MULTI-SPECIES OCCUPANCY MODELING OF MAMMALS AND ASSOCIATED VARIABLES IN DHORPATAN HUNTING RESERVE, NEPAL

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A thesis submitted in partial fulfillment of the requirements for the award of the Degree of Master of Science in Zoology with special paper Ecology and Environment.

Submitted to

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August 2022

DECLARATION

I hereby declare that the work presented in this thesis has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

Date: August 26, 2022

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LETTER OF APPROVAL

On the recommendation of the supervisor, Assoc. Prof. Dr. Hari Prasad Sharma, this thesis submitted by Mr. Sandeep Regmi entitled " Multi-species occupancy modeling of mammals and associated variables in Dhorpatan Hunting Reserve, Nepal " is approved for the examination for the partial fulfillment of the requirements for the degree of Master of Science in Zoology with special paper Ecology and Environment.

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CERTIFICATE OF ACCEPTANCE

The thesis work submitted by Mr. Sandeep Regmi entitled "Multi-species occupancy modeling of mammal and associated variables in Dhorpatan Hunting Reserve, Nepal" has been accepted as partial fulfillment for the requirements of the Master's Degree of Science in Zoology with special paper Ecology and Environment.

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TABLE OF CONTENTS Page No.

LIST OF TABLES

LIST OF FIGURES

Figure No. Name of the Figures Page No.

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviated form	Details of abbreviation
BCI:	Bayesian Confidence Interval
DHR:	Dhorpatan Hunting Reserve
ESS:	Effective Sample Size
GLAMA:	Gap Light Analysis Mobile Application
GPS:	Global Positioning System
IUCN:	International Union for Conservation of Nature and Natural Resources
LCI:	Lower Confidence Interval
MCMC:	Markov Chain Monte Carlo
Md:	Median
Mu:	Mean
NDVI:	Normalized Differentiated Vegetation Index
PIR:	Photo Infrared
p:	Detection probability
psi:	Naïve occupancy
SCP:	Semi-automatic Classification Plugin
SD:	Standard Deviation
VIF:	Variation Inflation Factor

ABSTRACT

The species diversity is declining globally at an alarming rate, and it is more prominent in areas with high human activities and interventions. The knowledge of the spatial distribution of species and the factors acting on them is a prerequisite for developing management and conservation plans. Therefore, this study aimed to evaluate the community-level occupancy of mammal species in the Dhorpatan Hunting Reserve (DHR) using camera traps from March 15 – June 15, 2022. The study used multi-species hierarchical occupancy modeling using Markov Chain Monte Carlo simulations to gain insights into the impact of various environmental and anthropogenic variables on community-level occupancy of the detected mammal species. This study identified a highly heterogeneous mammal species community at DHR with the highest detection probability for Red Panda (*Ailurus fulgens*) and lowest for Blue Sheep (*Pseudois nayaur*). The highest value of naïve occupancy was recorded for Himalayan Goral and the lowest for Red Panda. The highest negative impact on community-level occupancy was from elevation, and the highest positive impact was documented for canopy cover. Anthropogenic factors such as distance from human settlement and the presence of livestock had a positive impact on the community level occupancy. The study also evaluated the relatively less impact of all the variables for Barking Deer (*Muntiacus muntjac*), Himalayan Goral (*Naemorhedus goral*), and Red Fox (*Vulpes vulpes*). For a more reliable assessment, this study recommends extending the survey to a broader area and incorporating the multi-season approach of community-level occupancy modeling.

1. INTRODUCTION

1.1 Background

Knowledge on species distribution and its associated factors at both spatial and temporal scale is one of the crucial part of ecology, conservation, and evolutionary biology (Gotelli and Colwell 2001), which is pictured on community and population, demographic processes and traits (Sutherland et al. 2013). In recent years, anthropogenic effect on species habitat has significantly increased and consequently reduced the global biodiversity (Drouilly et al. 2018). It suggests an immediate need to monitor and manage the species habitat and population changes with crucial factors of habitat characteristics, species ecology at both the species and community level (Kalle et al. 2013, Drouilly et al. 2018, Leweri et al. 2022). Combining these factors with species distribution helps to predict the answer on ecological and evolutionary questions on the species and ecosystem (Chelgren et al. 2011, Walpole et al. 2012). Several factors exert impact on species occurrence and their distribution, and are varied at site and species, generally specific and more pronounced on large home range sized mammals (Karanth et al. 2009, Leweri et al. 2022). However, most of the studies are focused on species level (Lambeck 1997, Carroll et al. 2001, Epps et al. 2011), which often limits us from gaining hidden information about the community and species interaction (Simberloff 1998, Wiens et al. 2008).

The information of species at community level can be gained through multi-species study (Yoccoz et al. 2001, Balmford et al. 2005). Among multi-species studies, the classical method like abundance usually need identification of particular individual and becomes difficult to replicate in many areas and to make accurate estimation (MacKenzie et al. 2004). For that occupancy modeling of species can be beneficial (MacKenzie et al. 2004), preferentially the community modeling under multi-species hierarchical occupancy models (Dorazio and Royle 2005) which is used for the estimation of species richness in the given area. Unlike other ecological surveys, multi-species occupancy modeling (MSOM) helps to explore the factors that affect the distribution of species, communities or functional groups (Tobler et al. 2015, Rich et al. 2016, Easter et al. 2019). The occupancy modeling uses presence and absence data and is also able to take account of imperfect detections (Yoccoz 2006). The occupancy models were first originated for single-species (MacKenzie et al. 2002), but were soon adapted and incorporated to MSOMs (Dorazio and Royle 2005, Dorazio et al. 2006). Further, the structural hierarchy of MSOMs allows in making of true inferences about the species richness of the given area which cannot be attained by species analysis (Guillera-Arroita et al. 2019). MSOMs can also be parameterized with the variables that are hypothesized to have effects on species or communities (Russell et al. 2009).

Camera trap can be used to get data on multiple species across range of habitats and are more useful particularly for elusive species detection (Tobler et al. 2015). The low cost, high efficiency and easy replication ability of camera trap makes it preferable to study terrestrial mammals (Ahumada et al. 2013, Guillera-Arroita et al. 2019). It also has an ability to perform remotely and has better performance other than alternative methods of species detection like sign sampling and direct observation (Long et al. 2007, Balme et al. 2009). This makes the camera trap more popular in the studies like population densities (Ramsey et al. 2015), community dynamics (Lesmeister et al. 2015), species distribution (O'Connell et al. 2011), and occupancy modeling (MacKenzie et al. 2002, Dorazio and Royle 2005). Though occupancy is a poor surrogate estimator of abundance (Burton et al. 2015), use of camera trap based presence-absence data provides a foundation to model probability of occurrence, while explicitly considering imperfect detections (MacKenzie et al. 2002, Ahumada et al. 2013).

In areas with high anthropogenic activities, the probability of encounter between human and wildlife becomes higher thus leading to conflicts between them (Treves and Karanth 2003). In these areas a sound relationship between wildlife and human should be maintained for their long term conservation. Animal abundance and their assessment is must to make goals and estimate the effectiveness of their management prospects needed to be taken (Blanc and Barnes 2007). In order to manage, the chance of sighting an individual should be combined with inferential methods including the potential influence of considered variables (Yoccoz et al. 2001, MacKenzie and Kendall 2002, Dorazio and Royle 2005), and these inferences work efficiently only if the system dynamics are generated by manipulative experiments (Fisher et al. 1943 , Pianka 1966, Hurlbert 1984). The recent advancements in camera trap based studies on multiple species are more concerned towards particular guilds (Stoner et al. 2007, Schuette et al. 2013). Only a little attempt has been done to study the whole community (Tobler et al. 2015, Rich et al. 2016) which highlights the necessity to study occupancy at community level.

1.2 Objectives

1.2.1 General Objective

The general objective of this thesis research was to identify the multi-species occupancy of mammal species and impacts of habitat variables in their occupancy in Dhorpatan Hunting Reserve (DHR), Gandaki Province, Nepal.

1.2.2 Specific Objectives

The specific objectives of the study were:

- To analyze the multi-species occupancy of mammal species in Dhorpatan Hunting Reserve, Nepal.
- To identify the factors affecting the multi-species occupancy of mammal species in Dhorpatan Hunting Reserve, Nepal.

1.3 Justification of the Study

Though many studies in species occupancy have been done in Nepal, most of them are focused on particular species only (Barber-Meyer et al. 2013, Thapa et al. 2017, Sharma et al. 2020, Thapa et al. 2020, Lamichhane et al. 2021, Lamichhane et al. 2022), and a very few studies have been done on occupancy of multiple species and community level. The DHR is one of the highland protected areas of Nepal with human access for resource utilization and intervention in the area. This increases the probability of encounter between human and wildlife and may result in fatality or other conflicts (Treves and Karanth 2003). Despite such probabilities, very little study and effort has been done in DHR on community level species ecology and the determinants of species presence which makes it difficult to manage a sound relationship between wildlife conservation and human. The data generated from this study on multi-species occupancy on community level and role of anthropogenic factors in determining their occupancy can be used by policy makers for developing site and species specific management plan. In addition, the findings can be replicated to other areas too.

2. LITERATURE REVIEW

2.1 Occupancy Modeling

Population parameters like abundance and density have been the focus of population studies of various species since a long time (O'Brien et al. 2010, Devarajan et al. 2020). However, these methods require extensive survey effort as well as unique identification of the species which might be problematic for many species (MacKenzie et al. 2002, MacKenzie et al. 2003, Devarajan et al. 2020). Other methods include capture recapture methods which also might not be possible for all species and in cases where population densities are expected to be low (O’Connell and Bailey 2011). In such cases, an alternative method occupancy study can be implemented in order to gain information about the population using presence absence data (MacKenzie et al. 2002, MacKenzie et al. 2004, Royle and Dorazio 2008). It is more practical and relatively less expensive to collect the data than abundance and density studies to make the inference about single or multiple species (MacKenzie et al. 2002, O'Connell et al. 2011).

Basically, occupancy is a function of abundance and parameters which affects the presence of species in an environment (Royle and Dorazio 2008) and for some species it can be used as a surrogate estimator of abundance (MacKenzie et al. 2004). It was initially limited to single species only (MacKenzie et al. 2002, MacKenzie et al. 2004) but was later extended for the study of multiple species and community (Royle and Dorazio 2008, Rota et al. 2016). These multi-species level occupancy studies are capable of accounting occupancy at community level and have evolved into different methods (O’Connell and Bailey 2011) including classical model fitting approaches (White and Burnham 1999) to hierarchical studies implementing Markov Chain Monte Carlo (MCMC) simulations (Royle and Dorazio 2008). Different data collection methods have been implemented in occupancy studies including techniques of indirect surveys (Garshelis 2006, MacKay et al. 2008, Pauli et al. 2008) and direct surveys (Murphy et al. 2010, Barner et al. 2018). However, it is difficult to gather proper data through direct observation due to the behavioral and ecological preferences of the species (Blanc et al. 2013). This is why researchers lean more towards indirect survey methods (Garshelis 2006, MacKay et al. 2008) like sign surveys as well as camera trapping. Recent advancement in use of camera traps in range of wildlife studies including population densities (Ramsey et al. 2015), species distribution (O’Connell and Bailey 2011), and occupancy modeling (MacKenzie et al. 2002, Dorazio and Royle 2005), has made it easy to study and understand the ecological and behavioral aspects even in case of elusive and less observed species (Tobler et al. 2015). The higher preferences on using camera traps might be due to its attributes like low cost, high efficiency, reliability (Ahumada et al. 2013, Guillera-Arroita et al. 2019) as well as an ability to operate remotely (Long et al. 2007, Balme et al. 2009).

Several occupancy studies have been carried out in Nepal to identify the impact of underlying environmental and anthropogenic variables on different species across different study areas (Sharma et al. 2020, Thapa et al. 2020, Lamichhane et al. 2022). These studies include mammal species like Chinese Pangolin (*Manis pentadactyla*; Sharma et al. 2020), Ganges River Dolphin (*Platanista gangetica*; Paudel et al. 2015), Leopard (*Panthera pardus*; Lamichhane et al. 2021), Red Panda (*Ailurus fulgens*; Thapa et al. 2020), Sloth Bear (*Melursus ursinus*; Paudel et al. 2022) and Tiger (*Panthera tigris tigris*; Barber-Meyer et al. 2013). However, beside some studies like Lamichhane et al. (2020) there are fewer amounts of researches on occupancy modeling at multi-species and community level in Nepal.

2.2 Determinants of Occupancy

The occupancy at both the species and community level is determined by some set of variables (Shmida and Wilson 1985) which includes both anthropogenic as well as natural factors. For example, anthropogenic variables like settlements, roads, livestock and natural variables like elevation, canopy cover, distance to water bodies have been included in several studies (Kinnaird and O'brien 2012, Rota et al. 2016, Soofi et al. 2018). However, the choice of variable is dependent on the objective of the study as some studies emphasize more on the impacts of natural variables (Rota et al. 2016) while other focus more on anthropogenic variables (Kinnaird and O'brien 2012, Soofi et al. 2018). However, recent studies focus on the impacts of both the anthropogenic and natural variables in determining the occupancy of species (Drouilly et al. 2018, Feng et al. 2021). Feng et al. (2021) mentioned that the anthropogenic variables like cattle detection rate as well as active road played a significant negative role in the occupancy at community level in China while variables like distance to settlement, human detection rate, and NDVI affected the occupancy positively. In rangelands of Karoo, South Africa, Drouilly et al. (2018) reported increase in occupancy of mammals and ground birds with the increasing livestock detection while decreased with an increase in human presence

Human settlement also exerts a negative impact on the species occupancy (Schuette et al. 2013, Cavada et al. 2019, Salvatori et al. 2022). Drouilly et al. (2018) mentioned that elevation determined the increased species occupancy in rangelands; however, decreased detection of species inside the protected areas. Karanth et al. (2009) also observed a negative impact of elevation on the occupancy of 20 mammal species in India. Van der Weyde et al. (2018), in his study on carnivore guild in Kalahari, Western Botswana reported no fixed impact of any variables in occupancy of carnivores where the study used variables distance to protected areas, distance to commercial farms as well as livestock detection frequency. Distance to water is another variable that plays a significant role in species presence and is usually observed to have a negative impact in the species occupancy (Rich et al. 2016). However, several studies including Leweri et al. (2022) observed a weak but positive relationship between distance to water and occupancy of herbivores. Canopy cover or cover transparency also plays a significant role in occupancy probability of species. In the study of rainforest mammals by Whitworth et al. (2019) in Manu Biosphere Reserve, Peru it is observed that occupancy increases with the increase in canopy cover and decrease with forest disturbance. Similar impact of canopy cover on species occupancy was also observed in the study of nocturnal mammals in African rainforests by Laurance et al. (2008) and mammalian carnivores in Brazil by Regolin et al. (2017).

Seasonal variation also plays a significant role in species occupancy at community level by affecting the impact of variables (Nichols et al. 2008, Leweri et al. 2022). In the study of Leweri et al. (2022), herbivore occupancy remained relatively stable in regards to distance from streams during wet season while it was observed to have positive relation during the dry season. In same study, the occupancy was positively impacted by the distance from settlement during wet season and negatively during the dry season.

3. METHODS

3.1. Study Area

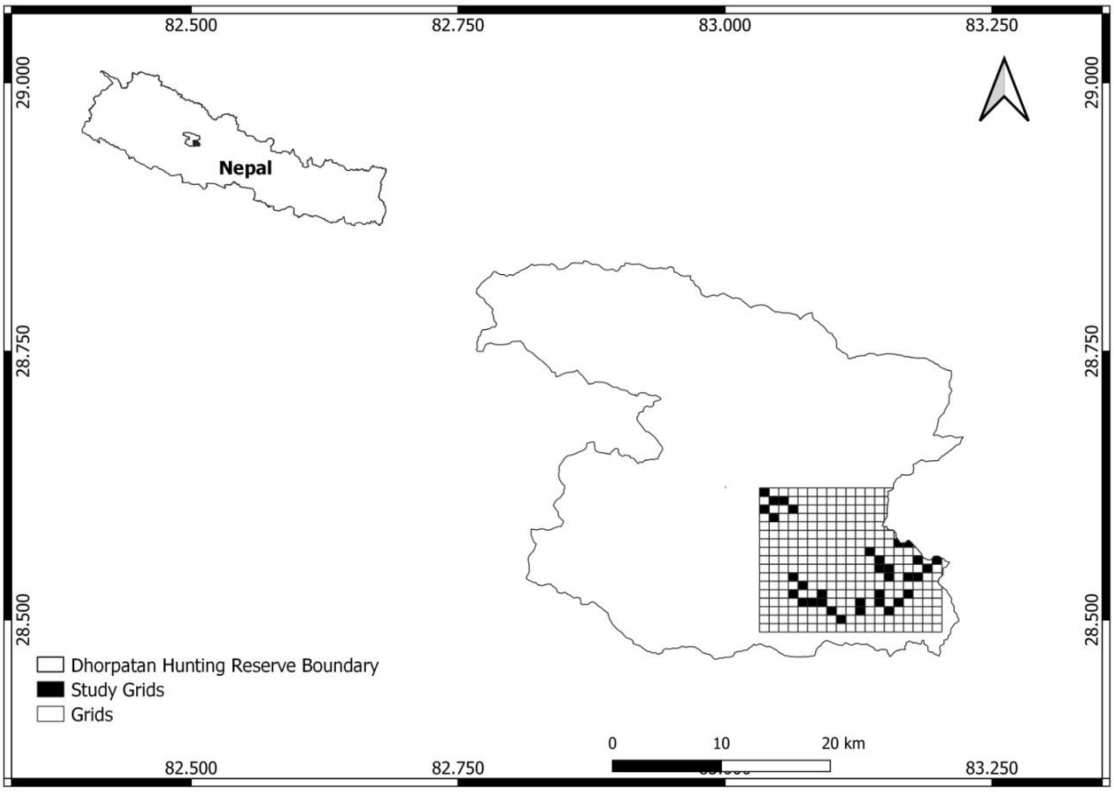


Figure 1: Study area at Dhorpatan Hunting Reserve, the grid size of 1 km × 1 km were designed for this study.

Dhorpatan Hunting Reserve (28°33'20"—28°48'00"N and 82°51'00" — 83°12'00"E) comprises an area of 1325 km^2 (Figure 1). It is the only hunting reserve of the country. DHR lies in Baglung, Myagdi, and Rukum districts in Dhawalagiri mountain range in western Nepal. The northern boundary of the reserve is marked by Putha, Churen and Gurja Himal. Dhorkhani, Jhalke and Lamakyang mountain ranges border the eastern region while Kharibanh khola, Pelma khola, Kulta, Bhanjyang and Jangla borders up in western region. Except for the northern side all other border regions of the reserve are bounded with villages. The DHR is situated within the elevational range from 3000-7000 m above sea level, with flat meadows above 4000 m, locally known as Patan, and is divided into seven blocks viz Surtibang(148 km^2), Barse (167 km^2), Fagune (327 km^2), Ghustung (201 km^2), Dogari (199 km^2), Seng (138 km^2), and Sundaha (145 km^2).

The reserve is attributed with alpine, subalpine and high temperate vegetation with mixed-hardwood forest including plant species like Rhododendron (*Rhododendron* *arboretum*), Pine (*Pinus roxburghii*), Fir (*Abies spectabilis*.), Birch (*Betula utilis*), Junipers (*Juniperus recurva*, *Juniperus indica*), Hemlock (*Tsuga dumosa*), Spruce (*Picea smithiana*), and Oak (*Quercus leucotrichophora*). At higher elevation more than 50% of the reserve is composed of pasturelands. Faunal diversity of the Reserve includes 32 mammal species such as Snow Leopard (*Panthera uncia*), Barking Deer (*Munticus vaginalis*), Blue Sheep (*Pseudois nayaur*), Himalayan Serow (*Capricornis tahr*), Himalayan Goral (*Naemorhedus goral*), Himalayan Serow (*Capricornis tahr*), Wild Boar (*Sus scorfa*), Leopard (*P. pardus*), Himalayan Black Bear (*Ursus thibetanus*), Red Panda (*Ailurus fulgens*), Wolf (*Canis lupus*), Rhesus Monkey (*Macaca mulatta*), and 149 avian species including Himalayan Monal (*Lopophorus impejanus*), and Cheer Pheasant (*Catreus wallichi*).

3.2 Data collection

3.2.1 Camera Traps

For identifying the presence and absence of species, a camera trap method was used in Fagune and Barse block of DHR. A total 290 plots of 1 km × 1 km were established within the study area for camera trap setting. A Stealth Cam (Model: STC-G45NG) was deployed randomly in 34 sites of 34 plots at the interval of approximately 1 km between two camera trap stations from March 15-June 15, 2022. The minimum required sample size (n = 37) for number of camera trap station was selected based on 95% confidence level at 15% margin of error (Krebs 2014), however, only 34 locations were used due to camera trap limitations and terrain location. . A total of 49 cameras were placed in 34 camera trap stations on 34 plots along the study area for 1190 trap days (34 stations * 35 days). Mostly the cameras were placed near the trials, water bodies and areas where species signs are found inside the grid. The camera traps were placed at the height of approximately 50-100 cm above the ground. Each camera was set in Photo Infrared (PIR) Photo mode with a setting to capture three photos at a time. Further, the PIR delay was set to 30 seconds, which is the delay in the time a camera takes to capture second set of pictures after capturing the first. This study took each week of the survey period as a single sampling occasion across the study area due to logistic and time factors. The array of cameras enclosed an area of 116 square kilometers. Only the data of wild mammal species detected was used for the study and detection of birds and other classes were discarded.

3.2.2 Covariates

The habitat covariates such as elevation, slope, aspect, number of livestock detected, forest canopy and ground cover, and nearest distance to water source and human settlement were recorded at each grid. Elevation (m) and coordinates of each camera trap station were recorded using Garmin GPSMAP64S. The slope (°) and aspect (°) were measured using a clinometer. The number of livestock detected was taken from the same camera traps. The forest canopy cover (%) was recorded using GLAMA (Gap Light Analysis Mobile Application) (Tichy 2016) and Canopeo app was used for ground cover vegetation (%) (Patrignani and Ochsner 2015). Canopy cover was measured using fisheye lens provided by GLAMA at 10 cm radius and ground cover was measured by clicking a downward photograph of the ground from the height of two meters. The nearest water distance and nearest human settlement were measured (m) using measuring tape, but if the distance is >200 m, the distance was measured using Google Earth. In addition, the Normalized Differentiated Vegetation Index (NDVI) for study site was calculated using satellite imageries and semi-automatic classification plugin (SCP) in QGIS. The captured animals were categorized under the IUCN Red List of Threatened Species (IUCN 2022).

3.3 Data Analysis

Data were filtered, arranged, and summarized using the packages dplyr and tidyverse in R Programming. The object data were created a matrix in which a species k denotes at least one detection at site i. The matrix contains the number of detection for each sampling replicate.

Correlation analysis was performed to identify whether the independent variables were highly correlated $|r| > 0.75$, and the correlated variables were discarded from the analysis. Among the variables NDVI and elevation (i.e. $r = -0.795$) were highly correlated (Appendix 1), therefore, NDVI was excluded. In addition, a Variation Inflation Factor (VIF) analysis was also done to identify the multi-collinearity between the variables. All covariates had VIF value below 5 (Appendix 2). Finally, selected covariates were used to develop a matrix of species presence for further analysis.

3.3.1 Stacked and Hierarchical Multi-species Occupancy

A Bayesian inferences approach was used for analysis. Stacked analysis was performed just by repeating a single-species occupancy model for 15 species following MacKenzie et al. (2002):

$y_{ij} \sim \text{Binomial}\ (\rho_k * z_{ik}, n_i)$

where,

$\rho_k \sim \text{Beta}\ (1,1)$

$z_{ik} \sim \text{Bernoulli}\ (\psi_k)$

$\psi_k \sim \text{Beta}\ (1,1)$

The hierarchial analysis was performed using the model of Royle and Dorazio (2008) in which the Beta was replaced prior for species-level ψ_k:

$\text{logit}(\psi_k) \sim \text{Normal}\ (\mu_{lpsi}, \sigma_{lpsi})$

The community-level hyperpriors were added in the following formula

$\bar{\psi} \sim \text{Beta}\ (1,1)$

$\mu_{lpsi} = \text{logit}\ (\bar{\psi})$

$\sigma_{lpsi} \sim \text{Uniform}\ (0,5)$

Both the analyses were subjected to Markov Chain Monte Carlo (MCMC) simulations to get the posterior distributions. A total of 12500 iterations were run for stacked and hierarchical analysis to get the posterior distributions. At the end the convergence of the MCMC output were noticed to identify whether the chains are mixed well. It was confirmed using trace plot diagnostics and Rhat value. If the optimal value of Rhat is <1.1, a further step in analysis was done until the Rhat became <1.05. Again the further step was decided with the value of probability (p) and naïve occupancy (psi) including mean and standard deviation of p and psi.

3.3.2 Hierarchical Analysis with Covariates

As the occupancy probability differs in regard to the sites, the occupancy was calculated for each species *k* at each site *i* using the following formula:

$logit\ (\psi_{ik}) = \beta_{0,k} + \beta_{cov,k}cov_i$

Where, the coefficients, β, differ between species. For this analysis, the species level priors are given as;

$\beta_{x,k} \sim Normal\ (\mu_x, \sigma_x)$, where μ_x and σ_x are the coefficients of random variable drawn from a normal distribution with mean and standard deviation to be estimated. Unlike previous two models where correlation between ψ and ρ was included, the correlation between β_0 and ρ was included where the intercept $\beta_{0,k}$, is the probability of occupancy of species k at a site with given combinations of covariates.

For community level hyperpriors a uniform Beta (1,1) prior for the probability was used and converted it to the logit scale.

$\bar{\beta}_0 \sim Beta\ (1,1)$

$\mu_0 = logit\ (\bar{\beta}_0)$

A uniform prior for the standard deviation (SD) was used as,

$\sigma_0 \sim Uniform\ (0,5)$

The coefficient value at logit scale will be around ± 5

Therefore,

$\mu_x = Uniform\ (-5, 5)$ and the SD is given by;

$\sigma_x = Uniform\ (0,5)$

For hierarchical analysis, an adaptive MCMC model with 50,000 iterations was run with three chains and 1000 adaptations.

All the occupancy analyses were done by using Just Another Gibbs Sampler in R Program (R Core Team 2022).

4. RESULTS

The camera traps of this study detected 15 mammal species belonging to eight families and four orders over the period of five weeks of camera trapping (Table 1; Photo Plates). Of the captured species only one species Red Panda has been categorized as an endangered species in IUCN Red list of threatened species. Three species are categorized as vulnerable, one near threatened, and remaining 10 is categorized as least concern in IUCN Red list of threatened species (Table 1). Similarly, according to the national red list series of Nepal 2018, two species were under the endangered species, three vulnerable, one near threatened, six were least concerned and the remaining three were under the category of data deficient (Table 1). The most observed species across the study was Red Fox (*Vulpes vulpes*) which was detected in total of 27 times across 16 sites, while the least observed species were Blue Sheep, Jungle Cat (*Felis chaus*), Hodgson's Giant Flying Squirrel (*Petaurista magnificus*) and Nepal Grey Langur (*Semnopithecus schistaceus*) which were recorded only once.

Table 1: Species name, species family, IUCN global status as well as national status of all the 15 species detected from March 15-June 15, 2022 in Dhorpatan Hunting Reserve, Nepal.

S.N	**Scientific Name**	**English Name**	**Family**	**IUCN Red List**	**National Red List (2018)**
1	*Ailurus fulgens*	Red Panda	Ursidae	EN	EN
2	*Canis aureus*	Golden Jackal	Canidae	LC	LC
3	*Capricornis sumatraensis*	Himalayan Serow	Bovidae	VU	DD
4	*Felis bengalensis*	Leopard Cat	Felidae	LC	VU
5	*Felis chaus*	Jungle Cat	Felidae	LC	LC
6	*Martes flavigula*	Yellow-throated Marten	Mustellidae	LC	LC
7	*Muntiacus vaginaliss*	Barking Deer	Cervidae	LC	VU
8	*Naemorhedus goral*	Himalayan Goral	Bovidae	NT	NT
9	*Panthera pardus*	Leopard	Felidae	VU	VU
10	*Petaurista magnificus*	Hodgson's Giant Flying Squirrel	Sciuridae	LC	DD
11	*Pseudois nayaur*	Blue Sheep	Bovidae	LC	LC
12	*Semnopithecus schistaceus*	Nepal Grey Langur	Cercopithecidae	LC	LC
13	*Sus scrofa*	Wild Boar	Suidae	LC	LC
14	*Ursus thibetanus*	Himalayan Black Bear	Ursidae	VU	EN
15	*Vulpes vulpes*	Red Fox	Canidae	LC	DD

EN - Endangered, VU - Vulnerable, NT - Near Threatened, LC -Least Concern and DD - Data Deficient

4.1 Stacked Occupancy Analysis (Species-level)

The Bayesian inference was run for the stacked analysis, which was visualized with good convergence between the MCMC chains for posterior distributions. All the parameters had a Rhat value below 1.05 (Table 2), which indicated that the parameters were successfully converged and were applicable to generate output.

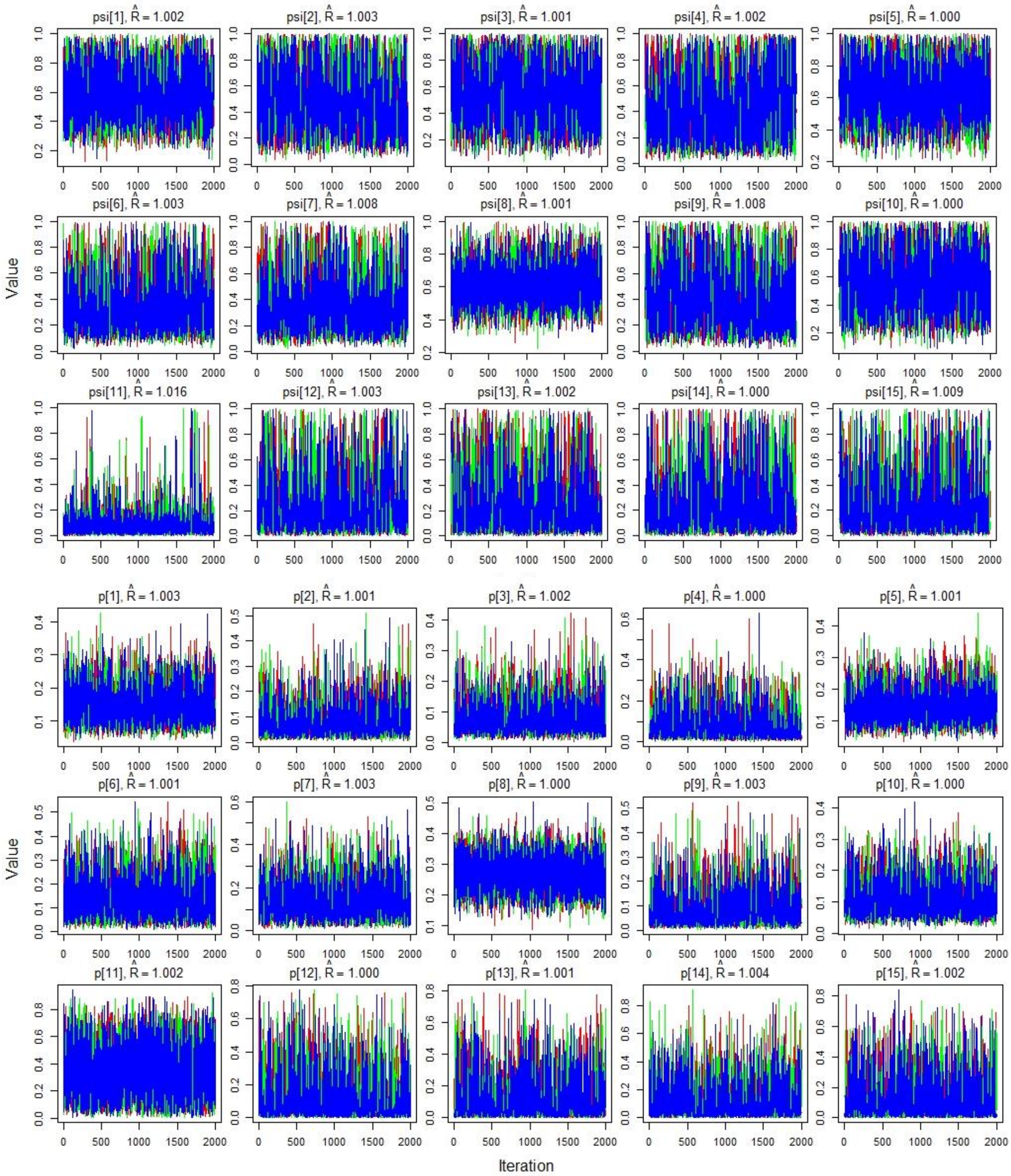


Figure 2: Trace plots visualizing the Markov Chain Monte Carlo (MCMC) convergence of detection probability (p) and naïve occupancy (psi).

Table 2: Detection probability (p) and naïve occupancy (psi) of species level occupancy analysis in Dhorpatan Hunting Reserve, Nepal.

	Detection probability (p)									**Naïve occupancy (psi)**								
Species Name	**Mu**	**SD**	**LCI**	**Md**	**UCI**	**Rhat**	**ESS**	**O**	**F**	**Mu**	**SD**	**LCI**	**Md**	**UCI**	**Rhat**	**ESS**	**O**	**F**
Barking Deer	0.149	0.057	0.064	0.140	0.281	1.003	711	0	1	0.589	0.186	0.277	0.569	0.956	1.002	808	0	1
Leopard	0.078	0.062	0.015	0.058	0.248	1.001	2210	0	1	0.502	0.250	0.117	0.472	0.966	1.003	733	0	1
Golden Jackal	0.080	0.054	0.019	0.064	0.226	1.002	2436	0	1	0.541	0.233	0.156	0.523	0.965	1.001	1569	0	1
Himalayan Black bear	0.079	0.070	0.012	0.056	0.280	1.000	5403	0	1	0.433	0.256	0.077	0.380	0.961	1.002	899	0	1
Himalayan Goral	0.144	0.053	0.066	0.135	0.270	1.001	3089	0	1	0.640	0.181	0.315	0.633	0.971	1.000	6000	0	1
Himalayan Serow	0.133	0.088	0.026	0.112	0.356	1.001	2303	0	1	0.357	0.217	0.085	0.297	0.900	1.003	781	0	1
Leopard Cat	0.133	0.088	0.026	0.111	0.344	1.003	776	0	1	0.360	0.219	0.083	0.299	0.904	1.008	378	0	1
Red Fox	0.266	0.058	0.160	0.263	0.386	1.000	6000	0	1	0.615	0.128	0.390	0.607	0.896	1.001	1775	0	1
Wild Boar	0.082	0.072	0.012	0.058	0.285	1.003	666	0	1	0.428	0.251	0.077	0.380	0.946	1.008	248	0	1
Yellow Throated Marten	0.106	0.056	0.036	0.093	0.250	1.000	6000	0	1	0.565	0.216	0.209	0.546	0.970	1.000	6000	0	1
Red Panda	0.329	0.200	0.028	0.309	0.741	1.002	860	0	1	0.100	0.119	0.009	0.066	0.451	1.016	722	0	1
Common Langur	0.118	0.137	0.004	0.060	0.510	1.000	2749	0	1	0.262	0.247	0.015	0.165	0.904	1.003	842	0	1
Jungle Cat	0.118	0.138	0.004	0.059	0.505	1.001	6000	0	1	0.269	0.253	0.017	0.166	0.902	1.002	1616	0	1
Giant Flying Squirrel	0.115	0.133	0.004	0.061	0.487	1.004	1302	0	1	0.264	0.250	0.016	0.165	0.906	1.000	5087	0	1
Blue Sheep	0.117	0.136	0.004	0.059	0.513	1.002	1033	0	1	0.263	0.249	0.014	0.165	0.894	1.009	320	0	1

Mean (Mu), standard deviation (SD), lower confidence interval (LCI), median (Md), upper confidence interval (UCI), Rhat, effective sample size (ESS), overlap0 (proportion of posterior with same size) and f statistics (f) of the distribution.

The highest detection probability was found for Red Panda (p = 0.33 ± 0.200) and followed by Red Fox (p = 0.27 ± 0.058). Whereas lowest detection probability was found for Himalayan Black Bear (p = 0.08 ± 0.070), Golden Jackal (p = 0.08 ± 0.054) and Leopard (p = 0.08 ± 0.062). The Himalayan Goral was recorded with the highest naïve occupancy (psi = 0.640 ± 0.181) and followed by Red fox (psi = 0.62±0.128), Yellow-throated Marten (psi = 0.60 ± 216), and Barking Deer (psi = 0.589 ± 0.186). The species with lowest naïve occupancy was observed for Red Panda (psi = 0.10) and followed by Nepal Grey Langur (psi = 0.26 ± 0.247), Hodgson's Giant Flying Squirrel (psi = 0.26 ± 0.250), Blue Sheep (psi = 0.26 ± 0.250) and Jungle Cat (psi = 0.30 ± 0.253).

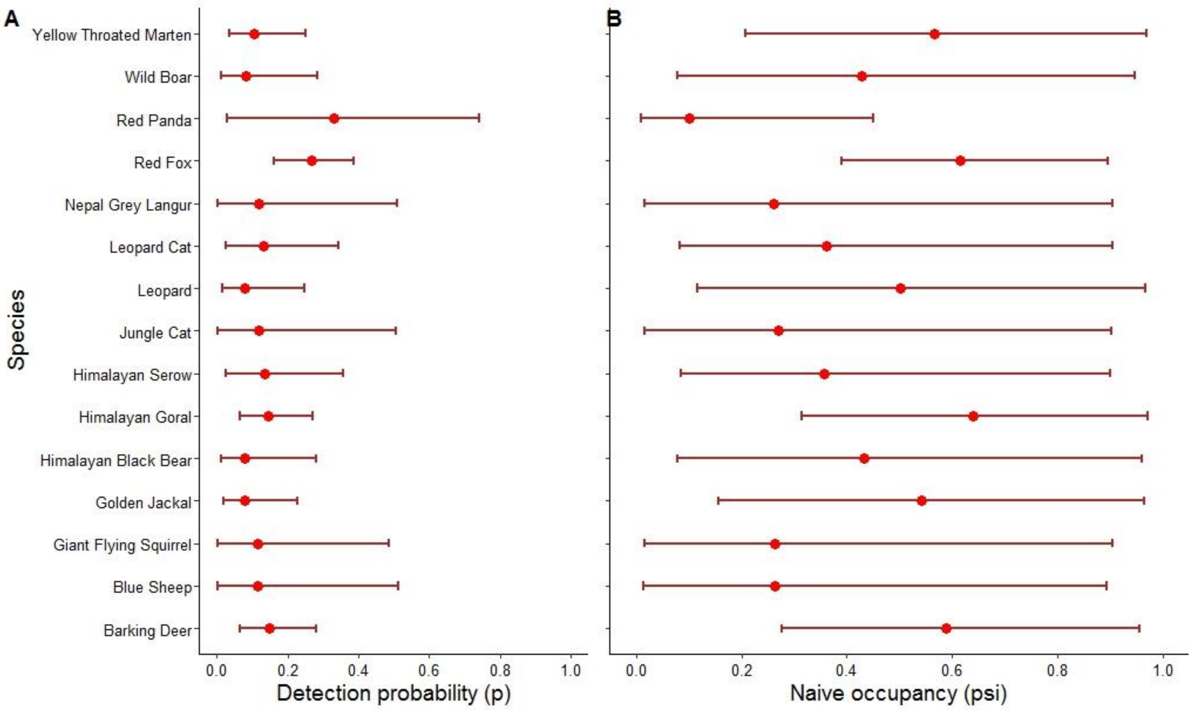
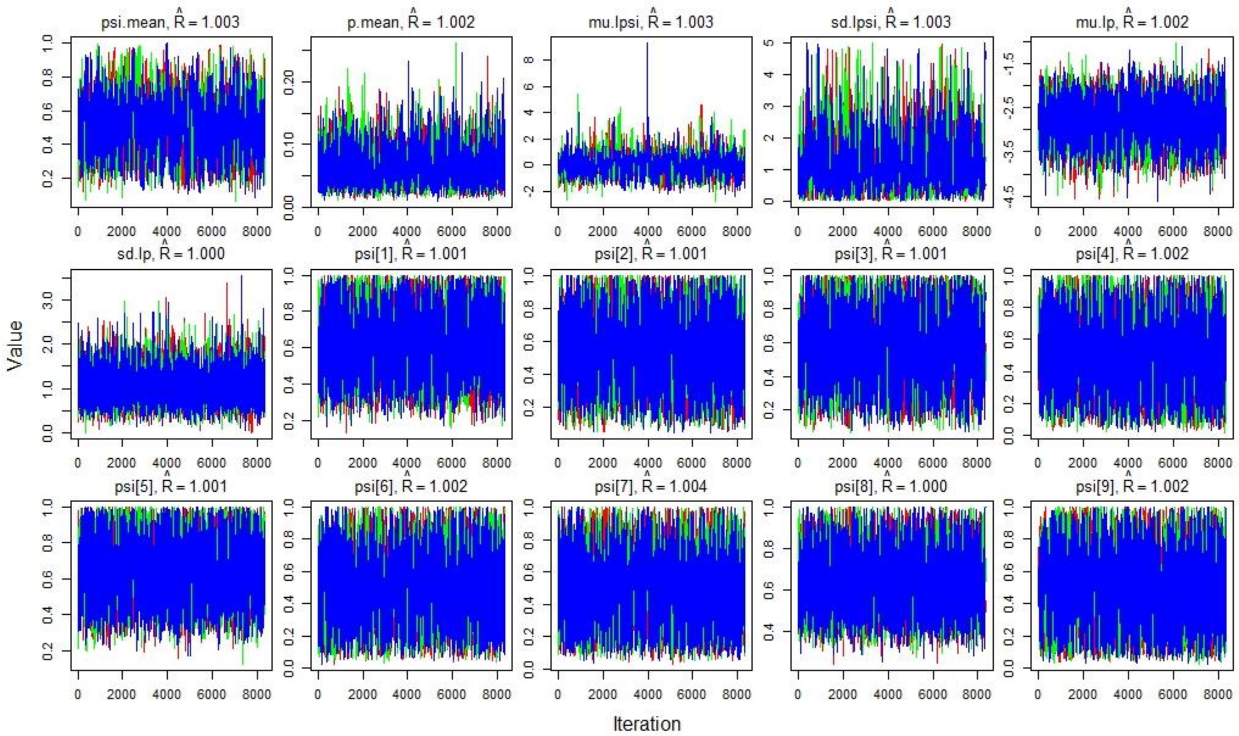
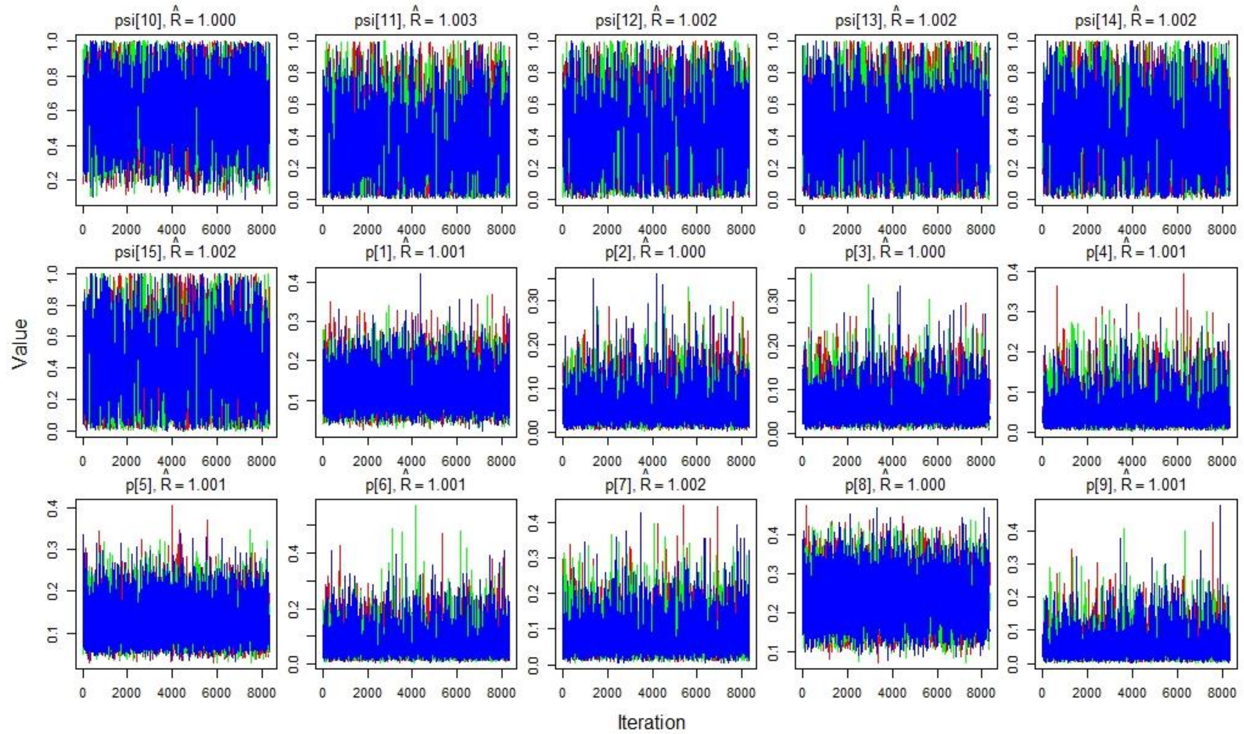


Figure 2: A- Detection probability (p) and naïve occupancy (psi) for each species across five replicate surveys. B- Naïve occupancy of each of the 15 species detected in Dhorpatan Hunting Reserve, Nepal.

4.2 Hierarchial Occupancy Analysis (Community-level)





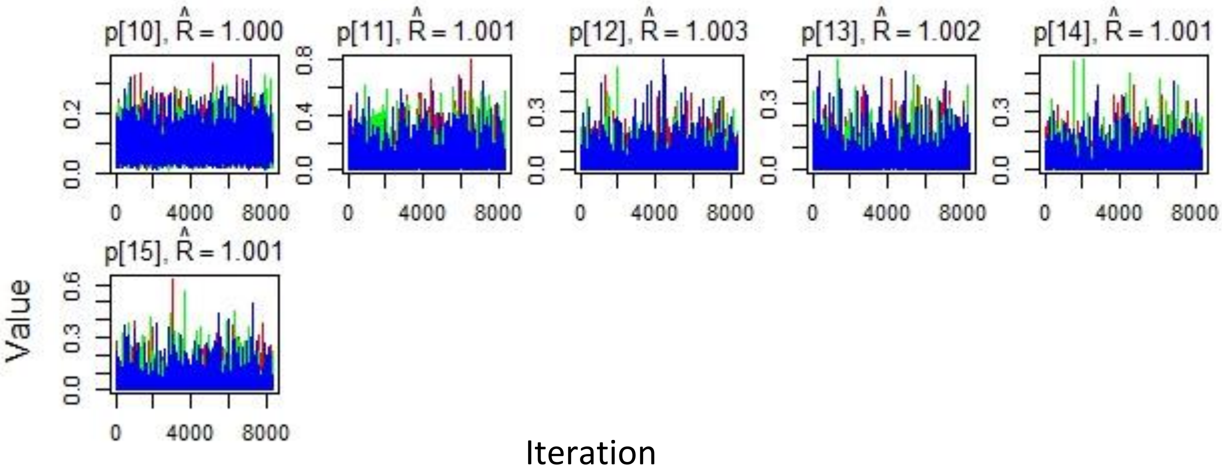


Figure 3: Traceplot for Markov Chain Monte Carlo convergence for hierarchical Bayesian inference. The plots reveal successful convergence of all the parameters.

Table 3: Community level occupancy estimates of occupancy for 15 mammal species from March 15 - June 15, 2022 in Dhorpatan Hunting Reserve, Nepal.

Parmeters	Mu	SD	LCI	Md	UCI	Rhat	ESS	O	F
psi.mean	0.516	0.158	0.232	0.508	0.861	1.003	670	0	1
p.mean	0.063	0.026	0.025	0.058	0.126	1.002	1136	0	1
mu.lpsi	0.099	0.767	-1.194	0.031	1.823	1.003	1037	1	0.52
sd.lpsi	1.075	0.788	0.059	0.940	3.066	1.003	1281	0	1
mu.lp	-2.785	0.439	-3.657	-2.783	-1.940	1.002	1035	0	1
sd.lp	0.971	0.339	0.401	0.936	1.751	1.300	7308	0	1

Mean (Mu), standard deviation (SD), lower confidence interval (LCI), median (Md), upper confidence interval (UCI), Rhat, effective sample size (ESS), overlap0 (proportion of posterior with same size) and f statistics (f) of the distribution.

In community level hierarchical analysis, the mean detection probability and mean naïve occupancy were found 0.063 ± 0.030 and 0.52 ± 0.16, respectively (Table 3, Figure 5). The highest deviation from the mean detection probability was found in Red Panda (p = 0.065 ± 0.065), and followed by Red Fox (p = 0.230 ± 0.056). The lowest deviation from the community level occupancy was found for Himalayan Black Bear (p = 0.050 ± 0.035) and followed by Leopard (p = 0.055 ± 0.034) and Golden Jackal (p = 0.059 ± 0.033). Furthermore, none of the species' detection probability was deviated below the range of mean community level detection probability. In addition, the higher fluctuation on each species was found in contrast to community level naïve occupancy. The highest deviation from naïve occupancy probability from the community was found in Himalayan Goral (0.65 ± 0.17) and followed by Red Fox (0.64 ± 0.14) and Barking Deer (0.62 ± 0.17). However, the lowest naïve occupancy probability was found for Red Panda (0.37 ± 0.24), and followed by Nepal Grey Langur, Giant Flying Squirrel, and Jungle Cat all with psi 0.42 ± 0.24. The naïve occupancy probability of all of these species was below the standard deviation range of mean community level naïve occupancy. The detection probability range from 0.04 to 0.23 means the community composition is comparatively heterogeneous and the naïve occupancy range between 0.37 to 0.65 means there is a comparatively high probability of occupancy change between the sites and replications.

Table 4: Detection probability (p) and naïve occupancy (psi) of the 15 species in a community level hierarchical occupancy analysis.

	Detection probability (p)									Naïve occupancy (psi)								
Species Name	**Mu**	**SD**	**LCI**	**Md**	**UCI**	**Rhat**	**ESS**	**O**	**F**	**Mu**	**SD**	**LCI**	**Md**	**UCI**	**Rhat**	**ESS**	**O**	**f**
Barking Deer	0.119	0.044	0.055	0.112	0.223	1.001	3577	0	1	0.623	0.174	0.323	0.606	0.977	1.001	2827	0	1
Leopard	0.055	0.034	0.014	0.046	0.145	1.000	8689	0	1	0.546	0.213	0.166	0.536	0.974	1.001	4328	0	1
Golden Jackal	0.059	0.033	0.018	0.052	0.143	1.000	4918	0	1	0.581	0.202	0.212	0.569	0.979	1.001	2569	0	1
Himalayan Black Bear	0.050	0.035	0.011	0.040	0.145	1.001	7108	0	1	0.515	0.222	0.126	0.507	0.968	1.002	1166	0	1
Himalayan Goral	0.121	0.042	0.058	0.115	0.221	1.001	4013	0	1	0.650	0.169	0.356	0.637	0.979	1.001	2427	0	1
Himalayan Serow	0.071	0.044	0.019	0.060	0.186	1.001	1784	0	1	0.505	0.213	0.144	0.492	0.955	1.002	1282	0	1
Leopard Cat	0.071	0.043	0.020	0.061	0.182	1.002	1144	0	1	0.500	0.210	0.140	0.488	0.947	1.004	492	0	1
Red Fox	0.228	0.056	0.130	0.225	0.348	1.000	24999	0	1	0.639	0.138	0.401	0.627	0.945	1.000	9330	0	1
Wild Boar	0.050	0.036	0.011	0.040	0.146	1.001	1886	0	1	0.513	0.223	0.121	0.505	0.964	1.002	960	0	1
Yellow Throated Marten	0.083	0.038	0.031	0.075	0.176	1.000	19336	0	1	0.598	0.190	0.258	0.584	0.977	1.000	4846	0	1
Red Panda	0.066	0.065	0.008	0.044	0.249	1.001	2230	0	1	0.367	0.240	0.029	0.345	0.875	1.003	677	0	1
Common Langur	0.041	0.040	0.005	0.028	0.150	1.003	1444	0	1	0.418	0.240	0.041	0.417	0.920	1.002	1249	0	1
Jungle Cat	0.041	0.040	0.004	0.028	0.150	1.002	1898	0	1	0.422	0.242	0.043	0.416	0.925	1.002	1254	0	1
Giant Flying Squirrel	0.041	0.040	0.004	0.028	0.151	1.001	3663	0	1	0.419	0.241	0.041	0.416	0.926	1.002	975	0	1
Blue Sheep	0.040	0.040	0.004	0.028	0.147	1.001	2413	0	1	0.427	0.244	0.043	0.424	0.938	1.002	864	0	1

Mean (Mu), standard deviation (SD), lower confidence interval (LCI), median (Md), upper confidence interval (UCI), Rhat, effective sample size (ESS), overlap (O) and proportion of posterior with same size as mean (f).

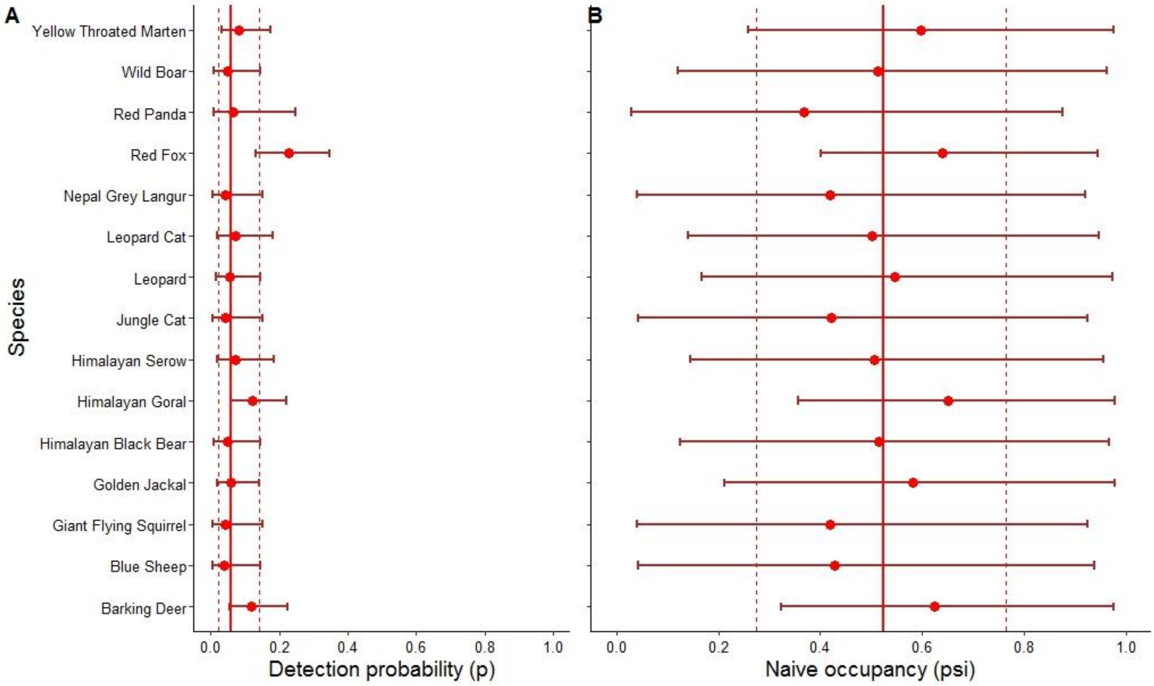


Figure 4: Detection probability and naive occupancy derived from a community level hierarchical occupancy analysis Dhorpatan Hunting Reserve, Nepal.

4.3 Effects of Covariates

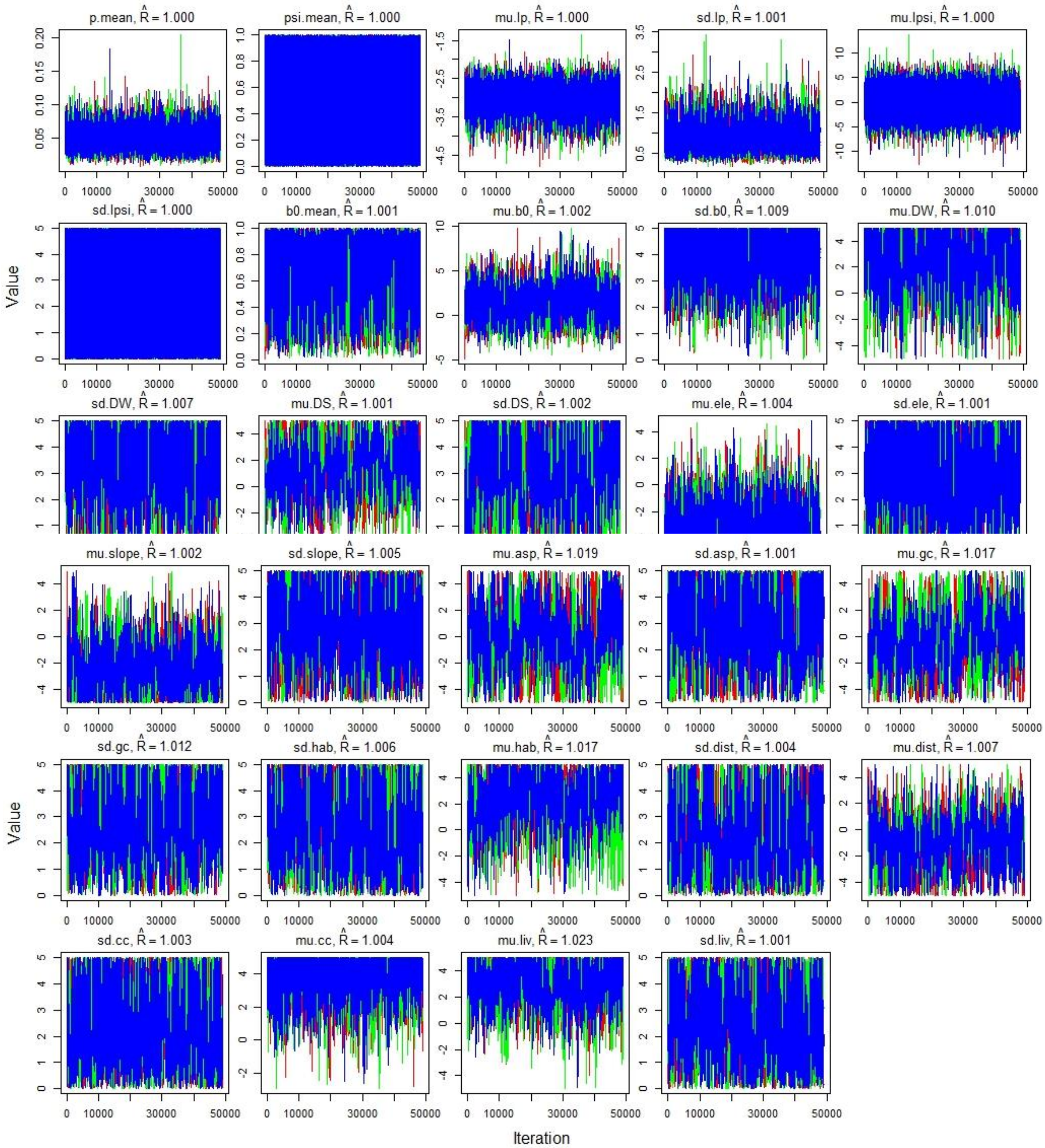


Figure 5: Traceplot for Markov Chain Monte Carlo convergence for hierarchical Bayesian inference for covariates. The plots reveals successful convergence of all the parameters (Rhat>1.1).

The average distance from the water sources across the study plots was 485.22 ± 560.3 m while the average distance from nearest human settlement was 1592.90 ± 1205.24 m. The average elevation of the study plots was 3552.74 ± 347.72 m above sea level and that of slope was 21.79 ± 11.65°. In case of aspect and ground cover, the mean values were 117.65 ± 110.70° and 21.79 ± 20.30%, respectively. Relatively higher range of variation was observed in mean number of livestock detected (24.82 ± 47.28) and mean canopy cover (21.09 ± 22.16%). The study revealed that the covariates the nearest distance to water sources, human settlement, forest canopy cover, and number of livestock detection had positive impact on the community level species occupancy (Table 5). The highest positive impact was found for forest canopy cover (3.82 ± 1.04), and followed by number of livestock detection (2.56 ± 1.64). Elevation, slope, aspect and ground cover exerted a negative impact on the community level occupancy. Of which, the highest negative impact was found for the elevation (-3.15 ± 1.34), and followed by slope (-2.26 ± 1.77; Table 5).

Table 5: Community-level summaries of covariates for occupancy probabilities of 15 mammal species.

Covariates	**Mu**	**SD**	**LCI**	**Md**	**UCI**	**Rhat**	**ESS**	**O**	**F**
Distance (water)	2.543	1.698	-1.158	2.719	4.908	0.100	96	1	0.917
Distance (settlement)	1.238	1.975	-2.578	1.380	4.398	1.032	49	1	0.719
Elevation	-3.152	1.342	-4.949	-3.431	0.199	1.042	39	1	0.958
Slope	-2.261	1.773	-4.888	-2.637	1.661	1.007	96	1	0.885
Aspect	-0.363	2.039	-4.341	-0.364	3.669	0.100	96	1	0.531
Ground cover	-0.162	1.956	-3.685	0.112	3.561	1.047	39	1	0.479
Canopy cover	3.817	1.040	1.545	4.015	4.957	1.025	96	0	0.990
Livestock detected	2.559	1.639	-1.322	2.731	4.860	1.015	96	1	0.906

Mean (mu), standard deviation (SD), lower confidence interval (LCI), median (md), upper confidence interval (UCI), Rhat, effective sample size (ESS), overlap (O) and proportion of posterior with same size as mean (f) of distribution.

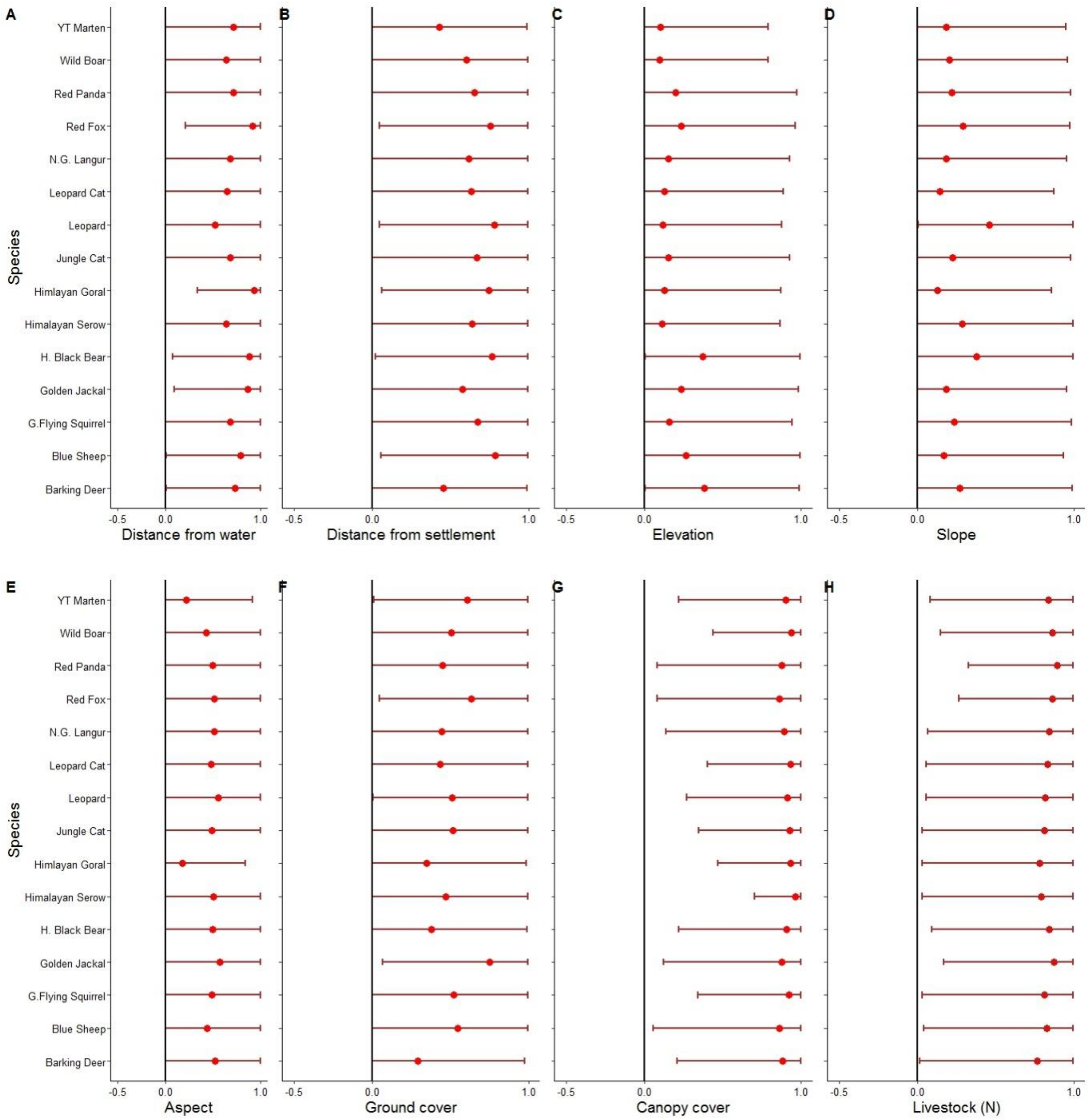


Figure 6: Caterpillar plots showing the effect size of the covariates on each species detection from March 15 - June 15, 2022 in Dhorpatan Hunting Reserve, Nepal (YT Marten: Yellow-throated Marten, NG Langur: Nepal Grey Langur, HB Bear: Himalayan Black Bear, GF Squirrel: Giant-flying Squirrel).

During this study, all species had positive correlation to the distance from water except for Leopard (intercept = -0.11, Bayesian Confidence Interval (BCI) = -2.58 – 67.28), which observed a slight decline in occupancy as the distance from water body increases. Nepal Grey Langur's occupancy (2.39, BCI = -4.80 - 7.73) increased the most as the distance from water body followed by Red Panda (intercept = 2.04, BCI = -3.73 –8.80) and Giant Flying Squirrel (intercept = 1.98, BCI = -5.55 – 8.54). While for Barking Deer (intercept = 2.01, BCI = -3.74 – 7.7), Red Fox (intercept = 4.47, BCI = -0.82 – 9.21) and

Yellow- throated Marten (intercept = 2.25, BCI = -4.15 – 6.49), the impact of nearest water distance to water sources stayed relatively constant. The occupancy of almost all species increased with the increasing in distance from human settlement where it remained relatively constant for Red Fox (intercept=1.76, BCI = -2.83 – 6.63). A steep decline was observed in the occupancy of Yellow-throated Marten (-1.2, BCI = -8.63 – 3.98) with the increase in the distance. The occupancy of almost all species fell sharply with the increase in elevation except Barking Deer (intercept=-0.48, BCI = -4.26 – 4.15). Just a slight decline in occupancy of Red Fox was observed with the increase in elevation (intercept=-2.28, BCI = -6.79 – 2.39).Similar impact was observed to have been exerted by slope on species occupancy except that of Barking Deer (intercept=-1.34, BCI = -6.54 – 4.39), Red Fox (intercept=-1.20, BCI = -5.20 – 3.21) and Leopard (intercept=-0.12, BCI = -2.25 – 6.14) which remained relatively constant.

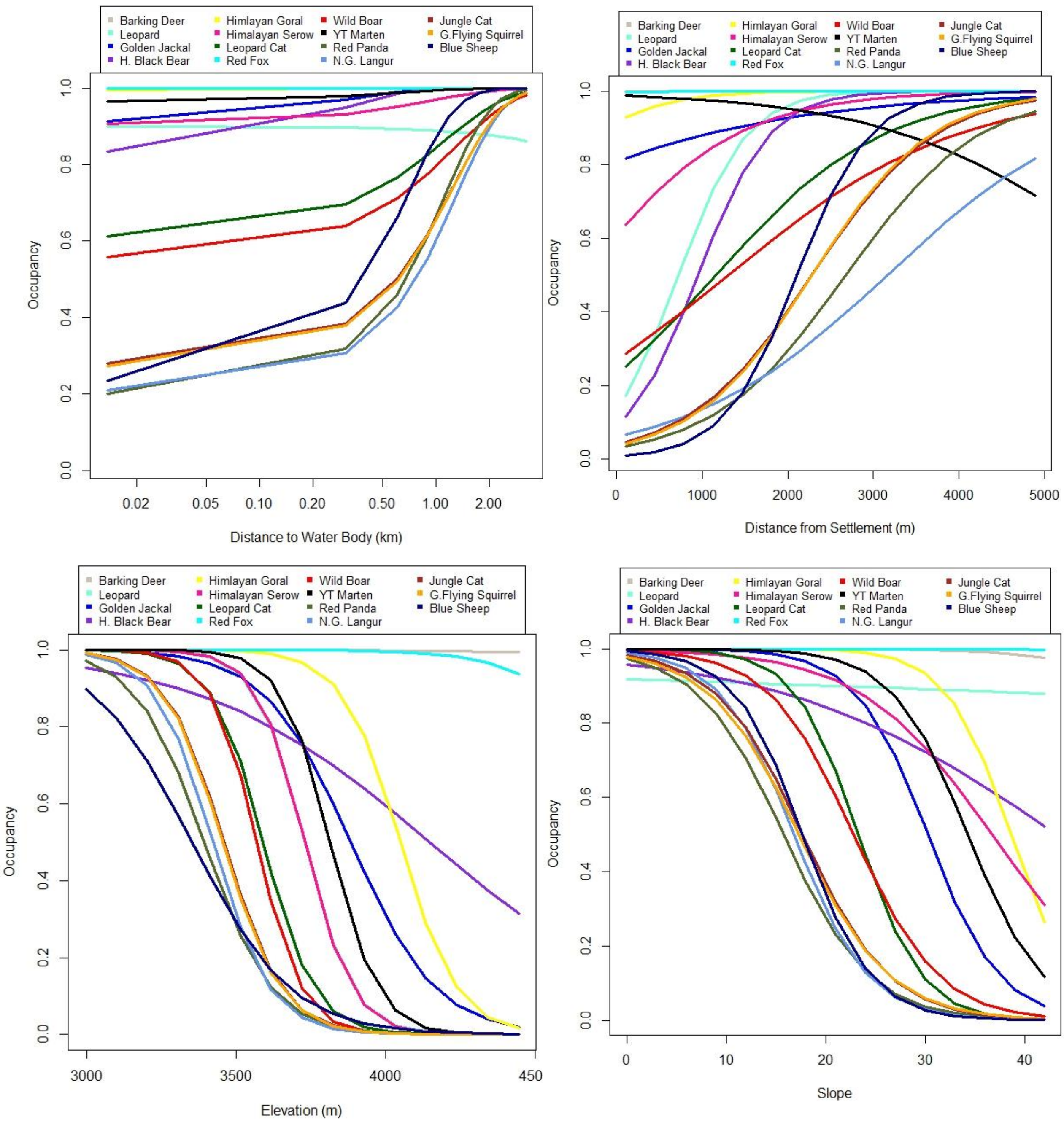


Figure 7: Effects of covariates distance to water, distance to settlement, elevation and slope on occupancy of 15 mammal species in Dhorpatan Hunting Reserve, Nepal (YT Marten: Yellow-throated Marten, NG Langur: Nepal Grey Langur, HB Bear: Himalayan Black Bear, GF Squirrel: Giant-flying Squirrel)

The mixed impact was found for aspect and ground vegetation on species occupancy. In both cases Barking Deer (aspect = 0.59, BCI = -4.36 – 6.94, ground cover = -1.87, BCI = -7.11 – 3.06) and Red Fox (aspect = 0.52, BCI = -6.86 – 5.72, ground cover = 1.05, BCI = -2.85 – 5.44)] had no effect. The occupancy of Yellow-throated Marten (intercept = -2.52, BCI = -8.88 – 2.47), Himalayan Goral (intercept = -3.44, BCI = -8.12 – 1.38) and Golden Jackal (intercept = 0.85, BCI = -4.92 – 7.21) was declined with the increase in aspect.

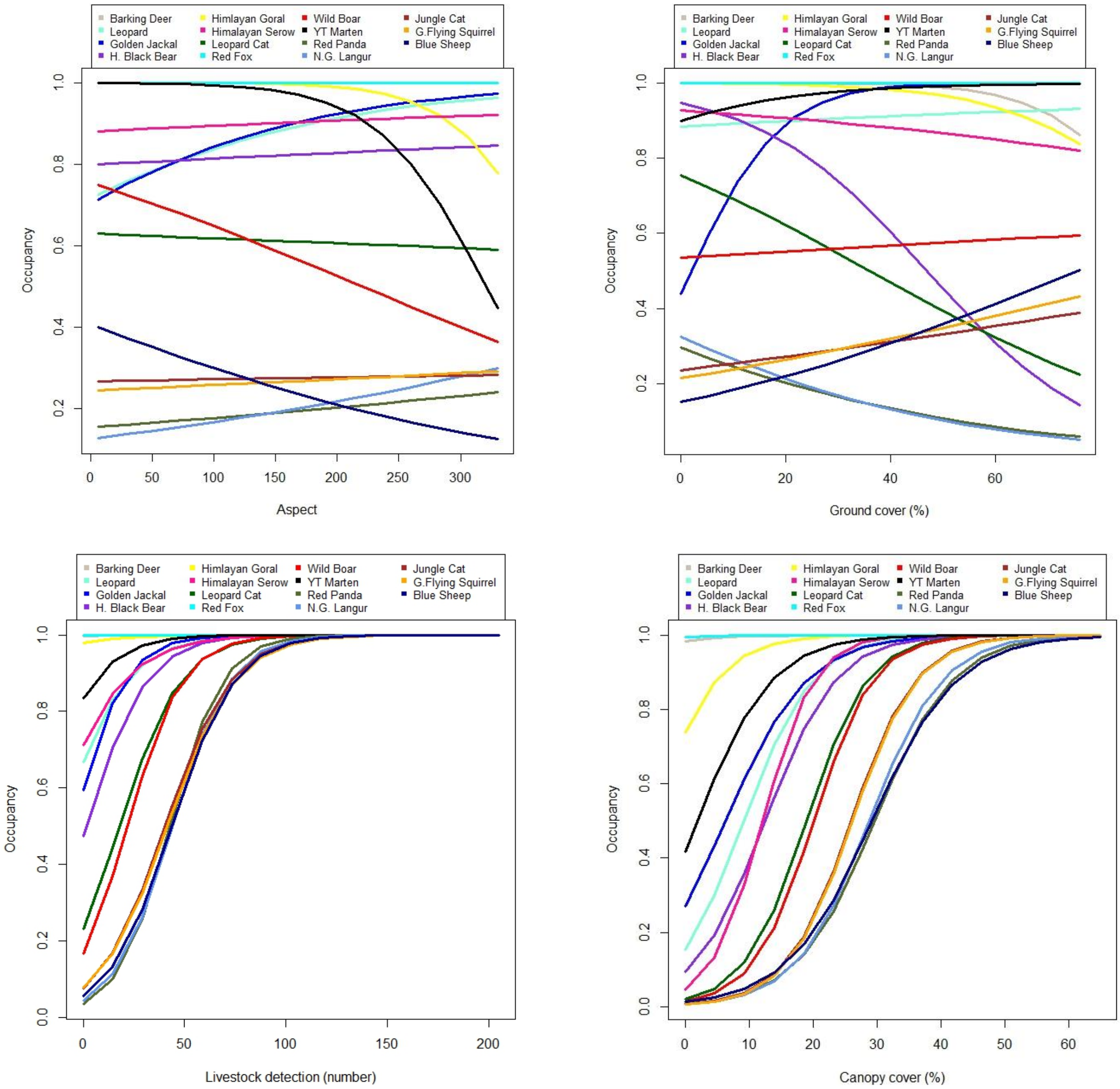


Figure 8: Effects of covariates aspect, ground cover, livestock detection number and canopy on occupancy of 15 mammal species in Dhorpatan Hunting Reserve, Nepal (YT Marten: Yellow-throated Marten, NG Langur: Nepal Grey Langur, HB Bear: Himalayan Black Bear, G Flying Squirrel: Giant-flying squirrel).

Occupancy of all species increased with increase in number of livestock detected at the site except for Red Fox (intercept = 2.95, BCI = -0.85 – 7.23) and Himalayan Goral (intercept = 2.34, BCI = -2.47 – 7.14), and similar case was also found in occupancy of species with response of canopy cover except for Red Fox (intercept = 3.67, BCI = -1.07 – 8.16), Barking Deer (intercept = 3.41, BCI = 0.56 – 8.26) and Himalayan Goral (intercept = 4.66, BCI = 0.94 – 11.86). The occupancy of Red Fox and Barking Deer was not affected by any of the covariates which indicated that they were widely distributed across the study area.

5. DISCUSSION

This study used presence absence camera trap data and Bayesian inference to analyze multi-species occupancy dynamics of 15 species of wild mammal as well as impact of associated natural and anthropogenic variables across the 1190 camera trap days in an area of 116 km^2 in DHR, Nepal. The study confirmed the higher heterogeneity of mammal species in the study area. The high value of standard deviation except for elevation means that the study plots also were highly heterogeneous in the variable composition. Both natural and anthropogenic variables are affecting the species occurrences. The study also identified a lesser to no effect of the environmental variables on the species like Red Fox, Barking Deer and Himalayan Goral. These species are widespread species (Jnawali et al. 2011) therefore, no major impact of these variables was observed.

Distance to water source, number of livestock detected, slope, and distance to nearest human settlement had distinct impact on the occupancy of the species detection. The variables exerted a mixed impact on the occupancy both at species and community level. Occupancy of all species in this study increased with the increase in distance to water sources except for the Leopard which might be due to sparsely located water bodies as well as presence of human settlements near the water bodies. In general however, occupancy of mammal species usually increases with the decrease in distance from water source (Rich et al. 2016), as it is one of the crucial resources for all the species. This trend is also prominent in herbivores during dry season (Leweri et al. 2022). The reason behind the decrease in occupancy with increase in water distance for Leopard might be due to it being an ambush hunter and prefers to stay close to water body to hunt prey species (Constant et al. 2015). Occupancy of all species increased with the increase in distance from human settlement except for Yellow Throated Marten. The increase in occupancy of all species with the increase in distance from human settlement generally relates with the increase of anthropogenic disturbance as human settlements offer different threats to wildlife like poaching as well as guard dogs (Schuette et al. 2013, Cavada et al. 2019, Salvatori et al. 2022). The impacts of hunting and poaching pressure is rather common observation in case of ungulates (Soh et al. 2014). Carnivores also prefer to roam away from settlements and are observed to avoid possible human encounters to avoid retaliation from local farmers (Kalle et al. 2013, Pia et al. 2013, Drouilly et al. 2018). The decrease in occupancy of Yellow Throated Marten with increase in distance from human settlement correlates to its prey preference as it prefers small livestock prey species like avian livestock (Baral et al. 2021), and human associated small mammal prey species like Rats (*Rattus rattus*) (Parr and Duckworth 2007, Zhou et al. 2008).

This study observed a decline in occupancy of almost all species with increase in elevation. At fine spatial scale and at higher elevation the abundance and species occurrence generally decrease (Brown 2001). This decrease in occupancy might be because of the scarcity of resources as well as low species diversity in the higher elevations due to higher endemism in higher elevations (Karanth et al. 2009). However, emphasizes of these studies might not be the case for all species, especially for more specialist species (Karanth et al. 2009, Drouilly et al. 2018). It can also be linked to other factors associated with elevation like atmospheric pressure, vegetation pattern, and temperature (Brown 2001) which generally become less favorable in higher altitudes. In case of slope, the occupancy of almost all species decreased with the increase in slope. Increase in occupancy with decrease in slope might be due to the difficulty as well as inaccessibility of the terrain (Mann et al. 2020, Pal et al. 2021) except for some rare species like Blue Sheep. Aspect and ground cover, however, exerted a mixed effect on the species. Ground cover usually provides suitable habitats for ground-dwelling mammals (Lunney et al. 1987, Griffiths and Brook 2014) and grazers (Heaton et al. 2022).

Number of livestock detection was observed to influence the species occupancy positively with a sharp increase in response. It might be due to common sharing of grazing grounds between livestock and wild herbivores or presence of both prey and carnivore species in the same habitat (Kalle et al. 2013). The DHR is one of the pastureland, therefore, local people or people near to the reserve leave their livestock for grazing which might support the co-existence of wild mammal species and livestock. The increase in forest canopy cover supported the increase in the occupancy of almost all species in this study. It might be due to their preferences towards dense habitat potentially to avoid human disturbances and hiding place with predators (Laurance et al. 2008, Regolin et al. 2017, Whitworth et al. 2019). The dense vegetation provides a better hideout for prey species as well as ambushing spots for predators (Monroy-Vilchis et al. 2009).

The occupancy of Barking Deer, Red Fox and Himalayan Goral remained relatively stable across all variables, which might be due to higher species abundance as well as the ecological aspects of the species in the study area. These species are observed to have widespread distribution range across Nepal (Jnawali et al. 2011). Higher site occupancy for Barking Deer was observed in the area where low impacts of variables are noticed (Letro et al. 2022). The occupancy of Red Fox was also high across different study sites in Tieqiaoshan Nature Reserve, China (Vitekere et al. 2020) with less extinction probabilities in sites (Vitekere et al. 2020) as well as relatively stable impacts of associated variables (MacDougall and Sander 2022). Himalayan Goral is also one of the species with higher occupancy across the study area and was observed to le less impacted by the variables involved. This might be due to the lesser preference of elevation by the species as well as low selectivity of the habitat (Bhattacharya et al. 2012).

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

A highly heterogeneous mammalian community was observed in DHR during this study period. At community level, the highest detection probability was observed for Red Panda while the highest naïve occupancy was observed for Himalayan Goral. The lowest detection probability was observed for Blue Sheep and the lowest naïve occupancy was for Red Panda. Environmental variables such as distance to water and canopy cover were observed to have positive impact on community level occupancy while elevation, slope, aspect and ground cover were observed to have a negative impact on the community level occupancy. Both the anthropogenic variables considered in the study, livestock detection and distance from settlement were observed to have a positive impact on the community level occupancy of the mammals in DHR which exemplifies a possibility of co-existence between human and wildlife community.

6.2 Recommendations

Based on the results, this study recommends a multi seasonal study on community level as some seasonal species might go undetected in a single season study. The study also recommends of extending the boundary of this research's study incorporating larger spatial scale. A proper management and monitoring plan with a regulated livestock grazing and human intervention is required to ensure a sound co-existence between wild mammals and human.

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APPENDIX

Appendix 1: Correlation table between the variables taken between March 15 – June 15 in Dhorpatan Hunting Reserve.

	Elevation (m)	Slope (°)	Aspect (°)	Canopy Cover (%)	Ground Cover (%)	Distance (Water) (m)	Distance (Settlement)(m)	NDVI	Livestock (n)
Elevation (m)	1.000	0.216	-0.063	-0.698	-0.306	0.586	0.110	-0.795	-0.130
Slope (°)	0.216	1.000	-0.123	-0.123	-0.248	0.150	-0.065	-0.048	-0.136
Aspect (°)	-0.063	-0.123	1.000	-0.111	-0.028	-0.387	-0.045	-0.034	0.108
Canopy Cover (%)	-0.698	-0.123	-0.111	1.000	0.205	-0.290	0.052	0.774	0.014
Ground Cover(%)	-0.306	-0.248	-0.028	0.205	1.000	-0.087	-0.054	0.250	-0.056
Distance (Water) (m)	0.586	0.150	-0.387	-0.290	-0.087	1.000	0.306	-0.470	0.142
Distance (Settlement) (m)	0.110	-0.065	-0.045	0.052	-0.054	0.306	1.000	-0.063	0.190
NDVI	-0.795	-0.048	-0.034	0.774	0.250	-0.470	-0.063	1.000	0.053
Livestock (n)	-0.130	-0.136	0.108	0.014	-0.056	0.142	0.190	0.053	1.000

Appendix 2: Collinearity analysis table for the variables taken during study.

Variables	Tolerance	Variance Inflation Factor (VIF)
Elevation (m)	0.231	4.333
Slope (°)	0.667	1.498
Aspect (°)	0.658	1.519
Canopy Cover (%)	0.292	3.422
Ground Cover (%)	0.828	1.208
Distance (Water) (m)	0.395	2.531
Distance (Settlement) (m)	0.661	1.513
NDVI	0.229	4.372

PHOTO PLATES


Blue Sheep


Barking Deer


Himalayan Goral


Jungle Cat


Hodgson’s Giant Flying Squirrel


Leopard


Himalayan Black Bear


Wild Boar


Red Panda


Himalayan Serow


Nepal Grey Langur


Leopard Cat


Golden Jackal


Yellow Throated Marten


Red Fox