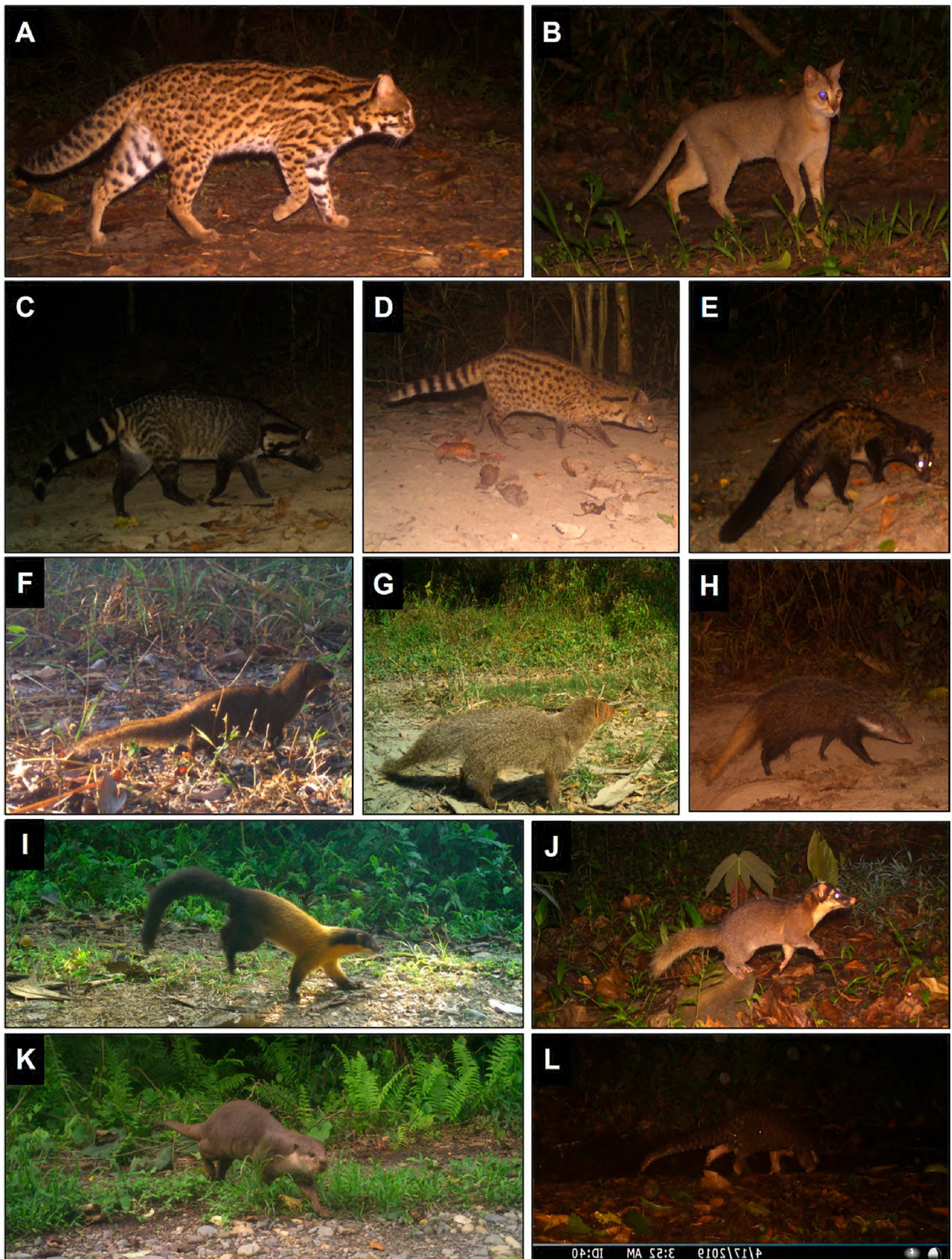
***Viverra zibetha zibetha* Linnaeus, 1758**

Large Indian Civet

Figure 6C

**Material examined.** INDIA – Assam • Baksa district,





**Figure 6.** Mammal species recorded through camera-trapping in Manas National Park, Assam, India. **A.** *Prionailurus bengalensis horsfieldii*. **B.** *Felis chaus affinis*. **C.** *Viverra zibetha zibetha*. **D.** *Viverricula indica indica*. **E.** *Paradoxurus hermaphroditus pallasi*. **F.** *Herpestes auropunctatus*. **G.** *Herpestes edwardsii nyula*. **H.** *Herpestes urva urva*. **I.** *Martes flavigula flavigula*. **J.** *Melogale moschata millsii*. **K.** *Lutrogale perspicillata perspicillata*. **L.** *Manis pentadactyla pentadactyla*.



Gobardhana, Manas National Park; camera stations 3, 5–9, 12, 20–21, 24, 29, 31–34, 38, 44, 46, 49–50, 54, 56, 60–61, 65, 70–71, 86, 97–98, 105, 111, 113, 116, 118–119, 123, 127, 129–130, 132, 137, 139, 143–144, 146, 151–153, 156–158, 160–161, 163–165, 178, 184, 188, 199–200, 203, 213, 221, 237, 239, 242, 257–258, 271, 276, 280, 284, 299, 301, 309, 312, 319, 370, 372, 392, 398, 400, 402, 404–405, 407, 413, 415, 420, 425, 428–431, 433, 435, 438–440; first capture on 10.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Large Indian Civets have large bodies that are grey or brown. They have black spots on the body as well as black and white stripes on the sides of the neck. In most cases, there are two white stripes and three black stripes. The tail has several black rings around it. The limbs are black.

***Viverricula indica indica* (É. Geoffroy Saint-Hilaire, 1803)**

Small Indian Civet

Figure 6D

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 11, 15, 18–19, 24–25, 31, 33, 38, 40, 46, 55, 60, 63, 71, 84, 86, 90, 94, 99–102, 105, 110–114, 116, 118, 120, 125–126, 129, 131, 135, 139, 143–144, 148–149, 153, 158, 167, 174, 177, 180, 188–189, 192, 197, 199, 201, 203, 205, 208, 210, 228, 230–231, 235, 252, 254–256, 262, 274, 276–277, 279–280, 288, 292–293, 295–297, 299, 301–303, 305–307, 310–312, 314, 316–319, 325–328, 330–332, 334–335, 338, 341, 342, 347, 351, 354–356, 359, 363, 365–367, 369, 371–374, 378–380, 390, 393, 396, 404–405, 407–408, 412–413, 416, 419, 425, 429–431, 434–435, 468; first capture on 16.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Small Indian Civets have brown, yellow, or tawny orange pelage ornamented with black and white rings on their necks, and small spots on the body converge into six to eight dark stripes on the back toward the black-and-white banded tails. The paws are typically dark brown or black, and the breast is a lighter brown or grey, with few markings. They are distinguished from closely related civets (*Viverra*) by their significantly smaller size, lack of a dorsal crest of fur, a smaller gap between their ears, and shorter rostra.

***Paradoxurus hermaphroditus pallasi* Gray, 1832**

Asian Palm Civet

Figure 6E

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 2, 5–6, 8, 11, 18, 20, 22, 27, 31, 35, 45–47, 69, 71, 74, 82, 86, 104–105, 108–110, 112, 114, 116, 118–121, 123, 125–126, 132–133, 137, 141–142, 144, 146, 149, 154–155, 163, 177, 183–184, 187, 189, 194, 198–199, 221, 223, 231, 237–239, 245, 252, 255, 257, 260, 267–268, 274–275, 282, 286,

295–297, 308, 312–313, 316, 322–324, 328, 332, 334, 341, 343, 345, 347, 351, 353–354, 357, 359–360, 363–364, 366, 377, 391–393, 401, 403, 405–406, 408–409, 413, 415, 417, 419, 423–424, 427, 429, 434–436, 440, 444, 448; first capture on 20.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** The long, stocky body of the Asian Palm Civet is covered with coarse, shaggy, usually greyish hair. It has a white mask across the forehead, a small white patch under each eye, a white spot on each side of the nostrils, and a narrow dark line between the eyes. The muzzle, ears, lower legs, and distal half of the tail are black, with three rows of black markings on the body.

Family Herpestidae Bonaparte, 1845

***Herpestes auropunctatus* (Hodgson, 1836)**

Small Indian Mongoose, Indian Mongoose

Figure 6F

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 18, 112, 125, 137, 139, 193, 196, 243, 290–292, 318, 326, 379, 443; first capture on 10.VI.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Small Indian Mongooses have a slender body with short legs. The head is elongated with a pointed muzzle. The tail is robustly muscular at the base and tapers gradually throughout its length, ending in tufts of slightly longer fur that paintbrush manufacturers prize. Ears are short and rounded and project only slightly beyond the fur. The fur is soft, pale to dark brown, and flecked with golden spots. The underside is paler than the rest of the body. Eyes are amber or brown but are blue-green in young animals.

***Herpestes edwardsii nyula* (Hodgson, 1836)**

Indian Grey Mongoose

Figure 6G

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera-trap photo; camera stations 97, 205, 215, 229, 311, 317, 329, 450, 471; first capture on 08.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Indian Grey Mongooses have long bodies and short legs. Their small legs are darker than their body. Their coats are thick and coarse in texture. The species has silver-grey, salt-and-pepper speckled fur and a white-tipped tail.

***Herpestes urva urva* (Hodgson, 1836)**

Crab-eating Mongoose

Figure 6H

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1, 11, 25, 46, 49, 60, 63, 69, 71, 84, 93, 112, 121, 126, 135, 143, 149, 158, 162, 177–178, 180–181, 183–184, 194, 196, 199,



210, 218, 223, 226, 232, 237, 249, 251, 255, 258, 261, 267, 276, 283, 309, 312–313, 329, 332, 344, 354–355, 373, 395–396, 400, 409, 415, 421, 423, 429, 431, 434–435, 439, 455, 469; first capture on 09.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Crab-eating Mongooses are grey on the sides and dusky brown on the neck, chest, belly, and limbs. They have a broad white stripe on the sides of the neck, extending from the cheeks to the shoulder. They have white specks on the top of the head; their chin is white, and their throat is grey. The eyes have a yellowish-brown iris. Their ears are short and rounded. They have webs between the digits.

Family Mustelidae Fischer de Waldheim, 1817

***Martes flavigula flavigula* (Boddaert, 1785)**

Yellow-throated Marten

Figure 6I

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 21, 55, 102, 118, 126, 149, 229, 312, 325, 327, 348; first capture on 09.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Yellow-throated Marten is a colourful animal, easily told apart from all other mustelids by its large size, long tail (two-thirds of the head and body length), and colouration. The fur is completely shorter, less dense, and more lustrous. It has a black face, crown, tail, and legs. The rest of the body is made up of shades of yellow: golden or canary yellow on the neck and upper back, brownish-yellow on the lower back up to the base of the tail, blond on the underside and deep orange or canary colour on the neck. It has longer fur, does not have naked skin above the plantar pads of the hind feet, and has more hair between the plantar and carpal pads of the forefeet than other subspecies.

***Melogale moschata millsii* (Thomas, 1922)**

Chinese Ferret Badger, Small-toothed Ferret Badger

Figure 6J

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 36, 186, 266; first capture on 29.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Chinese Ferret Badger is a small, dark grey animal that appears silvery grey against the light. It has a black bandit mask on its face and white lips, chin, throat, belly, and inner legs. Its tail is brownish grey with a white tip. The buff white forehead and cheeks match a white dorsal streak, which is broad at the forehead and tapers down to the shoulders.

***Lutrogale perspicillata perspicillata* (I. Geoffroy Saint-Hilaire, 1826)**

Smooth-coated Otter, Sea Otter

Figure 6K

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 209, 215–216, 218; first capture on 24.IV.2018; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** The fur of Smooth-coated Otters is shorter and smoother than other otters and appears velvety and shining. They have short, tightly packed underfur and longer water repellent guard hairs. The fur is light to dark brown dorsally and light brown to almost grey ventrally. They are distinguished from other otters by their rounder heads, prominent naked noses, and flattened tails. Their noses resemble an upside-down “V” or a distorted diamond. Like other otters, they have webbed feet and strong dexterous paws armed with sharp claws.

Order Pholidota Weber, 1904

Family Manidae Gray, 1821

***Manis pentadactyla pentadactyla* Linnaeus, 1758**

Chinese Pangolin

Figure 6L

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 88, 281; first capture on 12.VI.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Chinese Pangolins have a tubular snout, muscular tail, massive forefeet and claws, and a body covered dorsally with overlapping scales. A shorter tail that narrows towards its naked tip and 15–18 rows of scales with a depression in the skin near the anus, and a very pronounced ear pinna is the major external anatomical difference between this and Peninsular Indian Pangolin *Manis crassicaudata* É. Geoffroy Saint-Hilaire, 1803.

Order Proboscidea Illiger, 1811

Family Elephantidae Gray, 1821

***Elephas maximus indicus* Cuvier, 1798**

Asiatic Elephant, Asian Elephant

Figure 7A

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–4, 6–8, 10–13, 16–20, 22–23, 25, 27–46, 48–50, 52, 54–58, 60–61, 64–67, 70–73, 75–84, 87, 94, 98, 100, 102, 104–108, 110–117, 120–123, 125, 131, 134–138, 141, 143–153, 155–157, 159–165, 167–168, 175, 177–178, 180, 182, 184–185, 188–189, 191, 193, 196–203, 206–221, 223–226, 228–235, 237–238, 240–241, 243–244, 246–249, 251, 254–255, 262–264, 267–268, 271, 274–275, 278, 281–282, 288, 290, 296–297, 303–307, 309–311, 313–314, 317–323, 325–349, 351–353, 355–361, 363, 365–377, 379–391, 393–402, 404–405, 407, 410, 412–413, 415–417, 419–421, 425–431, 433–437, 439–446, 449, 451, 453–460, 462–468, 470; first capture on 06.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest, semi-evergreen forest and grassland.

**Identification.** Asiatic Elephants have grey skin that is covered with hair. In adults, this hair is sparse, while





**Figure 7.** Mammal species recorded through camera-trapping in Manas National Park, Assam, India. **A.** *Elephas maximus indicus*. **B.** *Rhinoceros unicornis*. **C.** *Bos gaurus*. **D.** *Bubalus arnee arnee*. **E.** *Naemorhedus goral goral*. **F.** *Axis axis*. **G.** *Muntiacus alvini vaginalis*. **H.** *Axis porcinus porcinus*. **I.** *Rusa unicolor unicolor*. **J.** *Sus scrofa cristatus*. **K.** *Hystrix brachyura hodgsoni*. **L.** *Atherurus macrourus*.

calves have thicker brown hair. The trunk is a distinctive feature of the elephant family. The males are much larger than the females. Males have tusks that elongate the second upper incisors, while females lack tusks and have tiny dental protuberances called tushes.

Order Perissodactyla Owen, 1848

Family Rhinocerotidae Gray, 1821

***Rhinoceros unicornis* Linnaeus, 1758**

Greater One-horned Rhinoceros, Indian One-horned Rhinoceros, Indian Rhinoceros

Figure 7B

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 7, 27, 43, 114, 125, 130, 135–136, 143, 178, 188, 232, 237–238, 240, 247, 249–250, 255, 330, 335, 337, 347, 355–356, 363, 386, 388, 393, 395, 404; first capture on 07.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and grassland.

**Identification.** The actual colour of the skin of Indian

Rhinoceros is a deep slate-grey, but it looks ashy when encrusted with alluvial mud or ink-black when wet. The skin is almost hairless. The hair is restricted to the tip of its small, naked tail, large and tubular ear tips, and eyelashes over small, beady eyes. The hooves are large and three-toed. Males and females have a single dark horn on the nose, made from agglutinated hairs. Two large folds of skin across its flanks and tubercles on its rear, which look like rivets on the skin, give it an armour-plated look. Newborns are pinkish-grey at birth and develop adult colouration in a few months. The horns start to grow by a year and a half.

Order Artiodactyla Owen, 1848

Family Bovidae Gray, 1821

***Bos gaurus* C.H. Smith, 1827**

Gaur, Indian Bison

Figure 7C

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–2,



4–5, 7–10, 12, 14–15, 17–25, 27, 29, 31–34, 38–40, 42–46, 48–50, 52, 54–57, 60–61, 64–66, 70–73, 75–78, 80–85, 87, 89, 91–92, 94–98, 106–107, 111, 113–114, 116–117, 119, 122–123, 125–128, 131, 135, 140, 144–145, 147, 149, 152–153, 155–157, 159–160, 162–165, 168–169, 171, 175–180, 182–183, 185–186, 188–189, 192–193, 195, 200–204, 206, 211, 213–214, 219–220, 223, 231, 233, 235–237, 246, 248–249, 253–254, 259, 263, 267, 269, 272–273, 275–276, 280, 285, 292, 297, 303, 306, 309–311, 314, 318, 324–327, 330–331, 333, 336–338, 342, 345, 348–350, 355–357, 365, 369–371, 373, 375, 377, 379, 381–383, 386–387, 389–391, 393–396, 398–402, 404–408, 410–419, 421–422, 424–431, 433–434, 436, 438, 443, 469; first capture on 08.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Gaurs have a huge head and a deep reddish-brown to black body. They have solid, sturdy limbs that are pale in colour, and they have a dewlap under their chin that extends between their front legs. They have a shoulder hump which is particularly pronounced in adult males. Males and females have horns up to about 1 m in length. They grow from the side of their head and curve upwards. They are yellow at the base and black at the tip.

***Bubalus arnee arnee* (Kerr, 1792)**

Wild Water Buffalo, Indian Water Buffalo

Figure 7D

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 2, 4, 8–9, 13–16, 19, 21, 23, 25, 27–31, 34, 37, 39, 42–44, 61, 65–66, 70–71, 73, 80, 82–83, 89, 97–98, 100–102, 107, 109, 114–115, 119, 123, 125, 127, 130, 135, 143, 146, 205, 213, 216, 218–219, 228, 230, 232, 235–237, 239–241, 245, 250–251, 253–254, 260–263, 266, 273, 288, 299, 303, 306–307, 309–311, 315, 318, 320, 329–331, 334–335, 337–338, 342, 350–351, 356–357, 359–360, 363, 366–367, 369, 371, 375, 386, 394–395, 397, 439, 442, 447, 458, 461, 467; first capture on 07.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and grassland.

**Identification.** The face of Wild Water Buffalos is long and narrow, with relatively small ears and large horns. The horns have the widest spread found in any bovid. Both sexes bear horns, although those of the female are smaller than those of the male. Horns of both sexes are heavy set at the base, ribbed, and triangular in cross-section. They have sparse hair that is long and ashy grey to black. Their relatively long tail is bushy at the tip. Their legs are often dirty white up to the knees. Adults are almost hairless, and their skin colour varies with weather conditions, though it is difficult to ascertain the skin colour as they are usually covered with mud. When not mud-covered and dry, the skin is dark grey; however, the skin is dark brown to black when moist and not mud-covered.

***Naemorhedus goral goral* (Hardwicke, 1825)**

Himalayan Goral, Goral

Figure 7E

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera station 353; first capture on 24.I.2019; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Himalayan Gorals are the smallest of the goat antelopes. They are shaggy and brownish grey in winter but sleeker and greyish brown in summer. They have a white upper throat patch and white spots on their muzzle. Their horns are short, ridged and backwards-pointing, and narrower in the females. A dark dorsal band extends to the tail. The underparts are pale brown, and the legs are bright brown, flecking on the forelegs just above the black hooves.

Family Cervidae Goldfuss, 1820

***Axis axis* (Erxleben, 1777)**

Chital, Spotted Deer, Axis Deer

Figure 7F

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera station 87; first capture on 17.VI.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** The body colour of Chitals is reddish with white on the belly, inner legs, and underneath their short tail. Males tend to be darker and have black facial markings. They also have antlers composed of three tines that can reach almost a meter in length. Characteristic white spots occur in both sexes and run longitudinally in rows throughout the animal's life. A dark dorsal stripe runs the length of the animal's back.

***Muntiacus muntjak vaginalis* (Boddaert, 1785)**

Barking Deer, Red Muntjac, Indian Muntjac

Figure 7G

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–2, 4–6, 8–13, 16, 19–25, 27, 29, 31–46, 48–52, 54–58, 60–61, 63–66, 69–73, 76–86, 88–89, 94–97, 99–100, 103–107, 109–112, 114, 116–120, 122–123, 125–129, 131–133, 135–138, 140, 142–146, 149–150, 154, 157–160, 163, 165, 171, 173–177, 181–186, 188–193, 195, 199, 201–202, 204, 208, 215, 218–220, 226, 230–231, 233, 235–236, 244–245, 250, 254–255, 257–261, 264, 266–267, 269–275, 277–283, 285, 287, 289–290, 292, 297, 299–301, 303, 306–315, 319–320, 322–325, 327–333, 336–337, 339, 341–344, 350, 352–354, 358, 365, 367–368, 373, 375–376, 381, 383–384, 386, 388–389, 391, 399, 401–402, 404–408, 410–411, 413–414, 417–418, 420, 422–430, 433–439, 443–444, 446, 448–449, 453–454, 456, 462–467, 470, 472; first capture on 07.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Barking Deer have a glossy, reddish-brown coat and greyish or white underparts. Their forelimbs are longer than the hind limbs. Males have long upper canines that are not always visible. Frontal ridges on the face are well developed, as are two slits indicating



a frontal gland. Males have well-developed but small antlers mounted on long pedicles, and two black lines mark these down the face. Antlers have a short brow tine and, at the tips, curve inwards. Females have bony frontal ridges but no antlers.

***Axis porcinus porcinus* (Zimmermann, 1780)**

Hog Deer

Figure 7H

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 8, 12, 16–17, 23, 25, 31, 48, 61, 65, 89, 98, 119, 136, 173, 178, 200, 209, 219, 221, 228, 250, 290–291, 294, 306, 311, 327, 329, 333, 350, 353, 363, 369, 371, 374–375, 379, 394, 397, 410, 412, 425, 447–449, 458, 461–462, 464–466, 468–469; first capture on 11.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and grassland.

**Identification.** Hog Deer are a relatively small yet powerful cervid with a stocky, muscular body. The limbs are noticeably short and delicate; the hindlimbs are longer than the forelimbs, raising the rump to a height greater than the shoulders. The face is short and wedge-shaped. Adults have a coarse pelage, and the overall colouration is a dark olive-brown; however, the guard hairs have white tips. Fawns are born with a pale sandy-yellow colour with cream-coloured horizontally distributed spots along their flanks. At approximately six months, this colouration gradually gives way to adult colouration. In the summer, an adult's coat often changes to reveal distributed spots, such as those found on the fawn. The rhinarium is always naked and brown. One distinctive feature is the enormous round ears fringed with white hairs. Also, the tail is particularly bushy due to long hairs in a dorsoventral pattern. The females are slightly smaller than males and lack antlers. The males have noticeably thick muscular necks. They also have antlers that tend to be small and unimpressive compared to other members of the genus *Axis* as well as the entire Family Cervidae. Typically, the antlers are three-tined; however, extra points are not uncommon. The antlers are covered in velvet for much of the year and project from conspicuous hairy pedicles.

***Rusa unicolor unicolor* (Kerr, 1792)**

Sambar

Figure 7I

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–4, 6, 8, 10–11, 13–20, 22–46, 48–58, 60–61, 63–67, 69–73, 75–78, 80–86, 89, 91–92, 94–95, 97–110, 112, 114–123, 125–133, 135–165, 167–169, 171, 173–180, 182–183, 185–186, 188–193, 195–197, 200–201, 203–204, 206, 208–210, 212–220, 223, 225–226, 229–232, 234–235, 237–242, 244–246, 249–250, 252, 254–258, 260, 262–263, 266–276, 279–285, 287–290, 293, 296–297, 301, 303, 305, 308–309, 311, 314–316, 318, 320, 322–327, 329–339, 341–356, 358–360, 363–370, 372–377, 380–389, 391, 393–396, 398–402, 404–408, 410–413, 415–431, 433–444,

449, 451, 453, 455–458, 460, 462, 464–466, 468–469; first capture on 06.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Sambars have a coarse coat of short, dark hair with light brown to creamy white hair on their undersides. The backsides and undersides of their bushy tails are white, and when raised, the tails are used as signals. Males are generally larger than females and possess a dense mane on their necks. Males have antlers with three or four tines, which are periodically shed and replaced.

Family Suidae Gray, 1821

***Sus scrofa cristatus* Wagner, 1839**

Asiatic Wild Pig, Wild Boar

Figure 7J

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 1–4, 6–8, 10–13, 15–17, 19–20, 22–23, 25–33, 35–38, 40, 42–46, 48–55, 57–61, 63, 65, 70–71, 73, 76–78, 80–81, 83–89, 91–97, 99–100, 103–105, 107, 112, 114–116, 119–120, 122, 125, 127–132, 134–136, 139, 141, 144–147, 149, 156, 158, 160, 163, 165, 168–169, 171, 173–176, 178, 183–186, 188–189, 191–193, 201–202, 204, 206–207, 209, 211–215, 217–220, 223, 225, 228–232, 235, 237–242, 244–245, 248–252, 254–255, 257–259, 262–263, 266–267, 271–272, 274–276, 278, 280–281, 290–291, 294–295, 297, 299–300, 302, 304, 306–307, 309, 311, 313–314, 316, 319–320, 324–325, 329–332, 334, 340–341, 345–346, 349–352, 354–356, 360–361, 363, 365, 367–369, 371, 373, 375–376, 379–382, 384–390, 396–398, 402, 404–406, 408, 410–414, 416, 418–420, 423–430, 433–436, 442–444, 446–447, 449–451, 453–456, 458–470; first capture on 07.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Adult wild boars have thick, coarse hair covering their bodies. Their coat ranges from black to brownish-red to white. Depending on their geographic location, they can have a speckled or solid pelage colour. They may also have longer bristly hairs that grow down the middle of their backs. At birth, young boars generally have yellowish-brown stripes running down their backs that disappear into an even colouration within about four months.

Order Rodentia Bowdich, 1821

Family Hystricidae G. Fischer, 1817

***Hystrix brachyura hodgsoni* (Gray, 1847)**

Himalayan Crestless Porcupine, Malayan Porcupine

Figure 7K

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 4, 5, 8, 11, 13, 15, 18–19, 21–22, 27, 30, 32–33, 38, 46, 51, 65, 71, 78–79, 88–89, 92, 95–97, 99, 102, 104–105, 110–111, 113–114, 116–120, 125, 130–133, 135, 137, 140, 143–145, 147, 149, 153, 156–157, 162, 165, 171, 177–178, 180,



182, 185–186, 188–190, 197, 202–203, 205–207, 211–213, 215–220, 225–226, 229–232, 235, 239–240, 245–246, 250–251, 254–255, 257, 259–260, 264–265, 270–272, 276–281, 283, 293, 296, 299, 301, 303, 306–307, 310, 314, 316–320, 322, 324, 327, 329, 331, 338–339, 341–344, 347–348, 351, 353, 355, 357, 359–360, 363, 365, 367, 373, 376, 380, 382, 389, 391, 405, 407, 412–413, 420, 424–425, 428–429, 431, 433–436, 439, 447, 451, 453, 458, 464–465, 467, 469; first capture on 16.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Malayan Porcupine differs from the Indian Crested Porcupine *Hystrix indica* Kerr, 1792 by its shorter dorsal crest, small tail instead of a visible tail with white quills, narrower body quills, and smaller body size. Its dorsal quills have one dark band, while the Indian porcupine has more than two.

***Atherurus macrourus* (Linnaeus, 1758)**

Asiatic Brush-tailed Porcupine

Figure 7L

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 418, 428; first capture on 12.III.2019; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Asiatic Brush-tailed Porcupines are the smallest of Indian porcupines. They lack the long body quills of the other species. Fur colouration on the upper back is black-brown to grey-brown. Individual hairs have whitish tips. The first third of its long, scaly tail (to the size of head and body) is spineless, and the rest is covered in quills that seem beaded due to rice-grain-sized thickenings on them.

Order Primates Linnaeus, 1758

Family Cercopithecidae Gray, 1821

***Macaca mulatta* (Zimmermann, 1780)**

Rhesus Macaque, Rhesus Monkey

Figure 8A

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 7, 9, 37, 39, 48, 58, 63, 65, 71, 73, 89, 93–94, 96–97, 119, 146, 150, 173, 180, 208, 210, 216, 218, 220–221, 223, 257, 260–261, 266, 273, 275–276, 291–292, 295, 297, 299, 305, 310–313, 317, 326–327, 330, 335, 350, 356, 370, 386, 399, 407, 428, 430, 435, 450, 471; first capture on 09.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Rhesus macaques have grizzled-brown fur dorsally, with the fur on the ventral being slightly lighter coloured. The hair is short on the head. The orangish tint to the fur on its hindquarters and loins is constant and distinguishes it from the similar-looking Assamese Macaque. Infants have pink faces, hands and feet that change to flesh-coloured in two months. Subadult males have a pink scrotum that turns red in adult males.

***Macaca assamensis assamensis* (M'Clelland, 1840)**

Assamese Macaque, Assam Macaque

Figure 8B

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 47, 119, 146, 184; first capture on 26.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Assamese Macaques have yellowish-grey to dark brown pelage. The facial skin is dark brownish to purplish. The head has a dark fringe of hair on the cheeks directed backwards to the ears. The hair on the crown is parted in the middle. The shoulders, head, and arms are paler than the hindquarters, which are greyish. The tail is well-haired and short.

***Trachypithecus pileatus tenebricus* (Hinton, 1923)**

Capped Langur, Capped Leaf Monkey

Figure 8C

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 29, 45, 74, 103, 260, 267, 373; first capture on 13.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest.

**Identification.** Capped langurs vary in appearance. The species is named for the thick hair on their head, usually black or grey. Their dorsal side is generally covered in grey, brown, or black hair. They have a cream belly in males and a cream tinged with an orangish-red belly in females. They have the nearly black, darkest forehead of all four subspecies.

Order Lagomorpha Brandt, 1855

Family Leporidae Fischer, 1817

***Lepus nigricollis sadiya* Kloss, 1918**

Indian Hare, Black-naped Hare

Figure 8D

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 24, 40, 43–44, 46, 63, 72, 96, 150, 155, 175, 178, 209–210, 217–218, 223, 225–226, 229, 234, 237, 306–307, 310, 317, 324, 329, 357, 363, 370, 372, 391, 394, 398–399, 460; first capture on 11.IV.2017; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and semi-evergreen forest.

**Identification.** Indian Hares are also called Black-naped Hares due to the patch of black fur that runs along the nape of the neck. The tail's top is also black, and the back and face are brown, with black hairs scattered throughout. The underparts are white. Like all hares, they have long ears and large hind feet, which are well-furred.

***Caprolagus hispidus* (Pearson, 1839)**

Hispid Hare, Assam Rabbit, Bristly Rabbit

Figure 8E

**Material examined.** INDIA – Assam • Baksa district, Gobardhana, Manas National Park; camera stations 228,





**Figure 8.** Mammal species recorded through camera-trapping in Manas National Park, Assam, India. **A.** *Macaca mulatta*. **B.** *Macaca assamensis assamensis*. **C.** *Trachypitecus pileatus tenebricus*. **D.** *Lepus nigricollis sadiya*. **E.** *Caprolagus hispidus*.

276, 363; first capture on 24.IV.2018; Urjit Bhatt obs.; camera-trap photo; moist mixed deciduous forest and grassland.

**Identification.** Hispid Hares have short, broad ears and small eyes. There are two layers of fur: a coarse, bristly outer layer and an underlayer shorter and finer. The pelage's top layer is dark brown due to a mixture of black and brownish-white hairs, whereas the bottom layer consists of strictly brownish-white hair. The tail also has two layers of pelage, both brown; the top layer is darkest.

## Discussion

Baseline data on diversity and abundance are crucial for several species of concern to monitor the success of conservation activities in various regions of a protected area. This study broadly described the diversity, species composition, relative abundance index, and threat status of mammalian fauna in MNP. The study confirmed 39 mammalian species through camera-trapping ( $n = 34$ ) and direct sightings ( $n = 5$ ), reported in strictly forested habitats. Our findings indicate that MNP supports a diversity of mammalian fauna of conservation concern, of which 20 (51%) are threatened species. Although our camera-trapping survey underrepresented species groups such as primates, rodents, arboreal species, and habitat specialist species, direct observational records confirm the presence of one species of Cervidae [*Rucervus duvaucelii ranjitsinhi*, VU], one species of Cercopithecidae (*Trachypitecus geei geei* Khajuria, 1956, EN), and three species of Sciuridae [*Ratufa bicolor gigantea* (McClelland, 1839), NT; *Tamiops maclellandii maclellandii* (Horsfield, 1840), LC; *Callosciurus pygerythrus lokroides* (Hodgson, 1836), LC]. Despite a long history of ethnopolitical conflict, almost all mammalian species

expected to occur in the region were present and detected during the study.

Mammals ( $n = 34$ ) observed through camera-trapping in this study were higher as compared with previous studies conducted in MNP: 32 species (Goswami and Ganesh 2014), 25 species (Lahkar et al. 2018), and 32 species (Jhala et al. 2020). These studies recorded mammals using multiple methods (camera-traps, line transects, and direct opportunistic sightings). The current study was based exclusively on camera-trapping; hence, combining the above techniques may have resulted in the detection of more species. For example, four primate species have been reported in the region, but only three of these could be photo-captured. Most previous studies focused on medium to large-sized mammals with a sampling design of 2 km<sup>2</sup> of grid-size or higher. In contrast, we conducted camera-trapping more intensively (grid-size: 1 km<sup>2</sup>, and an average distance between two cameras: 672 m  $\pm$  15.73 SE) to photo-capture all small, medium, and large mammals. Our study had the highest number of mammalian fauna recorded using camera-traps alone, which shows that our methodology efficiently sampled the species in the region.

The plateau of the accumulation curve indicated that our camera-trap survey effort was sufficient to capture relatively common species (Tobler et al. 2008). Although there is a stabilisation of the SAC in our study, other species that also occur in the park, as per the previous studies, stayed undetected in our study. Our intensive camera-trapping design was unable to photograph rare mammal species, including three felid species [Marbled Cat *Pardofelis marmorata* (Martin, 1837), NT (Borah et al. 2012b; Lahkar et al. 2018); Asiatic Golden Cat *Catopuma temminckii* (Vigors and Horsfield, 1827), NT (Borah et al. 2012b; Ghosh et al. 2014); and Fishing Cat



*Prionailurus viverrinus* (Bennett, 1833), VU (Borah et al. 2012b; Ghosh et al. 2014)] and one species each of Canidae [Golden Jackal *Canis aureus* Linnaeus, 1758, LC (Borah et al. 2012a; Ghosh et al. 2014; Lahkar et al. 2018)]; Ursidae [Sloth Bear *Melursus ursinus* (Shaw, 1791), VU (Borah et al. 2012a, 2012b; Ghosh et al. 2014)]; Bovidae [Himalayan Serow *Capricornis sumatraensis* (Bechstein, 1799), VU (Deka et al. 2021)]; Cervidae [*Rucervus duvaucelii*, VU (Borah et al. 2013; Lahkar et al. 2018, 2020)]; and Suidae [*Porcula salvania*, EN (Ghosh et al. 2014; Goswami and Ganesh 2014)]. Four of these seven species, namely *Rucervus duvaucelii*, *Porcula salvania*, *Prionailurus viverrinus*, and *Canis aureus*, could not be photo-captured in our cameras. This is largely because *Porcula salvania* strictly inhabits grassland habitats (Duckworth et al. 2015; Meijaard et al. 2019), while the *Prionailurus viverrinus* resides near marshes, ponds, lakes, streams, and swamps (Mukherjee et al. 2016), and *Canis aureus* prefers to live near human habitations with open (desert), savannas, and arid grasslands (Hoffmann et al. 2018). As we primarily deployed cameras in the national park's core area with forested habitats (moist mixed deciduous and semi-evergreen), our sampling design restricted us from photo-capturing these habitat-specialist species. The remaining four species (*Pardofelis marmorata*, *Catopuma temminckii*, *Melursus ursinus*, and *Capricornis sumatraensis*) mainly prefer higher elevations and were previously reported within the MNP–RMNP boundary areas. This highlights the general challenges of assessing mammal species richness and suggests that even a high sampling effort does not necessarily yield a complete mammal species list for a given area (Bowler et al. 2017).

Hence, systematic or randomised sampling protocols (such as our terrestrial camera-trapping monitoring scheme) are perhaps insufficient to obtain a complete mammal inventory. Though camera-traps effectively record species composition and abundance of mammals, the drawbacks of small data sets for some species still exist. Adaptive survey designs such as arboreal (Bowler et al. 2017) and baited (Ferrerias et al. 2018) camera-trapping, and surveys in specific habitats, may be required to assess the presence or absence of rare and highly specialised species (Thompson 2004). Limitations, such as the inability to account for detection probabilities, which are bound to vary with species, camera-trap methods, or species' behavioural responses to traps, should be considered (Harmsen et al. 2010; Ramesh et al. 2012).

In this study, camera-traps were used as a biodiversity monitoring tool. Camera-trap detected most of the mammals of the study region, including the rare and elusive *Atherurus macrourus* (Linnaeus, 1758) and *Naemorhedus goral goral*, which were detected for the first time in MNP. Further, after nearly two decades, our camera-traps photo-captured *Axis axis* (Bhatt et al. 2018) from the region. Evidently, our study using camera-traps has effectively recorded most mammal species irrespective of their body size. However, our sampling method

also revealed some limitations in this landscape. These include (1) reduced the effective camera-trapping period due to the high sensitivity of infrared sensor camera units, which resulted in photographic captures of low moving clouds and movement of vegetation due to wind; (2) temporary camera damage/failure due to elephants and high rainfall; and (3) loss of the camera-trap units from remote alpine areas as well as from dense forest near human habitation along with several instances of loss of memory card also reduced the effective camera-trapping period. Considering the benefits and limitations, we believe that in MNP, camera-trapping can provide a reliable and standardised means for MNP staff to document the presence of mammals and, if systematically placed and regularly monitored, can help estimate the precise abundance of mammals with or without identifiable features.

MNP is interconnected to Manas Reserve Forest (RF) in the west, Deodhara RF in the east, and RMNP, Bhutan, in the north, forming a vast landscape with habitats ranging from tropical grasslands at 40–150 m to subtropical forest at 300 m to warm broad-leaved forest above 1000 m rising up to 2000 m (Borah et al. 2012b). This healthy connectivity with a range of habitats and varied elevations makes MNP the world's only national park with eight species of wild cats (felids), i.e., *Panthera tigris tigris*, *Panthera pardus fusca* (Meyer, 1794), *Neofelis nebulosa macrosceloides*, *Pardofelis marmorata*, *Catopuma temminckii*, *Prionailurus bengalensis horsfieldii* (Gray, 1842), *Felis chaus affinis* Gray, 1830, and *Prionailurus viverrinus* being recorded and coexisting in the same area. These cats also share the same habitat with the other carnivores, such as *Cuon alpinus adjutus* Pocock, 1941, *Melursus ursinus*, and *Ursus thibetanus laniger* (Pocock, 1932), adding to the uniqueness of MNP.

Compared to the diversity recorded in the previous studies, our research indicated that Manas is on the path to recovery. To sustain this recovery, however, the combined efforts of the BTC, the Assam Forest Department, the local community, and stakeholders would be critical (Goswami and Ganesh 2011). We can hope for the emergence of a stronger and more resilient Manas with an extended favourable social and political climate, popular support for conservation activities, and rigorous science informing political decision-making (Goswami and Ganesh 2011). Conservation, both political lobbying and on-the-ground management, can only be effective with full knowledge of what species are present, their distribution, and relative abundance. The study found that camera-trap surveys are more cost-efficient in the tropical semi-evergreen forest than other survey methods in terms of finance and human effort. They document rare, elusive, shy, and cryptic mammalian fauna and their relative abundance. Long-term studies are needed to obtain information on the viability of populations of threatened species, which will aid conservation actions. We believe our results provide important baseline data that can be used to monitor future changes in several species'



capture rates, assist in evaluating the effectiveness of conservation efforts and further implement an improved management plan in MNP.

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## Authors' Contributions

Conceptualization: SL, UB. Data curation: UB. Formal analysis: UB, SL. Funding acquisition: SL. Investigation: SL. Methodology: SL, UB. Resources: SL. Supervision: SL, BSA. Validation: UB, SL. Visualisation: UB. Writing – original draft: UB. Writing – review and editing: UB, SL.

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