frontiers | Frontiers in Ecology and Evolution

TYPE Original Research
PUBLISHED 27 February 2024
DOI 10.3389/fevo.2023.1106329

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RECEIVED 23 November 2022
ACCEPTED 30 November 2023
PUBLISHED 27 February 2024

CITATION
Ahmad A and Gopi GV (2024) Site occupancy of select mammals in the tropical forest of Eastern Himalaya.
Front. Ecol. Evol. 11:1106329.
doi: 10.3389/fevo.2023.1106329

Site occupancy of select mammals in the tropical forest of Eastern Himalaya

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Introduction: Terrestrial mammals play a pivotal role in tropical forest ecosystems, representing a rich and functionally diverse component of these biomes. However, they confront formidable threats globally, such as hunting, habitat loss, and fragmentation, amidst the expansion of human-altered landscapes in tropical regions. Understanding the impacts of these changes on mammal communities is crucial for designing effective conservation interventions. Northeast India's tropical forests, a biodiversity hotspot, host a diverse array of mammalian fauna. The primary challenge faced by these species involves anthropogenic activities leading to the shrinkage and fragmentation of forested habitats.

Methodology: In this study, we conducted systematic camera trapping in Mehao Wildlife Sanctuary (WLS) to assess mammal status and distribution. Employing single-season occupancy models, we evaluated factors influencing mammalian species' detection probability and spatial utilization within the landscape.

Results: The study documented 27 mammalian species, with 12 identified as "threatened" on the IUCN Red List. Species like clouded leopard, marbled cat, Gongshan muntjac, red goral, Mishmi takin, and sambar were recorded but observed infrequently. Notably, we reported the Asiatic brush-tailed porcupine's first sighting in Mehao. Our findings revealed that undisturbed forest habitats were preferred by all species. Mainland serow dominated most of the sanctuary's area, followed by northern red muntjac, yellow-throated marten, and masked palm civet.

Discussion: The response of mammalian species to ecological and anthropogenic covariates varied significantly, underscoring the necessity for species-specific management strategies alongside a landscape-scale conservation approach. These outcomes emphasize the urgency of managing and safeguarding rare and elusive mammalian species within and around Mehao WLS.

KEYWORDS

tropical forest, biodiversity hotspot, mammalian species, occupancy model, Mehao WLS, camera trapping

1 Introduction

Though tropical forests cover less than 10% of the Earth's land surface (Bradshaw et al., 2009), they are incredibly diverse and support at least two-thirds of the world's biodiversity (Raven, 1988). Current research estimates that tropical forests will have one of the highest rates of natural vegetation loss in the near future (Smith, et al., 2023). Protecting tropical forests is the central thrust of several national and international biodiversity conservation strategies (CBD, 2015; Panfil & Harvey, 2015). Tropical forest provides substantial local, regional, and global benefits through economic goods and ecosystem services. As they have greater species diversity than other ecosystems, tropical forest biodiversity losses are likely greater (Rosenzweig, 1992). Mammals in tropical forests are a priority group as they represent a rich and functionally diverse component of this biome even as they face threats such as hunting, habitat loss, and habitat fragmentation (Ceballos et al., 2005; Schipper et al., 2008; Visconti et al., 2011; Ahumada et al., 2011). Tropical mammals are among the most threatened species globally, yet their status remains challenging to establish due to the inherent difficulty in their observation (Linkie et al., 2007). It is important to consider that their long-term trends may not be well-established, and the 'most threatened' designation assumes certain knowledge about their status. Information on distribution, habitat utilization, and threat response are critical to developing conservation strategies (Espartosa et al., 2011).

Mammals play a crucial role in maintaining ecosystem functions, including forest structures, nutrient cycling, carbon storage, seed dispersal and trophic management (Brodie et al., 2009; Jansen et al., 2010; Estes et al., 2011; Sobral et al., 2017). However, the secretive and cryptic nature of forest-dwelling mammals hinders data collection and the development of conservation measures. Statistical techniques, such as occupancy modeling, which considers and corrects imperfect detection, are essential to generate evidence for environmental policies (MacKenzie et al., 2002; Brodie et al., 2015; Guillera-Arroita, 2017). Track and sign surveys, direct observations, camera trapping, and interviews with local communities and hunters currently detect mammalian fauna (Ramesh and Downs, 2014; De Bondi et al., 2010; Aiyudurai et al., 2010). Numerous studies indicate that camera traps are an effective method to survey mammals, including rare, elusive, and nocturnal species (Silveira et al., 2003; Tobler et al., 2008; Harmsen et al., 2010; Espartosa et al., 2011; O'Connell et al., 2011). The use of camera traps to collect data on the distribution and abundance of mammals can provide a wealth of information (Rowcliffe and Carbone, 2008; Tobler et al., 2009; Pettorelli et al., 2010; Kinnaird and O'Brien, 2012; Ramesh et al., 2012; Ramesh et al., 2013). Sign surveys (Carrillo et al., 2000; Naughton-Treves et al., 2003; Harvey et al., 2006; Bali et al., 2007; Parry et al., 2007; Norris et al., 2008) are increasingly being used to survey tropical forest mammals. In tropical forests, suitable substrates for footprint impressions are not always present, and weather conditions lead to biases in sign surveys (Dirzo and Miranda, 1990; Norris et al., 2008).

To reconcile conservation and development, it is increasingly important to comprehend how human-modified landscapes in the tropics affect mammal communities (Boron et al., 2019). In tropical rainforests, habitat loss, hunting, land-use change, and deforestation threaten biodiversity conservation (Schipper et al., 2008; Visconti et al., 2011; Barlow et al., 2016; Hansen et al., 2008; Laurance and Luarance, 1999). Agriculture and tree plantations are rapidly increasing across the tropics to meet rising human demand for food, timber, and fiber (Hansen et al., 2013; Abood et al., 2015; Haddad et al., 2015; Riitters et al., 2016). These developments are lowering the area of forests and fragmenting or reducing wildlife habitat (Laurance et al., 2002; Fischer and Lindenmayer, 2007; Laurance et al., 2011). In addition, the problem of hunting has worsened due to expanding human populations, easier access to remote forests, and the use of modern hunting techniques and weapons. According to recent estimates, hunting pressure and land-use changes have caused mammalian populations to decline by more than 80% and 30%, respectively (Almeida-Rocha et al., 2017; Benítez-López et al., 2017). The native populations of local communities in northeast India have more in common with Southeast Asian cultures than peninsular India, and hunting is common (Datta, 2007). Hunting is common in Arunachal Pradesh, and it has decimated wildlife populations in the state (Datta, 2002; Hilaluddin and Ghose, 2005; Mishra et al., 2006).

Several surveys and documentation have been carried out in Arunachal Pradesh on large and small mammals (Athreya et al., 1997; Chowdhury, 1997; Datta, 1998; Datta et al., 2008a; Mishra et al., 2006; Gopi et al., 2010; Gopi et al., 2012; Selvan, 2013; Dasgupta et al., 2014; Selvan et al., 2014b; Dasgupta et al., 2015; Adhikarimayum and Gopi, 2018), Malayan sun bear (Sethy and Chauhan, 2012) and red panda (Kakati, 1996). Most wildlife surveys in Arunachal have been restricted to low and mid-elevation forests and have focused on rare species (Katti et al., 1990; Athreya and Johnsingh, 1995; Selvan et al., 2013; Roy et al., 2015). Very few surveys or ecological research in the state have produced significant discoveries and information (Datta and Goyal, 1997; Selvan et al., 2014a) of new species like leaf deer (Datta et al., 2003), Chinese goral (Mishra et al., 2004) and Arunachal macaque (Sinha et al., 2005).

In this context, we initiated the first systematic camera trapping study to evaluate the assemblage of terrestrial mammals in Mehao WLS and to understand factors affecting detection probability and occupancy. Mehao WLS is located in Arunachal Pradesh in the eastern Himalayas, which has been recognized as a global biodiversity hotspot (Myers et al., 2000). The rugged terrain and dense forest cover of Mehao WLS harbor 60 species of mammals (Chakraborty and Sen, 1991). Idu Mishmi and Adi are the main communities living around Mehao WLS. The Idu Mishmi community has social taboos restricting hunting and forest use, which may have contributed to protecting biodiversity in the area (Nijhawan and Mihu, 2020). Few studies have been conducted on mammals in Mehao WLS (Katti et al., 1990; Chakraborty and Sen, 1991; Sarma et al., 2015; Ahmad et al., 2023). The ones that have been carried out focus primarily on the status and distribution of hoolock gibbon (Chetry et al., 2010; Roy et al., 2015), while a write-up on Mehao WLS was published by Sinha (1984).

Our specific objectives for this research were (1) To determine the species richness and relative detection rate of mammals in and around Mehao WLS and (2) To investigate the factors influencing the detection probability and occupancy of mammalian fauna. The findings of this study are of paramount importance for managing and conserving rare and elusive species in and around Mehao WLS.

2 Study area

The current study was conducted in Mehao WLS, Lower Dibang Valley district of Arunachal Pradesh (Figure 1). The sanctuary was established in 1980 and is home to numerous species of wildlife, including tigers, leopards, hoolock gibbons, tree shrews, wild dogs, and clouded leopards. Mehao WLS lies between 28˚ 05' and 28˚ 15' north latitude and 93˚ 30' and 95˚ 45' east longitudes and is spread over an area of 281.5 sq km. The terrain in Mehao WLS is plain in the southern section and hilly in the northern sections, with an elevation range of 400-3,568m above mean sea level. The valleys are narrow around river courses. The sanctuary is dotted with small flat areas at various elevations that provide habitat for various wildlife species. All the streams flow into the Dibang River, which later empties into the Lohit River—an important tributary of the Brahmaputra River. Several seasonal streams drain into these rivers, which flow rapidly during the monsoon.

Champion and Seth (1968) state that the study area falls within 8B/CI East Himalayan Sub-tropical Wet Hill Forests. The forest type changes with altitude in Mehao WLS. It includes tropical evergreen forest (900m amsl), subtropical and temperate forest (900m-1,800m amsl), temperate broad leave forest (1,800m-2,800m amsl), and temperate conifer forest (2,800m-3,500m amsl). The forest is dominated by *Terminalia myriocarpa*, *Messua ferrea*, *Dillenia indica, Castanopsis indica*, and *Albizia lucida* while primary shrub and herb species include *Clerodendrum viscosum*, *Tephrosia candida, Maesa indica*, and *Solanum khasianum*. Bamboo species in the area include *Dendrocalamus giganteus*, *Phyllostachys bambusoides*, *Bambusa pallida*, *Dendrocalamus hamiltonii*, and *Melocanna baccifera*. Mehao WLS is also home to Mishmi teeta (*Coptis teeta*), an extremely valuable medicinal herb and threatened holoparasitic plant, *Sapria himalayana* (Ahmad et al., 2020). The sanctuary is warmer at lower altitudes and cooler at higher altitudes. In the summer, the average temperature at a lower altitude is around 38°C and falls to 4°C-12°C in the winter. At higher altitudes, the summer temperature is around 12°C, and it experiences snowfall in the winter with temperatures around -3°C.

Numerous Idu Mishmi villages along the sanctuary's periphery include Koronu, Injuno, Abango, Balek, Simari, and Tiwarigaon. Strong taboos exist among the Idu Mishmi, prohibiting hunting gibbons and other wild animals. This has probably contributed to the abundance of wildlife in the region.

3 Methodology and data analysis

The field survey was conducted between November 2017 to February 2018. Reconnaissance was carried out during the initial

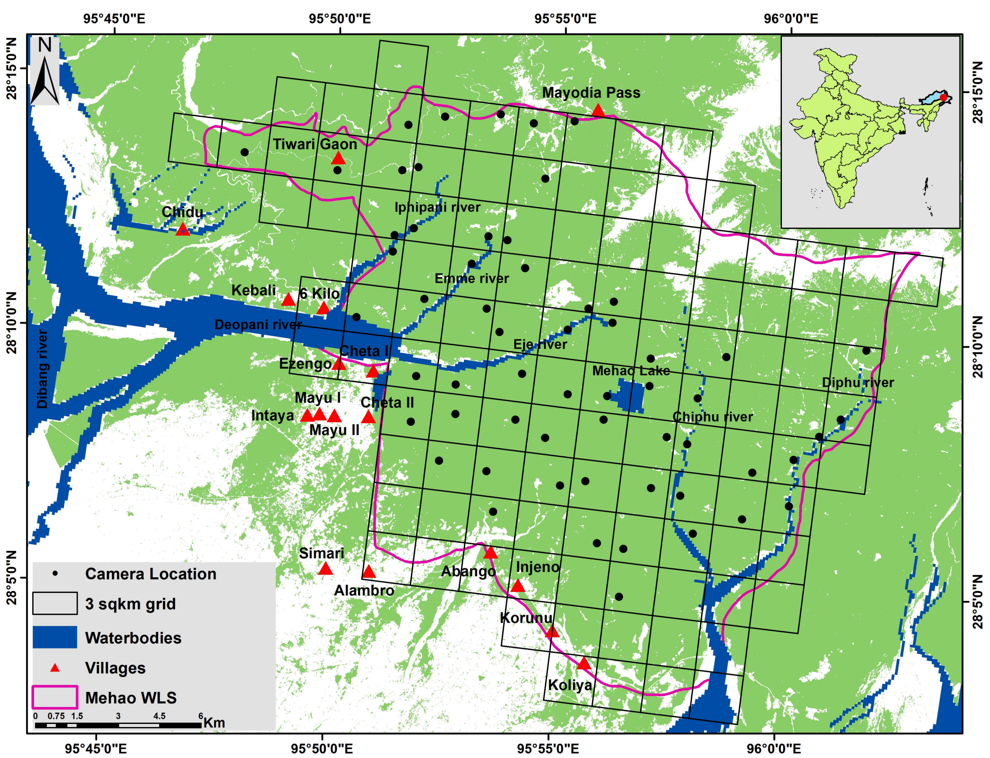

FIGURE 1
Map showing the location of camera trap, grids, and forest cover (green) in Mehao Wildlife Sanctuary.

months of the study period to develop adequate knowledge and understanding of the area while also collecting baseline data for further intensive sampling. An effort was made to deploy camera trap units randomly throughout the study area. A total of 58 camera traps were deployed with only one per 3 sq km grid, thus covering an area of 174 sq km. Cuddeback C1 camera traps were used. They have a trigger speed of 1.4 seconds, a detection range of 100 feet and were programmed to recover as fast as possible (FAP) after being triggered. Along animal trails, cameras were placed 20 cm above the ground and left active for 24 hours to capture images of all mammalian species encountered. Each grid contained one camera trap site with an average distance of 1.2 to 1.5 km between each trap. Then, we calculated Global Moran's I (Moran, 1950) using the Spatial Autocorrelation tool in ArcGIS (version 10.3) to determine whether the spatially rarified occurrence data assumed the random distribution after applying spatial filtering (version 10.3). Each camera was installed for 50 days. Thus, there were a total of 2,900 trap nights. Trap sites were placed throughout the study area.

Visual encounters or sightings are rare in the study area due to many species' elusive and nocturnal nature. In addition, several species found in the study area cannot be studied using standard photographic images for capture-recapture estimation techniques as individuals lack unique identifiable features. In the monsoon season, bridges often get washed away, and frequent landslides impede field research. Droppings, scats, and pellets are often degraded due to incessant rain in the monsoon. Thus, there is limited scope for conventional research methods in this landscape to monitor the abundance of mammals.

During this research, we could not inspect some camera units during the winter and pre-monsoon periods, as the access routes were inaccessible after heavy snowfall and rainfall. Extensive fieldwork could not be conducted in the northern part of Mehao WLS as the area remained inaccessible.

3.1 Relative detection rate

The relative detection rate (RDR) was obtained by dividing the total number of independent photographs for each species by the total number of trap nights and multiplying by 100 (Carbone et al., 2001). Multiple photographs of single individuals within 30 minutes were recorded as one effective photograph (O'Brien et al., 2003).

3.2 Species accumulation curve

The species accumulation curve of mammals in Mehao WLS was calculated using rarefaction. It estimates the species richness or the assemblage for a particular level of 'camera effort' (Magurran, 2021). After repeated re-sampling, it is estimated by calculating the mean of all pooled individuals or samples (Gotelli and Colwell, 2001). Thus, the sample-based rarefaction curves can account for natural sampling heterogeneity in data. The rarefaction curve of the mammalian species in Mehao WLS was calculated using the "*vegan*" package of R software 3.4.0.

3.3 Occupancy modeling

We documented the occupancy and relative detection rate of mammals in the sanctuary through a camera trap survey. Since estimating the abundance or density of many species is difficult, Relative detection rate (RDR) is the primary measure of species diversity. Occupancy can be determined by the presence/absence of a species at camera trap sites during a sampling session. For each camera location, we created a mammalian species detection history (1100100), with '1' indicating species detection during the sampling event and '0' indicating non-detection (Otis et al., 1978). In some instances, certain individuals were recorded multiple times at a camera station within a short time frame (≤30 minutes). To prevent counting these repeated observations as multiple detections and thereby avoiding the issue of pseudoreplication, we treated the initial capture of the animal within that time frame as a distinct and independent record or detection, following the guidance provided (O'Brien et al., 2003). Site occupancy is defined as the proportion of an area or sites occupied by a species (MacKenzie et al., 2018). Naive occupancy is the ratio of sites where it is detected compared to the total number of sites surveyed without accounting for imperfect detection (MacKenzie et al., 2018). The detection probability is detecting a species through repeated site surveys, which permits an unbiased estimation of site occupancy (MacKenzie et al., 2018).

The main advantage of occupancy models is that they explicitly account for imperfect detection or the probability of missing a species present in the area. In wildlife research, especially ones using camera trap surveys, imperfect detection is unavoidable. A failure to account for imperfect detection can substantially affect model results and bias inferences (Gu and Swihart, 2004; MacKenzie, 2005; Sollmann et al., 2013).

We calculated each camera site's independent photographic detection rate for Mithun (*Bos frontalis*) and humans per 100 trap nights. For large-scale monitoring of several species, site occupancy gives an impartial measure of species status and is cost-effective (Sarmento et al., 2011; Kinnaird and O'Brien, 2012). The camera trapping period was limited to 50 days to reduce the probability of changes in occupancy. The single-season occupancy model (MacKenzie et al., 2018) was used to predict the likelihood of a species occupying a specified site and the detection probability (p). However, it identifies ecological and anthropological factors underlying mammal distributions.

3.4 Covariates

To improve model convergence, we z-standardized all continuous covariates using the formula z = (x-x')/SD, where x is the individual value, x' is the factor mean, and SD is the standard deviation (Sunarto et al., 2012). Correlations between independent variables were calculated to eliminate multicollinearity issues (Graham, 2003). First, a Variance Inflation Factor (VIF) was calculated for each covariate to assess multicollinearity among variables; those with a VIF<3 were included in the model. Then, Pearson correlation tests were conducted, and correlated variables

(Pearson correlation coefficient>0.70) were excluded from the model (Supplementary Figure 1). Using the "*camtrapR package*", we created species-specific detection matrices for several mammal species (version 1.2.3) (Niedballa et al., 2016). We used the "*unmarked package*" to model occupancy (version 0.12-2) (Fiske et al., 2017).

We investigated several natural and anthropogenic covariates that could influence the space utilization of mammals in the study area (Table 1). Based on previous research (Hebblewhite et al., 2014; Li et al., 2017; Wang et al., 2018; Xiao et al., 2018; Yang et al., 2019), we investigated variables such as vegetation, ruggedness, elevation, Mithun encounter rates, and distance to a water body, as well as settlements and roads, which may influence species occupancy. We calculated the distance (m) from each camera to settlements, roads, and rivers using ArcToolbox in ArcGIS 10.3 (ESRI Inc.).

We used portable GPS receivers to determine the elevation of each location. We determined ruggedness using a one-kilometre radius and a topographic position index derived from the Shuttle Radar Topography Mission (SRTM) 30-m digital elevation model. Mithun and human presence are assumed to influence the animal's detection rate and 30 minutes of independence for each record. Mithun and human encounter rates for each camera station were calculated as the number of detections per 100 camera trap days over the entire sampling period (O'Brien et al., 2003). We created a 10 sq m circular plot around each camera location and recorded covariates such as elevation, habitat type, forest type, and tree/vegetation cover percentage. The habitat characteristics for each camera location were also assessed (including ground cover, shrub cover, and canopy cover visual estimation) (Kushwaha et al., 2004; Ramesh et al., 2013).

TABLE 1 Factors hypothesized to influence patterns of occupancy (ψ) and detection probability in Mehao WLS.

Covariates	Description	Justification of selection of covariate	A prior hypothesis	
			p	ψ
Distance to water sources (WB)	Estimated by calculating the Euclidean distance from rivers, streams (both permanent and seasonal) and stagnant water bodies	Water bodies are expected to impact the abundance positively, hence the site use by mammalian species.		+
Elevation (DEM)	Computed using the SRTM digital elevation model-30m	Elevation can both positively and negatively influence the habitat use of the studied species (Thapa & Kelly, 2017; Phumanee et al., 2020)		+/-
Distance to nearest human settlement (DHS)	Estimated by calculating the Euclidean distance from agriculture, settlements, built-up areas and roads	DHS is a surrogate measure of prolonged disturbance in the study site associated with human activities such as grazing, hunting and resource extraction (Vinitpornsawan, 2013; Thapa & Kelly, 2017).		–
Human Detection rate (HD)	Relative abundance of humans in camera trap	The anthropogenic activities could negatively impact habitat use and the population of mammals in the study area (Thapa & Kelly, 2017; Jornburom et al., 2020; Phumanee et al., 2020)		–
Mithun Detection Rate (Mdet)	Relative abundance of Mithun in camera traps	Mithun presence inside the study area was likely to negatively impact ungulate populations through competition for forage.	–	
Terrain Ruggedness Index (TRI)	TRI is derived from the DEM using the terrain analysis function.	It is an important ecological component affecting the distribution of mammals and vegetation.		+/-
Terrain Wetness Index (TWI)	Terrain Wetness Index is defined as ln(a/tanβ) where 'a' is the local upslope area draining through a certain cell per unit contour length in a DEM, and 'tanβ' is the local slope.	It is a geomorphometric parameter used to describe the distribution of mammals.		+/-
Canopy cover (CC)	Canopy cover was calculated for each plot through visual observation in a 10m circular plot centered on each trap station.	Canopy cover is known to affect occupancy by mammals (Li et al., 2018).		+/-
Topographical Position Index (TPI)	Topographic Position Index is the mean difference between a grid cell and a neighbouring grid cell in a digital elevation model (DEM)	It indicates areas accumulating water flow, often with seasonally and permanently waterlogged ground, which influences the occupancy of mammals and vegetation structure.		+/-
Bamboo-mixed forest (BMF)	Proportion of bamboo and mixed forest extracted from LU/LC map prepare for the study	Different vegetation structures associated with forest types could influence the occupancy of studied mammalian species.		+/-
Mixed forest (MF)	Mixed forest was extracted from LU/LC map prepared for the study			+/-
Shrub cover (SC)	Shrub cover was estimated for each plot based on visual observations in a 5m circular plot centered on each trap station.			+/-

4 Result

4.1 Relative detection rate, sampling effort and trap nights

We carried out 50 camera-trapping days at 58 sites (n=2,900 trap nights) and recorded 27 wild mammals, Mithun (semi-domesticated) species, and humans. We focused our on-site occupancy analyses on 10 of the 27 species for which we had sufficient data. However, we analyzed the detection rate for all terrestrial mammals.

The 27 species of mammals recorded in the camera trap survey included 12 carnivore species (four Felids, three Viverrids, two Mustelidae, two Canids, and one species each from the Ursidae and Prionodontidae families) and seven herbivore species (four Bovidae, two Cervidae, and one Suidae) species. In the carnivore guild, we recorded Indo-Chinese clouded leopard *(Neofelis nebulosa)*, marbled cat (*Pardofelis marmorata*), leopard cat (*Prionailurus bengalensis*), Asiatic golden cat (*Catopuma temminckii*), masked palm civet (*Paguma larvata*), common palm civet (*Paradoxurus hermaphroditus*), large Indian civet (*Viverra zibetha*), wild dog (*Cuon alpinus*), spotted linsang (*Prionodon pardicolor*), Asiatic black bear (*Ursus thibetanus*), golden jackal (*Canis aureus*), and yellow-throated marten (*Martes flavigula*). In the herbivore guild, we recorded Mishmi takin (*Budorcas taxicolor*), red goral (*Naemorhedus baileyi*), mainland serow (*Capricornis sumatraensis*), mithun (*Bos frontalis*), Indian muntjac (*Muntiacus vaginalis*), sambar (*Rusa unicolor*), and Indian wild pig (*Sus scrofa*). We also recorded seven other species (two Hystricidae, three Sicuridae and a species each from Hylobatidae, Herpestidae and Cercopithecidae). This included Malayan porcupine (*Hystrix brachyura*), Asiatic brush-tailed porcupine (*Atherurus macrourus*), black giant squirrel (*Ratufa bicolor*), Himalayan striped squirrel (*Tamiops macclellandi*), Pallas's squirrel (*Callosciurus erythraeus*), crab-eating mongoose (*Herpestes urva*), Western hoolock gibbon (*Hoolock hoolock*), and northern pig-tailed macaque (*Macaca leonina*). Through sign surveys, direct sightings, questionnaire surveys, and camera trappings, we identified 27 species present in Mehao WLS. Twelve of the 27 species recorded are of high global conservation importance in the IUCN Red List, and the conservation status of species is listed as Endangered (2), Vulnerable (9) and Near Threatened (3) Least Concern (11) (IUCN 2010) (Supplementary Table 1).

The Relative detection rate was calculated for Asiatic brush-tailed porcupine (RDR=4 ± 3.6 SE), followed by Mainland serow (RDR=3.21 ± 0.77 SE), northern red muntjac (RDR=3.06 ± 0.97 SE), Mishmi takin (RDR=1.34 ± 1.25 SE), mithun (RDR=1.28 ± 0.51 SE), Indian wild pig (RDR=0.70 ± 0.36 SE), yellow-throated marten (RDR=0.56 ± 0.16 SE), masked palm civet (RDR=0.47 ± 0.18 SE), Himalayan black bear (RDR=0.24 ± 0.11 SE), Asian golden cat (RDR=0.17 ± 0.09 SE) and leopard cat (RDR=0.17 ± 0.08 SE). According to RDR estimates, the most abundant mammalian species was the Asiatic brush-tailed porcupine (Figure 2). Yellow-throated marten was the most abundant carnivore. According to RDR value, yellow-throated marten, masked palm civet, large Indian civet, leopard cat, marbled cat, Asiatic Golden Cat, clouded leopard, wild dog, and Asiatic black bear are the major predators in Mehao WLS. Figure 3 represents the mainland serow, Northern red muntjac and Yellow-throated marten distributions across the study area. Asiatic brush-tailed porcupine was present in the southern part of the sanctuary.

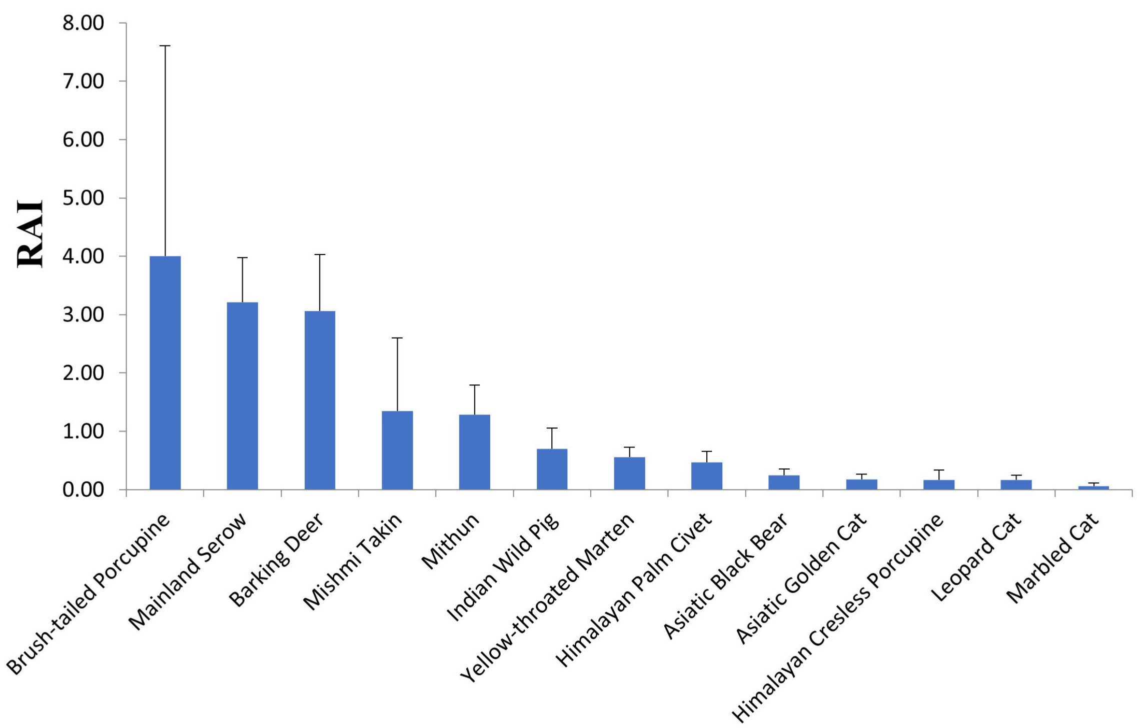

FIGURE 2
Graph showing Relative detection rate (RDR) of photo-captured mammals in the sanctuary.

4.2 Species accumulation curve

The Species Accumulation Curve shows that species richness for camera traps in Mehao WLS has not reached an asymptote after 80 trap nights (Figure 4). This insight highlights the need for additional survey efforts to obtain a more comprehensive understanding of the species present in the area.

4.3 Occupancy

Table 2 lists the site occupancy and detection probability of selected mammalian species. Naive occupancy was highest for mainland serow (0.48) followed by northern red muntjac (0.28), Asiatic brush-tailed porcupine (0.25), Asiatic golden cat (0.25), yellow-throated marten (0.21), masked palm civet (0.19), and lowest for Asiatic black bear (0.09), leopard cat (0.07), and Mishmi takin (0.05).

4.4 Estimates of occupancy

Estimates of site occupancy for all species with standard errors ranged from 0.07 ± 0.04 to 0.58 ± 0.08. Mainland serow has the highest probability of occupancy [ψ(.)SE ψ(.): 0.58 ± 0.08] followed by northern red muntjac [ψ(.) SE ψ(.): 0.30 ± 0.06], brush-tailed

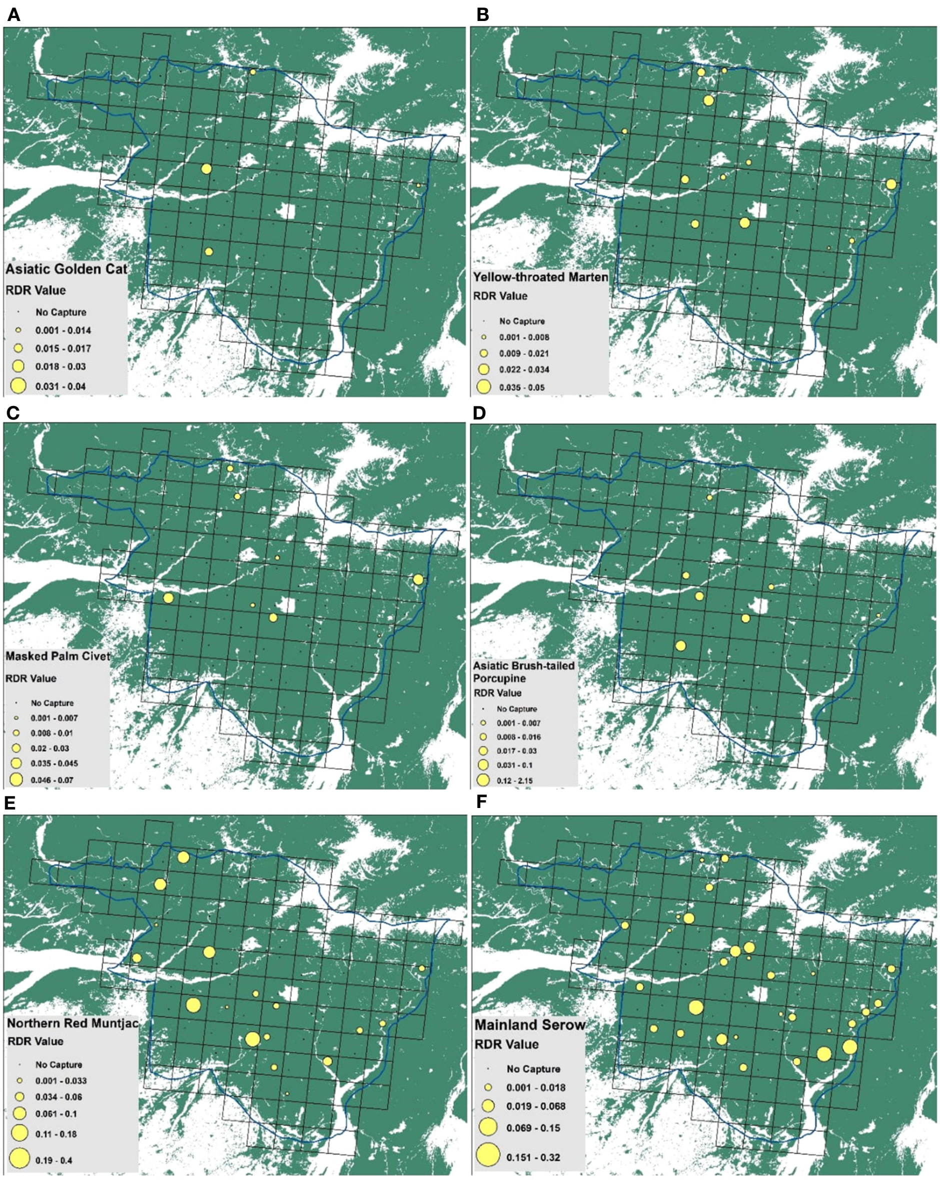

FIGURE 3
Spatial distribution maps of **(A)** Asian golden cat, **(B)** yellow-throated marten, **(C)** masked palm civet, **(D)** Asiatic brush-tailed porcupine, **(E)** northern red muntjac and **(F)** mainland serow in Mehao WLS.

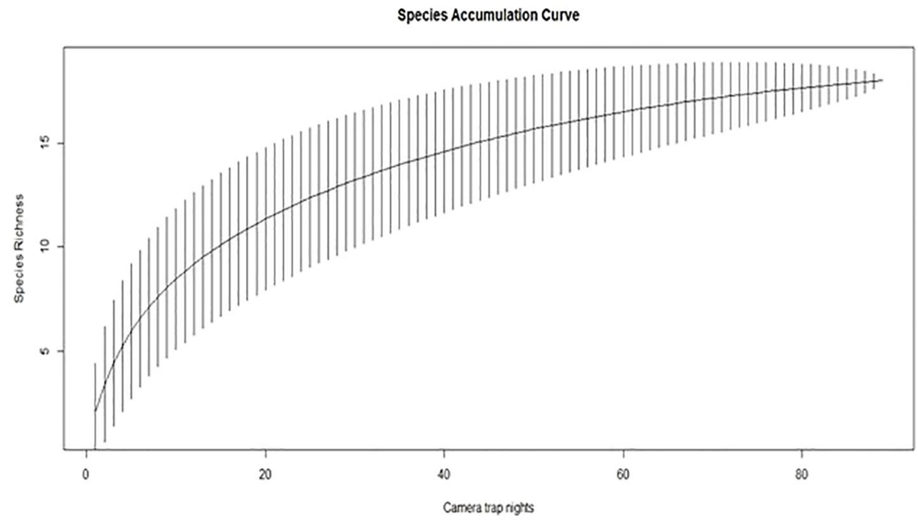

FIGURE 4
Species rarefaction curve of mammals in mehao wildlife sanctuary.

porcupine [ψ(.) SE ψ(.): 0.26 ± 0.06], Asian golden cat [ψ(.) SE ψ(.): 0.26 ± 0.06], yellow-throated marten [ψ(.)SE ψ(.): 0.25 ± 0.07], masked palm civet [ψ(.) SE ψ(.): 0.21 ± 0.09], and leopard cat [ψ(.) SE ψ(.): 0.184 ± 0.161], Mishmi takin [ψ(.) SE ψ(.): 0.07 ± 0.04], Asiatic black bear [ψ(.) SE ψ(.): 0.15 ± 0.08] and wild boar [ψ(.) SE ψ(.): 0.14 ± 0.08] have the lowest occupancy probability (Table 2). The estimated occupancy probability for all these species is larger than the naïve estimates.

TABLE 2 Occupancy and probability of detection.

Species	(Naïve ψ occupancy)	ψ ± SE	ρ ± SE
Northern red muntjac	0.28	0.30 ± 0.06	0.18 ± 0.02
Mainland serow	0.48	0.58 ± 0.08	0.11 ± 0.02
Brush-tailed porcupine	0.25	0.26 ± 0.06	0.24 ± 0.03
Asian golden cat	0.25	0.26 ± 0.06	0.11 ± 0.01
Asiatic black bear	0.09	0.15 ± 0.08	0.05 ± 0.03
Yellow-throated marten	0.21	0.25 ± 0.07	0.11 ± 0.02
Masked palm civet	0.19	0.21 ± 0.09	0.17 ± 0.03
Mishmi takin	0.05	0.07 ± 0.04	0.10 ± 0.04
Wild boar	0.09	0.14 ± 0.08	0.06 ± 0.03
Leopard cat	0.07	0.18 ± 0.16	0.03 ± 0.02

4.5 Detection probability

The estimates for the probability of detection with standard error range from 0.03 ± 0.02 to 0.24 ± 0.03. The probability of detection was highest for brush-tailed porcupine (ρ = 0.24 ± 0.03), followed by northern red muntjac (ρ = 0.18 ± 0.02), mainland serow (ρ = 0.11 ± 0.02), masked palm civet (ρ = 0.17 ± 0.03), Asian golden cat (ρ = 0.11 ± 0.01), yellow-throated marten (ρ = 0.11 ± 0.02), and Mishmi takin (ρ =0.10 ± 0.04). The leopard cat, wild boar, and Asiatic black bear have the lowest (< 0.1) probability of detection. The results of the top four models are summarized here, while a more comprehensive overview of the model selection process can be found in Table 3 of the Supplementary Materials (Supplementary Table 2). In Table 3, the site occupancy models for species such as the Asian golden cat and the masked palm civet, we used a constant detection p(.) probability. In the case of northern red muntjac, the presence of mithun had a positive impact on detection (Mdet, ρ = 0.25 ± 0.09) (Table 4). Figure 5 summarizes the influence of mithun on the northern red muntjac detection probability.

4.6 Influence of covariates on occupancy probability

The site use probability was modeled using an information-theoretic approach and the detection probability model that best fit the data. Table 5 summarizes the best predictive models for species occupancy, including a complete set of models and regression coefficient estimates for each model. Figure 6 provides an overview of the influence of covariates on the studied species' occupancy probability. The best model for northern red muntjac revealed that bamboo-mixed forest (BMF) (βestimate: 1.08 ± 0.48) and distance from waterbody (WB) (βestimate: 0.65 ± 0.35) had a positive influence on occurrence probability. The strongest ecological correlate for mainland serow was a negative response

TABLE 3 Results of model selection to determine ecological and anthropogenic covariates that influence the probability of habitat use by mammals in Mehao Wildlife Sanctuary, Arunachal Pradesh.

Northern red muntjac (*Muntiacus muntjak*)					
Model	nPars	AIC	delta	AICwt	cumltvWt
p(Mdet)psi(BMF+WB)	5	323.5	0	0.45007	0.45
p(Mdet)psi(BMF+TRI)	5	325.74	2.23	0.14747	0.6
p(Mdet)psi(BMF)	4	325.91	2.4	0.1354	0.73
p(Mdet)psi(BMF+HD)	5	327.88	4.38	0.05048	0.86
Mainland serow (Capricornis sumatraensis)					
Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(WB)	3	434.77	0	0.7216	0.72
p(.)psi(DEM)	3	441.03	6.26	0.0316	0.91
p(.)psi(MF)	3	442	7.22	0.0195	0.93
p(.)psi(SC)	3	442.36	7.59	0.0162	0.95
Asiatic brush-tailed porcupine *(Atherurus macrourus)*					
Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(WB)	3	185.57	0	0.306	0.31
p(.)psi(.)	2	187.07	1.5	0.145	0.45
p(.)psi(TRI+MF)	4	187.74	2.18	0.103	0.55
p(.)psi(TRI)	3	187.8	2.24	0.1	0.65

Mdet-Mithun detection; BMF- Bamboo-mixed Forest; WB, Distance to water sources; DEM- Elevation; HD, Human Detection rate; TRI, Terrain Ruggedness Index; TWI, Terrain Wetness Index; CC, Canopy cover; MF, Mixed Forest; SC, Shrub cover.
Number of parameters (K), Akaike Information Criterion (AIC), and Akaike weights (ωi).

to distance from WB (βestimate: -1.85 ± 0.78). The Asiatic brush-tailed porcupine is their best model with 31% AIC weight. The response to distance from a WB was the strongest ecological correlation (βestimate: 0.6 ± 0.32).

5 Discussion

This study documented several rare and elusive species in Mehao WLS (Supplementary Figure 2). During the camera trap survey and direct sightings, 27 species of mammals were recorded. However, our analysis of six distinct mammalian species revealed novel information with regard to the conservation value of the study area. We documented that Mehao WLS supports rare and threatened species such as clouded leopard, spotted linsang, marbled cat, hoolock gibbon, sambar, mainland serow, etc. The analysis revealed that mammalian fauna in this area responded to ecological and anthropogenic factors in various ways, but the responses were species-specific, as predicted. Species responded differently to different covariates, implying that management actions must be prioritized based on the relative importance of species in terms of conservation needs. Habitat and anthropogenic disturbance include habitat restoration and protection, invasive species control, and biodiversity conservation. For anthropogenic disturbance, mitigation efforts may focus on reducing human-wildlife conflicts, sustainable land use planning, wildlife-friendly infrastructure design, and regulatory measures to limit harmful activities. These management actions can help mitigate the negative impacts of habitat loss and anthropogenic disturbance on wildlife species and promote ecosystem conservation and sustainable management. We did not conduct sampling outside the sanctuary, but the species in this study may also be present in agricultural and human-occupied landscapes. –

TABLE 4 Estimates of β coefficient values (standard errors, SE) of northern red muntjac detection probability for different covariates based on the models Δ AIC < 2.

Species	Covariate	Estimate	SE
Northern red muntjac	(Intercept)	-1.633	0.183
	Mdet*	0.257	0.097

(*indicate statistical significance as defined by $\beta \pm 1.96 \times SE$ not overlapping 0.).

Including species in ecological models with covariates relies significantly on their detection rates in camera trap data, reflecting their presence and behavior within a studied habitat. In our analysis, the Asiatic golden cat, leopard cat, Himalayan black bear, yellow-throated marten, masked palm civet, Mishmi takin, and wild boar were regrettably omitted due to their notably lower capture rates. While these species undoubtedly contribute to the region's biodiversity, their infrequent appearance in camera trap records posed a challenge in establishing reliable relationships with the covariates under investigation. Focusing on species with higher

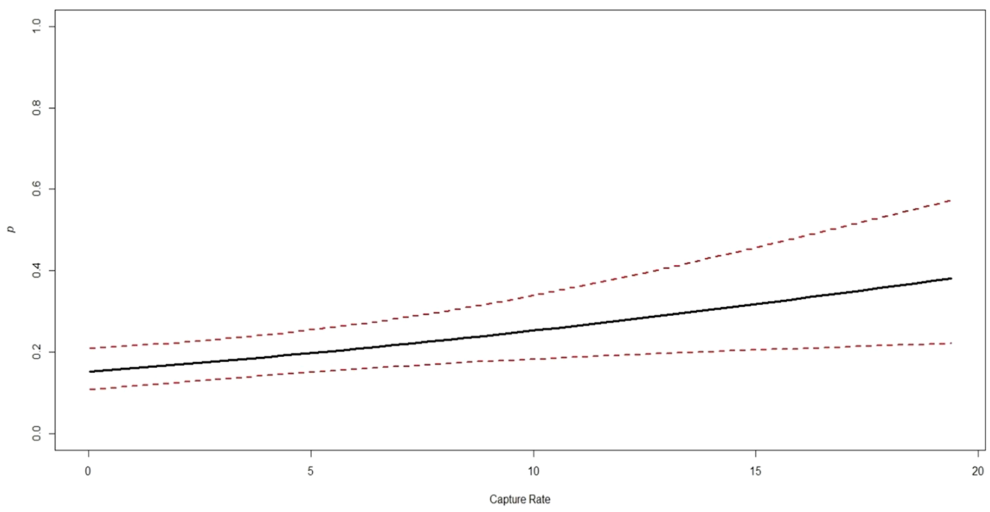

FIGURE 5
Association between the highly influential covariates (based on estimates of regression parameters (β) and 95% CI from the best models) and the probability of northern red muntjac occupancy in Mehao wildlife sanctuary, Arunachal Pradesh.

capture rates ensures robustness in our model, allowing for a more comprehensive understanding of the ecological dynamics between covariates and the more frequently observed wildlife within this ecosystem.

Given our predictions, the detection probability of northern red muntjac showed positive significance to the presence of mithun as compared to mainland serow, as the former is more of generalist species (Paudel & Kindlmann, 2012). However, this study has observed that northern red muntjac are close to human settlement areas with gentle slopes (Paudel and Kindlmann, 2012), and mithun is a semi-domesticated bovid species that prefers to live near human settlements. Our occupancy survey revealed that northern red muntjac primarily choose dense forests with low-growing vegetation, such as bamboo-mixed forest for foraging and rest (Teng et al., 2004; Odden and Wegge, 2007).

Mainland serow showed a significant association with water bodies. Due to the absence of dense understory vegetation on steep slopes, the serow is primarily found in the mountain's deeply dissected rocky gorges and ravines, which also provide shelter (Wu and Zhang, 2004). There are steep hills and deep valleys with multiple rocky streams and some perennial rivers surrounded by dense forests and patches of grass. This provides a suitable habitat for serow, which feeds on vegetation growing near water bodies and provides cover from predators such as black bears and humans. Serows also use dense forests near water habitats to maintain their body temperature (Aryal, 2009).

TABLE 5 Estimates of β coefficient values (standard errors, SE) of mammals' site-use probability for different individual covariates based on the models Δ AIC < 2.

Species	Covariate	βEstimate	SE
Northern red muntjac	(Intercept)	-0.943	0.349
	BMF*	1.082	0.487
	WB*	0.645	0.35
Mainland serow	(Intercept)	0.108	0.403
	WB*	-1.853	0.783
Brush-tailed porcupine	(Intercept)	-2.248	0.475
	WB	0.599	0.32

(*indicate statistical significance as defined by $\beta \pm 1.96 \times SE$ not overlapping 0.).

The Asiatic brush-tailed porcupine is a lesser-known rodent species in northeast India (Talukdar et al., 2019; Molur, 2020). This is the first record of this species from Mehao WLS. They prefer the plain area with a gentle slope in the dense forest of Mehao WLS. They have moderate temperature tolerance, and the dense forest near waterbodies provides cover and moisture to maintain their body temperature. The species was recorded from other forests in Arunachal Pradesh, including Namdapha NP, Pakke WLS, and Changlang district (Agarwal, 2000; Datta et al., 2008a, Datta et al., 2008b).

However, the Asiatic golden cat is one the least studied species in tropical Asia (Yongdrup et al., 2019), and it is thought to be rare due to limited sightings (Grassman et al., 2005). It is a solitary hunter and forest-dependent species whose range is threatened by significant habitat loss and fragmentation (McCarthy et al., 2015). Over time, land use has changed forest cover, and human pressure on natural resources has increased at lower elevations. The species has also been recorded in the high-altitude ranges from India to Bhutan (Bashir et al., 2011; Jigme, 2011; Dhendup, 2016). During the survey, we captured four different morphs of the Asiatic golden cat in Mehao WLS.

We found that yellow-throated marten prefers elevated areas. Forest habitat quality is correlated with elevation, especially since there is relatively less anthropogenic disturbance at higher altitudes, as urban areas, agricultural fields, and orchards are generally found at lower altitudes (Lee et al., 2021). The presence of yellow-throated martens decreased in areas with rugged terrain because they tend to avoid shrub-covered regions, given their preference for an arboreal

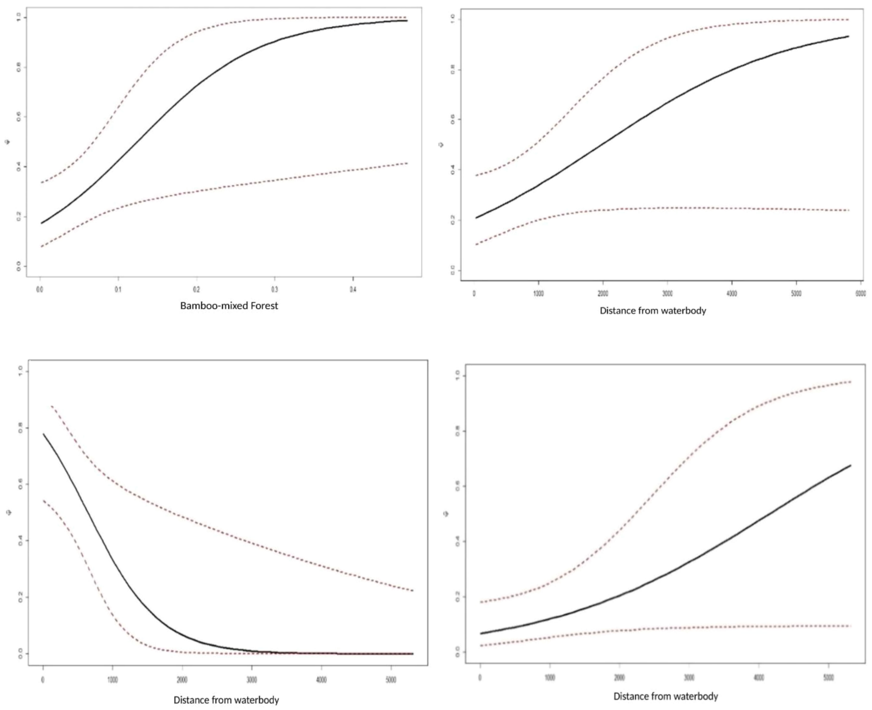

FIGURE 6
Association between probability and highly influential covariates (based on estimates of regression parameters (β) and 95% CI from the best models of northern red muntjac (top left, top right), mainland serow (bottom left), and Asiatic brush-tailed porcupine (bottom right) occupancy in Mehao Wildlife Sanctuary, Arunachal Pradesh.

lifestyle (Duckworth, 1997; Appel and Khatiwada, 2014). The masked palm civet prefers forest habitats in lowland areas with ample amounts of water, where they feed on berries, seeds, molluscs, small mammals, amphibians, insects, and arthropods (Zhou et al., 2008; Matsuo and Ochiai, 2009; Belden et al., 2014). Though there is anthropogenic pressure, this species still survives in lowland areas as it has a degree of tolerance to habitat alteration (Zhou et al., 2008; Semiadi et al., 2016).

The Idu Mishmi community has intricate animistic beliefs linked to the forests and the landscape, which ensures prudent resource management. The practice of social taboos by local people can be harnessed by conservation projects so that local people appreciate and willingly engage in community-based conservation projects. Current scientific literature reveals that habitat fragmentation and loss of habitat due to anthropogenic pressure (like expansion of agricultural land, built-up area, and construction of highways) leads to local threats to these species. Such anthropogenic pressures may also affect species distribution and abundance in the landscape (Aiyadurai et al., 2010).

6 Conservation implications

Mehao WLS is an important landscape for mammalian species due to its diverse topography, vegetation, and climatic conditions. Our study provides quantitative insights for multi-species conservation decision-making as it accounts for significant ecological variables. The modeling of multi-species occupancy provided data to predict mammalian responses to land-use changes. These insights are important for decision-making by forest officials. This would benefit various mammalian species and help formulate an informed land-use policy.

This study also provides crucial ecological data for various mammalian species. It exemplifies a simple method to estimate the distribution and habitat occupancy of rare and elusive mammals in Mehao WLS. Due to the varied nature of species targeted in our study, we recognize that the data available for analysis may differ significantly. This disparity can introduce limitations to the comprehensiveness of our study, as it may not provide sufficient insights into the behaviours and patterns of certain species. To overcome this limitation, it is essential to conduct additional sampling efforts across multiple seasons. This approach is necessary to ensure a more comprehensive and robust analysis, particularly when surveying rare and elusive species. However, microhabitats are essential for managing and conserving mammalian species. Such data is crucial for designing and implementing species-specific conservation initiatives and effectively managing protected areas. To date, there has been little supporting information on mammalian species in Mehao WLS (Ahmad et al., 2023), and it is important to carry out a long-term study on mammals in the landscape (Katti et al., 1990).

The effectiveness of patrolling along with other management and conservation interventions will be effective with continued monitoring that can reveal the presence of various species, identify threats, and monitor the prevalence of invasive species. The cameras deployed in this study remained operational throughout the day, and the data indicates that the arboreal nature of certain species may limit the number of photographic records. Despite this possible limitation, it is important to initiate conservation efforts for various species according to available data, which indicates that the species occur in small numbers and require greater protection. Data analysis of mammalian species throughout their range is critical for effectively and efficiently conserving these species in a continuously changing landscape.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by Wildlife Institute of India, Dehradun. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

AA carried out field work, analyzed the data, and led the writing of the manuscript. GG conceived ideas and designed methodology. Both authors contributed to the article and approved the submitted version.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. Funding support was received from Department of Science and Technology (DST), Government of India.

Acknowledgments

The authors thank the Director and Dean of Wildlife Institute of India, Dehradun, for institutional support, the Forest Department of Arunachal Pradesh for providing the necessary field permission and the Department of Science and Technology. We also thank Mr. Kenjum Rina (DFO-Roing) and Mr. Ipra Mekola (Member of Arunachal Pradesh State Board of Wildlife) for their kind support in facilitating our fieldwork. We thank our field assistants, Mr Kiran Pulu, Mr Ashok Sherpa, and Mr Rajan Lingi, for their hard work and rigorous efforts during field data collection. In addition, the first author thanks Dr. Anukul Nath for comments and suggestions on an earlier manuscript draft.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1106329/full#supplementary-material

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