PATTERNS OF MAMMALIAN ASSEMBLAGES IN FORESTED RIVERSCAPE IN KOYNA WILDLIFE SANCTUARY, THE NORTHERN WESTERN GHATS, INDIA

A THESIS

Submitted by

SHAH NAWAZ JELIL

For the award of the Degree of

DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE

Under the Guidance of

Dr. K. RAMESH (Supervisor)

Dr. MATT W. HAYWARD (Co-supervisor)

Wildlife Institute of India, Dehradun

Saurashtra University

Rajkot - 360 005

AUGUST, 2021

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DECLARATION

I hereby declare that the work conducted under the thesis entitled "**Patterns of mammalian assemblages in forested riverscape in Koyna Wildlife Sanctuary, the northern Western Ghats, India**", is a record of original research work, done by me and subsequently submitted for the award of the degree of doctor of Philosophy in Wildlife Science to Saurashtra University, Rajkot. This research work has been carried out under the guidance and supervision of Dr. K. Ramesh, Scientist-E, Wildlife Institute of India, Dehradun and co-supervision of Dr. Matt W. Hayward, Associate Professor, University of Newcastle, Australia. The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation and understanding and the particulars given in it are true to the best of my knowledge.

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Shah Nawaz Jelil

Place: WII, Dehradun

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CERTIFICATE

This is to certify that the thesis by **Mr. Shah Nawaz Jelil** entitled **'Patterns of mammalian assemblages in forested riverscape in Koyna Wildlife Sanctuary, the northern Western Ghats, India'**, is an original and independent research work submitted to the **Saurashtra University, Rajkot (Gujarat)**, for the award of the degree of **Doctor of Philosophy** in **Wildlife Science**.

Mr. Shah Nawaz Jelil has put more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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To whom it may concern

Re.: Confirmation of the original research of Shah Nawaz Jelil

This is to certify that Mr. Shah Nawaz Jelil has produced original research in this thesis entitled 'Patterns of mammalian assemblages in forested riverscape in Koyna Wildlife Sanctuary, the northern Western Ghats' for the award of the PhD degree submitted to Saurashtra University, Rajkot (Gujarat). I attest that Mr. Jelil has invested more than six terms of research, which is embodied in this thesis under my co-supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

It has been a privilege to co-supervise his research.

Yours sincerely

Matt

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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DEDICATION

To my late parents

Sara Begum

Teacher, author, lifelong ailing yet a fierce mother

&

Abdul Jalil

Humble office clerk, labour union leader, cancer fighter and a devoted father

ACKNOWLEDGEMENT

This thesis (and my research career) would not have been possible without the support of scores of motivating people and organizations. The chief person amongst them is of course Dr. Ramesh Krishnamurthy, my principal PhD supervisor. Dr. Ramesh picked me up and offered me an opportunity when I was in dire need and starting to question my research capacity. I am and will always be indebted to him. He has tried to provide direction and stability amongst all. I hope I have been able to heed his advice and apologize if I still seem a tad unstable and hurried in my decisions. The Wildlife Institute of India gave me the confidence, lovely company of fellow researchers and the research setting which came to me at the right time in my life. Secondly, I am indebted to Dr. Matt Hayward for unfailingly supporting my research ambitions since my masters in 2015. All other scientists at WII have been supportive and some have provided crucial inputs in the thesis.

In the field, Dr. Clement Ben, Ms. Vinita Vyas, Mr. Satyajit Gujar, Mr. Samadhan Chavan, Mr. Uttam Sawant, Mr. M. Mohite, all ACFs, and RFOs of Sahyadri Tiger Reserve have cooperated well, provided necessary logistics and supported my field data collection, as and when necessary. In the field while exploring Koyna and collecting data, all beat guards and watchmen, especially the boatman Mr. Ramesh Zendekar have been amazingly helpful and have unfailingly held my hand all along the way. This was vital for successful and timely data collection. Special thanks to my multipurpose field assistants Sandeep and Akshay for helping me out in so many ways.

Field and lab mates at the Wildlife Institute, Avinash, Rabi, Goutham, Nazrukh, Kamna, Natasha, Anurag, Surabhi S, Surabhi W, Orvil, Karthik, Vaishali, Sankarshan da, Raj Sekhar da, Tanvi, Deepti, Meghna, Arun, Ankita di, Tryambak, and Alljo have all been supportive in their respective capacities and have made my time at the institute and in the field enjoyable and something that I will cherish for life. Special thanks to Vaishali for contributing intellectually to the spatial prioritization chapter (Chapter VII) and helping out with the spatial analysis and writing of the chapter. My heartfelt thanks goes out to Ashish, Rahul and Priyanka for assisting in administrative tasks. From assisting in applying for and receiving field allowance, fellowship and extension of tenure every year in a timely manner, their help has been vital. The humble villagers of Helwak, Koynanagar and Patan have eased my time in the field. It was sort of a culture shock for me in the beginning; however, the time that I have spent in the state would suggest that I have handled it quite well. The Marathas are a proud and generous and caring people. They have always welcomed me and tried to include me as part of their rich tradition. Away from the institute, Dr. Kuladip Sarma, Dr. Bidyut Sarania, Dr. Narayan Sharma, Dr. Kripaljyoti Mazumdar, Dr. Jaydev Mandal, Mr. Sudipta Nag, Dr. Anjan Sangma, Dr. Prasanta Kumar Saikia, Dr. Malabika Kakati Saikia, Dr. Bhrigu Prasad Saikia have always been pleasant and supportive of my research.

On a more personal note, my PhD life, surely, has not been easy. I registered for my PhD in 2018 during which my father had been diagnosed of oral cancer and had to undergo chemotherapy and later that year, also had to remove his gall bladder. I had to miss some of my classes and some research time while taking care of him back home. I am indebted to Dr Ramesh for granting me time away from work. In 2019, my

father's cancer had resurged and metastasized into lung cancer and he finally passed away in April that year. If these two years were not difficult enough, 2020 came with possibly the worst pandemic that any of us have had to face in our lifetime. Overcoming these days and carrying on with my thesis would not have been possible without the support of an indomitably spirited brother, extended family and friends. Also, Drs. Ramesh and Hayward have been exceptionally patient with me during these years, for which I am highly obliged to them. I deeply value the support and patience which I needed to bounce back every time. My family, especially my brother, have been supportive of my time away from home, especially during my father's demise during my second year of PhD in 2019. He bore almost all of the family responsibilities and tried to de-burden me as much as possible, and I will always be thankful to him for that. I owe thanks to friends and colleagues outside of the institute who have always held on to me, Pranjal, Shakeel, Pranoy, Murchana, Rashmi (not in any order).

Finally, the beauty of Sahyadri has captivated me every single day from the very first day that I arrived in January 2017. It remains one of the lesser-studied landscapes in the country owing to various reasons. I am hopeful in the future this will not be the case and much of the data on the biological wealth of Sahyadri will be available with us to carefully plan and protect this lesser known landscape.

Shah Nawaz Jelil

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SUMMARY

This thesis deals with understanding mammal abundance and habitat status in an altered watershed, a dammed river that now forms a part of the Koyna Wildlife Sanctuary, in the northern Western Ghats, Maharashtra, India. As a developing economy, India struggles with the dilemma of power generation to support the growing human populace, while preserving inviolate forests and rivers. Hence, the debate about positives and negatives of dams has long existed and still continues to exist. While the negative after-effects of dam construction are well known on downstream river stretch and riparian forests, I aimed to understand habitat status and mammal abundance along the stream network within upstream Koyna Reservoir, 55 years after its construction. By doing this, I aimed to understand and draw conclusions on generally how reservoirs are functioning as protected areas. This study is particularly relevant and important for the threatened and unique landscapes of the Western Ghats. While the southern Western Ghats has been researched quite extensively, the northern Western Ghats still remain a comparatively unknown region. This study was also an ardent attempt to fill some of the knowledge gaps of mammal abundance from this region.

A catchment-wide field design along a stream gradient in Koyna was adopted and used. Here, different stream orders were considered as sampling units — perennial, intermittent, ephemeral and headwater streams. A total of 72 sites were selected and sampled to collect riparian habitat and mammal occupancy data. I found that the quality of forests along the stream network in Koyna is high (riparian quality index

(QBR) ranges from 65 to 100). The riparian tree diversity ranged from 0 to 1.83 at the 72 sites. Riparian tree diversity was significantly influenced by stream type ($F_{3, 61}$ = 2.34, p = 0.01) whereby it was highest along headwater streams. Interestingly, livestock presence showed no effect on tree richness.

Camera trap surveys recorded 19 terrestrial mammals along the riparian areas. Non-target mammals such as the southwestern langur *Semnopithecus hypoleucos*, bonnet macaque *Macaca radiata* and Indian giant squirrel *Ratufa indica* were also recorded along with occasional captures of birds. It was found that riparian areas are dominated by large ungulates such as gaur ($\psi = 0.84 \pm 0.12$ SE), wild pig ($\psi = 0.77 \pm 0.07$ SE) and sambar ($\psi = 0.49 \pm 0.10$ SE). Tiger was not recorded during the survey, but other large carnivores *viz.* leopard *Panthera pardus*, dhole *Cuon alpinus*, and sloth bear *Melursus ursinus* were recorded, however with low capture rates. Hence, multi-season models could not be constructed for the predators.

Finally, systematic conservation prioritization analysis was conducted to assess which areas within Koyna should be prioritized for effective allocation of management resources. For this, I used camera trap data collected from the whole of the Koyna landscape/watershed (with 1*1 grids). Firstly, I used ensemble species distribution modelling to generate species maps across the landscape. These maps converted to a raster stack were then used as feature data to predict a scenario for conserving mammal assemblage in Koyna. Four scenarios were created *i.e.,* targeting the conservation of 20%, 30%, 50% or 70% of the mammal assemblage within the Koyna riverscape, as per Aichi 10, 11 and 12 Targets and Post 2020 global biodiversity framework of UN

CBD. I found that to conserve a 20% representation of the overall mammal assemblage, a 61 km^2 area needs to be protected and managed. Similarly, for 30%, 50% and 70% targets of mammal conservation, area sizes of 97 km^2, 179 km^2, and 288 km^2 respectively need to be conserved and managed. Such an assessment is critical from the management perspective. With such key information, management authorities can calibrate their time, effort and monetary budget (however limited) to fulfill local, national or international targets.

Overall, using robust modelling approaches, the thesis reports about the present status of riparian forests and mammals using these riparian areas in Koyna Wildlife Sanctuary. Finally, recommendations are made using the key findings of the study. These recommendations incorporated within the already used monitoring protocol for Koyna is expected to yield better management outcomes.

CHAPTER I

GENERAL INTRODUCTION

1.1. Introduction: Riverine landscapes are complex mosaics of habitat types and environmental gradients, characterized by high connectivity and spatial complexity, increasingly termed as riverscapes (Faush et al. 2002; Schlosser 1991; Ward et al. 2002), a unit that is amenable to study over a wide range of scales from an entire braided river and its valley catchment (Tockner et al. 2002), to small habitat patches (Palmer et al. 2000). Riverscapes are structurally complex habitats, wherein the habitat heterogeneity hypothesis fits in well, a hypothesis that states that increasing habitat heterogeneity facilitates higher species diversity (Simpson 1949; MacArthur and Wilson 1967; Lack 1969). The hypothesis is one of the cornerstones of ecological research. Further, river valley bottoms are also more nutrient rich than adjacent areas, and hence are likely to support richer biodiversity. Riverscapes provide more niches and diverse ways of utilizing environmental resources, thereby increase species diversity (Bazzaz 1975). It is now well established that aquatic and terrestrial systems exist in continuum (Jenerette and Lal, 2005; Lauerwald et al. 2017), through energy and matter flux. Riparian forests and fauna therein, are representative of this continuum. The concept of large mammals into this equation was first provided through pioneering work by Naiman (1998) and Naiman and Rogers (1999). However, this concept needs more research such that it gains a permanent place in ecology and conservation and in diverse ecosystems. This study was one such attempt.

The approach in this thesis was based on the terrestrial-riverine continuum concept which has its roots in the river continuum concept (RCC) (Vannote et al. 1980). Streams and their adjacent riparian zones are complex systems that respond to transfers of water, sediment, nutrients, organic matter and heat both laterally and longitudinally, all of which vary on time scales ranging from diurnal, seasonal to decadal and much longer. Forested riparian areas are filters that intercept sediments and nutrients that would otherwise enter streams (Lowrance et al. 1997). Vegetation growing along riparian areas helps in the stabilization of the stream channel, and also provides essential cover to terrestrial animals and a corridor for their movement. The fauna of riverscapes comprises of a mix of obligate terrestrial species ranging from microfauna (Ward et al. 1998) to mammals such as elephants (Dudgeon 2000), in addition to semi-terrestrial and aquatic species. In the Pacific coastal region of North America, 29% of all the known species are riparian obligates (Naiman et al. 2000). In Switzerland, 85% of species in some faunal groups inhabit floodplains (Tockner and Ward 1999). Over 15% of the non-aquatic Amazonian avifauna (Remsen Jr. and Parker III, 1983) and 76% of the bird species in the Biebrza River Valley in Poland (Dobrowolski, 1994) use habitats associated with rivers for breeding, foraging and migration. Although ecologists understand that the interaction between water, energy and matter shape the physical characteristics and habitat patches of river corridors, the significance of large animals in shaping the character of riverine corridors has received little recognition (Naiman and Rogers, 1997).

Important aspects of dynamic riverine landscapes for animals include landscapes mosaics, and environmental gradient that meet varying requirements during complex life cycles (habitat-species successional patterns, reproduction and nursery areas), refugia and fragmentation (population sustenance, genetic maintenance, diversity of species traits), corridor dynamics (migration and dispersal pathways) and fauna-habitat feedbacks (ecosystem engineering, faunal distributions and successional mosaics in faunal assemblages). A better understanding of the complex interaction between landscape components and biotic properties is necessary for a more effective, dynamic and integrative resource management strategy (Stanford et al. 1996). Studies on species-habitat relationships in aquatic systems have majorly focused on fishes and other obligate stream dependent biota such as zooplankton and phytoplankton. However, the role of streams or riverscapes in the life of higher taxa, such as terrestrial mammals, cannot be overlooked. The use of streams or riverscapes by mammals varies in space and time depending on the availability, structure and permeability as riverscapes are dynamic ecosystems. Unlike perennial rivers, smaller streams, such as headwaters, undergo a dry phase that is crucial for large mammal occupancy and movement across and within landscapes and landscape units. These temporary streams with associated riparian forests facilitate movement by provide vital corridors with sufficient cover. The drying of streams may also affect species assemblage, with seasonal exit of some species and seasonal colonization of other species. For example, van der Merwe and Hellgren (2016) imply that for wetland-associated species, fluctuating water levels can potentially affect habitat quality which in turn affect trophic diversity. Further, Bhaskar and Karthick (2015) argue that river conservation cannot be considered as an isolated concept; riparian zones are terrestrial-aquatic interfaces. It serves as an ecological continuum both between habitats and across elevation zones, and also as refugia protecting species against extreme temperature. This implies that the riparian zones will potentially become hotspots for adaptation to climate change in the future (Seavy et al. 2009; Capon et al. 2013). Furthermore, many management strategies inadvertently simplify riparian corridors by not being attentive to basic principles governing large animals in highly variable environments. The result of such strategies is a reduction in compositional, structural and functional biodiversity that goes far beyond the effects of modifying the population dynamics of a single species (Naiman and Rogers 1997). Focusing merely on one charismatic or flagship species is not sufficient to maintain biodiversity and other ecosystem scale attributes for the future. An emphasis on management for variability and interaction is especially appropriate for rivers and riparian forests, where ecological integrity and long-term viability are created and maintained by sustained spatial and temporal variability and by strong interactions among environmental components (Naiman et al. 1992). In the past, species-focused management was dominated by concepts such as carrying capacity which estimates the optimal number of large animals for an area and implies a balance of nature viewpoint (e.g., Hayward et al. 2007). By contrast, ecosystem management, as discussed by Naiman and Rogers (1997) focuses on managing spatiotemporal variability, i.e., flux of nature concept. The former approach dampens extreme population and community changes as well as ecosystem resilience, whereas the latter generates complexity and heterogeneity which increases ecosystem resilience to disturbances. Hence, it is vital to understand the species assemblages of a stream network and associated riverscapes to plan, strategize and manage wildlife populations therein.

1.2. Objectives: The objectives set were:

1. Assess the structure and quality of stream network and associated riparian forests in Koyna in the context of mammalian assemblage;
2. Investigate the habitat use, occupancy and species-habitat relationships of terrestrial mammals (medium to large) in riparian forests; and

3. Spatial prioritization of key habitats towards management inputs

1.3. Organization of the thesis: The thesis has been synthesized into eight chapters, *viz.* I Introduction; II Review of literature; III Study area; IV Study design and methodology; V Riparian habitat structure and quality of Koyna Wildlife Sanctuary; VI Terrestrial mammal occupancy across a stream gradient; VII Systematic conservation prioritization of Koyna and VIII Management recommendations.

Chapter I is the introductory chapter and discusses the background of mammal habitat relationship and the role of streams and rivers in lives of terrestrial mammals. Chapter II introduces and discusses the existing literature on mammals in riverscapes and riparian forests. It also discusses the concept of river continuum concept (RCC) and intermittent rivers and ephemeral streams (IRES) which are important concepts based on which the present work was completed. Chapter III elaborates on the overall landscape under study and then narrows down to the importance and present status of the intensive study area selected *i.e.,* Koyna. Chapter IV discusses about the importance of robust design in ecological studied and then elaborates on the overall design and methods adopted for the present work. Chapter V discusses the quality and structure of riparian forests of Koyna. This chapter also shows the adoption of QBR index or riparian quality index and provides a framework which could be used to assess quality of riparian forests especially for Indian reserves. Chapter VI discusses the objectives and results obtained from the camera trap sampling in riparian forests. It further elaborates on the use of occupancy models to estimate probability of occupancy and detection of multiple species and more importantly to assess which habitat parameter mostly affected mammals. For this, both single season and multiple season occupancy models were run and analyzed. Multi season models revealed the factors significant to increase seasonal colonization and decreased seasonal extinction of five ungulate species. Chapter VII deals with the overall Koyna landscape on a PA or watershed scale. Using camera trap presence records of mammals and species distribution maps, priority conservation areas were highlighted to achieve equal representation of overall mammalian assemblage within Koyna. A suite of scenarios was created to achieve different levels of targets which estimated the area required to achieve each of the targets. Finally, chapter VIII is dedicated to management of the overall riparian forests, PA and biodiversity features of Koyna. General recommendations have been made using the results from Chapter V, VI and VII such that Koyna can be preserved as is and even enhanced by active management efforts, and serve as an ideal PA in the future. All the references cited in the chapters were compiled and listed together in the final section named literature cited. The appendices cited in different chapters were compiled in the final part of thesis after literature cited section.

CHAPTER II

REVIEW OF LITERATURE

2.1. Introduction: Large animal ecology in riparian forests was probably highlighted in mainstream conservation science by pioneering studies of Naiman (1988), Pastor et al. (1988) and Naiman and Rogers (1997). These studies summarized how large ungulates influence riparian system dynamics primarily by their foraging behavior. Large animals significantly modify the structure (channel geomorphology, vegetative characteristics, and biodiversity) and function (productivity, connectivity and resistance and resilience to disturbance) of river corridors which has long term ecosystem-level consequences (Butler 1995; Johnston, 1995; Naiman, 1998). By eating plants, moving soil, and dispersing seeds, large herbivores alter vegetation composition and structure, modify channel morphology and assist in developing micro-topography. The ecosystem-level consequences of these physical and trophic activities go far beyond supplying individuals with food and habitat (McNaughton et al. 1988; Johnston, 1995; Jones and Lawton, 1995; Naiman 1998). There have been few studies highlighting the importance of riparian forests for forest mammals, but the riverine-continuum concept is slowly gaining traction across various ecosystems, especially with important works of Santos et al. (2011) and Zimbres et al. (2018). In India, research on riparian forest has mainly focused on riparian obligate species like otters ((Umapathy and Durairaj, 1995; Hussain and Choudhury 1997; Anoop and Hussain, 2006a,b; Perinchery et al., 2011; Prakash et al., 2012; Raha and Hussain, 2016), and wetland dependent species such as Asiatic buffalo and rhinocerous (Chatterjee and Bhattacharya 2021). Even with such studies Chatterjee and Bhattacharya (2021) found that there remains a large gap in regards to these species' ecology and conservation (Jelil et al. 2021).

A novel avenue for riparian ecology research opened up with studies of Datry et al. (2014; 2016; 2017a, b). These studies stressed on the ecology of dry and intermittent rivers. Historically, research attention has hitherto primarily been focused on perennial rives compared to streams that dry up. These temporary streams however play important ecological roles. Recent research has elaborated much on these temporary river systems called intermittent rivers and ephemeral streams (IRES). Datry et al. (2017b) have elucidated on the concepts and importance of lower order streams. Datry et al. (2017a) argue that IRES have always been perceived to be out of scope of both terrestrial and aquatic sciences and have been overlooked by many disciplines. Consequently, the persuasive conceptual developments in river research, science and management have been from and for perennial river systems which are poorly applicable to IRES (Datry et al. 2014). IRES are now known to support high and unique biodiversity, important ecosystem processes, and provide valuable goods and services (Acuña et al. 2014; Boulton, 2014). Riparian vegetation of IRES provide valuable wildlife habitat (Steward et al. 2012; Acuña et al. 2014); they are vital for maintaining fish populations by preventing non-native species invasion and preserving native species (Acuña et al. 2014). When these dry up, the dry riverbeds provide an opportunity for colonization by various terrestrial organisms. Despite the recent research interest on IRES (Larned et al. 2010; Acuña et al. 2014; Datry et al. 2014), there is a dearth of interdisciplinary scientific syntheses. Following the research on fluvial dynamics of perennial and temporary rivers, Sánchez-Montoya et al. (2016) studied dry streams as corridors for large mammals using an innovative animal footprint method. These studies have all contributed to the development of the terrestrial riverine continuum concept. However, these have been conducted largely in free-flowing rivers and associated riparian forests. Within altered habitats, especially in upstream hydropower reservoirs, research on forest mammals in riparian forests is still lacking. These altered habitats are interesting especially because the forests experience high levels of flooding and drought owing to uneven rainfall patterns. Unlike natural watersheds, the water level in reservoirs is operated by dam authorities which alters the normal hydrological cycle of a river (Alho 2011).

It is noteworthy that although altered, riparian forests remnants present a huge potential for planning and implementing conservation actions and further building connectivity among habitats. Managing these habitats will not only ensure the retention of relict forest habitat but also maintain the flux of many forests species across landscapes, ultimately contributing to a healthier ecosystem functioning (Crooks and Sanjayan, 2006). Riparian forests and remnants ultimately contribute to the health of the hydrological ecosystem services across entire regions by acting as microclimatic and biophysical buffers, and protecting water quality and stream morphology (Naiman et al. 1993). Zimbres et al. (2016) suggest that appropriate management of these critical landscape features therefore needs to be prioritized in the face of relentless tropical deforestation and should take into account a mounting body of literature and knowledge of applied landscape ecology.

2.2. Temporal trend of publication: I conducted a comprehensive literature search on the Google Scholar platform with the key term combination of 'mammal + riparian'. This returned a total of 209 publications published in journals, as books, book chapters and thesis. The first publication was in 1967 as a master's dissertation on small mammals (Kaufman 1967). An increase in the research attention can be observed over the years, with a plateauing after 2000 (Fig. 2.1). I found a significant difference in the annual number of publications (χ^2= 107.01, df = 4, p = 0.001) among the decadal periods of 1970 to 2020.

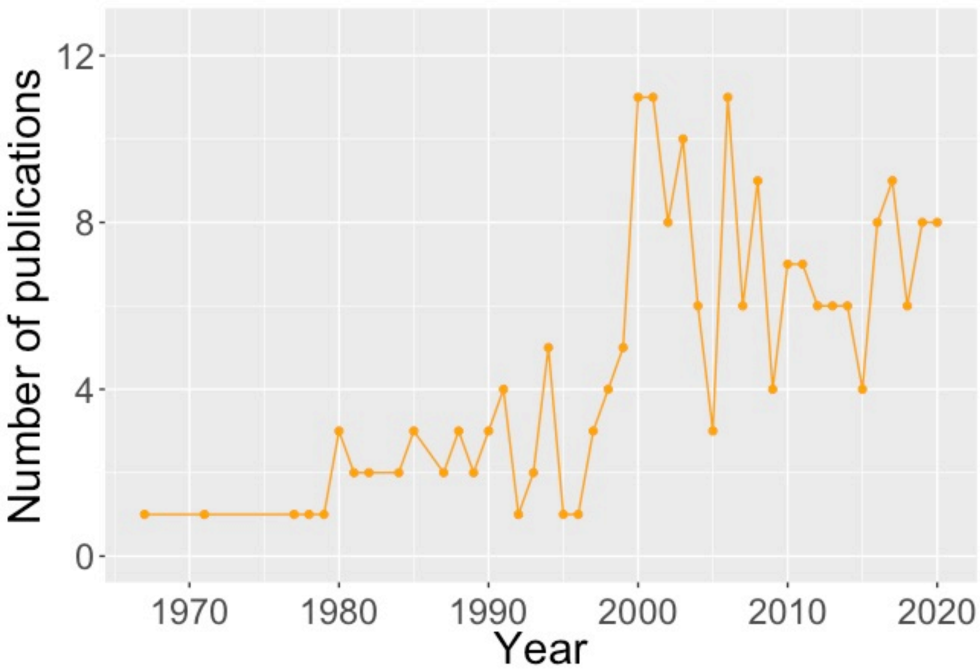

Fig. 2.1: Number of publications by year

Focal taxa of these studies, beyond mammals, include birds (Lees and Peres 2008; Macdonald et al. 2006; Moser and Witmer 2000; Nilsson and Dynesius 1994; Shardlow and Hyatt 2013; Vance et al. 2012; Perez-Amezola et al. 2020; Soykan et al. 2012; Sanchez-Montoya et al. 2017), herpetofauna (Bateman and Ostoja, 2012; Kavanagh and Webb 1998; Waters et al. 2001; Sánchez-Montoya et al. 2017; Perez-Amezola et al. 2020; Vance et al. 2012; MacCraken 2002; Jenkins et al. 2015; Macdonald et al. 2006; Ford et al. 1999; Soykan et al. 2012), plants (Boutin et al. 2003;

Perez-Amezola et al. 2020; Soykan et al. 2012), arthropod (Marczak et al. 2010), spiders (Soykan et al. 2012), butterflies (Soykan et al. 2012); beetles (Soykan et al. 2012) and fishes (Perez-Amezola et al. 2020). Among mammals, the highest number of publications were on rodents (18), which included beavers, mouse, rats and muskrats. This was followed by bats (14), carnivores (10), mustelids (8), ungulates (5), monkeys (3), brush rabbits (3), wombat (1), quoll (1) and armadillo (1) (Fig. 2.2).

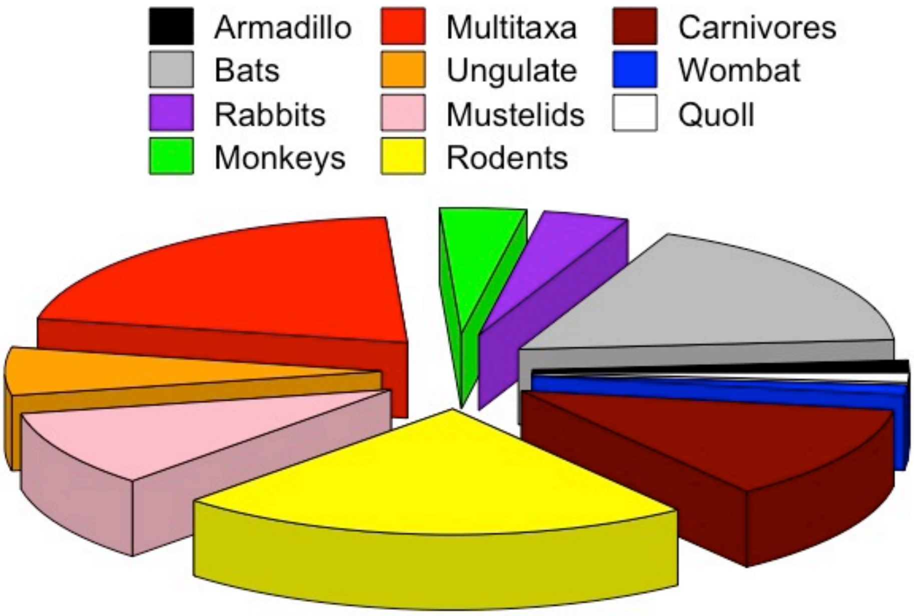

Fig. 2.2: Proportion of mammal groups in published papers

2.3. Thematic trend: When sorted into relevant themes, I found that the highest number of papers were the ones which studied species abundance (44), followed by habitat use (39), richness (18), behavior (17), anthropogenic effect (16), diversity (16), review (11), population (6), disease (5) and genetics (3) (Fig. 2.3).

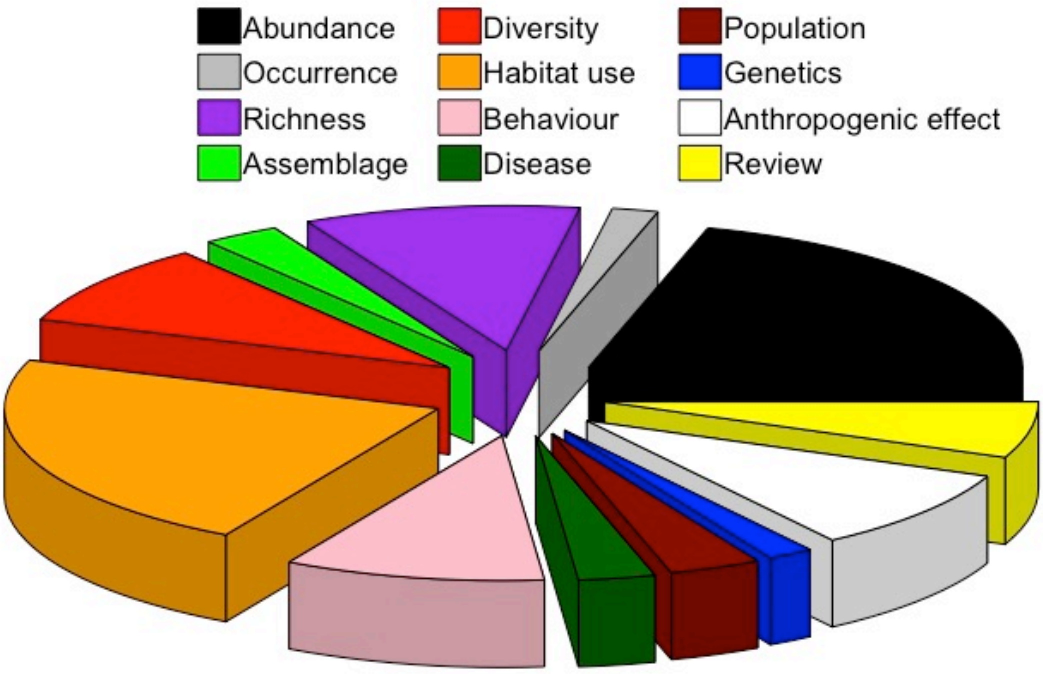

Fig. 2.3: Proportion of publications by theme

2.4. Geographical trend: Published papers were recorded from 36 countries. The highest number of research papers (111) reported studies from the US, followed by Canada (17), Australia (7), Brazil (7), Mexico (6), Portugal (5), Spain (5), Japan (4), Chile (3), Costa Rica (3), Colombia (3), UK (2), Poland (2), Malaysia (2), Italy (2), Netherland (2), Scotland (2), South Africa (2). India, Serbia, Herzegovina, Bosnia, Croatia, Slovenia, Zambia, Uruguay, South Korea, Norway, Ireland, Iberia, Czech Republic, Brunei Darussalam, Belarus, Argentina and Peru had only 1 paper each (Fig. 2.4).

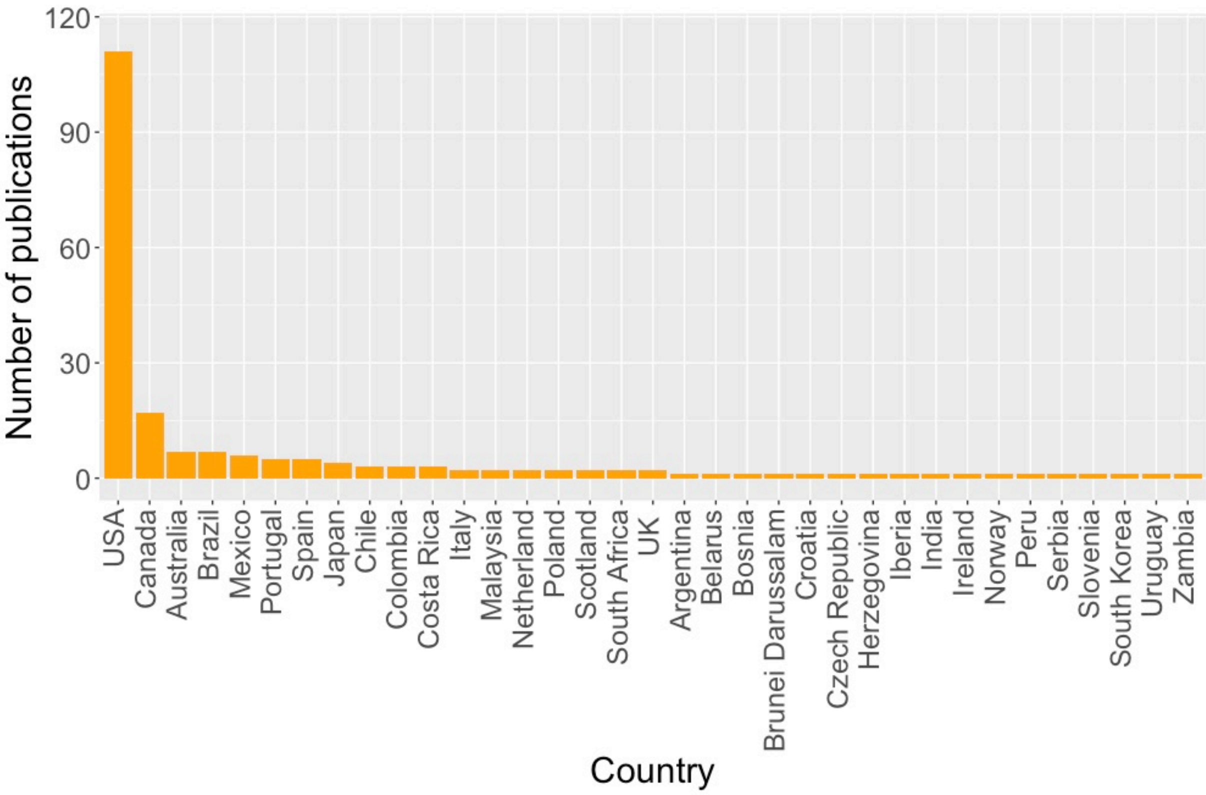

Fig. 2.4: Number of publications by country

CHAPTER III

STUDY AREA: KOYNA WILDLIFE SANCTUARY

3.1. Background and brief history: The larger Sahyadri landscape spans from the Dang region in Gujarat to Dandeli in Karnataka. This landscape is, however, fragmented at many locations owing to human habitation and presence of huge megalopolises such as Nashik and Pune, hindering the movement of tigers and other large mammals. However, the southern corridor of the landscape from Sahyadri Tiger Reserve to Dandeli in Karnataka is less fragmented than the northern corridor. Nevertheless, these fragments do provide prospect for animals to range and move around this stretch (Jelil et al. 2020; Fig. 3.1). The Sahyadri Tiger Reserve (Fig. 3.2), nestled in the northern Western Ghats in India, is the only tiger reserve in western Maharashtra. Sahyadri boasts a long and glorious history of the reign of the Emperor Shivaji and his successors. This history of empires also parallels with the history of wild tigers. Tigers have been known to occur commonly in the Sahyadri mountain ranges; the hunting records of Shahu Maharaj (regnal years 1894–1922) of Kolhapur prove that tigers were fairly common in the Sahyadri, in the Western Ghats within the state of Maharashtra, in the early part of the last century. With the onset of the 21st century, tiger populations declined in the entire nation. The population decreased overtime with escalating human population and pressure. Although with low density of tigers, Sahyadri Tiger Reserve was formed in 2008 by combining Chandoli National Park and Koyna Wildlife Sanctuary. Apart from tigers, the Sahyadri mountain region is known for water security and provides various ecosystem services to the region. Owing to the glorious history of empires, many historical monuments in the form of forts are still found in the region. Within the tiger reserve boundary, famous forts such as Bhairavgad, Prachitgad, Vasota, Pali, Jungti are found.

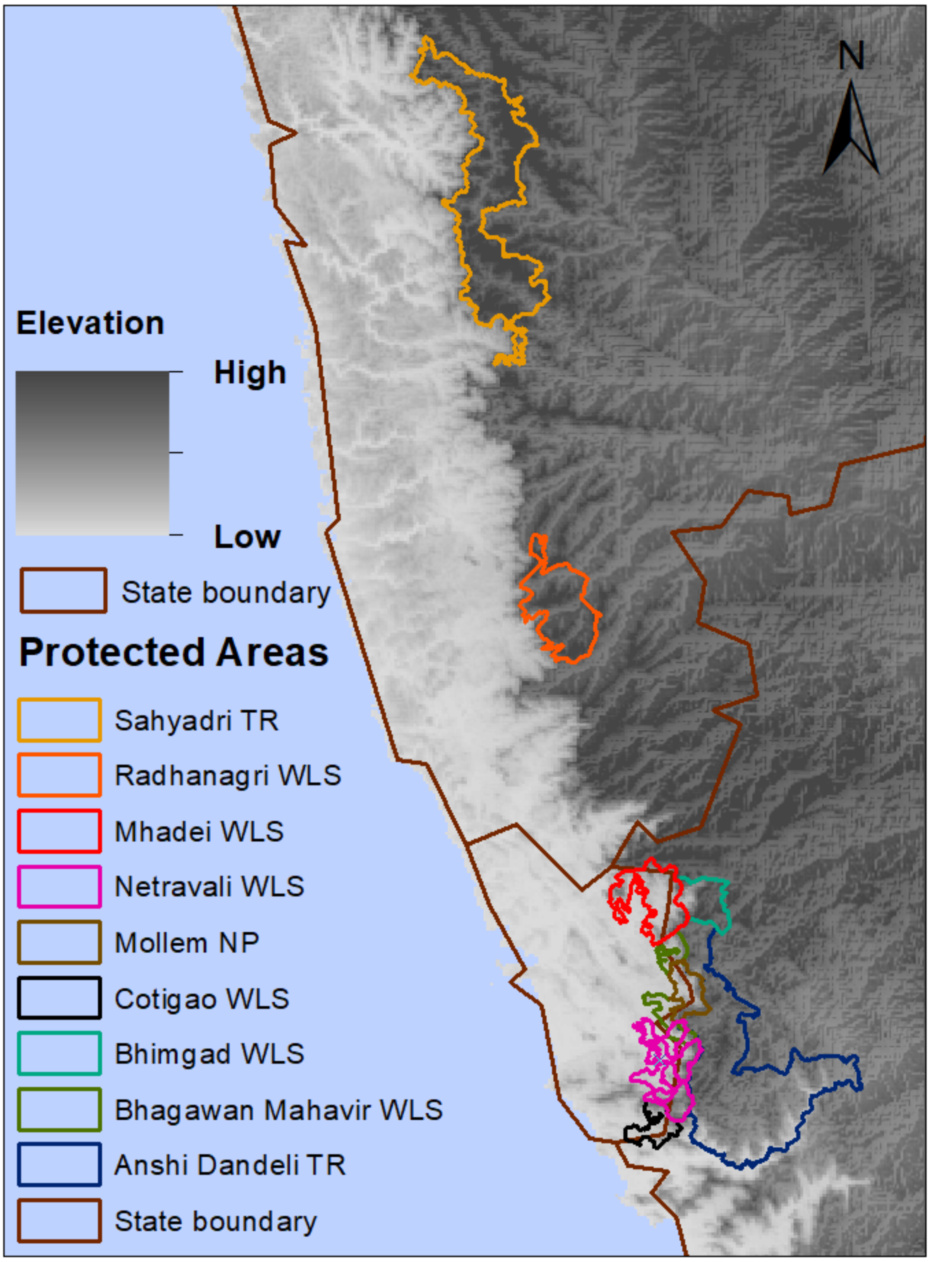

Fig. 3.1: Southern corridor of the Sahyadri landscape

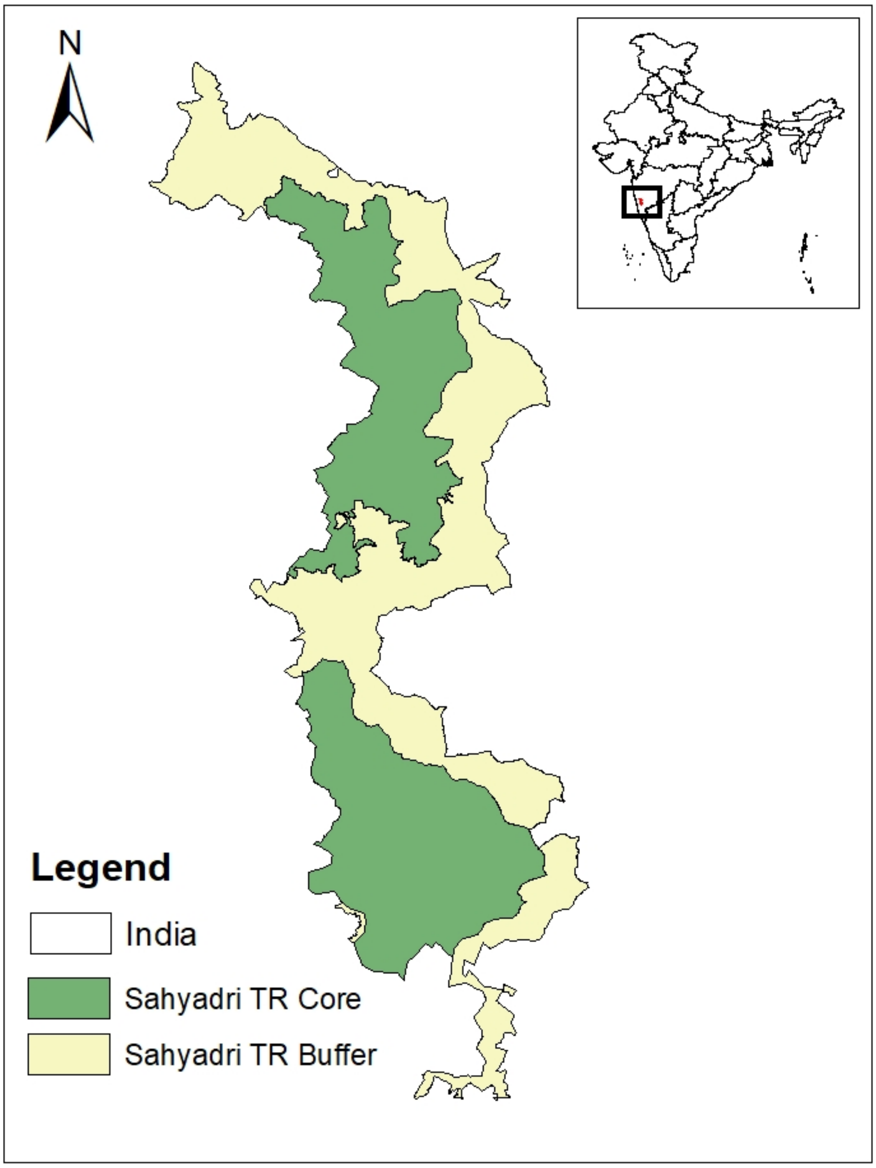

Fig. 3.2: Sahyadri Tiger Reserve with core and buffer areas

3.2. Location and administration: The Sahyadri Tiger Reserve is located in Maharashtra state and takes its name due to the geographical position in the Sahyadri range of the Western Ghats. It is constituted by combining the Chandoli National Park and Koyna Wildlife Sanctuary. In terms of political administration boundary, it is situated at the juncture of four districts Satara (Mahabaleshwar, Jawali, Satara and Patan tehsils), Sangli (Shirala tehsil), Kolhapur (Shahuwadi tehsil) and Ratnagiri (Sangameshwar and Khed tehsils).

3.3. Area: The study area encompasses a total area of 1166 km^2, jointly comprised by Koyna Wildlife Sanctuary and Chandoli National Park. The core area combining both protected areas is 600.12 km^2 and buffer area of 565 km^2.

3.4. Climate and rainfall: The climate in the region is typically warm; winter persists from November to February. Monsoon is a major seasonal characteristic of the region. Rainfall is around 5000 mm which majorly falls from June to September. The months of March, April and May are the warmest reaching temperatures as high as 40° C.

3.5. Geology and vegetation: The Western Ghats in Maharashtra (Sahyadris) form a major water divide between the two geomorphic zones. The area is an amalgamation of flat topped mountains, steep and broad valleys. The Sahyadri region also exhibits a stepped appearance, with steep escarpment zones. In contrast to the southern Western Ghats, these northern forests grow where rainfall is relatively lower and unequally distributed, having a marked dry season. These forests occur between 1000 m and 1700 m and typically occur in Mahabaleshwar at 1300 m. The neighbouring forests are of the dry deciduous type. Champion and Seth (1968) describe the crestline forests in Maharashtra as type C2-Western subtropical broad-leaved hill forests as having unique features. When it is well-developed, these broad-leaved hill forests form a dense evergreen of mixed species, where the height does not exceed 15 m. The trees have a typical spreading habit. The old trunks become hollow. Occasionally large emergent are *Terminalias* or *Stereospermum* trees of great girth. These forests mainly grow above 100 m in Maharashtra. The soil is formed from basaltic trap which is covered by a thick lateritic cap especially over the flat plateau tops that are devoid of tree cover but have a profusion of ground flora with endemic and rare plants.

3.6. Topography and drainage pattern: Sahyadri has a rugged and undulating terrain with an altitudinal gradient of 350–1250 m (Fig. 3.3). Such a topography influences small water flows, runoffs and flow lines. This makes the landscape possess a complex stream network, hence making Sahyadri well known for water availability and security.

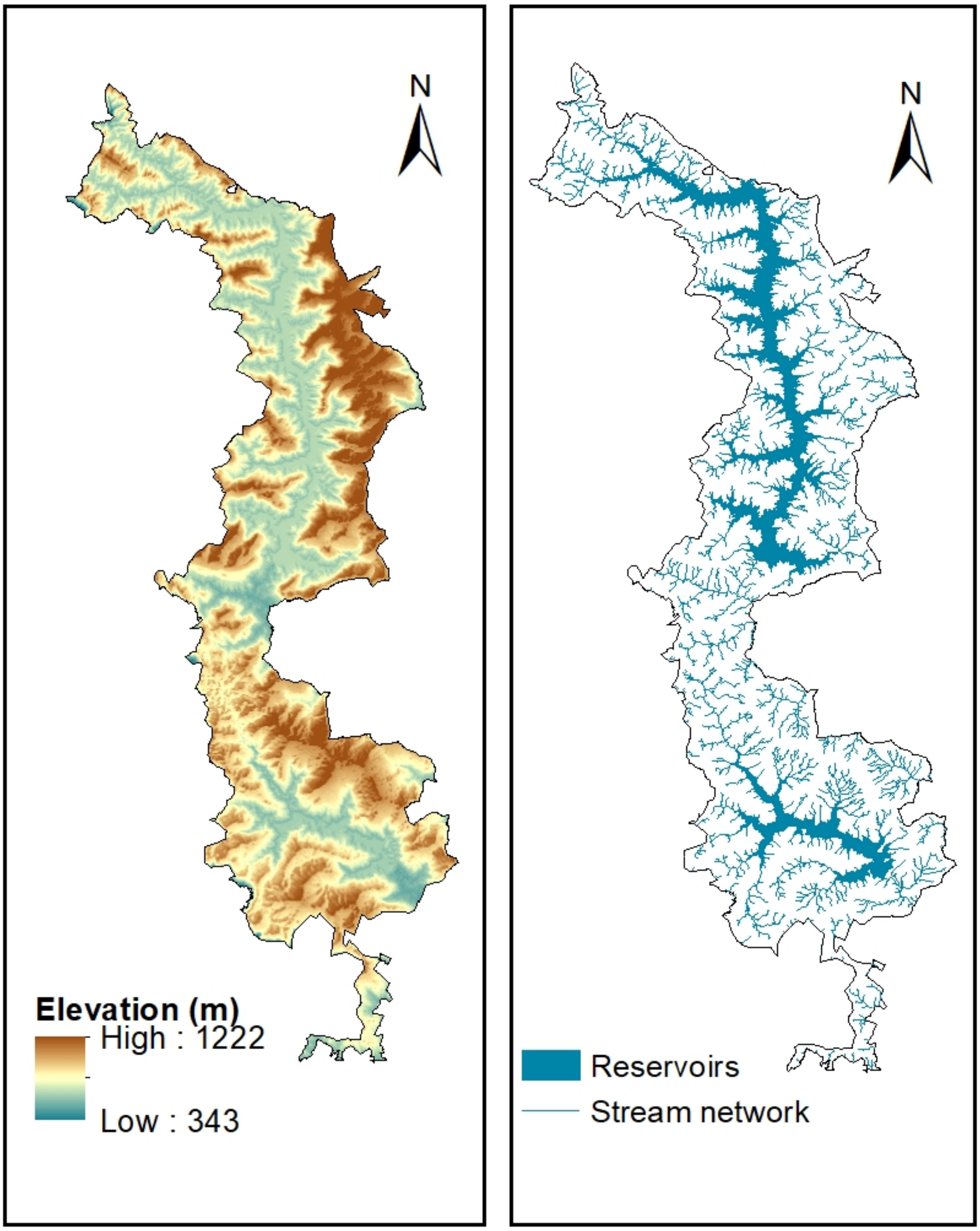

Fig. 3.3: Elevation gradient and stream network of Sahyadri Tiger Reserve

3.7. Land-use and land cover: Land use classes in Sahyadri are dense, barren land, open forest, scrubland, water body, agricultural land and reservoir bed (Table 3.1; Fig. 3.4) (Jelil et al. 2020).

Table 3.1: Land use classes with area covered by each land use class

Land use class	Area (km^2)
Dense forest	408.72
Open forest	220.94
Scrubland	134.29
Barren land	305.64
Agricultural land	20.76
Water body	75.86
Reservoir bed	11.79

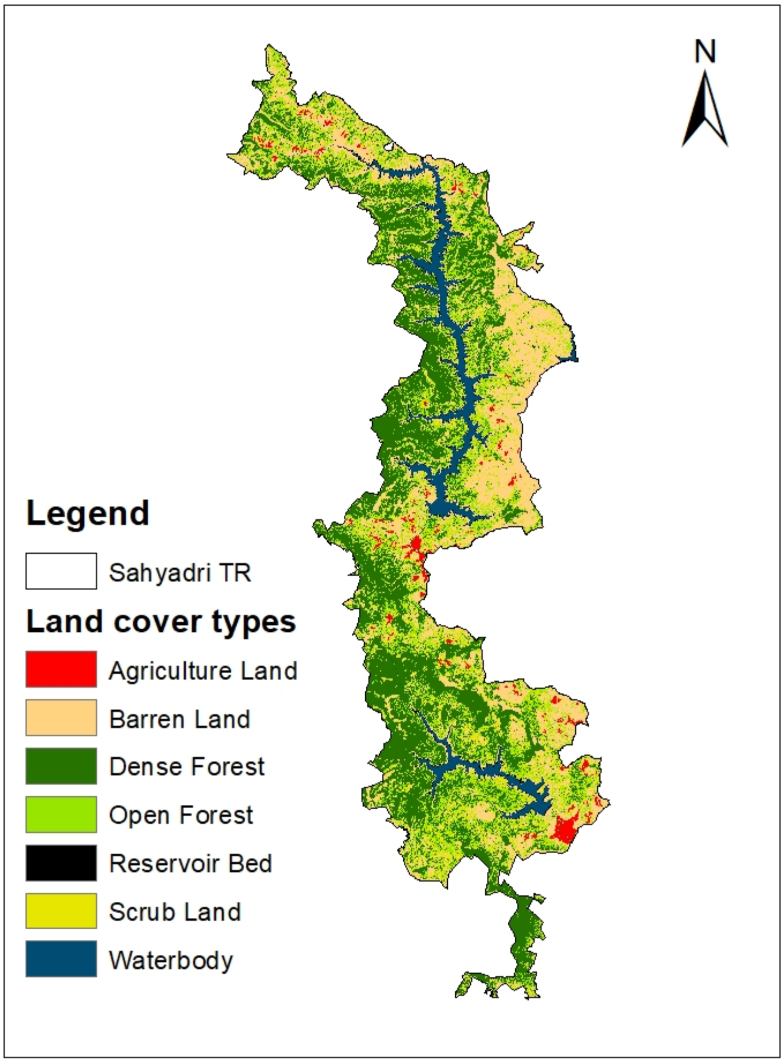

Fig. 3.4: Land Use Land Cover map of Sahyadri

Structurally, the buffer area connects the two parts of the tiger reserve, i.e. Chandoli National Park and Koyna Wildlife Sanctuary. While the configuration of the Sahyadri landscape is generally linear, it consists of large patches that can support large animal presence and persistence.

3.8. Floral and faunal account: Twenty-five species of mammals belonging to 14 families have been recorded through intensive camera trapping exercise from 2017 till date, within the Sahyadri Tiger Reserve (Ramesh et al. 2020). Tiger *Panthera tigris*, leopard *Panthera pardus*, jungle cat *Felis chaus*, leopard cat *Prionailurus bengalensis*, rusty spotted cat *Prionailurus rubiginosus*, dhole *Cuon alpinus*, common palm civet *Paradoxurus hemaphroditus*, brown palm civet *Paradoxurus jerdoni*, small Indian civet *Viverricula indica*, ruddy mongoose *Herpestes smithii*, grey mongoose *Herpestes edwardsi*, stripe-necked mongoose *Herpestes vitticollis*, sambar *Rusa unicolor*, barking deer *Muntiacus muntjac*, gaur *Bos gaurus*, four-horned antelope *Tetracerus quadricornis*, wild pig *Sus scrofa*, mouse deer *Moschiola indica*, Indian crested porcupine *Hystrix indica*, sloth bear *Melursus ursinus*, Indian pangolin *Manis crassicaudata*, Indian hare *Lepus nigricollis*, smooth coated otter *Lutrogale perspicillata*, southwestern langur *Semnopithecus hypoluecos*, bonnet macaque *Macaca radiata*, Indian giant squirrel *Ratufa indica.* According to latest estimates, among ungulates, wild pig has the highest density (per km^2) in the reserve (18.64) followed by barking deer with 15.29, gaur 8.88, mouse deer 3.47, sambar 3.07 (Ramesh et al. 2020). Recent trends suggest that wild pig, gaur and barking population remains stable and is steadily increasing. Sambar and mouse deer densities have remained almost constant over the last three years (Ramesh et al. 2020). Tiger was recorded in 2018 after eight long years (Jelil et al. 2020). After that tiger scats were again recorded in 2019 (Ramesh et al. 2020).

The park also houses a diverse range of herpetofaunal species. Although a complete account of all species is yet to be compiled, various notable observations have been published (Karthik et al. 2018; Karthik et al. 2019; Karthik and Dutta, 2020). Sajjan et al (2018) recorded 27 species of amphibians belonging to 18 genera and 9 families and 2 orders from Chandoli National Park of the tiger reserve. Johnson et al. (2019) recorded 50 fish species from the rivers of tiger reserve. Commonly found tree species are Anjan *Memecylon*, Jamun *Syzigium*, Pisa *Actinodaphne hookeri*, Hirda *Terminalia* chebula, Amla *Emblica officinalis*, Umbar *Ficus racemosa*, Narkya *Nathopodytas nimmoniana*, Ombh *Euphoria longan*, Gera *Catunaregam spinosa*.

3.9. Human dimension: When Sahyadri was declared as a tiger reserve in 2010, there were 134 villages within the reserve limit. There are 79 villages in five ranges of the tiger reserve, of which 18 are in core and 61 in the buffer area. The total number of households in the five ranges is 3601 (Ramesh et al. 2018). The village having the highest population is Rasati with total population 2050 in buffer area of Helwak range and the village having the lowest population is Khemese with total population of 15 in buffer of Helwak. The total village population is 39731 out of which 9506 people live in the core while the other 30255 people live in the buffer. Major communities residing in this area are Maratha (87.04%), nomadic tribe (7.74%), Bodh (5.03%) and Muslim community (0.19%). As for livelihood, most residents are farmer (69%), public or private service sectors (12%), housewives (4%), labourers (3%), retired government servants (2%), students (2%), shopkeepers (2%), village heads (1%), business owners (1%) and others (1%). The locals use forest products as fuelwood (56.98%), fruits (26.93%), livestock grazing (11.12%), medicinal plants (3.67%), fodder (0.64%) and honey (0.64%) (Ramesh et al. 2018).

3.10. Intensive study area: Koyna Wildlife Sanctuary (hereafter referred to as 'Koyna') (Fig. 3.5), the northern part of Sahyadri, was selected as intensive study area for the thesis. Koyna covers an area of 423.55 km^2, and experiences a mean annual rainfall of 5000 mm, which falls during June–September (Joglekar et al. 2015). Red clay is the main soil type and the vegetation in Koyna is classified as southern tropical evergreen forest and southern moist deciduous forest (Champion and Seth, 1968). The elevation in Koyna ranges from 345–1222 m (Fig. 3.6). Previously occupied private forests and human habitations now remain as grasslands, scrub and moist deciduous forests. Joglekar et al (2015) report that due to its relative inaccessibility and undulating terrain, the sanctuary supports some of the few remaining undisturbed tall evergreen forests in the northern Western Ghats and hosts large mammal species such as common leopard *Panthera pardus*, dhole *Cuon alpinus*, sloth bear *Melursus ursinus*, Indian gaur *Bos gaurus*, and sambar *Rusa unicolor*. Riparian forests of Koyna are diverse. In some parts, these are dominated by plantations of introduced *Eucalyptus, Acacia* and *Casuarica*, whereas in other parts, naturally occurring plants such *Memecylon* and *Syzygium* dominate. The river valleys are predominantly vegetated with tropical evergreen forest. Joglekar et al (2015) recorded 108 species of tree species (with GBH $\geq$ 15 cm) belonging to 41 families. Out of 41 families, Melastomataceae, Myrtaceae and Moraceae were dominant. They also identified a subtype of *Memecylon–Syzigium–Olea* based on the dominance from Koyna. Administratively, Koyna Wildlife Sanctuary comprises of two ranges *viz.* Bamnoli and Koyna ranges and 34 beats including both core and buffer beats.

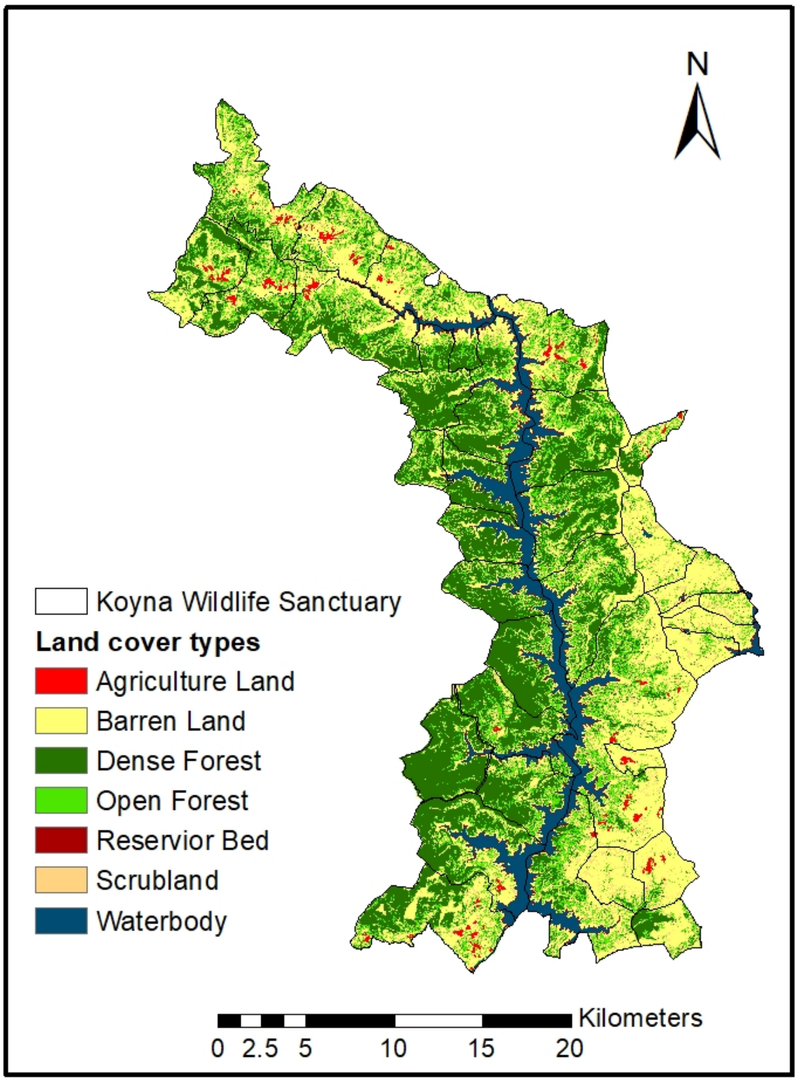

Fig. 3.5: Land cover types of Koyna Wildlife Sanctuary with beat boundaries

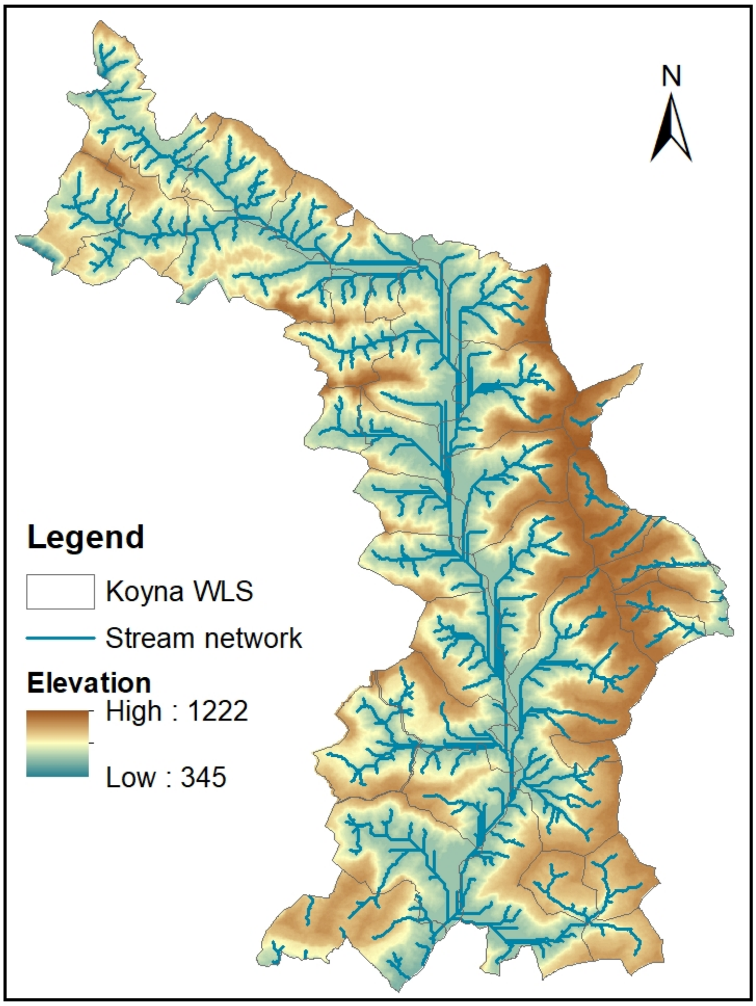

Fig. 3.6: Stream network with elevation gradient of Koyna Wildlife Sanctuary

CHAPTER IV

STUDY DESIGN AND METHODOLOGY

4.1. Introduction: Robust scientific methods are critically important in ecological studies (Stephens et al. 2015) and survey efforts at sufficient sites and scales need to be coupled with these robust methods. This is fundamental to scientific advancement (Hayward et al. 2015). Hence, lately the application of statistical and mathematical models in ecology has seen a rapid increase. A model is, simply, an abstraction of the real-world systems (MacKenzie et al. 2006), and hence will not reflect all of reality (Burnham and Anderson 2002). So, a mathematical model can be thought of as a representation of one or more hypotheses or theories about a system under study. Therefore, multiple theories or hypotheses can be set into competing mathematical models and applying each model to the same set of available data, it is possible to determine which model (or hypothesis) has a greater degree of support given the data at hand (MacKenzie et al. 2006). Good models represent a scientific hypothesis, and in conjunction with a good set of relevant data can provide insight into the underlying biological process and structure (Burnham and Anderson, 2002). An ideal model would be appropriately simple and based on concepts of parsimony (Breiman 1992; Zhang 1994), which achieves a proper tradeoff between bias and variance (Burnham and Anderson 2002).

Models that deal with abundance are amongst the chief models used in ecology. However, a key parameter to be calibrated in these models is the detection probability. This may be addressed in two major ways. Firstly, to standardize the surveys to attain similar detection of species across sites. However, this may not always work as some factors will always remain outside of control of surveyors/ researchers (Conroy and Nichols 1996; MacKenzie et al. 2006). The second approach is to account for detection probabilities while modelling abundance. This provides a more flexible and robust framework and hence approaches that simultaneously estimate abundance and detectability, such as occupancy models are preferred over only abundance indices (Hayward et al. 2015). MacKenzie et al. (2006) argue that estimation of both absolute and relative abundance requires information about detection probability (MacKenzie et al. 2006). Occupancy models further provide the opportunity to identify uncontrollable factors that could influence detection probability and incorporate them as covariates into analyses (MacKenzie et al. 2006). Occupancy models also offer flexibility of sampling approaches in that, any sort of animal observations may be used into the framework. These may be visual surveys of animals, use of traps and mist nets to capture animals, animal sign surveys, detections based on animal vocalizations, and even based on remote camera traps (MacKenzie et al. 2006).

Camera traps have been highly used for monitoring of medium-sized to large mammals (Rovero and Zimmermann 2016). Camera traps are non-invasive, cost-efficient devices for animal detection despite the initial investment of purchasing the equipment (Silveira et al. 2003; Rovero and Marshall 2009; De Bondi et al. 2010; Rovero and Zimmermann 2016). It has been successfully used across countries and species. A detailed history of use of camera traps in wildlife research has been very well illustrated by O'Connell et al. (2011), Rovero and Zimmermann (2016) and Wearn and Glover-Kapfer (2017). Camera trap data can be analyzed through the occupancy framework using short-interval temporal replicates. The presence-absence surveys detection histories can be built using these temporal replicates. A brief background of how researchers have identified and used temporal replicates can be found in Rovero and Zimmermann (2016). Photographic capture data from camera traps could also be utilized to process the presence locations of species to help building habitat suitability models or predict potential species distribution, especially over a large landscape.

In this thesis, I adopted the use of camera trap data to explore on occupancy and persistence of mammals along riparian forests, as well as to spatially prioritize key areas of mammal richness across the Koyna landscape for effective management and protection.

4.2. Field study design: I used stream types as sampling strata with the river stretch divided into three sections (Fig. 4.1; details of stream types see Table 4.1). In each section; I assessed riparian forests associated with a perennial order, two intermittent orders, four ephemeral orders and eight headwater order streams (Fig. 4.1; Fig. 4.2). Four sampling locations in the perennial order, four locations in intermittent order, eight in ephemeral order and eight in headwater order were surveyed, totalling 24 sampling locations in each of the sections. Hence a total of 72 locations were surveyed. The riparian buffer was set at 1 km in either direction of the stream edge in the perennial, at 500 m in intermittent, 200 m in ephemeral and 100 m in headwater streams. In all 72 locations camera traps were deployed and habitat surveys were conducted to record fine scale habitat factors.

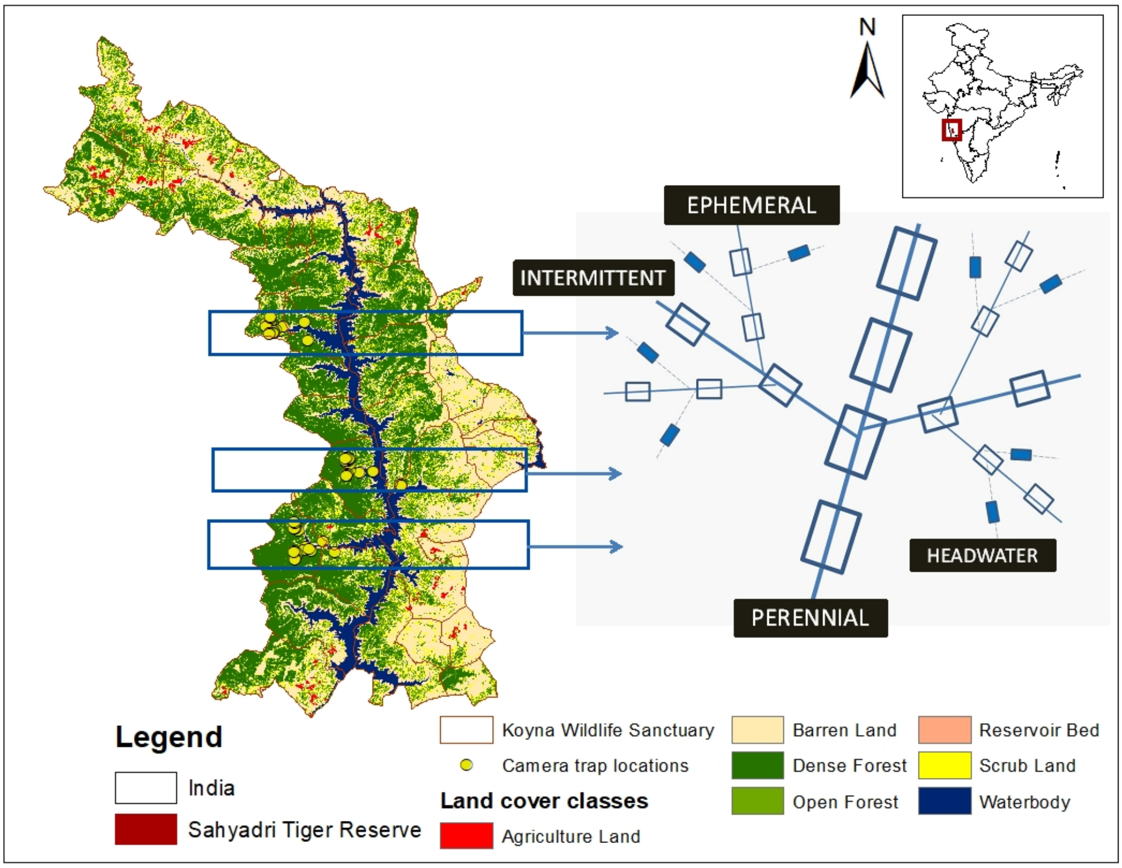

Fig. 4.1: Field sampling design: Case study area was the northern part of Sahyadri Tiger Reserve which is the Koyna Wildlife Sanctuary. I selected three sections in Koyna. In every section I selected a network structure of streams which had one perennial stretch, two intermittent streams, four ephemeral streams and eight ephemeral streams.

Table 4.1: Description of riparian habitat complexes/habitat types selected for the study and the rationale/basis for selecting the habitat types. Two criteria were considered, (a) water flow in the stream types (b) mean elevation of habitats. The riparian buffer selected for perennial streams was 1000m, intermittent streams was 500m, ephemeral streams was 200m and headwater streams was 100m

Stream type	Description	Mean altitude ±SE (m)	Buffer width fixed (m)	Mean distance of cameras from stream edge ±SE (m)
Perennial	Water flows in these stretches all year round	645.67 (±1.27)	1000	251.08 (±16.68)
Intermittent	Water flows for more than half of the year (6–8)	649.58 (±1.08)	500	123.08 (±8.05)
Ephemeral	Water flows for less than half of the year (3–5)	653.25 (±2.12)	200	66.67 (±2.92)
Headwater	Water drains out immediately (>1 month)	666.29 (±3.31)	100	15.62 (±1.57)

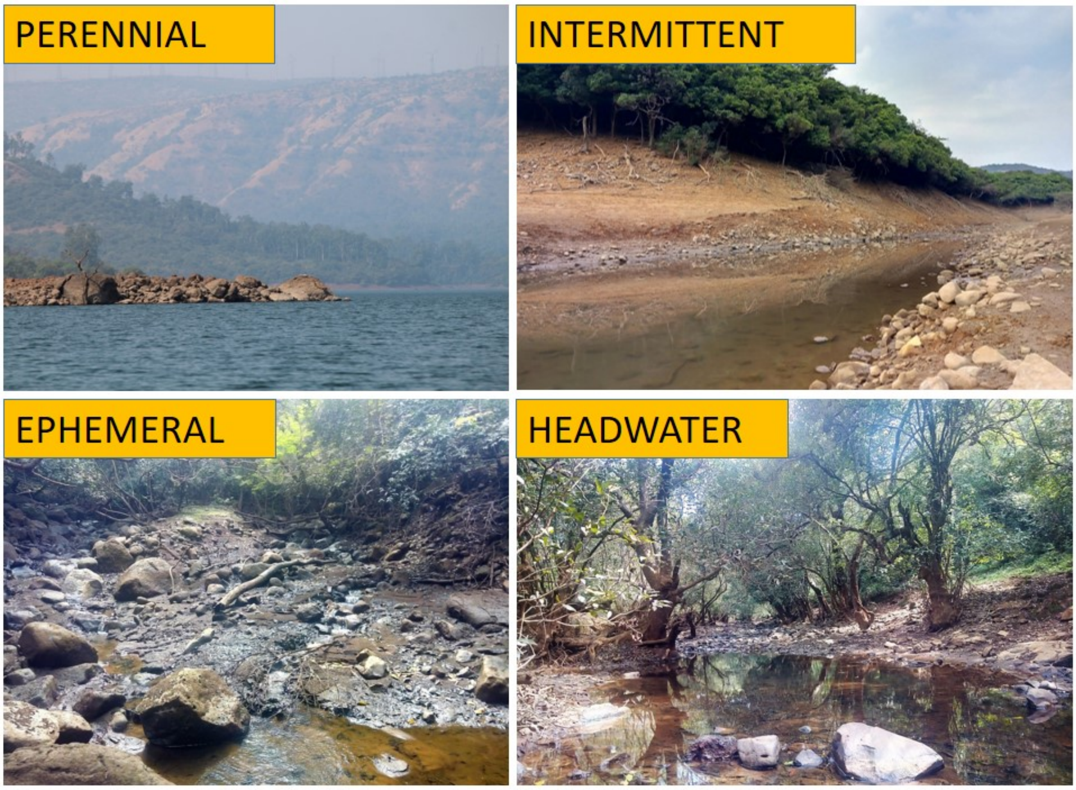

Fig. 4.2: Types of stream/habitats in Koyna

4.3. Sampling effort and intensity: Field work was carried out for two years and four seasons, viz. summer 2018, winter 2018, summer 2019 and winter 2019. Field work was completed in February 2020. Summer field work was conducted from April to June and winter field work was conducted from November to February, totaling about 7 months per year. This amounted to 420 days for the two-year period.

4.4. Quantitative and analytical methods: Camera traps were majorly used in the study. All data from SD cards from each of the camera traps were retrieved and stored in an external hard drive. Camera trap data were sorted based on animal identification till species level. Camera trap data were used to build species specific single season and multi-season occupancy models (MacKenzie 2002; 2006) were built in PRESENCE 12.6. Other statistical data were analyzed using R 3.6.3 and R. 4.0.0 (R Core Team, 2020). Habitat data was analyzed using the vegan package (Oksanen et al. 2019) in R 4.0.0. (R Core Team 2020). Other analyses were conducted using the basic package in R. For the spatial prioritization chapter, using the dismo package (Hijmans et al. 2020), I used ensemble species distribution models viz. maxent (Phillips et al. 2006; Elith et al. 2010), random forest (Breiman et al. 1984; Breimen 2001b) and support vector machines (Vapnik 1998; Guo et al. 2005) to generate maps of species distribution across Koyna landscape. The predictor layers were prepared partly in ArcGIS 10.2 and QGIS 3.16. Later in the prioritization analysis, prioritzr (Hanson et al. 2020) R package was used. Specific field and analytical methods by objectives of the study are elaborated in the following chapters.

4.5. Organization of fieldwork: Fieldwork for the whole study was operated from one basecamp in Helwak Range Forest Quarters in Helwak, Satara district. The sampling sites were accessed by a motorboat of the forest department and stations in field were the beat huts of Koyna Wildlife Sanctuary. The motorboat ran on petrol, hence fuel for the boat was acquired from the nearest town Patan (~22 km from basecamp). On an average *ca.* 70 litres of petrol were purchased every time for field survey and data collection. This was transported via the field vehicle (Mahindra Camper) from Patan to Koyna jetty. Owing to the design of the study, intermediate halts were done in four beats namely, Kusawade (Awsari kuti), Karanjawade, Maldev and Shirshinghe.

4.6. Limitation of the study: Field work during the monsoon was not possible because of high intensity rainfall and flood/landslide situations and also inaccessibility to most areas. Hence interpretation of all the models mostly relates to summer and winter seasons only.

CHAPTER V

QUALITY AND STRUCTURE OF RIPARIAN FOREST HABITAT

Abstract: Reservoir deltas are understudied and their contribution to overall riverine biodiversity is virtually unknown. Being core components of terrestrial-riverine continua, riparian forest quality represents the overall health of the entire landscape. I aimed to understand (a) drivers of riparian tree diversity, (b) factors that influence tree richness and (c) riparian quality by adopting a unique version of the QBR (*Qualitat del Bosc de Ribera*) or riparian quality index for Indian systems. I used a catchment-wide field design where different stream orders were considered sampling units — perennial, intermittent, ephemeral and headwater streams in Koyna Wildlife Sanctuary, India. I sampled 72 sites to collect riparian habitat data. Riparian tree diversity ranged from 0 to 1.83. Using permutation tests in CCA, I found that riparian tree richness was significantly influenced by site variables ($F_{7, 61} = 1.46$, $p = 0.04$). However, only stream type significantly affected riparian tree diversity ($F_{3, 61} = 2.34$, $p = 0.01$). The QBR score ranged from 65 to 100 reflecting high quality riparian forests. My results showed that riparian tree diversity was highest along headwater streams. Hence management and conservation of temporary (headwater) streams is recommended, along with maintaining the protection of perennial streams. Overall, the riparian quality of Koyna was high, hence I suggest that strict protection in terms of management of its core areas would help to keep this constant, or even enhance riparian quality in future. I also recommend the use of QBR index to assess riparian quality annually to strengthen management plans.

Keywords: ecosystem health, QBR index, reservoir biodiversity, temporary streams, regulated rivers, Western Ghats, tropical riverine landscapes

5.1. Introduction: Riparian forests are unique habitats supporting high species diversity, providing water quality protection, naturally controlling floods, stabilizing stream banks, providing wildlife habitat, and allowing for direct human benefits such as recreation and aesthetics (Opperman and Merenlender 2000; Greenwald and Brubaker 2001; Tockner and Stanford 2002; Carver et al. 2004). Riparian habitats are biodiversity corridors that harbour diverse collections of species (Corbacho et al. 2003) and support a wide range of vegetation communities (Leibowitz 2003) that function as a link between terrestrial and aquatic zones (Malason 1993) and act as an ecotone between these two ecosystems. Riparian habitats also provide diverse foraging and breeding sites that facilitate the coexistence of many wildlife species (Tucker and Wayne 1990). However, these are among the most threatened ecosystems globally, despite providing quintessential ecosystem services (Alpert et al. 1999; Tockner and Stanford 2002). Riparian areas are subject to several natural disturbances such as flooding, fire, wind, insects and diseases. Anthropogenic disturbances, such as building dams, channelizing streams, agricultural conversion and urban development, destroy natural vegetation and floodplains, and alter flooding cycles for the riparian area (Friedman et al. 1995; Raven et al. 1998; Bunn et al. 1999; Salinas et al. 2000). Pervasive human impacts, such as livestock grazing and vegetation clearing for cultivation in riparian zones, may change the composition of plant communities along riverine systems (Dudgeon 2006; Lorion and Kennedy 2009). Unregulated livestock grazing in riparian areas also increases erosion and reduces plant vigor and forage production, altering the plant age structure and species diversity (Mligo 2016). These activities affect not only the structure of riparian ecosystems but also degrade their quality. This in-turn affects faunal composition, and conversely, also impacts stream structure and water quality triggering a two-way feedback mechanism that is facilitated through changes in riparian vegetation, habitat structure and health.

In developing countries, these impacts may not have happened but appear to be inevitable as development occurs, leading to a trajectory towards the environmental devastation that has occurred in the developed world. Nonetheless, watershed protection can be used to justify the creation of protected areas that otherwise might not have been otherwise established, and water supply agencies make powerful allies for protected areas that also protect watersheds. The total costs of establishing and managing reserves that protect catchment areas can often be met and justified as part of a hydrological investment (McNeely 1987). However, a balance must be achieved if sustainable development is desired. Evidently, the costs of protecting watersheds should be an automatic component of irrigation projects based on a sound foundation of ecological science (McNeely 1987). Qualitative and quantitative assessments of riparian habitat quality in a post dam construction period can inform how well protected areas established partnering with irrigation agencies are performing.

Globally, we have insufficient data and understanding of the factors driving riparian forest structure and quality. Here I present the case of Koyna Wildlife Sanctuary (Koyna) in the Sahyadri Mountains of India which provides a unique landscape in which to test hypotheses on the factors affecting the terrestrial-riparian continuum in that a large dam was constructed forming the Koyna or *Shivsagar* reservoir. It now also hosts a large number of feral livestock within the core areas of the sanctuary that were abandoned as a result of village relocation after the dam was built. Such a landscape provides an excellent opportunity to test the status of riparian forests along the backwaters/reservoir and which are under added livestock grazing pressure. Hence in this study, I investigated, for the first time (a) the drivers of riparian tree diversity, (b) the factors that influence riparian tree diversity and (c) the riparian forest quality of Koyna Wildlife Sanctuary, Sahyadri Tiger Reserve in Western India.

5.2. Materials and methods

5.2.1. Riparian habitat structure sampling: Detailed field design is described in Section 4.2 of Chapter IV. I used stream types as sampling strata with the river stretch divided into three sections (Fig. 5.1; Table 5.1). A total of 72 riparian sites were selected for survey. Circular vegetation plots were established in all the 72 riparian buffers. The number of tree species and fallen logs were assessed in 10 m radius plots (covering 314 m^2). Percent canopy cover, understory, elevation, the adjacent stream type and the distance to the stream edge were also recorded from the center of the plot. A 5 m radius plot was placed inside the 10 m plot to count number of saplings. A 1 m radius plot was also established inside the 10 m radius circle where ground cover was documented along with the percentage of dry leaf litter, dry grass, green grass and open ground. The survey was carried out in April–June 2019.

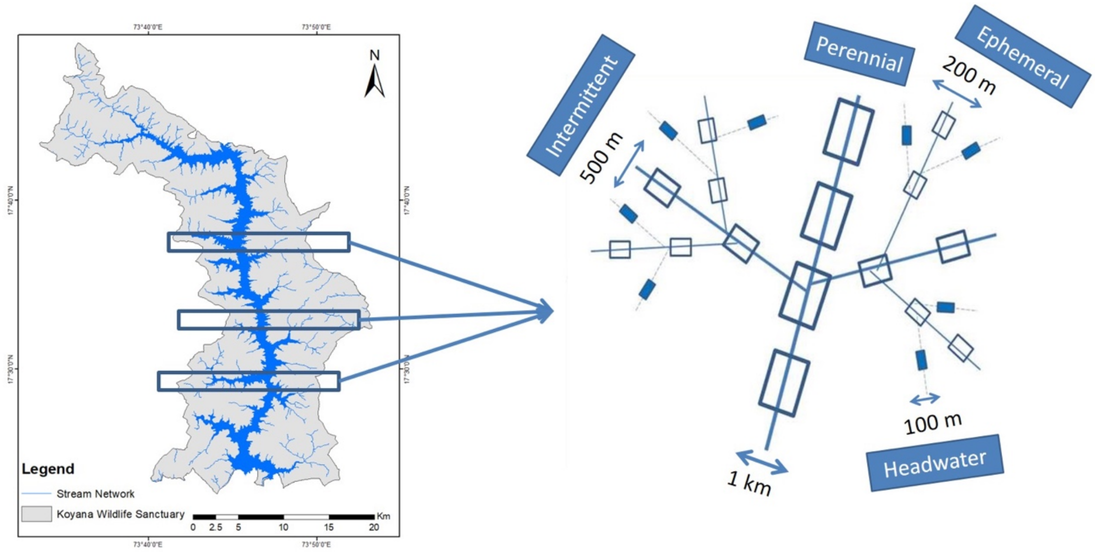

Fig. 5.1: Map of Koyna Wildlife Sanctuary and design of study (detailed map Fig 4.1 in Chapter IV)

5.2.2. Riparian habitat quality (QBR): The QBR (*Qualitat del Bosc de Ribera* in Catalan) or riparian habitat quality index was originally proposed by Munné et al. (1998) for Mediterranean ecosystems. This has since been adapted to a variety of ecosystems (Munné et al. 2003; Sirombra and Mesa 2012; Fernández et al. 2016; Castro-López et al. 2019). The index uses a scoring system in the field using easily identified and measurable features of a habitat (Munné et al. 2003). It is the sum of scores based on four aspects of riparian quality, i. e. total riparian cover, cover structure, cover quality and channel alteration (see Appendix I). The final score ranges between 0 and 100 (Munné et al. 2003). I adopted the original QBR index and modified it to fit my study. The first section (total riparian cover) was kept the same as Munné et al. (2003). The other three sections were based on Sirombra and Mesa (2012) with a few modifications. In the second section (cover structure), I replaced tree cover and shrub cover with canopy cover and understory cover. I included fallen logs or snags in this section as these are important for small mammal occupancy. Section 3 was modified into a simplified version of the basic Munné et al. (2003) index, where cover quality was assessed taking into account the percentage of native and exotic species independent of their number and the geomorphologic or stream type, following Sirombra and Mesa (2012). The fourth section was kept the same as Sirombra and Mesa (2012) QBR index.

5.2.3. Camera trapping: I conducted camera trapping in the 72 riparian sample sites in the same plots as the circular vegetation plots (details in Chapter IV). Cuddeback white flash (C1) camera traps were affixed to suitable trees at *c.* 60–70 cm above the ground. They were set to take consecutive images set 5 seconds apart when triggered, and were kept active between 11 and 48 days. Camera trap sampling was conducted for two years (2018 and 2019) covering four season (viz. summer and winter for both years). For this chapter, camera trap dataset of summer (April–July) 2019 was used.

5.2.4. Quantitative analyses: I employed basic community statistics using the *vegan* (v 2.5–6) package (Oksanen et al. 2019) in R 4.0.0 (R Core Team 2020). I constructed a species accumulation curve in the *vegan* package. I calculated the Shannon diversity index for each site to test if diversity differed among stream types and was related with other habitat factors. Using permutation tests in canonical correspondence analyses (CCA), I tested if riparian tree richness was influenced by site (habitat structure) covariates (i. e., elevation, distance to stream edge, and adjacent stream type). CCA allows ecologists to test the abundance of species to environmental variables. Using *lm* function in R, I ran linear and non-linear (second and third order polynomial) models to test if site covariates had any effect on riparian tree diversity (Shannon diversity index).

I also hypothesized that the presence of livestock would negatively affect tree richness. From the camera trap dataset, I determined the number of independent photo captures of livestock. Images were considered independent when they were at least 30 minutes apart. I then constructed single season occupancy models (MacKenzie et al. 2002, 2006) for livestock in PRESENCE 12.6 (Hines, 2006). I constructed the capture history matrix by arranging the camera images into 7 day occasions to record detection and non-detection. Hence, I had 6 replicates. The occupancy probability (ψ) estimate was obtained through the null model. I used both independent captures and conditional occupancy values in the CCA to test if livestock had any significant effect on riparian tree richness.

For the QBR index, I estimated the site scores using the field datasheet. I later divided the sites into different categories. I then analyzed the percentage of sites by stream type. I also tested if there were any significant differences in habitat quality among different stream types using a one-way ANOVA.

5.3. Results:

5.3.1. Riparian habitat structure: I recorded 31 species of trees (Fig. 5.2) in the sampled riparian areas with *Memecylon umbellatum* (49.81 %) and *Syzigium cumini*

(17.11 %) being the dominant tree species. The mean number of trees was highest along perennial stretches (28 ±5.82 SE) and lowest along intermittent streams (13.25 ±2.96 SE). Canopy cover was highest along headwater streams (75.20 ±2.56 SE) and lowest along perennial streams (46.66 ±7.13 SE) (Table 5.1). I found that Shannon diversity ranged between 0 and 1.83 in the sampled sites.

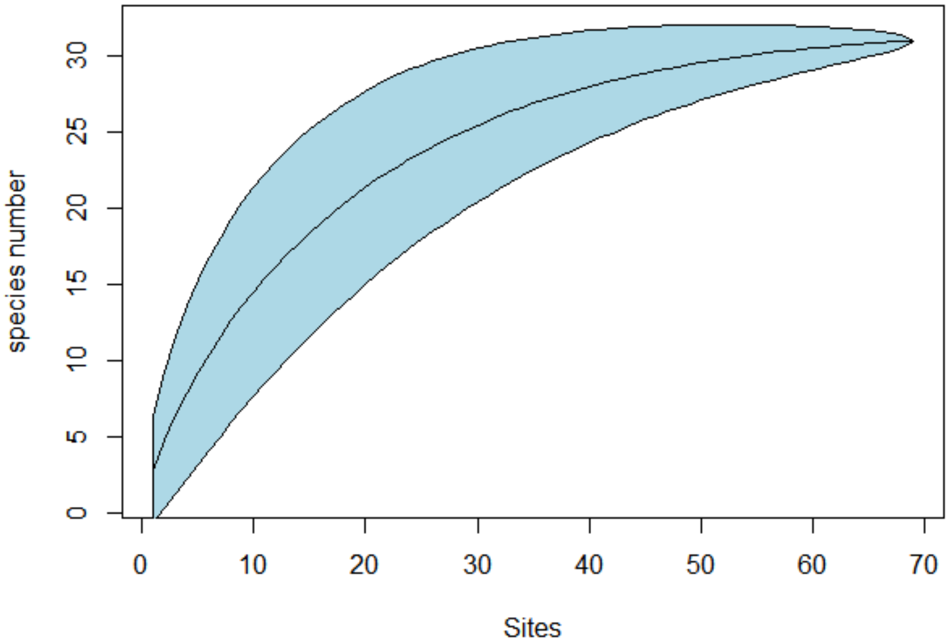

Fig. 5.2: Species accumulation curve of riparian trees

Table 5.1: Details of habitat characteristics/factors by stream types

Stream type	Perennial	Intermittent	Ephemeral	Headwater
Characteristics	Water flows in these stretches all year round	Water flows for more than half of the year (6–8)	Water flows for less than half of the year (3–5)	Water drains out immediately (>1 month)

Buffers fixed (m)	1000	500	200	100
Mean distance of plots from stream (+SE)	251.08 (±16.68)	123.08 (±8.05)	66.67 (±2.92)	15.62 (±1.57)
Mean number of trees (+SE)	28 (±5.82)	13.25 (±2.96)	18.25 (±3.18)	20.16 (±2.99)
Mean number of saplings (±SE)	8.58 (±1.53)	6.08 (±1.66)	5.29 (±0.87)	5.20 (±0.73)
Leaf litter (%)	49.16 (±9.88)	48.75 (±11.35)	48.75 (±7.02)	76.25 (±5.83)
Mean number of fallen logs (±SE)	14.16 (±4.91)	9.91 (±1.69)	7.66 (±1.41)	6.5 (±2.36)
Canopy cover (%)	46.66 (±7.13)	47.5 (±6.92)	61.66 (±3.81)	75.20 (±2.56)
Understory (%)	47.91 (±6.07)	57.5 (±6.29)	52.08 (±4.33)	63.75 (±2.93)
Altitude (+SE)	645.67 (±1.27)	649.58 (±1.08)	653.25 (±2.12)	666.29 (±3.31)

5.3.2. Factors affecting riparian tree diversity: From the linear and non-linear models, I found that only elevation had a significant effect on tree diversity ($F_{3, 65}$ = 3.07, p = 0.03, R^2 = 0.12) (Fig. 5.3). Among the three models, the second and third order polynomial models differed significantly only in case of elevation ($F_{1, 65}$ = 4.42, p = 0.039). For all other variables, all models performed similarly without any significant differences. I found that tree diversity decreased as distance from stream increased, but without any significant effect ($F_{3, 65}$ = 0.72, p = 0.54, R^2 = 0.03). The number of livestock photo-captures ($F_{3, 65}$ = 0.73, p=0.54, R^2 = 0.03) showed an increasing trend with increasing tree diversity, but tree diversity decreased as livestock occupancy increased ($F_{3, 65}$ = 0.86, p = 0.457, R^2 = 0.04). Among stream types I observed that tree diversity was highest along headwater streams (Fig. 5.4).

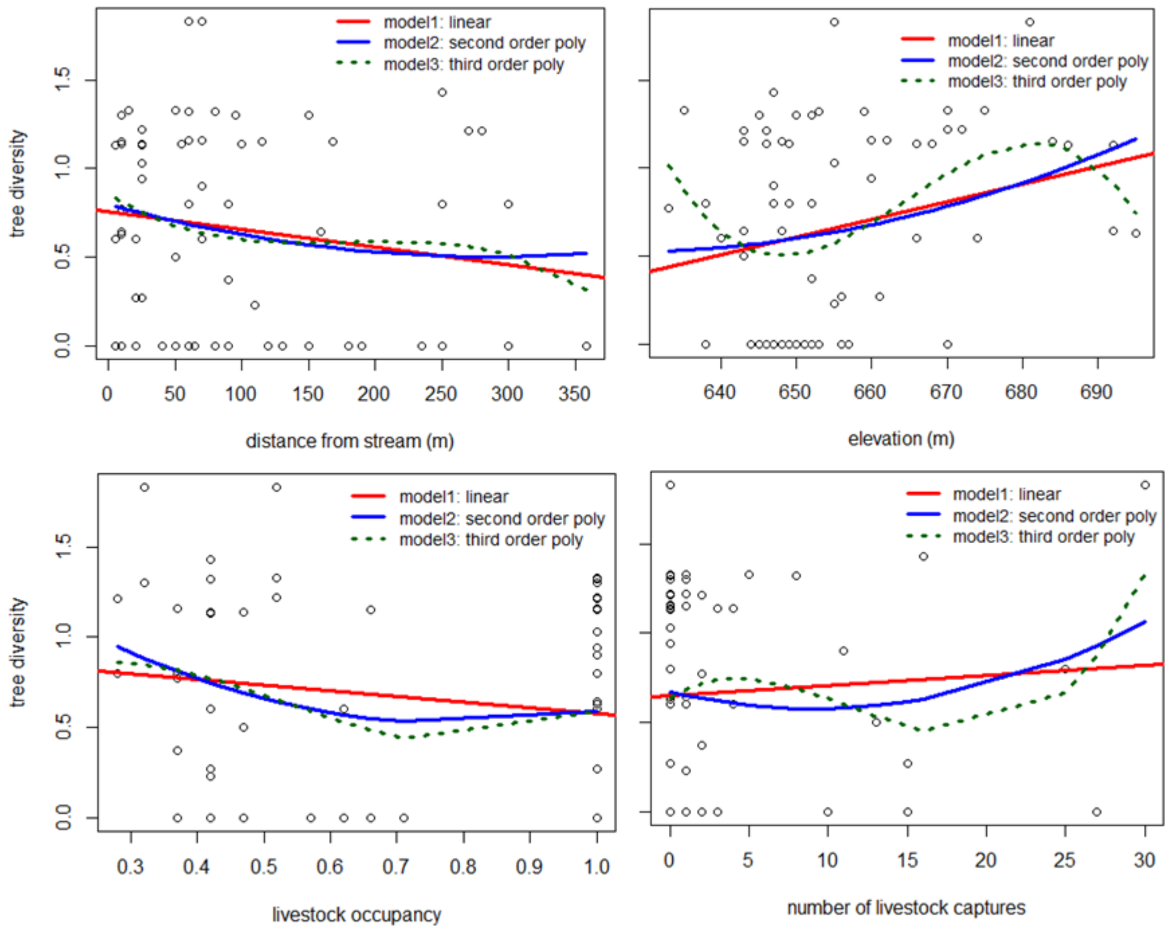

Fig. 5.3: Linear and non-linear fit of tree diversity with site covariates, viz. distance from stream, elevation, livestock occupancy and number of independent livestock photo captures in camera traps

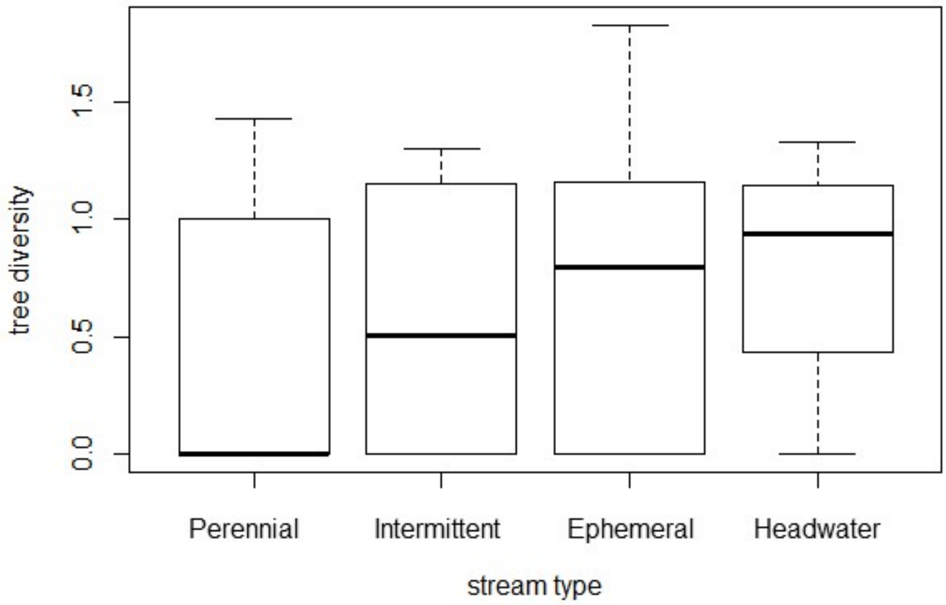

Fig. 5.4: Shannon diversity along different stream types

5.3.3. Factors affecting riparian tree richness: Using CCA, I found that riparian tree richness overall was significantly influenced by site variables ($F_{7, 61} = 1.46$, $p = 0.04$). However, only stream type significantly affected riparian tree richness ($F_{3, 61} = 2.34$, $p = 0.001$) (Table 5.2; Fig. 5.5). Livestock presence showed no significant effects on tree richness.

Table 5.2: Model values of the ANOVA tests in CCA (*significant values)

	df	χ^2	F	p
Model	7	0.97	1.46	0.041*
Stream type	3	0.67	2.34	0.001*
Elevation	1	0.09	0.99	0.379
Number of captures of livestock	1	0.11	1.19	0.251

Livestock occupancy (ψ)	1	0.04	0.46	0.969
Distance from stream edge	1	0.05	0.57	0.817
Residual	61	5.88	—	—

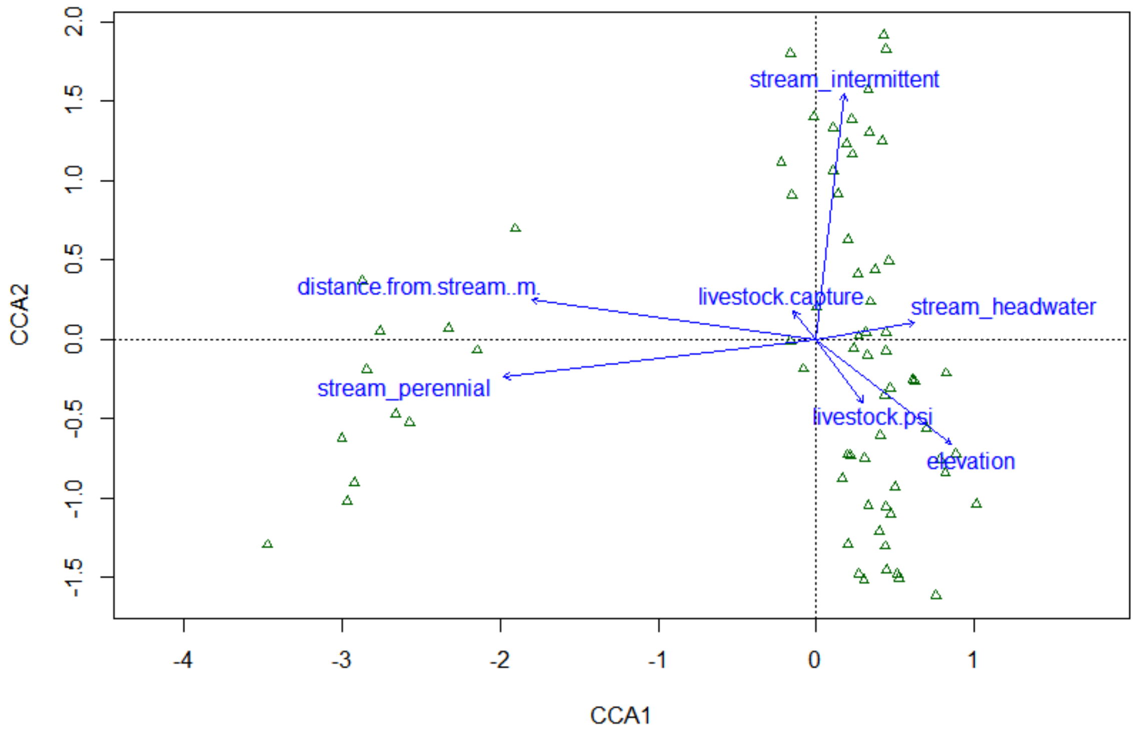

Fig. 5.5: CCA plot showing the habitat factors

5.3.4. Riparian habitat quality (QBR_K): Overall site scores with the adapted QBR index was high and ranged from 65 to 100. I found that overall 30.56% sites fell under Category I (excellent quality), 58.33% in Category II (good quality) and 11.11% in Category III (fair quality) (Table 5.3; Fig. 5.6). None of the sites fell under Category IV (poor quality) and Category V (poorest quality). Classifying stream types by riparian habitat quality, I found that headwater streams had the highest share in

Category I (13.89%), while ephemeral streams in Category II (19.44%) and perennial stretches in Category III (4.16%). I found that there was significant difference in habitat quality among the stream types ($F_{3, 68} = 2.71$, $p = 0.05$) (Table 5.4).

Table 5.3: Percentage of total and each stream type by riparian habitat quality class category

Riparian category	QBR	% total sites	% perennial	% intermittent	% ephemeral	% headwater
I: Excellent quality	≥95	30.56	1.38	4.16	11.11	13.89
II: Good quality	75–94	58.33	11.11	9.72	19.44	18.05
III: Fair quality	55–74	11.11	4.16	2.77	2.78	1.38
IV: Poor quality	26–54	0	0	0	0	0
V: Very poor quality	≤25	0	0	0	0	0

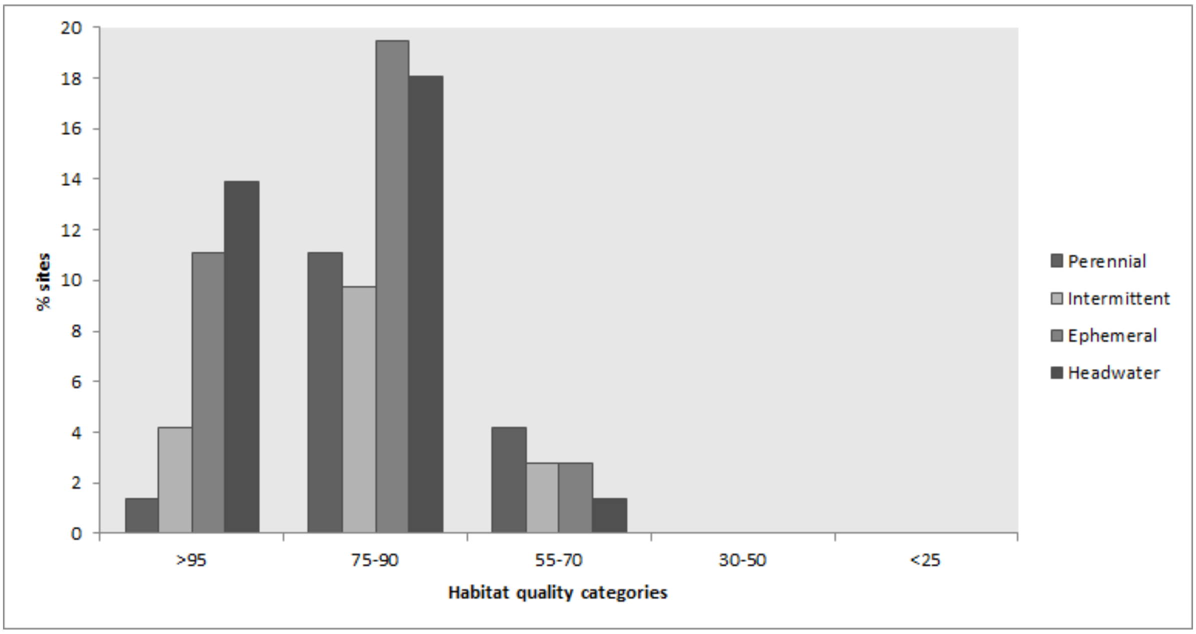

Fig. 5.6: Riparian habitat quality categories by stream types

Table 5.4: ANOVA results for riparian habitat quality

	df	Sum of squares (SS)	Mean SS	F	p
ind	3	794	264.6	2.71	0.05
Residual	68	6644	97.7		

5.3.5. Camera trapping and livestock captures and occupancy: Camera trap effort totaled 2868 trap nights in summer 2019 and recorded 16 species of terrestrial mammals along with livestock and two primate species, the bonnet macaque *Macaca radiata* and southwestern langur *Semnopithecus hypoleucos*. There were 211 independent images of livestock. I found that livestock occupancy using simple single season occupancy model was 0.71 (±0.11 SE). I found that livestock occupancy was higher along smaller stream types (intermittent and headwaters streams) (Fig. 5.7)

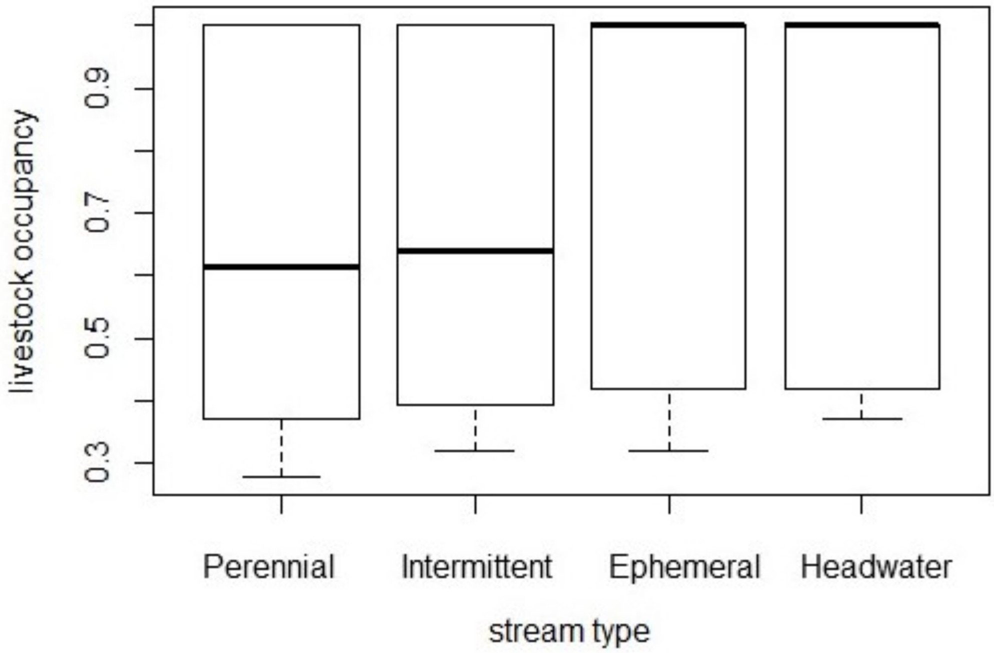

Fig. 5.7: Livestock occupancy along different stream types

5.4. Discussion: Koyna reservoir hosts high quality riparian forests. Riparian tree diversity was affected mostly by elevation whereas tree richness was affected by stream types. I also found that tree diversity was highest along headwater streams. Although livestock presence showed no effect on tree richness, livestock occupancy was highest in riparian forests associated with smaller stream types, indicating potential stress on trees in these riparian forests in future.

5.4.1. Riparian forest structure: Riparian vegetation has been identified as an important indicator in evaluating the ecological status of rivers for land use planning and ecosystem management (Suárez et al. 2002). However, evaluating, managing or restoring riparian ecosystems is a complex endeavor owing to heterogeneity and complexity (Chovanec et al. 2000; Reed and Carpenter 2002). The structure and quality of riparian forests is vital for understanding and further planning for monitoring, management or restoration purposes. Trees form the major structural and functional components of tropical forest ecosystems; they also serve as a robust indicator of changes and stressors at the landscape scale (Khan et al. 1997; Jayakumar and Nair 2013). Previously, Joglekar et al. (2015) recorded 108 tree species from the entire Koyna Wildlife Sanctuary landscape with *Memecylon umbellatum, Syyigium cumini, Xantolis tomentosa, Holigarna grahamii* and *Olea dioca* being the five most abundant species. Puri et al (1983) and Pascal (1988) classified mid-elevation tracts in the north Western Ghats as *Memecylon–Syzygium–Actinodaphne* type of floristic study. Joglekar et al. (2015) identified *Memecylon–Syzygium–Olea* subtype of forest in Koyna. I also found that *Memecylon* and *Syzygium* were the dominant trees in the riparian forests of Koyna, and that riparian forests associated with headwater streams were characterized by high canopy cover. Analyses showed that riparian tree diversity was highest along headwater streams, hence management and conservation of temporary streams along with perennial streams is highlighted.

5.4.2. Riparian quality: I found riparian forest quality of Koyna to be high as compared to earlier studies in different landscapes (Munné et al. 2003; Sirombra and Mesa 2012; Fernández et al. 2016; Castro-López et al. 2019). Even though overall riparian quality was higher, most reductions of my QBR index score were due to presence of invasive species. *Eucalyptus* and *Casuarina* trees had been introduced and planted in Koyna. Previously occupied villages consist of mango *Mangifera* and jackfruit *Artocarpus* orchards, which are now parts of the core area. Even with previous plantations of non-local species, riparian forest quality of Koyna remains high. Hence, I suggest that strict protection in terms of management of its core areas would help to keep this constant, or even enhance riparian quality in future. This was the first application of the QBR index in India to quantify riparian forest quality. I recommend the use of QBR index to assess riparian quality annually across the country, and beyond to strengthen management plans. The QBR index is intended for use by environmental managers at national and regional levels (Munné et al 2003). Globally, the index has previously been used to assess and monitor ecological quality of riparian forests (Munné et al. 2003; Sirombra and Mesa 2012; Fernández et al. 2016; Castro-López 2019), estimate costs for river rehabilitation (González del Tánago and Antón, 1998) and evaluate status and success of projects post completion (Landers 1997). I believe that this index has numerous other applications in various habitat restoration and wildlife management plans, especially to monitor and manage reservoirs which host significant wildlife populations.

5.4.3. Koyna post-dam scenario and possible threat to native wildlife habitat: The Koyna dam was completed in 1962–1963 whereupon it submerged 98 villages in the then Koyna valley (Bokil 1999). Many of these villages were relocated and most livestock were abandoned – ostensibly because of the Hindu aversion to killing cattle. Parts of the core area of Koyna Wildlife Sanctuary now hold substantial number of livestock. I found that livestock occupancy and tree diversity were highest along lower order streams (headwaters and intermittent streams). I hence tested if livestock presence posed any problem to trees in the riparian forests. However, my models revealed no significant effect of livestock presence on tree diversity or richness. I posit two possible explanations – (i) the intermediate disturbance hypothesis may be in play which posits that species diversity remain high and populations stable at intermediate levels of disturbances and (ii) that perhaps livestock have not been in the landscape long enough to influence tree diversity yet, given the longevity of trees.

Although I did not observe any significant effect of cattle numbers on riparian tree richness, field observations and camera trap images keep recording new born calves, which could be a matter of concern in the future because this expanding cattle population competes for food from dwindling native wildlife (Ripple et al. 2015). The present predators – leopard *Panthera pardus* and dhole *Cuon alpinus* do not preferentially kill livestock over natural prey (Hayward et al. 2006; 2014). In Koyna, dholes have been observed to chase and prey on sambar *Rusa unicolor* and leopards have been recorded to prey on smaller prey such as Indian chevrotain *Moschiola indica*, barking deer *Muntiacus muntjac* and occasionally even Indian giant squirrel *Ratufa indica* (pers. obs. SNJ). Koyna Wildlife Sanctuary and by extension the Sahyadri Tiger Reserve, is presently bereft of resident tiger populations This increase of livestock has severe implication towards tiger recovery in the tiger reserve, which is being planned (Ramesh et al. 2018; Jelil et al. 2020). Sahyadri has been a low tiger density area since its inception and the major reason for this is the low prey density. The increasing livestock provide an additional prey base for tigers. Tiger restoration in the landscape may help to stabilize the current situation.

5.4.4. Upstream dam impacts: To understand post dam scenarios completely, understanding status and health of riparian forests upstream and downstream is important. Although, downstream river stretches appear to bear the most burden, upstream stretches face their own challenges. Reservoir deltas are largely understudied and undermanaged. Their contribution to overall riverine biodiversity is virtually unknown. Only a few deltas around the world are managed to enhance vegetation heterogeneity or wildlife and fishery values. Moreover, current reservoir management does not consider effects of reservoir pool dynamics on the ecological condition of mainstream and tributary deltas (Johnson 2002) meaning that temporary streams such as ephemerals and headwaters should be considered equally important with perennial rivers in a landscape. Although, the impact of river regulation on riparian vegetation has been studied extensively in the last couple of decades, the predominant area of focus remains the downstream impacts of damming (New and Xie 2008). In upper riparian areas, the effects of hydrology on vegetation may be less obvious and therefore more uncertain (Tabacchi et al. 1998). An enormous knowledge void still persists in understanding of rivers, riparian forests and wildlife within a reservoir after a dam has been created.

In contrast to the narrowing and regulated water flow in the downstream of dams, the inundation of forests in the upstream reservoir is the major event that takes place once dams are completed (Nilsson and Berggren 2000). The yearly water fluctuations of dry (drought) and wet (flood) cycles then become a regular event. Terrestrial species lose most of their habitat due to this inundation and are forced to occupy higher grounds in the valley. The effect on mobiles species, such as mammals and birds, is not as pronounced compared to trees and other sessile species. In plants, Blom and Voesenek (1996) reported that some species quickly cease growth and eventually die if they are entirely inundated, while others respond by elongating their shoots that restores contact with open air. Hence, only resilient and adaptable species survive this flood and drought cycle in the long term. Prolonged understudied ecosystems may experience undetected irreversible repercussions in the long-term, especially naturally dynamic ecosystems such as rivers which are under added anthropogenic pressure. A paradigm shift towards understanding dam impacts on upstream reservoirs is vital among ecologists and wildlife managers alike. In practice, dams prevent human access providing some degree of protection which aid in park management and protection measures. However, if left unchecked, dams may have serious impacts on upstream reservoir wildlife habitat as well.

5.4.5. Implications and future course: Water is a quintessential resource for any species survival. For terrestrial mammals, access to water sources such as rivers, streams, lakes is hence important. Water sources and habitats that provide access to water sources are vital for wildlife persistence. I present a novel framework for quantification of riparian habitat structure and quality of riparian forests in upstream of dams/reservoirs. Indian wildlife management plans are exhaustive; however rarely riparian forest health monitoring has been included in such plans. Castro-López et al. (2019) emphasized that QBR index may be used for establishment of restoration plans and even inform plans to eliminate invasive species along rivers. In cases such as Sahyadri Tiger Reserve, inclusion of monitoring (and potential restoration) of riparian forest quality in an integrated management strategy for tiger recovery will prove vital to inform necessary on-ground actions, specifically for augmentation of prey and eventually the top order predator (i. e. tiger). In general, vegetation/habitat data are collected annually in all Indian tiger reserves as part of Phase I and Phase IV monitoring (Maraj and Seidensticker 2006; NTCA 2012), and also during the nation-wide population estimation of tiger, co-predator, prey species and habitat condition (Jhala et al. 2015) The riparian health assessment can be easily incorporated in separate but simple analyses to inform the status of riparian habitats. I recommend riparian habitat structure and quality assessment to be included in species-specific or landscape management plans, especially for large terrestrial carnivore such as tigers in India.

CHAPTER VI

TERRESTRIAL MAMMAL OCCUPANCY ALONG RIPARIAN FORESTS

Abstract: Riparian forests are a key constituent of terrestrial-aquatic systems, providing unique habitats to variety of wildlife species. A catchment-wide field design was adopted where different stream orders were sampled in Koyna to test the role of riparian habitat structure and stream type in determining mammalian occupancy and system response. Camera trapping carried out across 72 riparian sampling locations recorded 19 species of terrestrial mammals. Multi-season occupancy models showed that gaur and wild pig occupied highest proportion of areas (0.84 ± 0.12 SE, 0.77 ± 0.07 SE respectively). However, porcupine had the highest detection probability (0.43 ± 0.01 SE) followed by wild pig (0.37 ± 0.02 SE). Distance to stream edge best explained the occupancy of gaur suggesting that stream edges are intensively utilized by large ungulate species and it is perhaps linked to top-order predator absence. Ungulate populations in riparian forests not only reflect the terrestrial-riverine continuum, but are also facilitated by system response to top carnivore decline with management implications for population and habitat restoration. This robust sampling approach based on the terrestrial-riverine continuum concept can be applied globally to understand species assemblages aiding in multi-landscape and wildlife management planning.

Keywords camera trapping, intermittent rivers, riparian buffer, riverscapes, river continuum, terrestrial mammals

6.1. Introduction: Like river systems, riparian forests form their own continuum alongside rivers and streams from headwaters to perennial rivers. Riparian forests are, hence, essential components of terrestrial-riverine continua and reflect the functional status of an entire catchment. These forests protect river banks from erosion resulting in bank stability (Pinay et al. 2018) and drive organic matter and nutrients into streams (Vannote et al. 1980). Riparian woodlands moderate temperature extremes in river environments (Dugdale et al. 2018). Riparian ecosystems are also predicted to function as hotspots for climate change adaptation (Capon et al. 2013; Seavy et al. 2009). Riparian habitats are used by a large number of wildlife species and act as source of essential cover, food and water to small and large mammals (Thomas et al. 1979). Our understanding of mammalian species assemblages and space use patterns in riparian areas is limited, primarily because species-habitat relationship studies in riparian forests have focused on fish and other obligate stream dependent biota. However, the role of streams or riverscapes in the life of higher taxa such as terrestrial mammals cannot be overlooked. Further, riparian forests within large reservoirs undergo substantial transformation and mammal persistence in these areas are poorly known.

Large dams impact the riparian forests in two major ways, (i) inundation of vast areas of land and (ii) disruption of the seasonal flood regime along the river (Nilsson and Dynesius 1994). Large dams take a long time to complete – Koyna Dam construction began in 1954 and was completed in 1963. The formation of the reservoir displaces resident animals to nearby areas where higher densities of individuals of the same species are already resident. This phenomenon is termed as the reservoir's extended effect (Sá 1995; Alho 2011). However, once a reservoir is complete and a substantial amount of time has passed, mammals adapt to their surroundings. In case of Koyna, 55 years have passed since the dam was completed. The landscape has since experienced numerous changes in terms of land and river structure as well the socio-political context. Many villages in the valley have been relocated, firstly when the dam was being constructed and secondly when the area was notified as a wildlife sanctuary in 1985. Tigers also experience local extinction from Koyna landscape with the last confirmed tiger record from Koyna in 2007. With this study, we know the present status of wildlife in the reservoir, acknowledging that severe changes in mammal community may have taken place which went predominantly undocumented. However, this may be treated as a baseline study on mammal ecology in reference to the Koyna Hydropower Dam five decades after its construction.

To encompass the whole watershed and to understand mammal occupancy patterns along all types of streams, I adopted an integrative approach wherein overall dynamics of an entire river system could be understood. In this chapter I aimed to (i) assess patterns of occupancy as surrogate of space use intensity of terrestrial mammals and (ii) the factors affecting species occupancy in riparian forests of Koyna Wildlife Sanctuary. Such an approach is unique and provides understanding of mammalian species assemblages in riparian forests not only adjacent to perennial streams, but also riparian forests linked to temporary streams. This provides cues on the mammalian species dependent on these forests for better management of their habitat.

6.2. Materials and methods

6.2.1. Camera trapping surveys: 72 camera traps were deployed along a stream gradient; in the perennial stream cameras were distanced at 1 km; at 500 m in the intermittent stream, at 200 m in the ephemeral stream and 100 m in headwater (detailed in Fig. 4.1 of Chapter IV and Fig. 5.1 of Chapter V). As the buffers extended to 1 km, 500 m, 200 m and 100 m in both directions from the stream edge respectively in perennial, ephemeral, intermittent and headwater streams, this design gave good variability. I positioned my camera stations randomly within these distance categories while also keeping an eye on the feasibility and practicality in the field. However, since the ephemeral and headwater streams sometimes reflected each other in the field in that their riparian forests are sometimes shared and also undergo a terrestrial phase during summer, I put the cameras close to the edge of these streams (e. g. ~ 10 m). At each of the 72 sites, a single motion-triggered digital camera was deployed by affixing it at a height of *c.* 60–70 cm to suitable trees. I used the Cuddeback white flash (C1 model) camera traps. These were set to take consecutive images (set 5 seconds apart) when triggered. In summer 2019, two cameras stopped working and in winter 2019, 5 cameras stopped working after deployment.

6.2.2. Riparian habitat assessment: Circular vegetation plots were established in all the 72 riparian buffers. The number of trees and fallen logs were assessed in 10 m radius plots (covering 314 m^2). Percent canopy cover, elevation, the adjacent stream type and the distance to stream edge were recorded from the center of the plot. A 5 m radius plot was placed inside the 10 m plot to document number of saplings and seedlings.

6.2.3. Data analyses:

6.2.4. Photographic captures: Images retrieved from the camera traps were stored in an external hard drive. Animals were identified to species level excluding random captures of birds and data were sorted into species-specific folders for all sites by season. Images were considered to be independent captures when they were at least 30 minutes apart (Linkie and Ridout, 2011; Rovero and Zimmerman, 2016; Allen et al. 2018). Once all data were identified, sorted and organized, I calculated the capture rates by dividing the number of independent captures by total number of camera trap nights (effort) and expressed it per 100 trap nights (Carbone et al. 2001).

6.2.5. Occupancy modelling framework: Multi-season occupancy models (MacKenzie 2002; 2006) using PRESENCE 12.6 (Hines 2006) were constructed to model occupancy of species that had at least 20 independent captures across all four seasons. I arranged the camera trap data into 7 day occasions (weekly replicates) to record detection and non-detection to create detection history matrices. A detection was coded as (1), non-detection as (0) and a missing survey as (.), which in my study meant that a camera stopped working during the deployed time. One strength of occupancy modelling is that it can account for incomplete detection histories. For example, a detection history of "10.1" indicates that the target species was detected in the first replicate and fourth replicate and not detected in the second replicate. The third replicate was a missed survey because of camera malfunction. Cameras were hence checked regularly in field after deployment to limit the missing survey replicates. I finally compiled detection history matrices with four replicates in summer 2018, seven replicates for winter 2018, summer 2019 and winter 2019. Hence 25 replicates across all four seasons.

For all multi-season models, the model parameterization was fixed to initial occupancy, local colonization, extinction and detection. The parameters used in the models were:

ψ: occupancy probability (probability that the area is occupied by the species)

pi: detection probability (probability of detection species in survey i, given the species is presence)

γi: colonization probability (probability of unoccupied site being colonized between seasons i and i +1)

εi: extinction probability (probability of occupied site going extinct between seasons i and i + 1)

The estimates of occupancy (ψ), seasonal colonization (γ), local extinction (ε) and detection probability (p) were obtained through the null model.

6.2.6. Predictor variables: The riparian habitat covariates were selected *a priori* because of their likely importance in driving wildlife occupancy along streams (Table 6.1). To minimize model overfitting which often risks the inclusion of spurious variables (Burnham and Anderson, 2002), we tested for pair-wise correlations between covariates using Pearson's correlation analyses. This was done using the *cor* function and plotted using *corrplot* function in R corrplot (Wei and Simko 2017) package in R 4.0.0 (R Core Team 2020). Correlation threshold was fixed at $r \geq 0.7$ (Dornmann et al. 2013), and when correlation

between two variables was higher than 0.7, one of the two covariates was removed.

I expected a correlation between the distance from stream edge with the stream type, as cameras were set at specific distances from stream edge at each of the stream types. Among the variables considered for modelling, stream type was a categorical variable and hence it was not possible to test for its correlation with any of the variables using the Pearson's correlation. Regression models allow to test for this by using square root of the R^2 value as surrogate that can be treated similar to correlation. I used distance from stream edge (continuous) as dependent variable and stream type (categorical) as independent variable. The same threshold of 0.7 was fixed to test for correlation. Simultaneously, a principal component analysis (PCA) to test for multicollinearity in the dataset was also run, using the *prcomp* function in the factoextra 1.0.7 package (Kassambara and Mundt 2020) in R.

Table 6.1: Description of covariates with *a priori* hypotheses along riparian forests

Covariate	Expected influence		Supporting citation
	Species	Parameter with expected effect	
Elevation	Gaur, Sambar, Barking deer	ψ (+), γ (+), ε (-)	Schaller (1967); Johnsingh et al. (2004) Timmins et al. (2015); Timmins et al. (2016)
	Porcupine, Wild pig	ψ (+), γ (+), ε (-)	
Number of trees	Gaur, Sambar, Barking deer, Porcupine	ψ (+), γ (+), ε (-)	Schaller (1967)
	Wild pig	ψ (-), γ (-), ε (+)	

Canopy cover	Gaur, Sambar, Barking deer, Porcupine, Wild pig	ψ (+), γ (+), ε (-)	Duckworth et al. (1999); Duckworth and Hedges (1998); Greiser Johns (2000)
Distance from stream	Gaur, sambar, barking deer, porcupine, wild pig	p (-)	Timmins et al. (2015)
Season	Gaur, sambar, barking deer, porcupine, wild pig	p (+/-)	

6.2.7. Model selection: For model selection, χ^2 goodness-of-fit test (MacKenzie and Bailey 2004) using 999 parametric bootstraps was run to estimate overdispersion parameter $\hat{c}$ (Burnham and Anderson 2002). This was done only for the global model (model with all the covariates) as recommended by Burnham and Anderson (2002). Model fit was evaluated in program PRESENCE by using the 'assess model fit' function, while creating the design matrix of the global model. Finally, to account for overdispersion (where $\hat{c} > 1$) indicating a lack of fit, the model selection was done using quasi AIC (QAIC), and model parameters were adjusted by multiplying the standard errors by a factor $\sqrt{\hat{c}}$ (Burham and Anderson, 2002; Mackenzie and Bailey 2004). The QAIC was computed using the following formula:

$$\text{QAIC} = -2 \log \text{Like} / \hat{c} + 2k$$

where,

log Like = log likelihood of the model

$\hat{c}$ =dispersion parameter from the global model

k=number of parameters in the model

The estimates of occupancy (ψ), seasonal colonization (γ), local extinction (ε) and detection probability (p) were obtained through the null models of each species. Graphs were created using ggplot2 (Wickham 2016) and ggpubr 0.4.0 (Kassambara 2020) R packages. I present all parameter and β estimates with standard error (SE) values throughout the paper.

6.3. Results: The camera trap effort amounted to a total of 10, 021 trap nights across all four seasons — 1757 trap nights in summer 2018, 2872 in winter 2018, 2868 in summer 2019 and 2524 in winter 2019. Nineteen species of terrestrial mammals were photo-captured across all four seasons. The camera capture threshold criteria of at least 20 independent captures was fulfilled by ten species in summer 2018, winter 2018, and winter 2019 respectively, and six species in summer 2019. Only five species fulfilled this criterion across all four seasons and hence multi-season models were run for these five species — gaur (*Bos gaurus*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), barking deer (*Muntiacus muntjac*) and porcupine (*Hystrix indica*). Seven species did not fulfill this criterion in any of the sampled seasons. These were — Indian pangolin (*Manis crassicaudata*), Indian hare (*Lepus nigricollis*), grey mongoose (*Herpestes edwardsii*), Indian gerbil (*Tatera indica*), stripe-necked mongoose (*Herpestes vitticollis*), rusty spotted cat (*Prionailurus rubiginosus*) and brown palm civet (*Paradoxurus jerdonii*).

Camera traps also captured livestock and two primate species — southwestern langur (*Semnopithecus hypoleucos*) and bonnet macaque (*Macaca radiata*). The Indian giant squirrel (*Ratufa indica*) was also incidentally recorded on ground once in summer 2018. Along with mammals, we also recorded several bird species, some of which were not identifiable to species level (owing to captures at night or blurry captures while in flight), except for grey wagtail (*Motacilla cinerea*), red wattled lapwing (*Vanellus indica*), Indian peafowl (*Pavo cristatus*), purple sunbird (*Cinnyris asiaticus*), Asian paradise flycatcher (*Terpsiphone paradise*), Malabar whistling thrush (*Mycophomus horsfieldii*), orange headed thrush (*Geokichla citrina*), Indian blackbird (*Turdus simillimus*) and Indian eagle owl (*Bubo bengalensis*). Ground dwelling birds — the grey jungle fowl (*Gallus sonneratti*) was photo captured across all four seasons and red spurfowl (*Galloperdix spadicea*) was captured only in winter 2019.

6.3.1. Photographic captures: Porcupine was among the highest photo-captured species in all seasons (Table 6.2; Fig. 6.1). Other frequently photo-captured species were wild pig, gaur, sambar and barking deer. Among carnivores, leopards, dhole and sloth bears were photo-captured (Table 6.2; Fig. 6.1). Elusive small mammals, gerbil and brown palm civet were captured only in one season, while the rusty spotted cat was captured in the winter seasons.

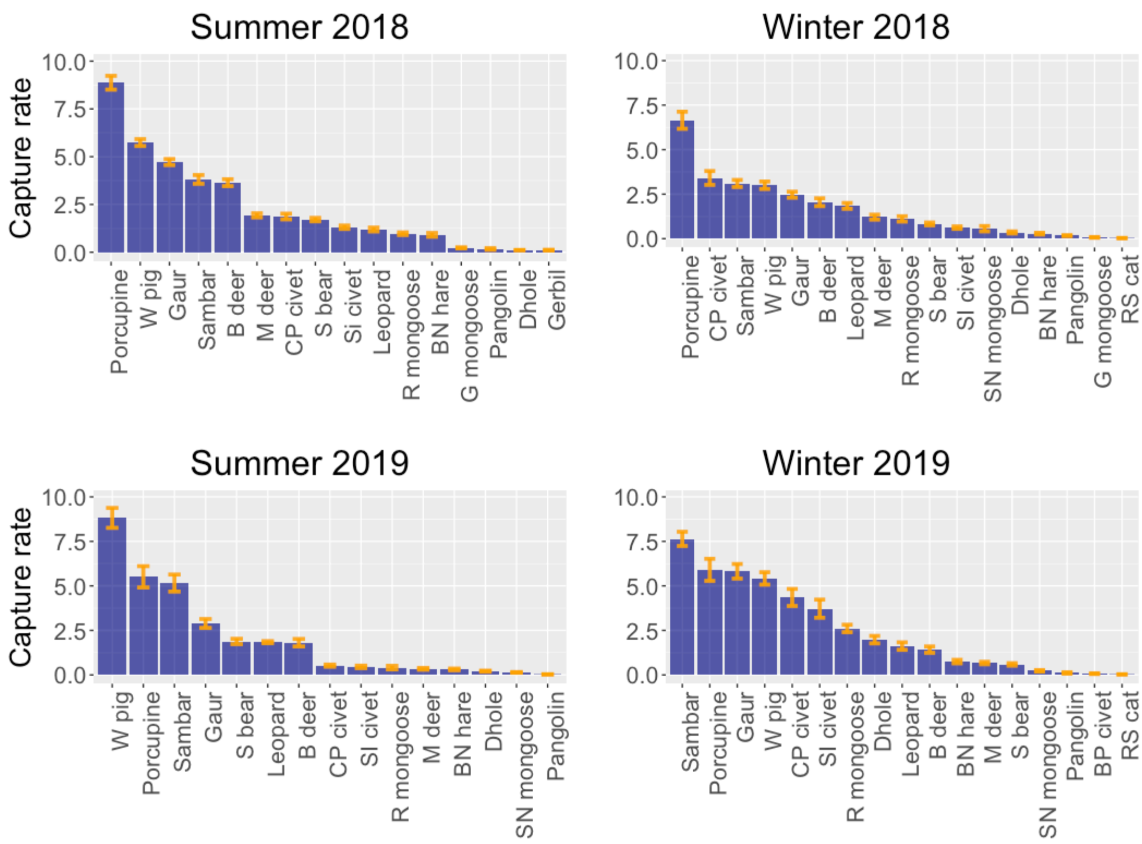

Fig. 6.1: Capture rates of all species captured in across all four seasons (codes for species: W pig: wild pig; CP: common palm civet; SI civet: Small Indian civet; BP civet: Brown palm civet; R mongoose: ruddy mongoose; SN mongoose: stripe necked mongoose; G mongoose: grey mongoose; B deer: barking deeer; M deer: mouse deer; BN hare: black naped hare; S bear: sloth bear)

Table 6.2: Number of captures and capture rates (within parentheses) of all terrestrial mammals recorded over all seasons.

Species	Summer 18	Winter 18	Summer 19	Winter 19
Porcupine	156 (8.87)	191 (6.65)	158 (5.51)	149 (5.90)
Gaur	83 (4.72)	71 (2.47)	83 (2.89)	147 (5.82)

Wild pig	101 (5.74)	86 (3.00)	253 (8.82)	137 (5.42)
Sambar	67 (3.81)	89 (3.10)	148 (5.16)	193 (7.64)
Barking deer	64 (3.64)	59 (2.05)	52 (1.81)	36 (1.42)
Mouse deer	34 (1.93)	35 (1.21)	10 (0.34)	17 (0.67)
Sloth bear	30 (1.71)	24 (0.83)	54 (1.88)	15 (0.59)
Leopard	21 (1.19)	53 (1.84)	17 (0.59)	41 (1.62)
Common palm civet	33 (1.87)	98 (3.41)	15 (0.52)	110 (4.35)
Small Indian civet	23 (1.31)	18 (0.62)	13 (0.45)	94 (3.72)
Ruddy mongoose	17 (0.97)	32 (1.11)	12 (0.41)	66 (2.61)
Dhole	2 (0.11)	10 (0.35)	6 (0.21)	50 (1.98)
Indian pangolin	3 (0.17)	5 (0.17)	1 (0.034)	3 (0.11)
Grey mongoose	4 (0.23)	2 (0.07)	—	—
Indian hare	16 (0.91)	8 (0.28)	9 (0.31)	19 (0.75)
Indian gerbil	2 (0.11)	—	—	—
Stripe-necked mongoose	—	16 (0.56)	4 (0.14)	6 (0.23)
Rusty spotted cat	—	1 (0.03)	—	1 (0.039)
Brown palm civet	—	—	—	2 (0.079)

6.3.2. Final set of predictor variables used for occupancy modelling: The pairwise correlation test showed that distance from stream edge and stream type had high correlation (0.94) and hence stream type was removed from the final set of variables. For all the continuous variables, no correlation was detected (Fig. 6.2). The PCA demonstrated that distance from stream, number of fallen logs and percent understory cover to have low contribution in the overall dataset (Fig. 6.3), and hence these were not considered for testing species occupancy. However, distance from stream was retained as a covariate to test species detection, as I expected it to be an important variable for species detection along riparian forests. The final set of covariates after both correlation and multicollinearity tests were used as occupancy, seasonal colonization, local extinction and detection covariates in the occupancy models (Table 6.3).

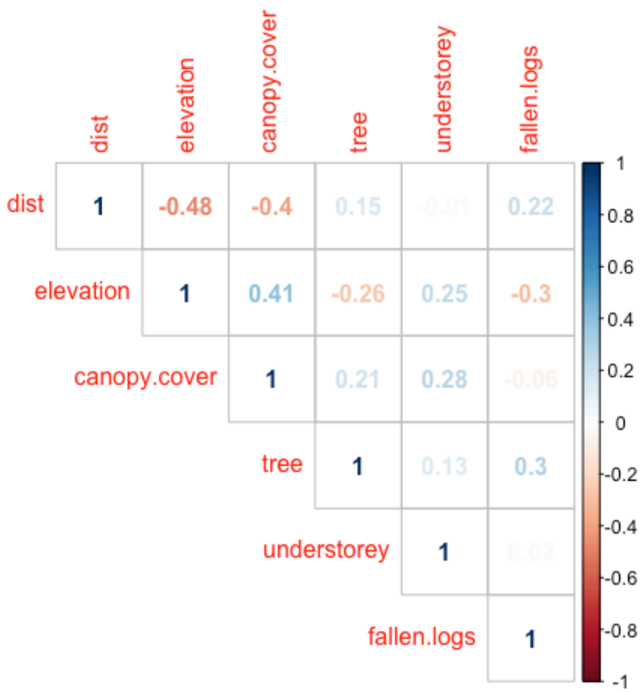

Fig. 6.2: Correlation plot for the variables considered for occupancy models

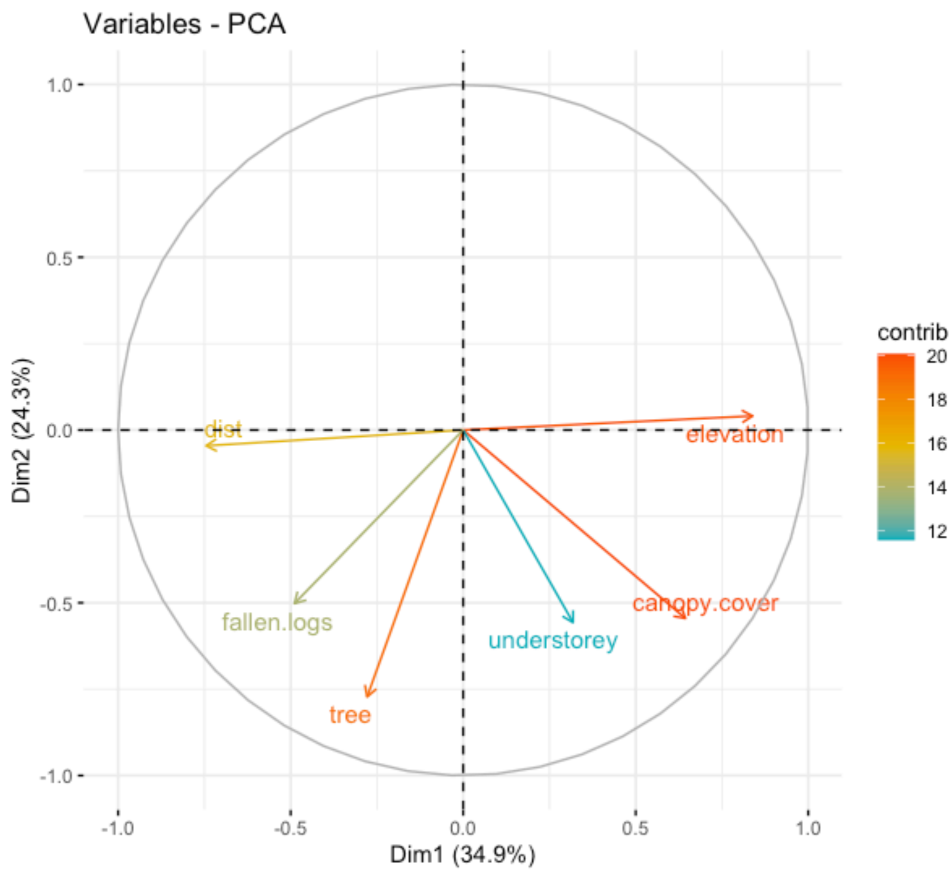

Fig. 6.3: Test of multi-collinearity among all covariates using Principal Component Analysis (PCA). Figure also shows individual contribution of all covariates in a 2-dimensional space.

Table 6.3: Final list of habitat covariates used in the occupancy models

Parameter	Site-specific covariate	Type of variable	Mean values (range)
ψ, γ, ε	Elevation (m)	Continuous	655.72 (633–695)
	Canopy cover (%)	Continuous	61.15 (0–90)
	Number of trees	Continuous	19.68 (0–50)

p	Distance from stream edge (m)	Continuous	Perennial: 251.08 (90–358) Intermittent: 123.08 (90–168) Ephemeral: 66.67 (40–100) Headwater: 15.62 (5–25)
	Season	Categorical	—

6.3.3. Model selection: Model overdispersion was observed for two species viz. gaur ($\hat{c}$ = 2.83) and sambar ($\hat{c}$ = 2.05) (Table 6.4). No model overdispersion was detected for barking deer ($\hat{c}$ = 0.03), wild pig ($\hat{c}$ = 0.88) and porcupine ($\hat{c}$ = 0.85) (Table 6.4). Top ranking models for each species (ΔQAIC ≤ 2) were considered which accounted for 83% and 95% of the QAIC model weight for sambar and gaur respectively. For barking deer, porcupine and wild pig, top ranking models (ΔAIC ≤ 2) accounted for 67%, 81% and 93% of AIC model weights, respectively.

Table 6.4: Global occupancy models for all five species. [Codes used: AIC: Akaike Information Criteria; QAIC: quasi Akaike Information Criteria; ΔAIC: AIC difference between candidate models with AIC; ΔQAIC: difference between candidate models with QAIC; w: AIC weight of each candidate model; k: number of parameters in each candidate model; $\hat{c}$: overdispersion parameter; p: significance value]. [Covariate codes: ele: elevation; canopy: canopy cover (%), dist.: distance from stream edge; tree: number of trees]

Species	Model	QAIC/ AIC	ΔQAIC/ ΔAIC	w	k	$\hat{c}$	p
Gaur	ψ (ele+canopy+tree), γ (ele+canopy+tree), ε (ele+canopy+tree), p (season)	480.56	33.65	0	16	2.83	0.08
Sambar	ψ (ele+canopy+tree), γ (ele+canopy+tree), ε (ele+canopy+tree), p (season)	22611.98	21898.97	0.00	16	2.05	0.07
Barking deer	ψ (ele+canopy+tree), γ (ele+canopy+tree), ε (ele+canopy+tree), p (dist)	821.62	0.6	0.28	14	0.03	0.91
Porcupine	ψ (ele+canopy+tree), γ (ele+canopy+tree), ε (ele+canopy+tree), p (season+dist)	1392.82	5.4	0.02	17	0.85	0.41
Wild pig	ψ (ele+canopy+tree), γ (ele+canopy+tree), ε (ele+canopy+tree), p (dist + season)	1527.36	6.02	0.05	17	0.88	0.39

6.3.4. Occupancy modelling results: Indian gaur (0.84 ± 0.12) had the highest proportion of sites occupied followed by wild pig (0.77 ± 0.07), porcupine (0.65 ± 0.07), sambar (0.49 ± 0.10) and barking deer (0.49 ± 0.08) (Table 6.5; Fig. 6.4). Sambar (0.63 ± 0.10) had the highest probability to colonize unoccupied sites between seasons, followed by wild pig (0.62 ± 0.08), gaur (0.57 ± 0.15), porcupine (0.47 ± 0.06) and barking deer (0.24 ± 0.05). Barking deer (0.59 ± 0.07) had the highest probability to go extinct from an occupied site between seasons, porcupine (0.43 ± 0.05), gaur (0.39 ± 0.11), wild pig (0.32 ± 0.04) and sambar (0.15 ± 0.07). Porcupine (0.43 ± 0.01) had the highest detection probability followed by wild pig (0.37 ± 0.02), sambar (0.31 ± 0.01), barking deer (0.29 ± 0.02) and gaur (0.27 ± 0.03) (Table 6.5; Fig. 6.4).

Table 6.5: Probability estimates of site occupancy, local colonization, extinction and detection of species

Species	ψ (±SE)	γ (±SE)	ε (±SE)	p (±SE)
Barking deer	0.49 (± 0.08)	0.24 (± 0.05)	0.59 (± 0.07)	0.29 (± 0.02)
Gaur	0.84 (± 0.12)	0.57 (± 0.15)	0.39 (± 0.11)	0.27 (± 0.03)
Porcupine	0.65 (± 0.07)	0.47 (± 0.06)	0.43 (± 0.05)	0.43 (± 0.01)
Sambar	0.49 (± 0.10)	0.63 (± 0.10)	0.15 (± 0.07)	0.31 (± 0.01)
Wild pig	0.77 (± 0.07)	0.62 (± 0.08)	0.32 (± 0.04)	0.37 (± 0.02)

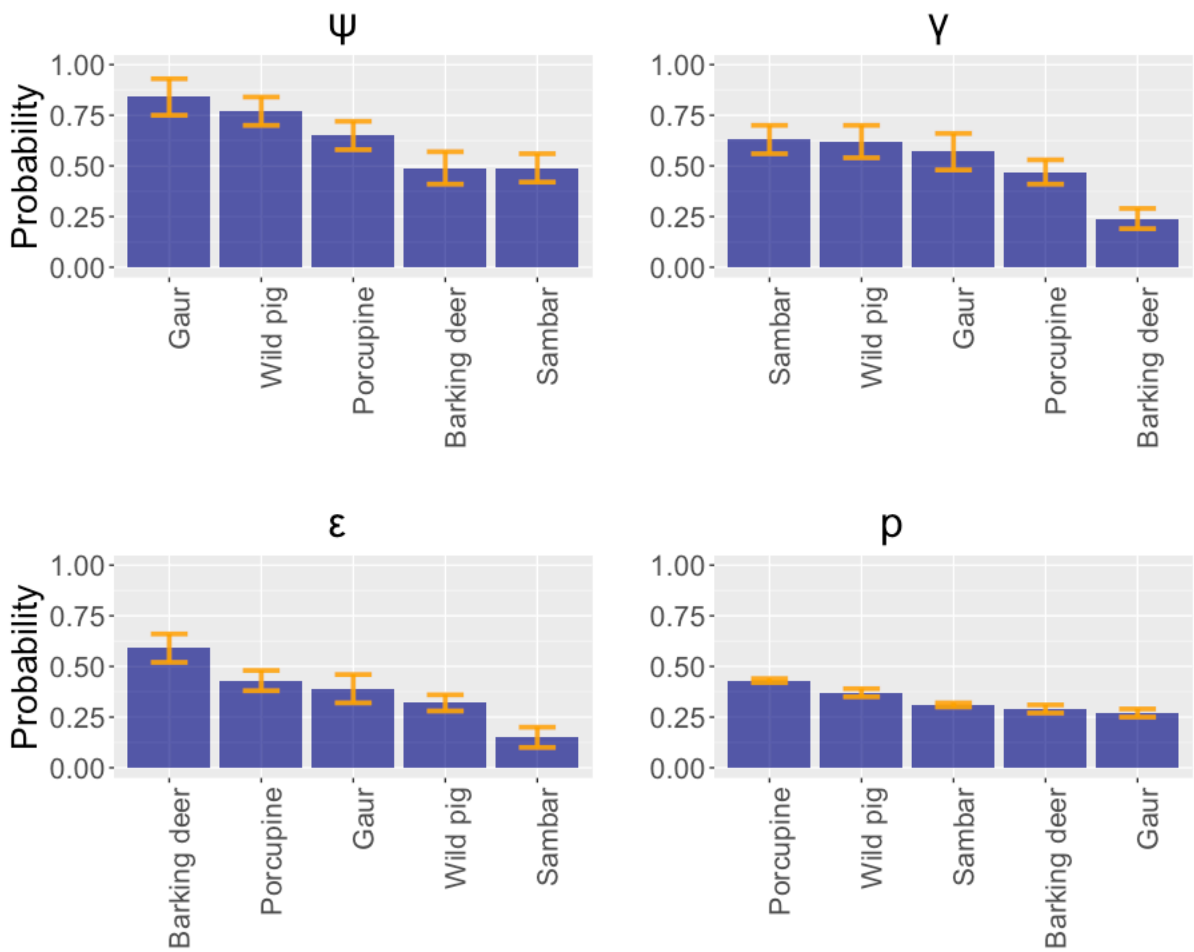

Fig. 6.4: Estimates of occupancy, colonization, extinction and detection probabilities

6.3.5. Predictors of occupancy, detection, local colonization and extinction between seasons (β estimates with standard error SE are reported within parentheses)**:**

Barking deer: Barking deer occupancy was positively affected by elevation (0.09 ± 0.01) and number of trees (0.05 ± 0.02), and negatively by canopy cover (-0.06 ± 0.01). Its colonization probability was positively affected by canopy cover (0.03 ± 0.01), and negatively by elevation (-0.04 ± 0.01) and number of trees (-0.01 ± 0.02). Its extinction probability was negatively affected by elevation (-0.05 ± 0.01), canopy cover (-0.01 ±

0.01) and number of trees (-0.05 ± 0.02). Its detection was higher at sites near to streams (-0.01 ± 0.01) (Fig. 6.5–6.6; Tables 6.6–6.9).

Porcupine: Porcupine occupancy was positively affected by canopy cover (0.01 ± 0.01), number of trees (0.03 ± 0.01), and negatively by elevation (-0.01 ± 0.01). Its colonization probability was positively affected by canopy cover (0.02 ± 0.01), number of trees (0.01 ± 0.01) and negatively by elevation (-0.03 ± 0.01). Its detection was higher closer to streams (-0.001 ± 0.001) and it was also affected by season. None of the covariates considered could explain porcupine extinction probability (Fig. 6.5–6.6; Tables 6.6–6.9).

Gaur: Gaur detection (-0.02 ± 0.01) were higher at sites near streams. Its detection was also affected by season. Its occupancy, colonization and extinction probabilities were not explained by any of the covariates considered in the occupancy models (Fig. 6.5–6.6; Tables 6.6–6.9).

Sambar: Sambar occupancy, colonization and extinction probability were not influenced by any of covariates. However, sites near to streams (-0.001 ± 0.001) and season affected its detection probability (Fig. 6.5–6.6; Tables 6.6–6.9).

Wild pig: Wild pig extinction probability was positively affected by elevation (0.02 ± 0.01), and negatively by canopy cover (-0.02 ± 0.01), number of trees (-0.06 ± 0.08). Its detection was higher near streams (-0.01 ± 0.01), and was also affected by season.

No factors could explain its occupancy and colonization (Fig. 6.5–6.6; Tables 6.6–6.9).

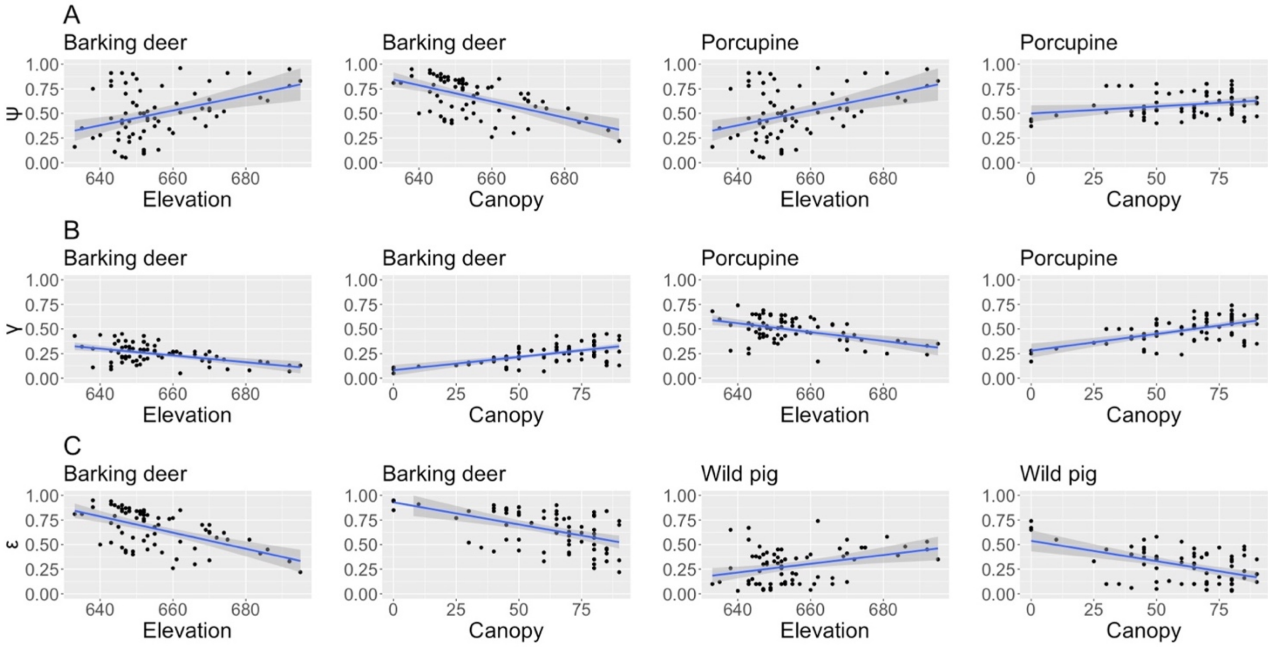

Fig 6.5: Factors affecting species (A) occupancy, (B) colonization, and (C) extinction probabilities of common mammal species. The number of trees also showed statistically significant relationships to these probabilities, similar to those of canopy openness shown here (Tables 6.6–6.9).

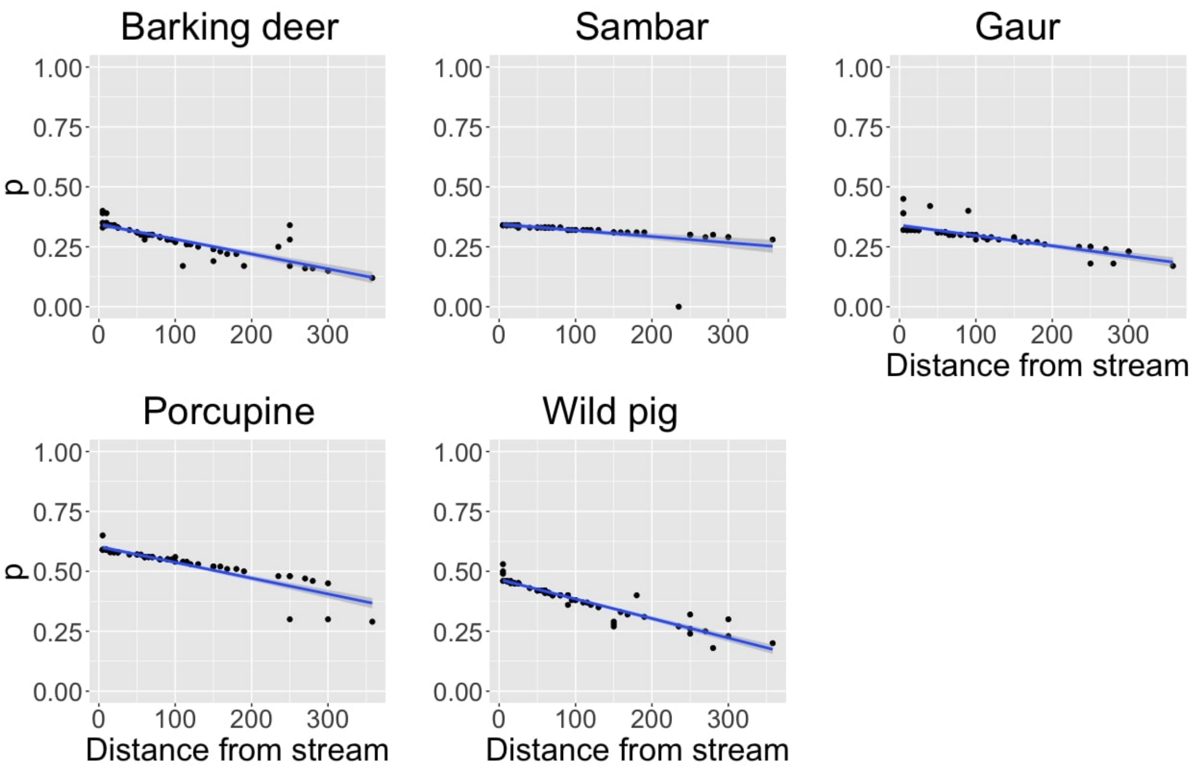

Fig. 6.6: Effect of distance from stream on species detection probabilities

Table 6.6: Candidate models for detection probability (p) of species. [For codes, please refer to Table 6.4]

Species	Model	QAIC/ AIC	ΔQAIC/ ΔAIC	w	k
Gaur	p (season)	446.91	0	0.33	7
	p (.)	447.07	0.16	0.30	10
	p (dist)	448.16	1.26	0.17	5
	p (season+dist)	448.58	1.67	0.14	8
Sambar	p (season)	713.00	0.00	0.58	7
	p (dist+season)	714.74	1.73	0.24	8

	p (.)	716.17	3.16	0.12	4
	p (dist)	717.80	4.79	0.05	5
Barking deer	p (dist)	821.02	0	0.38	8
	p (dist+season)	825.72	4.7	0.04	8
	p (.)	828.89	7.87	0.01	4
	p (season)	829.54	8.52	0.01	7
Porcupine	p (season+dist)	1387.42	0	0.35	8
	p (season)	1388.9	1.48	0.17	7
	p(.)	1392.56	5.14	0.03	4
	p (dist)	1393.51	6.09	0.02	5
Wild pig	p (dist + season)	1521.34	0	0.93	11
	p (dist)	1534.48	13.14	0.00	5
	p (season)	1536.34	15	0.00	7
	p (.)	1538.92	17.58	0.00	4

Table 6.7: Candidate models for species occupancy (ψ)

Species	Model	QAIC/ AIC	ΔQAIC/ ΔAIC	w	k
Gaur	ψ (.)	446.91	0	0.33	7
	ψ (tree)	448.69	2.78	0.05	5
	ψ (canopy)	449.89	2.99	0.03	5
	ψ (ele)	449.89	2.99	0.03	5
	ψ (ele+tree)	451.89	4.98	0.01	6

	ψ (canopy+tree)	451.89	4.98	0.01	6
	ψ (ele+canopy)	451.89	4.98	0.01	6
	ψ (ele+canopy+tree)	454.28	7.37	0.00	10
Sambar	ψ (.)	713.00	0.00	0.58	7
	ψ (tree)	717.75	4.75	0.04	5
	ψ (canopy)	717.82	4.82	0.04	5
	ψ (ele)	718.14	5.14	0.03	5
	ψ (canopy+tree)	719.09	6.09	0.05	6
	ψ (ele+canopy)	719.55	6.55	0.05	6
	ψ (ele+tree)	719.64	6.64	0.05	6
	ψ (ele+canopy+tree)	22602.99	21889.99	0.00	10
Barking deer	ψ (ele+canopy+tree)	821.02	0	0.38	8
	ψ (.)	824.6	3.58	0.06	5
	ψ (ele+canopy)	824.75	3.73	0.0483	6
	ψ (ele)	825.88	4.86	0.03	5
	ψ (ele+tree)	827.34	6.32	0.0132	6
	ψ (canopy)	830.58	9.56	0.00	5
	ψ (tree)	830.86	9.84	0.00	5
	ψ (canopy+tree)	832.48	11.46	0.001	6
Porcupine	ψ (.)	1387.42	0	0.35	8
	ψ (ele+canopy+tree)	1389.32	1.9	0.14	11
	ψ (tree)	1391.29	3.87	0.04	5
	ψ (ele+tree)	1392.98	5.56	0.0163	6

	ψ (canopy+tree)	1393.28	5.86	0.014	6
	ψ(ele)	1393.62	6.2	0.01	5
	ψ(canopy)	1394.14	6.72	0.01	5
	ψ (ele+canopy)	1394.48	7.06	0.0077	6
Wild pig	ψ (.)	1521.34	0	0.93	11
	ψ (ele+canopy+tree)	1527.36	6.02	0.05	17
	ψ (canopy)	1549.16	27.82	0	5
	ψ (tree)	1549.16	27.82	0	5
	ψ (canopy+tree)	1551.16	29.82	0	6
	ψ (ele)	1551.67	30.33	0	5
	ψ (ele+tree)	1553.67	32.33	0	6
	ψ (ele+canopy)	1553.67	32.33	0	6

Table 6.8: Candidate models for species seasonal colonization (γ)

Species	Model	QAIC/ AIC	ΔQAIC/ ΔAIC	w	k
Gaur	γ (.)	446.91	0	0.33	7
	γ (ele)	447.59	2.68	0.10	5
	γ (tree)	448.89	2.98	0.05	5
	γ (canopy)	448.94	2.99	0.04	5
	γ (ele+canopy)	449.57	3.66	0.03	6
	γ (ele+tree)	449.59	3.68	0.03	6
	γ (canopy+tree)	450.70	3.79	0.02	6

	γ (ele+canopy+tree)	451.12	4.21	0.04	10
Sambar	γ (.)	713.00	0.00	0.58	7
	γ (tree)	718.16	5.16	0.03	5
	γ (ele)	727.63	14.63	0.00	5
	γ (canopy)	727.63	14.63	0.00	5
	γ (ele+canopy)	729.63	16.63	0.03	6
	γ (ele+tree)	729.63	16.63	0.03	6
	γ (canopy+tree)	729.63	16.63	0.03	6
	γ (ele+canopy+tree)	22603.42	21890.41	0.00	10
Barking	γ (.)	821.02	0	0.38	8
deer	γ (ele+canopy+tree)	821.62	0.6	0.28	14
	γ (canopy)	826.6	5.58	0.02	5
	γ (ele+canopy)	827.34	6.32	0.0132	6
	γ (tree)	829.78	8.76	0.00	5
	γ (ele)	830.77	9.75	0.00	5
	g γ (ele+tree)	831.77	10.75	0.00	6
	γ (canopy+tree)	832.48	11.46	0.00	6
Porcupine	γ (.)	1387.42	0	0.35	8
	γ (ele+canopy+tree)	1389.14	1.72	0.15	11
	γ (ele+canopy)	1391.69	4.27	0.031	6
	γ (tree)	1392.8	5.38	0.02	5
	γ (elevation)	1392.94	5.52	0.02	5
	γ (canopy)	1393.06	5.64	0.02	5

	γ (canopy+tree)	1393.79	6.37	0.0109	6
	γ (ele+tree)	1393.93	6.51	0.0101	6
Wild pig	γ (.)	1521.34	0	0.93	11
	γ (ele+canopy+tree)	1527.36	6.02	0.05	17
	γ (tree)	1540.21	18.87	0.0001	5
	γ (canopy)	1540.39	19.05	0.0001	5
	γ (ele)	1540.85	19.51	0.0001	5
	γ (canopy+tree)	1541.84	20.5	0	6
	γ (ele+canopy)	1542.03	20.69	0	6
	γ (ele+tree)	1542.21	20.87	0	6

Table 6.9: Candidate models for species local extinction (ε)

Species	Model	QAIC/ AIC	ΔQAIC/ ΔAIC	w	k
Gaur	ε (.)	446.91	0	0.33	7
	ε (tree)	447.57	2.66	0.08	5
	ε (canopy)	448.18	3.27	0.06	5
	ε (ele)	448.60	3.69	0.05	5
	ε (canopy+tree)	448.42	3.51	0.05	6
	ε (ele+tree)	449.40	4.49	0.03	6
	ε (ele+canopy)	449.95	5.04	0.02	6
	ε (ele+canopy+tree)	461.40	14.48	0.001	10
Sambar	ε (.)	713.00	0.00	0.58	7

	ε (tree)	716.51	3.51	0.08	5
	ε (canopy)	725.24	12.24	0.00	5
	ε (ele)	725.76	12.76	0.00	5
	ε (canopy+tree)	727.24	14.24	0.03	6
	ε (ele+tree)	727.76	14.76	0.03	6
	ε (ele+canopy)	727.76	14.76	0.03	6
	ε (ele+canopy+tree)	22605.44	21892.43	0.00	10
Barking deer	ε (.)	821.02	0	0.38	8
	ε (ele+canopy+tree)	821.62	0.6	0.28	14
	ε (ele+tree)	826.06	5.04	0.0251	6
	ε (canopy+tree)	828.26	7.24	0.0084	6
	ε (tree)	828.61	7.59	0.01	5
	ε (canopy)	828.96	7.94	0.01	5
	ε (ele+canopy)	830.41	9.39	0.0029	6
	ε (ele)	938.29	117.27	0	5
Porcupine	ε (.)	1387.42	0	0.35	8
	ε (ele+canopy+tree)	1389.48	2.06	0.13	11
	ε (ele)	1393.14	5.72	0.02	5
	ε (ele+tree)	1393.34	5.92	0.0136	6
	ε (tree)	1393.78	6.36	0.01	5
	ε (canopy)	1394.55	7.13	0.01	5
	ε (ele+canopy)	1394.98	7.56	0.006	6
	ε (canopy+tree)	1395.77	8.35	0.004	6

Wild pig	ε (ele+canopy+tree)	1521.34	0	0.93	11
	ε (tree)	1529.08	7.74	0.0184	5
	ε (canopy+tree)	1529.2	7.86	0.0174	6
	ε (.)	1529.68	8.34	0.01	8
	ε (ele+tree)	1531.07	9.73	0.0068	6
	ε (ele+canopy)	1534.72	13.38	0.0011	6
	ε (canopy)	1536.22	14.88	0.0005	5
	ε (ele)	1539.69	18.35	0.0001	5

6.4. Discussion: Three key patterns emerge here. Firstly, riparian forests within Koyna are dominated by ungulates. We did not record any tigers. The large carnivores that were phot-captured from the landscape were leopard, dhole and sloth bear. However due to fewer captures, occupancy could not be modelled for any of the carnivores. Pioneering studies by Naiman (1988), Pastor et al. (1988) and Naiman and Rogers (1997) found substantial evidence of large ungulates shaping structure of riparian forests in temperate ecosystems by selective browsing, dispersing seeds, and thereby affecting riparian plant community and ultimately modifying channel morphology (Naiman and Rogers 1997). In absence of top predator, this can be even more pronounced. Since tigers have become functionally extinct from the landscape (Jelil et al. 2020), the intensive space use of ungulates near streams may be a system response to carnivore population with management implications for population and habitat restoration.

Secondly, an ungulate body size effect on colonization and extinction probabilities was observed, in that smaller ungulates (barking deer) had highest extinction probability (0.59 ± 0.07 SE) and lowest colonization probability (0.24 ± 0.05 SE), while sambar had the highest colonization probability (0.63 ± 0.10) and lowest extinction probability (0.15 ± 0.07 SE) (Fig. 6.4). This indicates that smaller sized ungulates are more vulnerable to local extinction than large sized ungulates. Occupancy models revealed that maintaining higher canopy cover is key to increase the probability that barking deer would colonize previously unoccupied sites.

Thirdly, distance from stream edges was a dominant predictor of mammal detection probability (Fig. 6.6). As distance from stream increase, a drop in probabilities was observed, suggesting that ungulates in riparian forests congregate streams. It is now well established that rivers, riparian forests and adjacent upland forests are part of a single large contiguous systems composed of different smaller units of landscape. Hence viewing riparian forests as part of river continuum framework is essential.

These findings have high relevance for riparian forests and accordingly species management. Habitat variables that contribute to species-specific occupancy and long-term well-being were identified in this chapter; these can be prioritized in management plans. By conserving these factors, wildlife authorities can increase long term species persistence and strategically attempt to limit seasonal and local species extinctions. In addition to highlighting species-habitat relationship patterns of mammals utilizing riparian forests, the information generated in this study provides a strong empirical basis for developing catchment-wide and multi-species strategies for conservation management. Management strategies that have focused only on one key aspect and have simplified riverscapes have inevitably failed. Multi-landscape planning that encompasses streams, rivers and adjacent riparian forests which go beyond conventional planning of a single landscape unit have had overarching benefits (Naiman and Rogers, 1997; Hermosa et al. 2012; Adams et al. 2014). I further show that by incorporating habitat variables into multi-season occupancy models, managers could narrow down on important variables/factors that could prevent species from being locally extinct from an occupied site and increase chances of occupancy of unoccupied sites. These factors work as concrete evidence for managers and inform them what sort of habitat factors should receive priority. A novel field design to study riparian forest use across an entire catchment was implemented in this chapter. This approach employs a robust sampling design by incorporating riparian forests adjacent to all stream types of a catchment which presents a better understanding of mammalian occupancy along different stream types. Following this design, researchers can study species assemblage and help management agencies to efficiently draft plans that manage multiple species rather than focusing on only one charismatic species. This design can even be extended to reinforce plans in existing site-specific wildlife management plans. For example, in Sahyadri Tiger Reserve, efforts are being undertaken to restore tiger populations following local extirpation from the park (Jelil et al. 2020). Since riparian forests attract congregations of ungulates (tiger prey) as found by this study, the conservation and management of riparian forests will help boost tiger recovery efforts in the reserve. Further, comparative analyses of ungulate occupancy in different tiger population areas will offer insights on the prey-predator relationship influencing spatial occupancy pattern and thus, indicating early diagnoses of predator decline and their conservation management in the terrestrial-aquatic continuum framework.

CHAPTER VII

SYSTEMATIC CONSERVATION PLANNING: PRIORITIZING AREAS TO CONSERVE MAMMAL ASSEMBLAGES

Abstract: Protected Area (henceforth PAs) have been established globally to protect and conserve species and ecological diversity. They are indeed crucial instrument to achieve targets of conservation of ecological diversity, preventing habitat loss and arresting species extinction. Systematic conservation planning is an objective and robust method of creation of protected areas. However, areas within protected areas that would benefit from increased management efforts (such as ranger patrols, anti-poaching patrols, snare removal, etc.) can also benefit from this framework. In this study, I used species distribution models and systematic conservation planning to assess targets of conserving and protecting mammal assemblage rather than focusing on one charismatic mammal species. 63 camera traps nested in 1 x 1 km grids were used to generate species occurrence data, which were used to predict and construct spatial distribution maps. These maps were then used as feature data to analyze and estimate priority areas to achieve targets of mammal assemblage, using R prioritizr. Costs of conservation of planning units were calculated using three surrogates (a) area/size of the unit, (b) landscape resistance to foot patrolling, and (c) human influence index. Based on Aichi Targets 10, 11 and 12 (also included as National Biodiversity target 6) and post 2020 global biodiversity framework, a suite of four scenarios were predicted to achieve targets of 20%, 30%, 50% and 70% of mammal conservation. Area sizes of 61 km^2, 97 km^2, 179 km^2 and 288 km^2 were prioritized to respectively achieve 20%, 30%, 50% and 70% targets. Such an assessment provides important information for management authorities who can achieve targets with limited available logistics and manpower, given that effort is focused on the priority areas to achieve timely results. Taking cue from this study, other PAs in India, and

beyond, can calibrate their targets and costs and identify priority areas to achieve various regional, national and international targets of biodiversity conservation.

Keywords: conservation investment, conservation decision support, environmental economics, priority landscape units

7.1. Introduction: Wildlife conservation is a long-term and resource-intensive effort. With limited conservation budgets especially in developing economies such as India, a strategic investment of available resources to achieve desired outputs is crucial. Although biodiversity conservation should not be envisaged to be limited to protected areas only, protected area networks are vital instruments for conservation as they enjoy protected status under direct control of state and federal governments. Globally, PA networks have been maintained and have been timely updated by adding newer areas into the network to reach an estimated conservation targets of 17% of global land area by 2020 (CBD 2015; Visconti et al. 2019, Rija et al. 2020). PAs, however, continue to experience wildlife declines suggesting that solely protecting a larger land area does not necessarily lead to conservation success (Geldmann et al. 2019), because the effectiveness of PAs is challenged by factors such as governance, resource deficiency (Waldron et al. 2013; Venter et al. 2018; Schleicher et al. 2017), habitat loss and illegal hunting (Jones et al. 2018; Benitez-López et al. 2017; Geldmann et al. 2013).

To this effect, PA authorities need to first identity and then monitor priority areas which contain high biodiversity features. We propose that the spatial conservation planning framework (which is used to delineate areas as protected areas) may be adopted to identify areas containing key biodiversity features within PAs. These identified (biodiversity rich) areas need to be prioritized for effective patrolling and resource allocation with the available management resources. A systematic approach for effective patrolling and other resource allocation design ensures higher biodiversity protection levels. With this backdrop, we conducted a case study in Koyna to demonstrate the use of this framework to identify and spatially prioritize biodiversity rich areas within a protected area. This landscape is unique in that tigers have experienced local extirpation and occur occasionally in this region (Jelil et al. 2020). And present efforts for tiger recovery is underway. However, when conserving the habitat for one species, such as the tier, the focus is directed away from lesser-known or non-charismatic species. Since each species has a unique role to play in the natural system (including as key prey resources for tigers), protection of mammal assemblage is important to truly achieve conservation targets. When planning for conservation, considering multiple species ensures that the complexity and diversity of species assemblage in an area is also maintained.

Species distribution models (SDMs) have been frequently used for spatial prioritization, and ultimately for decision support. There has been much debate regarding the benefits and limitations of many of the variety of species distribution algorithms (Ishihama et al. 2019; Sofaer et al. 2019). However, traditional regression-based modelling approaches have been outperformed by the advent of machine learning algorithms, like Maxent (Philips et al. 2006; Phillips and Dudik, 2008; Rather et al. 2020). Further the use of integer linear programming solvers such as the open source SYMPHONY and commercial Gurobi used in R prioritizr package (Hanson et al. 2020) have shown to outperform simulated annealing approaches like Marxan (Ball et al. 2009) for optimizing and solving systematic conservation planning problems (Schuster et al. 2020). In this chapter, I model mammal species distribution and estimate the minimum area that needs to be conserved to achieve mammal conservation targets in Koyna. In so doing, I identify the areas that should be prioritized by ranger patrols, effective allocation of management equipment, etc. to curb human disturbance majorly in the form of poaching, in the landscape. To the best of our knowledge, this is the first application of the SDM-spatial conservation planning framework in India

7.2. Methods: 63 camera traps in 1 km^2 (1 x 1 km) grids were deployed in Koyna (Fig. 7.1). At each of the camera trap sites, a single motion-triggered digital camera was deployed by affixing it at a height of *c.* 60–70 cm to suitable trees or snags. I used Cuddeback white flash (C1model) camera traps which were set to take consecutive images set 5 seconds apart, when triggered (Jelil et al. 2021). The study was conducted in summer season (April to July) in 2019.

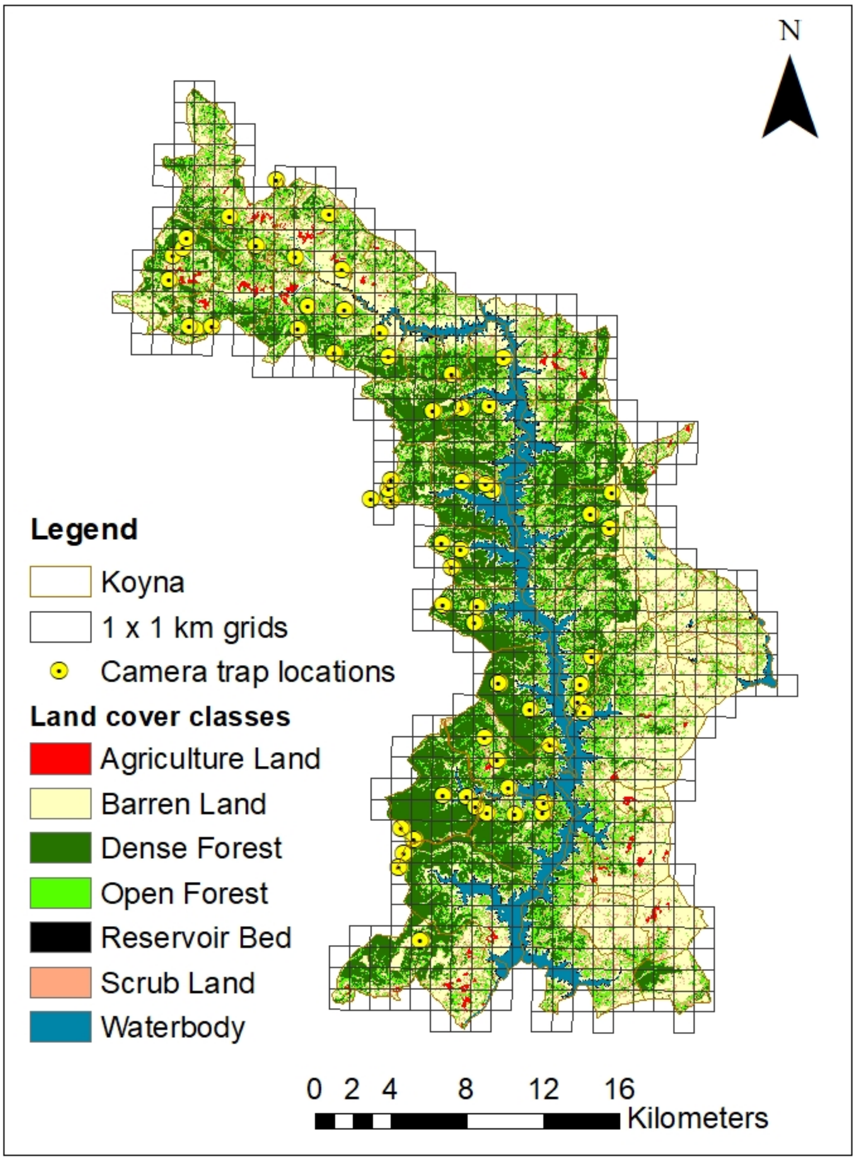

Fig. 7.1: Camera trap locations with the 2 x 2 grids in Koyna

7.2.1. Quantitative analyses and modelling approach: Photo-captured animals were identified to species level excluding random captures of birds and data were sorted into species-specific folders for all sites. Once all the data were identified, sorted and organized, the presence locations of all species were identified and listed. Species that had photographic captures from fewer than 20 locations out of the total sampled 63 locations were not considered for creating predictive distribution maps.

7.2.2. Predictor variables and test for multicollinearity: The variables considered for the predictive distribution modelling were land cover, slope, digital elevation model (DEM), distance from drainage, distance from road and bioclimatic variables. These were selected *a priori* because of their likely importance in driving wildlife presence (Table 7.1). Landsat 8 imagery was used for LULC classification. ASTER DEM (30 m) was used to generate slope raster in ArcMap 10.2. Drainage network was derived with the help of ArcHydro Tools in ArcMap 10.2 using SRTM DEM. Road network was extracted from Open Street Maps (OpenStreetMap contributors 2017) for the study area. The distance raster for drainage and road were created using Euclidean distance. Nineteen (19) bioclimatic variables were extracted from WorldClim 2 dataset (Fick and Hijmans, 2017). The raster layers were clipped to the Koyna Wildlife Sanctuary extent and spatial resolution was brought to 1 km using nearest neighbor sampling. The raster layers were converted to ASCII format and extent was aligned in ArcMap 10. All variables except for land cover were continuous variables. We then used the usdm package (Naimi et al. 2014) to calculate the variable inflation factor (VIF) for the set of bioclimatic variables. Predictors with a VIF higher than 10 were removed from the variable set. This was to avoid over-fitting of models potentially induced by correlation among explanatory variables.

Table 7.1: Predictor variables selected *a priori* for each species

Species	Predictor variable	Supporting citation
Sambar	Land cover, DEM, road, drainage, slope	Sankar and Acharya (2004); Lynam et al. (2012); Timmins et al. (2015)
Gaur	Land cover, DEM, road, drainage, slope	Schaller (1967); Conry (1989); Sahai (1972); Duckworth et al. (2016)
Barking deer	Land cover, DEM, road	Oka (1998); Laidlaw (2000); Azlan (2006); Tyson (2007); Timmins et al. (2016); Jelil et al. (2021)
Porcupine	Land cover, DEM, road	Amori et al. (2016); Jelil et al. (2021)
Wild pig	Land cover, DEM, road, drainage	Spitz (1999); Palomo and Gisbert (2002); Keuling and Leus (2019); Jelil et al. (2021)
Sloth bear	Land cover, DEM, road	Joshi et al. (1995); Sreekumar and Balakrishnan (2002); Johnsingh (2003); Akhtar et al. (2004); Yoganand et al. (2006); Seidensticker et al. (2011); Ramesh et al. (2012)
Mouse deer	Land cover, DEM, road, drainage	Prater (1971); Raman (2004); Duckworth and Timmins (2015)
Leopard	Land cover, DEM, road	Stein et al. (2020)

7.2.3. Species distribution modelling: We adopted an ensemble species distribution modelling approach using three algorithms for predicting spatial distribution, viz., maxent (Phillips et al. 2006; Elith et al. 2010), random forest (RF) (Breiman et al. 1984; Breiman 2001b), and support vector machines (SVM) (Vapnik 1998; Guo et al. 2005). All models were run in R 3.6.2 (R Core Team 2020) using the packages dismo 3.3-13 (Hijmans et al. 2020), randomForest (Liaw and Wiener 2002) and kernlab (Karatzoglou et al. 2004). A 5-fold cross validation was used splitting the available data into five equal parts for creating training and test datasets. Models were evaluated by their AUC scores using the *evaluate* function in dismo package. For each species, models were combined and weighted by their AUC and kappa scores to prepare a final weighted mean predictive map. The mean predictive maps were then extracted in ASCII format using the *writeRaster* function, stacked using the *stack* function and plotted using the *spplot* function in R raster package 3.4-5 (Hijmans 2020). The raster stack was used as feature data for the prioritization algorithm.

7.2.4. Systematic conservation planning: The prioritizr 5.0.2 package (Hanson et al. 2020) was used for prioritization analysis in R 3.6.2 (R Core Team 2020). I used the open source integer linear programming solver SYMPHONY to achieve faster output (Schuster et al. 2020). The following components were created for the prioritization analysis:

a. Planning unit: The 1 x 1 km gird with the extent same as that of Koyna Wildlife Sanctuary was used as planning unit. Each grid was assigned a unique ID and cost of conservation.

b. Conservation feature: The species distribution maps generated through the ensemble species were stacked as a single raster and used as conservation features. These maps were used to calculate the abundance data (amount of conservation features in each of the planning unit).

c. Conservation cost: Costs of conservation were estimated by considering three variables (a) the area of each grid, (b) topographic resistance values as surrogate for cost of foot patrolling, and (c) human footprint index as surrogate of anthropogenic pressure.

Landscape resistance to patrolling and area of planning units constitute the recurring management costs. Topography and road network affects patrolling effort, while the management cost for each of the planning unit remains same due to a common administrative mechanism. Landscape resistance to patrolling was computed using walking energy formula available in r.walk tool in QGIS 3.14. It requires three main inputs – (a) DEM, (b) friction cost of land cover, and (c) starting points of patrol. The ASTER DEM of Koyna at 30 m resolution was used. Friction values were provided based on walking experience in this landscape through different land cover types (Table 7.2). Since areas on either side of the roads are comparatively easier to access using vehicles (as opposed to walking on foot), additional classes in the land cover map were created by creating a union with a 500 m buffer of roads and trails. All the entry points into the sanctuary (roads and trails leading inside the sanctuary) and beat huts were used as starting points for patrolling. The road network was digitized from Survey of India topographic maps available at 1:50,000 scale. The pixel values in the resulting raster output indicated the resistance offered to reach that pixel from the nearest starting point. These resistance values (sum) were exported to the 1 km vector grid and the values were rescaled to 0-1.

Table 7.2: Friction values assigned as per land cover in Koyna

Land Cover	Friction values
Dense Forest	60
Open Forest	50
Scrubland	20
Waterbody	80
Barren land	20
Reservoir bed (unflooded)	20
Agriculture	20
Land use class within 500 m buffer of road (except water)	10

Human footprint data was derived from the Global Human Footprint Index (Last of Wild v2, 2005) (WCS-CIESIN-Columbia University, 2005) available at 1 km resolution. The data was reprojected and clipped using Koyna shapefile. The values (sum) were exported to a 1 km grid in vector format.

The final cost for each planning unit was calculated by adding the rescaled human footprint values (0–1), rescaled resistance values (0–1) and 1 for the area of each planning unit. The costs of planning units ranged from 1.01–2.31.

d. Conservation targets: Considering the targets proposed by Aichi 10, 11, 12 and post 2020 global biodiversity framework by United Nations Convention on Biological Diversity (CBD), a suite of four target scenarios of 20%, 30%, 50% and 70% of conservation of mammal assemblage were projected with minimum costs. The area needed to achieve each of the targets were estimated and mapped.

7.3. Results: The camera trap survey totaled an effort of 3366 trap nights with an average 53.43 trap nights per site. Nineteen species of terrestrial mammals were recorded along with livestock, feral dogs, bonnet macaque *Macaca radiata* and southwestern langur *Semnopithecus hypoleucos*. Our camera capture threshold criterion of captures from at least 20 locations out of the 63 sampled locations was fulfilled by eight species viz. barking deer recorded (49), gaur (47), leopard (35), mouse deer (26), porcupine (46), sambar (36), sloth bear (29), and wild pig (54).

7.3.1. Final set of predictor variables: Using the VIF removal method, the final list of variables used for distribution modelling were digital elevation model, land cover, slope, distance from drainage, distance from road, isothermality, temperature seasonality, minimum temperature of coldest month, temperature annual range, annual precipitation, precipitation of driest month, precipitation of warmest quarter, precipitation of coldest quarter (Table 7.3).

Table 7.3: Final set of predictor variables considered for species distribution models

Variable	Code	Source
Land cover	lc	Landsat
DEM	dem	ASTER
Slope	slope	ASTER
Drainage	drainage	SRTM
Road network	road	Open Street Maps
Isothermality	bio 3	WorldClim
Temperature seasonality	bio 4	WorldClim
Minimum temperature of coldest month	bio 6	WorldClim
Temperature annual range	bio 7	WorldClim
Annual precipitation	bio 12	WorldClim
Precipitation of driest month	bio 14	WorldClim
Precipitation of warmest quarter	bio 18	WorldClim
Precipitation of coldest quarter	bio 19	WorldClim

7.3.2. Species distribution maps: Random forest models based on AUC scores performed better than maxent and SVM in case of barking deer, gaur, leopard, porcupine, sloth bear and wild pig. For mouse deer, SVM and for sambar, maxent performed best (Table 7.4; Fig 7.2–7.9). The map of weighted mean of AUC of all species is presented in Fig. 7.10.

Table 7.4: Model performances of all three models for each species

Model	Species	AUC	kappa
Maxent	Barking deer	0.75	0.67
	Gaur	0.76	0.45
	Leopard	0.65	0.71
	Mouse deer	0.62	0.82
	Porcupine	0.71	0.81
	Sambar	0.87	0.63
	Sloth bear	0.71	0.82
	Wild pig	0.81	0.65
Random forest	Barking deer	0.78	0.37
	Gaur	0.84	0.37
	Leopard	0.83	0.31
	Mouse deer	0.75	0.53
	Porcupine	0.85	0.32
	Sambar	0.82	0.55
	Sloth bear	0.85	0.33
	Wild pig	0.83	0.59
Support Vector Machine	Barking deer	0.60	0.34
	Gaur	0.68	0.85
	Leopard	0.61	0.11
	Mouse deer	0.80	0.24
	Porcupine	0.61	0.55

	Sambar	0.81	0.76
	Sloth bear	0.60	0.55
	Wild pig	0.78	0.38

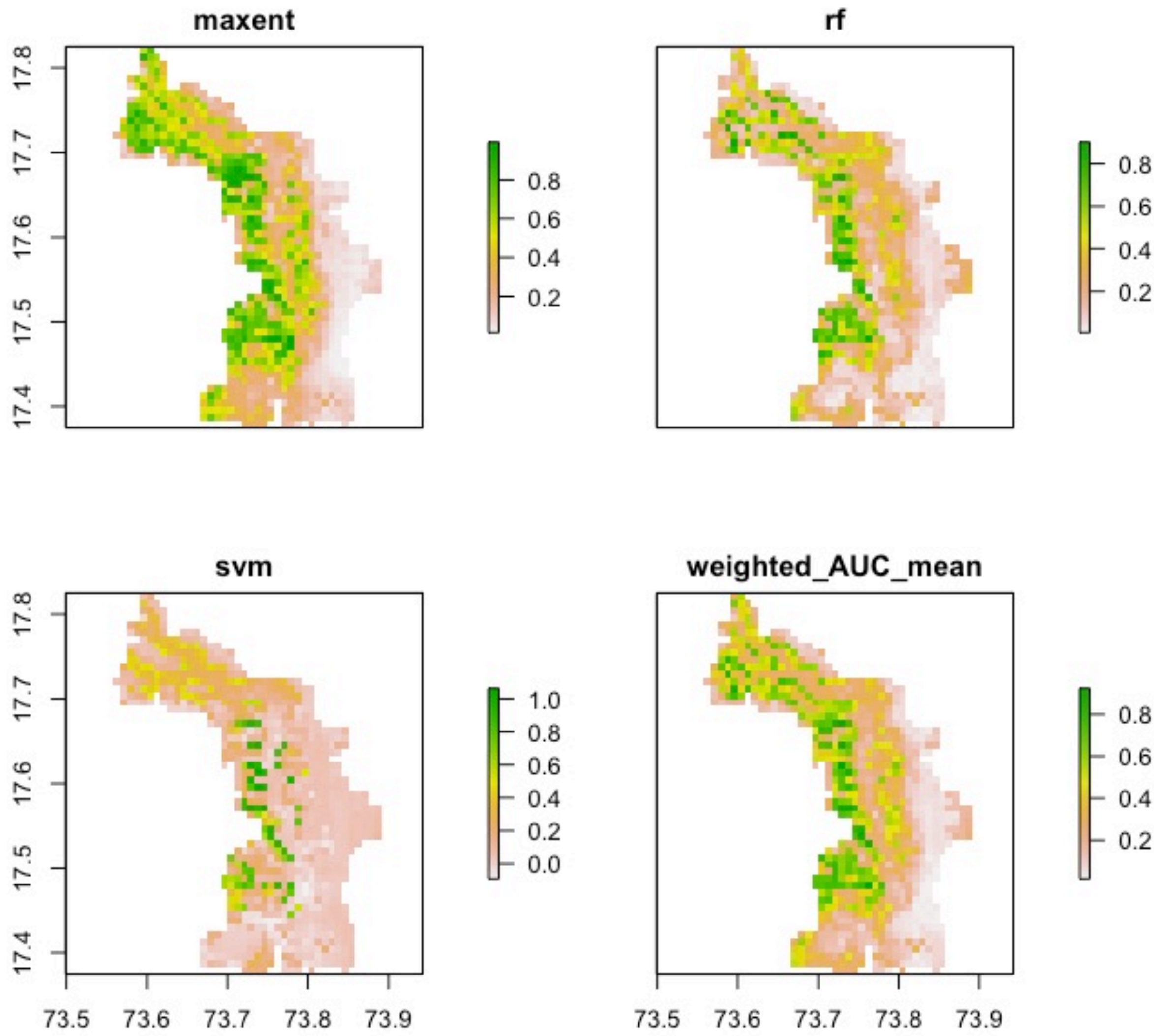

Fig. 7.2: Predicted distribution map for barking deer *Muntiacus muntjak*

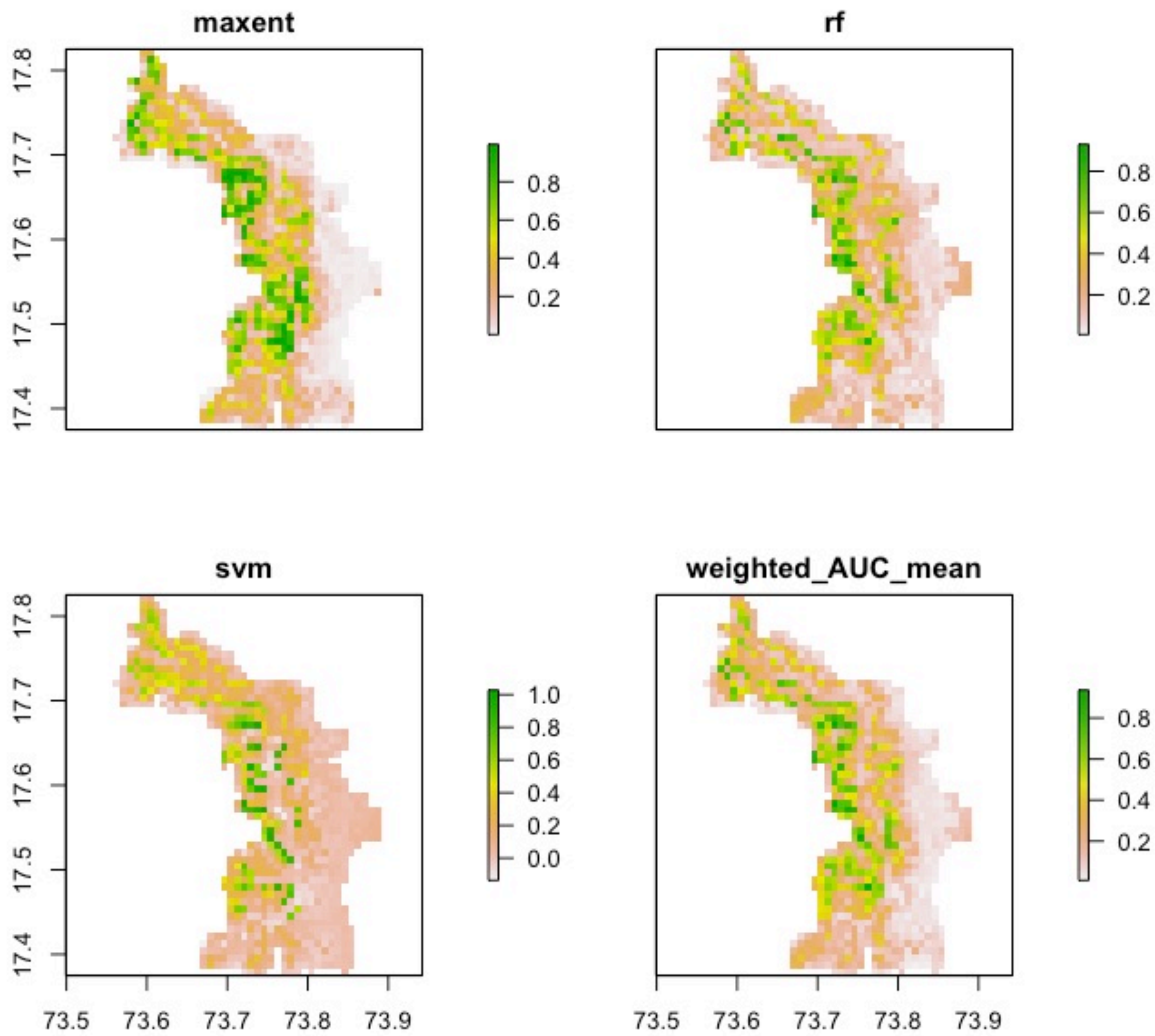

Fig. 7.3: Predicted distribution map for gaur *Bos gaurus*

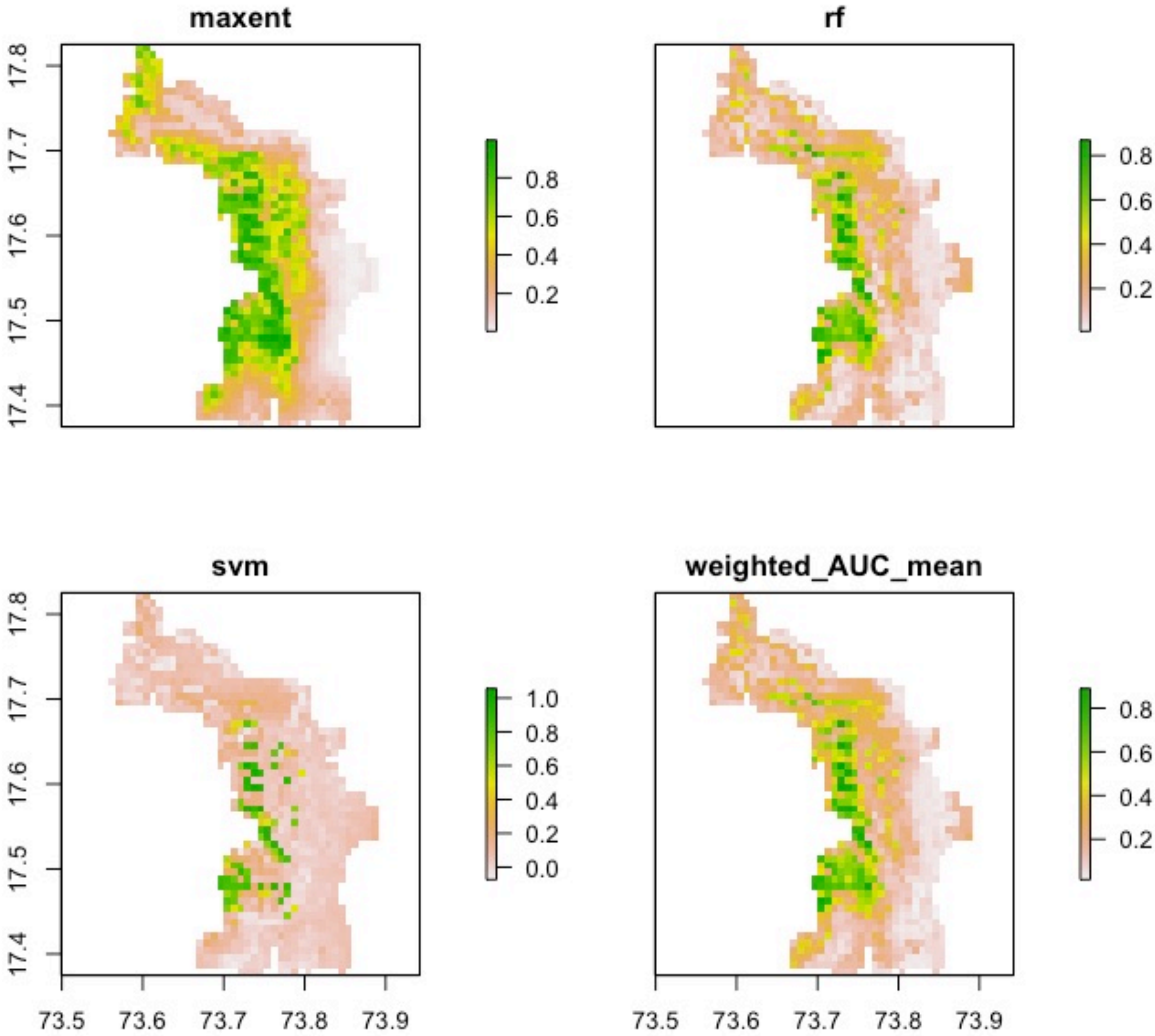

Fig. 7.4: Predicted distribution map for leopard *Panthera pardus*

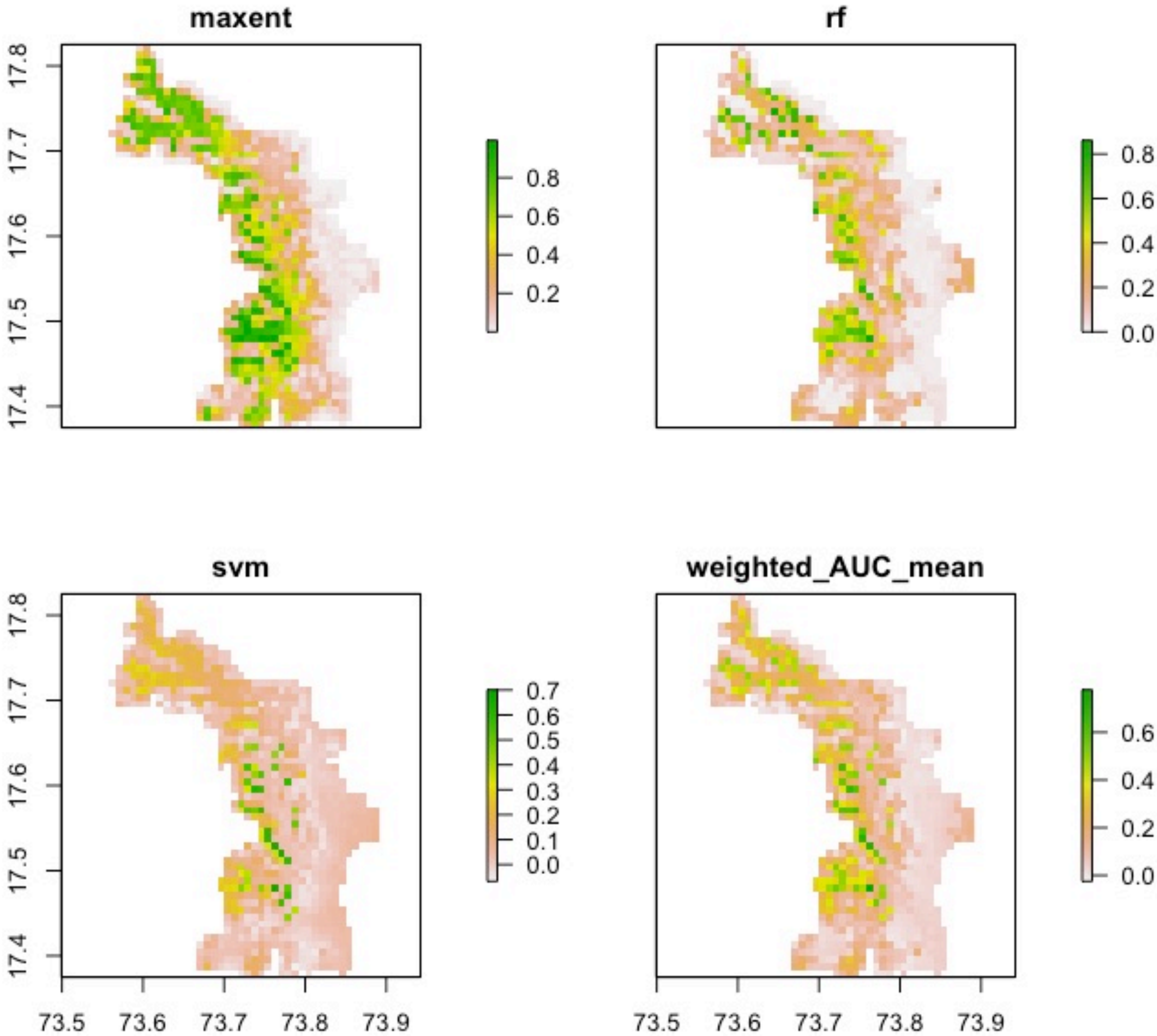

Fig. 7.5: Predicted distribution map for mouse deer *Moschiola indica*

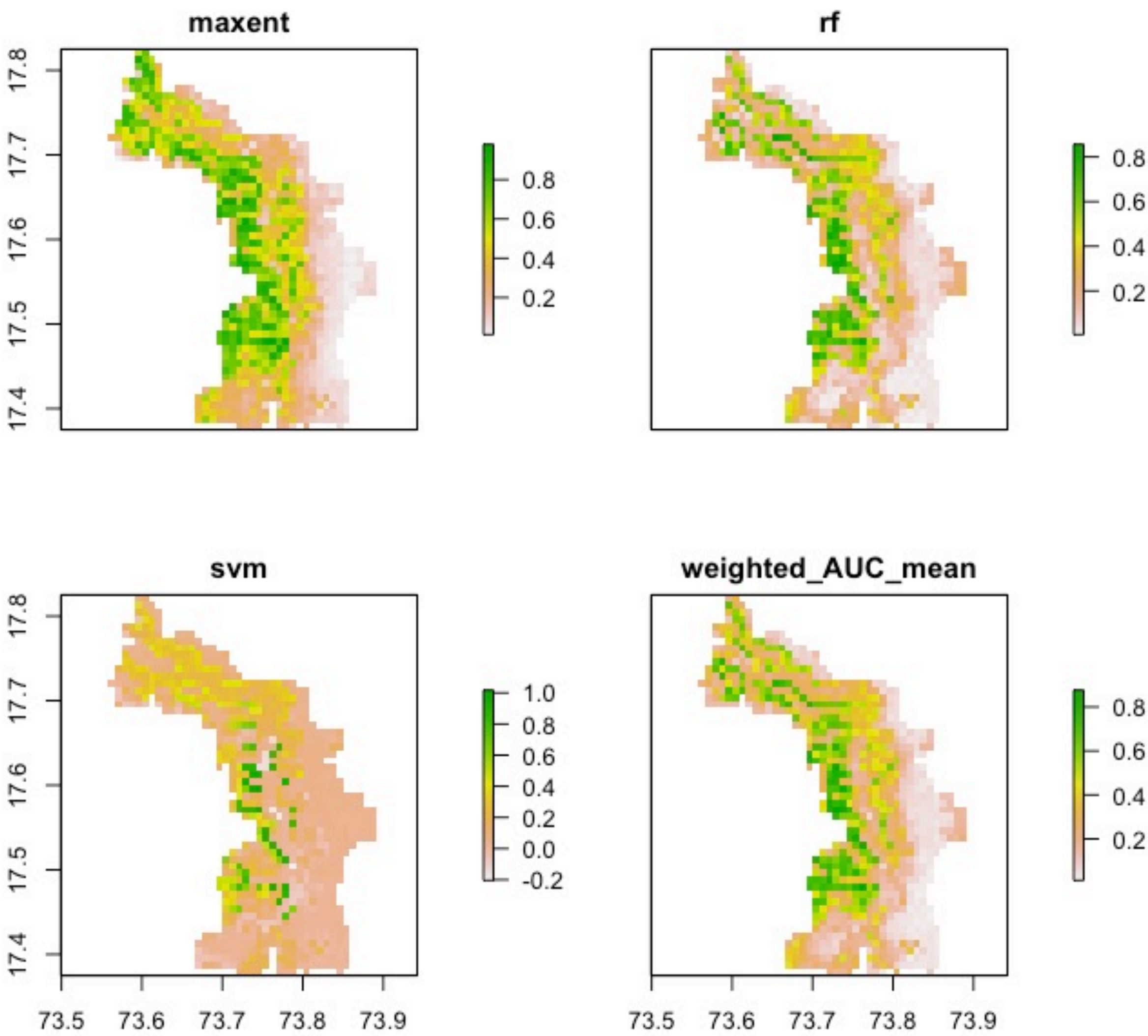

Fig. 7.6: Predicted distribution maps for porcupine *Hystrix indica*

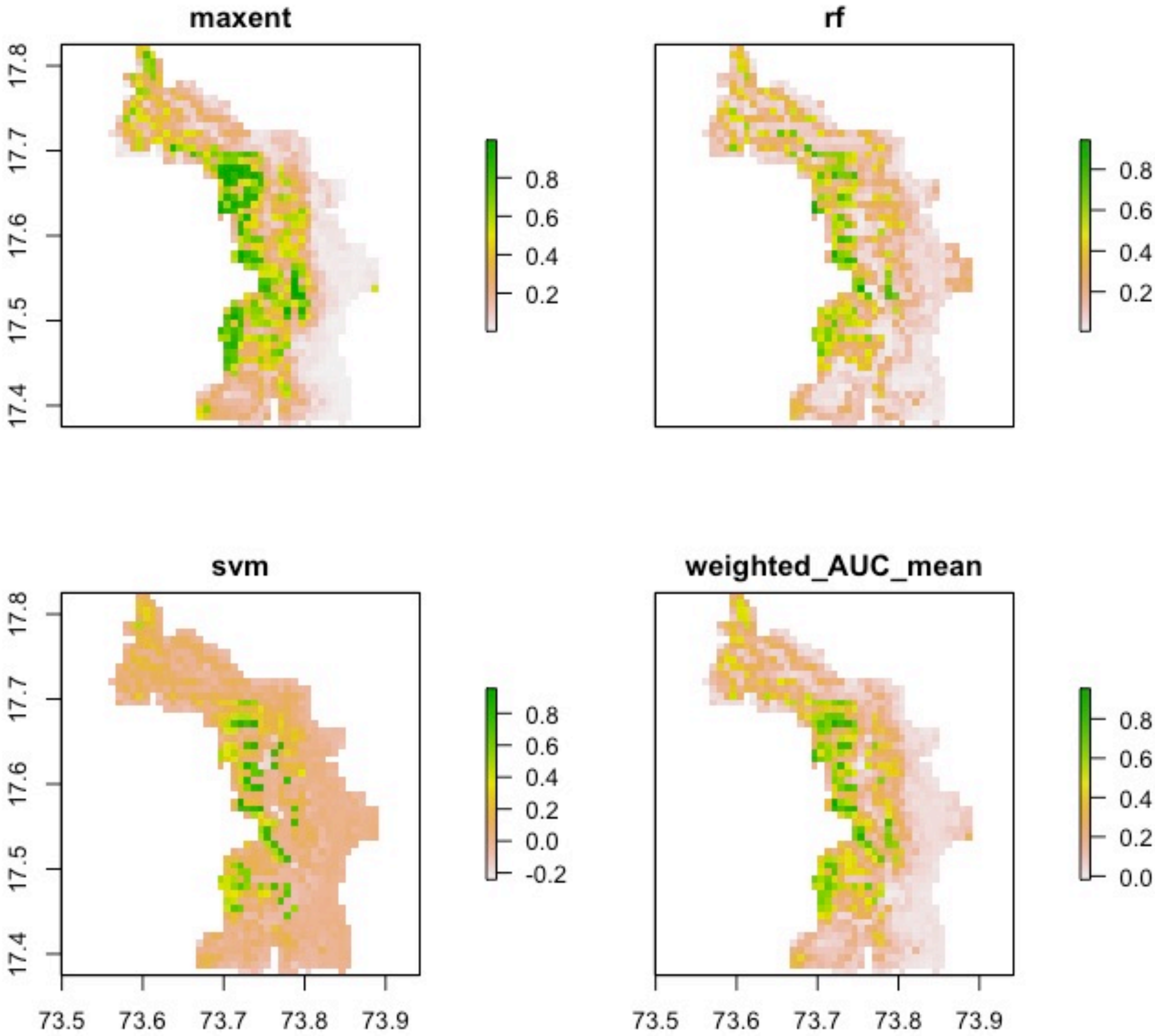

Fig. 7.7: Predicted distribution of sambar *Rusa unicolor*

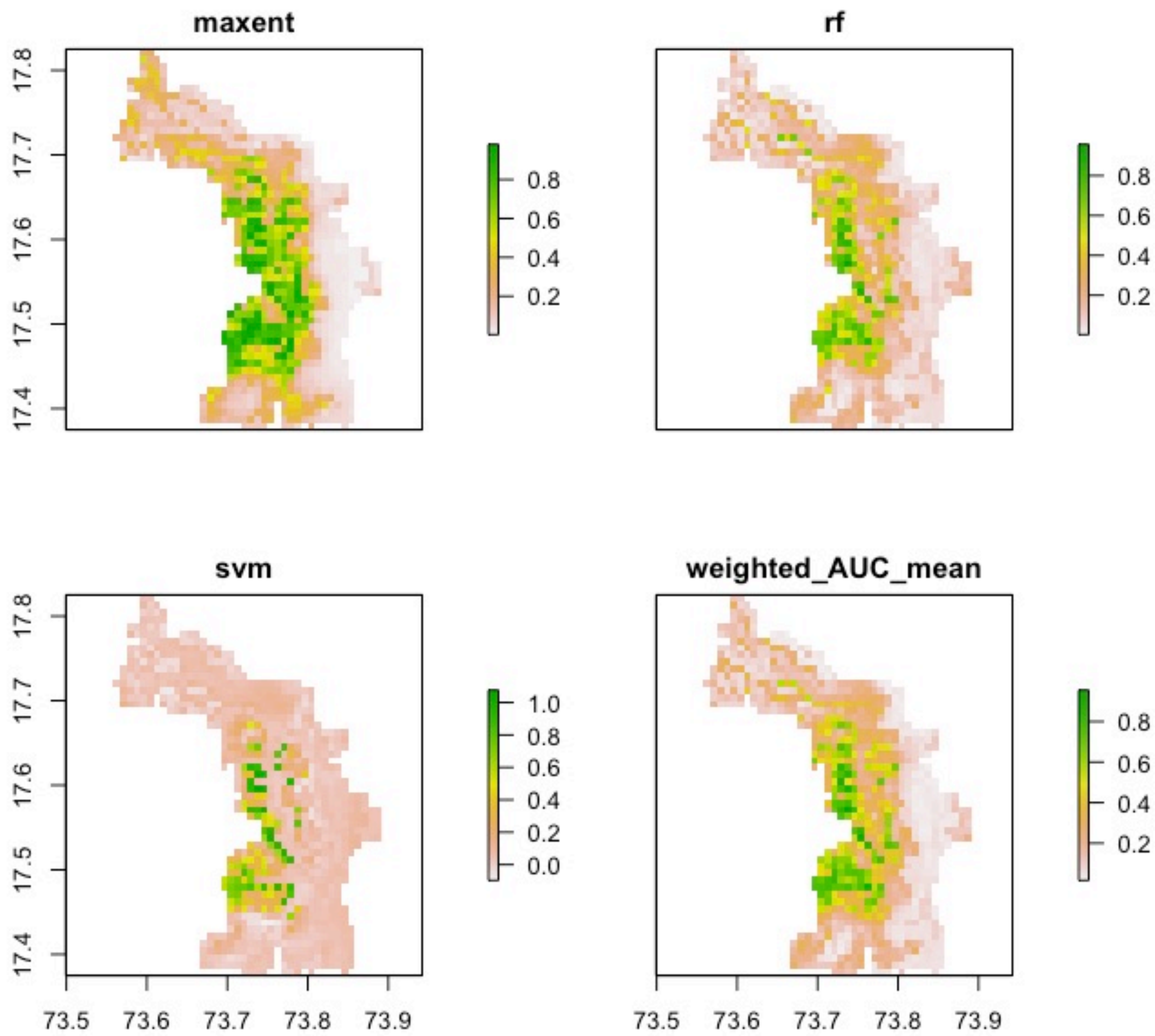

Fig. 7.8: Predicted distribution map for sloth bear *Melursus ursinus*

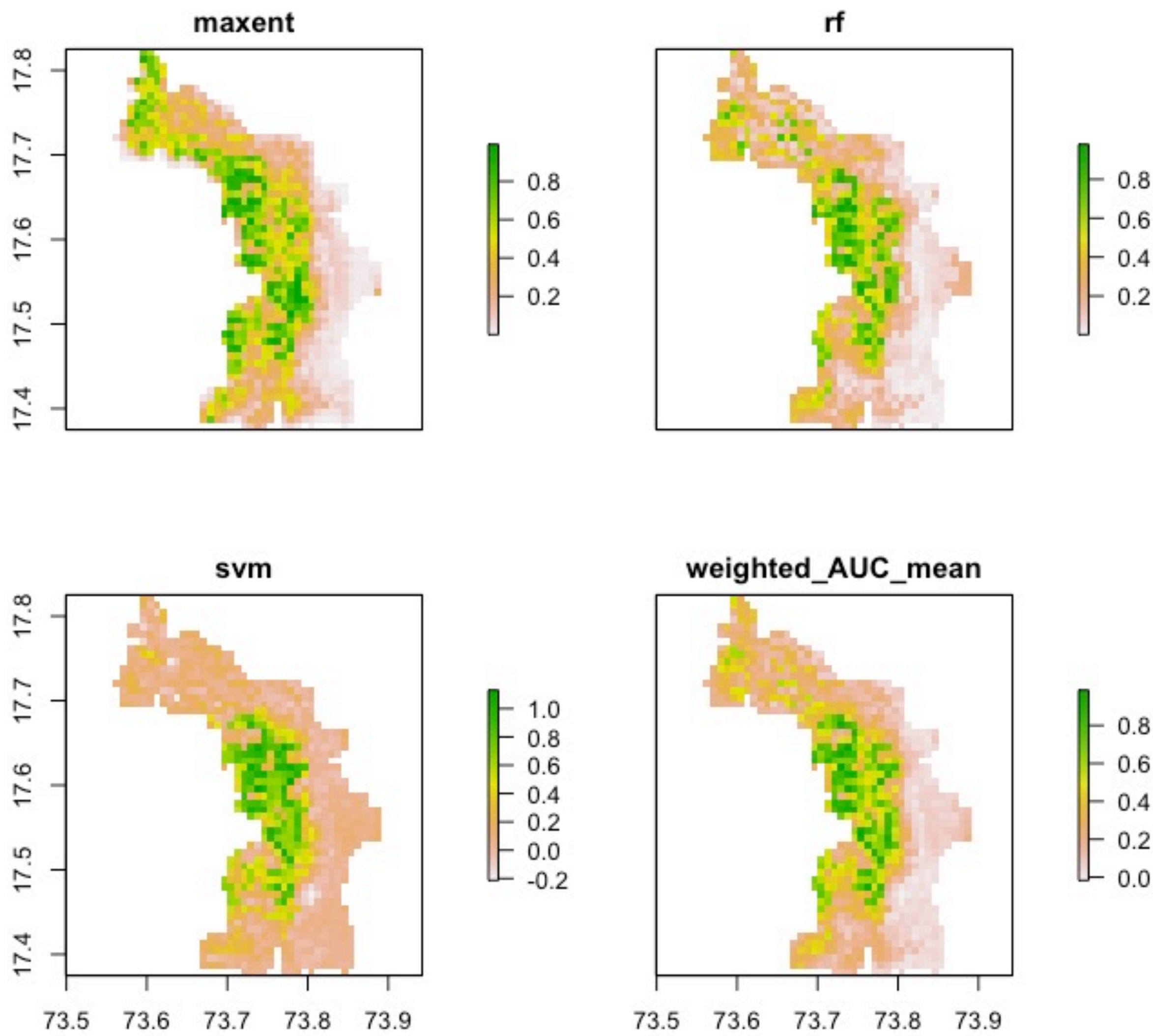

Fig. 7.9: Predicted distribution map for wild pig *Sus scrofa*

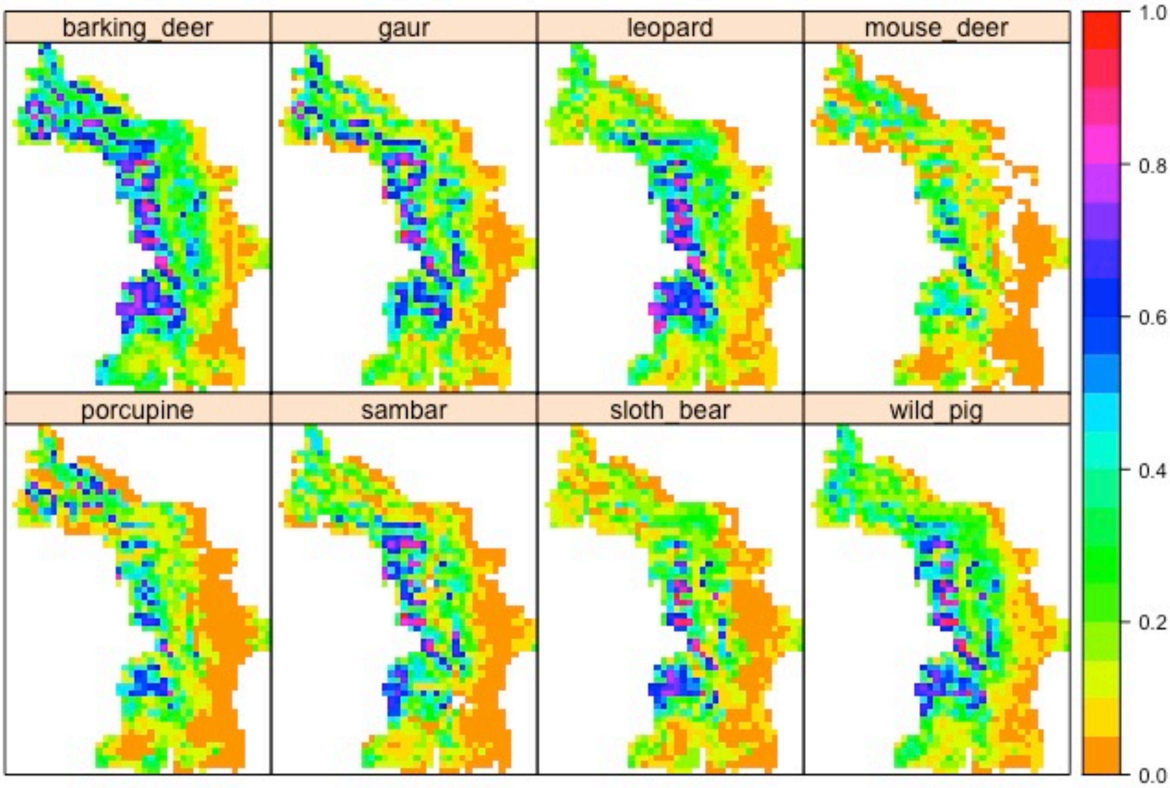

Fig. 7.10: Species distribution maps of all 8 species

7.3.3. Systematic conservation planning: The abundance of barking deer was the highest (280.03) and lowest for mouse deer (121.23) (Table 7.5). It was found that in order to achieve 20% equal representation of all mammal species, an area of 61 km^2 would need to conserved and managed. To achieve 30%, 50%, and 70% of targets, an area of 97 km^2, 179 km^2, 288 km^2 must be conserved respectively (Fig. 7.11).

Table 7.5: Abundance of species as features in Koyna

Feature/Species	Abundance	Abundance (per km^2)
Barking deer	280.03	1.94E-08
Gaur	225.65	1.57E-08

Leopard	218.82	1.52E-08
Mouse deer	121.24	8.42E-09
Porcupine	162.92	1.13E-08
Sambar	190.01	1.32E-08
Sloth bear	164.38	1.14E-08
Wild pig	225.96	1.57E-08

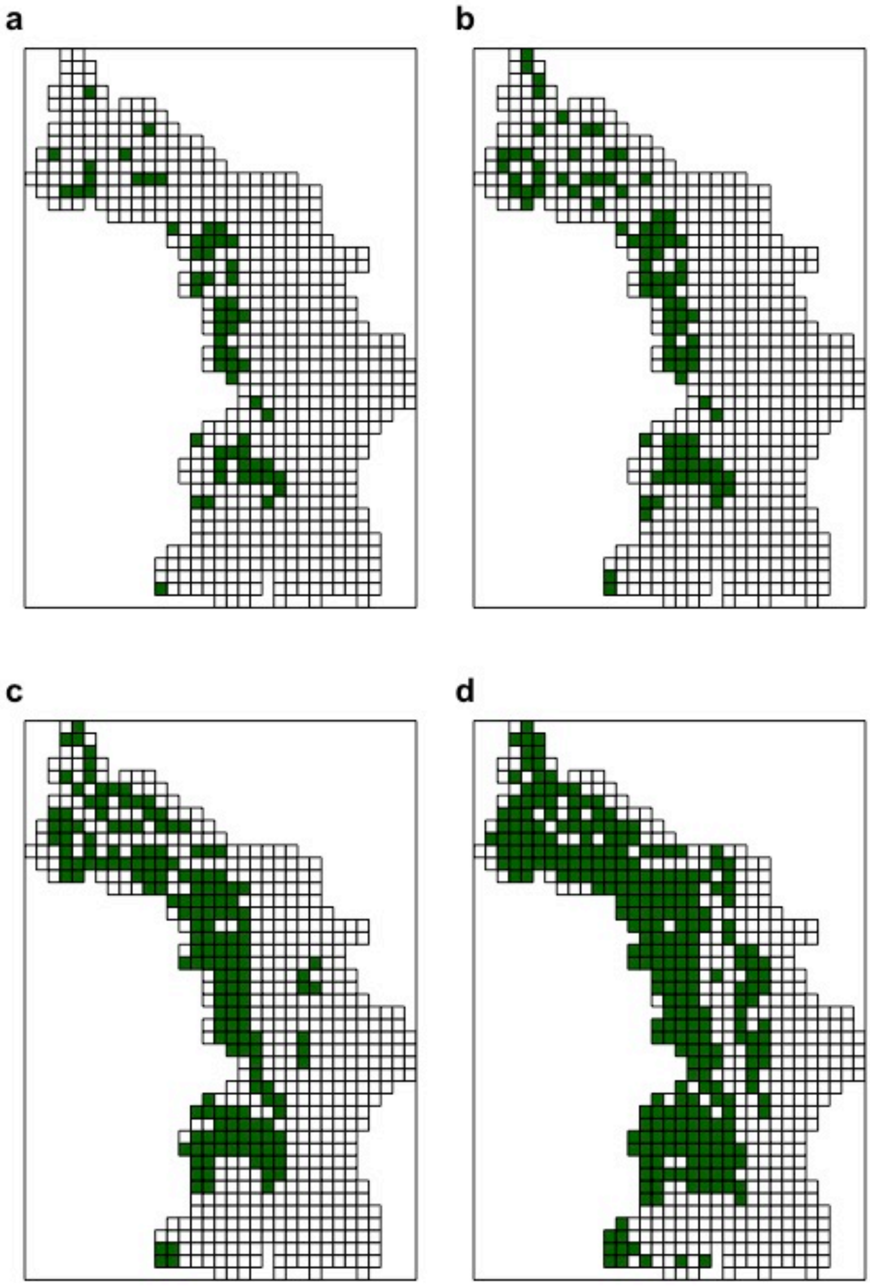

Fig. 7.11: a: Target scenario of 20%; b: Target scenario of 30%; c: Target scenario of 50%; d: Target scenario of 70% of equal representation of all mammal species

7.4. Discussion: International agreements, such as the United Nations CBD and World Heritage Convention, provide global frameworks for guiding and the establishment and management of PAs. Yet, the effectiveness of PAs depends, at least in part, on the quality and quantity of the scientific research that is available on the at-risk species that the PAs aim to protect. The effectiveness of the CBD and other such policy instruments are dependent on a range of factors, including country-specific constrains such as funding, government involvement, social capital, ecosystems and ecosystem services, and multiple other factors that drive conservation policy (Martin-López et al. 2009). Even so, having the best available science to inform policy development, decision making and implementation is beneficial. However, widespread data deficiencies (Bland et al. 2015) and conservation research biases (Clark and May 2002) is common. This deficiency could be best addressed at finer scales such as regional or PA scale and this chapter demonstrated just that. For mammals, a global conservation prioritization analysis has been conducted by Brum et al. (2017). Although a global perspective is helpful, it is uninformative on finer scales such as a PA. And since, local protection and management measures are undertaken within a PA, finer scale data serves better in terms of spatial projections and overall decision making and implementation. I use fine scale data in this chapter and also provide a framework whereby camera traps could be used to collect robust data on mammal presence, which can then be used as feature data for spatial prioritization. Reassessing our existing PAs as per the current goals of the concerned authorities is important. My emphasis was also to move away from habitat prioritization for on only one or two charismatic species and rather focus on larger faunal communities.

Given the inadequate funding available for conservation (James et al. 1999; Anyango-van Zwieten et al. 2019; Buxton et al. 2020), optimizing conservation management efforts should be a priority. This study shows that ranger patrols can be prioritized in relatively small areas of PAs to optimize their conservation benefits. If the majority of the ranger patrols occurred in 61 km^2, then 20% of all mammal species detection would have better protection, and if this increases to 288 km^2, 70% of mammals can have enhanced protection. This is to not say that other areas should be excluded from ranger patrols, but rather ranger patrols could be less frequent in them, especially when manpower is limited. Such an assessment is important and timely for an area like Koyna because reintroduction of apex predator (tiger) is being planned in Koyna and nearby Chandoli National Park (both of which combined forms the Sahyadri Tiger Reserve) (Jelil et al. 2020). While restoring apex predator population is important to conserve the top-down interactions within a trophic web, it is equally important and desirable to conserve the existing mammal species assemblage in the landscape. Such an approach and assessment with focused targets could be directly incorporated in already existing management plans to achieve better and timely results.

To the best of my knowledge, this was the first application of the SDM-spatial conservation planning framework in an Indian wildlife reserve. The adoption of an ensemble approach rather than a single distribution model algorithm provides more strength/robustness to the overall projections. Ensemble modelling has been widely used (Araújo and New 2007, Hao et al. 2019a) and they are believed to be superior for prediction compared to individual models (Hao et al. 2019a). Marmion et al (2009) found that ensemble models performed better than individual models when validating using a subset of the full dataset, which proves that ensembles can predict well to withheld or limited data within the same space and time as the training data. For the conservation planning, it has been found that integer linear programming outperform traditional annealing approaches as used in Marxan (Schuster et al 2020). Overall, I used a similar framework of numerical targets (such as setting aside 10%, 20% of geographical area under PA network) used for land area protection, as used by CBD. Only in this case, the percentages of conservation targets were percentages of total land area within a PA and not the otherwise understood geographical land area of a country or region. Increasing the PA network area is important, but it is equally important to prioritize areas within already existing PAs to effectively allocate resources so as to achieve better conservation targets.

Finally, an extension of this approach could be adopted by other PA authorities in India and beyond. Large protected areas such as the Murchison Falls NP in Uganda could use this to prioritize areas to effectively patrol sites where snares are set. This can also be used for elephant poaching patrols in Kenya, rhino poaching patrols in Kruger, South Africa and other PAs worldwide. The advantage of this framework is the flexibility of calibrating objectives and costs as per regional targets. PA authorities can set their objectives and incorporate costs to effectively achieve their regional targets by following this approach or a modified version of it outlined in this chapter. Hence this can be adopted, improvised and applied practically anywhere in the world.

CHAPTER VIII

MANAGEMENT RECOMMENDATIONS

Management and conservation of biodiversity and landscapes is highly complicated owing to various factors, including anthropogenic pressure, poaching, encroachment risks and competing goals by various stakeholders. However, desired levels of protection and management can be achieved through effective brainstorming, efficient use of limited information and logistics, and inter-organizational cooperation from various state and national government, non-governmental and research institutions. Research is an important and the most basic component for effective management of biodiversity and natural resources, and this thesis was an ardent effort to provide information and framework through which management can be highly benefitted. Based on regular monitoring and update of information gathered through regular research activities, management can adapt monitoring activities, an adaptive management approach. All the technical chapters (*i.e.,* Chapter V, VI and VII) have high management applications. These range from assessment of riparian forest quality and understanding the occupancy of forest mammals along riparian forests to cost effective protection measures to be based on spatial prioritization analyses.

Chapter V: Based on the findings of this chapter, I recommend that riparian habitat structure and quality assessment could be included in species-specific or larger landscape management plans, especially for large terrestrial carnivore such as tigers. The riparian quality index can be easily incorporated in the existing monitoring and management effectiveness protocols. Along with the riparian forest quality, it is equally important to understand the overall vegetation cover, stand structure and tree richness and diversity especially in riparian areas. This is because tree stand structure provides important cover for terrestrial mammals, birds and many other tree dependent lower taxa species. For the assessment of tree richness and diversity, the design used in this thesis can be adopted as it is easy to use and generates substantial information in a limited timeframe. Using similar designs, several yearly assessments could be done which would be crucial information for management authorities. This would enable them to understand the spatial and temporal trend of vegetation along riparian forests. With such an integrated management strategy, streams and rivers would also highly benefit. A better approach will be to adopt a comprehensive and inclusive monitoring protocol which would benefit conservation of multiple landscapes and multiple taxa therein.

Chapter VI: The approach used in this chapter is unique both in design and application of available of robust monitoring and modelling tools. It highlights the importance of camera traps in surveying mammal composition in riparian forests. Data collected using a hierarchical design covering all types of riparian forests, species occupancy along streams was modelled. More importantly, fine scale habitat factors were identified and modelled to assess which of the parameters were influencing species occupancy, seasonal colonization, local extinction and detection. Using similar approaches seasonally or annually would highly benefit the forest department in terms of baseline information of species occupancy and habitat factors which are most important for species occupancy. I illustrate the use of multi-season data for informed decision making of species and habitat conservation. Although this can be done with single-season data, multiple season surveys are ideal to understand seasonal effects and also narrow down on the habitat factors which are influencing species local colonization and extinction. With such information, management plans can focus on achieving better outputs within a limited timeframe and budget.

Chapter VII: This chapter provides the most relevant information for management purposes which the forest department and other local authorities can use to achieve targets in a timely manner. The costs of protected area management are high and with limited budget, manpower and logistical constraints, it often feels overambitious to conserve a large patch of land with high levels of biodiversity. By using the results described in chapter VII, management authorities can set their own targets based on regional requirements or national and global protection agenda. Systematic prioritization and planning provides high quality tools for PA management and even increase PA networks. However, on a national scale, such approaches seem to be rarely used in India. Cost effective management can be ideally achieved with such an approach. In the thesis, I provide an approach on how to prioritize areas to achieve desired target levels. The data needed for such an assessment is quite often already available with the forest department, state and national research institutes and authorities. If these are not available, then the data collection framework described in chapter VII can be easily adopted.

REFERENCES

Acuña, V., Datry, T., Marshall, J., Barceló, Dahm, C. N., Ginebreda, A., McGregor, G., Sabater, S., Tockner, K. and Palmer, M. A. (2014): Why should be care about temporary waterways. Science 343: 1080–1082.

Adams, V. M., Álvarez, J. G., Carwardine, J., Cattarino, L., Hermosa, V., Kennard, M. J., Linke, S., Pressey, R. L. and Stoeckl, N. (2014): Planning across freshwater and terrestrial realms: cobenefits and tradeoffs between conservation actions. Conservation Letters 7(5): 425–440. http://dx.doi.org/10.1111/conl.12080

Alho, C. J. R. (2011): Environmental effects of hydropower reservoirs on wild mammals and freshwater turtles in Amazonia: a review. Oecologia Australis 15(3): 593–604. https://doi.org/10.4257/oeco.2011.1503.11

Akhtar, N., Bargali, H.S. and Chauhan, N.P.S. (2004): Sloth bear habitat use in disturbed and unprotected areas of Madhya Pradesh, India. Ursus 15: 203-211.

Allen, M. L., Peterson, B. and Krofel, M. (2018): No respect for apex carnivores: distribution and activity patterns of honey badgers in the Serengeti. Mammalian Biology 89: 90–94. https://doi.org/10.1016/j.mambio.2018.01.001

Alpert, P., Griggs, F. T., & Peterson, D. R. (1999). Riparian forest restoration along large rivers: Initial results from the Sacramento River Project. Restoration Ecology, 7(4), 360–368. https://doi.org/10.1046/j.1526-100X.1999.72030.x

Amori, G., Hutterer, R., Krystufek, B., Yigit, N., Mitsain, G. and Palomo, L. J. (2006): *Hystrix indica*. The IUCN Red List of Threatened Species 2016: eT10751A115099509. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T10751A22231834.en

Anoop, K. R., and Hussain S. A. (2006 a): Food and feeding habits of smooth-coated otters (*Lutra perspicillata*) and their significance to the fish population of Kerala, India. Journal of Zoology 266(1): 15–23.

Anoop, K. R., and Hussain, S. A. (2006 b): Factors affecting habitat selection by smooth-coated otters (*Lutra perspicillata*) in Kerala, India. Journal of Zoology 263(4): 417–423.

Anyango-van Zwieten, N., Lamers, M. and van der Duim, R. (2019): Funding for nature conservation: a study of public finance networks at World Wide Fund for nature (WWF). Biodiversity and Conservation 28: 3749–3766. https://doi.org/10.1007/s10531-019-01848-y

Araújo, M. B. and New, M. (2007): Ensemble forecasting of species distributions. Trends in Ecology and Evolution 22(1):42–47. http://dx.doi.org/10.1016/j.tree.2006.09.010

Azlan, J. M. (2006): Mammal diversity and conservation in a secondary forest in Peninsular Malaysia. Biodiversity and Conservation 15: 1013–1025.

Ball, I.R., H.P. Possingham, and M. Watts. (2009): Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185–195 In: Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.

Bateman, H. L. and Ostoja, S. M. (2012): Invasive woody plants affect the composition of native lizard and small mammal communities in riparian woodlands. Animal Conservation. 15(3): 294–304. https://doi.org/10.1111/j.1469-1795.2011.00517.x

Bazzaz, F. A. (1975): Plant species diversity in old-field successional ecosystems in southern Illinois. Ecology 56: 485–488.

Benitez-López, A., Alkemade, R., Schipper, A. M., Ingram, D. J., Verweij, P. A., Eikelbloom, J. A. J. and Huijbregts, M. A. J. (2017): The impact of hunting on tropical mammal and bird populations. Science 356(6334): 180–183. https://doi.org/10.1126/science.aaj1891

Bhaskar, A. and Karthick, N. M. (2015): Riparian forests for healthy rivers. Current Science 108(10): 1788–1789.

Bland, L. M., Collen, B., David, C., Orme, L. and Bielby, J. (2015): Predicting the conservation status of data-deficient species. Conservation Biology 29(1): 250–259. https://doi.org/10.1111/cobi.12372

Blom, C. W. P. M. and Voesenek, L. A. C. J. (1996): Flooding: the survival strategies of plants. Trends in Ecology and Evolution 11: 290–295. https://doi.org/10.1016/0169-5347(96)10034-3

Bokil, M. S. (1999): People in protected areas: Koyna sanctuary in Maharashtra. Economic and Political Weekly 34(5): 293–299. http://www.jstor.org/stable/4407610

Boulton, A. J. (2014): Conservation of ephemeral streams and their ecosystem services: what are I missing? Aquatic Conservation: Marine and Freshwater Ecosystems. 24: 733–738.

Boutin, C., Jobin, B. and Belanger, L. (2003): Importance of riparian habitats to flora conservation in farming landscapes of southern Quebec, Canada. Agriculture, Ecosystems & Environment. 94(1): 73–87. https://doi.org/10.1016/S0167-8809(02)00014-2

Breiman, L. (1992): The little bootstrap and other methods for dimensionality selection in regression: *X*-fixed prediction error. Journal of the American Statistical Association. 87: 738–754.

Breiman, L., Friedman, J., Stone, C. J. and Olshen, R. A. (1984): Classification and regression trees. Chapman and hall/CRC.

Breiman, L. (2001b): Random Forests. Machine Learning 45: 5–32. https://doi.org/10.1023/A:1010933404324

Brum, F. T., Graham, C. H., Costa, G. C., Hedges, S. B., Penone, C., Radeloff, V. C., Rondinini, C., Loyola, R. and Davidson, A. D. (2017): Global priorities for conservation across multiple dimensions of mammalian diversity. PNAS 114(29): 7641–7646. https://doi.org/10.1073/pnas.1706461114

Bunn, S. E., Davies, P. M and Mosisch, T. D. (1999): Ecosystem measures of river health and their response to riparian and catchment degradation. Freshwater Biology 41: 333–345. https://doi.org/10.1046/j.1365-2427.1999.00434.x

Burnham, K. P. and Anderson, D. R. (2002): Model selection and multimodel inference: a practical information-theoretic approach. Springer. New York, USA.

Butler, D. R. (1995): Zoogeomorphology: animals as geographic agents. Cambridge University Press, New York.

Buxton, R. T., Avery-Gomm, S., Lin, H. Y., Smith, P. A., Cooke, S. J. and Bennett, J. R. (2020): Half of resources in threatened species conservation plans are allocated to research and monitoring. Nature Communications 11: 4668. https://doi.org/10.1038/s41467-020-18486-6

Capon, S. J., Chambers, L. E., Mac Nally, R., Naiman, R. J., Davies, P., Marshall, N., Pittock, J., Reid, M., Capon, T., Douglas, M., Catford, J., Baldwin, D. S., Stewardson, M.,
Roberts, J., Parsons, M. and Williams, S. E. (2013): Riparian ecosystems in the 21st century: Hotspots for climate change adaptation? Ecosystems 16: 359–381. http://doi.org/10.1007/s10021-013-9656-1

Carbone, C. Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J. R., Griffiths, M., Holden J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D. W., Martyr, D., McDougal, C., Nath, L., O'Brien, T., Seidensticker, J., Smith, D. J. L., Sunquist, M., Tilson, R. and Shahruddin, W. N. W. (2001): The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation 4: 75–79. https://doi.org/10.1017/S1367943001001081

Carver, A. D., Danskin, S. D., Zaczek, J. J., Mangun, J. C. and Williard, K. W. J. (2004): A GIS methodology for generating riparian tree plantation recommendations. Northern Journal of Applied Forestry, 21(2): 100–106.

Castro-López, D., Guerra-Cobián, V. and Prat, N. (2019): The role of riparian vegetation in the evaluation of ecosystem health: The case of semiarid conditions in Northern Mexico. River Research and Application 35: 48–59. http://dx.doi.org/10.1002/rra.3383

CBD, Convention on Biological Diversity (2015): Aichi Biodiversity Targets. Available at https://www.cbd.int/sp/default.shtml

Champion, H. G. and Seth, S. K. (1968): Revised survey of the forest types of India. Government of India publications, New Delhi, India.

Chatterjee, A., and Bhattacharyya, S. (2021): Assessing the threats facing wetland mammals in india using an evidence-based conservation approach. Mammal Review https://doi.org/10.1111/mam.12242

Chonavec, A., Schiemer, F., Cabela, A., Gressler, S., Grotzer, C., Pascher, K., Raab, R., Teufl, H., Wimmer, R. (2000): Constructed inshore zones as river corridors through urban areas–The Danube in Vienna: preliminary results. Regulated Rivers: Research & Management 16(2): 175–187. https://doi.org/10.1002/(SICI)1099-1646(200003/04)16:2%3C175::AID-RRR578%3E3.0.CO;2-C

Clark, J. A. and May, R. M. (2002): Taxonomic bias in conservation research. Science, 297(5579): 191–192. https://doi.org/10.1126/science.297.5579.191b

Conroy, M. J. and Nichols, J. D. (1996): Designing a study to assess mammalian diversity. In: Measuring and Monitoring Biological Diversity: Standard Methods for Mammals (D. E. Wilson, F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster, eds.), pp. 41–49. Smithsonian Institution Press, Washington, D.C.

Conry, P. J. (1989): Gaur (*Bos gaurus*) and development in Malaysia. Biological Conservation 49: 47–65.

Corbacho, C., Sánchez, J. M. and Costillo, E. (2003): Patterns of structural complexity and human disturbance of riparian vegetation in agricultural landscapes of a Mediterranean area. Agricultural Ecosystems and Environment, 95(2–3): 495–507. http://dx.doi.org/10.1016/S0167-8809(02)00218-9

Crooks, K. R. and Sanjayan, M. (2006): Connectivity conservation. Cambridge University Press, Cambridge, United Kingdom.

Datry, T., Larned, S. T. and K. Tockner. 2014. Intermittent rivers: A challenge for freshwater ecology. BioScience 64(3): 229–235. https://doi,org/10,1093/biosci/bit027

Datry, T., Pella, H., Leigh, C., Bonada, N. and B. Huguney. 2016. A landscape approach to advance intermittent river ecology. Freshwater Biology https://doi.org/10.1111/fwb.12645

Datry, T., Singer, G., Sauquet, E., Jorda-Capdevilla, D., Von Schiller, D., Subbington, R., Magand, C., Pařil, P., Miliša, M., Acuña, V., Alves, M., Augeard, B., Brunke, M., Cid, N., Csabai, Z., England, J., Froebrich, J., Koundouri, P., Lamouroux, N., Martí, E., Morais, M., Munné, A., Mutz, M., Pesic, V., Previšić, A., Reynaud, A., Robinson, C., Sadler, J., Skoulikidis, N., Terrier, B., Tockner, K., Vesely, D. and A. Zoppini. 2017a. Science and Management of Intermittent Rivers and Ephemeral Streams (SMIRES). Research Ideas and Outcomes 3, e21774. https://doi.org/10.3897/rio.3.e21774

Datry, T., Singer, G., Sauquet, E., Jorda-Capdevilla, D., Von Schiller, D., Subbington, R., Magand, C., Pařil, P., Miliša, M., Acuña, V., Alves, M. H., Augeard, B., Brunke, M., Cid, N., Csabai, Z., England, J., Froebrich, J., Koundouri, P., Lamouroux, N., Martí E., Morais, M., Munné A., Mutz M., Pesic, V., Previšić, A., Reynaud, A., Robinson, C., Sadler, J., Skoulikidis, N., Terrier, B., Tockner, K., Vesely, D. and Zoppini, A. (2017a): Science and management of intermittent rivers and ephemeral streams (SMIRES). Research Ideas and Outcomes 3: e21774. https://doi.org/10.3897/rio.3.e21774

Datry, T., Bonada, N. and A. Boulton. 2017b. Intermittent rivers and ephemeral streams ecology and management. Academic Press, USA.

De Bondi, N., White, J. G., Stevens, M. and Cooke, R. (2010): A comparison of the effectiveness of camera trapping and live trapping for sampling terrestrial small-mammal communities. Wildlife Research 37: 456–465.

Dobrowolski, K. A. (1994): Bird diversity in ecotonal habitats. Vanhandlungen der Internationalen Vereinigung für Theorestische und Angewandte Limnologie 25: 2491–2493.

Dornmann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquez, J. R. G., Gruber, B., Lafourcade, B., Leitao, P. J., Munkemuller, T., McClean, C., Osborne, P. E., Reineking, B., Schroder, B., Skidmore, A. K., Zurell, D. and Lautenbach, S. (2013): Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36: 27–046. http://doi.org/10.1111/j.1600-0587. 2012.07348.x

Duckworth, J. W., and Hedges, S. (1998): A review of the status of tiger, Asian elephant, gaur and banteng in Vietnam, Lao, Camobodia and Yunnan (China), with recommendations for future conservation action. WWF Indochina Programme, Hanoi, Vietnam.

Duckworth, J. W., Salter, R. E., and Khounbline, K. (1999): Wildlife in Lao PDR: 1999 Status Report. IUCN, Vientiane, Laos.

Duckworth, J.W. and Timmins, R. (2015): Moschiola indica. The IUCN Red List of Threatened Species 2015: e.T136585A61979067. http://dx.doi.org/10.2305/IUCN.UK.2015-2.RLTS.T136585A61979067.en

Duckworth, J. W., Sankar, K., Williams, A. C., Sambar Kumar, N. and Timmins, R. J. (2016): *Bos gaurus*. The IUCN Red List of Threatened Species 2016: e.T2891A46363646. http://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T2891A46363646.en

Dudgeon, D. (2000). The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. Annual Review of Ecology and Systematics. 31: 239–263. https://doi.org/10.1146/annurev.ecolsys.31.1.239

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A., Soto, D., Stiassny, M. L. J. and Sullivan, C. A. (2006): Freshwater biodiversity: importance, threats, status and conservation challenges. 81(2): 163–182. https://doi.org/10.1017/S1464793105006950

Dugdale, S. J., Malcolm, I. A., Kantola, K. and D. M. Hannah. (2018): Stream temperature under contrasting riparian forest cover: Understanding thermal dynamics and heat exchange processes. Science of the Total Environment 610–611: 1375–1389. http://dx.doi.org/10.1016/j.scitotenv.2017.08.198

Elith, J., Phillips, S. J., Hastie, T., Dudik, M., Chee, Y. E. and Yates, C. J. (2010): A statistical explanation of MaxEnt for ecologists. 17(1): 43–57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

Faush, K. D., Torgersen, C. E., Baxter, C. V. and Li, H. W. (2002): Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52: 483–498.

Fernández, R. D., Ceballos, S. J., Achem, A. L. G., Hidalgo, M. V. and Fernández, H. R. (2016): Quality and conservation of riparian forest in a mountain subtropical basin of Argentina. International Journal of Ecology Article ID 4842165. http://dx.doi.org/10.1155/2016/4842165

Fick, S. E. and Hijmans, R. J. (2017): WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37(12): 4302–4315. https://doi.org/10.1002/joc.5086

Ford, W. M., Menzel, M. A., McGill, D. W., Laerm, J. and McCay, T. S. (1999): Effects of a community restoration fire on small mammals and herpetofauna in the southern Appalachians. Forest Ecology and Management 114: 233–243.

Friedman, J. M. and Scott, M. L., Lewis Jr., W. M. (1995): Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19(4): 547–557. https://doi.org/10.1007/BF02471966

González del Tánago, M., and Antón, N. (1998): Plan forestal de la Comunidad de Madrid. Subprograma de ríos y riberas. E.T.S Ingenieros de Montes, UPM: Madrid.

Geldmann, J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M. and Burgess, N. D. (2013): Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biological Conservation 161: 230–238. https://doi.org/10.1016/j.biocon.2013.02.018

Geldmann, J., Manica, A., Burgess, N. D., Coad, L. and Balmford, A. (2019): A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. Proceedings of the National Academy of Sciences 116(46): 23209–23215. https://doi.org/10.1073/pnas.1908221116

Greenwald, D. N. and Brubaker, L. B. (2001): A 5000-year record of disturbance and vegetation change in riparian forests of the Queets River, Washington, USA. Canadian Journal of Forest Research, 31, 1375–1385.

Greiser Johns, A. (ed.) (2000): Pu Mat: a biodiversity survey of a Vietnamese protected area. Social Forestry and Nature Conservation in Nghe An Province, SFNC Project, Vinh, Nghe An Province, Vietnam.

Guo, Q., Kelly, M. and Graham, C. H. (2005): Support vector machines for predicting distribution of Sudden Oak Death in California. Ecological Modelling 182: 75–90. https://doi.org/10.1016/j.ecolmodel.2004.07.012

Hanson, J. O., Schuster, R., Morrell, N., Strimas-Mackey, M., Watts, M. E., Arcese, P., Bennett, J., Possingham, H. P. (2020): prioritizr: Systematic Conservation Prioritization in R. R package version 5.0.2. https://CRAN.R-project.org/package=prioritizr

Hao, T., Elith, J., Guillera-Arroita, G., Lahoz-Monfort, J. J. (2019a): A review of evidence about use and performance of species distribution modelling ensembles like BIOMOD. Diversity and Distributions 25(5): 839–852. https://doi.org/10.1111/ddi.12892

Hayward, M. W., Henschel, P., O'Brien, J., Hofmeyr, M., Balme, G. and Kerley, G. I. H. (2006): Prey preferences of the leopard (*Panthera pardus*). Journal of Zoology 270: 298–313. https://doi.org/10.1111/j.1469-7998.2006.00139.x

Hayward, M. W., O'Brien, J. and Kerley, G. I. H. (2007): Carrying capacity of large African predators: predictions and tests. Biological Conservation 139: 219–229. https://doi.org/10.1016/j.biocon.2007.06.018

Hayward, M. W., Lyngdoh, S. and Habib, B. (2014): Diet and prey preferences of dholes (*Cuon alpinus*): dietary competition within Asia's apex predator guild. Journal of Zoology 294: 255–266. https://doi.org/10.1111/jzo.12171

Hayward, M. W., Boitani, L., Burrows, N. D., Funston, P. J., Karanth, U. K., MacKenzie, D. I., Pollock, K. H. and Yarnell, R. W. (2015): Ecologists need robust survey designs, sampling and analytical methods. Journal of Applied Ecology 52: 286–290. http://doi.org/10.1111/1365-2664.12408

Hermosa, V., Kennard, M. J. and S. Linke. (2012): Integrating multidirectional connectivity requirements in systematic conservation planning for freshwater systems. Diversity and Distributions 18(5): 448–458. https://doi.org/10.1111/j.1472-4642.2011.00879.x

Hijmans, R. J. (2020). raster: Geographic Data Analysis and Modeling. R package version 3.4-5. https://CRAN.R-project.org/package=raster

Hijmans, R. J., Phillips, S., Leathwick, J. and Elith, J. (2020): dismo: Species distribution modelling. R package version 1.3-3. https://CRAN.R-project.org/package=dismo

Hines, J. E. (2006): PRESENCE – software to estimate patch occupancy and related parameters. USGS – PWRC. URL: http://www.mbr-pwrc.usgs.gov/software/presence.html

Hussain, S. A. and Choudhury, B. C. (1997): Distribution and status of the smooth-coated otter *Lutra perspicillata* in National Chambal Wildlife Sanctuary, India. Biological Conservation 80(2): 199–206.

Ishihama, F., Takenaka, A., Yokomizo, H., Kadoya, T. (2019): Evaluation of the ecological niche model approach in spatial conservation prioritization. PLoS ONE 14(12): e0226971. https://doi.org/10.1371/journal.pone.0226971

James, A. N., Green, M. J. B. and Paine, J. R. (1999): A global review of protected areas budgest and staffing. WCMC – World Conservation Press, Cambridge, UK. vi + 46pp.

Jayakumar, R. and Nair, K. K. (2013): Species diversity and tree regeneration patterns in tropical forests of the Western Ghats, India. International Scholarly Research Notices, Article ID 890862. http://dx.doi.org/10.1155/2013/890862

Jelil, S. N., Gaykar, A., Girkar, N., Vyas, V., Ben, V. C. and K. Ramesh. 2020. Recent record of tiger from Sahyadri Tiger Reserve, India. CATnews 71: 16–17.

Jelil, S. N., Gaykar, A., Girkar, N., Ben, C., Hayward, M. W. and Krishnamurthy, R. (2021): Mammal persistence along riparian forests in western India within a hydropower reservoir 55 years post construction. *Frontiers in Ecology and Evolution*. 9:643285 https://doi.org/10.3389/fevo.2021.643285

Jenerette, G. D. and Lal, R. (2005): Hydrologic sources of carbon cycling uncertainty throughout the terrestrial-aquatic continuum. Global Change Biology, 11: 1873–1882. https://doi.org/10.1111/j.1365-2486.2005.01021.x

Jenkins, K. J., Chelgren, N. D., Sager-Fradkin, K. A., Happe, P. J. and Adams, M. J. (2015): Occupancy patterns of mammals and lentic amphibians in the Elwha River riparian zone before dam removal. River Research and Applications 31(2): 193–206. https://doi.org/10.1002/rra.2723

Jhala, Y. V., Qureshi, Q. and Gopal, R. (eds.) (2015): The status of tigers in India 2014. National Tiger Conservation Authority, New Delhi & The Wildlife Institute of India, Dehradun.

Joglekar, A., Tadwalkar, M., Mhaskar, M., Chavan, B., Ganeshaiah, K. N. and Patwardhan, A. (2015): Tree species composition in Koyna Wildlife Sanctuary, Northern Western Ghats of India. Current Science 108 (9): 1688–1693.

Johnsingh, A. J. T. (2003): Bear conservation in India. The Journal of the Bombay Natural History Society 100: 190-201.

Johnsingh, A. J. T., Qureshi, Q., Goyal, S. P., Rawat, G. S., Ramesh, K., David, A., Rajapandian, K., and Prasad, S. (2004): Conservation status of tiger and associated species in the Terai-Arc landscape, India

Johnson, W. C. (2002): Riparian vegetation diversity along regulated rivers: contribution of novel and relict habitats. Freshwater Biology 47(4): 749–759. https://doi.org/10.1046/j.1365-2427.2002.00910.x

Johnson, J. A., Rokade, A., Atkore, V., Sivakumar, K. and Ben, V. C. (2019): Fishes of Sahyadri Tiger Reserve, Maharashtra: Field Guide. Wildlife Institute of India, Dehradun. Technical Report, TR No/2019/01 pp 78.

Johnston, C. A. (1995): Effects of animals on landscape pattern. In: Mosaic landscapes and ecological processes. (Hansson, R. Fahnig, L. and Merricom, G. eds.). pg. 57–80. Chapman and Hall, London.

Jones, C. G. and Lawton, J. H. (eds.) (1995): Linking Species to ecosystems. Chapman and Hill, New York.

Jones, K. R., Venter, O., Fuller, R. A., Allan, J. R., Maxwell, S. L., Negret, P. N., Watson, J. E. M. (2018): One-third of global protected land is under intense human pressure. Science 360(6390): 788–791. https://doi.org/10.1126/science.aap9565

Joshi, A. R., Garshelis, D. L. and Smith, L. D. (1995): Home ranges of sloth bears to Nepal: Implications for conservation. Journal of Wildlife Management 59: 204-214.

Karatzoglou, A., Smola, A., Hornik, K. and Zeileis, A. (2004): kernlab – An S4 package for kernel methods in R. Journal of Statistical Software 11(9): 1–20. http://www.jstatsoft.org/v11/i09

Karthik, P., Sharma, P., Nazareth, O. J. (2018): Deccan ground gecko: an unusual body pattern of *Cyrtodactylus deccanensis* (Günther, 1864) from Sahyadri Tiger Reserve, northern Western Ghats, India. Reptile Rap # 189. In: Zoo's Print 33(11): 12–14.

Karthik, P., Nazareth, O. J., Baskaran, N. and Ishwar, N. M. (2019): Notes on the cryptic gecko *Hemidactylus gleadowi* Murrya, 1884 from the Sahyadri Tiger Reserve, northern Western Ghats, India. Sauria 41(2): 70–76.

Karthik, P. and Dutta, S. K. (2020): A range extension of the Karnataka bronzeback, *Dendrelaphis chairecacos* (Boie 1827), from the northern Western Ghats, India. IRCF Reptiles & Amphibians 26 (3): 237–239.

Kassambara, A. (2020): ggpubr: 'ggplot2' based publication ready plots. R package version 0.4.0. https://CRAN.R-project.org/package=ggpubr

Kassambara, A., and Mundt, F. (2020): factoextra: extract and visualize the results of multivariate data analyses. R package version 1.0.7. https://CRAN.R-project.org/package=factoextra

Kaufman, D. W. (1967): A small mammal continuum in grassland and riparian communities of North-Central Kansas. MSc. Thesis. Fort Hays Kansas State College https://scholars.fhsu.edu/theses/1065

Kavanagh, R. P. and Webb, G. A. (1998): Effects of variable-intensity logging on mammals, reptiles and amphibians at Waratah Creek, southeastern New South Wales. Pacific Conservation Biology 4(4): 326–347. https://doi.org/10.1071/PC980326

Keuling, O. & Leus, K. (2019): *Sus scrofa*. The IUCN Red List of Threatened Species 2019: e.T41775A44141833. http://dx.doi.org/10.2305/IUCN.UK.2019 3.RLTS.T41775A44141833.en

Khan, M. L., Menon, S. and Bawa, K. S. (1997): Effectiveness of the protected area network in biodiversity conservation: a case study of Meghalaya state. Biodiversity and Conservation 6: 853–868. https://doi.org/10.1023/B:BIOC.0000010406.35667.c0

Lack, D. (1969): The numbers of bird species on islands. Bird Study 16: 193–209.

Laidlaw, R. K. (2000): Effects of habitat disturbance and protected areas on mammals of Peninsular Malyasia. Conservation Biology 14(6): 1639–1648.

Larned, S., Datry, T., Arscott, D., Tockner, K. (2010): Emerging concepts in temporary-river ecology. Freshwater Biology 55(4): 717–738.

Landers, D. H. (1997): Riparian restoration: current status and the reach to the future. Restoration Ecology 5(4): 113–121. https://doi.org/10.1111/j.1526-100X.1997.tb00210.x

Lauerwald, R., Regnier, P., Camino-Serrano, M., Guenet, B., Guimberteau, M., Ducharne, A., Polcher, J. and Ciais, P. (2017): ORCHILEAK (revision 3875): a new model branch to simulate carbon transfers along the terrestrial–aquatic continuum of the Amazon basin. Geoscientific Model Development, European Geosciences Union, 10 (10): 3821–3859. https://doi.org/10.5194/gmd-10-3821-2017

Lees, A. C. and Peres, C. A. (2008): Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. Conservation Biology 22(2): 439–449. https://doi.org/10.1111/j.1523-1739.2007.00870.x

Leibowitz, S. G. (2003): Isolated wetlands and their functions: an ecological perspective. Wetland 23: 517–531. https://doi.org/10.1672/0277-5212(2003)023[0517:IWATFA]2.0.CO;2

Liaw, A. and Wiener, M. (2002): Classification and regression by randomForest. R News 2(3): 18–22. https://CRAN.R-project.org/doc/Rnews/

Linkie, M. and Ridout, M. S. (2011): Assessing tiger-prey interactions in Sumatran rainforests. Journal of Zoology 284(3): 224–229. https://doi.org/10.1111/j.1469-7998.2011.00801.x

Lorion, C. M. and Kennedy, B. P. (2009): Relationships between deforestation, riparian forest buffers and benthic macroinvertebrates in neo-tropical headwater streams. Freshwater Biology 54: 165–180. https://doi.org/10.1111/j.1365-2427.2008.02092.x

Lowrance, R., Altier, L. S., Newbold, J. D., Schnabel, R. R., Groffman, P. M. and Denver, J. M. (1997): Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed. Environmental Management 21: 687–712.

Lynam, A. J., Tantipisanuh, N., Chutipong, W., Ngoprasert, D., Baker, M. C., Cutter, P., Gale, G., Kitamura, S., Steinmetz, R., Sukmasuang, R. and Thunhikorn, S. (2012): Comparative sensitivity to environmental variation and human disturbance of Asian tapirs (*Tapirus indicus*) and other wild ungulates in Thailand. Integrative Zoology 7(4): 389–399.

MacArthur, R. H. and Wilson, E. O. (1967): The theory of island biogeography. Princeton University Press, Princeton.

MacCraken, J. G. (2002): Response of forest floor vertebrates to riparian hardwood conversion along the bear river, Southwest Washington. Forest Science 48(2): 299–308. https://doi.org/10.1093/forestscience/48.2.299

Macdonald, S. E., Eaton, B., Machtans, C. S., Paszkowski, C., Hannon, S. and Boutin, S. (2006): Is forest close to lakes ecologically unique?: Analysis of vegetation, small mammals, amphibians, and songbirds. Forest Ecology and Management 223: 1–17. https://doi.org/10.1016/j.foreco.2005.06.017

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. Ecology, 83, 2248–2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

MacKenzie, D. I., and Bailey, L. L. (2004): Assessing the fit of site-occupancy models. Journal of Agricultural, Biological and Environmental Statistics 9(3): 300–318. https://doi.org/10.1198/108571104X3361

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Hines, J. E., and Bailey, L. L. (2006): Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence. San Diego, CA: Elsevier.

Malason, G. P. (1993). Riparian landscapes. Cambridge University Press, Cambridge.

Marczak, L. B., Sakamaki, T., Turvey, S. L., Deguise, I., Wood, S. L. R. and Richardson, J. S. (2010): Are forested buffers an effective conservation strategy for riparian fauna? An assessment using meta-analysis. Ecological Applications. 20(1): 126–134. https://doi.org/10.1890/08-2064.1

Martin-López, B., Montes, C., Ramírez, L. and Benayas, J. (2009): What drives policy decision-making related to species conservation? Biological Conservation 142(7): 1370–1380. https://doi.org/10.1016/j.biocon.2009.01.030

Maraj, R. and Seidensticker, J. (2006): Assessment of a framework for monitoring tiger population trends. Report submitted to IUCN: World Conservation Union and India's Project Tiger. pp. 33.

Marmion, M., Parviainen, M., Luoto, M., Heikkinen, R. K. and Thuiller, W. (2009): Evaluation of consensus methods in predictive species modelling. Diversity and Distributions 15: 59–69. https://doi.org/10.1111/j.1472-4642.2008.00491.x

McNaughton, S. J., Ruess, R. W. and Seagle, S. W. (1988): Large animals and process dynamics in African ecosystems. BioScience 38: 794–800.

McNeely, J. A. (1987): How dams and wildlife conservation can coexist: natural habitats, agriculture, and major water resource development projects in tropical Asia. Conservation Biology 1(3): 228–238. http://www.jstor.org/stable/2385879

Mligo, C. (2016): Diversity and distribution pattern of riparian plant species in the Wami River system, Tanzania. Journal of Plant Ecology 10(2): 259–270. http://dx.doi.org/10.1093/jpe/rtw021

Moser, B. W. and Witmer, G. W. (2000): The effects of elk and cattle foraging on the vegetation, birds, and small mammals of the Bridge Creek Wildlife Area, Oregon. International Biodeterioration & Biodegradation 45: 151–157. https://doi.org/10.1016/S0964-8305(00)00036-6

Munné, A., Solà, C. and Prat, N. (1988): QBR: Uníndice rápido para la evaluación de la calidad de los ecosistemas de ribera. Tecnología del Agua 175: 20–37.

Munné, A., Prat, N., Solà, C., Bonanda, N. and Rieradevall, M. (2003): A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index. Aquatic Conservation: Marine and Freshwater Ecosystems 13: 147–163. http://dx.doi.org/10.1002/aqc.529

Naiman, R. J. (1988): Animal influences on ecosystem dynamics. BioScience 38(11): 750–752. https://doi.org/10.2307/1310783

Naiman, R. J., Becchie, T. J., Benda, L. E., Berg, D. R., Bisson, P. A., MacDonald, L. H., O'Connor, M. D., Olson, P. L. and Steel, E. A. (1992): Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In: Naiman, R. J. (ed.): Watershed management: balancing sustainability and environmental change. Pg. 127–188. Springer-Verlag, New York.

Naiman, R. J., Decamps, H. and Pollock, M. (1993): The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209–212.

Naiman, R. J. and Rogers, K. H. (1997): Large animals and system-level characteristics in river corridors: Implications for river management. Bioscience 47(8): 521–529.

Naiman, R. J. and Décamps, H. (1997): The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28: 621–658.

Naiman, R. J., Bilby, R. E. and Bisson, P. A. (2000): Riparian ecology and management in the pacific coastal rain forest. BioScience 50: 996–1011.

Naimi, B., Hamm, N. A. S., Groen, T. A., Skidmore, A. K. and Toxopeus, A. G. (2014). Where is positional uncertainty a problem for species distribution modelling? Ecography 37: 191–203. https://doi.org/10.1111/j.1600-0587.2013.00205.x

New, T. and Xie, Z. (2008): Impacts of large dams on riparian vegetation: applying global experience to the case of China's Three Gorges dam. Biodiversity and Conservation 17: 3149–3163. http://dx.doi.org/10.1007/s10531-008-9416-2

Nilsson, C. and Dynesius, M. (1994): Ecological effects of river regulation on mammals and birds: A review. Regulated Rivers: Research & Management 9 (1): 45–53. https://doi.org/10.1002/rrr.3450090105

Nilsson, C. and Berggren, K. (2000): Alterations of riparian ecosystems caused by river regulation. BioScience 50(9): 783–792. https://doi.org/10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2

NTCA (2012): A protocol on Phase IV monitoring. Continuous monitoring of tiger reserves/tiger source areas Technical document number 1/2011 pp. 57.

O'Connell, A. F., Nichols, J. D. and Karanth, K. U. (2011): Camera traps in animal ecology: Methods and analyses. Springer, Tokyo. http://doi.org/10.1007/978-4-431-99495-4

Oka, G. M. (1998): Factors affecting the management of Muntjac deer (*Muntiacus muntjak*) in Bali Barat National Park, Indonesia. University of Western Sydney.

Oksanen, J., Blanchet, G.F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., and Wagner, H. (2019). vegan: community ecology package. R package version 2.5–6, https://CRAN.R=project.org/package=vegan

OpenStreetMap contributors (2017): Planet dump retrieved from https://planet.osm.org. URL: https://openstreetmap.org

Opperman, J. J. and Merenlender, A. M. (2000): Deer herbivory as an ecological constraint to restoration of degraded corridors. Restoration Ecology, 8(1), 41–47. https://doi.org/10.1046/j.1526-100x.2000.80006.x

Palmer, M. A., Swan, C. M., Nelson, K., Silver, P. and Alvestad, R. (2000): Streambed landscapes: evidence that stream invertebrates respond to the type and spatial arrangement of patches. Landscape Ecology 15: 563–576.

Palomo, L.J. and Gisbert, J. (200): Atlas de los mamíferos terrestres de España. Dirección General de Conservación de la Naturaleza. SECEM-SECEMU, Madrid, Spain.

Pascal, J. (1988): Wet evergreen forests of Western Ghats: ecology, structure, floristic composition and succession. Insitut Francais Pondi-cherry, Travaux. *De la Sci. et Techn.*, XX, 1–365.

Pastor, J., Naiman, R. J., Dewey, B. and P. McInnes. (1988): Moose, microbes and the boreal forest. BioScience 38 (11): 770–777. https://doi.org/10.2307/1310786

Perez-Amezola, M. C., Gatica-Colina, A. B., Cuevas-Ortalejo, D. M., Martinez-Calderas, J. M. and Vital-Garcia, C. (2020): Riparian biota of the protected area of flora and fauna Santa Elena Canyon, Mexico. Revista Bios Ciencias 7: e798. http://dx.doi.org/10.15741/revbio.07.e798

Perinchery, A., Jathanna, D., and Kumar, A. (2011): Factors determining occupancy and habitat use by Asian small-clawed otters in the Western Ghats, India. Journal of Mammalogy 92(4): 796–802.

Phillips, S. J., Anderson, R. P. and Schapire, R. E. (2006): Maximum entropy modeling of species geographic distributions. Ecological Modelling 190(3–4): 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S. J. and Dudik, M. (2008): Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31(2): 161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Pinay, G., Bernal, S., Abbott, B. W., Lupon, A., Marti, E., Sabater, F. and S. Krause. (2018): Riparian corridors: a new conceptual framework for assessing nitrogen buffering across biomes. Frontiers in Environmental Science 6: 47. https://doi.org/10.3389/fenvs.2018.00047

Prakash, N., Mudappa, D., Shankar Raman, T. R. and Kumar, A. (2012): Conservation of the Asian small-clawed otter (*Aonyx cinereus*) in human-modified landscapes, Western Ghats, India. Tropical Science Conservation 5(1): 67–78.

Prater, S. (1971): The Book of Indian Animals. Bombay Natural History Society, Bombay, India.

Puri, G., Meher-Homji, V., Gupta, R. and Puri, S. (1983): Forest ecology. Volume I. Phytogeography and Forest Conservation, Oxford and IBH, New Delhi.

Raha, A., and Hussain, S. A. (2016): Factors affecting habitat selection by three sympatric otter species in the southern Western Ghats, India. Acta Ecologica Sinica 36(1): 45–49.

Raman, T.R.S. (2004): Mouse deer (*Moschiola meminna* Erxleben, 1777). ENVIS

Bulletin 7: 131–140.

Ramesh, T., Kalle, R., Sankar, K., and Qureshi, Q. (2012): Factors affecting habitat patch use by sloth bears in Mudumalai Tiger Reserve, Western Ghats, India. Ursus 23(1): 78-85.

Ramesh, K., Ben, V. C., Jelil, S. N., Gaykar, A., Pal, R. S., Pokhariya, K., Sherwani, N., Kale, R., and Mujawar, A. (2018): Tiger recovery strategy and long-term monitoring in Sahyadri Tiger Reserve, Maharashtra: Feasibility assessment and strategic action plan. Wildlife Institute of India, Dehradun and Sahyadri Tiger Conservation Foundation, Kolhapur, 100 pp.

Ramesh, K. Gujar, S., Jelil, S. N., Gaykar, A., Girkar, N., Pal, R. S., Raja, G. A., Kale, R., Vyas, V. and Ben, V. C. (2020): Tiger recovery strategy and long-term monitoring in Sahyadri Tiger Reserve, Maharashtra. Interim Technical Report (2018–2020). Wildlife Institute of India and Sahyadri Tiger Foundation. pp. 33.

Rather, T. A., Kumar, S. and Khan, J. A. (2020): Multi-scale habitat modelling and predicting change in the distribution of tiger and leopard using random forest algorithm. Scientific Reports 10: 11473. https://doi.org/10.1038/s41598-020-68167-z

Raven, P. J. Holmes, N. T. H. Dawson, F. H. and Everard, M. (1998): Quality assessment using river habitat survey data. Aquatic Conservation: Marine and Freshwater Ecosystems 8(4): 477–499. https://doi.org/10.1002/(SICI)1099-0755(199807/08)8:4%3C477::AID-AQC299%3E3.0.CO;2-K

Reed, T. and Carpenter, S. R. (2002): Comparisons of p-yield, riparian buffer strips, and land cover in six agricultural watersheds. Ecosystems 5: 568–577. https://doi.org/10.1007/s10021-002-0159-8

Remsen Jr., J. V. and Parker III, T. A. (1983): Contribution of river-created habitats to bird species richness in Amazonia. 15(3): 223–231. https://doi.org/10.2307/2387833

R Core Team (2020): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, URL https://www.R-project.org/

Rija A. A., Critchlow, R., Thomas, C. D., Beale, C. M. (2020): Global extent and drivers of mammal population declines in protected areas under illegal hunting pressure. PLoS ONE 15(8): e0227163. https://doi.org/10.1371/journal.pone.0227163

Ripple, W. J., Newsome, T. M., Wolf, C., Dirzo, R., Everatt, K. T., Galetti, M., Hayward, M. W., Kerley, G. I. H., Levi, T., Lindsey, P. A., Macdonald, D. W., Malhi, Y., Painter, L. E., Sandom, C. J., Terborgh, J. and Van Valkenburgh, B. (2015): Collapse of the world's largest herbivores. Science Advances 1(4): e1400103. http://dx.doi.org/10.1126/sciadv.1400103

Rovero, F. and Marshall, A. R. (2009): Camera trapping photographic capture rate as an index of density in forest ungulates. Journal of Applied Ecology 46: 1011–1017.

Rovero, F. and Zimmermann, F. (2016): Camera trapping for wildlife research. Exeter: Pelagic Publishing, UK.

Sá, R. M. L. (1995): Effects of the Sanuel Hydroelectric Dam on mammal and bird communities in a heterogenous Amazonian lowland forest. 140. PhD thesis. University o Florida, Gainesville, FL.

Sahai, R. C. (1972): Distribution, composition and herd size of gaur (*Bos gaurus*) in Palamau, Bihar. Cheetal 15(1): 60–66.

Sajjan, M. B., Yadav, O. V., Jadhav, B. V. and Patil, R. N. (2018): Checklist of Amphibian Fauna of Chandoli National Park, District Sangli, Maharashtra, India. International Journal of Life Sciences, Special Issue, A10: 165–169.

Salinas, M. J., Blanca, G. and Romero, A. T. (2000): Evaluating riparian vegetation in semi-arid Mediterranean water courses in the south-eastern Iberian Peninsula. Environmental Conservation 27(1): 24–35. https://doi.org/10.1017/S0376892900000047

Sánchez-Montoya, M. M., Moleón, M., Sánchez-Zapata, J. A. and Tockner, K. (2016): Dry riverbeds: corridors for terrestrial vertebrates. Ecosphere 7(10): e01508. http://doi.org/10.1002/ecs2.1508

Sánchez-Montoya, M., Moleón, M., Sánchez-Zapata, J. and Escoriza, D. (2017): The Biota of Intermittent and Ephemeral Rivers: Amphibians, Reptiles, Birds, and Mammals. In: Intermittent rivers and Ephemeral Streams: Ecology and Management (T. Datry, N. Bonada and A. Boulton, eds.) pp. 299–322. http://doi.org/10.1016/B978-0-12-803835-2.00011-5

Sankar, K. and Acharya, B. (2004): Sambar (*Cervus unicolor* Kerr, 1792). ENVIS Bulletin (Wildlife Institute of India, Dehra Dun) 7: 163–170.

Santos, M. J., Matos, H. M., Palomares, F. and Santos-Reis, M. (2011): Factors affecting mammalian carnivore use of riparian ecosystems in Mediterranean climates. Journal of Mammalogy 92: 1060–1069. http://doi.org/10.1644/10-mamm-a-009.1

Schaller, G. B. (1967): The deer and the tiger. A study of wildlife in India. Chicago, IL: University of Chicago Press.

Schlosser, I. J. (1991): Stream fish ecology: a landscape perspective. BioScience 41: 704–712.

Schleicher, J., Peres, C. A., Amano, T., Llactayo, W. and Leader-Williams, N. (2017): Conservation performance of different conservation governance regimes in the Peruvian Amazon. Scientific reports 7(1): 1–10. https://doi.org/10.1038/s41598-017-10736-w

Schuster, R., Hansen, J. O., Strimas-Mackey, M. and Bennett, J. R. (2020): Exact linear programming solvers outperform simulated annealing for solving planning problems. PeerJ 8:e9258 https://doi.org/10.7717/peerj.9258.

Seavy, N. E., Gardali, T., Golet, G. H., Griggs, T., Howell, C. A., Kesley, R., Small, S. L., Viers, J. H and J. F. Weigand. (2009): Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecological Restoration 27(3): 330–338. http://www.jstor.org/stable/43441301

Seidensticker, J., Yoganand, K., and Johnsingh, A.J.T. (2011): Sloth bears living in seasonally dry tropical and moist broadleaf forests and their conservation. In: Dry forests of Asia: conservation and ecology (W. McShea, S. Davies, and N. Bhumpakphan eds.) pp. 217-236. Smithsonian Institution Press, Washington, D.C.

Shardlow, T. F. and Hyatt, K. D. (2013): Quantifying associations of large vertebrates with salmon in riparian areas of British Columbia by means of camera-traps, bait stations, and hair samples. Ecological Indicators 27: 97–107. https://doi.org/10.1016/j.ecolind.2012.11.011

Silveira, L., Jacomo, A. T. A. and Diniz-Filho, J. A. F. (2003): Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114: 351–355.

Simpson, E. H. (1949): Measurement of diversity. Nature 163: 688

Sirombra, M. G. and Mesa, L. M. (2012): A method for assessing the ecological quality of riparian forests in subtropical Andean streams: QBRy index. Ecological Indicators 20: 324–331. https://dx.doi.org/10.1016/j.ecolind.2012.02.021

Sofaer, H. R., Jarnevich, C. S., Pearse, I. S., Smyth, R. L., Auer, S., Cook, G. L., Edwards Jr, T. C., Guala, G. F., Howard, T. G., Morisette, J. T. and Hamilton, H. (2019): Development and delivery of species distribution models to inform decision-making. BioScience 69(7): 544–557. https://doi.org/10.1093/biosci/biz045

Soykan, C. U., Brand, L. A., Ries, L., Stromberg, J. C., Haas, C., Simmons Jr, D. A., Patterson, W. J. D. and Sabo, J. L. (2012): Multitaxonomic diversity patterns along a desert riparian-upland gradient. PLoS ONE 7(1): e28235. https://doi.org/10.1371/journal.pone.002823

Spitz, F. (1999): *Sus scrofa*. In: The Atlas of European Mammals (A. J. Mitchell-Jones, G. Amori, W. Bogdanowicz, B. Kryštufek, P. J. H. Reijnders, F. Spitzenberger, M. Stubbe, J. B. M. Thissen, V. Vohralík and J. Zima eds.). Academic Press, London, UK

Sreekumar, P. G. and Balakrishnan, M. (2002): Seed dispersal by the sloth bear (Melursus ursinus) in South India. Biotropica 34: 474-477.

Stanford, J. A., Ward, J. V., Liss, W. J., Frissel, C. A., Williams, R. N., Lichatowich, J. A. and Coutant, C. C. (1996): A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391–413.

Stein, A.B., Athreya, V., Gerngross, P., Balme, G., Henschel, P., Karanth, U., Miquelle, D., Rostro-Garcia, S., Kamler, J.F., Laguardia, A., Khorozyan, I. and Ghoddousi, A. (2020): Panthera pardus (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T15954A163991139. https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T15954A163991139.en)

Stephens, P. A., Pettorelli, N., Barlow, J., Whittingham, M. J. and Cadotte, M. W. (2015): Management of proxy? The use of indices in applied ecology. Journal of Applied Ecology 52: 1–6.

Steward, A. L., Schiller, Dv., Tockner, K., Marshall, J. C. and Bunn, S. E. (2012): When the river runs dry: human and ecological values of dry riverbeds. Frontiers in Ecology and the Environment 10(4): 202–209.

Suárez, M. L., Vidal-Abarca, M. R., Sánchez-Montoya, M., Alba, J., Álvarez, M., Avilés, J., Bonanda, N., Casas, J., Jaimez-Cuéllar, P., Munné, A., Pardo, I., Prat, N., Rieradevall, M., Salinas, J., Toro, M. and Vivas, S. (2002): Las riberas de los ríos mediterráneos y su calidad: El uso del índice QBR. Limnetica, 21(3-4): 135-148.

Tabacchi, E., Correll, D. L., Hauer, R., Pinay, G., Planty-Tabacchi, A. M. and Wissmar, C. (1998): Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40(3): 497–516. https://doi.org/10.1046/j.1365-2427.1998.00381.x

Thomas, J. W., Maser, C. and J. E. Rodiek. (1979): Riparian zones. Pp. 40–47 in Wildlife habitats in managed forests: The Blue Mountains of Oregon and Washington (J. W. Thomas, ed.). USDA Forest Service, Agriculture Handbook 553. Washington D.C., USA.

Timmins, R. Kawanishi, K., Giman, B., Lynam, A., Chan, B., Steinmetz, R., Sagar Baral, H., and Sambar Kumar, N. (2015): *Rusa unicolor*. The IUCN red list of threatened species 2015.

Timmins, R. J., Duckworth, J. W., and Hedges, S. (2016): *Muntiacus muntjak*. The IUCN red list of threatened species 2016: eT42190A56005589. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T42190A56005589.en

Tockner, K. and Ward, J. V. (1999): Biodiversity along riparian corridors. Archiv für Hydrobiologie Suppl. 115: 293–310.

Tockner , K., Ward, J. V., Edwards, P. J. and Kollmann, J. (2002): Riverine landscapes: an introduction. Freshwater Biology 47: 497–500.

Tockner, K., & Stanford, J. A. (2002). Riverine flood plains: present state and future trends. Environmental Conservation, 29(3), 308–330.

Tucker, S. T. and Wayne, C. L. (1990): Differences in riparian vegetation structure between grazed areas and exclosures. Journal of Range Management 43: 295–299. https://doi.org/10.2307/3898920

Tyson, M. J. (2007): The ecology of Muntjak deer (*Muntiacus muntjak*) in Baluran National Park, Java and their interactions with other mammal species. Thesis, Manchester Metropolitan University.

Umapathy, G. and Durairaj, G. (1995): Preliminary studies on the feeding ecology of the otter *Lutra lutra* at Pitchavaram, East Coast of India. IUCN Otter Specialist Group Bulletin 11: 24–26.

Vance, J. A., Angus, N. B. and Anderson, J. T. (2012): Riparian and riverine wildlife response to a newly created bridge crossing. Natural Resources 3(4): 213–228. http://dx.doi.org/10.4236/nr.2012.34029

van der Merwe, J. and Hellgren, E. C. (2016): Spatial variation in trophic ecology of small mammals in wetlands: support for hydrological drivers. Ecosphere 7(11): e01567. https://doi.org/10.1002/ecs2.1567

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. and C. E. Cushing. (1980): River continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37 (1): 130–137. https://doi.org/10.1139/f80-017

Vapnik, V. (1998): Statistical Learning Theory. Wiley, New York.

Venter, O., Magrach, a., Outram, N., Klein, C. J., Possingham, H. P., Di Marco, M. and Watson, J. E. M. (2018): Bias in protected-area locations and its effects on long-term aspirations of biodiversity conventions. Conservation Biology 32(1): 127–134. https://doi.org/10.1111/cobi.12970

Visconti, P., Butchart, S. H. M., Brooks, T. M., Langhammer, P. F., Marnewick, D., Vergara, S., Yanosky, A. and Watson, J. E. M. (2019): Protected area targets post 2020. Science. 364(6436): 239–241. https://doi.org/10.1126/science.aav6886

Waldron, A., Mooers, A. O., Miller, D. C., Nibbelink, N., Redding, D., Kuhn, T. S., Roberts, J. T. and Gittleman, J. L. (2013): Targeting global conservation funding to limit immediate biodiversity declines. Proceedings of the National Academy of Sciences 110(29): 12144–12148. https://doi.org/10.1073/pnas.1221370110

Ward, J. V., Bretschko, G., Brunke, M., Danielpol, D., Gibert, J., Gonser, T. and Hildrew, A. G. (1998): The boundaries of river systems: the metazoan perspective. Freshwater Biology 40: 531–570.

Ward, J. V., Tockner, K., Arscott, D. B. and Claret, C. (2002): Riverine landscape diversity: an introduction. Freshwater Biology 47: 517–539.

Waters, J. R., Zabel, C. J., McKelvey, K. S. and Welsh, H. H. (2001): Vegetation patterns and abundances of amphibians and small mammals along small streams in a northwestern California watershed. Northwest Science 75(1): 37–52. https://www.srs.fs.usda.gov/pubs/52887

Wearn, O. R. and Glover-Kapfer, P. (2017): Camera-trapping for conservation: a guide to best-practices. WWF Conservation Technology Series 1(1). WWF-UK, Woking, United Kingdom.

Wei, T. and Simko, V. (2017): R package “corrplot”: visualization of a correlatin matrix (vesion 0.84). Available from https://github.com/taiyun/corrplot

Wickham, H. (2016): ggplot2: elegant graphics for data analysis. Springer-Verlag New York. URL: https://ggplot2.tidyverse.org

Wildlife Conservation Society – WCS, and Center for International Earth Science Information Network – CIESIN – Columbia University (2005): Last of the Wild Project, version 2, 2005 (LWP - 2): Global human footprint database (Geographic). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4M61H5F. Accessed 5 JUNE 2018.

Yoganand, K, Rice, C.G., Johnsingh, A.J.T. and Seidensticker, J. 2006. Is the sloth bear in India secure? A preliminary report on distribution, threats and conservation requirements. Journal of the Bombay Natural History Society 103(2-3): 172-181.

Zhang, P. (1994): On the choice of penalty term in generalized FPE criterion. In: Selecting models from data (P. Cheeseman and R. W. Oldford eds.), pp. 41–49. Springer-Verlag, New York, NY.

Zimbres, B., Peres, C. A. and Machado, R. B. (2016): Terrestrial mammal responses to habitat structure and quality of remnant riparian forests in an Amazonian cattle-ranching landscape. Biological Conservation. 206: 283–292. http://dx.doi.org/10.1016/j.biocon.2016.11.033

Zimbres, B., Peres, C. A., Penindo, G. and Machado, R. B. (2018): Threshold of riparian forest use by terrestrial mammals in a fragmented Amazonian deforestation frontier. Biodiversity and Conservation 27: 2815–2836. http://doi.org/10.1007/s10531-018-1571-5

Appendix I: QBR_k index: Riparian habitat quality datasheet (Chapter V)

Date

Score of each part cannot be negative or exceed 25 Site

Section	Score	Description	Score
Total riparian cover	25	>80% of riparian cover	
	10	50–80% of riparian cover	
	5	10–50% of riparian cover	
	0	<10% of riparian cover	
	+10	If connectivity between riparian forest and woodland in total	
	+5	If connectivity is higher than 50%	
	-5	If connectivity between 25 and 50%	
	-10	If connectivity lower than 25%	
Cover structure	25	>75% of canopy cover	
	10	50–75% of canopy cover or 25–50% canopy cover but 25% understory cover	
	5	Canopy cover lower than 50% but understory at least between 10 and 25%	
	0	<10% of either canopy or understory	
	+10	At least 50% of the plot has shrubs	
	+5	If 25–50% of the plot has shrubs	
	+5	If fallen logs are present in the plot	
	-5	If fallen logs are absent	
	-5	If trees are regularly distributed and shrubland is >50%	
	-5	Trees distributed regularly and shrubland <50%	
Cover quality	25	All native trees	
	10	75% of native tree cover and <25% of isolated non-native trees	
	5	25–50% of native tree cover and 50–75% of isolated non-native trees	
	0	>50% of isolated non-native tree cover	
	+10	>75% of native shrub cover	
	+5	50–75% of native shrub cover and 25–50% of non-native shrub cover	
	-5	25–50% of native shrub cover and 50–75% of non-native shrub cover	

	-10	<25% of native shrub cover	
	-10	Exotic/introduced species forming monoespecific communities (trees or shrubs)	
Channel alteration	25	Unmodified river channel	
	15	Modifications in one fluvial terrace adjacent to the river bed, constraining the river channel	
	10	Modifications in both fluvial terraces adjacent to the river bed, constraining the river bed	
	10	Channel modified by rigid structures along one margin	
	5	Channel modified by rigid structures along both margins	
	0	Channelized river	
	-10	River bed with rigid structures (e.g. wells)	
	-10	Transverse structures into the channel (e. weirs)	
	-10	If there are discharge of urban solid waste and/or industrial effluents	
	-10	Intense gravel or sand extraction	
	-5	Some gravel or sand extraction	
Final score (sum of four sections)			

Peer-reviewed publications from the research

Jelil, S. N., Gaykar, A., Girkar, N., Ben, C., Hayward, M. W. and Krishnamurthy, R. (2021): Mammal persistence along riparian forests in western India within a hydropower reservoir 55 years post construction. *Frontiers in Ecology and Evolution*. 9:643285 https://doi.org/10.3389/fevo.2021.643285

Jelil, S. N., Paul, A., Gaykar, A., Girkar, N., Gujar, S., Ben, C., Hayward, M. W. and Krishnamurthy, R. (first review completed): Riparian quality index as a tool to measure forest quality and support wildlife habitat management along the terrestrial-riverine continuum. *River Research and Applications* (Manuscript ID: RRA-20-0169)

Jelil, S. N., Vasudeva, V., Sawant, U. S., Hayward, M. W. and Krishnamurthy, R. (in preparation): Where to effectively allocate management resources within protected areas? A spatial conservation planning approach. Prepared for *Conservation Letters*.

Conference presentations from the research

Jelil, S. N., Vasudeva, V., Sawant, U., Hayward, M. W. and Ramesh, K. (2021): Where to effectively allocate management resources within protected areas? A spatial conservation planning approach. 30th International Congress for Conservation Biology. December 13–15. **(Accepted)**

Jelil, S. N., Ben, V. C., Hayward, M. W. and Ramesh, K. (2019): Terrestrial mammal occupancy pattern in a tropical Indian forest-stream network. Association of Tropical Biology and Conservation – Asia Pacific meet, Thulhiriya, Sri Lanka. September 10–13.

Jelil, S. N., Ben, V. C., Hayward, M. W. and Ramesh, K. (2019): Terrestrial mammalian occupancy assemblages and occupancy pattern along forest-stream network in Sahyadri Tiger Reserve, Maharashtra. Internal Annual Research Seminar, Wildlife Institute of India. August 19–20.

frontiers
in Ecology and Evolution

ORIGINAL RESEARCH
published: 16 April 2021
doi: 10.3389/fevo.2021.643285

Mammal Persistence Along Riparian Forests in Western India Within a Hydropower Reservoir 55 Years Post Construction

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OPEN ACCESS

Edited by:
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Guangxi University, China

Reviewed by:
Riddhika Ramesh (Kalle),
Salim Ali Center for Ornithology and Natural History, India
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Specialty section:
This article was submitted to Conservation and Restoration Ecology,
a section of the journal Frontiers in Ecology and Evolution

Received: 17 December 2020
Accepted: 26 March 2021
Published: 16 April 2021

Citation:
Jelil SN, Gaykar A, Girkar N, Ben C, Hayward MW and Krishnamurthy R (2021) Mammal Persistence Along Riparian Forests in Western India Within a Hydropower Reservoir 55 Years Post Construction. Front. Ecol. Evol. 9:643285. doi: 10.3389/fevo.2021.643285

While the negative impacts of dam construction on downstream river stretches and riparian forests are well studied, the status of wildlife presence and persistence in upstream reservoir deltas is virtually unknown. We investigated the drivers of terrestrial mammal occupancy and persistence along riparian forests of Koyna reservoir in western India 55 years after its construction. We adopted a catchment-wide field design grounded in the river continuum concept and sampled different stream orders within the reservoir. Camera traps, nested in an occupancy modeling framework, were deployed across 72 riparian sites and replicated for four seasons across all stream types. We recorded a total of nineteen species of terrestrial mammals during the study period. Multi-season occupancy models revealed three key patterns of mammal persistence: (a) ungulates were more frequently photo-captured in riparian forests; gaur and wild pig had the highest proportions of the total sampled area (0.84 ± 0.12 SE; 0.77 ± 0.07 SE, respectively); (b) small-sized ungulates were more vulnerable to local extinction than large-bodied ungulates; extinction probability was highest for barking deer (0.59 ± 0.07) and lowest for sambar (0.15 ± 0.07); and (c) distance from stream played major roles in determining mammal detection. Riparian forests are fundamentally important to ecosystem functioning and biodiversity conservation, and using the data from this study, managers can plan to sustain high mammal persistence along riparian forests at Koyna reservoir or similar Indian reserves. Further, our robust sampling approach, grounded in the terrestrial-riverine continuum concept, can be applied globally to understand species assemblages, aiding in multi-landscape and wildlife management planning.

Keywords: dammed river, occupancy modeling, colonization, extinction, reservoir biodiversity, river continuum

INTRODUCTION

The river continuum concept was the first unified hypothesis proposing that rivers and associated watersheds should be viewed as a continuum to understand the complete structure and functioning of a river (Vannote et al., 1980). Like river systems, riparian forests form their own continuum running along rivers and streams, from headwaters to perennial rivers, and hence riparian vegetation is also likely to conform to the river continuum concept. Riparian forests as ecotones protect riverbanks from erosion resulting in bank stability (Pinay et al., 2018), drive organic matter and nutrients into streams (Vannote et al., 1980), moderate temperature extremes in river environments (Dugdale et al., 2018), and are predicted to function as hotspots for climate change adaptation (Seavy et al., 2009; Capon et al., 2013). Hence, riparian forests are key constituents of terrestrial-aquatic continua and reflect the functional status of an entire catchment. Large animal ecology in riparian forests has been long studied and was probably first highlighted in mainstream conservation science by the pioneering studies of Naiman (1988); Pastor et al. (1988), and Naiman and Rogers (1997). These studies summarized how large ungulates influence riparian system dynamics primarily by their foraging behavior. There have been few recent studies highlighting the importance of riparian forests for forest mammals, but the riverine-continuum concept is slowly gaining traction across various ecosystems, especially with important works of Santos et al. (2011) and Zimbres et al. (2018). In India, there have been frequent general discussions about dam effects on biodiversity, but detailed empirical studies on the dynamics and distribution of forest mammals within riparian forests remain virtually non-existent. In regards to riparian forests, studies have mainly focused on riparian obligate species like otters (Umapathy and Durairaj, 1995; Hussain and Choudhury, 1997; Anoop and Hussain, 2006a,b; Perinchery et al., 2011; Prakash et al., 2012; Raha and Hussain, 2016), or certain large mammals in floodplains/wetland-dependent species, such as Asiatic buffalo and rhinocerous (Chatterjee and Bhattacharyya, 2021). Chatterjee and Bhattacharyya (2021) found that even though wetland-dependent mammals have been studied, there remains a large knowledge gap in regards to these species ecology and conservation.

A novel avenue for riparian ecology research opened up very recently with studies of Datry et al. (2014, 2016, 2017a,b), which stressed the ecology of dry and intermittent rivers, as perennial river systems have received the majority of research attention historically. Following the research on fluvial dynamics of perennial and temporary rivers, Sánchez-Montoya et al. (2016) studied dry streams as corridors for large mammals using an innovative animal footprint method. These studies have all contributed to the development of the terrestrial riverine continuum concept, but they have also all been conducted largely in free-flowing rivers and associated riparian forests. Within altered habitats, especially in upstream hydropower reservoirs, research on forest mammals in riparian forests is still lacking. These altered habitats are interesting especially because the riparian forests experience high levels of flooding and drought owing to uneven rainfall patterns. Unlike natural watersheds, the water level in reservoirs is operated by dam authorities which alters the normal hydrological cycle of the river (Alho, 2011). Species occupancy patterns in an environment of such dynamic water level fluctuations is key to provide insights into how species persist within these reservoirs. With this background in the river continuum framework, we aimed to identify the drivers of mammal assembly and persistence in a human-altered watershed, a dammed river which now forms the Koyna Wildlife Sanctuary in the northern Western Ghats.

MATERIALS AND METHODS

Study Area: The Koyna Hydroelectric Project is the largest completed hydropower station in India with a total capacity of 1960 MW. It is comprised of four dams, the largest of which, the Koyna Dam, was completed in 1963, forming the Shivsagar Reservoir (Bokil, 1999). The reservoir is now protected as Koyna Wildlife Sanctuary (hereafter referred to as "Koyna"). Koyna forms an important corridor between Mahabaleshwar-Panchgani Ecologically Sensitive Zone in the north and Chandoli National Park in the south; Koyna and the Chandoli National Park together form the Sahyadri Tiger Reserve. With seven land cover types (Jelil et al., 2020; **Figure 1**), Koyna covers 423.55 km^2 and the vegetation in the sanctuary is classified as southern tropical evergreen forest and southern moist deciduous forest (Champion and Seth, 1968). Red clay is the main soil type. The mean annual rainfall in Koyna is $\sim$ 5,000 mm, which falls predominantly from June–September (Joglekar et al., 2015). Koyna was declared a wildlife sanctuary in 1985, and private forests owned by villagers before resettlement now persist as grasslands, scrub and moist deciduous forests (Joglekar et al., 2015). Joglekar et al. (2015) reported that the relative inaccessibility and undulating terrain supports some of the few remaining undisturbed tall evergreen forests in the northern Western Ghats, and hosts large mammals such as the common leopard (*Panther pardus*), dhole (*Cuon alpinus*), sloth bear (*Melursus ursinus*), Indian gaur (*Bos gaurus*), and sambar (*Rusa unicolor*). The last confirmed record of tiger (*Panthera tigris*) from Chandoli National Park was in 2018 (Jelil et al., 2020), but the species has not been recorded in Koyna since 2007.

Field Study Design: We used stream types as sampling strata with the river stretch divided into three sections (**Table 1**). In each section, we assessed riparian forests associated with a perennial order, two intermittent orders, four ephemeral orders and eight headwater orders (**Figures 1**, **2**). We sampled four locations in both the perennial and intermittent order and eight locations in both ephemeral and headwaters orders. In total, we sampled 24 locations in each of the three sections resulting in 72 total sampled locations. The riparian buffer was set at 1 km in either direction of the stream edge in the perennial habitat, at 500 m in the intermittent, 200 m in ephemeral and 100 m in headwater streams. The study was carried out from April 2018 to March 2020 encompassing four seasons (two summer and winter seasons, i.e., summer 2018, winter 2018, summer 2019, and winter 2019). Summer season data collection was conducted from April to July and winter data collection from November to February. This amounted to *c.* 480 days of survey effort in the 2 year period.

Camera Trapping Surveys: The camera traps were deployed up to 1 km from the waterway for the perennial stream-type, up to 500 m for the intermittent stream-type, up to 200 m for the

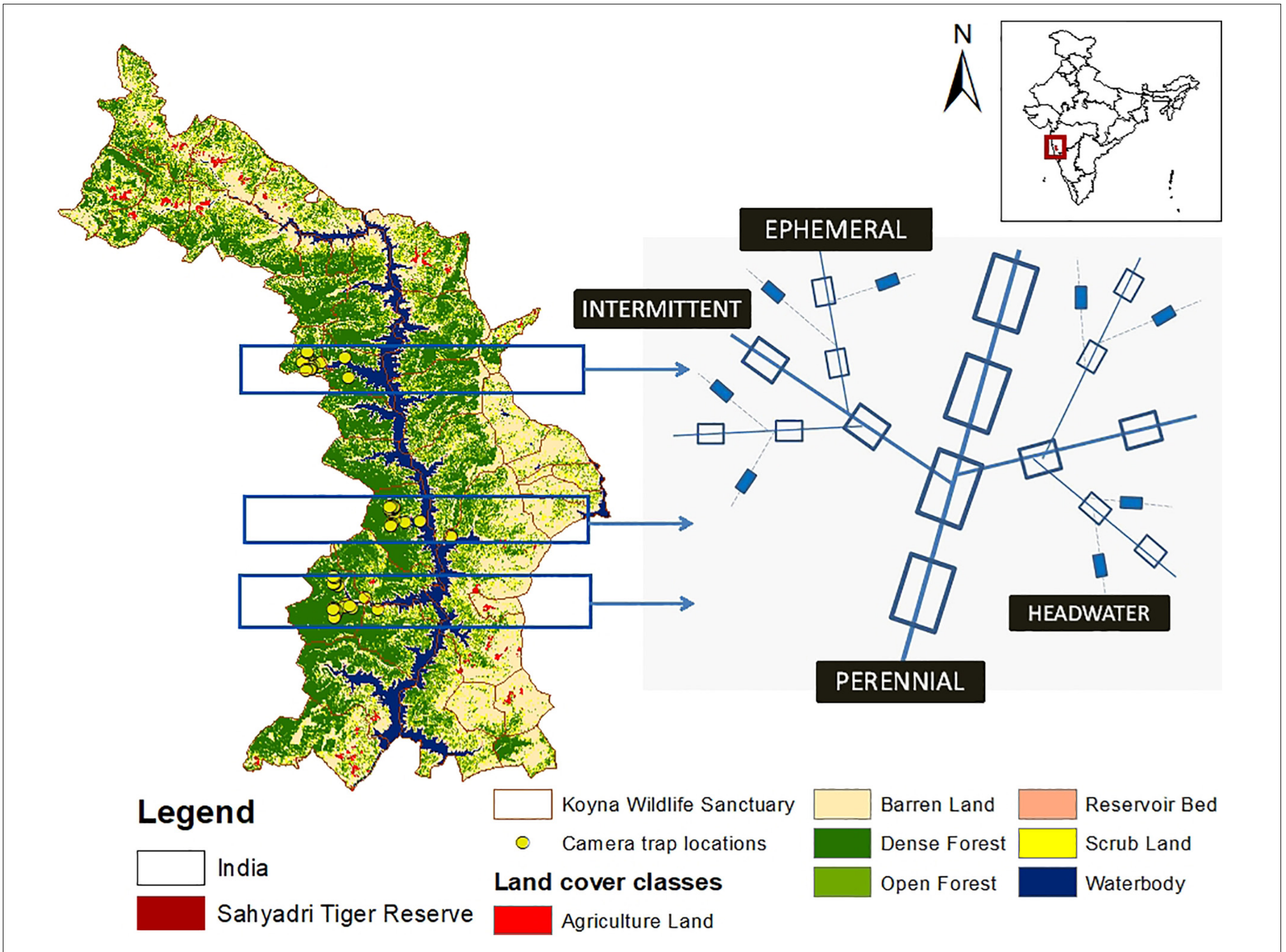

FIGURE 1 | Map of study area detailing the field survey design and the camera trap locations. In each of three sections of the river we sampled four kinds of stream types: perennial, intermittent, ephemeral and headwater streams.

TABLE 1 | Description of riparian habitat complexes/habitat types selected for the study and the rationale/basis for selecting the habitat types.

Stream type	Description	Mean altitude ± SE (m)	Buffer width fixed (m)	Mean distance of cameras from stream edge ± SE (m)
Perennial	Water flows in these stretches all year round	645.67 (±1.27)	1,000	251.08 (±16.68)
Intermittent	Water flows for more than half of the year (6–8)	649.58 (±1.08)	500	123.08 (±8.05)
Ephemeral	Water flows for less than half of the year (3–5)	653.25 (±2.12)	200	66.67 (±2.92)
Headwater	Water drains out immediately (>1 month)	666.29 (±3.31)	100	15.62 (±1.57)

Two criteria were considered, (a) water flow in the stream types (b) mean elevation of habitats. The riparian buffer selected for perennial streams was 1,000 m, intermittent streams was 500 m, ephemeral streams was 200 m and headwater streams was 100 m.

ephemeral stream type, and up to 100 m for headwater stream type. Mean values for the distance of the camera-trap site to the waterway shown in **Table 1**. At each of the 72 sites, a single Cuddeback white flash (C1 model) camera trap was deployed by affixing it at a height of *c.* 60–70 cm to suitable trees. These were set to take consecutive images (set 5 s apart) when triggered. Cameras were checked regularly in field after deployment to limit the missing survey replicates. The mean of the trapping days in summer 2018 was 24.4 (±0.62 SE) days, winter 2018 was 39.89 (±1.75 SE), summer 2019 was 40.97 (±0.89 SE) days and winter 2019 was 35.05 (±1.73 SE) days. The trapping effort in summer 2018 was lower because initially we had fewer number of

FIGURE 2 | Different habitat types selected for the study.

camera traps available for this study, and hence, we had to cover the 72 sites in two rounds. However, during the next sessions, more camera traps were at our disposal and all 72 cameras could be deployed at once. In any case, the different number of camera traps days is likely to increase confidence intervals and thereby means that any differences in effects due to variable effort are conservative.

Riparian Habitat Assessment: To test habitat factors influencing species occupancy, circular vegetation plots were established in all the 72 riparian buffers for collection of fine-scale habitat data. Keeping the camera trap location as the center, the number of trees and fallen logs were assessed within 10 m radius plots covering 314 m^2. Percent canopy cover, elevation, the adjacent stream type and the distance to stream edge were recorded from the center of the plot. We set the radius of the plot to be short to conserve time in the field.

Data Analyses: Images retrieved from the camera traps were identified to species level excluding random captures of birds, and data were sorted into species-specific folders for all sites by season. Images were considered to be independent when they were at least 30 min apart (Linkie and Ridout, 2011; Rovero and Zimmerman, 2016; Allen et al., 2018, 2020).

Occupancy Modeling Framework: We constructed species-specific multi-season occupancy models (MacKenzie et al., 2002, 2006) using PRESENCE 12.6 (Hines, 2006). We modeled occupancy of species that had at least 20 independent captures across all four seasons. We arranged our camera trap data into 7 day occasions (weekly replicates) to record detection and non-detection to create detection history matrices for each site. A detection was coded as (1), non-detection was coded as (0) and a missing survey was coded as (.), which in our case would mean that a camera stopped working during the deployed time. We finally compiled our detection history matrices with four replicates for summer 2018, seven for winter 2018, summer 2019 and winter 2019. Hence, we had 25 replicates across all four seasons, i.e., we had 25 × 7 days = 175 occasions for each of the 72 sites covering all four seasons.

For all multi-season models, the model parameterization was fixed to initial occupancy, local colonization, extinction and detection. The parameters used in multi-season models were:

ψ: occupancy probability (probability that the area is occupied by the species)
p_i: detection probability (probability of detection species in survey i, given the species is present)
γ_i: colonization probability (probability of unoccupied site being colonized between seasons i and i + 1)
ε_i: extinction probability (probability of occupied site going extinct between seasons i and i + 1)

Predictor Variables: The riparian habitat covariates were selected *a priori* because of their likely importance in driving wildlife occupancy along streams (**Table 2**). To minimize model overfitting, which often risks the inclusion of spurious variables (Burnham and Anderson, 2002), we tested for pair-wise correlations between covariates using Pearson's correlation analyses. This was done using *cor* function and plotted using *corrplot* function in the corrplot 0.84 (Wei and Simko, 2017) package in R 4.0.0 (R Core Team, 2020). Correlation threshold was fixed at $r \geq 0.7$ (Dornmann et al., 2013; **Supplementary Code 1** and **Supplementary Figure 1**) and when correlation between two variables was higher than 0.7, we removed one of the two covariates. Since cameras were set at specific distances from stream edge at each of the stream types, we sensed a possible correlation of habitat type with distance to stream. However, since habitat type was a categorical variable it was not possible to test for correlation using the above method, since that only works with continuous variables. Regression models allow to test for this by using square root of the R^2 value as a surrogate that can be treated similarly to correlation. This works for a regression model considering a continuous variable (in our case distance from stream edge) as dependent variable and a categorical variable (stream type) as independent variable. Again, the correlation threshold was fixed at 0.7 (**Supplementary Code 2**).

Simultaneously, we ran a principal component analysis (PCA) to test for multicollinearity in addition to the pair-wise correlation analysis. We ran the PCA using the *prcomp* function in the factoextra 1.0.7 package (Kassambara and Mundt, 2020) in R (**Supplementary Code 3**, **Supplementary Figure 2**, and **Supplementary Table 1**).

Model Selection: For model selection, χ^2 goodness-of-fit test (MacKenzie and Bailey, 2004) using 999 parametric bootstraps was run to estimate overdispersion parameter $\hat{c}$ (Burnham and Anderson, 2002). This was done keeping in mind the caveat described by Burnham and Anderson (2002) that estimating $\hat{c}$ for every model would make the correct use of model selection criteria tricky, hence they recommend that the global model should be used as the basis for estimating a single variance inflation factor $\hat{c}$. We evaluated model fit with program PRESENCE by using the "assess model fit" function, while creating the design matrix of the global model. Finally, to account for overdispersion (where $\hat{c} > 1$) indicating a lack of fit, the model selection was done using quasi AIC (QAIC), and model parameters were adjusted by multiplying the standard errors by

TABLE 2 | Description of covariates with *a priori* hypotheses along riparian forests.

Covariate	Expected influence		Supporting citation
	Species	Parameter with expected effect	
Elevation	Gaur, sambar, barking deer	ψ (+), γ (+), ε (−)	Schaller, 1967; Johnsingh et al., 2004
	Porcupine, wild pig	ψ (+), γ (+), ε (−)	Timmins et al., 2015, 2016
Number of trees	Gaur, sambar, barking deer, porcupine	ψ (+), γ (+), ε (−)	Schaller, 1967
	Wild pig	ψ (−), γ (−), ε (+)	
Canopy cover	Gaur, sambar, barking deer, porcupine, wild pig	ψ (+), γ (+), ε (−)	Duckworth and Hedges, 1998; Duckworth et al., 1999; Greiser Johns, 2000; Timmins and Ou, 2001
Distance from stream	Gaur, sambar, barking deer, porcupine, wild pig	p (−)	Timmins et al., 2015
Season	Gaur, sambar, barking deer, porcupine, wild pig	p (+/−)	

a factor of $\sqrt{\hat{c}}$ (Burnham and Anderson, 2002). The QAIC was computed using the following formula:

$$\text{QAIC} = -2\log \text{Like}/\hat{c} + 2k$$

where,

log Like = log likelihood of the model

$\hat{c}$ = dispersion parameter from the global model

k = number of parameters in the model

The estimates of occupancy (ψ), seasonal colonization (γ), local extinction (ε), and detection probability (p) were obtained through the null models of each species. Graphs were created using ggplot2 (Wickham, 2016) and ggpubr 0.4.0 (Kassambara, 2020) R packages.

RESULTS

Our camera trap efforts accounted for 10, 021 trap nights across all four seasons—1757 trap nights in summer 2018, 2872 in winter 2018, 2868 in summer 2019 and 2524 in winter 2019. We photo-captured 19 species of terrestrial mammals (**Table 3** and **Figure 3**). Our camera capture threshold criterion of at least 20 independent captures was fulfilled by 10 species in summer 2018, 10 in winter 2018, six in summer 2019 and 10 in winter 2019. Only five species fulfilled this criterion across all four seasons and hence multi-season models were run for these five species—gaur (*Bos gaurus*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), barking deer (*Muntiacus muntjak*), and porcupine (*Hyxtrix indica*).

Final Set of Predictor Variables: The pairwise correlation test showed that distance from stream edge and type of stream/habitat had high correlation (0.94) (**Supplementary Code 2**) and hence stream type was removed from the final variable set. Further, distance from stream, number of fallen logs, and percent understory cover were removed from the occupancy, colonization and extinction models because the test for multi-collinearity (PCA) demonstrated these covariates to have low contribution in the overall dataset. However, we retained distance from stream as a covariate to model species detection probabilities. The final list of covariates after both correlation and multi-collinearity analyses were used as occupancy, seasonal colonization, local extinction and detection probability covariates in the occupancy models (**Table 4**).

Model Selection: We detected evidence of overdispersion for two species viz., gaur ($\hat{c}$ = 2.83) and sambar ($\hat{c}$ = 2.05) (**Table 4**). No model overdispersion was detected for barking deer ($\hat{c}$ = 0.03), wild pig ($\hat{c}$ = 0.88) and porcupine ($\hat{c}$ = 0.85) (**Supplementary Table 2**). Top ranking models for each species (ΔQAIC $\leq$ 2) were considered which accounted for 83 and 95% of the QAIC model weight for sambar and gaur, respectively. For barking deer, porcupine and wild pig, top ranking models (ΔAIC $\leq$ 2) accounted for 67, 81, and 93% of AIC model weights, respectively.

Occupancy modeling results (occupancy, colonization, extinction and detection probability parameter estimates with standard error SE are reported within parentheses):

Porcupine (0.43 $\pm$ 0.01) had the highest detection probability followed by wild pig (0.37 $\pm$ 0.02), sambar (0.31 $\pm$ 0.01), barking deer (0.29 $\pm$ 0.02), and gaur (0.27 $\pm$ 0.03). Indian gaur (0.84 $\pm$ 0.12) had the highest proportion of occupied sites followed by wild pig (0.77 $\pm$ 0.07), porcupine (0.65 $\pm$ 0.07), sambar (0.49 $\pm$ 0.10), and barking deer (0.49 $\pm$ 0.08). Sambar (0.63 $\pm$ 0.10) had the highest probability to colonize unoccupied sites between seasons, followed by wild pig (0.62 $\pm$ 0.08), gaur (0.57 $\pm$ 0.15), porcupine (0.47 $\pm$ 0.06), and barking deer (0.24 $\pm$ 0.05). Barking deer (0.59 $\pm$ 0.07) had the highest probability to go extinct from a previously occupied site between seasons, followed by porcupine (0.43 $\pm$ 0.05), gaur (0.39 $\pm$ 0.11), wild pig (0.32 $\pm$ 0.04), and sambar (0.15 $\pm$ 0.07) (**Figure 4**).

Predictors of species occupancy, detection, local colonization and extinction between seasons (β estimates with standard error SE are reported within parentheses):

Barking Deer: Barking deer occupancy was positively affected by elevation (0.09 $\pm$ 0.01) and number of trees (0.05 $\pm$ 0.02), and negatively by canopy cover (−0.06 $\pm$ 0.01). Its colonization probability was positively affected by canopy cover (0.03 $\pm$ 0.01), and negatively by elevation (−0.04 $\pm$ 0.01) and number of trees (−0.01 $\pm$ 0.02). Its extinction probability was negatively affected by elevation (−0.05 $\pm$ 0.01), canopy cover (−0.01 $\pm$ 0.01), and number of trees (−0.05 $\pm$ 0.02). Its detection was higher at sites near to streams (−0.01 $\pm$ 0.01) (**Figures 5**, **6** and **Supplementary Tables 3–6**).

TABLE 3 | List of all species photo-captured during the study period from riparian forests of Koyna Wildlife Sanctuary.

Species	Summer 2018	Winter 2018	Summer 2019	Winter 2019
Porcupine	156 (8.87)	191 (6.65)	158 (5.51)	149 (5.90)
Gaur	83 (4.72)	71 (2.47)	83 (2.89)	147 (5.82)
Wild pig	101 (5.74)	86 (3.00)	253 (8.82)	137 (5.42)
Sambar	67 (3.81)	89 (3.10)	148 (5.16)	193 (7.64)
Barking deer	64 (3.64)	59 (2.05)	52 (1.81)	36 (1.42)
Mouse deer	34 (1.93)	35 (1.21)	10 (0.34)	17 (0.67)
Sloth bear	30 (1.71)	24 (0.83)	54 (1.88)	15 (0.59)
Leopard	21 (1.19)	53 (1.84)	17 (0.59)	41 (1.62)
Common palm civet	33 (1.87)	98 (3.41)	15 (0.52)	110 (4.35)
Small Indian civet	23 (1.31)	18 (0.62)	13 (0.45)	94 (3.72)
Ruddy mongoose	17 (0.97)	32 (1.11)	12 (0.41)	66 (2.61)
Dhole	2 (0.11)	10 (0.35)	6 (0.21)	50 (1.98)
Indian pangolin	3 (0.17)	5 (0.17)	1 (0.034)	3 (0.11)
Gray mongoose	4 (0.23)	2 (0.07)	–	–
Indian hare	16 (0.91)	8 (0.28)	9 (0.31)	19 (0.75)
Indian gerbil	2 (0.11)	–	–	–
Stripe-necked mongoose	–	16 (0.56)	4 (0.14)	6 (0.23)
Rusty spotted cat	–	1 (0.03)	–	1 (0.039)
Brown palm civet	–	–	–	2 (0.079)

We report the number of captures and overall capture rates (expressed per 100 trap nights in parentheses) across all four seasons.

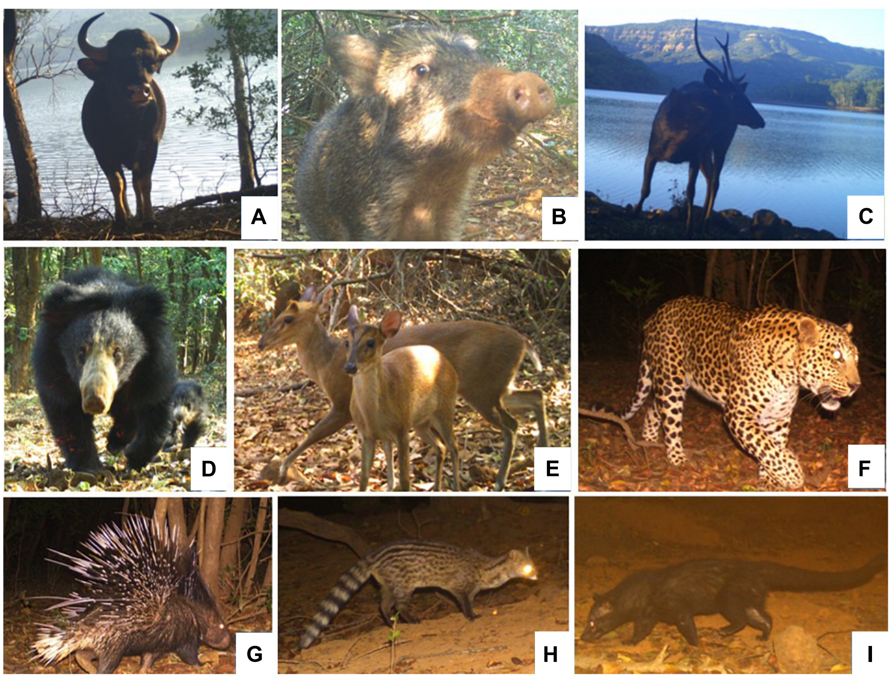

FIGURE 3 | Select camera trap images of highly 'phot-captured' mammals during the study. **(A)** 'gaur' *Bos gaurus*; **(B)** wild pig *Sus scrofa*; **(C)** sambar *Rusa unicolor*; **(D)** sloth bear *Melursus ursinus*; **(E)** barking deer *Muntiacus 'muntjac'*; **(F)** leopard *Panthera pardus*; **(G)** porcupine *Hystrix indica*; **(H)** small Indian civet *'Viverricula' indica*; **(I)** common palm civet *Paradoxurus 'hermaphrodites'*.

Porcupine: Porcupine occupancy was positively affected by canopy cover (0.01 ± 0.01), number of trees (0.03 ± 0.01), and negatively by elevation (−0.01 ± 0.01). Its colonization probability was positively affected by canopy cover (0.02 ± 0.01), number of trees (0.01 ± 0.01) and negatively by elevation (−0.03 ± 0.01). Its detection was higher closer to streams (−0.001 ± 0.001) and it was also affected by season. None of the covariates considered could explain porcupine extinction probability (**Figures 5**, **6** and **Supplementary Tables 3–6**).

TABLE 4 | Final list of habitat covariates used in the occupancy models.

Parameter	Site-specific covariate	Type of variable	Mean values (range)
ψ, γ, ε	Elevation (m)	Continuous	655.72 (633–695)
	Canopy cover (%)	Continuous	61.15 (0–90)
	Number of trees	Continuous	19.68 (0–50)
p	Distance from stream edge (m)	Continuous	Perennial: 251.08 (90–358) Intermittent: 123.08 (90–168) Ephemeral: 66.67 (40–100) Headwater: 15.62 (5–25)
	Season	Categorical	–

Gaur: Gaur detection (-0.02 ± 0.01) were higher at sites near streams. Its detection was also affected by season. Its occupancy, colonization and extinction probabilities were not explained by any of the covariates considered in the occupancy models (**Figure 6** and **Supplementary Tables 3–6**).

Sambar: Sambar occupancy, colonization and extinction probability were not influenced by any of covariates. However, sites near to streams (-0.001 ± 0.001) and season affected its detection probability (**Figure 6** and **Supplementary Tables 3–6**).

Wild Pig: Wild pig extinction probability was positively affected by elevation (0.02 ± 0.01), and negatively by canopy cover (-0.02 ± 0.01), number of trees (-0.06 ± 0.08). Its detection was higher near streams (-0.01 ± 0.01), and was also affected by season. No factors could explain its occupancy and colonization (**Figures 5**, **6**; **Supplementary Tables 3–6**).

DISCUSSION

Three key patterns emerge from our study. Firstly, ungulates were the most frequently photo-captured mammals in camera traps, with higher occupancy probability in riparian forests. Apart from ungulates, small mammals were also captured, however, large carnivores which included leopard *Panthera pardus*, dhole *Cuon alpinus* and sloth bear *Melursus ursinus* had low captures rates (**Table 3**). Pioneering studies by Naiman (1988); Pastor et al. (1988), and Naiman and Rogers (1997) found substantial evidence of large ungulates shaping structure of riparian forests in temperate ecosystems by selective browsing, dispersing seeds, and thereby affecting riparian plant community and ultimately modifying channel morphology (Naiman and Rogers, 1997). A similar kind of ungulate dominance in terms of high occupancy and persistence was found in riparian forests in Koyna.

Secondly, we observed an ungulate body size effect on colonization and extinction probabilities, in that the smallest ungulate, barking deer (20–30 kg), had highest extinction probability (0.59 ± 0.07) and lowest colonization probability (0.24 ± 0.05), while the much larger sambar (100–350 kg) had highest colonization probability (0.63 ± 0.10) and lowest extinction probability (0.15 ± 0.07) (**Figure 4** and **Supplementary Table 7**). This indicates that smaller ungulates are more vulnerable to vacate previously occupied sites (local extinction) than larger ungulates, perhaps due to resource competition. In a larger landscape context, however, the opposite of this pattern has been recorded, i.e., large herbivores are more vulnerable to extinction through large-scale anthropogenic factors (Ripple et al., 2015). However, at local scales, more empirical studies are needed to understand this pattern further. Body size has been successfully used to explain ungulate niche differentiation with regards to food requirements and predator sensitivity (Veldhuis et al., 2019). Previous studies in parts of Asia show that smaller ungulate species persist more widely than larger species (Karanth, 2016; Phumanee et al., 2020). Whereas muntjac and wild pig occurred at more sites than sambar and gaur in Thailand (Phumanee et al., 2020), gaur and pig were the least and most wide-ranging species in Karnataka Western Ghats landscape (Karanth, 2016). Contrastingly, Lamichhane et al. (2020) found that barking deer had lowest site occupancy in comparison to other species in Shuklaphanta National Park, Nepal. Hence, there exists much variation in ungulate occupancy patterns in regards to body size, perhaps influenced by local habitat, environmental factors and anthropogenic pressure. We found that large ungulates occur at a higher number of sites, and that gaur and pig both had higher rates of occupancy, in contrast to Karanth (2016) study.

Thirdly, distance from stream edge was a dominant predictor of mammal detection probabilities (**Figure 6** and **Supplementary Table 3**). As distance from stream increased, we observed a drop in the probabilities suggesting that ungulates in riparian forests congregate near streams. It is now well established that rivers, riparian forests and adjacent upland forests are part of a single large contiguous system composed of different smaller units of landscape. Hence viewing riparian forests as part of river continuum framework is essential. Among other riparian habitat factors, elevation was an important feature that influenced species persistence across seasons conforming with the previous occupancy study by Karanth (2016). Canopy cover and number of trees also affected species occupancy, colonization and extinction in our study, as we had hypothesized (**Table 2**).

Testing the role of riparian forests, especially in regards to stream proximity, is important to understand how climate change will affect ungulate communities (Speakman and Król, 2010; Fuller et al., 2014; Shreshtha et al., 2014; Veldhuis et al., 2019), because increasing land temperatures, changing rainfall regimes and habitat fragmentation increase the risk of regional extinctions (Ripple et al., 2015). The integration of food and water requirements, predation risk and thermoregulation constraints yields a multi-dimensional framework that generates testable predictions to understand ungulate assemblages (Veldhuis et al., 2019). Our work adds to this framework by documenting persistence of forest mammals in riparian forests. Our testing focused on habitat cover and proximity to water and this offers insights into mammal persistence in an altered habitat regime.

Mammal Persistence in Koyna Reservoir: Nilsson and Dynesius (1994) report two major impacts of dams to be the permanent inundation of vast areas of land and disruption of the seasonal flood regime along the river. Other local disturbances due to dam construction may be highly variable globally; however, Alho (2011) generally describes what land mammals

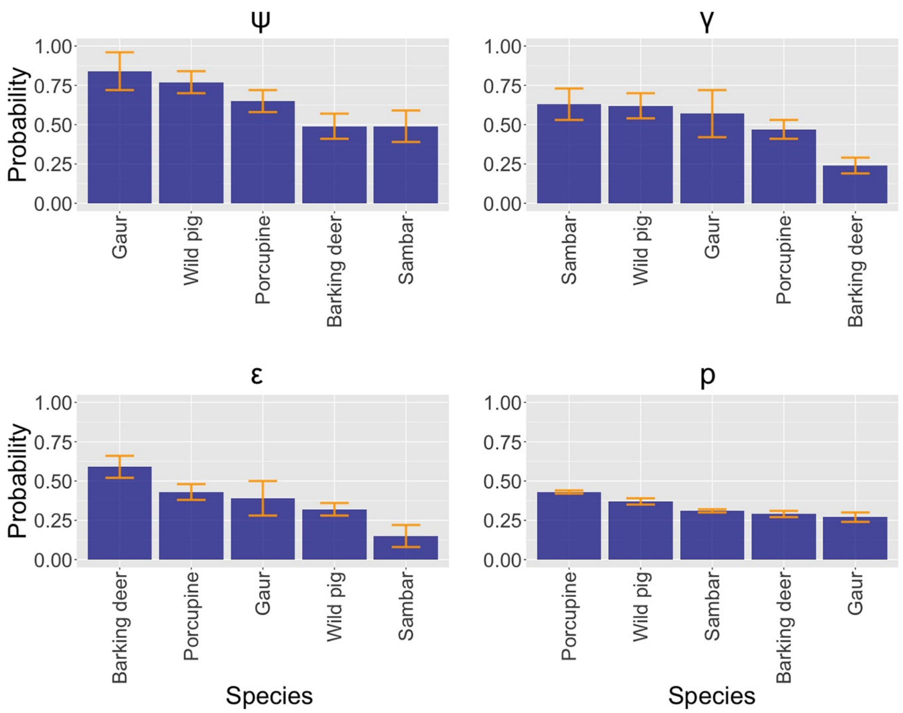

FIGURE 4 | Probability estimates of occupancy, colonization, extinction and detection of all the five species.

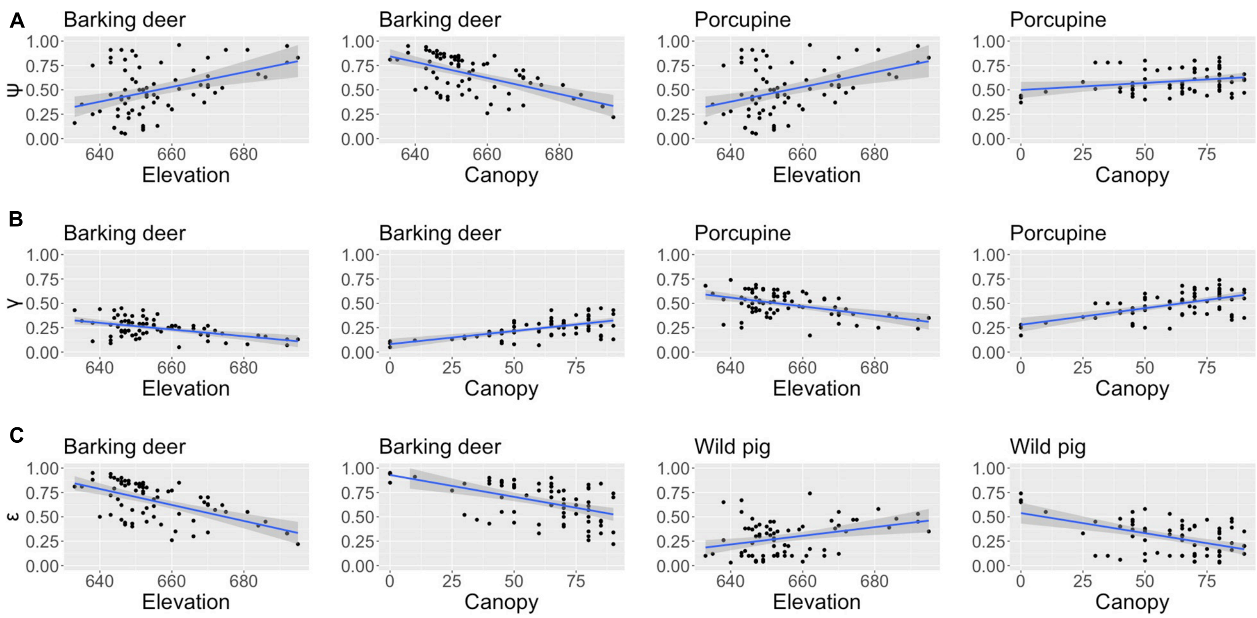

FIGURE 5 | Factors affecting species **(A)** occupancy, **(B)** colonization, and **(C)** extinction probabilities of common mammal species. The number of trees also showed statistically significant relationships to these probabilities, similar to those of canopy openness shown here (**Supplementary Tables 4–6**).

face when a river dam is constructed. The prolonged noise produced by machinery, light, presence of workers and other activities during the period of construction disturb wild animals, which will then try to escape to adjacent habitats. Large dams take a long time to complete—Koyna Dam construction began in 1954 and was completed in 1963. The formation of the reservoir displaces resident animals to nearby areas where higher densities of individuals of the same species are already resident. This phenomenon is termed as the reservoir's extended effect (Sá, 1995; Alho, 2011). This renders free ranging individuals

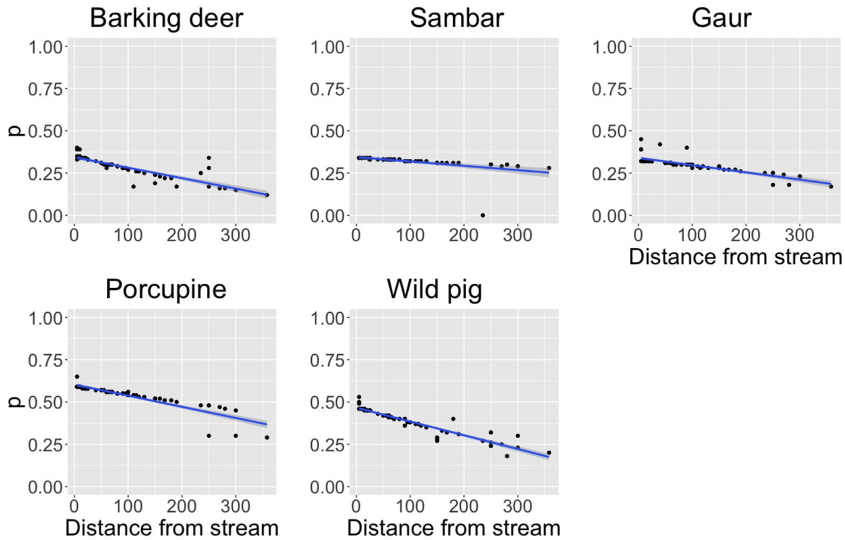

FIGURE 6 | Effect of distance from stream on species detection probabilities.

without fixed home ranges more vulnerable and they eventually submit to resident individuals in disputes/competition over natural resources. The result is that animals displaced by the effects of reservoir will die or move to more vulnerable areas. However, once a reservoir is complete and a substantial amount of time has passed, mammals adapt to their surroundings. In our case, 55 years have passed since the Koyna Dam was completed. The landscape has since experienced numerous changes in terms of land and river structure as well the socio-political context. Many villages in the valley have been relocated, firstly when the dam was being constructed and secondly when the area was notified as a wildlife sanctuary in 1985. Tigers also experienced local extinction from Koyna landscape with the last confirmed tiger record from Koyna in 2007. With this study, we know the present status of wildlife in the reservoir, acknowledging that severe changes in mammal community may have taken place which went predominantly undocumented. However, this may be treated as a baseline study on mammal ecology in reference to the Koyna Hydropower Dam five decades after its construction.

Management Implications: Our findings have high relevance for management of riparian forests and accordingly how species can be managed within a reservoir. Habitat variables that contribute to species-specific occupancy and long-term well-being were identified which can be prioritized in management plans. By conserving these factors, wildlife authorities can increase long term species persistence and strategically attempt to limit seasonal and local species extinctions. In addition to highlighting species-habitat relationship patterns of mammals utilizing riparian forests, the information generated in this study provides a strong empirical basis for developing catchment-wide and multi-species strategies for conservation management. Management strategies that have focused only on one key aspect and have simplified riverscapes have inevitably failed. Multi-landscape planning that encompasses streams, rivers and adjacent riparian forests which go beyond conventional planning of a single landscape unit, have had overarching benefits (Naiman and Rogers, 1997; Hermosa et al., 2012; Adams et al., 2014). We implemented a novel field design to study riparian forest use across an entire catchment. This approach employs a robust sampling design by incorporating riparian forests adjacent to all stream types of a catchment which presents a better understanding of mammalian occupancy along different stream types. Following this design, researchers can study species assemblages and help management agencies to efficiently draft plans that manage multiple species rather than focusing on only one charismatic species.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The animal study was reviewed and approved by the Wildlife Institute of India. There was no handling of animals. All surveys were non-invasive in nature (camera traps). All necessary codes of conduct were followed and surveys were permitted by national (Wildlife Institute of India/National Tiger Conservation Authority) and state (Maharashtra Forest Department) authorities.

AUTHOR CONTRIBUTIONS

RK, CB, and SJ: study design. SJ, AG, and NG: data collection. SJ: data analysis and writing. RK, MH: supervision, assistance with data analysis and writing. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by the Sahyadri Tiger Conservation Foundation and National Tiger Conservation Authority (NTCA).

ACKNOWLEDGMENTS

The study was part of a larger project entitled "Tiger Recovery Strategy and Long-term Monitoring in Sahyadri Tiger Reserve, Maharashtra." We thank the funding agencies for generous support. We also thank the Director and Dean of the Wildlife Institute of India. We thank the frontline staff of Koyna for support and cooperation during the field surveys. SJ especially thanks the boatman Mr. Ramesh Zendekar for guidance and support while accessing remote parts of Koyna Wildlife Sanctuary. Finally, we thank two reviewers for their suggestions and advice, which substantially helped to improve the quality of the paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.643285/full#supplementary-material

REFERENCES

Adams, V. M., Álvarez, J. G., Carwardine, J., Cattarino, L., Hermosa, V., Kennard, M. J., et al. (2014). Planning across freshwater and terrestrial realms: cobenefits and tradeoffs between conservation actions. *Conserv. Lett.* 7, 425–440. doi: 10.1111/conl.12080

Alho, C. J. R. (2011). Environmental effects of hydropower reservoirs on wild mammals and freshwater turtles in Amazonia: a review. *Oecol. Austr.* 15, 593–604. doi: 10.4257/oeco.2011.1503.11

Allen, M. L., Peterson, B., and Krofel, M. (2018). No respect for apex carnivores: distribution and activity patterns of honey badgers in the Serengeti. *Mammalian Biol.* 89, 90–94. doi: 10.1016/j.mambio.2018.01.001

Allen, M. L., Sibarani, M. C., Utoyo, L., and Krofel, M. (2020). Terrestrial mammal community richness and temporal overlap between tigers and other carnivores in Bukit Barisan Selatan National Park, Sumatra. *Animal Biodiv. Conserv.* 43, 97–107. doi: 10.32800/abc.2020.43.0097

Anoop, K. R., and Hussain, S. A. (2006a). Food and feeding habits of smooth-coated otters (*Lutra perspicillata*) and their significance to the fish population of Kerala. India. *J. Zool.* 266, 15–23. doi: 10.1017/s0952836905006540

Anoop, K. R., and Hussain, S. A. (2006b). Factors affecting habitat selection by smooth-coated otters (*Lutra perspicillata*) in Kerala, India. *J. Zool.* 263, 417–423. doi: 10.1017/s0952836904005461

Bokil, M. S. (1999). People in protected areas: Koyna sanctuary in Maharashtra. *Econ. Political Weekly.* 34, 293–299.

Burnham, K. P., and Anderson, D. R. (2002). *Model Selection and Miltimodel Inference: A Practical Information-Theoretic Approach*. New York, NY: Springer.

Capon, S. J., Chambers, L. E., Mac Nally, R., Naiman, R. J., Davies, P., Marshall, N., et al. (2013). Riparian ecosystems in the 21st century: hotspots for climate change adaptation? *Ecosystems* 16, 359–381. doi: 10.1007/s10021-013-9656-1

Champion, H. G., and Seth, S. K. (1968). *Revised Survey of the Forest Types of India*. New Delhi: Government of India Publications.

Chatterjee, A., and Bhattacharyya, S. (2021). Assessing the threats facing wetland mammals in india using an evidence-based conservation approach. *Mammal Rev.* doi: 10.1111/mam.12242

Datry, T., Larned, S. T., and Tockner, K. (2014). Intermittent rivers: a challenge for freshwater ecology. *BioScience* 64, 229–235. doi: 10.1093/biosci/bit027

Datry, T., Pella, H., Leigh, C., Bonada, N., and Huguney, B. (2016). A landscape approach to advance intermittent river ecology. *Freshw. Biol.* 61, 1200–1213. doi: 10.1111/fwb.12645

Datry, T., Singer, G., Sauquet, E., Jorda-Capdevilla, D., Von Schiller, D., Subbington, R., et al. (2017a). Science and management of intermittent rivers and ephemeral streams (SMIRES). *Res. Ideas Outcomes* 3, e21774. doi: 10.3897/rio.3.e21774

Datry, T., Bonada, N., and Boulton, A. (2017b). *Intermittent Rivers and Ephemeral Streams Ecology and Management*. Cambridge, MA: Academic Press.

Dornmann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., et al. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36, 027–046. doi: 10.1111/j.1600-0587.2012.07348.x

Duckworth, J. W., and Hedges, S. (1998). *A Review of the Status of Tiger, Asian Elephant, Gaur and Banteng in Vietnam, Lao, Camobodia and Yunnan (China), with Recommendations for Future Conservation Action*. Hanoi: WWF Indochina Programme.

Duckworth, J. W., Salter, R. E., and Khounbline, K. (1999). *Wildlife in Lao PDR: 1999 Status Report*. Vientiane: IUCN.

Dugdale, S. J., Malcolm, I. A., Kantola, K., and Hannah, D. M. (2018). Stream temperature under contrasting riparian forest cover: understanding thermal dynamics and heat exchange processes. *Sci. Total Environ. 610*– 611, 1375–1389. doi: 10.1016/j.scitotenv.2017.08.198

Fuller, A., Hetem, R. S., Maloney, S. K., and Mitchell, D. (2014). Adaptation to heat and water shortage in large, arid-zone mammals. *Physiology* 29, 159–167. doi: 10.1152/physiol.00049.2013

Greiser Johns, A. (2000). *Pu Mat: A Biodiversity Survey of a Vietnamese Protected Area. Social Forestry and Nature Conservation in Nghe An Province*. Vietnam: SFNC Project, Vinh, Nghe An Province.

Hermosa, V., Kennard, M. J., and Linke, S. (2012). Integrating multidirectional connectivity requirements in systematic conservation planning for freshwater systems. *Divers. Distrib.* 18, 448–458. doi: 10.1111/j.1472-4642.2011.00879.x

Hines, J. E. (2006). *PRESENCE – Software to Estimate Patch Occupancy and Related Parameters. USGS – PWRC*. Available online at: http://www.mbr-pwrc.usgs.gov/software/presence.html

Hussain, S. A., and Choudhury, B. C. (1997). Distribution and status of the smooth-coated otter *Lutra perspicillata* in National Chambal Wildlife Sanctuary, India. *Biol. Conserv.* 80, 199–206. doi: 10.1016/s0006-3207(96)00033-x

Jelil, S. N., Gaykar, A., Girkar, N., Vyas, V., Ben, V. C., and Ramesh, K. (2020). Recent record of tiger from Sahaydri Tiger Reserve, India. *CATnews* 71, 16–17.

Joglekar, A., Tadwalkar, M., Mhaskar, M., Chavan, B., Ganeshaiah, K. N., and Patwardhan, A. (2015). Tree species composition in Koyna Wildlife Sanctuary, Northern Western Ghats of India. *Curr. Sci.* 108, 1688–1693.

Johnsingh, A. J. T., Qureshi, Q., Goyal, S. P., Rawat, G. S., Ramesh, K., David, A., et al. (2004). *Conservation Status of Tiger and Associated Species in the Terai-Arc Landscape, India*. Dehradun: Wildlife Institute of India, 110.

Karanth, K. K. (2016). Wildlife in the matrix: Spatio-temporal patterns of herbivore occurrence in Karnataka, India. *Environ. Manage.* 57, 189–206. doi: 10.1007/s00267-015-0595-9

Kassambara, A. (2020). *ggpubr: 'ggplot2' Based Publication Ready Plots. R Package Version 0.4.0*. Vienna: R Foundation for Statistical Computing.

Kassambara, A., and Mundt, F. (2020). *factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R Package Version 1.0.7*. Vienna: R Foundation for Statistical Computing.

Lamichhane, S., Khanal, G., Karki, J. B., Aryal, C., and Acharya, S. (2020). Natural and anthropogenic correlates of habitat use by wild ungulates in Shuklaphanta National Park, Nepal. *Global Ecol. Conserv.* 24:e01338. doi: 10.1016/j.gecco.2020.e01338

Linkie, M., and Ridout, M. S. (2011). Assessing tiger-prey interactions in Sumatran rainforests. *J. Zool.* 284, 224–229. doi: 10.1111/j.1469-7998.2011.00801.x

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A., and Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83, 2248–2255. doi: 10.1890/0012-9658(2002)083[2248:esorwd]2.0.co;2

MacKenzie, D. I., and Bailey, L. L. (2004). Assessing the fit of site-occupancy models. *J. Agricul. Biol. Environ. Stat.* 9, 300–318. doi: 10.1198/108571104x3361

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Hines, J. E., and Bailey, L. L. (2006). *Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence*. San Diego, CA: Elsevier.

Naiman, R. J., and Rogers, K. H. (1997). Large animals and system-level characteristics in river corridors. *BioScience* 47, 521–529. doi: 10.2307/1313120

Naiman, R. J. (1988). Animal influences on ecosystem dynamics. *BioScience* 38, 750–752. doi: 10.2307/1310783

Nilsson, C., and Dynesius, M. (1994). Ecological effects of river regulation on mammals and birds: a review. *Regul. Rivers Res. Manage.* 9, 45–53. doi: 10.1002/rrr.3450090105

Pastor, J., Naiman, R. J., Dewey, B., and McInnes, P. (1988). Moose, microbes and the boreal forest. *BioScience* 38, 770–777. doi: 10.2307/1310786

Phumanee, W., Steinmetz, R., Phoonjampa, R., Bejraburnin, T., Grainer, M., and Savini, T. (2020). Occupancy-based monitoring of ungulate prey species in Thailand indicates population stability, but limited recovery. *Ecosphere* 11:e03208. doi: 10.1002/ecs2.3208

Pinay, G., Bernal, S., Abbott, B. W., Lupon, A., Marti, E., Sabater, F., et al. (2018). Riparian corridors: a new conceptual framework for assessing nitrogen buffering across biomes. *Front. Environ. Sci.* 6:47. doi: 10.3389/fenvs.2018.00047

Prakash, N., Mudappa, D., Shankar Raman, T. R., and Kumar, A. (2012). Conservation of the Asian small-clawed otter (*Aonyx cinereus*) in human-modified landscapes, Western Ghats, India. *Trop. Sci. Conserv.* 5, 67–78. doi: 10.1177/194008291200500107

Raha, A., and Hussain, S. A. (2016). Factors affecting habitat selection by three sympatric otter species in the southern Western Ghats, India. *Acta Ecol. Sinica* 36, 45–49. doi: 10.1016/j.chnaes.2015.12.002

R Core Team (2020). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Ripple, W. J., Newsome, T. M., Wolf, C., Dirzo, R., Everatt, K. T., Galetti, M., et al. (2015). Collapse of the world's largest herbivores. *Sci. Adv.* 1:e1400103. doi: 10.1126/sciadv.1400103

Rovero, F., and Zimmerman, F. (2016). *Camera Trapping for Wildlife Research, 1st Edition*. Exeter: Pelagic Publishing.

Sá, R. M. L. (1995). *Effects of the Samuel Hydroelectric Dam on Mammal and Bird Communities in A Heterogenous Amazonian Lowland Forest*. 140. [doctoral dissertation]. University of Florida, Gainesville, FL.

Sánchez-Montoya, M. M., Moleón, M., Sánchez-Zapata, J. A., and Tockner, K. (2016). Dry riverbeds: corridors for terrestrial vertebrates. *Ecosphere* 7:e01508. doi: 10.1002/ecs2.1508

Santos, M. J., Matos, H. M., Palomares, F., and Santos-Reis, M. (2011). Factors affecting mammalian carnivore use of riparian ecosystems in Mediterranean climates. *J. Mammal.* 92, 1060–1069. doi: 10.1644/10-mamm-a-009.1

Schaller, G. B. (1967). *The Deet and the Tiger. A Study of Wildlife in India*. Chicago, IL: University of Chicago Press.

Seavy, N. E., Gardali, T., Golet, G. H., Griggs, T., Howell, C. A., Kesley, R., et al. (2009). Why climate change makes riparian restoration more important than ever: recommendations for practice and research. *Ecol. Restor.* 27, 330–338. doi: 10.3368/er.27.3.330

Shreshtha, A. K., van Wieren, S. E., van Langevelde, F., Fuller, A., Hetem, R. S., Meyer, L., et al. (2014). Larger antelopes are sensitive to heat stress throughout all seasons but smaller antelopes only during summer in an African semi-arid environment. *Int. J. Biometeorol.* 58, 41–49. doi: 10.1007/s00484-012-0622-y

Speakman, J. R., and Król, E. (2010). Maximal heat dissipation capacity and hyperthermia risk: neglected key factors in the ecology of endotherms. *J. Animal Ecol.* 79, 726–746.

Timmins, R. J., and Ou, R. (2001). *The Importance of Phnom Prich Wildlife Sanctuary and Adjacent Areas for the Conservation of Tigers and Other Key Species*. Hanoi: WWF Indochina Programme.

Timmins, R., Kawanishi, K., Giman, B., Lynam, A., Chan, B., Steinmetz, R., et al. (2015). *Rusa Unicolor. The IUCN Red List of Threatened Species 2015*. Gland: IUCN.

Timmins, R. J., Duckworth, J. W., and Hedges, S. (2016). *Muntiacus Muntjak. The IUCN Red List of Threatened Species 2016*. Gland: IUCN.

Umapathy, G., and Durairaj, G. (1995). Preliminary studies on the feeding ecology of the otter Lutra lutra at Pitchavaram, East Coast of India. *IUCN Otter Special. Group Bull.* 11, 24–26.

Perinchery, A., Jathanna, D., and Kumar, A. (2011). Factors determining occupancy and habitat use by Asian small-clawed otters in the Western Ghats, India. *J. Mammal.* 92, 796–802. doi: 10.1644/10-mamm-a-323.1

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. (1980). River continuum concept. *Can. J. Fish. Aquat. Sci.* 37, 130–137. doi: 10.1139/f80-017

Veldhuis, M. P., Kihwle, E. S., Cromsigt, J. P. G. M., Ogutu, J. O., Hopcraft, J. G. C., Owen-Smith, N., et al. (2019). Large herbivore assemblages in a changing climate: incorporating water dependence and thermoregulation. *Ecol. Lett.* 22, 1536–1546. doi: 10.1111/ele.13350

Wei, T., and Simko, V. (2017). *R Package "Corrplot": Visualization of A Correlation Matrix (Version 0.84)*. Vienna: R Foundation for Statistical Computing.

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer-Verlag.

Zimbres, B., Peres, C., Penindo, G., and Machado, R. B. (2018). Threshold of riparian forest use by terrestrial mammals in a fragmented Amazonian deforestation frontier. *Biodiver. Conserv.* 27, 2815–2836. doi: 10.1007/s10531-018-1571-5

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