The Impact of Roads on Biodiversity in India

MSc Environmental Sciences Thesis

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ABSTRACT

The rapid economic development in countries such as India has large impacts, both on the social development of people as well as the environment. As a consequence of rapid economic development, road density and traffic volume have increased enormously. Current efforts to widen and improve roads continue. Against this backdrop it is important to look at the direct and indirect effects of all this connectivity and construction on biodiversity. In this thesis I examined the impacts that roads have on biodiversity in India, both directly and indirectly via secondary effects such as hunting access. This was done via a literature review of studies in India examining this effect of roads, and their relationship to biodiversity distribution. I also assess the area potentially impacted by roads and hunting in the case of 10 Biosphere Reserves in India. My study suggests that existing globally calibrated models may be applicable to India, however there is a need for more quantitative primary data to be obtained to get a better perspective on the specific situation in India. The relationship between roads and hunting activities are especially understudied. Finally, the examination of impacts on the Biosphere Reserves show that larger reserves with lower road density tend to have less impacted areas than medium-sized reserves with higher population and road density. That said, in almost all Reserves, more than 50% of the natural land use areas are likely to be at least somewhat disturbed due to roads, and a similarly large area could potentially be affected due to hunting activities. This brings into focus the need for smarter and better planned road and infrastructure expansion, and the need for a more thorough understanding of hunting practices within the country.

Contents

1 Introduction

With human population increasing three-fold over the course of the last century, and being predicted to grow by another 3 billion in the coming decades (U.N. Department of Economic and Social Affairs, 2017), the pressure on natural resources is large, and will continue to increase. To facilitate industrialisation and associated economic growth, a country's infrastructure, such as roads, powerlines, telecommunication towers and urban settlements will necessarily expand. Such increase in infrastructure, along with aiding economic growth, results in an increased pressure on natural resources and land use. This in turn can have consequences for biodiversity conservation, with less than 3% of the world's biodiversity hotspots remaining free of human pressure (Venter et al., 2016). The impacts of human development on wildlife and biodiversity are thus an important aspect to study, as biodiversity is crucial to the survival and resilience of ecosystems and ecosystem services (Millennium Ecosystem Assessment, 2005).

Infrastructure has both a direct and indirect impact on biodiversity. Direct impacts include biodiversity loss due to land use change or fragmentation (T. Dutta, Sharma, McRae, Roy, & DeFries, 2016; Nandy, Kushwaha, & Mukhopadhyay, 2007), disturbance of animals and birds due to traffic and road kills (Benitez-Lopez, Alkemade, & Verweij, 2010; Seshadri & Ganesh, 2011). Wild habitat is lost or altered, leading to small scale migrations or loss of numbers of various species. This in turn disrupts the food web around roads and other infrastructure. Large infrastructure projects such as canals, railroads and highways can prove to be major barriers to the movements of large mammals, like elephants (Nandy et al., 2007) or arboreal species (Laurance et al., 2006). Further, Laurance et al. (2006) found that mammal abundances reduce nearer to roads, in both hunted and protected areas.

Indirect impacts include higher human accessibility to wild food (Benitez-Lopez et al., 2017), increase in human-animal conflict, effects of domestic animals on wildlife, potentially increased rates of deforestation due to better road access and increase in tourism related disturbances (DeFries, Karanth, & Pareeth, 2010; Geneletti & Dawa, 2009). These usually have negative consequences for the ecosystem, and biodiversity.

Biodiversity in India is especially vulnerable to the aforementioned effects of infrastructure on biodiversity, as it has a significant rural population (over 75%) and is a country in the process of industrialisation. With planned expansion or upgrade of several thousand kilometres of the road network, especially in remote and hard-to-access border states (Planning Commission, 2013), there is ample opportunity for the expansion of settlements and increase in access to wild foods. Of course, this is not only favourable to local communities dependent on such foods, but also to illegal poaching in or around protected or wild areas. Additionally, the population growth rate in India is high (~1.2%) and is projected to remain high for another couple of decades (UN DESA, 2017). An increase in vehicular traffic is therefore likely to accompany this increase in population, as current trends indicate(R. D. Sharma, Jain, & Singh, 2011; Singh, 2005), potentially increasing the disturbance caused to wildlife. Analysis by Venter et al. (2016) shows a high footprint of human activity in the country, which underscores the need for a closer look at the impacts of socio-economic development.

A significant amount of India's road network expansion has been aimed at widening roads and increasing their quality rather than new construction (Gubbi, Poornesha, & Madhusudan, 2012). However, construction within protected areas is an increasing trend, and will potentially affect wildlife considerably. Extant studies in India have suggested that in low-disturbance areas with complicated and hard to reach terrain, species richness is still high (Roy & Behera, 2005). Expansion of infrastructure will likely impact these areas more than others. Road networks have also been reported to contribute to the decline of habitat suitable for the Great Indian Bustard (S. Dutta, Rahmani, & Jhala, 2011). Similarly, the Bengal Tiger's habitat is vulnerable to fragmentation (Gubbi et al., 2017), which is another effect of road networks on the natural landscape.

This intention of this study is to investigate the nature and magnitude of the impacts faced by biodiversity due to roads and other infrastructure. To this end I also analysed the impacts on certain *Protected Areas* in the country. Protected areas are critical to conservation strategies, both at a national and international level. Wildlife in some Protected Areas can be vulnerable to increased mortality from seasonal surges in traffic that lead to high mortality of fauna (Seshadri & Ganesh, 2011) and increase the barrier effect of roads. Protected areas are of different classes, and while some ban activities like hunting, others do not (Dudley, 2008). In either case, hunting activity near roads and settlements is likely to cause an alteration in the distribution of species and the structure of ecosystems on a local scale (Laurance et al., 2006).

The protected areas I have selected are certain Biosphere Reserves in India. A Biosphere Reserve in India is equivalent to a Category V Protected Area defined by the International Union for Conservation of Nature (ICUN), and may enclose Category II and IV areas within (Dudley, 2008). Category V Protected Areas are "Protected Landscapes or Seascapes", where the socio-cultural interaction between people and nature is deemed important to preserve. Category II areas like National Parks are core protected areas which have not been significantly disturbed but may be used for scientific and conservation friendly recreational activities (e.g. eco-tourism). Category IV PAs constitute "Habitat or Species Management Areas" that are aimed at conserving particular species or habitat types with the help of intervention policies. This mix of regions was deemed important to provide a realistic case where human activity occurs near biodiverse regions.

1.1 Cause-Effect Relations and System Description

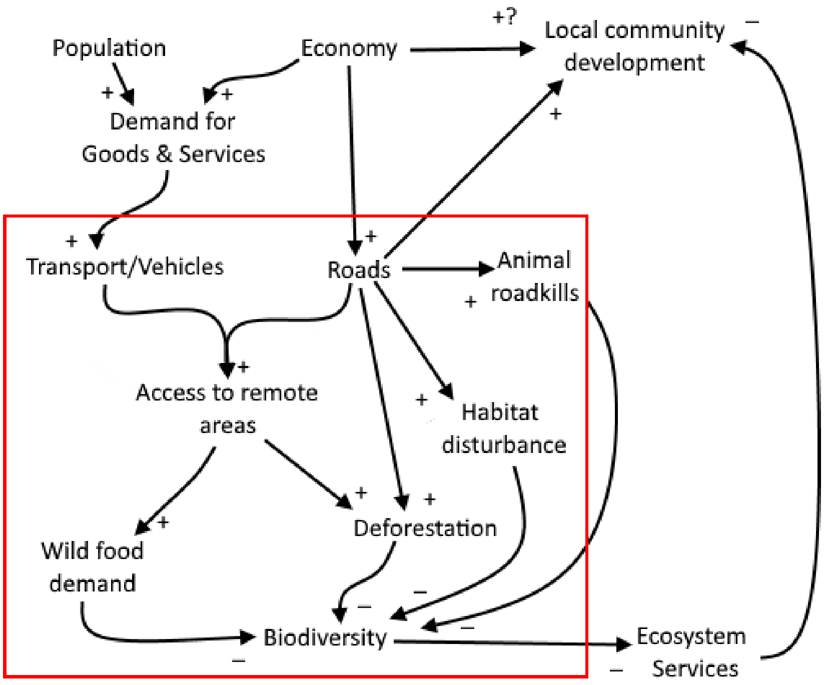

Figure 1-1: Conceptual System Diagram. Arrows show the direction of effect/relationship, and the plus or minus signs indicate a positive effect or negative effect. Boxed area is the sub-system under consideration (except deforestation).

The conceptual system under consideration is visualised in Figure 1-1. With the growth in population and economic development, a growth in demand for goods and services is assumed. To facilitate movement of goods and people, and to facilitate economic development and industrialisation, the demand for transport and infrastructure is assumed to increase. In response to this, it is expected that the road network will expand, and the number of vehicles increase. Consequently, the accessibility increases to areas previously hard to reach by either foot or vehicle – either due to terrain or danger from animals – and improves the access to various resources like timber, farmland, mines, and wild food sources. It also provides more opportunities for illegal hunting. These developments lead to the various direct and indirect impacts on biodiversity mentioned previously. In turn, this adversely alters the ecosystem, and consequently ecosystem services. Local communities may now not be able to benefit from provisioning services due to the collapse of the supporting regulating services.

1.2 Biodiversity and Abundance

The term "biodiversity" features prominently both in the opening text and in Figure 1-1. In this study, the term "biodiversity" is operationalised as:

> The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (Millennium Ecosystem Assessment, 2005, p. 18)

Biodiversity is essential not just to maintain a stable and rich variety of ecosystem services, but for the very survival of ecosystems themselves.

The Millennium Ecosystem Assessment (M.E.A.) acknowledges that measuring biodiversity is a complicated task, and that no single ecological indicator provides a complete picture of all aspects of biodiversity. However, **species richness** (i.e. number of species in a particular area) is stated as a key metric, but it is not enough by itself. Both the inter- and intra-species quantity, variability and spatial distribution of the species are important (M.E.A., 2005, p. 20).

The quantity or **abundance** of a species indicates "how much there is of any one type". Adequate **distribution** and abundances of species ensure local resilience and contributes to the quality and volume of ecosystem services, like provisioning and regulating services. Often the relative abundance is reported, i.e. the representation of the species relative to others in the ecosystem. The **variety** or **variability** refers to the genetic variation or the number of varieties among the species, and ensures a diversity of ecosystem roles and services, and geographical adaptations (M.E.A. 2005, p. 20).

As note in the Introduction (Section 1), increased road development has resulted in a much greater access to remote areas, and increased access to wild food sources. This has been instrumental in driving the **defaunation** of ecosystems due to overhunting (Benitez-Lopez et al., 2017), a process that involves the reduction of species richness, abundance, distribution and variability. This is often hard to detect from satellite imagery as it may occur independent of deforestation or other overt land-use changes. It is thus important to study such effects of development activities on biodiversity in a more focused manner.

1.3 Mean Species Abundance and Response Ratios

Benítez-López et al. (2017; 2010) developed relationships between roads and their impact on biodiversity based on various studies from across the world. They calculated effect sizes per species in both cases and aggregated the data to determine the general trend in species abundance variance and response to hunting, as a factor of distance from roads or access points.

Benitez-Lopez et al. (2010) found that roads can have an impact on species abundance, with birds exhibiting a decline in "mean species abundance" of approximately 32% on an average up to a distance of 2.58 km, and mammal species exhibiting a similar 32% decline in mean species abundance over 17 km. However, the effect essentially plateaus after a distance of 1 km and 5 km for birds and mammals respectively.

They model the relation between abundance and distance by the following formula:

$$MSA_{sd} = \frac{\Sigma_i R_{isd}}{N_s} \qquad (1)$$

Where MSA_{sd} is the relative Mean Species abundance determined for a particular study *s* at the specified distance *d*, R_{isd} is the ratio of abundance or density of the species *i* on the road compared to the abundance or density at distance *d,* and N_s is the number of species included in the study. MSA ranged between 0 and 1 in their study results.

Benitez-Lopez et al. (2017) found that that the abundance of birds reduced by close to 60% on an average, within 7km of places accessible by hunters, like roads and settlements. Mammal abundances were found to reduce by a little over 80% on an average, up to 40km from these access points. They used the following relationship to determine the aggregate response of mammals and birds to hunting pressure:

$$RR = \log \frac{X_h}{X_c} \qquad (2)$$

Where RR is the response ratio, calculated as the logarithm of the ratio of the abundances of mammals and birds in hunted locations X_h to non-hunted (control) locations X_c. They further used the "central-place foraging hypothesis" (i.e. hunting pressure is higher nearer to hunting sites) to generate gradients of hunting pressure using regression models based on data extracted from the studies.

However, given the relative lack of data on India in their studies, a more country-focused investigation will have to be performed first, to verify whether the global relationships hold for India.

1.4 Research Objective

To determine the impact of infrastructure development (especially roads) on biodiversity in India, with respect to:

1. Direct impacts such as disturbance by human activity
2. Indirect impacts, such as increased hunting access

The results will be contextualised with respect to the studies undertaken by Benitez-Lopez et al. (2017; 2010).

1.5 Research Questions

1. What is the impact of roads and other infrastructure on biodiversity in India?
2. What is the impact of roads with respect to legal and illegal hunting?
3. What would be the expected magnitude of impact on biodiversity in Indian Biosphere Reserves (ICUN Category V Protected Areas)?

2 Methodology

2.1 Literature Review

To answer Research Questions 1 and 2 (Section 1.5), I searched for studies that either examined species abundance, density or distribution of mammals and birds with respect to infrastructure (primarily roads). Further, papers on hunting were analysed for a relation between roads and hunting areas, or evidence of increased access to poachers.

Two databases were searched in. First, the Wageningen UR Library Database was used, as it offers access to multiple databases. In addition, the Web of Sciences Core Collection was used, for a proper systematic search, in accordance with the **PRISMA 2015** (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009) search plan.

Apart from this, the initial study material was provided by my supervisor, Dr Rob Alkemade, who introduced me to the topic and the papers by (Benitez-Lopez et al., 2017; Benitez-Lopez et al., 2010). Further, grey literature in the form of reports by various UN agencies along with the IUCN and the Government of India.

In addition, I reached out to the following people for papers and data (Table 2-1):

Table 2-1: Persons contacted for more data on hunting

Person	Institution	Response obtained?
Dr. Monowar Alam Khalid	Integral University, Lucknow, India	No
Dr Aparajita Datta	Nature Conservation Foundation, India	No
Akhilesh Yadav	IORA Ecological Solutions LLP, India	No
Nandani Velho	Centre for Tropical Environmental and Sustainability Science (TESS) and School of Marine and Tropical Biology, James Cook University, Cairns, Australia	Yes

2.1.1 Wageningen UR Library Database

As the interface offered no convenient way to save, filter, and merge results, this was done manually based on the inspection of the paper title and abstract. However, this method was found to be inadequate, unreliable and tedious, so it was dropped in favour of the Web of Science results. However, while some overlap exists between the useful results, there were some interesting papers obtained on hunting via this database, and hence it is being included here.

This database contained results from:

- Global Search – includes Library Catalogue and WUR Staff Publications.
- Google Scholar
- Scopus
- WUR MSc Thesis Online
- Web of Science: citation databases / Institute of for Sciences Information
- LexisNexis Academic

Searches were conducted throughout October and November 2017, and again between 01/01/2018 and 20/01/2018.

Unfortunately, there was no easy way to download these result lists, merge them and then remove duplicates. Manually going through all the results beyond the first few pages did not turn out to be a viable strategy either.

Papers on hunting by Nandani Velho et al. were obtained via this method however, which allowed me to contact her for more information.

2.1.2 Web of Science Core Collection Database

The Web of Science database allowed for easy downloading and saving of search results. This allowed the PRISMA 2015 review process to be followed easily. All search results were saved to EndNote (and thus merged) and then duplicates were removed.

Web of Science Core Collection Database was accessed on 23/01/18 and 24/01/2018. Results were filtered to only show articles and proceedings papers. The following terms were used, along with results (Table 2-2):

Table 2-2: Search terms used on Web of Science Core Collection Database

Search term	Number of Results
(India* AND (biodivers* OR (mammal* OR bird*)) AND (road* OR infrastruct*) AND impact)	29
India* AND (biodivers* OR (mammal* OR bird*)) AND (road* OR infrastruct*)	113
(India* AND (biodivers* OR (mammal* OR bird*)) AND (road* OR infrastruct*) AND disturb*)	12
(India* AND (biodivers* OR (mammal* OR bird*)) AND (road* OR infrastruct*) AND distanc*)	10
(India* AND (biodivers* OR (mammal* OR bird*)) AND (road* OR infrastruct*) AND hunt*)	3
(India* AND (wild* OR wildlife OR biodivers* OR mammal* OR bird*) AND (road* OR infrastruct*))	187
(India* AND (wild* OR wildlife OR biodivers* OR mammal* OR bird*) AND (road* OR infrastruct*) AND (impact* OR distan* OR disturb* OR hunt* OR road$effect zone OR power$line* OR fragment*))	103
Total after merging and removing duplicates:	187

No papers in Hindi turned up in the search, thus only English results were used. Additionally, no explicit effort was made to find papers published in Indian languages, as most (if not all) of scientific literature in India is published in English (this is my own experience).

2.1.3 Screening and Selection Process

According to the PRISMA 2015 method, the results needed to be screened for eligibility. To accomplish this, they were saved to a comma delimited file and imported to MS Excel. The records were cleaned (removal of irrelevant information and null values) and then manually screened for relevance based on titles and abstracts. The **rejection criteria** were as follows:

- Rejected if the paper is not related to India
- Rejected if the paper is related to India but is not about biodiversity distribution (for example, if it was about genetics or medical sciences then it was rejected)

Further, based on apparent relevance, the papers were categorized into the following:

- High, with direct or indirect relevance – papers that directly analysed the impact of roads or infrastructure on species abundance, distribution etc. These were deemed highly likely to contain quantitative information that could be used in the results of this thesis
- Medium, with direct or indirect relevance – papers that mentioned "distance from road" or similar phrases in the abstract, but for which it couldn't be ascertained whether they would actually have relevant usable quantitative data
- Low, with direct or indirect relevance – papers that were more likely to have qualitative data that could be used as supporting literature
- Very Low – papers that seemed only tangentially related to the topic of the thesis, but potentially contained some information that could be used as supporting literature
- Rejected – papers rejected based on the rejection criteria

Further, a relevance reason was provided for each paper was provided, for ease of reference later.

Next, following the PRISMA process, the screened papers were subject to full-text readings in order to check for eligibility. A note was made of each paper as to what it could provide, and some papers were rejected in the process. Studies that contained direct quantitative data that illustrated an effect of roads on mammals and birds were kept for the Results section. Distance to road of first contact, gradients of occurrence and comparisons of species abundance at various distances from roads or infrastructure were deemed key criteria.

From the WUR Library search results, a review of hunting studies done in India was used, authored by Velho et al. (2012). They reported that six of the studies that they found were directly related to hunting. The authors were contacted for a full list of included studies, out of which those six were checked for eligibility in the context of this review. Data related to the distance hunters travel from settlements, or other points of access such as trade hubs or roads, was searched for.

Mammal and bird abundances at different distances from roads, infrastructure or settlements were extracted when available. In cases where populations were not mentioned, the distance at which the animals were encountered or predicted to be encountered were extracted and combined with other studies if possible. Direct counts of the number of species at different distances were also noted when provided.

2.2 Applying the model

To answer Research Question 3 (Section 1.5), the area of impact in both the cases – the direct impact of roads and the impact with relation to hunting – was looked at for Indian Biosphere Reserves under the Man and Biosphere Programme. ArcMap 10.3.1 was used to plot and process the data.

Biosphere Reserves under the Man and Biosphere Programme were selected as they are monitored according to internationally agreed standards and thus offer a certain guarantee of ecological quality (UNESCO, 2018). The following Reserves in India are recognized under this programme:

- Nilgiri
- Gulf of Mannar
- Sunderban
- Nanda Devi
- Nokrek
- Pachmarhi
- Similipal
- Achanakmar-Amarkantak
- Great Nicobar
- Agasthyamala

UNESCO data was used to plot the coordinates of the reserves in ArcMap (Figure 2-1) and provide a high-level overview of the reserves and to aid commentary on the map results.

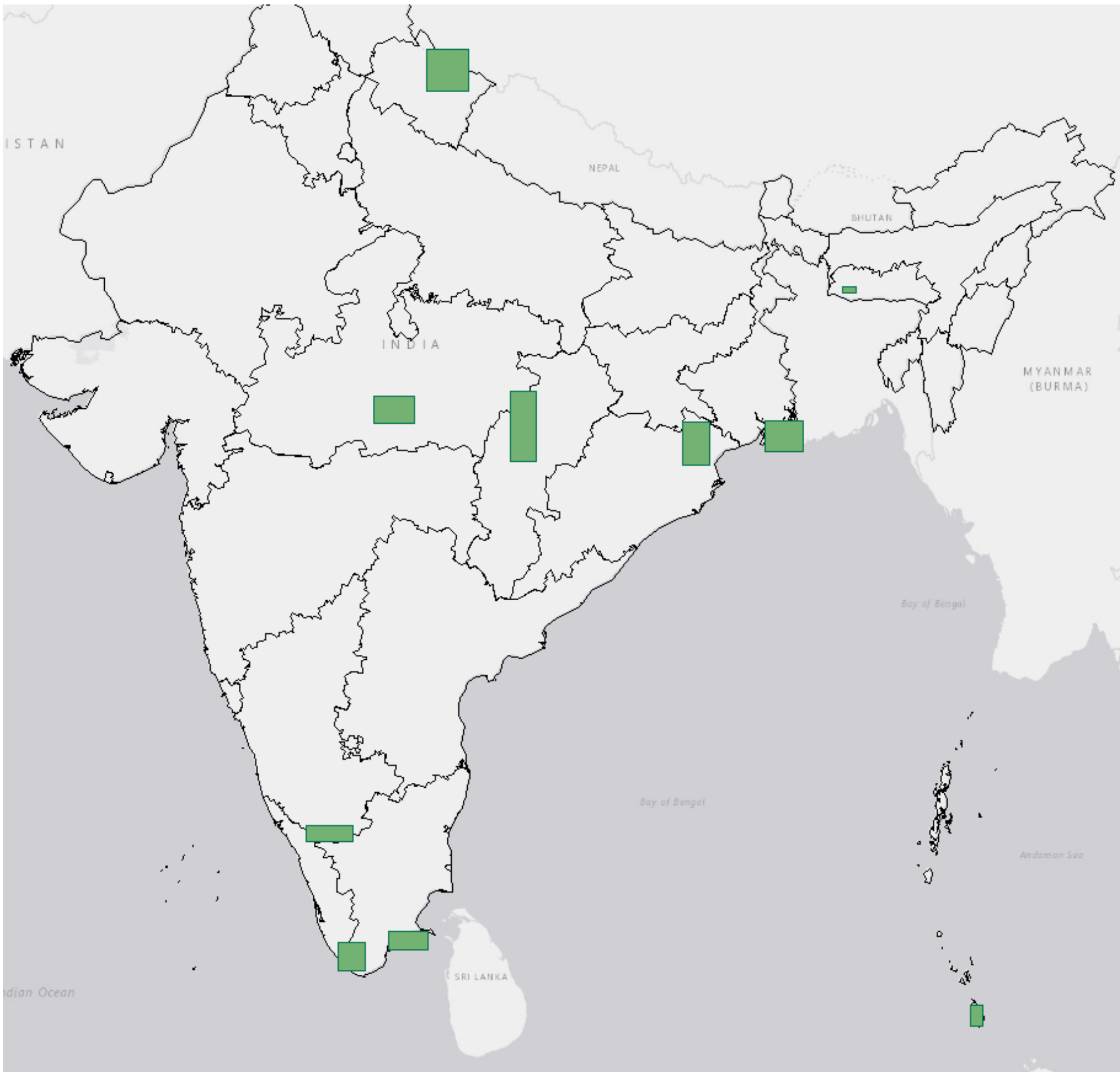

Figure 2-1: Location of Biosphere Reserves in India

The road map was obtained with the help of Johan Meijer of PBL Environmental Agency ("Global Roads Inventory Project," https://data.overheid.nl/). The map dataset is the Global Roads Inventory Project (GRIP), provided via Open Street Map data. OSM data includes land use classification, which was also used. Not all land use classes were deemed relevant to the model, and thus only the following classes were used (henceforth referred to as "**target land use classes**"):

- Forest
- Nature Reserve
- Orchard
- Scrub
- Heath

Thus, the selection query was:

```
"fclass" = 'forest' OR
"fclass" = 'nature_reserve' OR
"fclass" = 'orchard' OR
"fclass" = 'scrub' OR
"fclass" = 'heath'
```

However, there was some overlap in the classification of some areas, which had to be removed. For example, Nokrek National Park was reported as distinct but overlapping part of the forest in which Nokrek Biosphere Reserve is located. This led to overestimation of target land use area. Similar issues were found for the Great Nicobar and Nilgiri Biosphere Reserves.

Finally, each Biosphere Reserve was considered individually, as ArcMap's Dissolve tool did not work well with disjoint Buffers. To speed up this process, tools were made using the ModelBuilder to automate the process as much as possible. Parameterisation of tools along with Batch processing was attempted (Figure 2-2) as well.

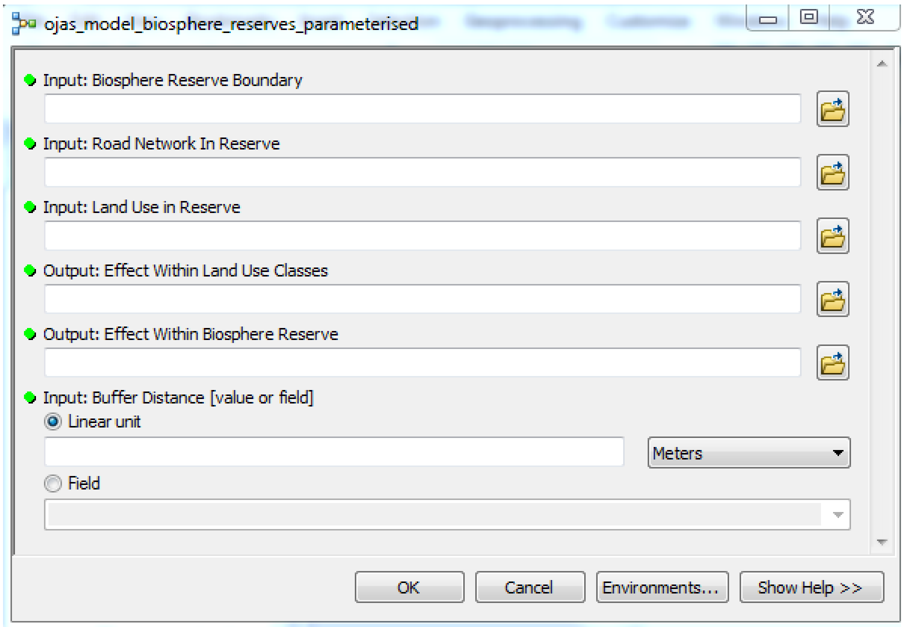

Figure 2-2: Parameter input window of developed tool

2.2.1 Impact of Roads on Biosphere Reserves

For the general impact analysis, only the following road classes were included:

- Motorway
- Trunk
- Primary
- Secondary
- Tertiary
- Unclassified
- Service

This selection covers all roads categorised as “Major Roads”, and the largest of the categories of “Minor Roads” and “Very Small Roads” (Ramm, 2017). The others were deemed irrelevant to the study or too small to carry any noteworthy volume of traffic. For example, residential roads are not a concern as their effect is likely to be negligible compared to (and masked by) larger roads around them.

The resulting selection query made was:

```
"fclass" = 'motorway' OR
"fclass" = 'primary' OR
"fclass" = 'secondary' OR
"fclass" = 'service' OR
"fclass" = 'tertiary' OR
"fclass" = 'trunk' OR
"fclass" = 'unclassified'
```

The geoprocessing steps taken were as follows:

1. The Biosphere Reserve boundaries were clipped with the road network to obtain the network within the Reserves only.
2. A buffer radius was applied to the road network for both birds and mammals:
   i. For birds, two buffers were drawn at 1km (core impact radius) and 2.58km (full impact radius) from the roads.
   ii. For mammals, two buffers were drawn at 5km (core impact radius) and 17km (full impact radius) from the roads.
   iii. Buffer ends were rounded, and all fields were dissolved.
3. The buffers were clipped to obtain only the effect size in the Reserve.
4. The buffer was clipped with target land use class polygons within the Reserves to see the effect size on just those parts. This was done to avoid results that suggested a high impact of roads where there was no significant natural habitat.
5. The area covered by both the total effect size and effect size on the target land use areas was determined.

Figure 2-3 illustrates the general model structure implemented in ArcMap, but it does not describe every step mentioned above.

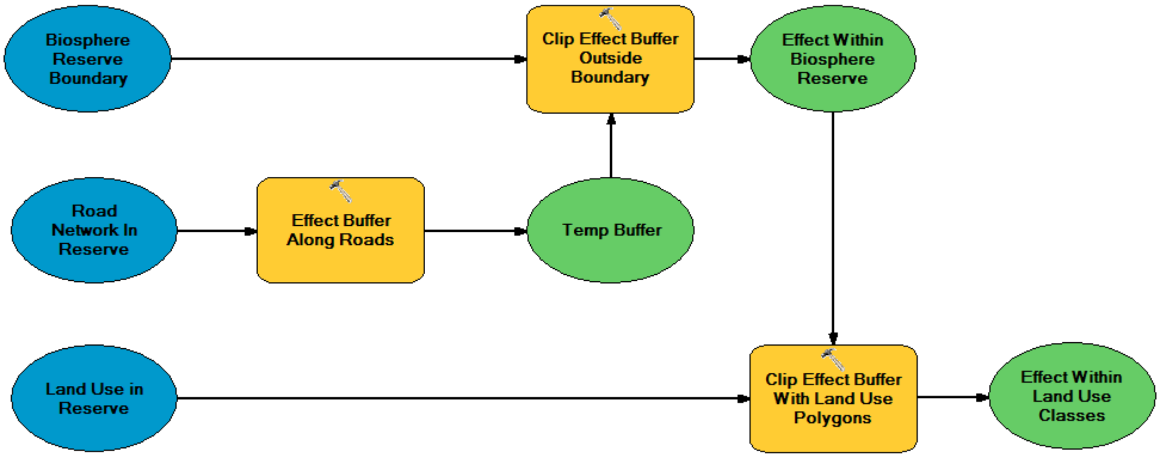

Figure 2-3: Basic geoprocessing model structure for direct impact area calculation

2.2.2 Impact of Hunting on Biosphere Reserves

The Biosphere Reserves being studied were too small for the 40km effect buffer to be a distinctive feature – that was enough to cover each of the reserves is their entirety. ArcMap also seemed to be unable to cope with drawing a 40km buffer around a sufficiently complex road network. Therefore, the area affected by hunting was only examined for birds. Additionally, any prohibition on hunting that might be in place in different protected areas of the Biosphere Reserves was ignored, as the process would require its own focused study and was outside the scope of this thesis. Thus, there is no distinction here between legal and illegal hunting.

For these results, the entire road network in the Biosphere Reserves was considered, as it was assumed that hunters wouldn't be constrained to motorable roads and may well use smaller road classes like dirt tracks. Further, settlements within the Biosphere Reserves were also used to calculate the effect areas. Settlements were assumed to be point locations.

The following settlement classes were used:

- National Capital
- City
- Town
- Suburb
- Village
- Hamlet

```
"fclass" = 'city' OR
"fclass" = 'hamlet' OR
"fclass" = 'national_capital' OR
"fclass" = 'town' OR
"fclass" = 'village' OR
"fclass" = 'suburb'
```

Suburbs were included to compensate for cities and towns being treated as point locations.

The geoprocessing steps taken were as follows:

1. The Biosphere Reserve boundaries were clipped with the road network to obtain the network within the Reserves only.
2. The dataset of places was clipped with the Biosphere Reserve boundaries to obtain the network within the Reserves only.
3. One 7km buffer each was applied both to the road network, and to each place within the reserve
    i. Buffer ends were rounded, and all fields were dissolved.
    ii. Both buffers were merged.
4. The combined buffer was clipped to obtain only the effect size in the Reserve.
5. The buffer was clipped with target land use class polygons within the Reserves to see the effect size on just those parts. This was done to avoid results that suggested a high impact of roads where there was no significant natural habitat.
6. The area covered by both the total effect size and effect size on the target land use areas was determined.

An example of the resulting ArcMap model for Birds is shown in Figure 2-4.

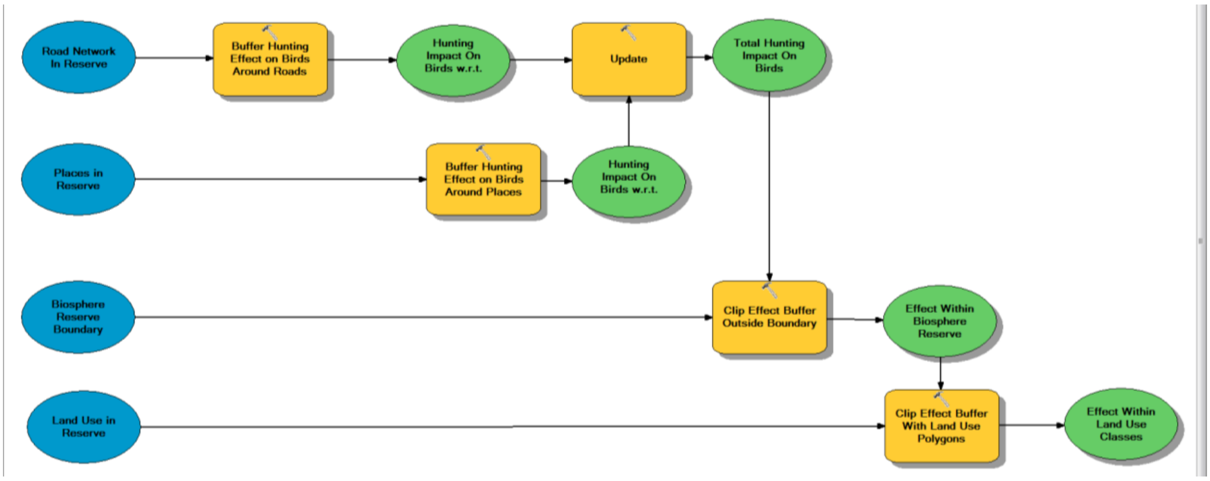

Figure 2-4: Model diagram for determining the area affected by hunting. Includes both roads and settlements within the biosphere reserve.

3 Results

3.1 Impact of roads/infrastructure on biodiversity

Of the 55 papers having information on the impact of roads on biodiversity in India, 9 provided some quantitative data that examined encounter rates at varying distances from roads. 33 studies provided qualitative data or supporting material for this thesis. 13 studies were not deemed usable as they could not provide relevant or sufficient qualitative or quantitative data. Most of the studies were from south, central, and north-east India, with some from the west and north of the country. Not enough data was obtained to statistically confirm or deny the findings of Benitez-Lopez et al. (2010) via the literature review, however *in general* their findings appear to be supported.

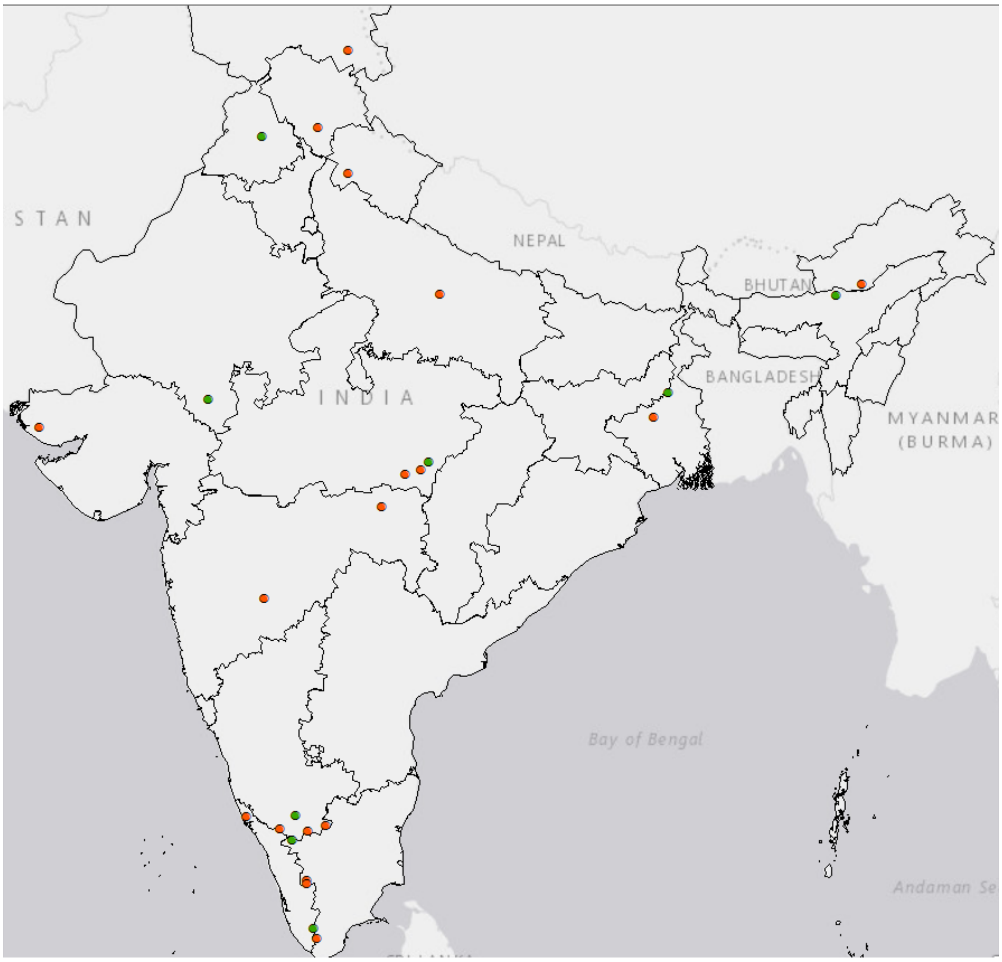

Figure 3-1: Approximate locations of the study sites in the reviewed papers. If multiple studies were carried out at the same place, those were not represented twice.

Before extensively describing the results, it is worth noting that no study appeared to explicitly examine the gradient of species or population abundances at varying distances to roads. Studies tend to use "line transect" methods at a fixed distance from the roads, but some choose random forest trails or unspecified routes through forests. Some just noted presence or absence along the road vs off-road numbers, while others compared densities or group size. The results are presented accordingly, with similar studies grouped together.

3.1.1 Studies that looked at gradients

Class	Species	Disturbance type	Sample Distances from disturbance(m)	Ratio, nearest sample to furthest sample (%)	Ratio, Disturbance vs control (total of samples, %)	Source
Aves	Multiple	Mining Infrastructure	<100, 500, 1000	11.76 (population) 20.83 (species)	40.44 (population) 32.05 (species)	(Saha & Padhy, 2011)

3.1.2 Line transect studies (near road/disturbance vs off road/away from disturbance)

S.no.	Class	Disturbance type	Sample Distances from disturbance	Relevant information recorded	Species	Ratio, near disturbance vs away (%)	Source
1.	Mammalia	Road	Unspecified, but within 8 km of road	Population Density (PD), Group Size (GS), Group Density (GD)	Gaur	31.98 (PD) 105.09 (GS) 30.95 (GD)	(Varman & Sukumar, 1995)
					Elephant	51.95 (PD) 82.16 (GS) 63.33 (GD)	
					Chitral	96.99 (PD) 93.76 (GS) 103.38 (GD)	
					Sambhar	11.37 (PD) 63.95 (GS) 17.79 (GD	
2.	Mammalia	Road	Unspecified, on road vs within Protected Areas	Groups/km	Bonnet Macaque	5.47*	(Erinjery et al., 2017)
3.	Aves	Road	1 km	Species abundance (SA), population per species (PPS)	68 species	51.47 (SA) 13.52 (avg. PPS) ** 26.28 (avg. PPS)***	(Dhindsa, Sandhu, Sandhu, & Toor, 1988)

**off-road groups/km was calculated by averaging data from 17 studies*
***Average population per species ratio calculated by averaging reported on-road vs off road occurrence ratio for all species. N=68.*
**** Average population per species ratio calculated by averaging reported on-road vs off road occurrence ratio for only those species which occurred on/near roads at all. N=35.*

3.1.3 Occurrence/Encounter distance studies

S.no.	Class	Disturbance type	Species	Encounter or occurrence distance from disturbance	Notes	Source
1.	Mammalia	Road	Gaur	3.93 km (calc. mean)	Modelled Euclidean distance based on observations	(Gangadharan, Vaidyanathan, & St Clair, 2017)
			Elephant	3.76 km (calc. mean)		
2.	Mammalia	Road, Railway line	Elephant	1 km to 5 km	"Buffer" determined using literature studies	(Hazarika & Saikia, 2013)
		Settlements		2 km		

3.	Mammalia	Road, trail	Indian Giant Flying Squirrel	43.50 m	Really large relative error (±41m)	(Koli, Bhatnagar, & Sharma, 2013)
4.	Mammalia	Road	Tiger	1.2 km	Modelled maximum probability of livestock kill, based on observations. Several confounding variables exist.	(Miller, Jhala, Jena, & Schmitz, 2015)
		Village		1.1 km		
5.	Mammalia	Road	Tiger, Leopard	1.2 km	Modelled maximum probability of livestock kill, based on observations. Several confounding variables exist.	(Miller, Jhala, & Jena, 2016)
		Village		1.0 km		

All three types of studies show an impact on mammals and birds within a 1-5 km radius from roads, infrastructure/settlements. However there is not enough data to statistically confirm or refute the study by (Benitez-Lopez et al., 2010). That said, several useful indicators were obtained. Population or species counts were available for 4 studies, that compared these metrics near and away from the disturbance source (although some did not specify the distance). The 5 remaining studies examined or reported the likelihood of encountering mammal species, describing the distance of maximum probability of an encounter.

For birds, abundances declined around 88% near the disturbance source, with a 49 to 80% reduction in species count. Larger mammals show a reduction of between 4% to 89%, depending on the species.

Confounding variables exist in many of the studies, however, and this will be discussed in Section 4. Finally, not enough studies attempt to look at an actual gradient of species abundance or individual populations from increasing distances from the road.

Since not all measures provided a direct estimate of abundance, the numbers in some cases had to be approximated or converted into a binary absent/present (0 or 1) form. For example, if a certain species wasn't encountered until 4km away from the road, then its relative population at 4km was considered 1 at 4km, and 0 at 0km (i.e. on the road).

Figure 3-2 and Figure 3-3 are charts that visually synthesise the above tables. Pairs of points represented per study: the first point represents the relative population (abundance) of the species at the source of the disturbance (i.e. road or infrastructure), while the second point represents the distance at which the abundance appears to stabilize. The relative abundance values were averaged across all the studies to obtain the trendlines.

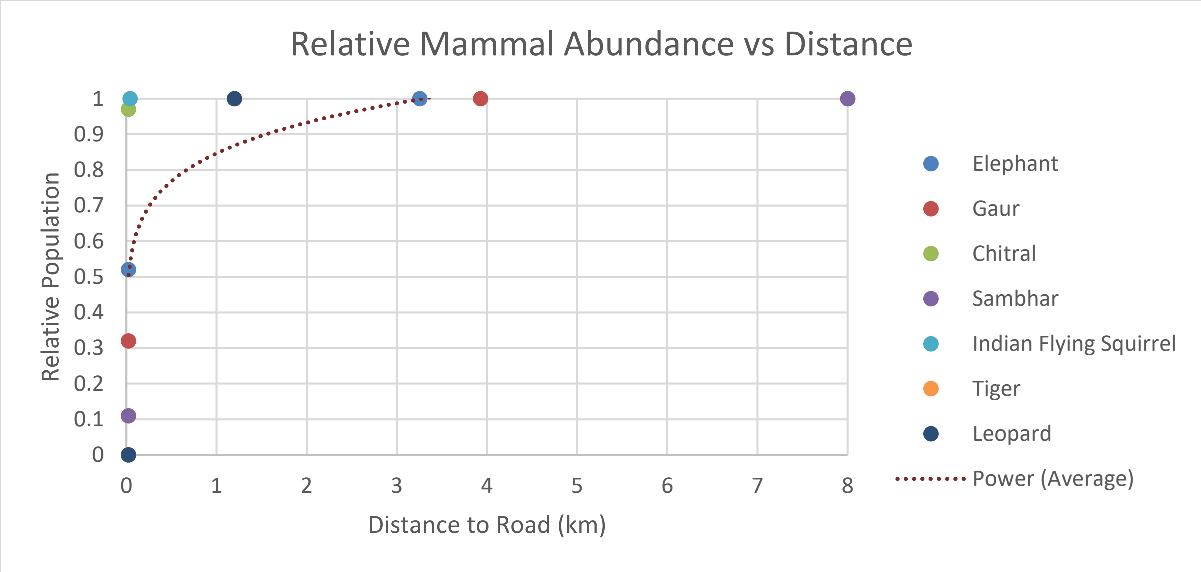

Figure 3-2: Visualisation of the synthesis of mammal studies, with the trendline indicated.

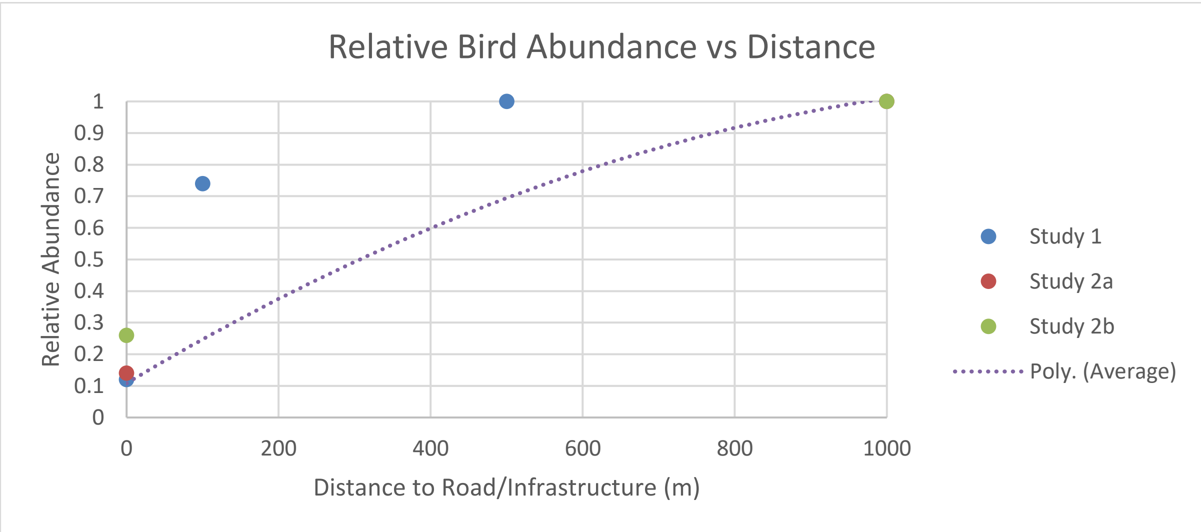

Figure 3-3: Visualisation of the synthesis of bird studies, with the trendline indicated.

3.2 Impact of Hunting with respect to roads

There was a severe lack of data regarding the use of roads by hunters, whether legal or illegal. While the Web of Science database search did not return any usable results, the Wageningen Library Search process was not easy to report and thus not reliably reproducible. Therefore, studies found by the latter method had to be ignored. However, using the meta-analysis on hunting in India by (Velho et al., 2012), and the details of hunting specific studies provided by N. Velho upon request, one such useful study did emerge.

It has been found that tribal hunters in the state of Arunachal Pradesh will travel for between half a day to over a week on hunts. Researchers converted this into distance classes that extend well beyond

5 km of the villages (Aiyadurai, Singh, & Milner-Gulland, 2010). No quantitative relation to roads was described. However, it was suggested that hunters increasingly must travel increasing distances due to a decline in wildlife population nearer to villages and settlements.

3.3 Modelling the general impact of roads

The results of my systematic review can only support the 1km and 5km effect distances for birds and mammals respectively, however the full 2.5km and 17km extents were analysed too, for the sake of completeness (see Table 3-1).

The magnitude of the area affected by roads was somewhat predictable – smaller Biosphere Reserves with a larger road network had a larger impact area. However, this doesn't tell the full story. As we will see with the results of individual areas, a large but dense road network may lead to a significant impact area, but it may cause less of an impact vs a smaller but more spread out road network (compare Agasthyamala and Nilgiri, for example).

Table 3-1: Impact area shown as a percentage of total Biosphere Reserve area. "Birds 1000m" = effect on birds within a 1km radius; "Mammals 5000m" = effect on mammals within a 5km radius, and so on.

Biosphere Reserve (BR) Name	Length of Roads	BR Area	Birds 1000m	Mammals 5000m	Birds 2580m	Mammals 17000m
	km	sq. km	%	%	%	%
Achanakmar-Amarkantak	2462.43	**15308.25**	25.12	49.74	70.85	**96.62**
Agasthyamala	**4587.04**	6579.70	**55.44**	**84.49**	**71.68**	**99.53**
Great Nicobar	57.32	2240.63	3.93	15.84	9.10	44.82
Gulf of Mannar	570.20	6050.50	12.49	23.13	19.10	42.71
Nanda Devi	1318.15	**15266.46**	9.30	29.53	18.62	69.76
Nilgiri	2791.22	6329.79	**52.01**	**91.94**	**76.64**	**100.00**
Nokrek	89.00	754.55	18.55	54.34	37.01	**99.73**
Pachmari	1922.31	9445.65	**30.49**	**75.82**	**55.07**	**99.66**
Simlipal	774.66	**10105.65**	13.58	54.00	31.67	**97.42**
Sunderban	935.67	**10015.22**	15.30	39.46	29.53	60.41

Further it seems apparent that the full impact area covers over 50% of the area of 4 biosphere reserves in the case of birds, and 8 biosphere reserves for mammals. The full impact radius for mammals in fact affects over 95% of the area of most reserves. Assuming the magnitude of impact on species found by Benitez-Lopez et al. (2010) holds good, this would imply that this area stands to see a potential reduction of species abundance by around 32% on an average. Of course, the bulk of this impact would be constrained to the 1km or 5km "core" radius, but even that is significant for Agasthyamala, Nilgiri and Pachmari reserves.

Biosphere Reserves are IUCN Category V protected areas, as noted previously in the text. This means that they will contain both human populated areas, as well as core protected areas (Category II and IV). Thus, not all the impact area is going to be relevant, and it is important to look at how much of an effect roads have on the target land use classes (see Methodology section 2.2) within the reserve, where the effect is likely to have the most pronounced impact (Table 3-2).

Table 3-2: Impact area on target land-use expressed as a percentage of total land use area. LU B1000 = effect on birds in target land use classes within 1km of roads, M5000 = effect on mammals in target land use classes within a 5km radius, etc.

Biosphere Reserve Name	**Land Use Area**	**LU Effect B1000**	**LU Effect M5000**	**LU Effect B2580**	**LU Effect M17000**
	sq. km	%	%	%	%
Achanakmar-Amarkantak	2882.07	9.42	39.82	23.18	**85.59**
Agasthyamala	2015.28	6.88	**80.35**	**48.98**	**100.00**
Great Nicobar	957.47	7.84	25.51	15.28	**70.95**
Gulf of Mannar	0.00	0.00	0.00	0.00	0.00
Nanda Devi	679.22	2.32	20.09	8.74	**67.38**
Nilgiri	3507.74	**22.25**	**85.47**	**54.47**	**100.00**
Nokrek	754.55	18.55	54.34	37.01	**99.73**
Pachmari	4237.49	13.17	**60.35**	33.59	**99.64**
Simlipal	4340.18	5.84	34.13	16.39	**94.11**
Sunderban	2902.54	0.44	8.81	2.48	36.69

The core impact area for birds is much lower in this case, as compared to the total affected area. Similar trends are noticeable for the core impact on mammals, and the full impact on birds. Agasthyamala and Nilgiri Biosphere Reserves are obvious outliers, however. When it comes to the full impact area with respect to mammals, over 60% of the land use area in 8 reserves is predicted to show some effect, with the percentage hovering around 100% for 4 reserves.

Gulf on Mannar is a marine reserve, thus has no relevant terrestrial land use coverage.

Table 3-3: Land use effected as a percentage of total Biosphere Reserve area

Biosphere Reserve Name	**BR Area**	**Land Use Area**	**LU Area**	**LU Effect B1000**	**LU Effect M5000**	**LU Effect B2580**	**LU Effect M17000**
	sq. km	sq. km	%	%	%	%	%
Achanakmar-Amarkantak	15308.25	2882.07	18.83	1.77	7.50	4.36	16.11
Agasthyamala	6579.70	2015.28	30.63	2.11	24.61	15.00	30.63
Great Nicobar	2240.63	957.47	42.73	3.35	10.90	6.53	30.32
Gulf of Mannar	6050.50	0.00	0.00	0.00	0.00	0.00	0.00
Nanda Devi	15266.46	679.22	4.45	0.10	0.89	0.39	3.00
Nilgiri	6329.79	3507.74	**55.42**	**12.33**	**47.37**	**30.19**	**55.42**
Nokrek	754.55	754.55	**100.00**	**18.55**	**54.34**	**37.01**	**99.73**
Pachmari	9445.65	4237.49	44.86	5.91	27.07	15.07	44.70
Simlipal	10105.65	4340.18	42.95	2.51	14.66	7.04	40.42
Sunderban	10015.22	2902.54	28.98	0.13	2.55	0.72	10.63

Combining both sets of data in Table 3-3 brings up another interesting aspect – the total area of the target land use classes within biosphere reserves affected by roads is relatively small in most cases, especially considering the "core impact" area. This means that the biosphere reserves likely contain a fairly diverse range of land use classes (and thus habitats) that aren't included in Open Street Map data. This is especially apparent when looking at the case of Nanda Devi Biosphere Reserve – it is a large reserve but mainly constitutes of mountainous terrain with unmarked land use classes. On the opposite end of the spectrum, Nokrek and Nilgiri Biosphere Reserves have significant forest cover, and thus the effect on target land use classes with respect to the entire reserve area is much larger.

A visual representation of the impact area within each Biosphere Reserve can be found in Appendix - C.

3.4 Modelling the impact of hunting with respect to roads

Hunter-gatherer tribes exist in almost all the biosphere reserves, however what, how far, or how frequently they hunt varies considerably across the country. My own review failed to turn up adequate data to comment on this within the Indian context, but what little evidence exists suggests that 7km is a reasonable number to work with. That said, it is still interesting to see how much of each Biosphere Reserve is likely to be affected due to hunting pressures, should they exist. As mentioned in Section 2.2.2, only the area of impact on bird populations was examined (see Table 3-4). This can be used as a proxy to estimate the minimum likely pressure on mammal species as well, albeit likely an underestimate.

Table 3-4: Area where birds are likely to be impacted (7km radius) as a percent of total Reserve area

Biosphere Reserve (BR) Name	Length of All Roads in BR	BR Area	Birds 7000m
	km	sq. km	%
Achanakmar-Amarkantak	2798.12	15308.25	81.00
Agasthyamala	5518.33	6579.70	93.13
Great Nicobar	91.83	2240.63	27.11
Gulf of Mannar	607.17	6050.50	26.46
Nanda Devi	1639.95	15266.46	54.12
Nilgiri	3126.98	6329.79	97.15
Nokrek	89.00	754.55	64.68
Pachmari	2034.75	9445.65	88.11
Simlipal	774.66	10105.65	70.74
Sunderban	1073.01	10015.22	51.34

On the face of it, all the reserves except Great Nicobar and the Gulf of Mannar are likely to have large area that is significantly affected by hunting. Of course, it is impossible to make a statement regarding fishing activities within the scope of this study. Sunderban and Nanda Devi Reserves are the least affected amongst the terrestrial Reserves.

Table 3-5: Impact on land use expressed as a percentage of total land use classes being considered

Biosphere Reserve Name	BR Area	Land Use Area	LU Effect B7000
	sq. km	sq. km	%
Achanakmar-Amarkantak	15308.25	2882.07	52.98
Agasthyamala	6579.70	2015.28	96.74
Great Nicobar	2240.63	957.47	43.78
Gulf of Mannar	6050.50	0.00	0.00
Nanda Devi	15266.46	679.22	60.79
Nilgiri	6329.79	3507.74	95.06
Nokrek	754.55	754.55	64.68
Pachmari	9445.65	4237.49	80.02
Simlipal	10105.65	4340.18	53.43
Sunderban	10015.22	2902.54	27.52

Confining the results to selected target land use classes (Table 3-5) presents a different angle. Sunderban Biosphere Reserve shows the least area affected by abundance reduction, and Great Nicobar shows a much higher impact area. The Nilgiri Biosphere Reserve seems vulnerable from either perspective.

Maps showing the extent of the effect on each Reserve can be found in Appendix D.

4 Discussion

The results of this study indicate that within India, there certainly exists an impact of roads and other types of infrastructure (in this case mining equipment and human settlements) on wildlife. Population density, abundance, herd/group sizes and group count all tend to decrease with increasing proximity to roads and other infrastructure for most mammals and birds, with some exceptions. The effect seems to last between 1-5km for most species. There are also indications that hunting pressures in some parts of India have depleted or reduced hunted species near the settlements of hunters, lending credence to the “central place foraging hypothesis” that the work by Benitez-Lopez et al. (2017) base their regression models on.

Further, the third research question (Section 1.3) intended to examine the theoretical impact that could be expected due to roads and hunting based on studies by Benitez-Lopez et al. (2017; 2010). Several Biosphere Reserves have a road network such that the area of impact covers a significant portion of their terrestrial surface area (>50%). Smaller protected areas with dense road networks and large human populations are especially adversely affected. However, the effect on certain natural land use classes is less severe in many cases, especially considering the impact on birds. On the other hand, hunting can potentially affect a much larger area (>50% of natural land use area for 8 out of 10 reserves), and thus adequate protection measures need to be in place to keep this in check.

According to the reviewed literature, the exact nature and magnitude of the impact varies quite a bit between species. Larger mammals like elephants, gaur and sambhar tend to avoid roads in general (Gangadharan et al., 2017; Varman & Sukumar, 1995). Settlements and densely populated areas are also known to block access to animals like elephants (Hazarika & Saikia, 2013) and tigers (Joshi, Vaidyanathan, Mondol, Edgaonkar, & Ramakrishnan, 2013; Rathore, Dubey, Shrivastava, Pathak, & Patil, 2012). The Indian Giant Flying Squirrel’s habitat is also reported to have been affected by highway construction and associated urbanisation and industrial construction (Koli et al., 2013).

On the other hand, some species prefer to inhabit areas near roads, due to the various opportunities they provide. For example, granivorous birds are attracted to grains spilled on to the roads, although that may also result in them getting hit by fast moving cars (Dhindsa et al., 1988). White-Rumped Vultures nest near roadsides to take advantage of road-kills, and there appears to be a lack of “direct evidence” suggesting that the birds are disturbed by traffic (Thakur, 2015). Chitral deer seem less affected by roads too, as they prefer open grassy areas to graze in, and roadside clearings provide this microhabitat (Varman & Sukumar, 1995). This opportunistic adaptation does not stop at roads either: some birds will take advantage of urban infrastructure and buildings even fairly close to busy roads, likely due to the protection such buildings provide to their nesting sites (Rao & Koli, 2017).

Further, there appear to be many interfering variables that affect the magnitude of the impact. In some parts of the country, roads provide easy access to resources like commercially important stones, and mining equipment is set up along these roads. Birds populations are adversely affected by the air pollution and noise caused by this mining infrastructure, with 60% reduction in individuals and almost 70% reduction in species count vs a similarly undisturbed area (Saha & Padhy, 2011). Thus, the issue here is less the presence of roads or infrastructure themselves, but more about the secondary effects caused by them – i.e. noise and pollution caused by mining equipment specifically. Vehicular traffic causes noise and pollution as well, so this insight is of relevance. With this in mind it is less surprising that mammals in protected areas are more affected by traffic volume, than the mere existence of roads themselves (Gubbi et al., 2012). As noted previously, when less disturbed, roads may in fact contribute to the creation of microhabitats for herbivores – however that also means that these animals are more susceptible to road kills, especially at night.

Amongst carnivores, tigers specifically appear to be more affected by road density, traffic volume and habitat edges than the mere presence of roads at all (Rathore et al., 2012). However, tigers seem adversely affected when high population density is combined with the presence of road and rail networks (T. Dutta et al., 2016). Additionally, a study of tiger and leopard depredation patterns on livestock suggests that livestock is most at risk about 1 kilometre away from roads and villages – however there is much higher correlation with other factors such as the distance of the kill sites from dense jungle (Miller et al., 2016).

Seasonal variations too play a role in how animals and humans interact with each other via the interface of roads. In India, there are many festivals that see the increase in pilgrimages to certain sites, and many of these sites are in forests, protected areas, or remote mountain locations. Increase in pilgrim traffic is usually accompanied by an increase in vehicular traffic to the pilgrimage sites. This sudden increase over short periods of time can significantly increase road mortality of animals within protected areas (Seshadri & Ganesh, 2011). Unrelated to mammals and birds, road kills of amphibians increase with rainfall received, while road mortality of reptiles was observed to be correlated to ambient air temperature (S. Dutta, Jana, Saha, & Mukhopadhyay, 2016). Another study by (Sundar & Kittur, 2012) suggests that woodland birds show higher roadside habitat occupancy in summer and winter as opposed to the monsoon season.

Thus, it is evident that in a country like India has significant diversity amongst not just its biodiversity, but its geography and socio-economic conditions as well. To fully characterise the impact roads have (or could potentially have) on biodiversity, additional data has to be taken into account. While the Mean Species Abundance ratio developed by (Benitez-Lopez et al., 2010) does not factor in road density, population density, traffic volume or the average speed of vehicles along certain roads, these appear to be important reoccurring themes among Indian studies reviewed for this study. This is especially significant in light of the fact that much of the road network expansion in recent years has dealt with expanding and improving existing roads (Gubbi et al., 2012) instead of building new ones. Species abundance and individual population counts per species of birds seem to be affected by the breadth and volume carried by a road as far back as 1988 (Dhindsa et al., 1988). Given the enormous rise in vehicular traffic in many parts of India in last several decades (Seshadri & Ganesh, 2011), this issue merits serious attention.

Limited data was available on the effects of roads and settlements on hunting. Previous studies indicate that the effects of hunting are considerably understudied in India (Velho et al., 2012). While the fact that hunting has a detrimental impact on wildlife in the country has long been known and recognised (Madhusudan & Karanth, 2002), the follow up in terms of monitoring seems to be absent or lacking. A study on hunters in the state of Arunachal Pradesh suggested a wide variety of species are hunted, however animals are killed more for cultural reasons than for food (Aiyadurai et al., 2010). While the authors do not describe an upper limit on the range of hunters, they do report that hunters have increasingly had to travel over 5km away from villages on week-long hunting trips, possibly due to depletion of mammals and birds within that range. This does give credence to the model proposed by (Benitez-Lopez et al., 2017). In other parts of India, the Indian Giant Flying squirrel was found to be hunted both for food, and for cultural reasons like myths and superstitions surrounding the species (Koli et al., 2013).

A study on poaching identified two hotspots in the country – one in the south-western coast, and another in the central Deccan Plateau region (K. Sharma, Wright, Joseph, & Desai, 2014). Other smaller hotspots include the northern regions along the Indo-Nepalese and Sino-Indian borders. Of higher relevance to this thesis, the study found that poachers have increasingly favoured to smuggle along rail routes as opposed to highways, as it is easier to avoid detection.

4.1 Limitations

There was unfortunately too little quantitative data available to come to any statistically sound conclusions. This was especially true in the case of studies looking at the relation between hunting and access via roads. Primary studies need to be conducted per protected area or biosphere reserve to fully understand how the various factors come together. More studies on hunting turned up in the WUR Library search process, however those results could not be used as they did not easily fit into the PRISMA 2015 workflow. Nevertheless, this suggests that there is a good opportunity to follow up with a focused review of hunting in India using this material.

The model could only be applied in a very general sense, i.e. the area of impact by roads or hunting access could be calculated, however no further insight could reliably be obtained. This is because there wasn't enough data to validate the model in, and calibrate it to, the Indian context. Additionally, The general impact of roads did not consider the differences in terrain, traffic volume or the number of lanes of roads. Additionally, the impact on mammal populations due to hunting was not modelled as the biosphere reserves were too small, and a 40km radius around access points would cover the entire reserve in all cases

Apart from this, the effect of roads and/or settlements outside the biosphere reserve boundary upon the reserves was not be determined. I did not consider expanding the area until much later on, however based on a manual inspection of the map features, this is unlikely to meaningfully impact the results. On the other hand, it appears that the Open Street Map data does not contain all the villages or land use classes in the reserves. This *is* likely to impact the results in some cases, like Nokrek and Nanda Devi reserves. Further, “Unclassified” and “Service” roads could be really small or remote and probably wouldn't carry traffic in some cases (e.g. in some parts of Nanda Devi Biosphere Reserve). Thus, there may be some over-estimation of the direct impact area.

5 Conclusions

One of the objectives of this thesis was to determine the direct impact that roads may have on Indian wildlife, and the consequences for biodiversity. Indian studies do suggest that roads and infrastructure appear to favour certain species over others – herbivores, generalists and scavengers seem to be able to take advantage of man-made ecological niches. Unfortunately, this comes at a cost of species diversity. Even then, animals that adapt to being in proximity to roads and settlements either become victims of road accidents or come into conflict with humans. Given ever expanding urban sprawls, ever widening roads, and continually increasing population, these issues are likely to increase at least until 2050. Being pushed further away from large swathes of land means higher pressure on relatively undisturbed natural habitats.

Multiple studies raise an alarm over the widening of roads. Road widening has severe effects – loss of roadside habitat is perhaps the most direct consequence. Wider and higher quality roads lead to higher traffic volume – which in turn leads to greater disturbance due to noise and pollution, and more chances of road kills. Large, busy roads pose a greater barrier to movement for animals as well. Given this, I think it is imperative that the Mean Species Abundance formula (Benitez-Lopez et al., 2010) be updated and expanded to include additional factors such as the width of roads.

Not enough data was found to confirm or deny the results of Benitez-Lopez et al. (2017; 2010), especially when it comes to the impact with respect to roads and hunting. However, it does appear that roads and infrastructure appear to reduce species diversity and abundance, and much of the effect appears to be constrained to a distance of around 1km for birds and up to 8km for mammals. This is in line with their findings (Benitez-Lopez et al., 2010). The trendline obtained for birds (Figure 3-3) in particular was similar to the lower confidence band obtained by Benitez-Lopez et al. (2010, p. 1311, Figure 1), so the global results may be applicable to India. However, further study is needed to assert this with any measure of confidence.

All these factors merit consideration for future conservation of Indian biodiversity. Planning around existing corridors, replanting roadside trees upon widening of roads, bypassing protected areas and creating bridges or other ways of crossing roads are important steps to take to mitigate the effects of roads on biodiversity.

The second objective of this thesis was to analyse the relationship between access points such as roads and settlements and the indirect impact on biodiversity around them. Unfortunately, this is an understudied field in the country. While both wild meat hunting and poaching have been considered serious threats to Indian wildlife, studies indicate that wild meat seems to be less important than ceremonial hunting or superstitious killing of certain animals (e.g. slow lorries and Giant Squirrel). None of the studies in the dataset examined the relationship to roads, though it has been suggested that improved road access to villages could mean less dependence on forest products.

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7 Appendix – A

Raw data tables for maps – general impact:

BR Name	Total Roads	BR Area	B1000	B2580	M5000	M17000
	m	sq. m	sq. m	sq. m	sq. m	sq. m
Achanakmar-Amarkantak	2462426.86	1.53E+10	3.84E+09	7.61E+09	7614006099	1.48E+10
Agasthyamala	4587043.45	6.58E+09	3.65E+09	4.72E+09	5558943686	6.55E+09
Great Nicobar	57319.5281	2.24E+09	88001591	2.04E+08	354912953	1E+09
Gulf of Mannar	570197.152	6.05E+09	7.56E+08	1.16E+09	1399551148	2.58E+09
Nanda Devi	1318145.62	1.53E+10	1.42E+09	2.84E+09	4508337871	1.06E+10
Nilgiri	2791217.51	6.33E+09	3.29E+09	4.85E+09	5819392396	6.33E+09
Nokrek	88999.4036	7.55E+08	1.4E+08	2.79E+08	410016229	7.53E+08
Pachmari	1922305.22	9.45E+09	2.88E+09	5.2E+09	7161982034	9.41E+09
Simlipal	774663.569	1.01E+10	1.37E+09	3.2E+09	5456802189	9.84E+09
Sunderban	935669.409	1E+10	1.53E+09	2.96E+09	3952285293	6.05E+09

BR Name	LU Area	LUE B1000	LUE B2580	LUE M5000	LUE M17000
	sq. m	sq. m	sq. m	sq. m	sq. m
Achanakmar-Amarkantak	2882069990	271505885	668162700	1.148E+09	2466844230
Agasthyamala	2015280979	138558515	987001245	1.619E+09	2015280979
Great Nicobar	957468024	75050800	146263493	244242634	679340516
Gulf of Mannar	0	0	0	0	0
Nanda Devi	679222121	15743613	59371433	136426237	457687672
Nilgiri	3507743435	780566809	1.911E+09	2.998E+09	3507743435
Nokrek	754547025	139944133	279229062	410016229	752521585
Pachmari	4237487878	558177794	1.423E+09	2.557E+09	4222376785
Simlipal	4340178505	253560816	711555583	1.481E+09	4084666514
Sunderban	2902540569	12671570	71911462	255735033	1064867212

Raw data for maps – hunting maps:

BR Name	Length of All R	BR Area	B7000	LU Area	LUE B7000	M40000	LUM40000
	m	sq. m	sq. m	sq. m	sq. m	sq. m	sq. m
Achanakmar-Amarkantak	2798124.041	1.5308E+10	1.24E+10	2882069990	1.527E+09		
Agasthyamala	5518325.282	6579700426	6.13E+09	2015280979	1.092E+09		
Great Nicobar	91830.34796	2240630566	6.07E+08	957468024	419177869		
Gulf of Mannar	607172.3842	6050496357	1.6E+09	0	0		
Nanda Devi	1639952.343	1.5266E+10	8.26E+09	679222121	412898501		
Nilgiri	3126977.612	6329793254	6.15E+09	3507743435	3.334E+09		
Nokrek	88999.40273	754547025	4.88E+08	754547025	488041459		
Pachmari	2034749.782	9445649741	8.32E+09	4237487878	3.391E+09		
Simlipal	774663.569	1.0106E+10	7.15E+09	4340178505	2.319E+09	1.01E+10	4.33E+09
Sunderban	1073009.92	1.0015E+10	5.14E+09	2902540569	798751970		

8 Appendix – B

Literature results synthesis tables for mammals and birds. Abundances reported for a particular distance have been reported as is. Some assumptions had to be made about when the abundance would become 100% (i.e. a ratio of 1) based on a combination of studies.

Mammals

Distance	Elephant	Gaur	Chitral	Sambhar	Indian Flying Squirrel	Tiger	Leopard	Average
0.025	0.52	0.32	0.97	0.11	0	0	0	0.274286
0.04					1			1
1.2						1	1	1
3.253333	1							1
3.93		1						1
8			1	1				1

Birds

Distance	Study 1	Study 2a	Study 2b	Average
0		0.14	0.26	0.2
100	0.12			0.12
500	0.74			0.74
1000	1	1	1	1

9 Appendix – C

9.1.1 Achanakmar-Amarkantak Biosphere Reserve

The Achanakmar-Amarkantak Biosphere Reserve is primarily located in the central-Indian state of Chhattisgarh, although the north-western corner crosses into Madya Pradesh. This area is not very densely populated, and thus the road network is less dense as well. Most of the roads lie outside the core protected area, however one major road crosses the entire width of the forested area. This does have a moderate "core impact" when it comes to mammals, but the area effecting bird species is much lower.

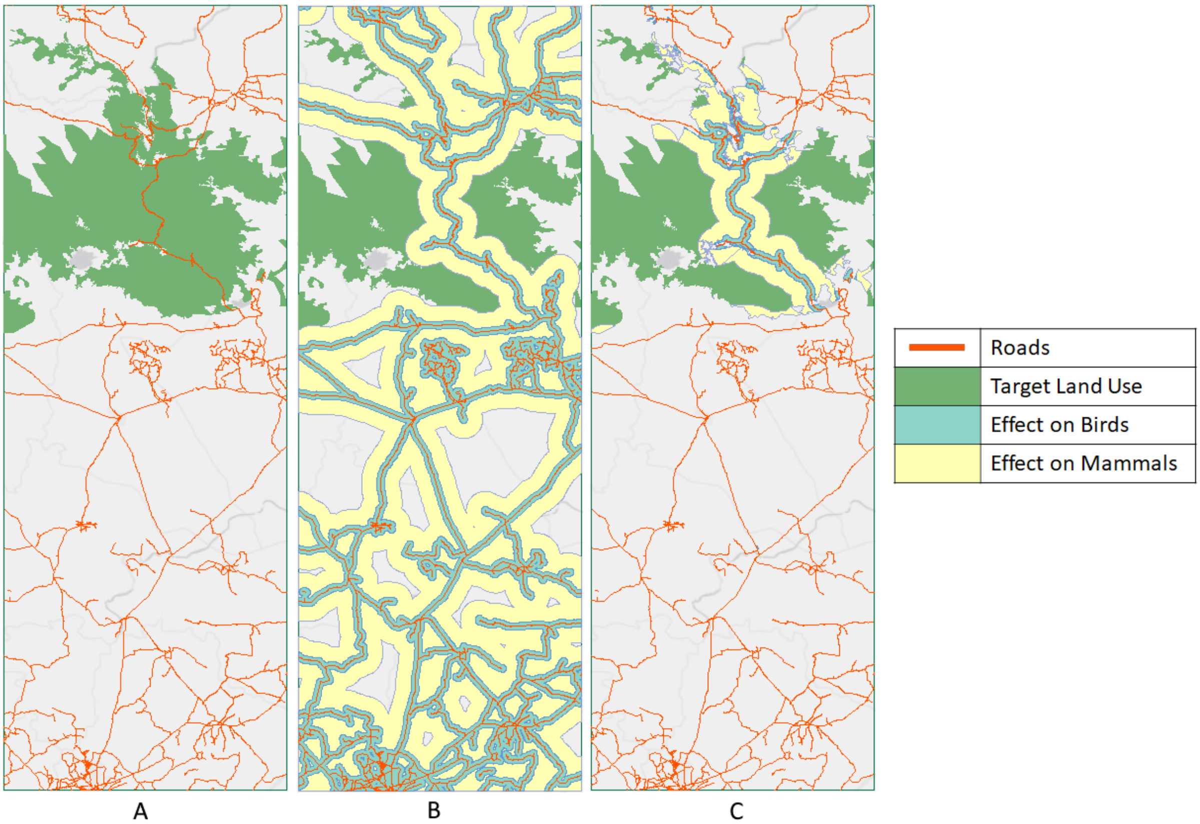


Figure 9-1: (A) Roads and target land use cover in Reserve. Grey patches indicate water bodies. (B) Core area of impact on birds and mammals. (C) Effect on natural land use classes only (as described in Methodology section 2.2.1).

The full impact from road related disturbances predicted on the reserve is much larger, and covers most of the core PA. Birds are still likely to be much less affected than mammals.

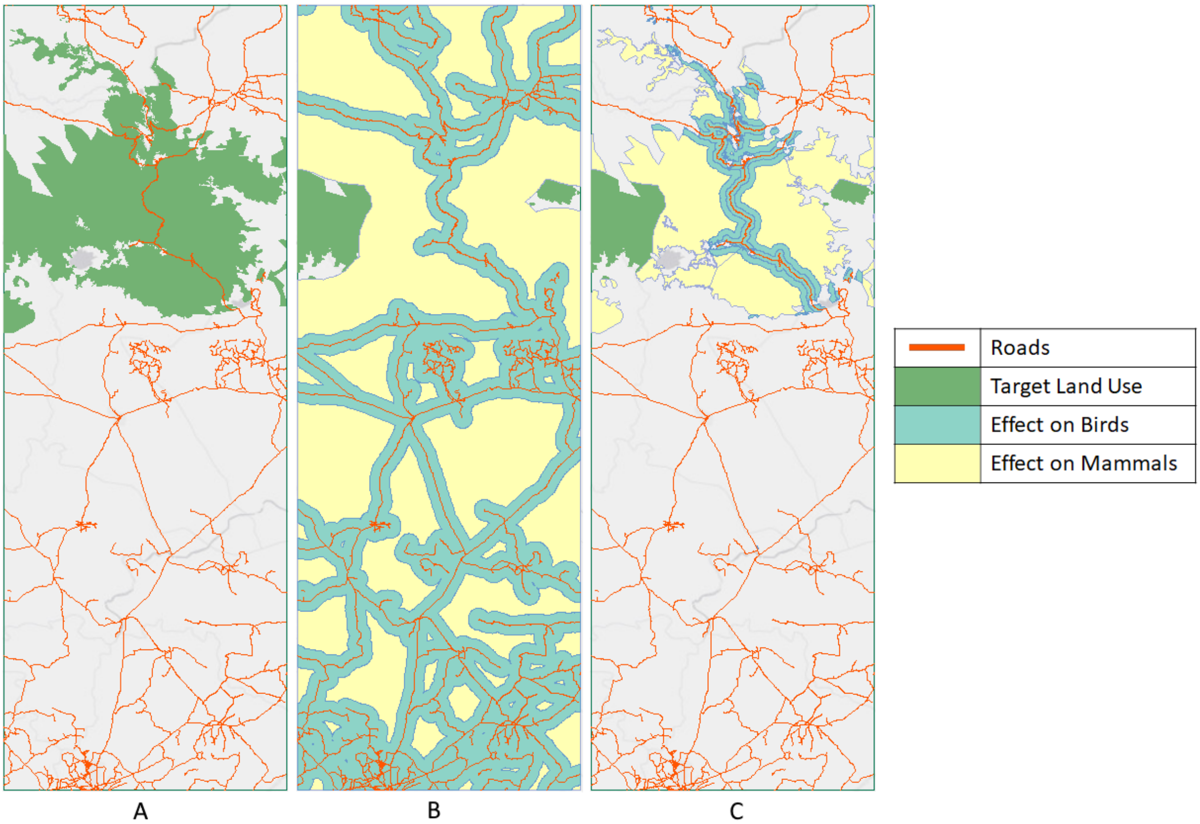
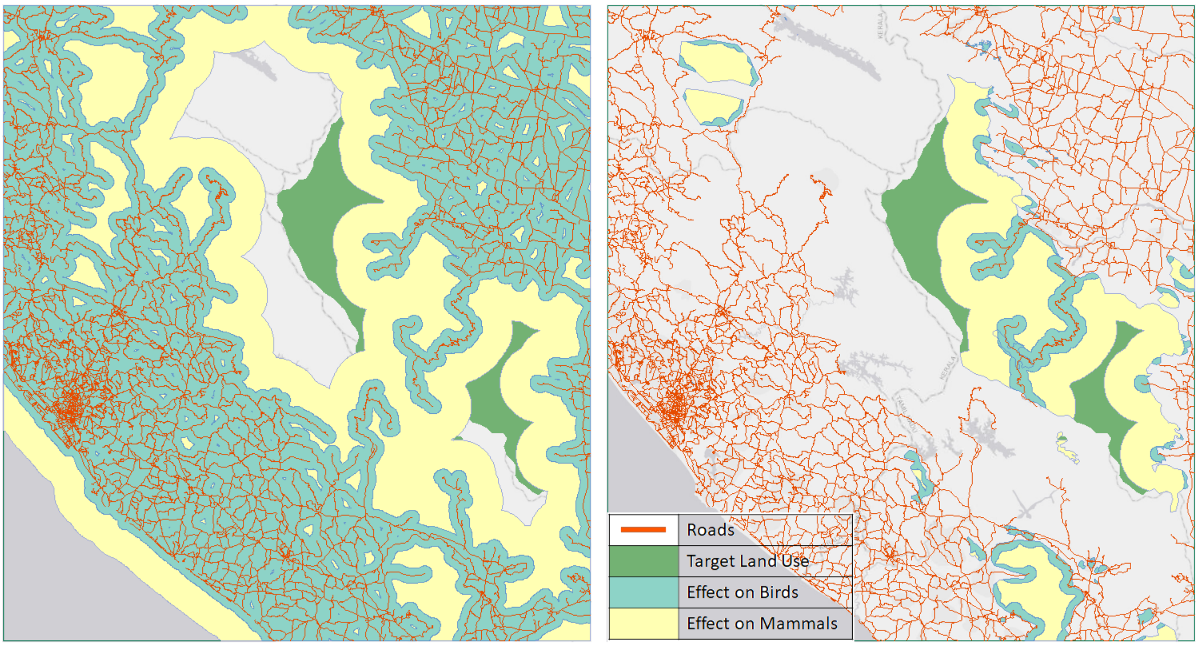


Figure 9-2: (A) Roads and target land use cover in Reserve. (B) Full area of impact on birds and mammals. (C) Effect on land use classes only

9.1.2 Agasthyamala Biosphere Reserve

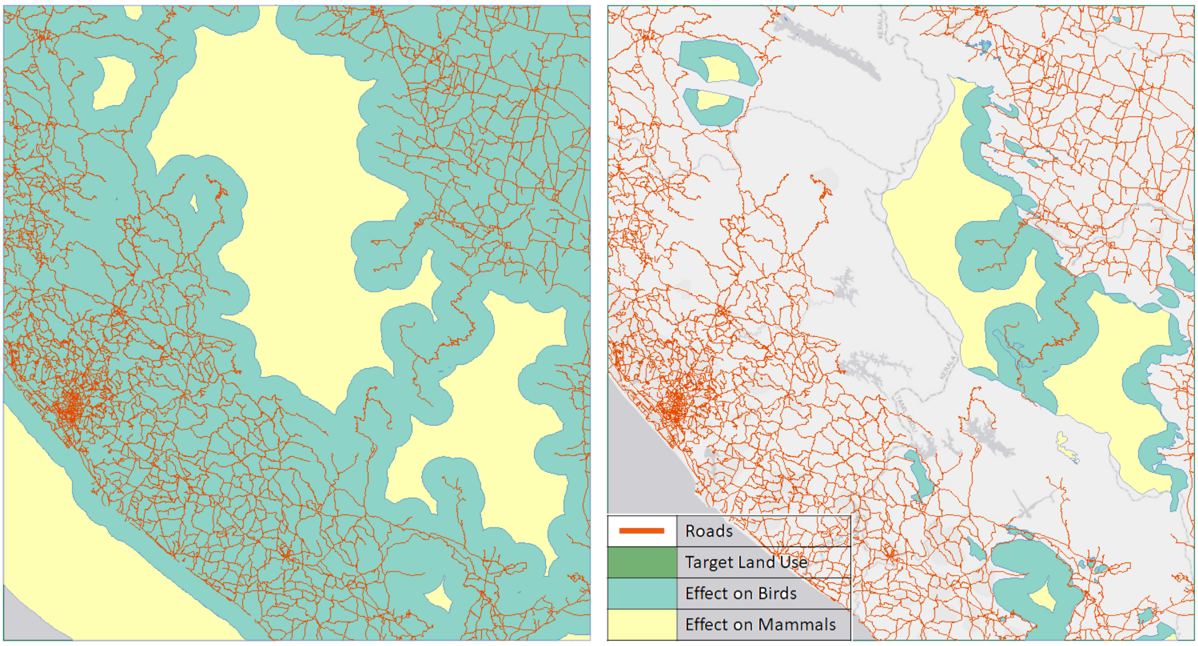
In sharp contrast to Achanakmar-Amarkantak, the Agasthyamala Biosphere Reserve is in the much more densely populated coast of the southern state of Kerala. At least one small city with a population of close to a million people is located nearby – Thiruvananthapuram. In the maps below, the city is evidenced by the dense network of roads along the coast.



A B

Figure 9-3: (A) Core area of impact on birds and mammals. (B) Effect on land use classes only

Naturally the denser road network will have a larger effect. The core effect area more or less covers the entire protected forest area in the middle of the reserve.



A B

Figure 9-4: (A) Full area of impact on birds and mammals. (B) Effect on land use classes only

The full impact radius predicts that the entire biosphere reserve will experience disturbance and decreased mammal and bird abundance.

9.1.3 Great Nicobar Biosphere Reserve

The only island Biosphere Reserve in this study, the Great Nicobar Biosphere Reserve has a small number of roads and human population alike. The Indian Ocean island is completely covered in forests, although not all the area is protected. A considerable marine component exists to the reserve as well.

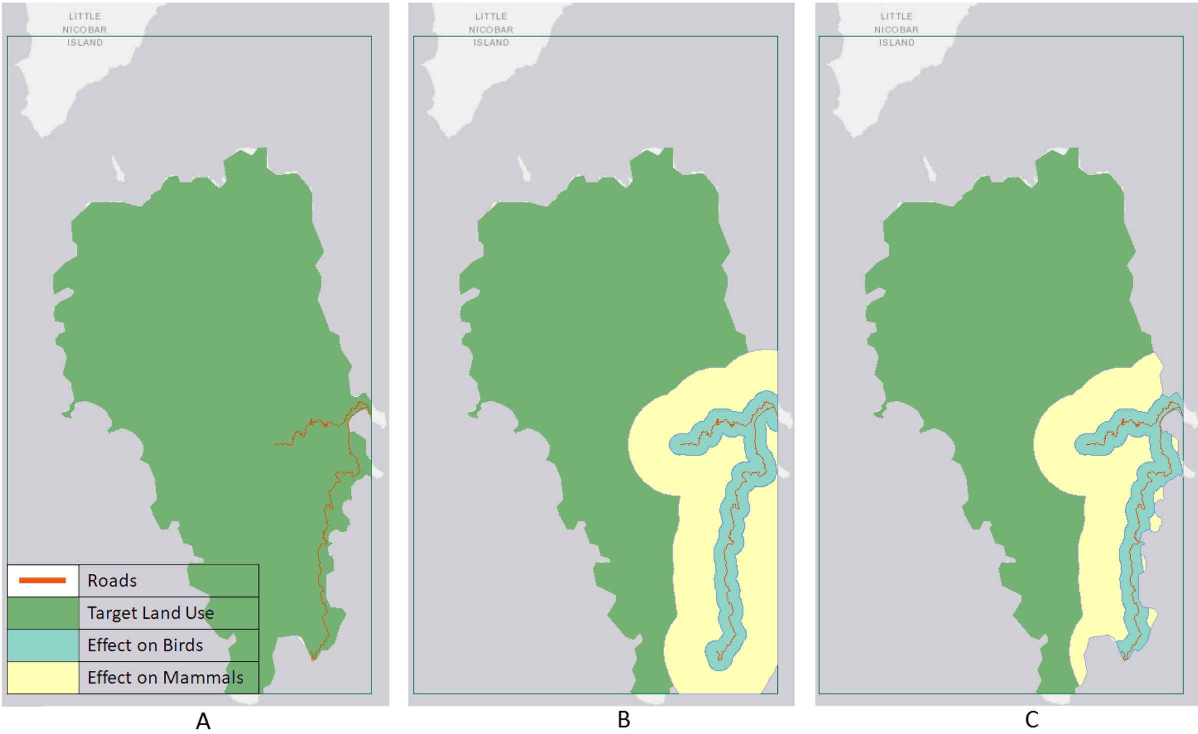


Figure 9-5: (A) Roads and target land use cover in Reserve. (B) Core area of impact on birds and mammals. (C) Effect on land use classes only

The "core impact" area is mostly restricted to the coast, although some impact is likely to be felt in the fringes of the protected forests. The "full impact" result tells a far more sobering tale, with over half the island affected when it comes to mammals. However, given the socio-economic characteristics of the island, such a large impact is likely an overestimation.

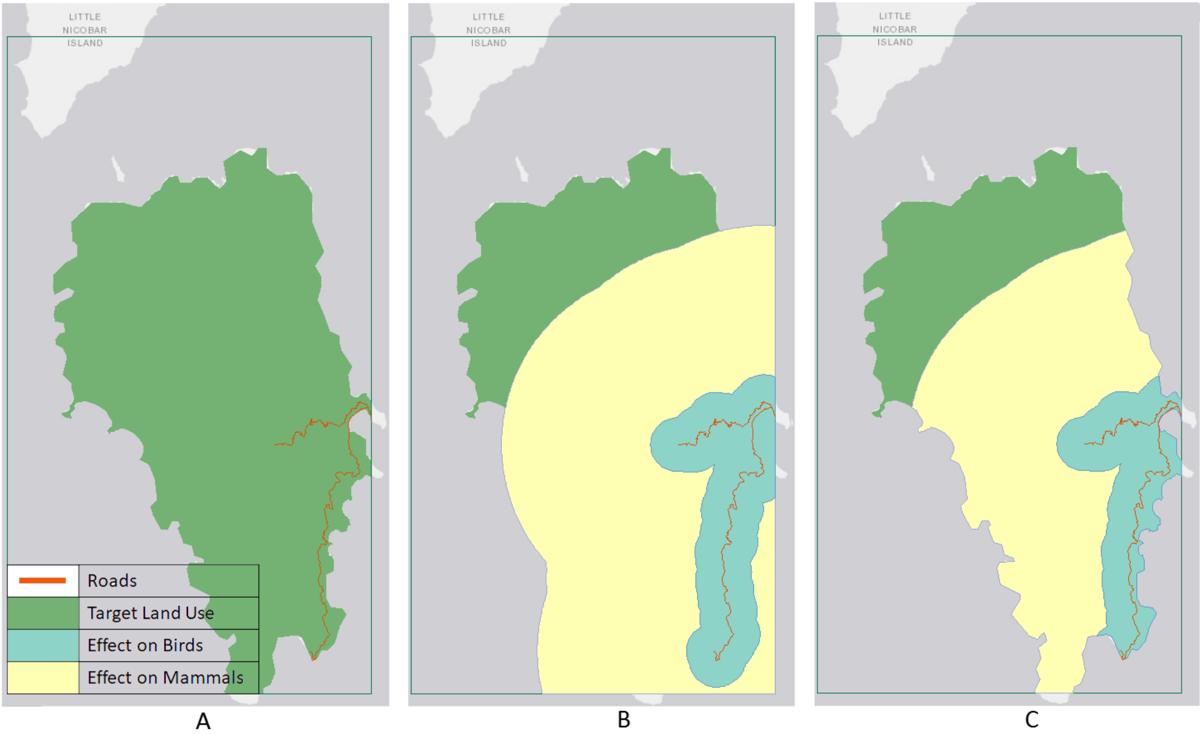


Figure 9-6: (A) Roads and target land use cover in Reserve. (B) Full area of impact on birds and mammals. (C) Effect on land use classes only

9.1.4 Gulf of Mannar Biosphere Reserve

The only completely marine biosphere reserve in this study, the Gulf of Mannar Biosphere Reserve does not offer much to talk about. The terrestrial area is mostly rural and agricultural in nature. It's hard to say much about the impact of roads on terrestrial wildlife in this case, and the model is not applicable to marine wildlife. Additionally, there appeared to be no relevant land use classes in the reserve.

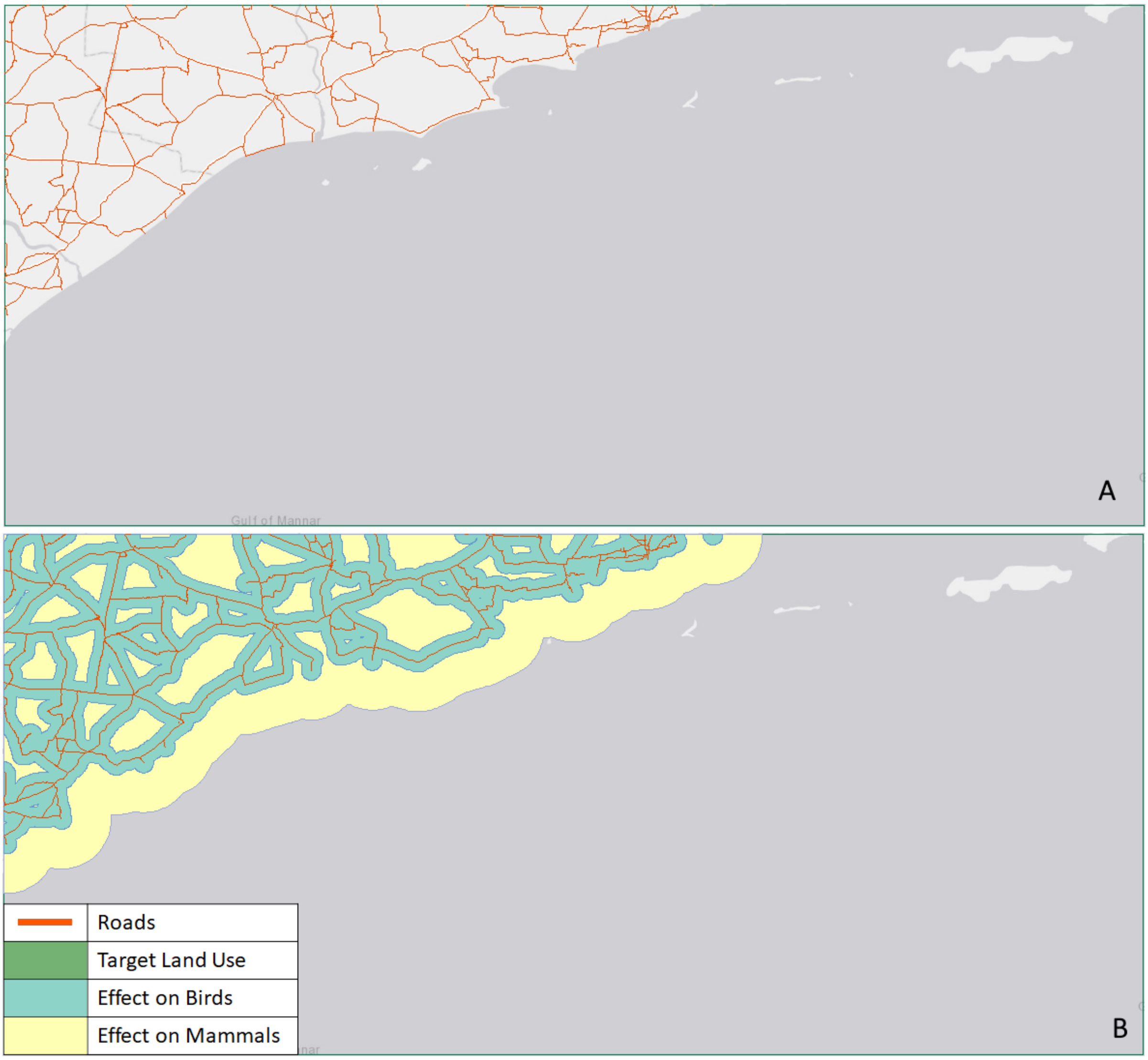


Figure 9-7: (A) Road map. (B) Core area of impact on birds and mammals

The “core impact” area was already sufficient to cover almost the entire terrestrial component of the biosphere reserve. Thus, the “full impact” effect area has not been shown.

9.1.5 Nanda Devi Biosphere Reserve

The Nanda Devi Biosphere Reserve is located in the northern hill state of Uttarakhand, along the Indo-China border. It’s a highly mountainous area with a number of alpine forests, meadows and alpine scrublands. It’s also the second biggest Biosphere Reserve in this study, after Achanakmar-Amarkantak.

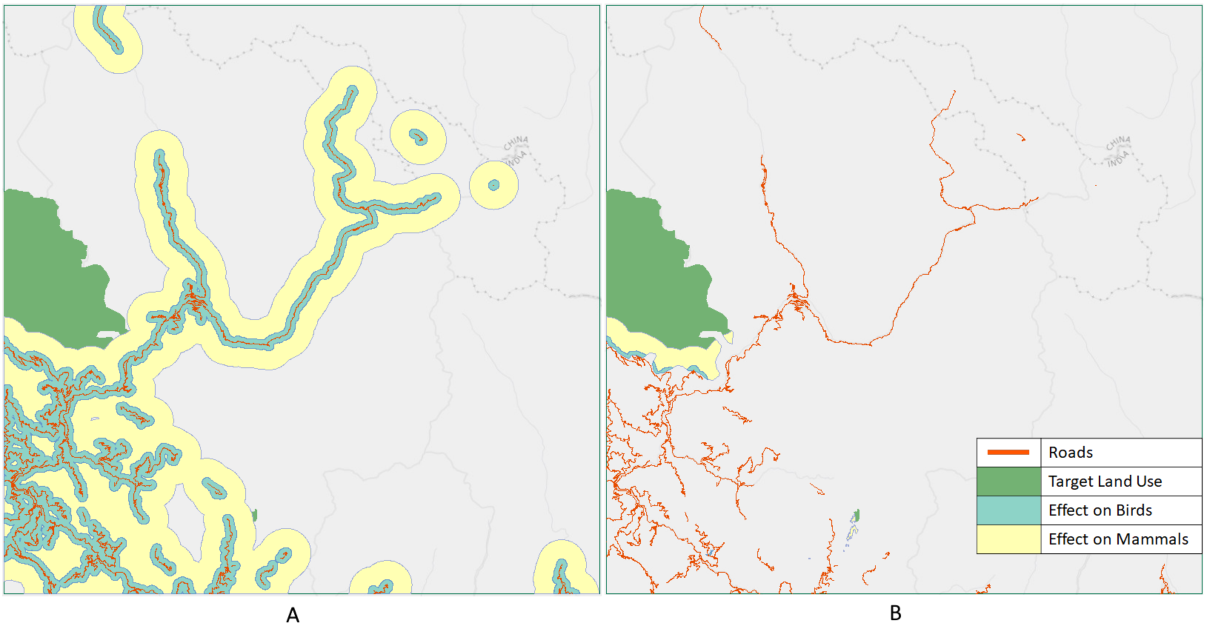


Figure 9-8: (A) Core area of impact on birds and mammals. (B) Effect on land use classes only

The topography presents some interesting questions to this model, however. Would mountains and valleys lessen the effect of roads and infrastructure? Intuitively it seems that the effects should be more localised. That said, road construction in mountains often involves blasting rock, which could cause a lot more disturbance to wildlife.

Unfortunately, the OSM data available did not properly illustrate the target land use classes in the area. The effect on forests and other land use classes of interest are thus likely to be understated in this study.

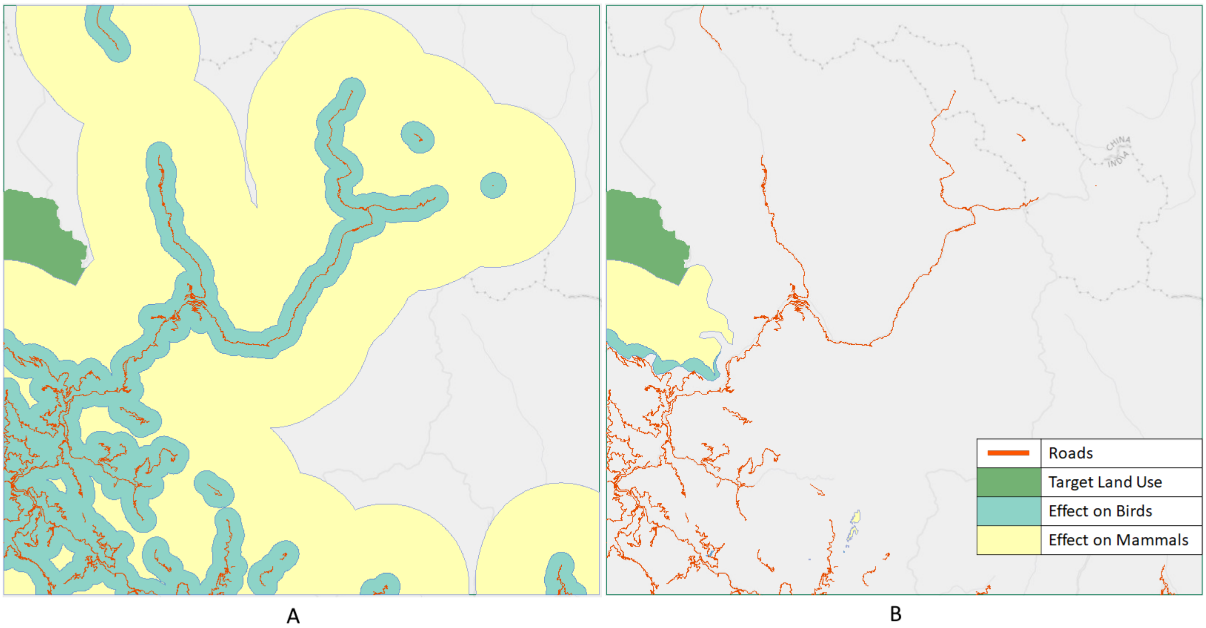


Figure 9-9:(A) Full area of impact on birds and mammals. (B) Effect on land use classes only

Additionally, animals such as snow leopards, bears and mountain goats may not be confined to forested areas. Thus for the Nanda Devi biosphere reserve, the total effect may be more noteworthy than just the effect on target land use classes.

9.1.6 Nilgiri Biosphere Reserve

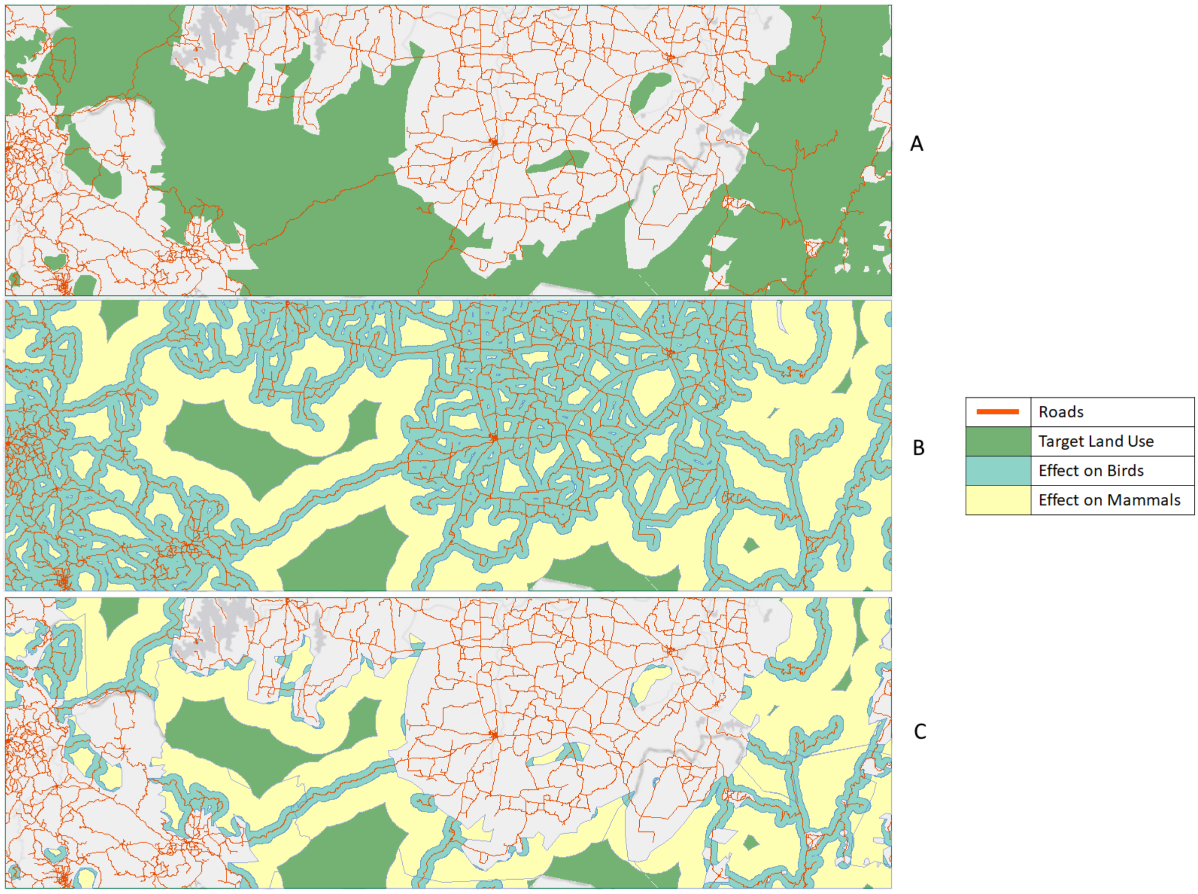


Figure 9-10: (A) Roads and target land use cover in Reserve. (B) Core area of impact on birds and mammals. (C) Effect on land use classes only

The Nilgiri Hills of southern India are a mix of forests and tea plantations. There is a large network of roads and villages all throughout the Biosphere Reserve. As is evident from the results, even the core impact area is significant, while the full impact indicates that wildlife in the entire reserve may be show signs of disturbance.

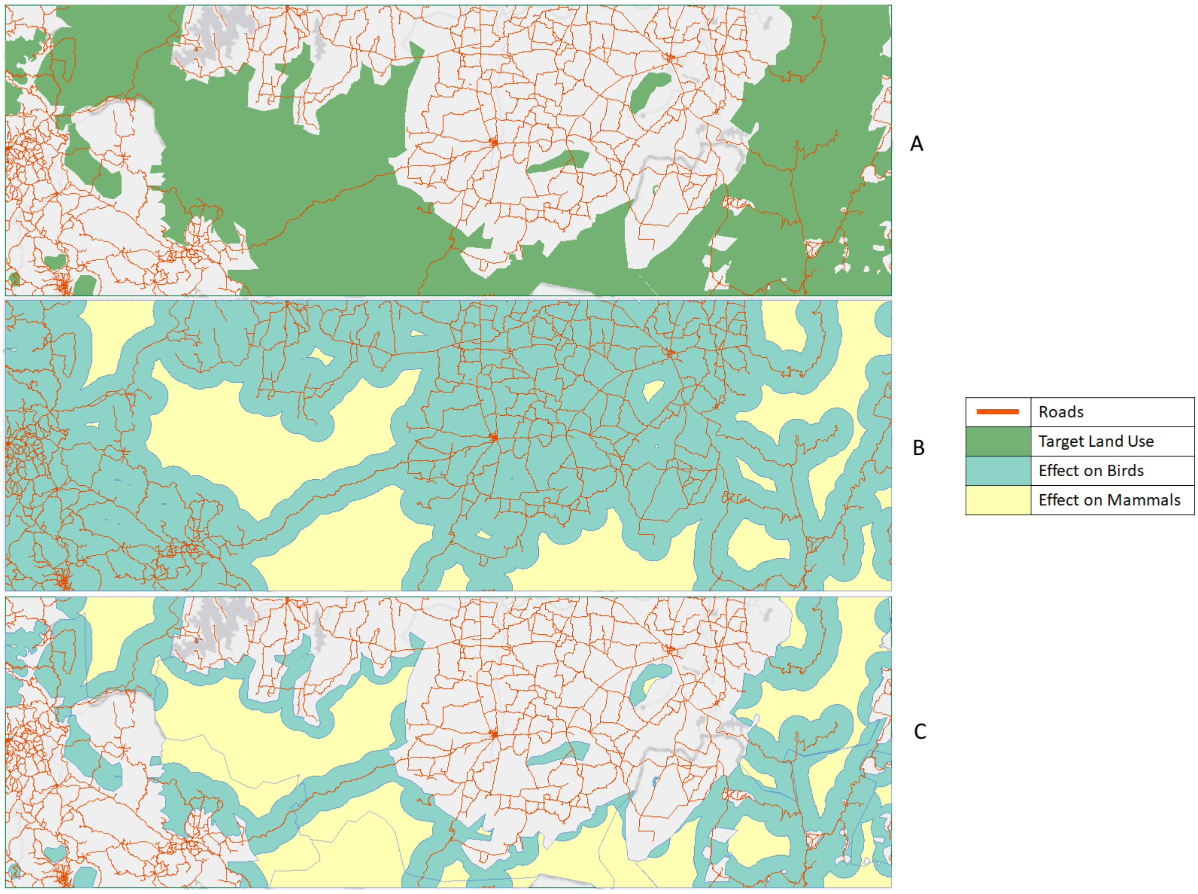


Figure 9-11: (A) Roads and target land use cover in Reserve. (B) Full area of impact on birds and mammals. (C) Effect on land use classes only

9.1.7 Nokrek Biosphere Reserve

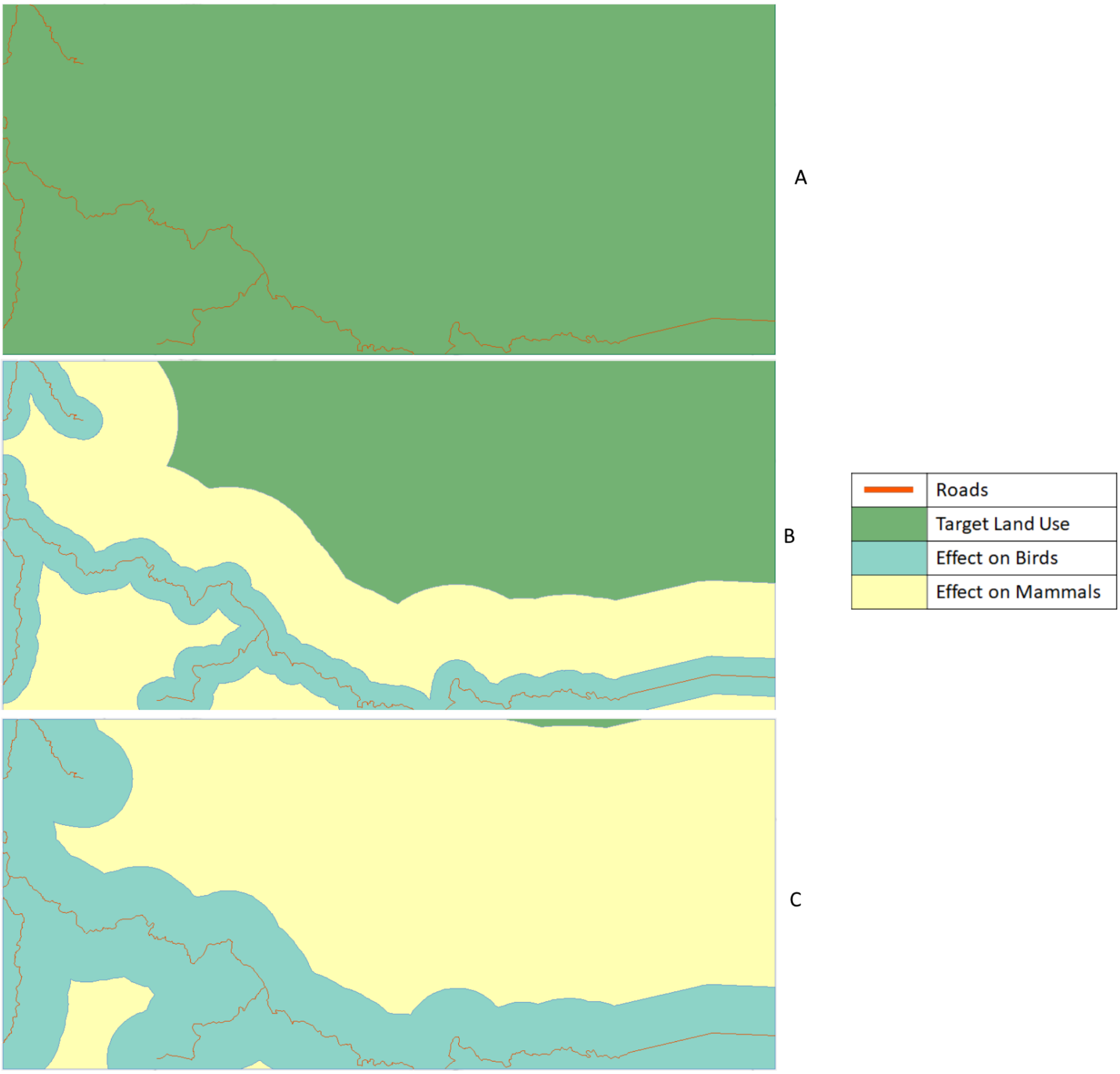


Figure 9-12: (A) Roads and target land use cover in Reserve. (B) Core area of impact on birds and mammals. (C) Full area of impact on birds and mammals

Nokrek Biosphere Reserve and the national park by the same name lie close to the India-Bangladesh border, in the north-Eastern state of Meghalaya. The Reserve is one of the smallest in the list, but it is completely covered by forest and does not have a lot of roads passing through. However, due to the small size, the impact is significant. While the more severe "core impact" area does not affect Nokrek National Park, the full impact on mammals may be felt throughout the reserve.

9.1.8 Pachmari Biosphere Reserve

Pachmari Biosphere Reserve is located in Madhya Pradesh. The Reserve contains three protected areas within it. Most of the denser road networks fall outside the key land use areas, however enough roads cross the forests that the size of the impacted area is not insignificant.

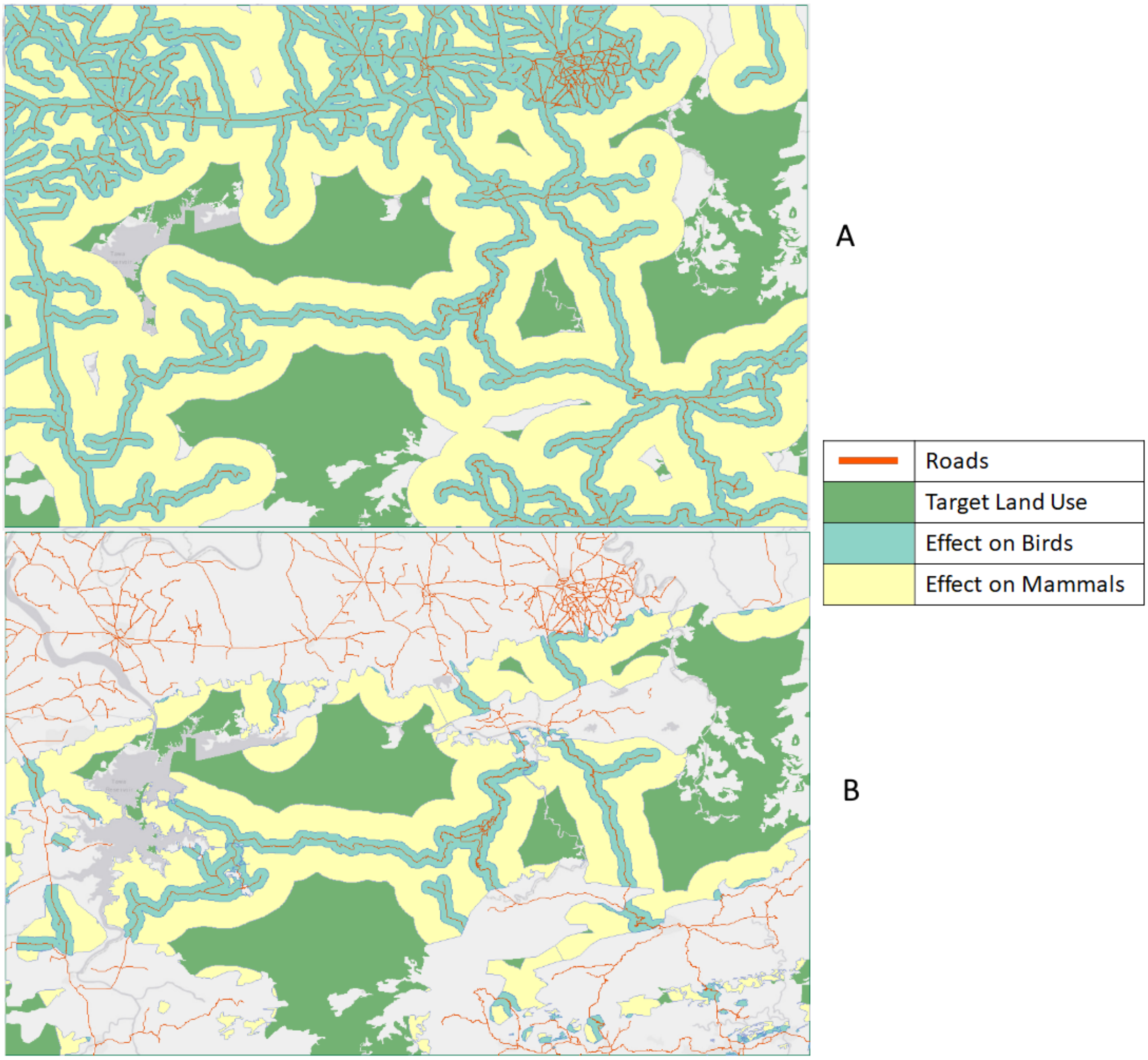


Figure 9-13: (A) Core area of impact on birds and mammals. (B) Effect on land use classes only

The “full impact” area covers almost the entire reserve, save for a small area in the east. Due to the socio-economic characteristics of the area, it is hard to tell whether this is a realistic picture.

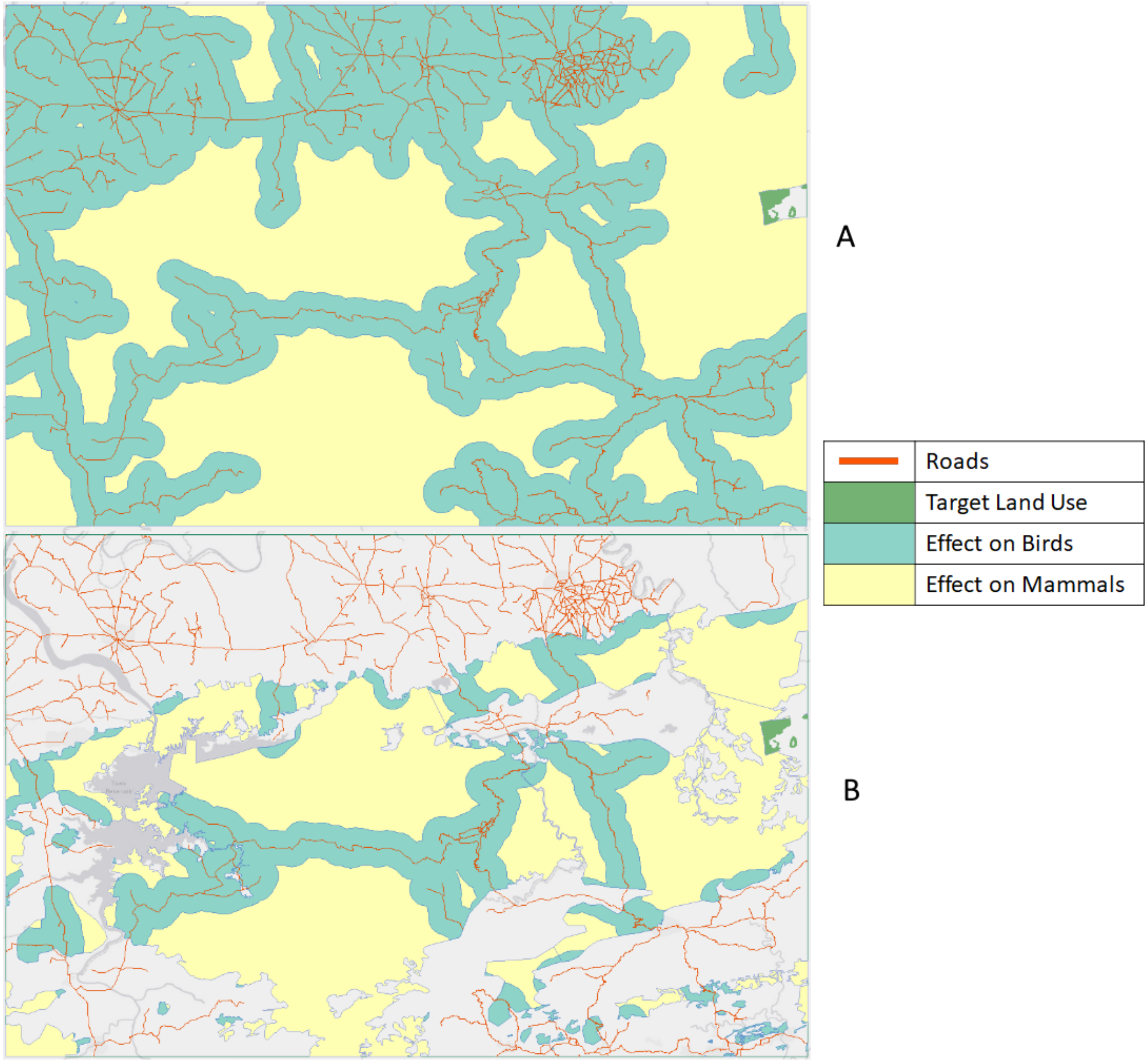


Figure 9-14: (A) Full area of impact on birds and mammals. (B) Effect on land use classes only

9.1.9 Simlipal Biosphere Reserve

The Simplipal Biosphere Reserve in the state of Orissa does not have a very dense road network, however it is a medium sized reserve and thus the effect on both forest and non-forested areas are sizable. While roads do cut across the reserve forests in a couple of places, the “core impact” area is not that much.

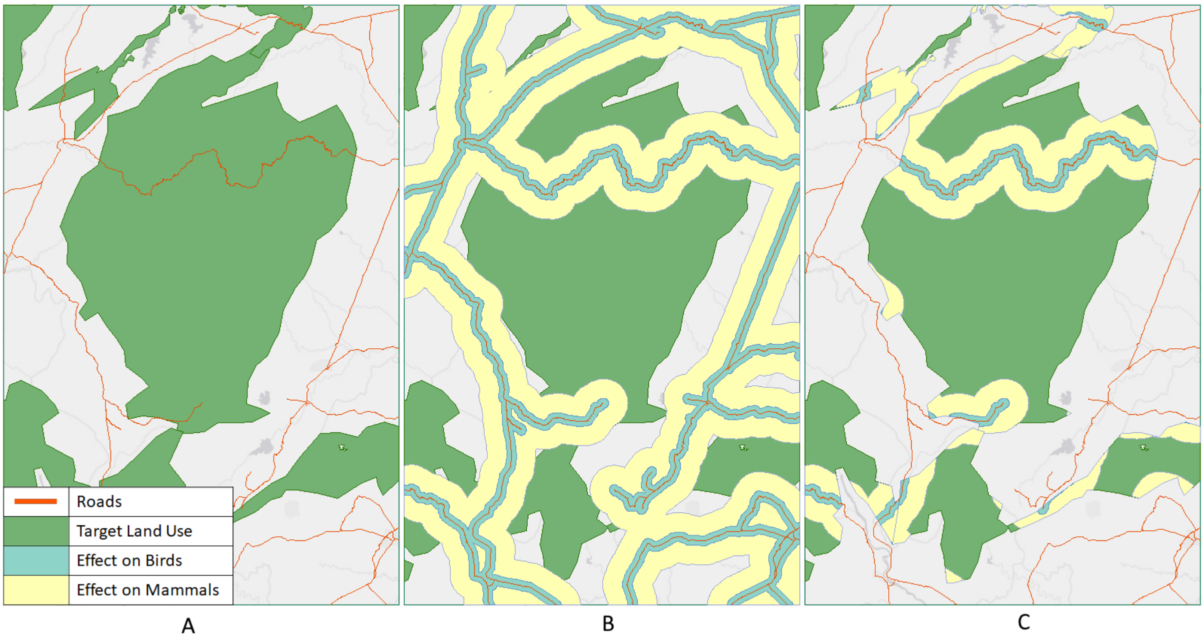


Figure 9-15: (A) Roads and target land use cover in Reserve. (B) Core area of impact on birds and mammals. (C) Effect on land use classes only

The many roads surrounding the forests mean that all but the very heart of the reserve is likely to be free of disturbance.

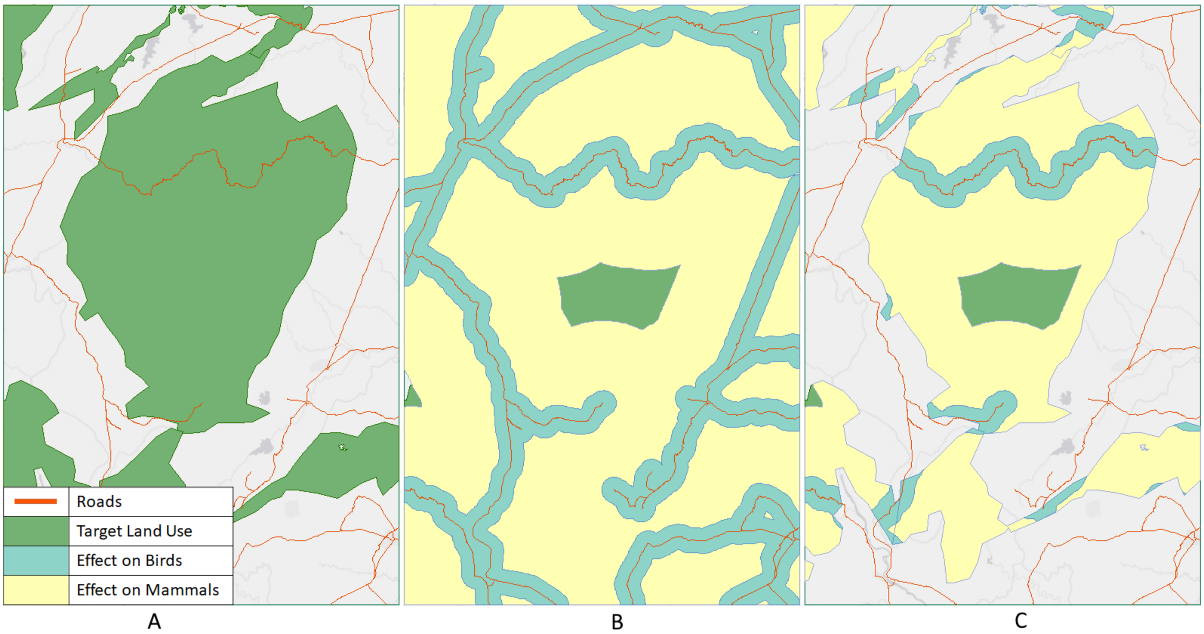
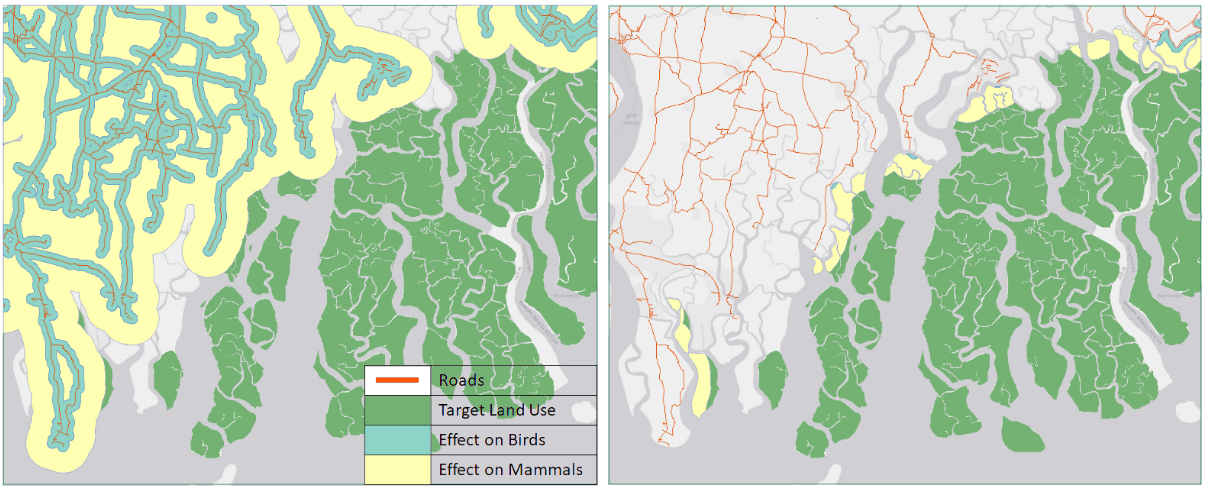


Figure 9-16: (A) Roads and target land use cover in Reserve. (B) Full area of impact on birds and mammals. (C) Effect on land use classes only

9.1.10 Sunderban Biosphere Reserve

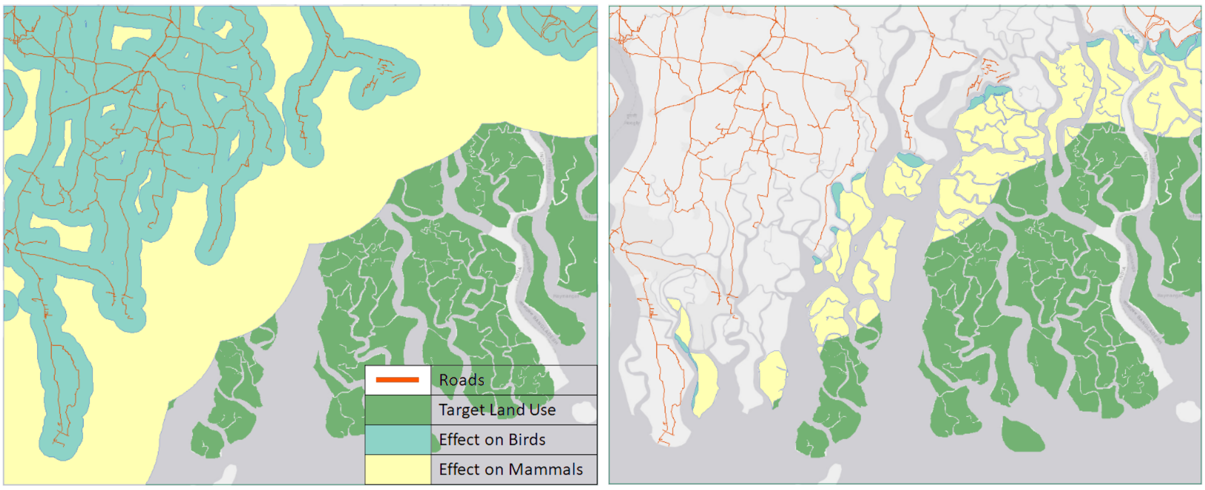
The Sunderban Biosphere Reserve in the eastern state of West Bengal encloses a part of the Sundarbans mangrove forest. The forest is shared between India and Bangladesh and has formed in the Ganga-Bramhaputra river delta. While mostly rural, the Biosphere Reserve is fairly close to the state capital of Kolkata, a major Indian city. The Sundarbans are a source of significant fisheries and forest related resources and are thus under increasing pressure from anthropogenic factors.



A B

Figure 9-17: (A) Core area of impact on birds and mammals. (B) Effect on land use classes only

That said, while there is a fairly dense network of roads in the Reserve, it's entirely outside of the protected National Park area. However, some roads do exist near the forest edges, so some effect is still felt. Despite that, my results indicate that the Sunderban Biosphere Reserve likely suffers the least impact to its bird and mammal populations from road networks.



A B

Figure 9-18: (A) Full area of impact on birds and mammals. (B) Effect on land use classes only

10 Appendix – D

10.1.1 Achanakmar-Amarkantak Biosphere Reserve

Achanakmar-Amarkantak has a rural population that depends on agriculture and Non-Timber Forest Products (NTFP). The hunting impact is likely to be lower than expected here. Despite that, about half the forest area is susceptible to a serve impact on its bird populations due to hunting.

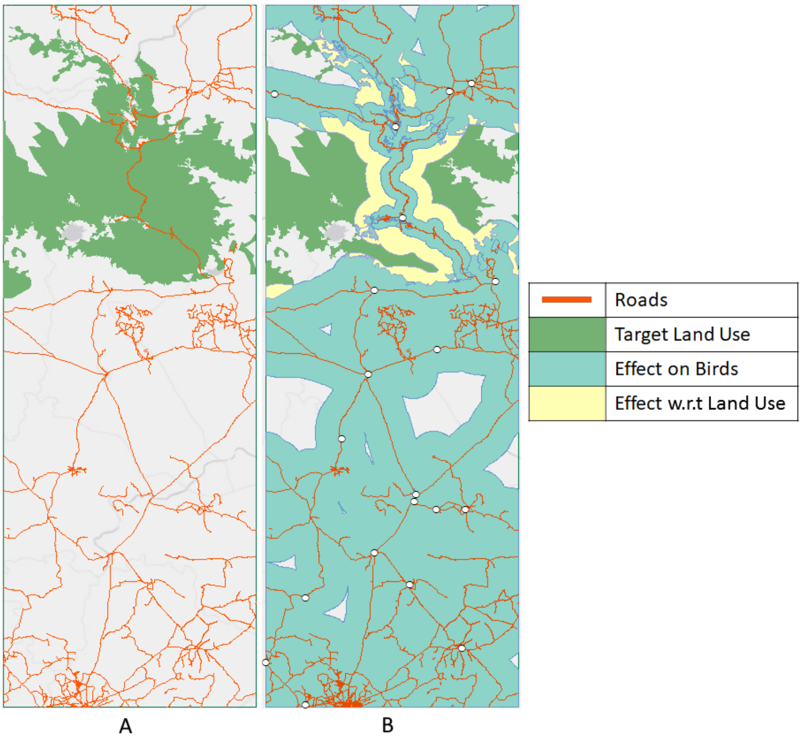


Figure 10-1: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.2 Agasthyamala Biosphere Reserve

The heavily populated Agasthyamala Biosphere Reserve has a dense road network with significant access points for potential hunters. Only a small central portion is likely to be unaffected in this case.

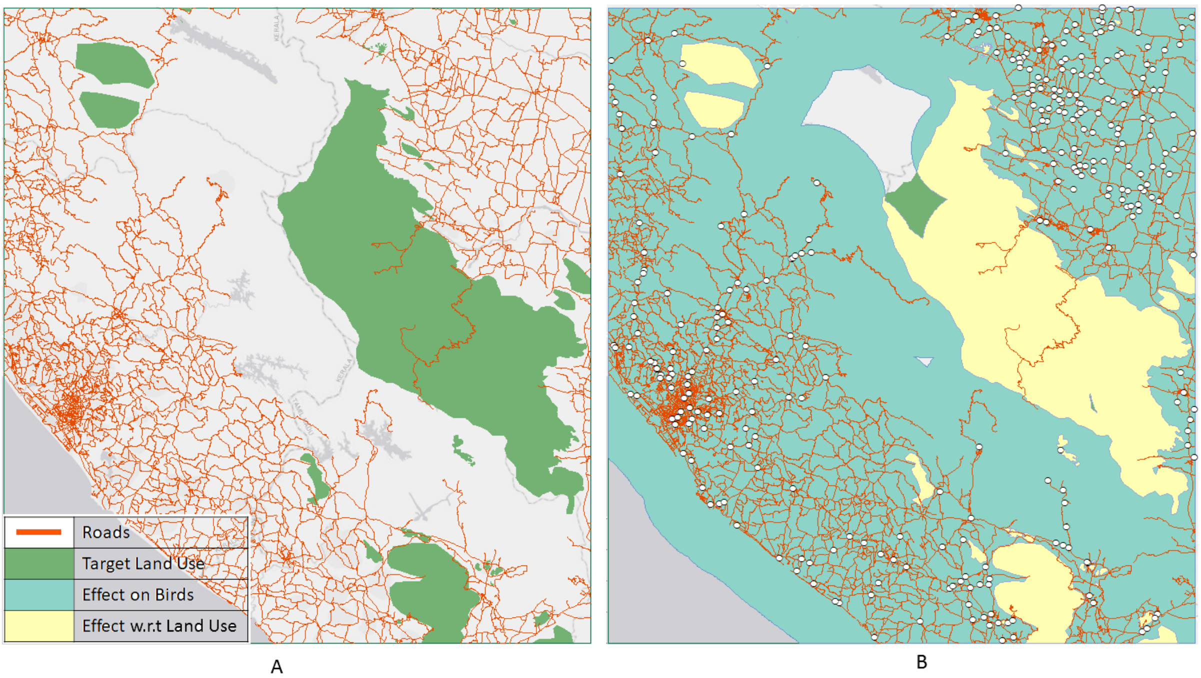


Figure 10-2: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.3 Great Nicobar Biosphere Reserve

A small tribe of hunter-gatherers lives on the island of Great Nicobar, within the Biosphere Reserve. While they likely have access to most of the island via boat, that is outside the scope of the study. The roads and settlements are limited to the east coast of the island, however the predicted impact of hunting is still expected to be felt across 40% of the island.

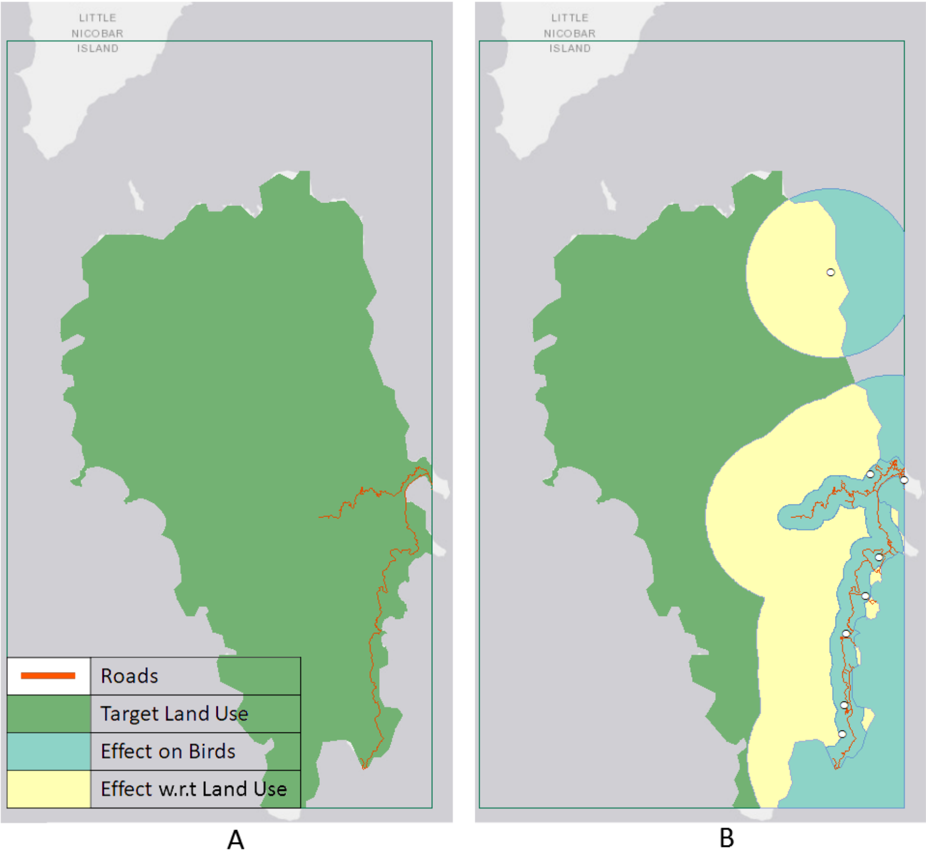


Figure 10-3: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.4 Gulf of Mannar Biosphere Reserve

As mentioned previously, this is a marine biosphere reserve. Much of the socio-economic activities in the region revolve around fisheries, therefore, determining the area impacted by hunting birds does not provide much insight here.

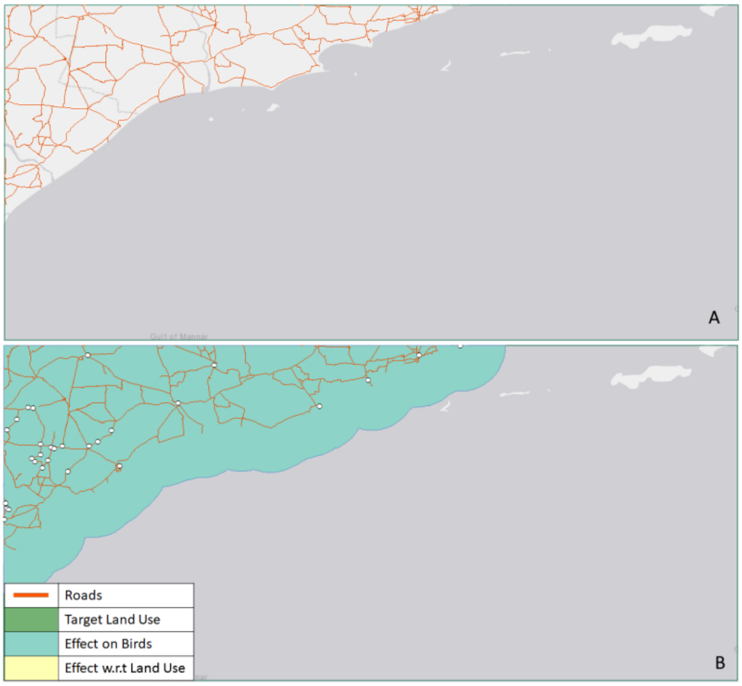


Figure 10-4: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.5 Nanda Devi Biosphere Reserve

The inhabitants of the Nanda Devi area mostly practice agriculture and animal husbandry. While there is dependence on timber and NTFPs, hunting is not common in this area. Therefore, the actual impact is likely to be much lower in the indicated effect area. Further, the mountainous terrain means that off-road access distances may not be that much, although cattle and goat trails provide off-road mobility in the Indian Himalayas.

As noted before, the OSM land use data does not sufficiently describe the Nanda Devi Biosphere Reserve, and thus the predicted impact area on target land use classes is likely inaccurate.

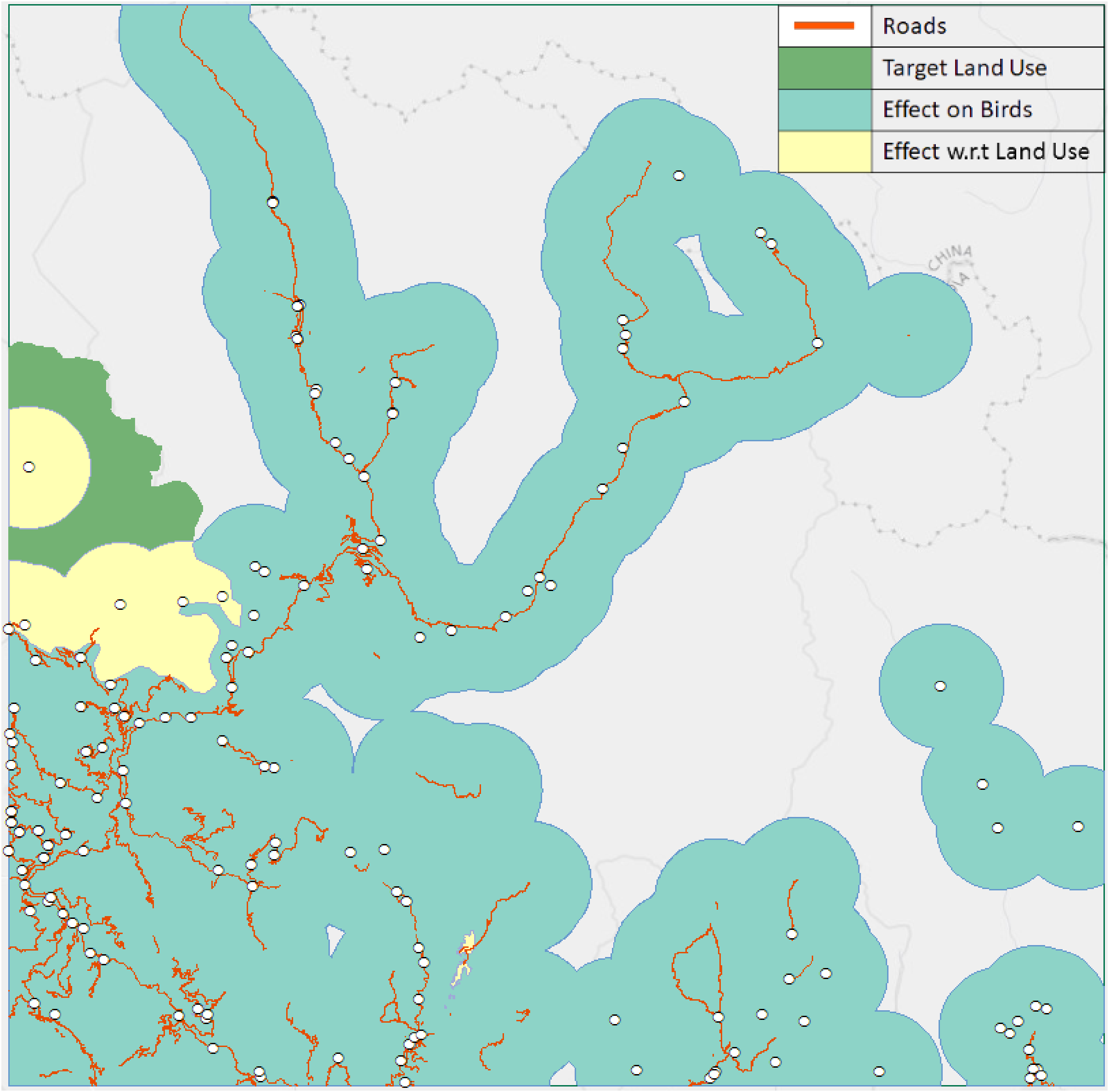


Figure 10-5: Map showing area in which birds are likely to be impacted by hunting, along with the area of affected land use classes

10.1.6 Nilgiri Biosphere Reserve

Much like the Agasthyamala Biosphere Reserve, the Nilgiri range is home to a significant human population and contains a dense network of roads. Hunter-gatherer tribes do exist in the region, so the results have higher importance in this case. Very few spots in the Biosphere Reserve are likely to be unaffected by hunters that are hunting birds.

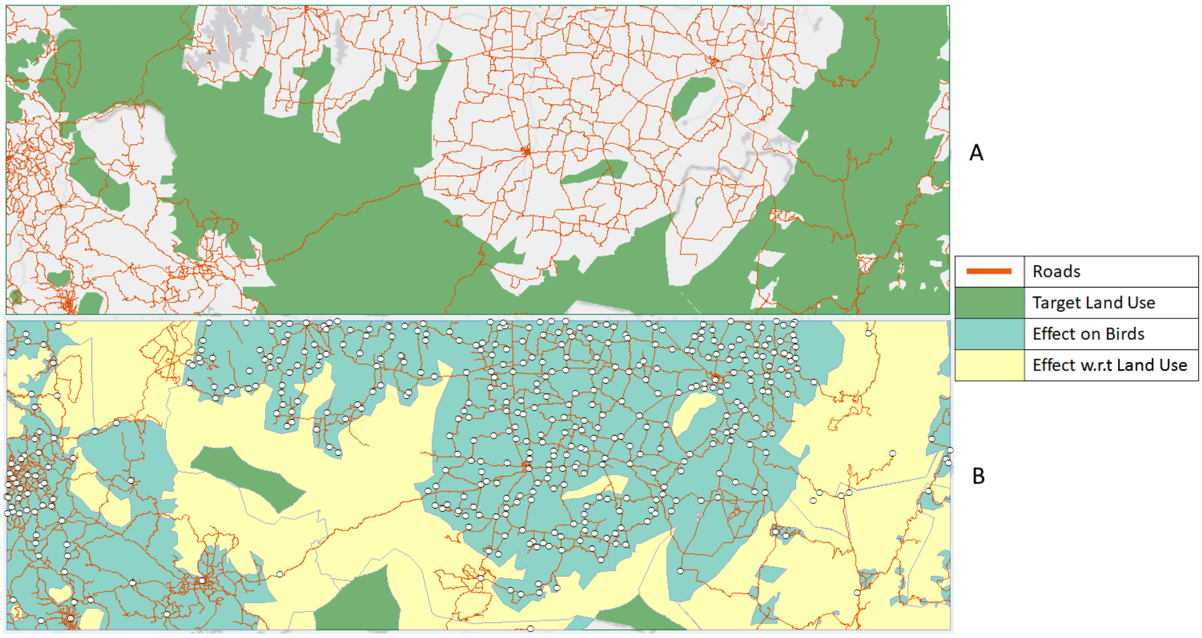


Figure 10-6: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.7 Nokrek Biosphere Reserve

The results for Nokrek require some discussion and caveats. According to the OSM dataset, there are no settlements within the Reserve, however some were present outside the western and southern boundary. However, UNESCO data indicates that around 22 thousand tribal and non-tribal peoples inhabit the area. There is a chance, therefore, that the actual area affected by potential hunting is larger – but that depends on where these settlements are located.

On the other hand, the populace seems to be mostly dependent on agriculture, timber and NTFPs. They do not appear to hunt for reasons other than ceremonial purposes, so the effect on birds may not be that significant in the area.

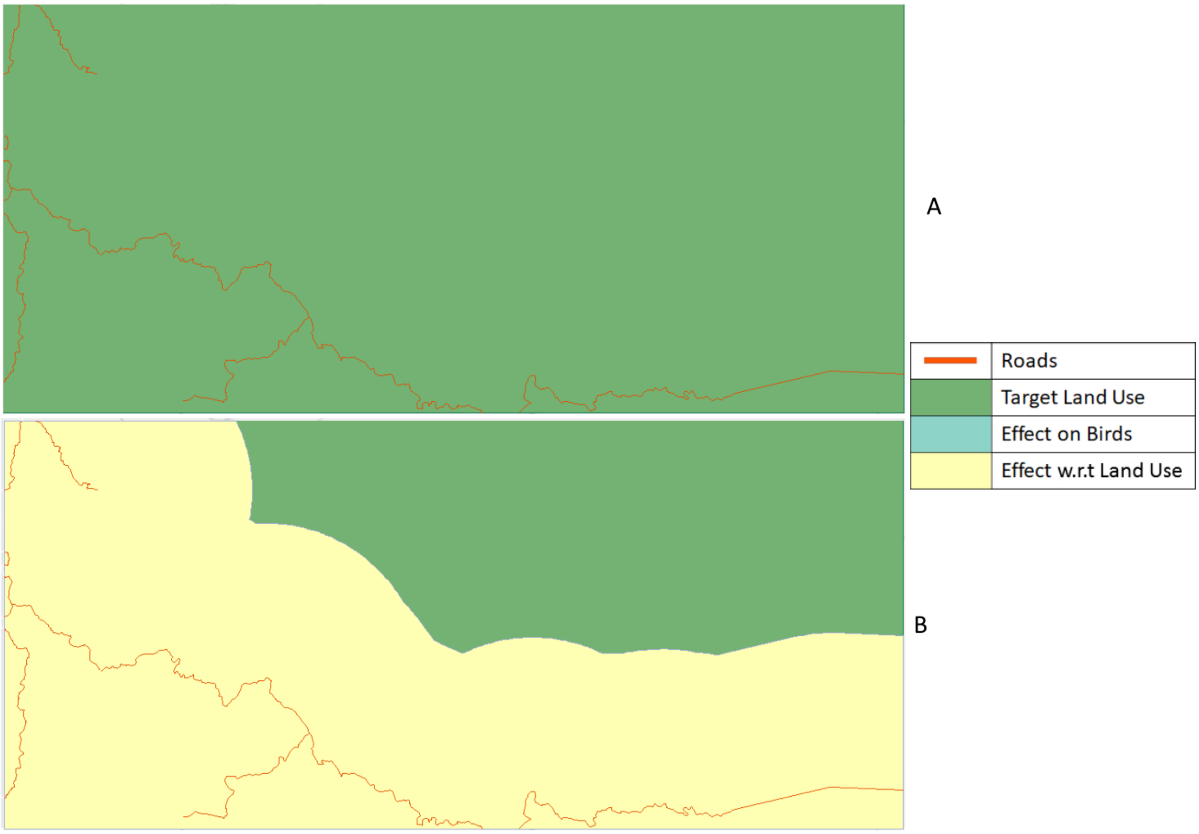


Figure 10-7: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.8 Pachmari Biosphere Reserve

A major portion of the Pachmari Biosphere Reserve is predicted to be affected by hunting practices. However, the tendency of local populations to hunt seems low. That said, there are large areas that are shown to be unaffected by potential hunting. The topography is hilly, which may provide a further reduction in hunting access.

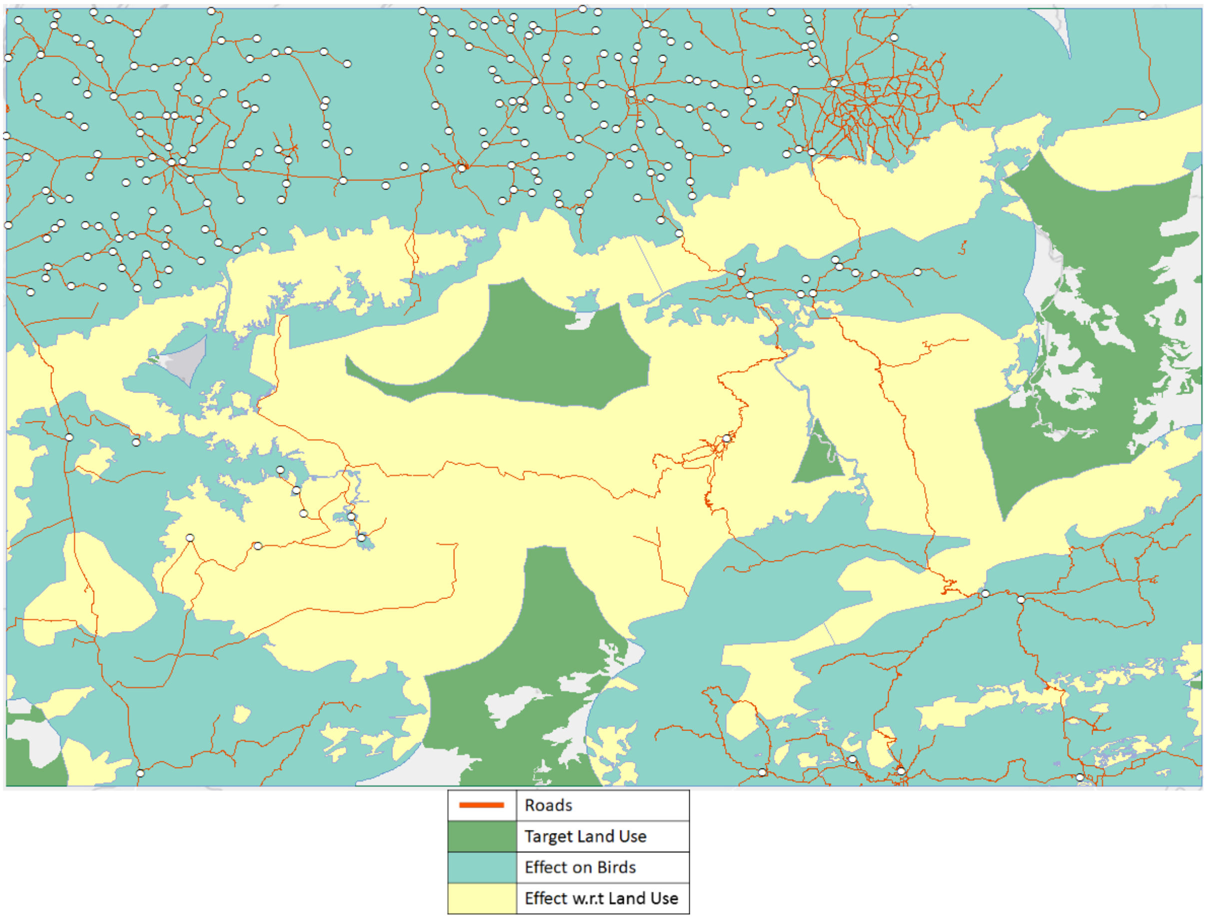


Figure 10-8: : (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.9 Simlipal Biosphere Reserve

Agriculture is the main activity of the tribal populations inhabiting the Simlipal Biosphere Reserve, suggesting a lower magnitude of effect on the species abundance of birds in predicted areas. The impact area predicted on land use classes is large, but a number of unaffected areas remain, which is a positive for wildlife conservation efforts.

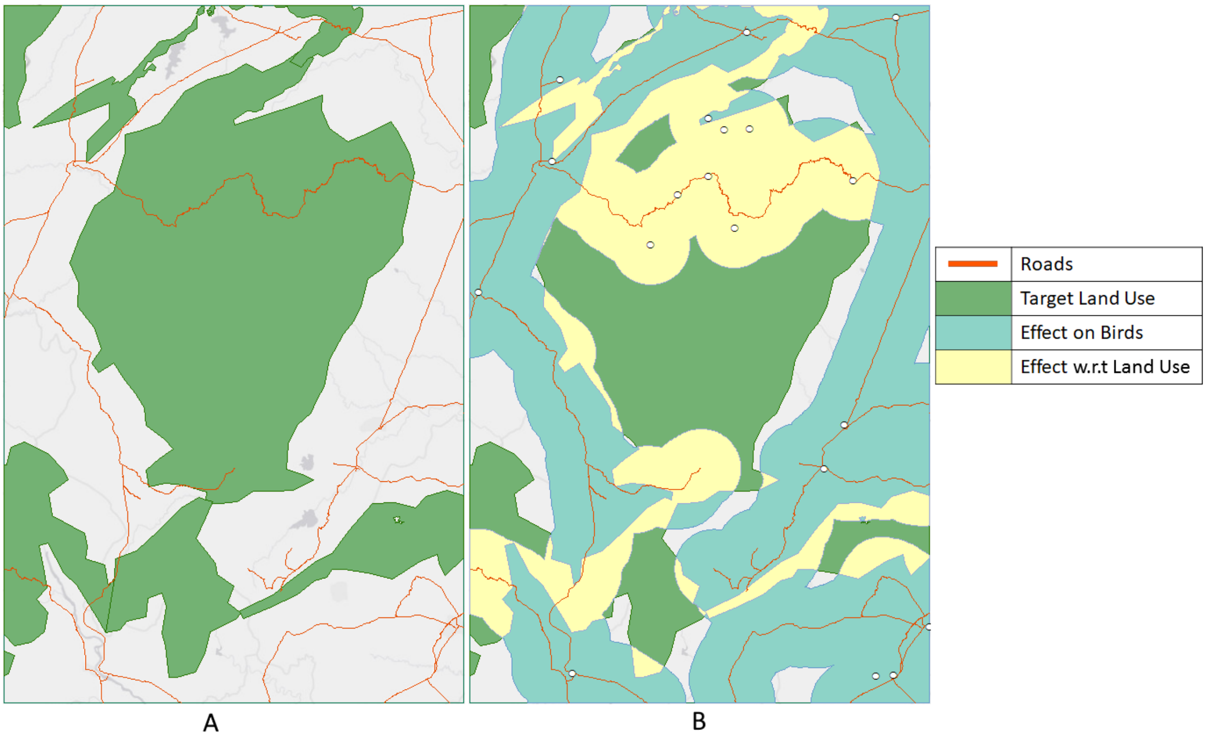


Figure 10-9: (A) Road map and land use classes within the Biosphere Reserve. (B) Effect area on birds, in total and with respect to land use classes

10.1.10 Sunderban Biosphere Reserve

The rural areas of the Sundarbans depend heavily on forest products and fisheries. Fortunately, much of the terrestrial access points available to potential hunters are located near the periphery of the forest area. A fiercely territorial tiger population also helps limit the access within the denser regions of the Reserve, however that is outside the scope of this study. Access by boat is highly likely, but this is not modelled here.

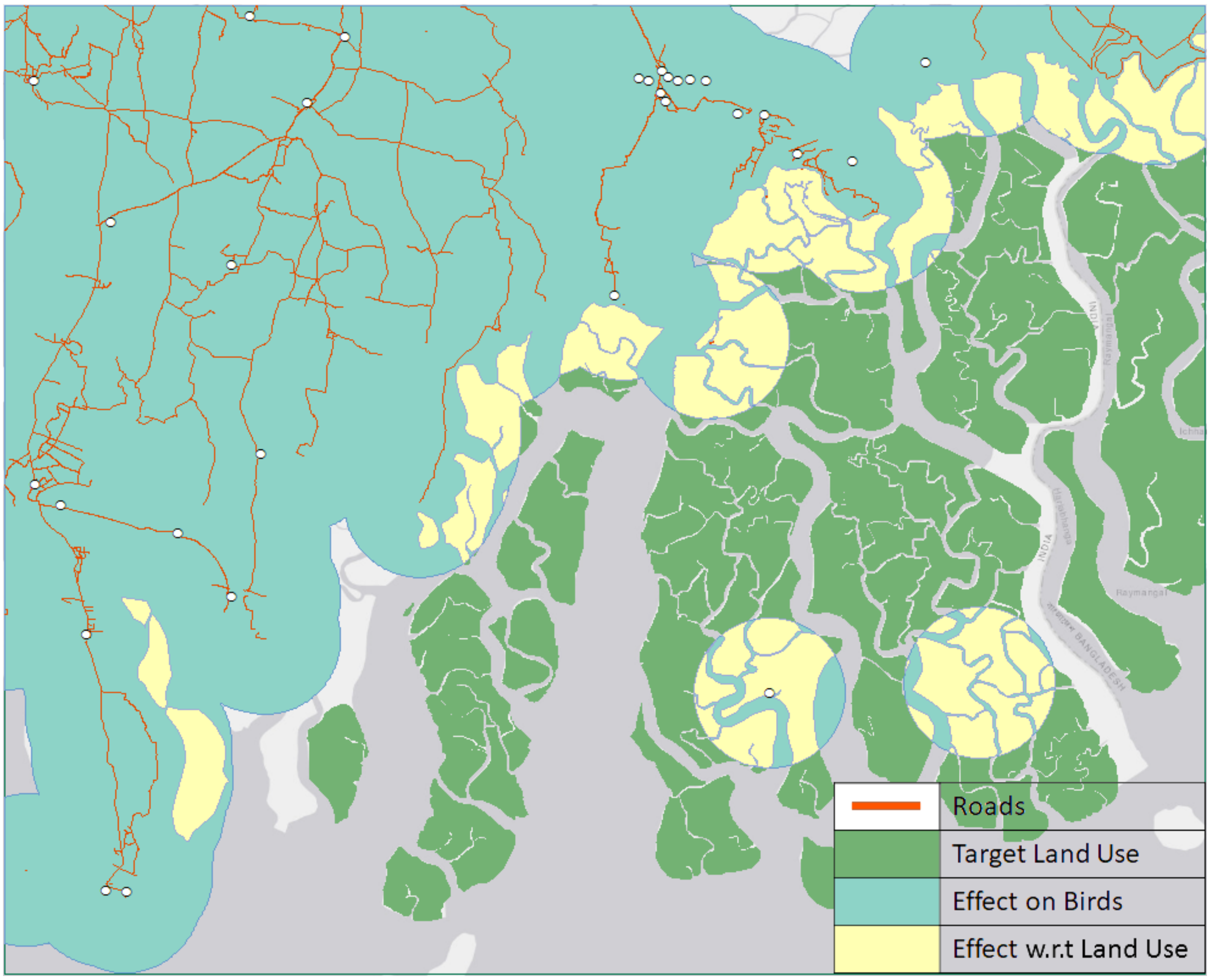


Figure 10-10: Map showing area in which birds are likely to be impacted by hunting, along with the area of affected land use classes