



Norwegian University
of Life Sciences

Master's Thesis 2022 60 ECTS

Faculty of Environmental Sciences and Natural Resource Management

Species-specific effect of forest cover on the occupancy of tropical forest mammals of Southeast Asia

Pradeep Raj Joshi

Master of Science in Ecology

Acknowledgements

I would like to express my gratitude to my supervisor Richard Bischof for his advice, ideas, critical help with the methodology and statistical analysis, and comments on improving the manuscript. I am grateful to Asunción Semper-Pascual and Andrea Fernanda Vallejo Vargas for their supervision throughout this thesis writing, especially mentoring my statistical analysis and write-up, and always being available at Sørhellinga or through Teams whenever I needed help.

Thanks are also to the TEAM Network for the camera trap data. In this regard, I would also like to acknowledge and thank all of the technicians who were involved during the camera trap deployment process, data collection and management.

Geneva 'Gigi' Lish deserves special thanks for her time to improve the quality of the write-up. I would also like to remember the support that I got from my friends in Norway and Nepal during the stressful days of the Coronavirus pandemic. Finally, I would like to thank my family back home for their constant love and support.

Pradeep Raj Joshi

15 May 2022,

Ås, Norway

Abstract

Tropical forests harbour more than half of the world's biodiversity and 63% of the world's terrestrial mammals. Today this biodiversity is under threat due to habitat loss and degradation by human activities. This makes tropical mammals vulnerable as mammals are very sensitive to changes in their habitat. In this regard, protected areas are critical for the conservation of tropical biodiversity including mammals because they are the core refuge and the best remaining habitats for many threatened mammals. Protected areas, however, are not unaffected by human activities and the forest cover within them is not uniform. How does forest cover relate to the occupancy of mammals in tropical protected areas? Do these relationships vary among species and/or groups of species? In this study, I analysed mammal occurrence and forest cover relations in tropical protected areas of Southeast Asia, and how these responses are modulated by species-specific functional traits.

I used systematic camera trap data of 2013/2014 from the TEAM (Tropical Ecology Assessment and Monitoring) Network. I analysed a total of 45,182 photographs of 37 mammal species captured through 4,178 trap days. First, I fitted single-season single-species occupancy models to assess the relationship between occupancy and forest cover. Second, I used the parameter estimates for forest cover and species' functional traits to understand how the occupancy-forest cover relations are governed by the species' functional traits.

The occupancy analysis resulted in 12 species whose results can be interpreted. I found a positive association between forest cover and occupancy. Although insignificant, there were variations in these associations across species and species groups and were defined by forest specialisation and the feeding guild of the species. Forest specialists and carnivores/omnivores had stronger and more positive associations than non-specialists and herbivores/insectivores. Because these forests are tropical protected areas, the lack of pronounced and clear effects suggests that there may not be enough variation in forest cover to observe differences in response. Furthermore, efforts to conserve biodiversity in these areas may still be effective. Using multiple years' data and following alternate statistical approaches of occupancy modelling and parameter estimation is recommended for future studies, to overcome the issues with sparse data.

Keywords: *camera-traps, forest cover, functional trait, occupancy model, mammals, protected area, southeast Asia, tropical forest*

Table of Contents

Acknowledgements.....	i
Abstract.....	ii
1. Introduction	1
1.1 Background	1
1.2 Hypotheses	3
2. Methodology.....	5
2.1 Study area.....	5
2.2 Data and sampling design	6
2.3 Occupancy analysis.....	6
2.4 Covariates.....	7
2.5 Functional trait analysis	9
3. Results	12
3.1 Species response to forest cover.....	12
3.2 Effect of functional traits.....	13
4. Discussion.....	15
4.1 Species response to forest cover.....	15
4.2 Effect of functional traits.....	16
5. Conclusion.....	19
References.....	20
Annex 1: Home ranges & references for the species	30
Annex 2: Functional traits of the species	32
Annex 3: Coefficients for the forest cover parameter and standard error for the species included in the functional trait analysis	33

1. Introduction

1.1 Background

Tropical forests are some of the richest biodiverse regions on Earth. (Muhammad Nawaz, 2018; Sodhi et al., 2004). Higher temperature (Brown, 2014), availability of diverse habitat and food resources, and safe sites to shelter and breed are considered important in supporting this high biodiversity (Muhammad Nawaz, 2018). All these factors have contributed to higher speciation rates (Rolland et al., 2014) making the tropical forests home to more than 50% of the planet's biodiversity (Lewis et al., 2015; Primack & Morrison, 2013) and almost two-thirds of the land species (Stork et al., 2009). A study by Pillay et al. (2022) found that a striking 63% of the global terrestrial mammal species live in these forests.

However, the tropical forests and their biodiversity are facing a severe threat from human activities (Morris, 2010) such as selective logging, commercial agriculture, cattle farming, palm-oil plantation, road expansion and increasing biofuel demand (Laurance, 2015). More than half of the tropical forest area is already lost (Wright, 2005), or degraded (Deere et al., 2020; Muhammad Nawaz, 2018). PAs (protected areas) are considered the most important tool in the conservation of biodiversity and habitat (Coetzee et al., 2014; Díaz et al., 2019; MacKinnon et al., 1986; Rodrigues et al., 2004). During the 2000s, the PA network across the tropics prevented 83,500 km² from being deforested (Kim & Anand, 2021). These PAs are core refuges or even the only suitable habitats for many threatened mammal species (Pacifci et al., 2020; Scullion et al., 2021). Additionally, since tropical forests harbour almost two-thirds of the terrestrial mammals (Pillay et al., 2022), protected areas of the tropics globally are critical for mammal conservation.

Unfortunately, most of the protected areas do not remain untouched or unaffected by human activities despite their protected status (Buckley et al., 2016; Palomo et al., 2014), leaving a mere few entirely pristine (Buckley et al., 2016). In fact, PAs including those in the tropical areas are facing the problem of deforestation and degradation due to human activities (Leisher et al., 2013; Zeng et al., 2005). Even the disturbance caused by low-intensity use over much longer times can significantly change their ecosystem (Josefsson et al., 2009). This results in a change in the quality of forests inside them. Further, climatic, geographical, and edaphic factors are also responsible for the variation in the quality of forests in the tropics (Corlett, 2014; Feeley et al., 2011; Wang, 2006). The variation in forest quality affects the occurrence and distribution of mammals (August, 1983; Haro-Carrión et al., 2021; Pardini et al., 2005; Püttker

et al., 2008) at varying levels (Feng et al., 2021; Zungu et al., 2020). Forest quality is “the significance and value of all ecological, social and economic components of the forest landscape” (Dudley et al., 2012). Forest cover and canopy height are among the most important indicators of forest quality and are related to biodiversity (Dudley et al., 2012; Foley et al., 2005; Moiseev et al., 2002; Moles et al., 2009).

It is important to assess how the occupancy of tropical forest mammals is affected by forest quality as the tropical forests’ quality is changing at an increased rate (Feeley et al., 2011; Phillips, 1996; Wright, 2005). Occupancy is defined as “the proportion of an area occupied by a species or fraction of landscape units where the species is present” (MacKenzie et al., 2006). It is considered as an alternative and cost-effective method of studying the abundance of a species because intraspecific abundance and occupancy are positively related (Gaston et al., 2000; He et al., 2002). Occupancy models integrate the environmental factors as covariates (MacKenzie & Bailey, 2004) to assess how these factors affect the presence of species.

Most mammals are sensitive to habitat quality change because of their specialised niches (Crooks et al., 2011; Rocha et al., 2018), yet species may respond differently to changes in habitat quality. Intrinsic characteristics of mammals also known as the functional traits, such as body size, habitat specialization or feeding guild influence how they respond to changes in their environment (Nock et al., 2016). Functional traits are “morphological, biochemical, physiological, structural, phenological or behavioural characteristics of organisms that influence performance or fitness” (Nock et al., 2016). Trait characteristics and trait-based assemblages are considered more informative than the individual or species level characteristics (Pollard & Yuan, 2010). Studies based on the functional trait approach give information on how organisms interact with their environment and how communities assemble, interact and function (McGill et al., 2006; Nock et al., 2016). This is especially useful to describe the response of the animal community to environmental changes (Nock et al., 2016). For instance, large mammals are particularly vulnerable to threats from the change in habitat quality due to higher resource and energy demand, low population densities, and their susceptibility to hunting by humans (Cardillo et al., 2005). Forest specialists are found to be associated with high forest cover while generalists with low forest cover (Salom-Pérez et al., 2021), Similarly, carnivore species richness is found positively related to forest cover (Regolin et al., 2017). Such relations determine their sensitivity towards changes in habitat. The nature of functional traits can be different like categorical (e.g. feeding guild, habitat specialisation), continuous (body mass), count (niche breadth), ordinal or binary (Nock et al., 2016).

An assessment like I have done in this research is important because of the representation of the tropical forests which harbour major mammalian biodiversity. Further, findings of such a study inside a protected area network can be used as a baseline for other similar studies. Moreover, as the protected areas are considered as the safest and most suitable habitats, these types of studies can reveal whether the biodiversity is witnessing the “trouble in paradise” by reflecting on the state of wildlife there.

1.2 Hypotheses

In this study, I have assessed the species-specific effect of forest quality on mammals in tropical forests on two approaches: occupancy analysis and functional trait analysis. The occupancy analysis focuses on the response of mammals towards forest quality, while the functional trait analysis focuses on what species characteristics are associated with those responses. In particular, I tried to find answers to 1) How are occupancy of mammal species related to forest quality, here represented by forest cover, and 2) Are there any differences in these relationships among the species groups due to their functional traits?

To address these questions, I have tested the following hypotheses, with associated predictions:

H1: The occupancy of most of the mammal species is positively related to forest cover

P1: The occupancy of mammals living in tropical forests is in general positively related to forest cover. However, there is between-species variation in the direction and magnitude of the effect of forest cover, as species react differently to forest cover.

H2: Relationships between occupancy and forest cover are determined by functional traits

P1: Occupancy of forest-specialist species is more strongly and positively related to forest cover than that of the non-forest-specialists (Salom-Pérez et al., 2021).

P2: Occupancy of carnivores and omnivores is positively associated with higher forest cover because of more prey availability and help in camouflage during predation (Lesmeister et al., 2015; Salom-Pérez et al., 2021).

P3: Occupancy of the species with larger body mass is more associated with forest cover. Larger mammals are more prone to hunting (Gallego-Zamorano et al., 2020) and a large area of forest with high cover provides a refuge from hunting as well as from predation (Núñez-Regueiro et al., 2015; Peres, 2001).

P4: Species with higher habitat breadth will be less associated with forest cover. Species with higher habitat breadth tend to be more generalists, and thus are not confined only to the forests.

2. Methodology

2.1 Study area

The study was conducted in three tropical protected areas of Southeast Asia (Fig: 1). Bukit Barisan Selatan (BBS) National Park of Indonesia has an area of 3568 km² (Government of the Republic of Indonesia, 2004) and is the third-largest protected area of Sumatra (O'Brien & Kinnaird, 1996). It lies in the elevation range of 0-1964m asl (Pusparini et al., 2018). It supports diverse habitats for wildlife due to its large elevation range (Pusparini et al., 2018) and is a UNESCO world heritage site (Weiskopf et al., 2019). Nam Kading (NAK) National Protected Area lies in central Laos (Hallam & Hedemark, 2012). It is about 1685 km² in area and stretches from 160 m to 1600 m altitude, most of which is rugged and inaccessible (Chanthavong et al., 2021). Four rivers including the Nam Kading River, a major tributary of the Mekong River, pass through the protected area (Hallam & Hedemark, 2012), providing habitat to many flora and fauna (Chanthavong et al., 2021). Pasoh Forest Reserve (PSH) lies 140 km southeast of Kuala Lumpur, Malaysia (Fletcher et al., 2012; Peters, 2001). It has an area of 139 km² and has a maximum altitude of 600 m and has oil palm plantations on three sides (Fletcher et al., 2012).

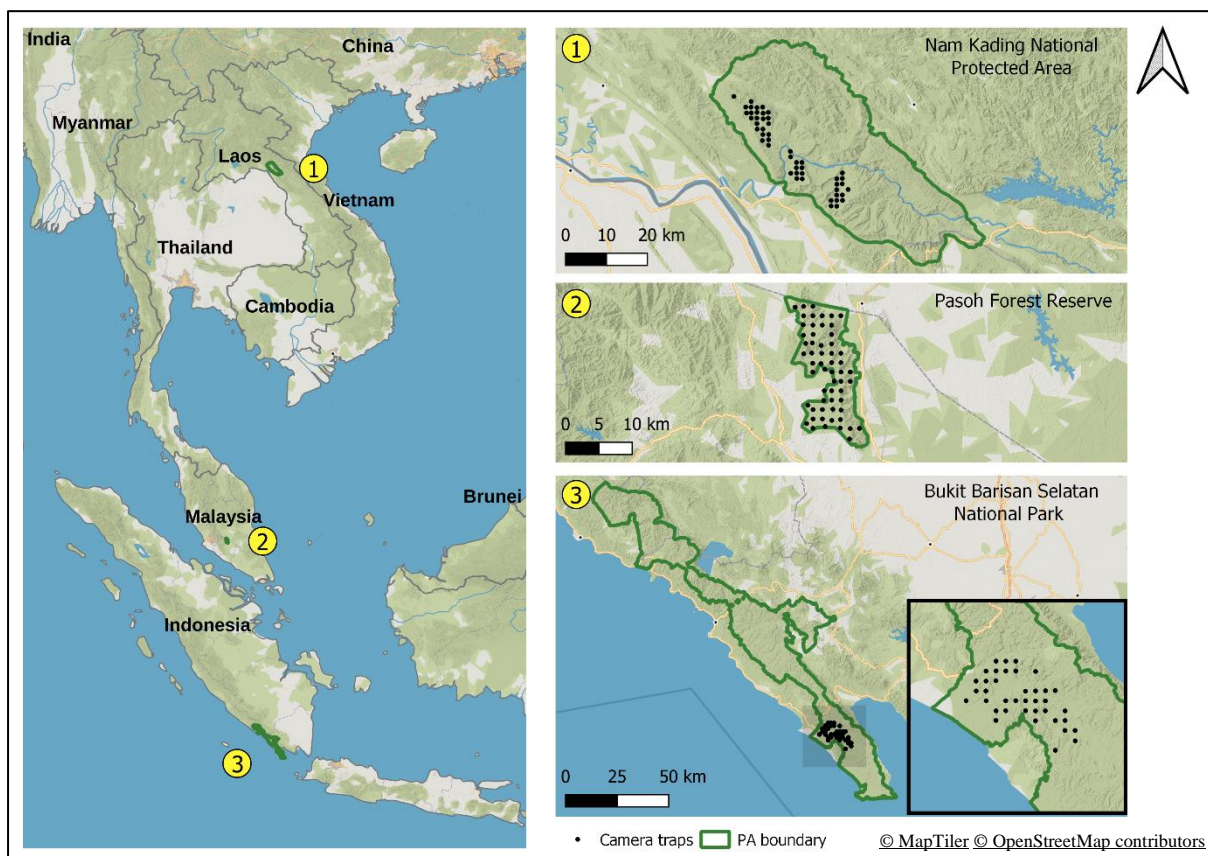


Fig 1: Map showing the locations of the three protected areas (dark green boundary) and camera trap deployment design (shown as black dots in the maps of the right column)

2.2 Data and sampling design

The data used in this study was obtained from the Tropical Ecology Assessment and Monitoring (TEAM) Network. The TEAM Network is a partnership between Conservation International, the Smithsonian, and the Wildlife Conservation Society, and uses standardised methods for monitoring terrestrial mammals and birds in 17 tropical protected areas across Africa, Asia, and Latin America (Beaudrot et al., 2016) including the protected areas included in this study. Camera traps deployment followed the standardised protocol developed by the TEAM network. Camera traps were placed at 38, 49 and 58 points in BBS, NAK and PSH respectively, each within a grid of 1.4 km inter-spacing. The deployment was divided into two or three sampling arrays with 20 -30 camera points each to allow sequential sampling (TEAM Network, 2011). At each point, a camera trap was deployed for at least 30 days (Jansen et al., 2014; TEAM Network, 2011). The camera traps were installed close to wildlife trails at 30-50 cm above and parallel to the ground (Rovero & Ahumada, 2017; TEAM Network, 2011). Photo management including tagging and species identification was done by site technicians of the TEAM (TEAM Network, 2011). Information including species ID (order, family, genus, species), coordinates, sampling unit, sampling period, date and time information, serial number and model of camera used, etc., was then exported to a standardised format ready to be analysed (TEAM Network, 2011).

I used camera trap data from a single sampling season during 2013/2014 (table 1). I excluded the images of humans and dogs during data analysis. Further, I only included species with an average body mass of more than 1 kg in the analysis because camera traps are less efficient in capturing small mammals as compared to medium and large-sized ones (Dundas et al., 2019).

Table 1: Camera trapping dates, number of days and number of trap points

Site	Start date	End date	No. of trap locations	Average no of days
BBS	2014-04-04	2014-07-21	38	24.63
NAK	2013-11-07	2014-02-28	49	32.22
PSH	2013-05-29	2014-02-12	58	28.67

2.3 Occupancy analysis

I followed the single-season single-species model, also called the static model approach for occupancy modelling using package “unmarked” (Fiske & Chandler, 2011) in R (R Core Team, 2021) through R Studio (RStudio Team, 2012). Unmarked follows hierarchical occupancy

modelling given in MacKenzie et al. (2002) and takes into account the imperfect detections that occur when the species is present but is not detected, and estimates the probability of occurrence of that species at that site. Thus, it includes both: i) state process – which deals with the species occurrence, and ii) observation process – which deals with the species detection (Kéry & Royle, 2016). The state process is the true occupancy status or the presence/absence status of the species at a site (1,0; if site is occupied or not, respectively). It is represented as a latent variable z_i , and is expressed as:

$$z_i \sim \text{Bernoulli}(\psi_i)$$

Where, ψ_i is the expected probability of occurrence or the occupancy probability at site i . The observation process is expressed as:

$$y_{ij}|z_i \sim \text{Bernoulli}(z_i * p_{ij})$$

where y_{ij} is the observed occurrence at site i during survey j , and p_{ij} is the detection probability of the species at site i during survey j . The term $y_{ij}|z_i$ indicates that y_{ij} depends on the conditions of z_i (Kéry & Royle, 2016).

I initially selected forest cover and canopy height as site covariates and as measures of forest quality. I later excluded canopy height from the covariates because it was highly correlated with forest cover ($r \geq 0.7$). I retained forest cover because it is more important to the occurrence of species (Regolin et al., 2017) than canopy height (Roll et al., 2015). Additionally, I used elevation and protected area (PA) as site covariates affecting occupancy and, slope and the camera trap model as covariates affecting detection. The covariates are included in the model through a logit-link function at PA i as:

$$\text{logit}(\psi_i) = \beta_0 + \beta_1 * \text{Forest cover}_i + \beta_2 * \text{Elevation}_i + \beta_3 * \text{PA}_i$$

$$\text{logit}(p_i) = \alpha_0 + \alpha_1 * \text{Slope}_i + \alpha_2 * \text{Camera model}_i$$

2.4 Covariates

Forest cover in 2013 was calculated using the global forest cover change dataset mapped by Hansen et al. (2013), defining forest pixels as those with tree canopy cover $> 75\%$ (Beaudrot et al., 2016). I used the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007) version 3 at 1 arc-second (approx. 30m) as the elevation data. I downloaded this elevation dataset from the United States Geological Survey's

Earthexplorer website provided by NASA’s Jet Propulsion Laboratory (NASA JPL, 2013). I used mean values for forest cover and elevation for all species at their respective home range sizes. For this, I calculated a radius size for a circular buffer from the home range information, rounded it to the nearest hundreds and used this buffer size to extract the means for the covariates around all camera trap points for all species. I used home range information from multiple sources as listed in annex 2. I included elevation as a site covariate because it is an important parameter influencing the abundance and distribution of species (Bateman et al., 2010; Campera et al., 2020; Feng et al., 2021; Ramírez-Bautista & Williams, 2019). I included ‘PA’ as a site covariate to capture the variance otherwise not captured by the other three covariates, that could arise due to the differences in PA characteristics such as disturbance, latitude, management practices of the PAs, water availability, etc. I calculated the slope at the original 30m resolution from the same SRTM DEM used for elevation. Camera model information was available in the exported camera trap database (table 2).

Table 2: Covariates used in occupancy analysis

Covariate	Notation used	Category	Description
Forest cover	Forest_Cover	Site covariate	The proportion of forest cover
Elevation	Elevation	Site covariate	Meters above sea level
Protected area	PA	Site covariate	The three protected areas used in this study (i.e., BBS, NAK, PSH)
Slope	Slope	Observation covariate	Slope in degrees at camera trap points
Camera model	Cam_model	Observation covariate	Different camera trap models used at the three sites: PC900 Professional, RM45 Rapidfire and HC500 Hyperfire

I standardised the continuous covariates before inclusion in the models. Standardising covariates helps in model convergence, prevents numerical problems, and enables comparison of the estimates (Kéry & Royle, 2016; Schielzeth, 2010). Since some of the species were present at a single PA or some of the PAs used only one camera model, I included covariate *PA* only when species were present at more than one PA. Similarly, I included the covariate *Camera model* only when more than one camera model was used in the PA where the species

was present (Table 3). I included forest cover in every model as this was the covariate of interest. After model fitting and running occupancy analysis for a species, I chose the model that has the lowest Akaike Information Criterion (AIC) (Akaike, 1998) value as the best-fitted occupancy model. Finally, among the best fit models, only the models with no convergence issue or Hessian singular error were included in the analysis.

Table 3: Candidate models for the occupancy analysis. $p()$ represents observation covariates and $\psi()$ represents site covariates. Models with PA and Cam_model were only included for species that were found at more than one PA and/or more than one camera trap model

SN	Candidate models
1	$p(.)\psi(\text{Forest_Cover})$
2	$p(.)\psi(\text{Forest_Cover} + \text{PA})$
3	$p(.)\psi(\text{Forest_Cover} + \text{Elevation})$
4	$p(.)\psi(\text{Forest_Cover} + \text{Elevation} + \text{PA})$
5	$p(\text{Slope})\psi(\text{Forest_Cover})$
6	$p(\text{Slope})\psi(\text{Forest_Cover} + \text{PA})$
7	$p(\text{Slope})\psi(\text{Forest_Cover} + \text{Elevation})$
8	$p(\text{Slope})\psi(\text{Forest_Cover} + \text{Elevation} + \text{PA})$
9	$p(\text{Cam_model})\psi(\text{Forest_Cover})$
10	$p(\text{Cam_model})\psi(\text{Forest_Cover} + \text{PA})$
11	$p(\text{Cam_model})\psi(\text{Forest_Cover} + \text{Elevation})$
12	$p(\text{Cam_model})\psi(\text{Forest_Cover} + \text{Elevation} + \text{PA})$
13	$p(\text{Cam_model} + \text{Slope})\psi(\text{Forest_Cover})$
14	$p(\text{Cam_model} + \text{Slope})\psi(\text{Forest_Cover} + \text{PA})$
15	$p(\text{Cam_model} + \text{Slope})\psi(\text{Forest_Cover} + \text{Elevation})$
16	$p(\text{Cam_model} + \text{Slope})\psi(\text{Forest_Cover} + \text{Elevation} + \text{PA})$

2.5 Functional trait analysis

I used species body mass, feeding guild, habitat breadth and information on whether the species is a forest specialist or not, in the functional trait analysis (Table 4). I used body mass and feeding guild information from Faurby et al. (2018) and habitat breadth information from Cooke et al. (2019). To determine whether a species is a forest specialist or not, I used the information from the ‘Habitat and Ecology in detail’ section of the IUCN red list for each species (www.iucnredlist.org). I categorised a species as a forest specialist when only the forest

habitat types were listed as suitable for that species. To match the hypothesis, I combined carnivores and omnivores into one group and herbivores and insectivores into another.

Table 4: Functional traits used and their properties

Functional trait	Type	Values/Range	Description
Forest specialisation	Categorical	Specialist Non-specialist	Whether a species is a forest specialist or not
Feeding guild	Categorical	Carnivore Omnivore Insectivore Herbivore	Group of species feeding on similar resources
Habitat breadth	Count	1 - 25	Different IUCN habitat types the species occupies
Body mass	Continuous	1842.5 gm – 3160000 gm	The average adult body mass of a species

To assess how the relationship between occupancy and forest cover is associated with species' functional traits, I extracted the estimated values (β) of the forest cover covariate from the best-fitted occupancy models and fitted linear models with individual functional traits as the predictor variables (fig 2). The uncertainty of estimation for forest cover was accounted for by weighting the linear models as $\omega = \frac{1}{SE(\beta_{forest\ cover})}$, where SE is the standard error of the estimate. I fitted a model for each functional trait as:

$$\beta_{Forest\ cover} = \alpha + \beta_1 * Forest\ specialisation$$

$$\beta_{Forest\ cover} = \alpha + \beta_2 * Feeding\ guild$$

$$\beta_{Forest\ cover} = \alpha + \beta_3 * Habitat\ breadth$$

$$\beta_{Forest\ cover} = \alpha + \beta_4 * \log Body\ mass$$

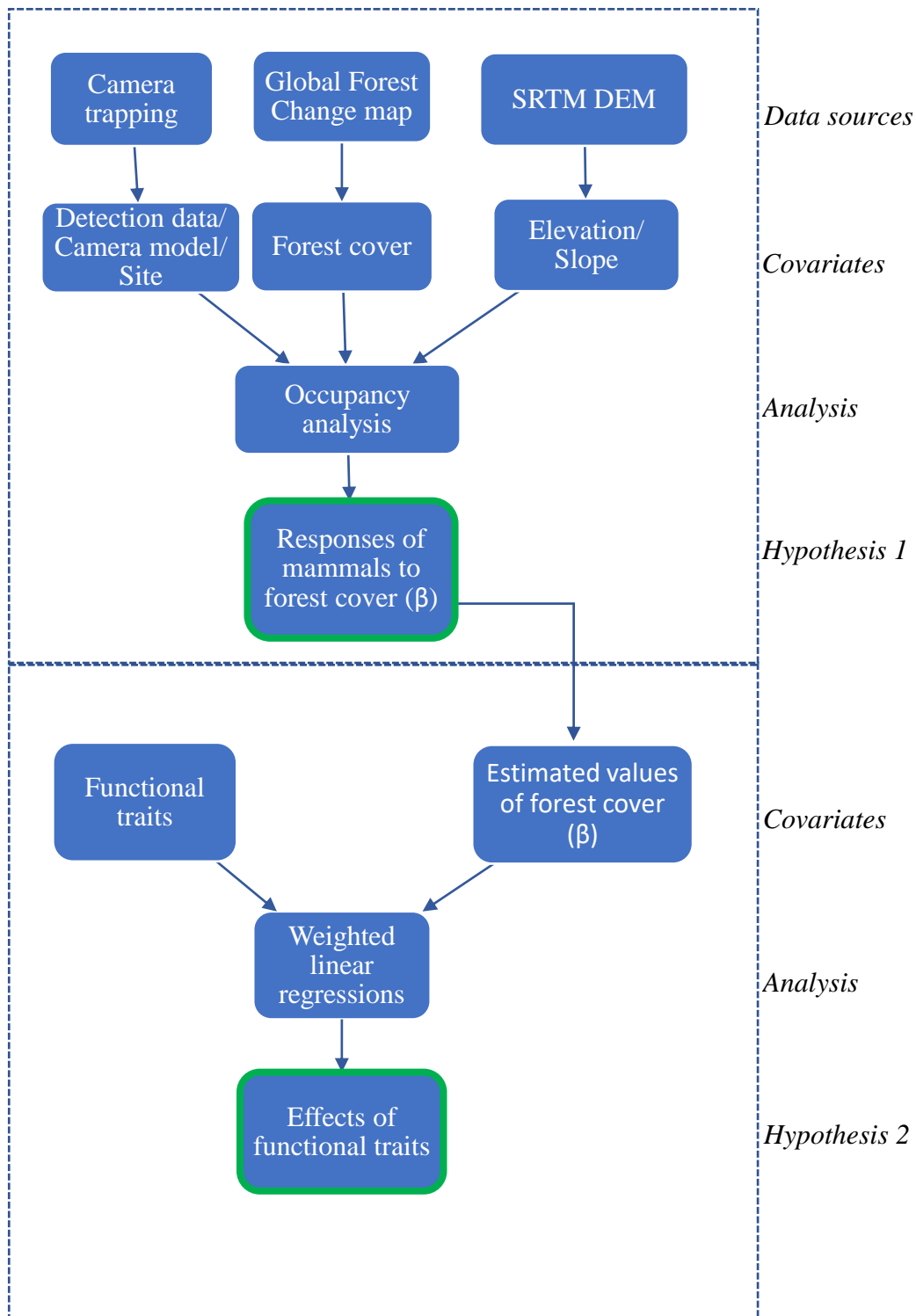


Fig 2: Flowchart representing statistical analysis

3. Results

The camera trap sampling period included an effort equivalent to 4,178 trap days (936 in BBS, 1579 in NAK, and 1663 in PSH) and 45,182 photographs of 37 mammal species (6,667 in BBS, 3,666 in NAK, and 36,487 in PSH) were included in the analysis. The number of mammal species captured was 20, 14 and 24 in BBS, NAK and PSH respectively. Out of the 37 species, 22 (59%) were captured at a single site, 9 (24%) were captured at any two of the sites and only 6 (16%) were captured at all three sites (Annex 1). Body mass ranged from 1.84 kg to 3,160 kg with a median weight of 6,750 kg (Annex 2). Out of the 37 species, 12 were forest specialists while 25 were not forest specialists (Annex 2). Similarly, 8 species were omnivores, 9 carnivores, 18 herbivores and 2 insectivores (Annex 2). The habitat breadth ranged from 1 to 25 with a median breadth of 5 (Annex 2).

In the occupancy analysis, only the best models for 12 species out of 37 converged. The other 24 species for which the best models did not converge, had low detections with naïve occupancy ranging from 0.0045 to 0.053. The best model for one species converged but produced boundary estimates for occupancy and detection with large estimates and SE for forest cover. Out of the 12 species for which the models converged, the detection of 5 species was affected by the camera model and that of 3 species was affected by the slope. The detection of 4 species, however, was neither affected by the camera model nor by the slope. The effect of elevation on occupancy was observed only on three species, while the effect of the PA was seen on five species.

3.1 Species response to forest cover

The occupancy of 8 (67%) species was positively related to forest cover with β values from 0.053 for barking deer (*Muntiacus muntjac*) to 6.63 for sambar (*Rusa unicolor*). Other species positively related to forest cover are wild boar (*Sus scrofa*), lesser mouse-deer (*Tragulus kanchil*), tiger (*Panthera tigris*), banded palm civet (*Hemigalus derbyanus*), short-tailed mongoose (*Herpestes brachyurus*), and marbled cat (*Pardofelis marmorata*). On the other hand, the occupancy of 4 (33%) species was negatively related to forest cover with β values from -0.002 for crab-eating macaque (*Macaca fascicularis*) to -1.31 for Malayan porcupine (*Hystrix brachyura*). Additionally, southern pig-tailed macaque (*Macaca nemestrina*) and Asiatic brush-tailed porcupine (*Atherurus macrourus*) were also negatively associated with forest cover (annex 3). But no significance was observed in this relation as the confidence intervals for all species overlap zero (Fig: 3).

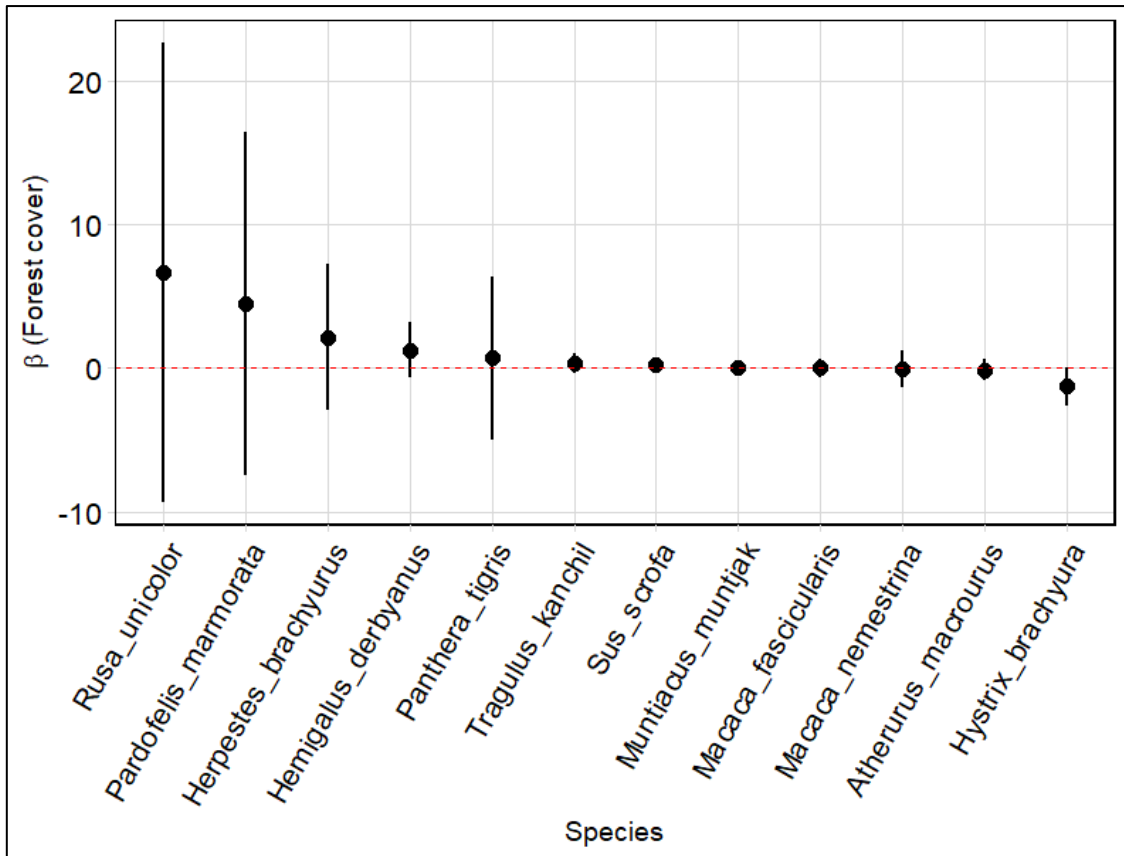


Fig 3: β -estimates of forest cover for species with standard error. The estimates are considered significant when the confident intervals do not overlap zero.

3.2 Effect of functional traits

On average, forest specialists had higher association with forest cover ($\beta = 0.574 \pm 1.12$) than non-specialists ($\beta = 0.059 \pm 0.55$) as predicted. Similarly, carnivores/omnivores were more related to forest cover than herbivores/insectivores with $\beta = 0.464 \pm 1.20$ compared to $\beta = 0.095 \pm 0.55$. Body mass and habitat breadth did not show any noticeable associations (Fig 4). I did not find any statistical significance in these associations of functional traits with forest cover ($p > 0.05$).

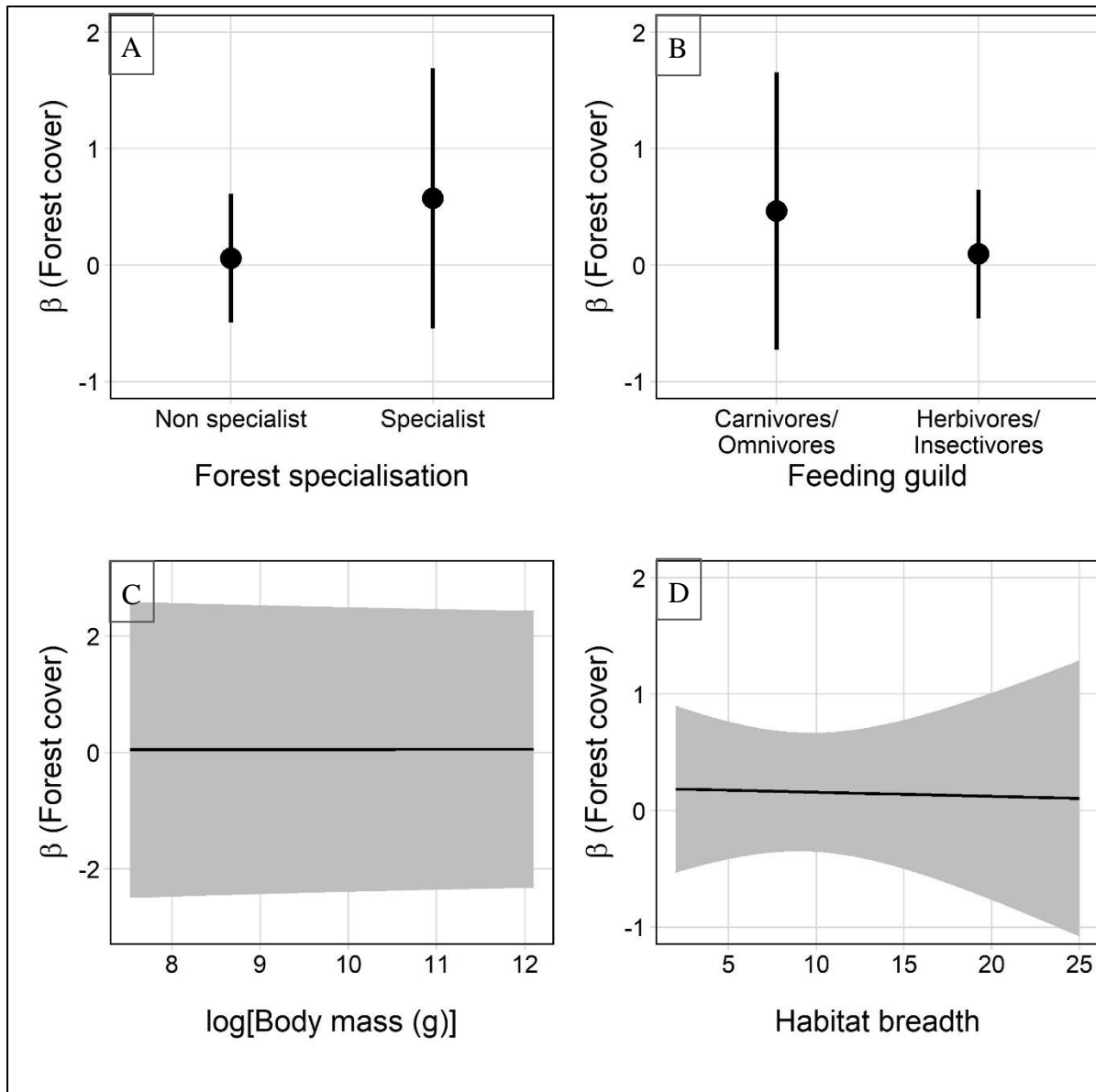


Fig 4: Plots between functional traits and forest cover parameter. The bars in plots A and B, and the grey areas in C and D are the 95% confidence intervals. The scale of the y-axis in C is different from other plots.

4. Discussion

In this study, I have found that while the occupancy of 67% of the species was positively related to forest cover, that of the other 33% was negatively related. In the functional trait analysis, forest specialists and carnivores/omnivores were more associated with forest cover than other assemblage groups. Body mass and habitat breadth did not show any strong direction or magnitude of the relationship. These associations were however not statistically significant.

4.1 Species response to forest cover

As hypothesised (H1), mammal species have varying associations between occupancy and forest cover given by the β values for forest cover which were distributed across a wide range. I found that two-thirds of the species were positively associated with forest cover while a third were negatively associated. In a similar study, Salom-Pérez et al. (2021) assessed the occupancy of mammals in a semi-protected strip including two protected areas and a corridor between them. They found that forest cover was the most important factor determining the occupancy of mammals but with different effects at the species level. Similarly, forest cover as an important factor associated with mammalian occupancy was also observed in protected areas of China (Feng et al., 2021) and South Africa (Zungu et al., 2020). Both studies again found that the response varied among species. Again, in another study conducted in Brazilian forests, Regolin et al. (2017) also observed varying degrees of association of mammals with forest cover. This shows that the occupancy of the majority of the mammal species is positively related to the forest cover, however, the direction and magnitude of the effect of forest cover vary between species.

The species with the highest positive association with forest cover was Sambar (*Rusa unicolor*). Other studies also have found its preference for areas with high forest cover (Haleem & Ilyas, 2022; Kushwaha et al., 2004) because of its shy disposition and preference for dense forests (Haleem & Ilyas, 2022). It faces threats from poaching because of its large size (Widodo et al., 2022) and thus may have chosen areas with higher forest cover as a refuge (Gallego-Zamorano et al., 2020). Similarly, the marbled cat (*Pardofelis marmorata*), short-tailed mongoose (*Herpestes brachyurus*), the banded palm civet (*Hemigalus derbyanus*), and tiger (*Panthera tigris*) also have higher and positive relations with forest cover. Studies of marbled cats have

found their preference for forested habitats (Nowell & Jackson, 1996; Rustam et al., 2016). The short-tailed mongoose (Jennings et al., 2010; Jennings & Veron, 2011), the banded palm civet (Dunn et al., 2022) and the tiger (Sunarto et al., 2012) are also reported to be positively associated with forest cover. The barking deer (*Muntiacus muntjac*) showed a faint positive association, as it has been reported to prefer medium tree cover of 19% (Hameed & Mian, 2009) at which it can move easily and escape from predators (Habiba et al., 2021).

The species most negatively related to the forest cover were Malayan porcupine (*Hystrix brachyura*) and Asiatic brush-tailed porcupine (*Atherurus macrourus*). The Malayan porcupine has been found associated with varieties of habitats ((Lunde et al., 2016; Talukdar et al., 2019) implying that forest cover may not be essential for it. However, the rarest of the porcupines, the Asiatic brush-tailed porcupine has been reported to be associated with forest cover and found in places with plenty of undergrowth (Molur et al., 2005; Talukdar et al., 2019), but this study suggests that it may as well occupy other habitat types. The two macaques, the southern pig-tailed macaque (*Macaca nemestrina*) and the crab-eating macaque (*Macaca fascicularis*) showed weak negative associations. These macaques are widely distributed and highly adaptable species (Hansen et al., 2021) and can use diverse types of habitats including artificial forests outside the PAs (Ang et al., 2020). This explains their weak association with forest cover.

4.2 Effect of functional traits

As predicted, the relationship between occupancy and forest cover in this study was stronger for the forest specialist than for the non-specialists. This is consistent with other studies where forest specialists are found to be more related to the amount of forest cover available (Beca et al., 2017; Bedoya-Durán et al., 2021; Salom-Pérez et al., 2021) than the generalists. This can be explained by the fact that more forest cover means more habitat available for forest specialists, and habitat amount is highly correlated with a species' occurrence (Fahrig, 2013). Non-specialists, on the other hand, were nominally associated with forest cover. In a study, Regolin et al. (2017) observed that the occurrence of generalists was not associated with forest cover. In another study, (Salom-Pérez et al., 2021) found that generalists were associated with lower forest cover. This can be explained as generalists are adapted to various habitat types (Schlinkert et al., 2016).

Considering the feeding guild, the carnivores-omnivores showed a higher association with forest cover than the herbivore-insectivores as predicted. Carnivores are positively related to forest cover as found by other studies (Regolin et al., 2017; Srivathsa et al., 2019). Higher prey availability, help in camouflage and reducing hunting pressure from humans (especially for large carnivores) are generally associated with this relation (Gallego-Zamorano et al., 2020; Phumanee et al., 2021; Salom-Pérez et al., 2021; Sunarto et al., 2012). Moreover, the availability of small prey species especially due to the presence of woody debris (Duckworth et al., 2016; Jennings & Veron, 2011; Mathai et al., 2017) explains the higher association of both carnivores and omnivores with forest cover.

Body mass and habitat breadth did not have any association with forest cover. But studies have shown that large mammals are often found to prefer intact forest areas to fragmented forests to meet the habitat amount requirement and to find refuge from hunting (Núñez-Regueiro et al., 2015; Regolin et al., 2017) as they are more susceptible to hunting because of their sizes (Gallego-Zamorano et al., 2020; Peres, 2001). Habitat breadth also did not explain the relationship between occupancy and forest cover. A species with lower habitat breadth can be arbitrarily related to any particular type of habitat, and one with higher habitat breadth (the generalist) can be associated with multiple types of habitats, and both may not necessarily show any strong relation with forest cover (Gallego-Zamorano et al., 2020; Salom-Pérez et al., 2021; Sunarto et al., 2012). This uncertainty of association of habitat breadth with forest cover might explain the findings of this study.

The lack of pronounced and clear effects can be attributed to some factors. This research is conducted in tropical protected areas where forest cover is often high. But there may still be places, for example, along the edges where forest cover is low. Still, I did not find pronounced and clear effects of forest cover on species occupancy which suggests that there may not be enough variation in forest cover to observe significant differences. In other words, the proportion of the forest cover in these sites may be above the threshold to observe differences in responses (Pardo Vargas et al., 2016; Regolin et al., 2017). Moreover, the findings can be interpreted as an indication that protection in these areas is still effective, although the absence of evidence of an effect is not evidence of absence. During the occupancy analysis, I observed problems of model convergence, getting boundary solutions for ψ and p , and large uncertainties in the estimates. These have been reported as the limitations of the likelihood approach of parameter estimation when maximizing full likelihood is involved (Karavarsamis, 2019; Welsh et al., 2013). This happens when data is sparse (Guillera-Arroita et al., 2010;

Welsh et al., 2013) or when the species are elusive, and the model does not have enough information to distinguish whether a site is truly unoccupied by a species or it is just a case of non-detection (MacKenzie et al., 2002). This suggests using more data from multiple years as well as other statistical approaches like Bayesian multi-species occupancy modelling, penalised likelihood method (Hutchinson et al., 2015), and the two-stage approach of occupancy modelling (Karavarsamis, 2019).

5. Conclusion

The occupancy of most mammals was positively related to forest cover and there were variations in this relationship across species and species groups. The functional traits of the species helped to understand these variations. It was observed that the occupancy-forest cover relations are defined by forest specialisation and the feeding guild of the species. Forest specialists and carnivores/omnivores had stronger and more positive associations than non-specialists and herbivores/insectivores. However, the lack of pronounced effects suggests that the protected areas considered in this study might not have enough variation in forest cover to find differences in responses or it can also be said that these areas are effective in protection. Finally, issues with sparse data were observed. Hence, I recommend future research include data from multiple years and follow alternate statistical approaches of occupancy modelling and parameter estimation.

References

- Akaike, H. (1998). Information Theory and an Extension of the Maximum Likelihood Principle. In Parzen, E., Tanabe, K. & Kitagawa, G. (eds) *Selected Papers of Hirotugu Akaike*, pp. 199-213. New York, NY: Springer New York.
- Ang, A., Boonratana, R., Choudhury, A. & Supriatna, J. (2020). *Macaca nemestrina*. The IUCN Red List of Threatened Species 2020. doi: <https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T12555A181324867.en> (accessed: 04/18/2022).
- August, P. V. (1983). The Role of Habitat Complexity and Heterogeneity in Structuring Tropical Mammal Communities. *Ecology*, 64 (6): 1495-1507. doi: <https://doi.org/10.2307/1937504>.
- Baskaran, N., Venkatesan, S., Mani, J., Srivastava, S. K. & Desai, A. A. (2011). Some aspects of the ecology of the Indian Giant Squirrel *Ratufa indica* (Erxleben, 1777) in the tropical forests of Mudumalai Wildlife Sanctuary, southern India and their conservation implications. *Journal of Threatened Taxa*, 3 (7): 1899-1908. doi: 10.11609/JoTT.o2593.1899-908.
- Bateman, B. L., Kutt, A. S., Vanderduys, E. P. & Kemp, J. E. (2010). Small-mammal species richness and abundance along a tropical altitudinal gradient: an Australian example. *Journal of Tropical Ecology*, 26 (2): 139-149. doi: 10.1017/S0266467409990460.
- Beaudrot, L., Ahumada, J. A., O'Brien, T., Alvarez-Loayza, P., Boekee, K., Campos-Arceiz, A., Eichberg, D., Espinosa, S., Fegraus, E., Fletcher, C., et al. (2016). Standardized Assessment of Biodiversity Trends in Tropical Forest Protected Areas: The End Is Not in Sight. *PLOS Biology*, 14 (1): e1002357. doi: <https://doi.org/10.1371/journal.pbio.1002357>.
- Beca, G., Vancine, M. H., Carvalho, C. S., Pedrosa, F., Alves, R. S. C., Buscariol, D., Peres, C. A., Ribeiro, M. C. & Galetti, M. (2017). High mammal species turnover in forest patches immersed in biofuel plantations. *Biological Conservation*, 210: 352-359. doi: <https://doi.org/10.1016/j.biocon.2017.02.033>.
- Bedoya-Durán, M. J., Murillo-García, O. E. & Branch, L. C. (2021). Factors outside privately protected areas determine mammal assemblages in a global biodiversity hotspot in the Andes. *Global Ecology and Conservation*, 32: e01921. doi: <https://doi.org/10.1016/j.gecco.2021.e01921>.
- Brown, J. H. (2014). Why are there so many species in the tropics? *Journal of Biogeography*, 41 (1): 8-22. doi: <https://doi.org/10.1111/jbi.12228>.
- Buckley, R., Zhou, R. & Zhong, L. (2016). How Pristine Are China's Parks? *Frontiers in Ecology and Evolution*, 4. doi: 10.3389/fevo.2016.00136.
- Campera, M., Santini, L., Balestri, M., Nekaris, K. A. I. & Donati, G. (2020). Elevation gradients of lemur abundance emphasise the importance of Madagascar's lowland rainforest for the conservation of endemic taxa. *Mammal Review*, 50 (1): 25-37. doi: <https://doi.org/10.1111/mam.12172>.
- Cardillo, M., Mace, G. M., Jones, K. E., Bielby, J., Bininda-Emonds, O. R. P., Sechrest, W., Orme, C. D. L. & Purvis, A. (2005). Multiple Causes of High Extinction Risk in Large Mammal Species. *Science*, 309 (5738): 1239-1241. doi: doi:10.1126/science.1116030.

- Chanthavong, B., Phompila, C., Van Khoa, P., Noda, K., Thongmanivong, S. & Chanthavong, H. (2021). A rapid assessment of burned areas in Nam Kading National Biodiversity Conservation Area (NBCA), Laos. *Remote Sensing Applications: Society and Environment*, 22: 100490. doi: <https://doi.org/10.1016/j.rsase.2021.100490>.
- Coetzee, B. W. T., Gaston, K. J. & Chown, S. L. (2014). Local Scale Comparisons of Biodiversity as a Test for Global Protected Area Ecological Performance: A Meta-Analysis. *PLOS ONE*, 9 (8): e105824. doi: 10.1371/journal.pone.0105824.
- Cooke, R. S. C., Eigenbrod, F. & Bates, A. E. (2019). Projected losses of global mammal and bird ecological strategies. *Nature Communications*, 10 (1): 2279. doi: 10.1038/s41467-019-10284-z.
- Corlett, R. T. (2014). Tropical Forests. In John Wiley & Sons, L. (ed.) *eLS*.
- Crooks, K. R., Burdett, C. L., Theobald, D. M., Rondinini, C. & Boitani, L. (2011). Global patterns of fragmentation and connectivity of mammalian carnivore habitat. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366 (1578): 2642-2651. doi: <https://doi.org/doi:10.1098/rstb.2011.0120>.
- Deere, N. J., Guillera-Arroita, G., Swinfield, T., Milodowski, D. T., Coomes, D. A., Bernard, H., Reynolds, G., Davies, Z. G. & Struebig, M. J. (2020). Maximizing the value of forest restoration for tropical mammals by detecting three-dimensional habitat associations. *Proc Natl Acad Sci U S A*, 117 (42): 26254-26262. doi: 10.1073/pnas.2001823117.
- Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K. & Butchart, S. H. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. doi: <https://doi.org/10.5281/zenodo.3553579>.
- Duckworth, J. W., Mathai, J., Ross, J. & Wilting, A. (2016). *Herpestes brachyurus*. The IUCN Red List of Threatened Species 2016. doi: <https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T41610A45206655.en>.
- Dudley, N., Schlaepfer, R., Jackson, W., Jeanrenaud, J.-P. & Stolton, S. (2012). *Forest quality: assessing forests at a landscape scale*: Routledge.
- Dundas, S. J., Ruthrof, K. X., Hardy, G. E. S. J. & Fleming, P. A. (2019). Pits or pictures: a comparative study of camera traps and pitfall trapping to survey small mammals and reptiles. *Wildlife Research*, 46 (2). doi: 10.1071/wr18074.
- Dunn, A., Amir, Z., Decoeur, H., Dehaut, B., Nursamsi, I., Mendes, C., Moore, J. H., Negret, P. J., Sovie, A. & Luskin, M. S. (2022). The ecology of the banded civet (*Hemigalus derbyanus*) in Southeast Asia with implications for mesopredator release, zoonotic diseases, and conservation. *Ecology and Evolution*, 12 (5): e8852. doi: <https://doi.org/10.1002/ece3.8852>.
- Fahrig, L. (2013). Rethinking patch size and isolation effects: the habitat amount hypothesis. *Journal of Biogeography*, 40 (9): 1649-1663. doi: <https://doi.org/10.1111/jbi.12130>.
- Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., et al. (2007). The Shuttle Radar Topography Mission. *Reviews of Geophysics*, 45 (2). doi: <https://doi.org/10.1029/2005RG000183>.

- Faurby, S., Davis, M., Pedersen, R. Ø., Schowanek, S. D., Antonelli, A. & Svenning, J.-C. (2018). PHYLACINE 1.2: The Phylogenetic Atlas of Mammal Macroecology. *Ecology*, 99 (11): 2626-2626. doi: <https://doi.org/10.1002/ecy.2443>.
- Feeley, K. J., Davies, S. J., Perez, R., Hubbell, S. P. & Foster, R. B. (2011). Directional changes in the species composition of a tropical forest. *Ecology*, 92 (4): 871-882. doi: <https://doi.org/10.1890/10-0724.1>.
- Feng, J., Sun, Y., Li, H., Xiao, Y., Zhang, D., Smith, J. L. D., Ge, J. & Wang, T. (2021). Assessing mammal species richness and occupancy in a Northeast Asian temperate forest shared by cattle. *Diversity and Distributions*, 27 (5): 857-872. doi: <https://doi.org/10.1111/ddi.13237>.
- Fiske, I. & Chandler, R. (2011). *unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance*.
- Fletcher, C., Abrams, M., Ibrahim, S., Musa, S. & Kassim, A. R. (2012). Fresh Perspectives on Malaysia's Pasoh Forest Reserve and Climate Change.
- Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., et al. (2005). Global Consequences of Land Use. *Science*, 309 (5734): 570-574. doi: doi:10.1126/science.1111772.
- Gallego-Zamorano, J., Benítez-López, A., Santini, L., Hilbers, J. P., Huijbregts, M. A. J. & Schipper, A. M. (2020). Combined effects of land use and hunting on distributions of tropical mammals. *Conservation Biology*, 34 (5): 1271-1280. doi: <https://doi.org/10.1111/cobi.13459>.
- Government of the Republic of Indonesia. (2004). *Submission for Nomination of Tropical Rainforest Heritage of Sumatra*.
- Grassman, L. I., Tewes, M. E. & Silvy, N. J. (2005). Ranging, habitat use and activity patterns of binturong *Arctictis binturong* and yellow-throated marten *Martes flavigula* in north-central Thailand. *Wildlife Biology*, 11 (1): 49-57, 9.
- Grassman, L. I., Jr., Tewes, M. E., Silvy, N. J. & Kreetiyutanont, K. (2005). Ecology of Three Sympatric Felids in a Mixed Evergreen Forest in North-Central Thailand. *Journal of Mammalogy*, 86 (1): 29-38. doi: 10.1644/1545-1542(2005)086<0029:EOTSFI>2.0.CO;2.
- Guillera-Arroita, G., Ridout, M. S. & Morgan, B. J. T. (2010). Design of occupancy studies with imperfect detection. *Methods in Ecology and Evolution*, 1 (2): 131-139. doi: <https://doi.org/10.1111/j.2041-210X.2010.00017.x>.
- Habiba, U., Anwar, M., Khatoon, R., Hussain, M., Khan, K. A., Khalil, S., Bano, S. A. & Hussain, A. (2021). Feeding habits and habitat use of barking deer (*Muntiacus vaginalis*) in Himalayan foothills, Pakistan. *PLOS ONE*, 16 (1): e0245279. doi: 10.1371/journal.pone.0245279.
- Haleem, A. & Ilyas, O. (2022). Status, abundance, and food habit of Sambar deer (*Rusa unicolor*) in tropical deciduous forest of Central India. *Mammalia*. doi: 10.1515/mammalia-2021-0109.
- Hallam, C. & Hedemark, M. (2012). Nam Kading National Protected Area. In *Evidence-based Conservation*, pp. 117-135: Routledge.
- Hameed, W. & Mian, A. (2009). Population features of barking deer (*Muntiacus muntjak*) in Margalla Hills National Park, Pakistan. *Pakistan Journal of Zoology*, 41 (2).

- Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 342 (6160): 850-853. doi: <https://doi.org/10.1126/science.1244693>.
- Hansen, M. F., Gill, M., Nawangsari, V., Sanchez, K., Cheyne, S., Nijman, V. & Fuentes, A. (2021). Conservation of Long-tailed Macaques: Implications of the Updated IUCN Status and the CoVID-19 Pandemic. *Primate Conservation*, 35.
- Haro-Carrión, X., Johnston, J. & Bedoya-Durán, M. J. (2021). Landscape Structure and Seasonality: Effects on Wildlife Species Richness and Occupancy in a Fragmented Dry Forest in Coastal Ecuador. *Remote Sensing*, 13 (18): 3762.
- Hutchinson, R. A., Valente, J. J., Emerson, S. C., Betts, M. G. & Dietterich, T. G. (2015). Penalized likelihood methods improve parameter estimates in occupancy models. *Methods in Ecology and Evolution*, 6 (8): 949-959. doi: <https://doi.org/10.1111/2041-210X.12368>.
- Jansen, P. A., Ahumada, J., Fegraus, E. & O'Brien, T. (2014). TEAM: a standardised camera trap survey to monitor terrestrial vertebrate communities in tropical forests. *Camera trapping: wildlife research and management*: 263-270.
- Jennings, A. P., Zubaid, A. & Veron, G. (2010). Home ranges, movements and activity of the short-tailed mongoose (*Herpestes brachyurus*) on Peninsular Malaysia. *Mammalia*, 74 (1): 43-50. doi: 10.1515/Mamm.2010.001.
- Jennings, A. P. & Veron, G. (2011). Predicted distributions and ecological niches of 8 civet and mongoose species in Southeast Asia. *Journal of Mammalogy*, 92 (2): 316-327. doi: 10.1644/10-mamm-a-155.1.
- Jones, K. E., Bielby, J., Cardillo, M., Fritz, S. A., O'Dell, J., Orme, C. D. L., Safi, K., Sechrest, W., Boakes, E. H., Carbone, C., et al. (2009). PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. *Ecology*, 90 (9): 2648-2648. doi: <https://doi.org/10.1890/08-1494.1>.
- José-Domínguez, J. M., Savini, T. & Asensio, N. (2015). Ranging and site fidelity in northern pigtailed macaques (*Macaca leonina*) over different temporal scales. *American Journal of Primatology*, 77 (8): 841-853. doi: <https://doi.org/10.1002/ajp.22409>.
- Josefsson, T., Hörnberg, G. & Östlund, L. (2009). Long-Term Human Impact and Vegetation Changes in a Boreal Forest Reserve: Implications for the Use of Protected Areas as Ecological References. *Ecosystems*, 12 (6): 1017-1036. doi: 10.1007/s10021-009-9276-y.
- Karavarsamis, N. (2019). *Estimating Occupancy and Fitting Models with the Two-Stage Approach*, Singapore: Springer Singapore.
- Kéry, M. & Royle, J. A. (2016). Chapter 10 - Modeling Static Occurrence and Species Distributions Using Site-occupancy Models. In Kéry, M. & Royle, J. A. (eds) *Applied Hierarchical Modeling in Ecology*, pp. 551-629. Boston: Academic Press.
- Kim, D.-H. & Anand, A. (2021). Effectiveness of Protected Areas in the Pan-Tropics and International Aid for Conservation. *Geomatics*, 1 (3): 335-346.
- Kushwaha, S., Khan, A., Habib, B., Quadri, A. & Singh, A. (2004). Evaluation of sambar and muntjak habitats using geostatistical modelling. *Current science*, 86: 1390-1400.

- Laurance, W. F. (2015). Emerging Threats to Tropical Forests. *Annals of the Missouri Botanical Garden*, 100 (3): 159-169, 11.
- Leisher, C., Touval, J., Hess, S. M., Boucher, T. M. & Reymondin, L. (2013). Land and Forest Degradation inside Protected Areas in Latin America. *Diversity*, 5 (4): 779-795.
- Leslie, D. M. (2011). *Rusa unicolor* (Artiodactyla: Cervidae). *Mammalian Species*, 43 (1): 1-30, 30.
- Lesmeister, D. B., Nielsen, C. K., Schauber, E. M. & Hellgren, E. C. (2015). Spatial and temporal structure of a mesocarnivore guild in midwestern north America. *Wildlife Monographs*, 191 (1): 1-61. doi: <https://doi.org/10.1002/wmon.1015>.
- Lewis, S. L., Edwards, D. P. & Galbraith, D. (2015). Increasing human dominance of tropical forests. *Science*, 349 (6250): 827-832. doi: doi:10.1126/science.aaa9932.
- Lim, N. T. L. & Ng, P. K. L. (2008). Home range, activity cycle and natal den usage of a female Sunda pangolin *Manis javanica* (Mammalia: Pholidota) in Singapore. *Endangered Species Research*, 4 (1-2): 233-240.
- Lunde, D., Aplin, K. & Molur, S. (2016). *Hystrix brachyura* (errata version published in 2017). The IUCN Red List of Threatened Species 2016. doi: <https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T10749A22232129.en> (accessed: 04/18/2022).
- MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Andrew Royle, J. & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83 (8): 2248-2255. doi: [https://doi.org/10.1890/0012-9658\(2002\)083\[2248:ESORWD\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2).
- MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L. & Hines, J. E. (2006). *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Boston: Academic Press.
- MacKinnon, J., MacKinnon, K., Child, G. & Thorsell, J. (1986). *Managing protected areas in the tropics*.
- Mathai, J., Sollmann, R., Meredith, M. E., Belant, J. L., Niedballa, J., Buckingham, L., Wong, S. T., Asad, S. & Wilting, A. (2017). Fine-scale distributions of carnivores in a logging concession in Sarawak, Malaysian Borneo. *Mammalian Biology*, 86 (1): 56-65. doi: 10.1016/j.mambio.2017.04.002.
- Matsubayashi, H., Bosi, E. & Kohshima, S. (2003). Activity and Habitat Use of Lesser Mouse-Deer (*Tragulus javanicus*). *Journal of Mammalogy*, 84 (1): 234-242. doi: 10.1644/1545-1542(2003)084<0234:Aahuol>2.0.Co;2.
- McCullough, D. R., Kurtis, C. J. P. & Wang, Y. (2000). Home Range, Activity Patterns, and Habitat Relations of Reeves' Muntjacs in Taiwan. *The Journal of Wildlife Management*, 64 (2): 430-441. doi: 10.2307/3803241.
- McGill, B. J., Enquist, B. J., Weiher, E. & Westoby, M. (2006). Rebuilding community ecology from functional traits. *Trends in Ecology & Evolution*, 21 (4): 178-185. doi: <https://doi.org/10.1016/j.tree.2006.02.002>.
- Moiseev, A., Dudley, E. & Cantin, D. (2002). *The Wellbeing of Forests: an E-tool for assessing environmental and social sustainability*: IUCN, Gland, Switzerland and Cambridge, UK.

- Moles, A. T., Warton, D. I., Warman, L., Swenson, N. G., Laffan, S. W., Zanne, A. E., Pitman, A., Hemmings, F. A. & Leishman, M. R. (2009). Global patterns in plant height. *Journal of Ecology*, 97 (5): 923-932. doi: <https://doi.org/10.1111/j.1365-2745.2009.01526.x>.
- Molur, S., Srinivasulu, C., Srinivasulu, B., Walker, S., Nameer, P. & Ravikumar, L. (2005). Status of south Asian non-volant small mammals: conservation assessment and management plan (CAMP) workshop report. *Zoo Outreach Organization/CBSG-South Asia, Coimbatore, India, 618pp*.
- Morris, R. J. (2010). Anthropogenic impacts on tropical forest biodiversity: a network structure and ecosystem functioning perspective. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 365 (1558): 3709-3718. doi: 10.1098/rstb.2010.0273.
- Muhammad Nawaz, R. (2018). Tropical Forests Are An Ideal Habitat for Wide Array of Wildlife Species. In Padmini, S., Madhugiri, N.-R. & Jaya, R. S. (eds) *Tropical Forests*. Rijeka: IntechOpen.
- NASA JPL. (2013). NASA Shuttle Radar Topography Mission Global 1 arc second [Data set]. NASA EOSDIS Land Processes DAAC, online database (no. <https://doi.org/10.5067/MEaSURES/SRTM/SRTMGL1.003>) (accessed: 2021-12-18).
- Ngcobo, S. P., Wilson, A.-L. & Downs, C. T. (2019). Home ranges of Cape porcupines on farmlands, peri-urban and suburban areas in KwaZulu-Natal, South Africa. *Mammalian Biology*, 96: 102-109. doi: <https://doi.org/10.1016/j.mambio.2018.10.006>.
- Nijman, V., Setiawan, A., Traeholt, C. & Manullang, B. (2020). *Presbytis melalophos*. *The IUCN Red List of Threatened Species 2020*. doi: <https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T39811A17954271.en>.
- Nock, C. A., Vogt, R. J. & Beisner, B. E. (2016). Functional Traits. In *eLS*, pp. 1-8.
- Nowell, K. & Jackson, P. (1996). *Wild cats: status survey and conservation action plan*, vol. 382: IUCN Gland.
- Núñez-Regueiro, M. M., Branch, L., Fletcher, R. J., Marás, G. A., Derlindati, E. & Tálamo, A. (2015). Spatial patterns of mammal occurrence in forest strips surrounded by agricultural crops of the Chaco region, Argentina. *Biological Conservation*, 187: 19-26. doi: <https://doi.org/10.1016/j.biocon.2015.04.001>.
- O'Brien, T. G. & Kinnaird, M. F. (1996). Birds and mammals of the Bukit Barisan Selatan National Park, Sumatra, Indonesia. *Oryx*, 30: 207-217.
- Pacifici, M., Di Marco, M. & Watson, J. E. M. (2020). Protected areas are now the last strongholds for many imperiled mammal species. *Conservation Letters*, 13 (6): e12748. doi: <https://doi.org/10.1111/conl.12748>.
- Pallemaerts, L., Adul, Kulu, I., Jeffers, K., Macdonald, D. & Cheyne, S. (2019). Bornean clouded leopard minimum home range analysis, Indonesian Borneo. 70: 32-35.
- Palomo, I., Montes, C., Martín-López, B., González, J. A., García-Llorente, M., Alcorlo, P. & Mora, M. R. G. (2014). Incorporating the Social–Ecological Approach in Protected Areas in the Anthropocene. *BioScience*, 64 (3): 181-191. doi: 10.1093/biosci/bit033.
- Pardini, R., de Souza, S. M., Braga-Neto, R. & Metzger, J. P. (2005). The role of forest structure, fragment size and corridors in maintaining small mammal abundance and

- diversity in an Atlantic forest landscape. *Biological Conservation*, 124 (2): 253-266. doi: <https://doi.org/10.1016/j.biocon.2005.01.033>.
- Pardo Vargas, L. E., Cove, M. V., Spinola, R. M., de la Cruz, J. C. & Saenz, J. C. (2016). Assessing species traits and landscape relationships of the mammalian carnivore community in a neotropical biological corridor. *Biodiversity and Conservation*, 25 (4): 739-752. doi: 10.1007/s10531-016-1089-7.
- Peres, C. A. (2001). Synergistic Effects of Subsistence Hunting and Habitat Fragmentation on Amazonian Forest Vertebrates. *Conservation Biology*, 15 (6): 1490-1505. doi: <https://doi.org/10.1046/j.1523-1739.2001.01089.x>.
- Peters, H. A. (2001). *Clidemia hirta* Invasion at the Pasoh Forest Reserve: An Unexpected Plant Invasion in an Undisturbed Tropical Forest1. *Biotropica*, 33 (1): 60-68. doi: <https://doi.org/10.1111/j.1744-7429.2001.tb00157.x>.
- Phillips, O. L. (1996). Long-term environmental change in tropical forests: increasing tree turnover. *Environmental Conservation*, 23 (3): 235-248. doi: <https://doi.org/10.1017/S0376892900038856>.
- Phumanee, W., Steinmetz, R., Phoonjampa, R., Bejraburnin, T., Bhumpakphan, N. & Savini, T. (2021). Coexistence of large carnivore species in relation to their major prey in Thailand. *Global Ecology and Conservation*, 32: e01930. doi: <https://doi.org/10.1016/j.gecco.2021.e01930>.
- Pillay, R., Venter, M., Aragon-Osejo, J., González-del-Pliego, P., Hansen, A. J., Watson, J. E. & Venter, O. (2022). Tropical forests are home to over half of the world's vertebrate species. *Frontiers in Ecology and the Environment*, 20 (1): 10-15. doi: <https://doi.org/10.1002/fee.2420>.
- Pollard, A. I. & Yuan, L. L. (2010). Assessing the consistency of response metrics of the invertebrate benthos: a comparison of trait- and identity-based measures. *Freshwater Biology*, 55 (7): 1420-1429. doi: <https://doi.org/10.1111/j.1365-2427.2009.02235.x>.
- Primack, R. B. & Morrison, R. A. (2013). Extinction, Causes of. In Levin, S. A. (ed.) *Encyclopedia of Biodiversity (Second Edition)*, pp. 401-412. Waltham: Academic Press.
- Pusparini, W., Batubara, T., Surahmat, F., Ardiantiono, u., Sugiharti, T., Muslich, M., Amama, F., Marthy, W. & Andayani, N. (2018). A pathway to recovery: the Critically Endangered Sumatran tiger *Panthera tigris sumatrae* in an 'in danger' UNESCO World Heritage Site. *Oryx*, 52 (1): 25-34. doi: 10.1017/S0030605317001144.
- Püttker, T., Pardini, R., Meyer-Lucht, Y. & Sommer, S. (2008). Responses of five small mammal species to micro-scale variations in vegetation structure in secondary Atlantic Forest remnants, Brazil. *BMC Ecology*, 8 (1): 9. doi: <https://doi.org/10.1186/1472-6785-8-9>.
- R Core Team. (2021). *R: A language and environment for statistical computing*: R Foundation for Statistical Computing, Vienna, Austria. Available at: <https://www.R-project.org/>.
- Ramírez-Bautista, A. & Williams, J. N. (2019). The importance of productivity and seasonality for structuring small rodent diversity across a tropical elevation gradient. *Oecologia*, 190 (2): 275-286. doi: 10.1007/s00442-018-4287-z.
- Regolin, A. L., Cherem, J. J., Graipel, M. E., Bogoni, J. A., Ribeiro, J. W., Vancine, M. H., Tortato, M. A., Oliveira-Santos, L. G., Fantacini, F. M., Luiz, M. R., et al. (2017).

- Forest cover influences occurrence of mammalian carnivores within Brazilian Atlantic Forest. *Journal of Mammalogy*, 98 (6): 1721-1731. doi: <https://doi.org/10.1093/jmammal/gyx103>.
- Rocha, E. C., Brito, D., Silva, P. M. e., Silva, J., Bernardo, P. V. d. S. & Juen, L. (2018). Effects of habitat fragmentation on the persistence of medium and large mammal species in the Brazilian Savanna of Goiás State. *Biota Neotropica*, 18 (3). doi: <https://doi.org/10.1590/1676-0611-BN-2017-0483>.
- Rodrigues, A. S. L., Akçakaya, H. R., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Chanson, J. S., Fishpool, L. D. C., Da Fonseca, G. A. B., Gaston, K. J., et al. (2004). Global Gap Analysis: Priority Regions for Expanding the Global Protected-Area Network. *BioScience*, 54 (12): 1092-1100. doi: 10.1641/0006-3568(2004)054[1092:GGAPRF]2.0.CO;2.
- Roll, U., Geffen, E. & Yom-Tov, Y. (2015). Linking vertebrate species richness to tree canopy height on a global scale. *Global Ecology and Biogeography*, 24 (7): 814-825. doi: <https://doi.org/10.1111/geb.12325>.
- Rolland, J., Condamine, F. L., Jiguet, F. & Morlon, H. (2014). Faster Speciation and Reduced Extinction in the Tropics Contribute to the Mammalian Latitudinal Diversity Gradient. *PLOS Biology*, 12 (1): e1001775. doi: 10.1371/journal.pbio.1001775.
- Rovero, F. & Ahumada, J. (2017). The Tropical Ecology, Assessment and Monitoring (TEAM) Network: An early warning system for tropical rain forests. *Science of The Total Environment*, 574: 914-923. doi: <https://doi.org/10.1016/j.scitotenv.2016.09.146>.
- RStudio Team. (2012). *RStudio: Integrated Development Environment for R*. Boston, MA: RStudio, PBC. Available at: <http://www.rstudio.com>.
- Rustam, R., Hearn, A., Ross, J., Alfred, R., Samejima, H., Heydon, M., Cheyne, S., Brodie, J., Giordano, A., Bernard, H., et al. (2016). Predicted distribution of the marbled cat *Pardofelis marmorata* (Mammalia: Carnivora: Felidae) on Borneo. 157-164.
- Salom-Pérez, R., Corrales-Gutiérrez, D., Araya-Gamboa, D., Espinoza-Muñoz, D., Finegan, B. & Petracca, L. S. (2021). Forest cover mediates large and medium-sized mammal occurrence in a critical link of the Mesoamerican Biological Corridor. *PLOS ONE*, 16 (3): e0249072. doi: 10.1371/journal.pone.0249072.
- Schielzeth, H. (2010). Simple means to improve the interpretability of regression coefficients. *Methods in Ecology and Evolution*, 1 (2): 103-113. doi: <https://doi.org/10.1111/j.2041-210X.2010.00012.x>.
- Schlinkert, H., Ludwig, M., Batáry, P., Holzschuh, A., Kovács-Hostyánszki, A., Tscharrntke, T. & Fischer, C. (2016). Forest specialist and generalist small mammals in forest edges and hedges. *Wildlife Biology*, 22 (3): 86-94, 9.
- Scullion, J. J., Fahrenholz, J., Huaytalla, V., Rengifo, E. M. & Lang, E. (2021). Mammal conservation in Amazonia's protected areas: A case study of Peru's Ichigkat Muja - Cordillera del Cóndor National Park. *Global Ecology and Conservation*, 26: e01451. doi: <https://doi.org/10.1016/j.gecco.2021.e01451>.
- Sodhi, N. S., Koh, L. P., Brook, B. W. & Ng, P. K. L. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution*, 19 (12): 654-660. doi: <https://doi.org/10.1016/j.tree.2004.09.006>.

- Srivathsa, A., Puri, M., Karanth, K. K., Patel, I. & Kumar, N. S. (2019). Examining human-carnivore interactions using a socio-ecological framework: sympatric wild canids in India as a case study. *R Soc Open Sci*, 6 (5): 182008. doi: 10.1098/rsos.182008.
- Stork, N. E., Coddington, J. A., Colwell, R. K., Chazdon, R. L., Dick, C. W., Peres, C. A., Sloan, S. & Willis, K. (2009). Vulnerability and resilience of tropical forest species to land-use change. *Conserv Biol*, 23 (6): 1438-47. doi: 10.1111/j.1523-1739.2009.01335.x.
- Sunarto, S., Kelly, M. J., Parakkasi, K., Klenzendorf, S., Septayuda, E. & Kurniawan, H. (2012). Tigers Need Cover: Multi-Scale Occupancy Study of the Big Cat in Sumatran Forest and Plantation Landscapes. *PLOS ONE*, 7 (1): e30859. doi: 10.1371/journal.pone.0030859.
- Takada, H., Nakamura, K., Watanabe, H. & Minami, M. (2020). Spatial organization and mating behavior of the Japanese serow under a low population density. *Mammalia*, 84 (3): 219-226. doi: doi:10.1515/mammalia-2019-0045.
- Talukdar, N. R., Choudhury, P. & Singh, B. (2019). Current records of porcupine in northeast India: distribution, habitat preference and conservation. *Tropical Ecology*, 60 (1): 41-51. doi: 10.1007/s42965-019-00005-4.
- Te Wong, S., Servheen, C. W. & Ambu, L. (2004). Home range, movement and activity patterns, and bedding sites of Malayan sun bears *Helarctos malayanus* in the Rainforest of Borneo. *Biological Conservation*, 119 (2): 169-181. doi: <https://doi.org/10.1016/j.biocon.2003.10.029>.
- TEAM Network. (2011). *Terrestrial Vertebrate Protocol Implementation Manual*, v. 3.1. Arlington, VA, USA: Tropical Ecology, Assessment and Monitoring Network, Center for Applied Biodiversity Science, Conservation International.
- Wang, Y.-C. (2006). Tropical Rain Forests: An Ecological and Biogeographical Comparison – Richard Primack and Richard Corlett. *Singapore Journal of Tropical Geography*, 27 (2): 221-223. doi: https://doi.org/10.1111/j.1467-9493.2006.00255_1.x.
- Wegge, P. & Mosand, H. M. (2015). Can the mating system of the size-monomorphic Indian muntjac (*Muntiacus muntjak*) be inferred from its social structure, spacing behaviour and habitat? A case study from lowland Nepal. *Ethology Ecology & Evolution*, 27 (2): 220-232. doi: 10.1080/03949370.2014.921794.
- Weiskopf, S. R., McCarthy, J. L., McCarthy, K. P., Shiklomanov, A. N., Wibisono, H. T. & Pusparini, W. (2019). The conservation value of forest fragments in the increasingly agrarian landscape of Sumatra. *Environmental Conservation*, 46 (4): 340-346. doi: 10.1017/S0376892919000195.
- Welsh, A. H., Lindenmayer, D. B. & Donnelly, C. F. (2013). Fitting and Interpreting Occupancy Models. *PLOS ONE*, 8 (1): e52015. doi: 10.1371/journal.pone.0052015.
- Widodo, F. A., Imron, M. A., Sunarto, S. & Giordano, A. J. (2022). Carnivores and their prey in Sumatra: Occupancy and activity in human-dominated forests. *PLOS ONE*, 17 (3): e0265440. doi: 10.1371/journal.pone.0265440.
- Wilting, A., Cord, A., Hearn, A. J., Hesse, D., Mohamed, A., Traeholdt, C., Cheyne, S. M., Sunarto, S., Jayasilan, M.-A., Ross, J., et al. (2010). Modelling the Species Distribution of Flat-Headed Cats (*Prionailurus planiceps*), an Endangered South-East Asian Small Felid. *PLOS ONE*, 5 (3): e9612. doi: 10.1371/journal.pone.0009612.

- Wright, S. J. (2005). Tropical forests in a changing environment. *Trends in Ecology & Evolution*, 20 (10): 553-560. doi: <https://doi.org/10.1016/j.tree.2005.07.009>.
- Yuan, M. K. D. (2016). *Tragulus napu* - Greater Mouse Deer. Available at: <https://wiki.nus.edu.sg/display/TAX/Tragulus+napu+-+Greater+Mouse+Deer> (accessed: 11-01-2022).
- Zeng, H., Sui, D. Z. & Wu, X. B. (2005). Human disturbances on landscapes in protected areas: a case study of the Wolong Nature Reserve. *Ecological Research*, 20 (4): 487-496. doi: <https://doi.org/10.1007/s11284-005-0065-6>.
- Zungu, M. M., Maseko, M. S. T., Kalle, R., Ramesh, T. & Downs, C. T. (2020). Factors affecting the occupancy of forest mammals in an urban-forest mosaic in EThekweni Municipality, Durban, South Africa. *Urban Forestry & Urban Greening*, 48: 126562. doi: <https://doi.org/10.1016/j.ufug.2019.126562>.

Annex

Annex 1: Home ranges & references for the species

Species	Site the species is detected at	Home range (km ²)	Reference species for home range*	Reference for home range
<i>Arctictis binturong</i>	NAK	6.2	<i>Arctictis binturong</i>	(Grassman, L. I. et al., 2005)
<i>Atherurus macrourus</i>	NAK, PSH	15	<i>Atherurus macrourus</i>	(Jones et al., 2009)
<i>Capricornis milneedwardsii</i>	NAK	0.5	<i>Capricornis crispus</i>	(Takada et al., 2020)
<i>Capricornis sumatraensis</i>	PSH	0.5	<i>Capricornis crispus</i>	(Takada et al., 2020)
<i>Catopuma temminckii</i>	BBS, NAK	47.7	<i>Catopuma temminckii</i>	(Grassman, L. I., Jr. et al., 2005)
<i>Elephas maximus</i>	BBS	38.36	<i>Elephas maximus</i>	(Jones et al., 2009)
<i>Helarctos malayanus</i>	BBS, NAK, PSH	14.8	<i>Helarctos malayanus</i>	(Te Wong et al., 2004)
<i>Hemigalus derbyanus</i>	BBS, PSH	2.88	<i>Paguma larvata</i>	(Jones et al., 2009)
<i>Herpestes brachyurus</i>	PSH	2.33	<i>Herpestes brachyurus</i>	(Jennings et al., 2010)
<i>Herpestes urva</i>	NAK	2.33	<i>Herpestes brachyurus</i>	(Jennings et al., 2010)
<i>Hystrix brachyura</i>	BBS, NAK, PSH	0.4	<i>Hystrix africaeaustralis</i>	(Ngcobo et al., 2019)
<i>Macaca fascicularis</i>	PSH	0.46	<i>Macaca fascicularis</i>	(Jones et al., 2009)
<i>Macaca leonina</i>	NAK	4.49	<i>Macaca leonina</i>	(José-Domínguez et al., 2015)
<i>Macaca nemestrina</i>	BBS, PSH	1.75	<i>Macaca nemestrina</i>	(Jones et al., 2009)
<i>Manis javanica</i>	PSH	0.05	<i>Manis javanica</i>	(Lim & Ng, 2008)
<i>Martes flavigula</i>	PSH	7.2	<i>Martes flavigula</i>	(Grassman, L. I. et al., 2005)
<i>Muntiacus montanus</i>	BBS	1.1	<i>Muntiacus reevesi</i>	(McCullough et al., 2000)

<i>Muntiacus muntjak</i>	BBS, NAK, PSH	0.77	<i>Muntiacus muntjak</i>	(Wegge & Mosand, 2015)
<i>Neofelis diardi</i>	BBS	2.2	<i>Neofelis diardi</i>	(Pallemaerts et al., 2019)
<i>Neofelis nebulosa</i>	PSH	30.8	<i>Clouded leopard</i>	(Grassman, L. I., Jr. et al., 2005)
<i>Paguma larvata</i>	BBS, PSH	2.88	<i>Paguma larvata</i>	(Jones et al., 2009)
<i>Panthera tigris</i>	BBS	64.89	<i>Panthera tigris</i>	(Jones et al., 2009)
<i>Paradoxurus hermaphroditus</i>	BBS, NAK	4.15	<i>Paradoxurus hermaphroditus</i>	(Jones et al., 2009)
<i>Pardofelis marmorata</i>	BBS, PSH	5.3	<i>Pardofelis marmorata</i>	(Grassman, L. I., Jr. et al., 2005)
<i>Presbytis melalophos</i>	BBS	14.3	<i>Presbytis melalophos</i>	(Nijman et al., 2020)
<i>Prionailurus bengalensis</i>	BBS, NAK, PSH	1.87	<i>Prionailurus bengalensis</i>	(Jones et al., 2009)
<i>Prionailurus planiceps</i>	PSH	4	<i>Prionailurus bengalensis</i>	(Wilting et al., 2010)
<i>Ratufa bicolor</i>	PSH	0.017	<i>Ratufa indica</i>	(Baskaran et al., 2011)
<i>Rusa unicolor</i>	BBS, PSH	15	<i>Rusa unicolor</i>	(Leslie, 2011)
<i>Sus scrofa</i>	BBS, NAK, PSH	1.18	<i>Sus scrofa</i>	(Jones et al., 2009)
<i>Tapirus indicus</i>	BBS, PSH	9.4	<i>Tapirus indicus</i>	(Jones et al., 2009)
<i>Trachypithecus obscurus</i>	PSH	0.18	<i>Trachypithecus obscurus</i>	(Jones et al., 2009)
<i>Tragulus javanicus</i>	NAK	5.9	<i>Tragulus javanicus</i>	(Matsubayashi et al., 2003)
<i>Tragulus kanchil</i>	BBS, NAK, PSH	0.06	<i>Tragulus kanchil</i>	(Jones et al., 2009)
<i>Tragulus napu</i>	BBS	0.06	<i>Tragulus kanchil</i>	(Yuan, 2016)
<i>Viverra megaspila</i>	PSH	9.36	<i>Viverra zibetha</i>	(Jones et al., 2009)
<i>Viverra zibetha</i>	PSH	9.36	<i>Viverra zibetha</i>	(Jones et al., 2009)

* = For some species whose home ranges were not found in the literature, home ranges of closely related species (reference species) were used

Annex 2: Functional traits of the species

Species	Feeding guild	Body mass (g)	Habitat breadth	Habitat specialisation: Forest
<i>Arctictis binturong</i>	Omnivorous	9875	4	Specialist
<i>Atherurus macrourus</i>	Herbivorous	2000	2	Specialist
<i>Capricornis milneedwardsii</i>	Herbivorous	130000	3	Non specialist
<i>Capricornis sumatraensis</i>	Herbivorous	87500	4	Non specialist
<i>Catopuma temminckii</i>	Carnivorous	11500	7	Non specialist
<i>Elephas maximus</i>	Herbivorous	3160000	7	Non specialist
<i>Helarctos malayanus</i>	Omnivorous	46500	4	Non specialist
<i>Hemigalus derbyanus</i>	Insectivorous	2322.5	3	Specialist
<i>Herpestes brachyurus</i>	Omnivorous	1853.5	3	Specialist
<i>Herpestes urva</i>	Omnivorous	1863.2	7	Non specialist
<i>Hystrix brachyura</i>	Herbivorous	8450	10	Non specialist
<i>Macaca fascicularis</i>	Omnivorous	3991.5	8	Non specialist
<i>Macaca leonina</i>	Herbivorous	6500	4	Specialist
<i>Macaca nemestrina</i>	Herbivorous	6296.5	7	Non specialist
<i>Manis javanica</i>	Insectivorous	5150	6	Non specialist
<i>Martes flavigula</i>	Carnivorous	1842.5	7	Non specialist
<i>Muntiacus montanus</i>	Herbivorous	17619.8	1	Specialist
<i>Muntiacus muntjak</i>	Herbivorous	15925.8	6	Non specialist
<i>Neofelis diardi</i>	Carnivorous	20500	2	Specialist
<i>Neofelis nebulosa</i>	Carnivorous	20500	3	Specialist
<i>Paguma larvata</i>	Omnivorous	4300	5	Non specialist
<i>Panthera tigris</i>	Carnivorous	162564	7	Non specialist
<i>Paradoxurus hermaphroditus</i>	Omnivorous	3156.7	11	Non specialist
<i>Pardofelis marmorata</i>	Carnivorous	2854.3	3	Specialist
<i>Presbytis melalophos</i>	Herbivorous	6300	2	Specialist
<i>Prionailurus bengalensis</i>	Carnivorous	3300	9	Non specialist
<i>Prionailurus planiceps</i>	Carnivorous	6750	7	Non specialist
<i>Ratufa bicolor</i>	Herbivorous	2050	2	Specialist

<i>Rusa unicolor</i>	Herbivorous	180344.4	13	Non specialist
<i>Sus scrofa</i>	Herbivorous	101052.1	25	Non specialist
<i>Tapirus indicus</i>	Herbivorous	296250	4	Non specialist
<i>Trachypithecus obscurus</i>	Herbivorous	7000	1	Specialist
<i>Tragulus javanicus</i>	Herbivorous	2775	3	Non specialist
<i>Tragulus kanchil</i>	Herbivorous	2000	7	Non specialist
<i>Tragulus napu</i>	Herbivorous	4000	3	Non specialist
<i>Viverra megaspila</i>	Omnivorous	9250	7	Non specialist
<i>Viverra zibetha</i>	Carnivorous	9500	8	Non specialist

Annex 3: Coefficients for the forest cover parameter and standard error for the species included in the functional trait analysis

Species	Forest specialisation	β _Forest cover	SE
<i>Atherurus macrourus</i>	Specialist	-0.147	0.375
<i>Hemigalus derbyanus</i>	Specialist	1.257	0.996
<i>Herpestes brachyurus</i>	Specialist	2.125	2.602
<i>Hystrix brachyura</i>	Non specialist	-1.305	0.692
<i>Macaca fascicularis</i>	Non specialist	-0.002	0.34
<i>Macaca nemestrina</i>	Non specialist	-0.076	0.645
<i>Muntiacus muntjak</i>	Non specialist	0.053	0.232
<i>Panthera tigris</i>	Non specialist	0.677	2.889
<i>Pardofelis marmorata</i>	Specialist	4.46	6.076
<i>Rusa unicolor</i>	Non specialist	6.635	8.159
<i>Sus scrofa</i>	Non specialist	0.214	0.269
<i>Tragulus kanchil</i>	Non specialist	0.333	0.339



Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitenskapelige universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway