

**ASSESSMENT OF THE EXISTING NATIONAL HIGHWAY-7
AND ITS PROPOSED WIDENING ON HABITAT USE AND
MOVEMENT OF WILD ANIMALS IN PENCH TIGER
RESERVE, MADHYA PRADESH**

Thesis submitted to the
Saurashtra University, Rajkot
Gujarat

For the Award of the Degree of
Doctor of Philosophy
in
Wildlife Science

By
A.Pragatheesh



भारतीय वन्यजीव संस्थान
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March 2019



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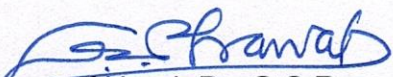
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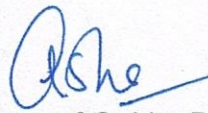
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Effect of human feeding on the road mortality of Rhesus Macaques on National Highway - 7 routed along Pench Tiger Reserve, Madhya Pradesh, India

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Date of publication (online): 26 April 2011
Date of publication (print): 26 April 2011
ISSN 0974-7907 (online) | 0974-7893 (print)

Editor: Mewa Singh

Manuscript details:

Ms # o2669
Received 06 January 2011
Final received 04 February 2011
Finally accepted 10 February 2011

Citation: Pragasheesh, A. (2011). Effect of human feeding on the road mortality of Rhesus Macaques on National Highway-7 routed along Pench Tiger Reserve, Madhya Pradesh, India. *Journal of Threatened Taxa* 3(4): 1656–1662.

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Author Details: A. PRAGASHEESH is a research fellow pursuing doctoral research at the Wildlife Institute of India (WII) on the topic "Assessment of the existing National Highway – 7 and its proposed widening on habitat use and movement of wild animals in Pench Tiger Reserve, Madhya Pradesh".

Acknowledgements: I thank the Director and Dean, Wildlife Institute of India and Madhya Pradesh Forest Department for providing permissions and logistic support. I acknowledge the help rendered by the field assistants-Shivanand and Dhanalal during the fieldwork. Dr. Asha Rajvanshi, Dr. K. Ramesh, Dr. J. Antony Johnson and Dr. Jatinder Chadha are thanked for their technical guidance and assistance in the preparation of the manuscript.



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Abstract: In Hindu mythology, Hanuman is worshipped as the monkey god and therefore there is a great reverence for macaques all across the country. Hindu devotees consider it their sacred duty to feed macaques along road, temples, parks and other public areas. Unfortunately, such food provisioning alters the habitat, food choice and behaviour of macaques. We studied the impact of feeding by humans on Rhesus Macaque *Macaca mulatta* feeding behaviour, distribution and also assessed the increased risk of accidents in the 11km road stretch of National Highway passing through Kanha-Pench corridor, from August 2009 to July 2010. Seasonal changes in macaque distribution and group sizes were assessed based on foot and vehicle transects. The numbers of road kills were monitored in early morning and late evening hours for different seasons. Five groups of macaques were occupying a minimum of 1.1 to a maximum of 1.7km stretch, together covering about 7.3km of road. Group size varied significantly in relation to the availability of food on the road. During the study, 54 macaques succumbed to road accidents. Maximum roadkill occurred during summer because of the greater inflow of tourists. Unless concerted efforts are made to increase awareness among people of the hazards of road-side feeding, incidences of macaque mortality are likely to increase.

Keywords: Behaviour, feeding, Pench Tiger Reserve, Rhesus Macaques, roadkills.

INTRODUCTION

India has long been known as one of the rich primate areas of the world, both in species diversity and population abundance. Eight species of macaques occur in India, namely, Rhesus Macaque *Macaca mulatta*, Bonnet Macaque *M. radiata*, Assamese Macaque *M. assamensis*, Stump-tailed Macaque *M. arctoides*, Pig-tailed Macaque *M. leonina*, Lion-tailed Macaque *M. silenus*, Arunachal Macaque *M. munzala* and Long-tailed Macaque *M. fascicularis umbrosa*. The Rhesus Macaque *Macaca mulatta* is one of the most common non-human primates in India. Among the non-human primate species of the world, the Rhesus macaque has the widest geographic distribution, occurring from Afghanistan in the west to Vietnam, Hong Kong and eastern China as far north as Beijing (Bangjie 1985). The Rhesus Macaque is a diurnal species occurring in a variety of habitats occupying both terrestrial and arboreal niches. They inhabit the deserts of Rajasthan, agricultural plains of the Gangetic basin, the tropical forests of southeastern Asia, the temperate pine forests of the Himalaya, and the rugged mountains of north central China (Southwick et al. 1994). In India, Rhesus Macaques are found from 1400m altitude in the Himalaya to the sea level in Sunderbans and in the south up to the river Godavari (Srivastava 1999). Range overlap with Bonnet Macaques occurs in the southern part of the country (Fooden et al. 1981). Rhesus

Macaques are the most adaptable of all non-human primates and have learned to live amidst human habitations. In India, 80 to 90 % of Rhesus Macaques live in close association with human populations, and are therefore highly dependent on people for food (Southwick et al. 1965, 1976).

This relationship between humans and monkeys dates back to ancient cultures and is deeply rooted in Hindu mythology. Monkeys are associated with Hanuman, the Monkey God in the epic Ramayana. Monkeys are believed to be the direct descendants of Lord Hanuman and are highly revered by Hindus. Feeding of monkeys on road sides is still a common practice across India. The increasing number of habituated macaque populations living in proximity to human settlements has become a major concern in India. Southwick et al. (1976) documented in detail the effect of artificial feeding on behaviour and ecology of Rhesus Macaques. The study not only highlighted the changes in the aggressive behaviour associated with artificial feeding but also recorded changes in their diet, home range, and primary habitat that further influenced social behaviour and the spatial distribution of the animals. Several authors have

recorded the negative effects of artificial feeding and roadkill studies on Hanuman Langurs *Semnopithecus entellus* in India (Mohnot 1974; Agoramorthy 1987; Rajpurohit 1987; Rajpurohit et al. 1997; Chhangani 2000, 2001, 2004).

Studies are lacking related to impacts of road side feeding by humans on distribution and risks of mortality in Rhesus Macaques in India; this study assesses these impacts.

Study area

The National Highway NH-7 runs along the north-south axis connecting Varanasi (northern India) with Nagpur (central India) and Hyderabad and Bengaluru (southern India). This study was conducted in the 11km stretch of NH-7 between the villages Kurai (21°49'N & 79°30'E) in the south to Gandatola (21°53'N & 79°32'E) in the north, aligned along on the eastern boundary of the Pench Tiger Reserve, Madhya Pradesh and bisecting the Kanha-Pench corridor. The portion of the road is routed along the eastern boundary of Pench Mowgli Sanctuary of the Pench Tiger Reserve for a length of 11km (Fig. 1). The topography of the study area is mostly undulating, characterized by small

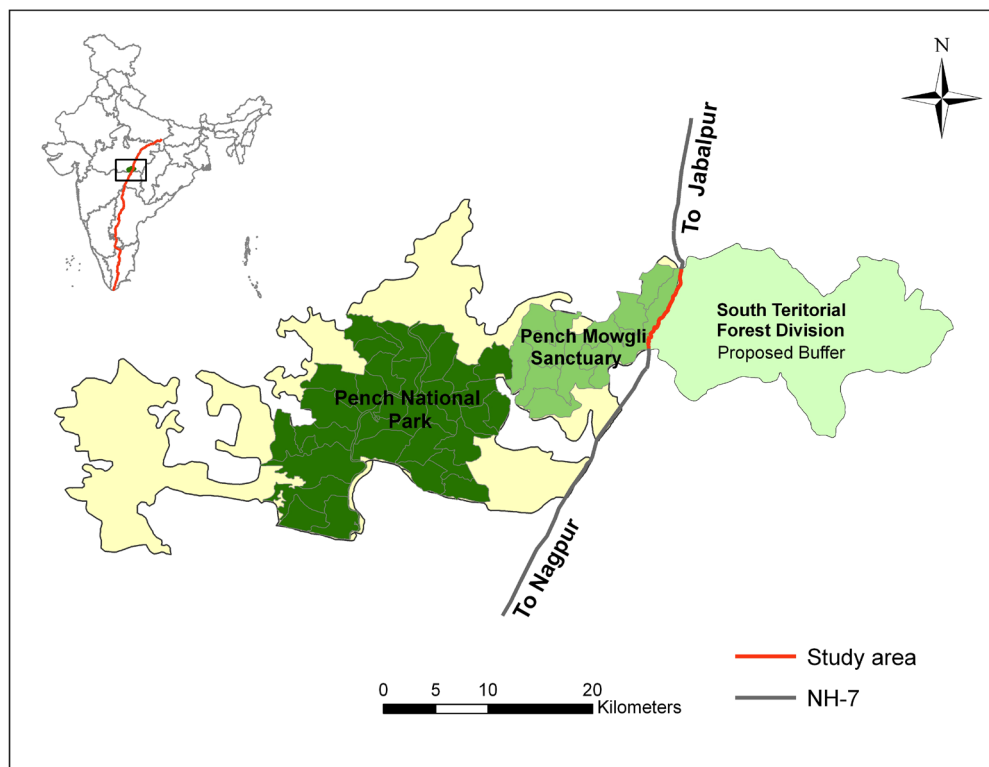


Figure 1. Section of the NH-7 representing the area of the study

ridges and hills having steep slopes and a number of seasonal streams or nallahs. The mean annual rainfall is around 1400mm with the south-west monsoon accounting for most of the rainfall in the region. The temperature varies from a minimum of 0°C in winter to 45°C in summer.

METHODS

Distribution of Rhesus Macaques along roads

Distribution was assessed via two methods: line transects and road transects. A total of 18 permanent line transects (2km length) were laid perpendicular to the highway over the 11-km stretch in different habitat types on both sides of the road. Each transect was walked four times in a season and information on the number of animals sighted, location, habitat, group size and age structure was collected. Presence of Rhesus Macaques was recorded at every 100m on the line transect based on direct evidence. A vehicle was driven along forest roads at a speed of <20 km/h on the transect road. When macaques were spotted, Global Positioning System (GPS; Garmin 72 unit) locations and observations on group size and habitat type were recorded. The same road was surveyed four times in every season. Presence of animals was marked at every 100m in GIS domain. In addition, National Highway 7 was also surveyed for macaques on and along the roadside. Encounter rates were calculated for adults and juveniles.

Roadkill data collection

The sampling period was divided into three seasons: monsoon (July to October), winter (November to February) and summer (March to June). From August

2009 to July 2010 the entire stretch of road (11km) was surveyed by vehicle (driven at 10- 20 km/hr). Data was recorded twice per day during early morning (0530-0630 hr) and late evening (1730-1830 hr) for road kills. When kills of Rhesus Macaque were encountered on the road, the team recorded GPS location, determined sex and age and took notes on roadside habitat features. The dead macaques were identified and removed from the road to avoid repeat count in subsequent surveys. We used a kernel density estimation method (Gitman & Levine 1970) for identifying high mortality zones using the spatial analyst toolbox for ArcGIS following Ramp et al. 2005, 2006 and Gomes et al. 2009. Traffic information was collected by continuous monitoring for three days per season to determine the per day traffic volume during the study period.

RESULTS

Group size and distribution along road

In the study area a total of five major groups of macaques identified as A, B, C, D and E were observed in the 11km section of road (Table 1, Fig. 3). These groups together comprised 305 animals representing 67 males, 158 females and 80 juveniles. Sometimes a group temporarily broke into smaller groups with varying numbers of individuals. Group size varied between 36 and 82 individuals, with mean 61 ± 19 . Group size was positively related to the number of people feeding monkeys on the road (Pearson-product moment $r = 0.968$, $p = 0.01$) (Table1). During summer and late winter all individuals in the five groups were attracted towards the road because of food offered by humans. The encounter rate of macaques on the line and road transects survey showed that the use of roadside

Table 1. Average number of Rhesus Macaque sighted on NH-7 along Pench Tiger Reserve

Group	Male	Female	Juvenile	Total no. of individual	Average no. of feedings by humans per day	Length occupied in km
A	9	26	10	45	14	1.1
B	15	35	17	67	32	1.6
C	17	34	24	75	37	1.7
D	7	18	11	36	16	1.4
E	19	45	18	82	47	1.5
Total	67	158	80	305	146	7.3

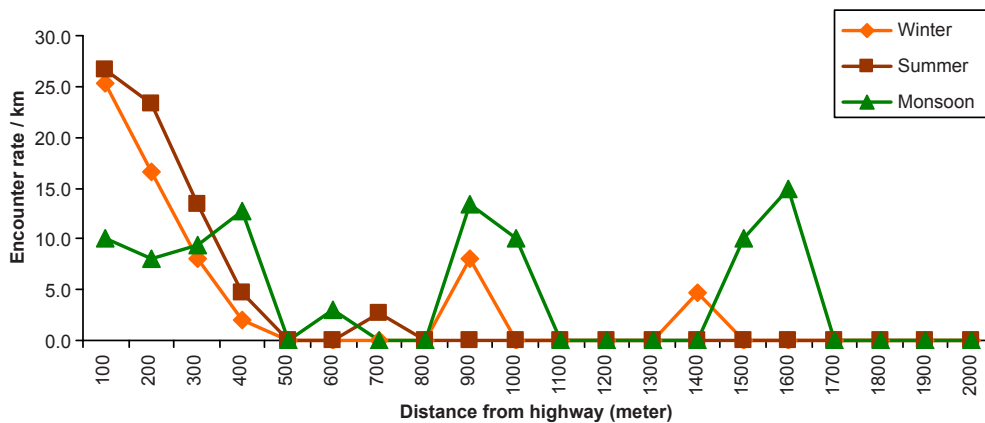


Figure 2. Encounter rate of Rhesus Macaque on the line transects

Table 2. Number of Rhesus Macaques killed on the NH-7 along Pench Tiger Reserve

Group	Male	Female	Juvenile	Total no. of individuals
A	3	2	2	7
B	2	3	0	5
C	4	7	3	14
D	1	6	1	8
E	8	11	1	20
Total	18	29	7	54

habitats in summer and winter was relatively high at 26.7 ± 7.5 individuals/km, and gradually decreased towards the forest interior, where no individuals were seen during summer (Fig. 2). The length of the road stretch occupied by different groups varied between 1.1 to 1.7 km together covering about 7.3km length (Table 1).

Roadkills

During the study period, 54 Rhesus Macaques were found killed on the road. The number of females killed was higher than the number of males and juveniles (Kruskal-Wallis $\chi^2 = 5.70$, $p = 0.05$. (Table 2). The number of road kills was 27, 19 and eight during summer, winter and monsoon respectively. Traffic intensity during summer, winter and monsoon was 3269, 2951 and 2884 vehicles/day respectively. Road kills were positively correlated with vehicular intensity (Spearman’s rho = 1.00, $p < 0.01$). Fatalities of the Rhesus Macaque occurred in a cluster on the road (Fig. 3). The kernel density method clearly revealed that the maximum number of roadkills was taking place at a location where the frequency of

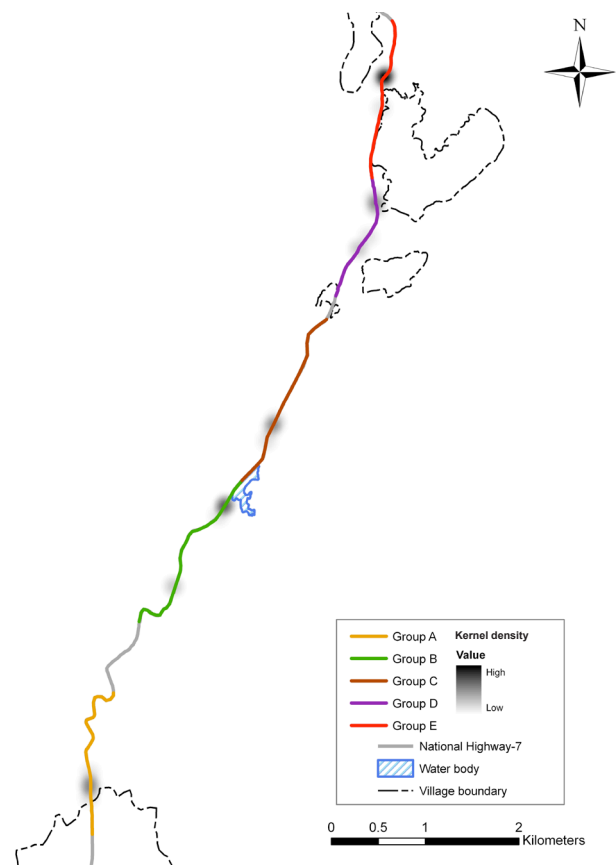


Figure 3. Location of Rhesus Macaque groups and location of road kills

feeding (artificial feeding) by passer-by was high.

DISCUSSION

Mean group sizes of macaques vary between 9.8-41 in forest (Southwick et al.1965; Mukherjee & Gupta 1965; Neville 1968; Singh 1969; Lindburg 1971;

Makwana 1978), and in urban area, it varies between 10-42 (Southwick et al. 1965; Mukherjee 1972) in urban and semiurban areas. The group size recorded in this study varied between 36- 82 individuals, mean 61 ± 19 . The higher group size found in the present study may be because of human feeding. The encounter rate of Rhesus Macaque shows the maximum number of animals using the roadside habitat during summer and late winter (Fig. 2). Southwick (1976) observed for 16 years that the Rhesus Macaques were found to use a specific location in all seasons. The study conducted in Asarori Forest in Dehradun by Makwana (1978) shows that foraging area for rhesus macaque was approximately 1.05 to 3.5 km. In this study rhesus macaque foraging area was a minimum of 1.1km to a maximum of 1.7km. The movement of the macaques was restricted by the availability of food from passers-by. The five group of macaques covered about 7.3km of the total length of the study area (Table 1).

In total 54 Rhesus Macaques were killed on this road (Table 2). This clearly reflects that the Rhesus macaque

is highly vulnerable to road accidents compared to other animals in the study area. Maximum number of road kills occurred during summer because of large numbers of tourist offering food (Image 1). The study conducted on Hanuman Langur by Chhangani (2004) showed that the maximum number of roadkills occurred during monsoons. Both studies showed that the passer-by behaviour of feeding animals influenced the road kills. The Rhesus Macaque is largely vegetarian but occasionally eats insects (Seth 2001). In earlier days, people used to feed macaques along the road by offering them gram or bananas. These days people offer all sorts of food including biscuits, chips and other snacks which are thrown in the middle of the roadway. Based on discussions with some passers-by and truck drivers, it was learnt that the people have adopted the practice of feeding macaques because they believed that monkeys do not get anything else to feed on. This irregular feeding makes macaques aggressive in their behaviour towards humans and other species (Bernstein & Mason 1963; Koford 1963; Loy 1970; Southwick et al. 1976). It is a common observation that when vehicles halt, macaques surround them forcing traveler(s) to offer eatables. In retaliation some people pelt stones. This indicates that the artificial feeding of wild macaques alters their habits and behaviour.

Roadkills of a wide array of wild animals are one of the major challenges in the current conservation scenario. Forest department and other non-government organizations are creating awareness amongst people by putting up hoardings along roadsides to educate people about the implications of feeding animals on the road (Image 2). These messages are generally ignored by people who continue to feed macaques because of the religious sentiments attached to this species. The monkey menace will only continue to grow unabated posing greater risks of road accidents, increasing human-wildlife conflicts and rising trends in mortality of macaques eventually leading to decline in their populations in the long term. Concerted efforts are needed by the conservation community, the state forest departments and civil society in raising awareness about the threats associated with artificial feeding of macaques.



Image 1. Rhesus Macaques being fed by a passer-by.



Image 2. Hoardings put up by the state forest department for creating awareness about hazards of feeding monkeys

REFERENCE

- Agoramoorthy, G. (1987).** Reproductive behaviour in Hanuman Langur, *Presbytis entellus*. PhD Thesis. University of Jodhpur, Jodhpur.
- Bangjie, T. (1985).** The status of primates in china. *Primate Conservation* 5: 63–81.
- Bernstein, I. & W.A. Mason (1963).** Activity patterns of rhesus monkeys in a social group. *Animal Behaviour* 11: 455–460.
- Chhangani, A.K. (2000).** Ecobehavioral diversity of langurs, *Presbytis entellus* living in different ecosystems. PhD Thesis. JNV University of Jodhpur, Jodhpur.
- Chhangani, A.K. (2001).** Threats to Kumbhalgarh Wildlife Sanctuary in relation to flora and fauna. *Journal of Nature Conservation* 13(2): 177–185.
- Chhangani, A.K. (2004).** Killing of Hanuman Langur in road accidents in Kumbhalgarh Wildlife Sanctuary, Rajasthan, India. *Primate Report* 69.
- Fooden, J., A. Mahabal & S.S. Saha (1981).** Redefinition of the Rhesus Macaques-Bonnet Macaque boundary in peninsular India. *Journal of the Bombay Natural History Society* 78: 463–474.
- Gitman, I., Levine, M.D. (1970).** An algorithm for detecting unimodal fuzzy sets and its application as a clustering technique. *IEEE Transactions on Computers* 19: 583–593.
- Gomes, L., C. Grilo, C. Silva & A. Mira (2009).** Identification methods and deterministic factors of owl road kill hotspot locations in Mediterranean landscapes. *Ecological Research* 24: 355–370.
- Koford, C. (1963).** Group relations in an island colony of Rhesus Monkeys, pp. 136–152. In: Southwick, C.H. (ed.). *Primate Social Behavior*. D. Van Nostrand Co., New York.
- Lindburg, D.G. (1971).** The Rhesus Monkey in north India: An ecological and behavioural study, pp. 1–106. In: Rosenblum, L.A. (ed.). *Primate Behaviour; Developments in Field and Laboratory Research*, Vol. 2. Academic Press, New York.
- Loy, J. (1970).** Behavioral response of free-ranging rhesus monkeys to food shortage. *American Journal of Physical Anthropology* 33: 263–271.
- Makwana, S.C. (1978).** Field ecology and behaviour of the Rhesus Macaque (*Macaca mulatta*): I. group composition, home range, roosting sites, and foraging routes in the Asarori forest. *Primates* 19(3): 483–492.
- Mohnot, S.M. (1974).** Ecology and behaviour of the common Indian langur, *Presbytis entellus*. PhD Thesis. University of Jodhpur, Jodhpur.
- Mukherjee, A.K. & S. Gupta (1965).** Habits of rhesus macaque, *Macaca mulatta* in the Sunderbans, West Bengal. *Journal of the Bombay Natural History Society* 62: 145–146.
- Mukherjee (1972).** Group composition and population density of Rhesus Monkey, *Macaca mulatta* in northern India. *Primates* 13: 65–70.
- Neville, M.K. (1968).** Ecology and activity of the Himalayan foot-hill Rhesus Monkeys (*Macaca mulatta*). *Ecology* 40: 110–123.
- Rajpurohit, L.S. & A.K. Chhangani (1997).** Males' number decreasing in langurs (*Presbytis entellus*) around Jodhpur. Abstracts - 1st Goettinger Freilandtage on Primate Socio-Ecology: Causes and Consequences of Variation in the Members of Males Per Group, German Primate Centre (DPZ), Göttingen (Germany). *Primate Report* 48(2): 30.
- Rajpurohit, L.S. (1987).** Male social organization in Hanuman Langur (*Presbytis entellus*). PhD Thesis. University of Jodhpur, Jodhpur.
- Ramp, D., J. Caldwell, A.E. Kathryn, D. Warton & D.B. Croft (2005).** Modeling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological Conservation* 126: 474–490.
- Ramp, D., V.K. Wilson & D.B. Croft (2006).** Assessing the impact of roads in peri-urban reserves: Road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biological Conservation* 129: 348–359.

- Seth, P.K., P.K. Chopra & S. Seth (2001).** Indian Rhesus Macaque: habitat, ecology and activity patterns of naturally occurring populations. In: Gupta, A.K. (ed.) *ENVIS Bulletin: Wildlife & Protected Areas, Non-Human Primates of India* 1(1): 68–80.
- Singh, S.D. (1969).** Urban monkeys. *Scientific American* 221: 108–115.
- Southwick, C.H., M.A. Beg & M.R. Siddiqi (1965).** Rhesus Monkeys in north India, pp. 111–159. In: DeVore, I. (ed.) *Primate Behavior: Field Studies of Monkeys and Apes*. New York.
- Southwick, C.H. & M.F. Siddiqi (1994).** Population status of primates in Asia, with emphasis on Rhesus Macaques in India. *American Journal of Primatology* 34: 51–59.
- Southwick, C.H., M.F. Siddiqi, M.Y. Farooqui & B.C. Pal (1976).** Effects of artificial feeding on aggressive behaviour of rhesus monkeys in India. *Animal Behavior* 24(1): 11–15.
- Srivastava, A. (1999).** Rhesus Macaque, pp. 141–145. In: *Primates of Northeast India*. Mega Diversity Press, India.



SPATIAL PATTERNS AND FACTORS INFLUENCING THE MORTALITY OF SNAKES ON THE NATIONAL HIGHWAY-7 ALONG PENCH TIGER RESERVE, MADHYA PRADESH, INDIA

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ABSTRACT

Road induced habitat reduction and animal mortality pose the greatest challenge of conserving wildlife species in protected areas with extensive road networks. This study was conducted in a 9 km stretch of National Highway-7 passing through Pench Tiger Reserve in central India with an objective to assess impacts on wildlife species and their habitats. Considering that snakes are a vital part of food webs of every ecosystem and are more susceptible to vehicular casualties, we present the ecological impacts of the highway on snakes in this Tiger Reserve. We surveyed this highway section for a total of 430 road cruising days spread equally across three seasons and over two years from August 2008 to July 2010. We collected data on different variables influencing use of road side habitat, the road surface and the factors influencing mortality of snakes. We recorded a total of 490 snake road kills (approx.1.13 snakes/10km/day) during the study. We recorded the highest mortality (50%) of snakes during monsoon. Barred wolf snake had the highest mortality (22%) followed by Common cat snake (11%) and Striped keel back (8%). We identified fatality hotspots in different sections of the highway using Kernel Density Method. The linear regression model showed that the road kills were positively related to high elevation and negatively related to proximity of the agriculture fields, animal crossings and water sources.

Keywords: Protected area; road; ecological impacts; habitat fragmentation; road kill.

RESUMO

PADRÕES ESPACIAIS E FATORES QUE INFLUENCIAM A MORTALIDADE DE SERPENTES NA NATIONAL HAIGHWAY 7, AO LONGO DA RESERVA DE TIGRES DE PENCH, MADHYA PRADESH, INDIA. A redução do habitat e a mortalidade dos animais provocada pelas estradas representam o maior desafio para a conservação das espécies selvagens em áreas protegidas com vasta rede rodoviária. Este estudo foi realizado em um trecho de 9 km da *National Highway 7*, ao longo da Reserva Pench Tiger, na Índia central, com o objetivo de avaliar os impactos sobre as espécies silvestres e seus habitats. Considerando que as serpentes são uma parte vital das cadeias alimentares de todo ecossistema e que são mais susceptíveis a acidentes com veículos, apresentamos os impactos ecológicos da estrada sobre as serpentes nessa Reserva de Tigres. Investigamos a seção da rodovia por 430 dias de amostragem distribuídos igualmente ao longo de três estações e durante dois anos, de Agosto de 2008 a Julho de 2010. Coletamos dados referentes a diferentes variáveis que influenciam o uso do habitat ao lado da estrada, o pavimento da estrada e os fatores que afetam a mortalidade das serpentes. Registramos um total de 490 serpentes mortas na estrada (1,13 serpente/10 km/dia) durante o estudo. Registramos a mais alta mortalidade das serpentes (50%) durante a monção. *Lycodon striatus* teve a maior mortalidade (22%), seguida por *Boiga trigonata* (11%) e *Amphiesma stolatum* (8%). Identificamos os *hotspots* de mortalidade nas diferentes seções da rodovia utilizando o Método Kernel de estimativa de Densidade. As mortes na estradas foram positivamente relacionadas à altitude e negativamente relacionada à proximidade com as lavouras, passagens de animais e fontes de água.

Palavras-chave: Áreas protegidas; estrada; impactos ecológicos; fragmentação de habitat; atropelamento.

RESUMEN

PATRONES ESPACIALES Y FACTORES QUE INFLUENCIAN LA MORTALIDAD DE SERPIENTES EN LA CARRETERA NACIONAL 7 A LO LARGO DE LA RESERVA DE TIGRES PENCH, MADHYA PRADESH, INDIA. La reducción de hábitat y mortalidad de animales debido a las carreteras representan el mayor desafío para la conservación de la vida silvestre en áreas protegidas con redes viales extensas. Este estudio fue realizado en un trecho de 9km de la Carretera Nacional 7, que pasa a través de la Reserva de Tigres Pench en India central, con el objetivo de evaluar su impacto en especies de fauna y sus hábitats. Considerando que las serpientes son parte vital de las cadenas tróficas de todo ecosistema y son susceptibles a los accidentes con carros, presentamos los impactos ecológicos de esta carretera sobre las serpientes en la Reserva. Monitoramos esta carretera durante un total de 430 días distribuidos equitativamente entre tres estaciones y durante dos años, de Agosto de 2008 a Julio de 2010. Obtuvimos datos sobre diferentes variables que afectan el uso del hábitat al lado de la carretera, la superficie de la carretera y los factores que influyen en la mortalidad de serpientes. Registramos un total de 490 muertes de serpientes (ca. 1,13 serpientes/10km/día) durante el día. La mayor mortalidad (50%) fue registrada en época de monzones. La serpiente lobo del norte (*Lycodon striatus*) tuvo la mayor mortalidad (22%) seguida de la serpiente gato común (*Boiga trigonata*) (11%) y la keelback rayada (*Amphiesma stolatum*) (8%). Identificamos *hotspots* de mortalidad en diferentes secciones de la carretera usando métodos de densidad por núcleos. El modelo de regresión lineal mostró que las muertes en carretera están relacionadas positivamente a elevaciones altas y negativamente con la proximidad de campos agrícolas, puntos de cruce para fauna y fuentes de agua.

Palabras clave: Área protegida; carretera; impactos ecológicos fragmentación de hábitat; muertes en carretera.

INTRODUCTION

India, with more than 3.31 million km existing road length, has the world's third largest road network (CIA 2013). Approximately 26,000km of road length traversing through wilderness areas are routed through as many as 30 tiger reserves spread across the country. The National Highway Authority of India proposes to further expand this network by adding new road links and also by widening existing roads to four lane roadway.

Roads represent one of the most widespread forms of modification of the natural landscape associated with expansion in transportation infrastructure that is often justified for facilitating linkages, enhancing mobility and improving accessibility. Several independent studies and comprehensive reviews of ecological impacts specific to roads have singled out roads as the largest factor posing the greatest threats to biodiversity (Treweek *et al.* 1993, Forman & Alexander 1998, Smith 2003, Spellerberg 2002, Trombulak & Frissell 2002, Seiler & Seiler 2004, Eigenbrod *et al.* 2008, Fahrig & Rytwinski 2009, Clevenger & Sawaya 2010, Beckmann *et al.* 2010).

These studies have demonstrated that roads increase fragmentation of habitats and populations; lead to isolation and obstruction of animal movements;

result in road induced mortality of animals and extinction of rare and endemic species (Oxley *et al.* 1974, Mader 1987, Mech 1989, Ashley & Robinson 1996, Richardson *et al.* 1997, Forman & Alexander 1998, Jackson 1999, Lode 2000, Trocme *et al.* 2002, Goosem 2007).

Road related mortality has been widely documented on different taxa. For example, butterflies (Mckenna *et al.* 2001); amphibians (van Gelder 1973, Hels & Buchwald 2001); snakes (Rosen & Lowe 1994, Andrews & Gibbons 2005, Row *et al.* 2006), birds (Reijnen *et al.* 1995, Erritzoe *et al.* 2003, Sundar 2004, Benitez-Lopez *et al.* 2010, Bujoczek *et al.* 2011) and mammals (Oxley *et al.* 1974, Vieira 1996, Clevenger *et al.* 2003, Roedenbeck & Voser 2008).

As snakes play an important ecological role both as predators and prey in the different ecosystems, they command high significance for conservation. Snakes represent an ideal target group for studying direct and indirect impacts of roads (Andrews & Gibbons 2005) not only because road related mortality has been documented for over half a century (for example, Krivda 1993, Smith & Dodd 2003, Gibson & Merkle 2004, Row *et al.* 2006), but also because of the breadth of ecological niches represented among snake species (Ernst & Ernst 2003) and their greater vulnerability to roads. The tendency of snakes to thermo regulate

on road surfaces, their relatively slow locomotion, life history characteristics, low reproductive rates and seasonal variability in habitat use are factors that increase their vulnerability to roads (Rosen & Lowe 1994, Rudolph *et al.* 1999, Jochimsen *et al.* 2004).

Although knowledge about the ecological impacts of road on snakes is rapidly accumulating from many parts of the world (Bernardino & Dalrymple 1992, Rosen & Lowe, 1994, Gibson & Merkle 2004, Shine *et al.* 2004, Jochimsen 2005, Andrews *et al.* 2007, Freeman & Bruce 2007, McDonald 2012), studies on impacts of roads on snakes are scarce in India. Also, most of the studies are limited to a few disparate records of road induced mortality of snakes in tropical evergreen and moist deciduous forests (Gokula 1997, Vijayakumar *et al.* 2001, Kannan 2007, Das *et al.* 2007, Baskaran & Boominathan 2010, Seshadri & Ganesh 2011, Bhupathy *et al.* 2011). No studies on road related impacts on snakes have been conducted in the forested landscapes in central India. The present study was undertaken to fill the void of such studies in the tropical dry deciduous forests of central India. The objective of our study was to (i)

estimate the road related mortality of snakes in the 9 km section of National Highway (NH) -7 passing through Pench Tiger Reserve, (ii) define the spatial distribution of road kills (iii) evaluate the factors influencing the mortality of snakes and (iv) propose mitigation options to prevent and reduce the road induced mortality of snakes for ensuring the long term conservation of the snakes in this landscape.

STUDY AREA

NH-7 runs across the country from North to South cuts through an important forest corridor which connects the two tiger reserves - Kanha and Pench Tiger Reserves in the central Indian landscape. Our study was conducted on a 9km stretch of National Highway (NH-7) between Kurai village (21° 49' N, 79° 30' E) and Gandatola village (21° 53' N, 79° 32' E) aligned along the Pench Mowgli Sanctuary, falling within the Eastern boundary of the Pench Tiger Reserve (Figure1). This NH-7 is a two lane, 7m wide roadway without a defined median strip for incoming and outgoing traffic lanes. NH-7 runs North-South

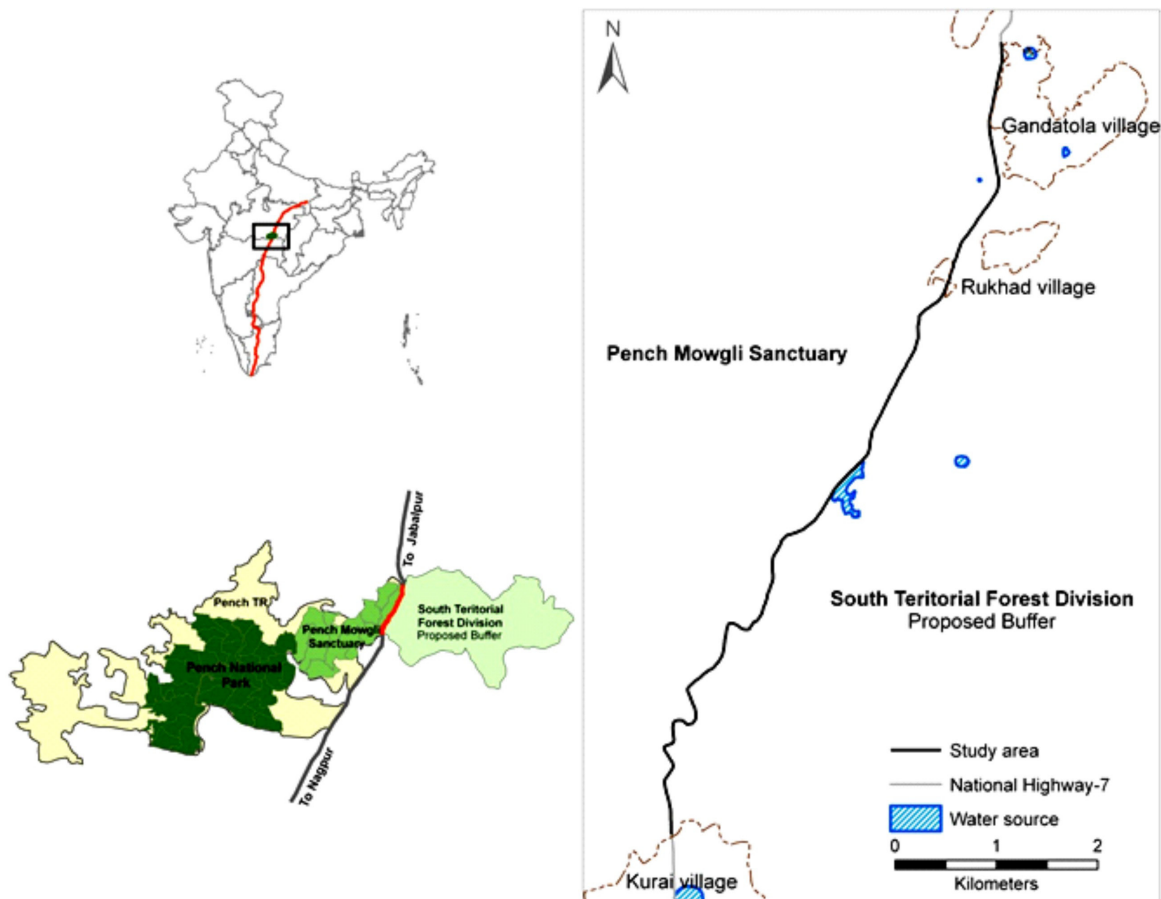


Figure 1. Study area and the Pench Tiger Reserve.

and has two topographically distinct sections: 4km of the northern portion of the road aligned in the flatter terrain and 5km of the southern road section aligned through a hilly terrain. The study area represents a forested tract buffering the Pench Tiger Reserve which is bifurcated by NH-7. The altitude of the road section ranges from approximately 400m to 600m above sea level. In the entire 9km section of the road, the area is characterized by *Tectona grandis* (teak) dominated forest which is interspersed with miscellaneous species such as *Acacia spp.*, *Anogeissus latifolia*, *Mallotus philippensis*, *Madhuca indica*, *Terminalia spp.* and species of bamboo on gentle and steep slopes and nine seasonal streams intersecting the road. The annual rainfall averages 1400mm with the South-West monsoon accounting for most of the rainfall in the region. The average daily maximum temperature was a minimum of 0° C in winter and maximum of 45° C in summer.

METHODS

ROAD-KILL DATA COLLECTION

We adopted road cruising and collecting method that has been widely used to determine species negatively impacted by roads (Ashley & Robinson 1996, Clevenger *et al.* 2003, Langen *et al.* 2007). The entire 9 km stretch of highway was surveyed for a total of 430 road cruising days spread equally across three seasons: monsoon/July to October (n=147), winter/November to February (n=143) and summer/March to June (n=140) between August 2008 to July 2010. On all cruising days, the vehicular survey was conducted in the morning (0530 – 0630 hrs) and in the evening (1730–1830 hrs) at a speed of 10- 20 km/hr. Observations about snake kills were recorded by two observers. Whenever the snake kills were encountered on the road, the vehicle was stopped to enable the team to identify the species (Whitaker & Captain 2004). Additionally information on the state of the road kills, geo-coordinates of the road kills (using Garmin 72 GPS) and roadside habitat features were recorded. After recording the information, the dead snakes were removed from the road to avoid repeat count during subsequent surveys. The 430 days of vehicular survey resulted

in a total effort of surveying 3870km. Information on average traffic volume per day and peak traffic was collected through continuous monitoring based on manual counts for three days per season in a two year period.

Data on average traffic volume on the road section passing along the Pench Tiger Reserve was generated based on continuous recording of the number of vehicles over a period of twenty four hours for three days per season. Total number of two wheelers, passenger cars, heavy vehicles, trucks and lorries moving. Data on traffic was collected on week and non week days and market days to capture any variations in traffic volume on different days.

PREDICTION OF FATALITY HOTSPOTS

Fatality hotspots were determined on the 9 km section of the road, using Kernel density estimation method (Gitman & Levine 1970) which is one of the common methods for analyzing the point event distribution data (Silverman 1986, Bailey & Gatrell 1995). This method generates a smooth surface map showing point data (kill location) on the basis of which the density of events (road kills per unit area) is determined to provide an estimate of kill concentration. This approach of identifying fatality hotspots provides a useful insight for planning mitigation strategies to avoid and reduce road kills in high mortality zones (Ramp *et al.* 2005, 2006, Gomes *et al.* 2009). The area of influence or a bandwidth chosen for this study was 200m. The kernel estimation for species fatalities was done using the Spatial Analyst toolbox of ArcGIS version-9 (ESRI 2004). Zero values were omitted to avoid confusion between zero density and no data.

FACTORS INFLUENCING THE ROAD KILL

The road area was also typified to assess the road features that may have influence on the frequency and abundance of snake mortality. The road was categorized into six categories following Clevenger *et al.* (2003): (i) road surface raised compared to surrounding landscape, (ii) no slope, (iii) road surface buried relative to surrounding landscape, (iv) one side flat, one buried, (v) one side flat, one side raised and (vi) one side buried, one raised.

We created land use land cover classified map using Landsat 7 Thematic Mapper (30m resolution) acquired on November 2009 (Path: 144, Row: 52) and downloaded from the US Geological Survey archive Global Visualization Viewer (<http://glovis.usgs.gov>). The image was classified into five major cover types spanning across both the sides of the road as (1) Teak dominant, (2) Miscellaneous, (3) Scrub forest, (4) Agriculture and (5) Water sources. A 50m buffer was created around each road kill location that was treated as a point in the GIS domain. Information was extracted from classified image on habitat type.

On encountering a snake kills on the road, the distance from the snake kill to the closest vegetation cover on both sides of the road was recorded using a range finder. The nearest distance at which the kill could have been visible to a driver of the vehicle was assessed by measuring the nearest distance between the point of road and an unobstructed view of the

approaching vehicle from either side of the highway. Spatial data (Table 1) on landscape related variables: distance of the kill from the agriculture, water sources, drainage and animal crossing structures was generated in GIS laboratory using the Euclidean distance method in Arc Info. Altitude (meter) and slope (degree) was derived from 30m resolution Digital Elevation Model (ASTER Global Digital Elevation Model).

A linear regression model was developed to relate the occurrence of road-kills to the landscape and road attributes. The 9km road was divided into 100m segments ($n=90$) and the road kill data was segregated for each of these segments. In each segment, number varied from 0 to 15 road kills. We chose 8 variables to describe site-specific attributes of each road-kill site (Table I). We used the SPSS statistical package (version 15.0, SPSS 2006) for all statistical analysis, Arc GIS 9 (ESRI 2004) and Microsoft Excel for all other analysis.

Table 1. Landscape and site variables and their description used in the analysis.

Variable name	Description	Source
Visibility (m)	Farthest distance from which the driver can locate a snake on the road	Field
Distance to cover (m)	Distance of vegetation cover from the location of the road kill	Field
Distance to water (m)	Distance of the road kill from the nearest water source (lake)	Euclidean distance(Arc Info)
Distance to animal crossing structure (m)	Distance of the road kill from the nearest animal crossing structure	Euclidean distance(Arc Info)
Distance to drainage (m)	Distance of the road kill to nearest seasonal drainage	Euclidean distance(Arc Info)
Distance to agriculture (m)	Distance of the road kill to nearest human settlements	Euclidean distance(Arc Info)
Altitude (m)	Mean ground altitude of the road (100m segments)	Digital elevation model
Slope (Degree)	Mean ground slope of the road (100m segment)	Digital elevation model

RESULTS

TRAFFIC VOLUME

From the data we collected (Figure 2) during the study, average traffic flow recorded on the 9 km road was 3035 ± 274 vehicle/day. The average traffic

volume varied between summer (3269 vehicle/day), winter (2952 vehicle/day) and monsoon (2884 vehicle/day). The highest average daily traffic was recorded on Sundays (3382 vehicle/day) during summer and minimum traffic was recorded on Tuesdays (2620 vehicle/day) during monsoon. Number of heavy vehicles (trucks) remained highest in the overall total

traffic volume in all of the three seasons). The traffic flow during late night and early morning hours was recorded to be the lowest (80 vehicles/hr/day) in all seasons. The traffic peaked (180 vehicles/hr/day)

during evening (1600hr and 1700hr) in all seasons. Road kills of snakes has a strong positive correlation with the number of vehicles plying on the road ($r=0.99$, $p<0.001$) in all seasons.

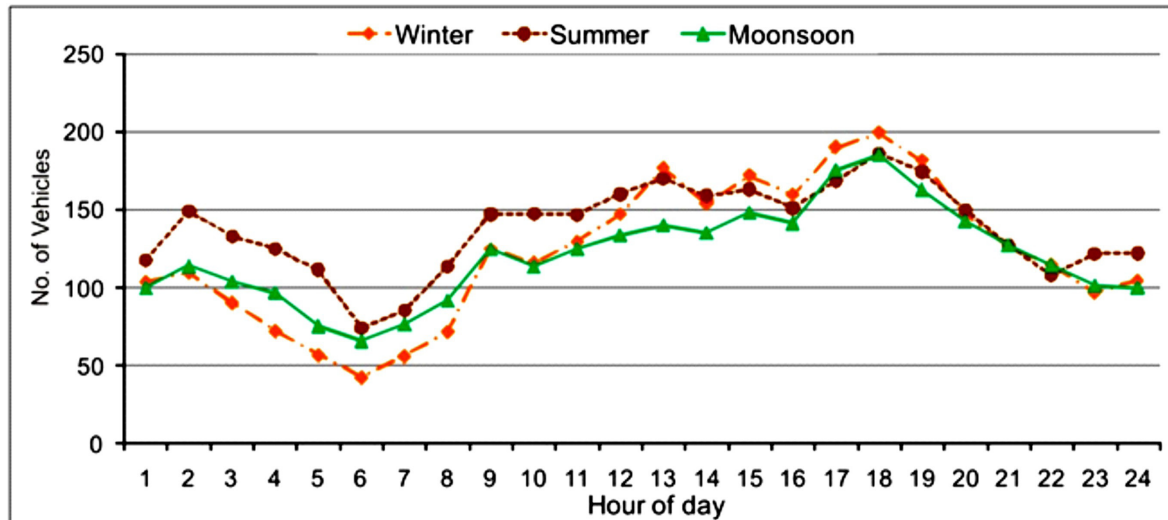


Figure 2. Average traffic volume on the National Highway - 7

SPECIES COMPOSITION AND TEMPORAL PATTERN OF ROAD KILLS

Based on 430 days of observations and 3870km of effort between August 2008 to July 2010, 490 road kills of snakes were recorded (Table 2). These together represented 20 different species. Many of the species that have contributed to the road kills command high conservation importance. The Indian rock python is listed under Schedule I and 4 species (Checkered keelback, Indian rat snake Russell's viper and Spectacled cobra are listed under Schedule II list of Indian Wild Life Protection Act (WPA), 1972. The Indian python

is also listed in Appendix -I of the CITES (2012).

The snakes were killed at the rate of 1.13 animal /10km/day. The number of snake kills varied seasonally. The highest mortality was recorded during monsoon (50%), followed by 37% of snakes killed in summer and 13% snakes killed in winter. Of the total count of 490 snakes kills recorded during the study, Barred wolf snake (*Lycodon striatus*) had the highest number of mortality (n=99) representing 22% of the total snakes killed. This was followed by Common cat snake, *Boiga trigonata* (n=49,) and Striped keelback, *Amphiesma stolatum* (n=38,) representing 11% and 8% of the total road kill respectively.

Table 2. List of snake species killed on National Highway -7.

Common name	Scientific name	Family	Percentage of taxa	WPA status*	CITES**
Bamboo pit viper	<i>Trimeresurus gramineus</i>	Viperidae	1	Schedule IV	not listed
Barred wolf snake	<i>Lycodon striatus</i>	Colubridae	22	Schedule IV	not listed
Beaked worm snake	<i>Grypotyphlops acutus</i>	Typhlopidae	3	Schedule IV	not listed
Checkered keelback	<i>Xenochrophis piscator</i>	Colubridae	3	Schedule II	Appendix III

Continuation Table 2

Common name	Scientific name	Family	Percentage of taxa	WPA status*	CITES**
Common bronzeback tree snake	<i>Dendrelaphis tristis</i>	Colubridae	3	Schedule IV	not listed
Common cat snake	<i>Boiga trigonata</i>	Colubridae	11	Schedule IV	not listed
Common krait	<i>Bungarus caeruleus</i>	Elapidae	3	Schedule IV	not listed
Common kukri snake	<i>Oligodon arnesis</i>	Colubridae	2	Schedule IV	not listed
Common sand boa	<i>Gongylophis conicus</i>	Boidae	2	Schedule IV	Appendix II
Common trinket snake	<i>Coelognathus helena helena</i>	Colubridae	5	Schedule IV	not listed
Common wolf snake	<i>Lycodon aulicus</i>	Colubridae	3	Schedule IV	not listed
Forstens cat snake	<i>Boiga forsteni</i>	Colubridae	2	Schedule IV	not listed
Green keelback	<i>Macropisthodon plumbicolor</i>	Colubridae	4	Schedule IV	not listed
Indian rat snake	<i>Ptyas mucosa</i>	Colubridae	2	Schedule II	Appendix II
Indian rock python	<i>Python molurus molurus</i>	Pythonidae	3	Schedule I	Appendix I
Russell's kukri snake	<i>Oligodon taeniolatus</i>	Colubridae	2	Schedule IV	not listed
Russell's viper	<i>Daboia russelii</i>	Viperidae	4	Schedule II	Appendix III
Saw scaled viper	<i>Echis carinatus</i>	Viperidae	4	Schedule IV	not listed
Spectacled cobra	<i>Naja naja</i>	Elapidae	1	Schedule II	Appendix II
Striped keelback	<i>Amphiesma stolatum</i>	Colubridae	8	Schedule IV	not listed
Unidentified	—	—	12	—	—

*WPA-Wildlife Protection Act, 1972

**CITES- Convention on International Trade in Endangered Species of Wild Fauna and Flora

PREDICTION OF FATALITY HOTSPOTS

Mortality of snakes occurred almost on the entire length of the road which traversed through rich tracts of wildlife habitats and cut across dispersal corridors of many endangered species. The Kernel density estimates of snakes (Figure 3), reflects that the high abundance of fatalities of snake occur on the road section aligned through the flatter areas and in locations nearer to villages that have agriculture fields. In the hilly area, kills were mostly concentrated in the road bends.

FACTORS INFLUENCING THE ROAD KILL

In general, the movement of snakes is likely to be influenced by habitat type, terrain and land-use. In our study, we also attempted to associate snake kills with road topography that is differentiated into six categories (buried, buried-raised, flat, part buried, part raised and raised) for the purpose of this study. Percentage of snake kills recorded in the flat section of the road (Figure 4) is highest (42%) when compared to 27% of road kills recorded in the hilly area where the road is partly buried and partly raised.

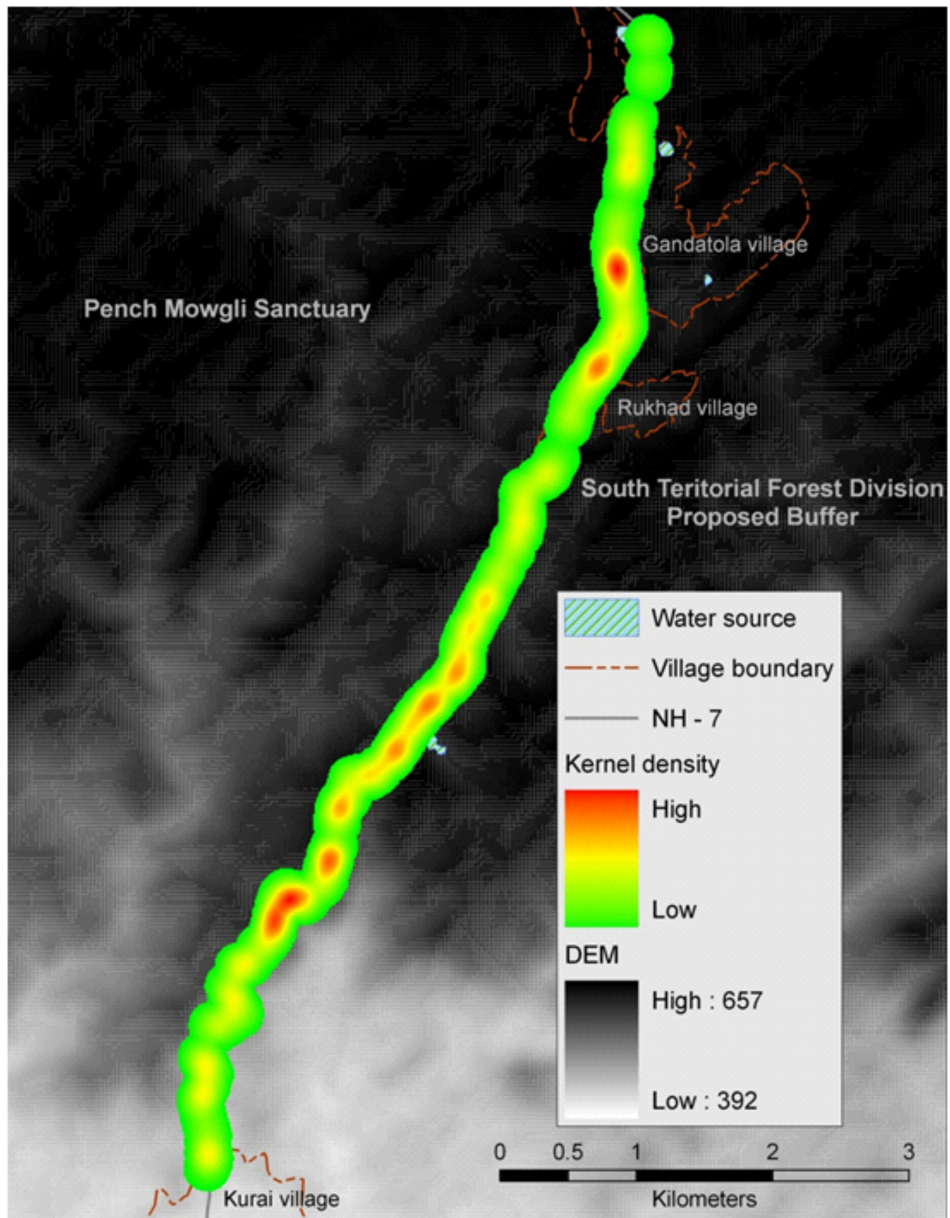


Figure 3. Kernel density estimation of snake fatalities.

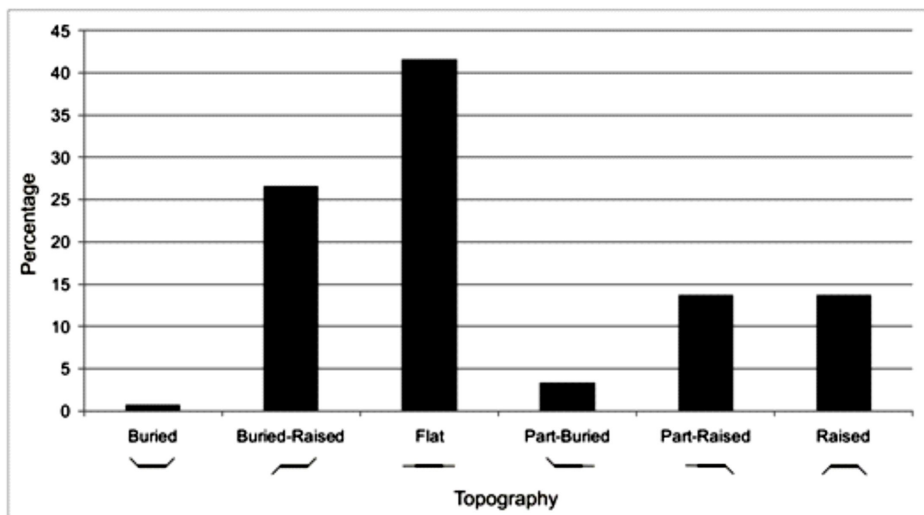


Figure 4. Percentage of snake kills in different topography.

Our data shows that the highest percentage of snake mortality (43%) occurred in road sections passing through Teak dominated forest (Figure 5). These forest tracts on either side of the road offer excellent habitat for varied species of animal ranging from large carnivores (for example, tiger, leopard and wild dog) and herbivores (for example, chital, sambar and nilgai) to smaller creeping animals (snakes) that frequently use the road as a conduit for movement across the two habitats. The results of our studies are similar to other studies that indicate that

concentrations of road-killed animals generally occur where wooded areas or cover adjoins both sides of a road (Hodson 1962, Bellis & Graves 1971, Bennett 1991, Clevenger *et al.* 2003). The lowest mortality (6%) of snakes occurred in road sections passing through Scrub forest which is a fairly degraded habitat. As the large water body (Figure 1) forms the aquatic habitat just abutting the road in the hilly section, it is mostly avoided by snakes. This explains the low percentage of snake kills on the road segment near the water body.

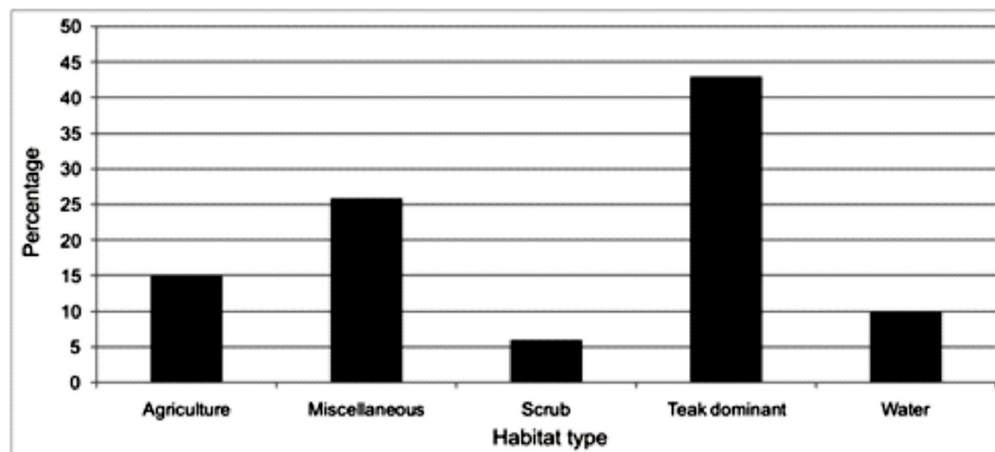


Figure 5. Mortality rate in different habitat type.

The linear regression ($R^2 = 0.79$) shows that the snake kill is positively correlated with elevation and negatively correlated with the distance to agricultures fields, water and the animal crossings. Other variables such as distance to vegetation cover,

visibility distance, distance to drainage and slope did not influence the probability of the road kill (Table 3). Most of the flatter segment of the road where highest number of snake kills has been recorded is aligned through the elevated areas in the landscape.

Table 3. Linear regression of snake kills with the selected variables, B - Regression coefficient, $S.E$ - standard error of the regression coefficient, P - significance level

Variables	B	$S.E$	P
Distance to cover	0.035	0.045	0.556
Distance to drainage	0.021	0.002	0.730
Distance to animal crossings	-0.127	0.001	0.098
Distance to agriculture	-0.432	0.000	0.001
Distance to water	-0.126	0.000	0.058
Elevation	0.780	0.003	0.001
Slope	0.071	0.044	0.295
Visibility	-0.050	0.004	0.417

DISCUSSION

A total of 490 snake kills representing 20 different species were recorded during the study. Of the nearly 270 species of snakes reported (Whitaker & Captain 2004) from different parts of the country, approximately 40 species have been reported from the central Indian landscape (Chandra & Gajbe 2005) and of these, 19 species have been reported from Pench Tiger Reserve, by Pasha *et al.* (2000). The present study supports the occurrence of as many as 20 species in this area. It is an already acknowledged fact that snake kills serve as a good indicators of the herpetofaunal species of the area (Hels & Buchwald 2001) and the road cruising and collecting methods are valuable tools for studying snakes (Gibson *et al.* 2004, Mukherjee 2007). We suspect that there may be more species of snakes occurring in this area. Subsequent road cruising and collection efforts may thus be useful in the inventorying of snake species of this area.

The average mortality rate (1.13 animal/10km/day) of snakes varied seasonally. Coelho *et al.* (2008) also observed seasonal variation in the road kill pattern. This variability may be associated with changes in movement patterns of snakes during breeding and dispersal seasons. This variability could also be a reflection of spatial and temporal variations in environmental characteristics and availability of resources. The high mortality during monsoon can be explained by the fact that snakes are cold blooded

animal and they tend to rest on road surfaces during cooler nights (Dodd *et al.* 1989, Rosen & Lowe 1994, Shine *et al.* 2004).

Road kills of snakes has a strong positive correlation with traffic on the road ($r=0.99$, $p<0.001$). Szerlag & McRobert (2006) also reported positive relationship between traffic volume and mortality of herpetofauna. Compared to other herpetofauna, snakes are at the highest risk of mortality as their movement is relatively slower on a smooth road as compared to other surfaces (Bonnet *et al.* 1999, Roe *et al.* 2006). Row *et al.* (2007) observed that some drivers deliberately run the vehicles over snakes because they dislike snakes. In the present study also, one of the authors observed the drivers attempting to kill the snakes moving on the road.

Nearly 72% of the snakes that get killed are nocturnal. Some species of snakes that actively forage during night time are relatively more vulnerable to the vehicles when compared to snakes that sit and wait for their prey and snakes which are active throughout the day. In the present study, high mortality of snakes could be explained because 52 % of the snakes were nocturnal and actively feeding during night (Figure 6), 23% of the snakes sit and wait for the prey and are therefore less vulnerable to traffic. Of the total count of 490 snakes kills recorded during the study, Barred wolf snake and Common cat snakes which accounted for nearly 22% and 11% of road kills respectively are both nocturnal and active feeders (Whitaker & Captain 2004).

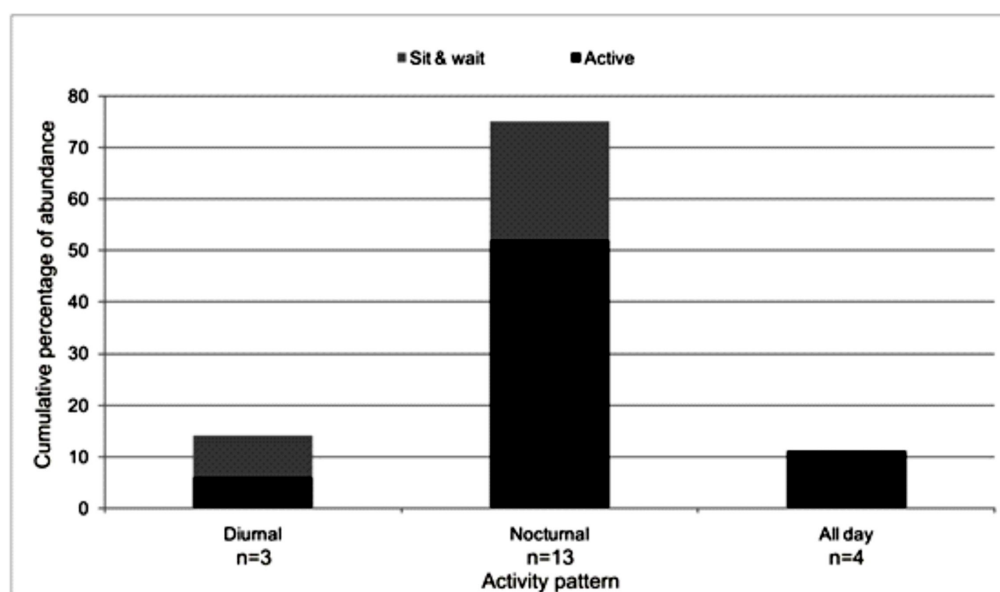


Figure 6. Activity pattern and foraging habit of the snake kills.

Our study indicates that fatalities of snakes occur throughout the entire length of the road. This observation renders support to the fact that snakes continue to attempt to use habitat that has been dissected by the road which poses a major barrier for their movement. Similar conclusions that road act as barrier for snakes especially for smaller species were also drawn from studies by Andrews & Gibbons (2005), Aresco (2005), Row *et al.* (2007), Shepard *et al.* (2008).

Although fatalities were recorded throughout the road, kills did not occur randomly along the entire 9 km length of the roads but were spatially clustered. Kernel density and linear regression analysis indicates higher snake mortalities near areas of anthropogenic influence including human settlements and agricultural fields in flat areas (Figure 3). Prey availability in the agricultural area tends to attract nocturnal snakes on the road during night that are more often killed by speeding vehicles in flat areas. Our findings support the observations of Puglisi *et al.* (1974), Clevenger *et al.* (2001), Joyce & Mahoney (2001), Huijser *et al.* (2006) that wildlife-vehicle collisions do not occur randomly along roads but are spatially clustered.

Several factors including specific habitats, terrain and adjacent land-use types that influence wildlife movements also play an important role in determining locations of higher probability of road mortality compared to other locations (Forman & Alexander 1998). We attempted to relate road kills with landscape and site variables within the road corridor (Table1). Higher moisture, lower temperature and presence of leaf litter that modify the micro habitat conditions in culverts and the prey availability in agricultural fields both improve the prospects of use of by active feeders. More kills therefore occurred at locations that were closer to drainage channels and near agricultural areas. Similarly, in sections of road that were closer to water bodies, more kills were recorded. This is perhaps because many of the snake species that get attracted to the prey species occurring near water sources attempt to cross the road and get killed in the process.

IMPLICATIONS FOR CONSERVATION

Road mortality plays a significant role in the decline of snake populations. This poses significant

conservation challenges for species that are already endangered or species that are at risk on account of alteration of their habitat conditions. During our study, we recorded 12 kills of Indian rock python which is listed in schedule-I under the Wild Life (Protection) Act, 1972, Government of India. Of these, 9 individuals were juvenile. The road induced loss of dispersing juveniles and consequent isolation is likely to have impact upon the gene flow across the landscape. Ciesiolkiewicz *et al.* (2006) also recorded that juvenile snakes appear to be most susceptible to road mortality, especially during hatching and dispersal.

Common bronzeback tree snake, constituting 3% (n=14) of species killed by the vehicle during this study, is an arboreal species that is threatened by the reduction of canopy connectivity and by the road induced fragmentation of connectivity between the road side habitat. The threat to snake species may vary with differential mortality of animals that cross more slowly (eg. Russell's viper) than with snakes that immobilize, or freeze in response to a passing vehicle.

Drawing population estimates for the various species of snakes based on our records of snakes killed on road alone could be misleading as the relative kill rates by species may not correspond to their relative abundance locally. It is important to consider that low mortality percentages of some species of snakes (Green keelback, Beaked worm snakes and Russell's kukri snakes) could be a function of a smaller population of uncommon snakes (Whitaker & Captain 2004) found in the forested habitat outside protected areas.

MITIGATION

Habitat fragmentation of wildlife habitats by roads is globally recognised as one of the biggest threats to conservation of biodiversity (Andrews 1990, Seiler 2001, Bekker *et al.* 2003, Andrews & Gibbons 2005, Shepard *et al.* 2008). This study serves as a useful template for assessing the nature and magnitude of vehicle induced mortality of snakes based on observations on a section of National Highway-7 aligned along an important protected area in central India. Understanding these impacts is critical for determining appropriate conservation strategy because of the importance of snakes as

trophic components of terrestrial ecosystems (Rosen & Lowe 1994). Mitigation approaches to address road induced mortality of snakes have been well discussed by many workers (Aresco 2005, Jochimsen *et al.* 2004, Trembath & Fearn 2008, Coelho *et al.* 2008). These approaches have focused largely on improving the permeability of roads as passage for wildlife, managing traffic to reduce barrier effect of moving vehicles and managing wildlife areas to prevent snakes frequenting on roads.

In the present context, construction of speed breakers in fatality hotspots, and use of fences specifically engineered for snakes are some of the conventional approaches that can be effective in reducing road induced mortality. Most of these post-construction mitigation measures would however serve only as second best option because they are not targeted to avoid the effects of roads in first place. Further, planning of retrofitting measures is often more costly. Developing ecologically sensitive approaches and innovative design that can be applied both at the planning stage and also subsequently as a retrofit would be most effective in controlling road kills. One such measure of constructing 1m high wall with a lip

on the high end along the road length through forest stretches is recommended by Dodd *et al.* (2004) for preventing snakes from getting on to the road. The feasibility and success of such measures will however depend on the characteristics of the road corridor.

The authors have likewise considered the options of proposing a mitigation measure to address the ecological requirement of thermoregulation that may be the primary factor influencing the number of individual snakes on roads or the time spent on the road surface during any foray to a road (Brattstrom 1965, Moore 1978, Sullivan 1981, Bernardino & Dalrymple 1992, Ashley & Robinson 1996). The authors recommend placing strips of individual surfaces that are attractive from a thermoregulatory perspective along the road in high mortality zones determined in this study (Figure 7). Such measures can be initially implemented on the experimental basis and once tested for their effectiveness, can be subsequently replicated in other road schemes. Results and practical guidance from this research should significantly reduce the mortality of Indian rock python and Russell's viper that command high conservation importance.

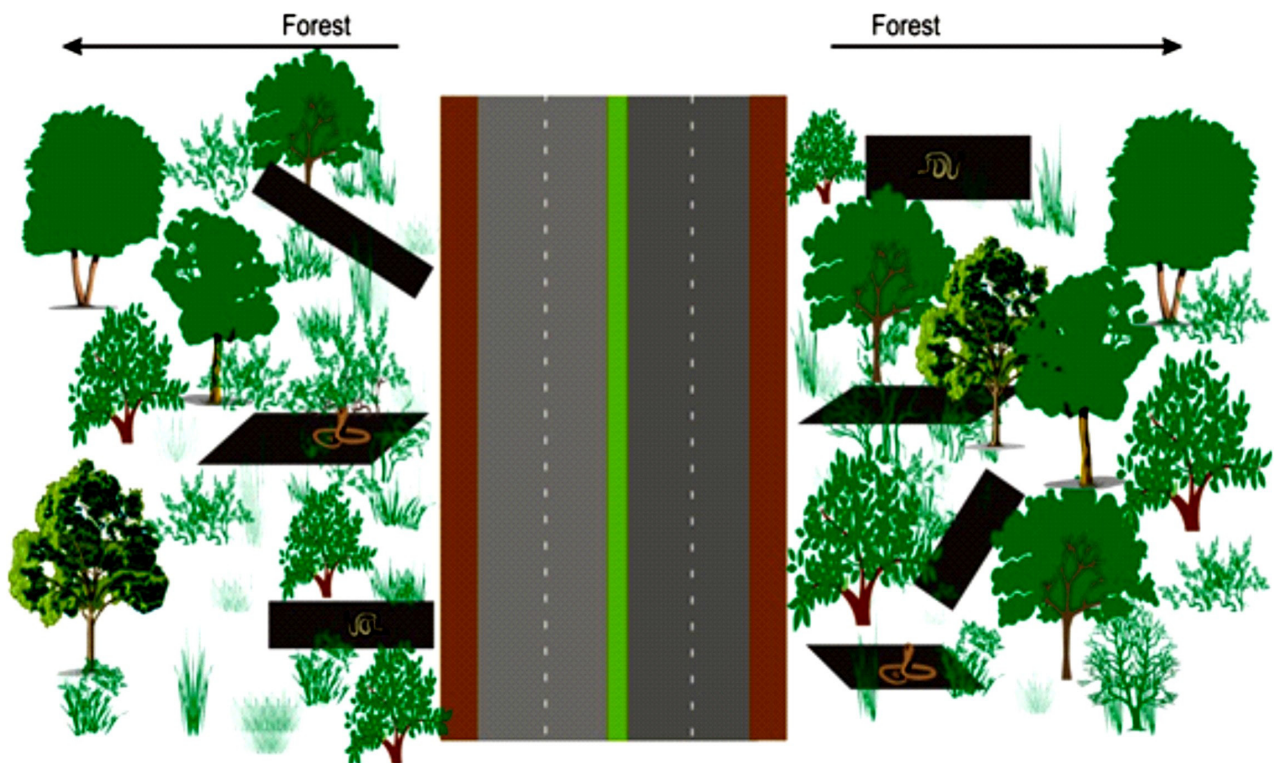


Figure 7. Creation of alternative sites for thermoregulation of snakes.

ACKNOWLEDGEMENTS: We thankfully acknowledge Director and Dean, Wildlife Institute of India for their support and encouragement to undertake this study. We are grateful to the Chief Wildlife Warden, Madhya Pradesh Forest Department for permitting us to conduct field studies in the Pench Tiger Reserve. We greatly benefitted from interactions with colleagues Dr. K. Ramesh, Mr. Qamar Qureshi and Dr. Karthikeyan Vasudevan from Wildlife Institute of India in the preparation of the manuscript.

REFERENCES

- ANDREWS, A. 1990. Fragmentation of habitat by road and utility corridors: A review. *Australian Zoologist*, 26: 130-142.
- ANDREWS, K.M. & GIBBONS J.W. 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia*, 772-782, [http://dx.doi.org/10.1643/0045-8511\(2005\)005\[0772:HDHISM\]2.0.CO;2](http://dx.doi.org/10.1643/0045-8511(2005)005[0772:HDHISM]2.0.CO;2)
- ANDREWS, K.M.; GIBBONS, J.W. & JOCHIMSEN, M. 2007. Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation*, 3.
- ARESCO, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida Lake. *Journal of Wildlife Management*, 69: 540-551, [http://dx.doi.org/10.2193/0022-541X\(2005\)069\[0549:MMTRHM\]2.0.CO;2](http://dx.doi.org/10.2193/0022-541X(2005)069[0549:MMTRHM]2.0.CO;2)
- ASHLEY, E.P. & ROBINSON, J.T. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. *Canadian Field- Naturalist*, 110: 403-412.
- BAILEY, T.C. & GATRELL, A.C. 1995. Interactive Spatial Data Analysis. Longman, New York. 413p.
- BASKARAN, N. & BOOMINATHAN, D. 2010. Road kill of animals by highway traffic in the tropical forests of Mudumalai Tiger Reserve, southern India. *Journal of Threatened Taxa*, 2: 753-759.
- BECKMANN, J.P.; CLEVINGER, A.P.; HUIJSER, M.P. & HILTY, J.A. (eds.). 2010. Safe passages: highways, wildlife and habitat connectivity. Island Press, Washington, D.C. 424p.
- BEKKER, L.B.; CUPERUS, G.J.; DUFEK, R.; HICKS, F.G.; KELLER, H.V.; ROSELL, C.; SANGWINE, T.; WANDALL & MAIRE, B.L. 2003. Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solution. Pp. 1-14. *In: The XXII Ind PIARC World Road Congress*. Durban, South Africa. 1 CD-ROM.
- BELLIS, E.D. & GRAVES, H.B. 1971. Deer mortality on a Pennsylvania interstate highway. *Journal of Wildlife Management*, 35: 232-237, <http://dx.doi.org/10.2307/3799596>
- BENITEZ-LOPEZ, A.; ALKEMADE, R. & VERWEIJ, P.A. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. *Biological Conservation*, 143:1307-1316, <http://dx.doi.org/10.1016/j.biocon.2010.02.009>
- BENNETT, A.F. 1991. Roads, roadsides and wildlife conservation: a review. Pp. 99-117. *In: D.A. Saunders & R.J. Hobbs (eds.) Nature Conservation 2: the Role of Corridors*. Surrey Beatty & Sons, Chipping Norton, Australia.
- BERNARDINO, J. & DALRYMPLE, G.H. 1992. Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. *Biological Conservation*, 61: 71-75, [http://dx.doi.org/10.1016/0006-3207\(92\)90928-G](http://dx.doi.org/10.1016/0006-3207(92)90928-G)
- BHUPATHY, S.; SRINIVAS, G.; SATHISH, N.; KARTHIK, T. & MADHIVANAN, A. 2011. Herpetofaunal mortality due to vehicular traffic in the western ghats, India: A case study. *Herpetotropicos*, 5: 119-126.
- BONNET, X.; NAULLEAU, G. & SHINE, R. 1999. The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation*, 89: 39-50, [http://dx.doi.org/10.1016/S0006-3207\(98\)00140-2](http://dx.doi.org/10.1016/S0006-3207(98)00140-2)
- BRATTSTROM, B.H. 1965. Body temperatures of reptiles. *American Midland Naturalist*, 73: 376- 422, <http://dx.doi.org/10.2307/2423461>
- BUJOCZEK, M.; CIACH, M. & YOSEF, R. 2011. Road-kills affect avian population quality. *Biological Conservation*, 144: 1036-1039, <http://dx.doi.org/10.1016/j.biocon.2010.12.022>
- Central Intelligence Agency. 2013. The World Factbook. <https://www.cia.gov/library/publications/the-world-factbook/rankorder/2085rank.html>
- CHANDRA, K. & GAJBE, P.U. 2005. An inventory of Herpetofauna of Madhya Pradesh and Chhattisgarh. *Zoos' Print Journal*, 20: 1812-1819, <http://dx.doi.org/10.11609/JoTT.ZPJ.1087.1812-9>
- CIESIOLKIEWICZ, J.; RLOWSKI, G. & ELZANOWSKI, A. 2006. High juvenile mortality of grass snakes *Natrix natrix* (L.) on a suburban road. *Polish Journal of Ecology*, 54: 465-472.
- CLEVINGER, A.P.; CHRUSZCZ, B. & GUNSON, K.E. 2001. Highway mitigation fencing reduces wildlife vehicle collisions. *Wildlife Society Bulletin*, 29: 646-653.
- CLEVINGER, A.P. & SAWAYA, M.A. 2010. Piloting a non-invasive genetic sampling methods for evaluating population-level benefit of wildlife crossing structure. *Ecology and Society*, 15: 7.

- CLEVENGER, A.P.; CHRUSZCZ, B & GUNSON, K.E. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological Conservation*, 109: 15-26, [http://dx.doi.org/10.1016/S0006-3207\(02\)00127-1](http://dx.doi.org/10.1016/S0006-3207(02)00127-1)
- COELHO, I.P.; KINDELAND, A. & COELHO, A.V.P. 2008. Roadkills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. *European Journal Wildlife Reserch*, 54: 689-699, <http://dx.doi.org/10.1007/s10344-008-0197-4>
- CITES (CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES OF WILD FAUNA AND FLORA). Reservations Entered by Parties. <www.cites.org>. (Acesso em 26/08/2012).
- DAS, A.; AHMED, M.F.; LAHKAR, B.P. & SHARMA, P. 2007. A preliminary report of reptilian mortality on road due to vehicular movement near Kaziranga National Park, Assam, India. *Zoos' Print Journal*, 22: 2742-2744.
- DODD, C. K.; ENGE, K.M. & STUART, J.N. 1989. Reptiles on highways in north-central Alabama, USA. *Journal of Herpetology*, 23: 197-200, <http://dx.doi.org/10.2307/1564036>
- DODD, C.K.; BARICHIVICH, W.J. & SMITH, L.L. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. *Biological Conservation*, 118: 619-631, <http://dx.doi.org/10.1016/j.biocon.2003.10.011>
- EIGENBROD, F.; HECNAR, S.J. & FAHRIG, L. 2008. Accessible habitat: an improved measure of the effects of habitat loss and roads on wildlife populations. *Landscape Ecology*, 23: 159-168, <http://dx.doi.org/10.1007/s10980-007-9174-7>
- ERNST, C.H. & ERNST, E.M. 2003. Snakes of the United States and Canada. Smithsonian Press, Washington, D.C.
- ERRITZOE, J.; MAZGAJSKI, T.D. & REJT, L. 2003. Bird casualties on European roads-a review. *Acta Ornithologica*, 38: 77-93.
- ESRI. 2004. ArcGIS 9. Environmental System Research Institute, New York.
- FAHRIG, L. & RYTWINSKI, T. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society*, 14: 21.
- FORMAN, R.T.T. & ALEXANDER, L.F. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29: 207-231, <http://dx.doi.org/10.1146/annurev.ecolsys.29.1.207>
- FREEMAN, A. & BRUCE, C. 2007. The things you find on the road: road-kill and incidental data as an indicator of habitat use in two species of tropical pythons. Pp. 152-165. *In*: R. Henderson & R. Powell (eds.). *Biology of the Boas and Pythons*. Eagle Mountain Publishing, Eagle Mountain.
- GIBSON, J.D. & MERKLE, D.A. 2004. Road Mortality of Snakes in Central Virginia. *Banisteria*, 24: 8-14.
- GITMAN, I. & LEVINE, M.D. 1970. An algorithm for detecting unimodal fuzzy sets and its application as a clustering technique. *IEEE Trans Computer*, 19: 583-593, <http://dx.doi.org/10.1109/T-C.1970.222992>
- GOKULA, V. 1997. Impact of vehicular traffic on snakes in Mudumalai Wildlife Sanctuary. *Cobra*, 27: 26-30.
- GOMES, L.; GRILO, C.; SILVA, C. & MIRA, A. 2009. Identification methods and deterministic factors of owl road kill hotspot locations in Mediterranean landscapes. *Ecological Research*, 24: 355-370, <http://dx.doi.org/10.1007/s11284-008-0515-z>
- GOOSEM, M. 2007. Fragmentation impacts caused by roads through rainforests. *Current Science*, 93: 1587-1595.
- HELMS, T. & BUCHWALD, E. 2001. The effect of road kills on amphibian populations. *Biological Conservation*, 99: 331-340, [http://dx.doi.org/10.1016/S0006-3207\(00\)00215-9](http://dx.doi.org/10.1016/S0006-3207(00)00215-9)
- HODSON, N.L. 1962. Some notes on the causes of bird road casualties. *Bird Study*, 9: 168-173, <http://dx.doi.org/10.1080/00063656209476024>
- HUIJSER, M.P.; GUNSON, K.E. & ABRAMS, C. 2006. Wildlife-vehicle collisions and Habitat Connectivity Along Montana Highway 83 in the Seeley-Swan Valley, Montana: A Reconnaissance. Western Transportation Institute Report No. FHWA/MT-05-009/8177, Montana State University, Bozeman, MT. 160p.
- JACKSON, S. 1999. Overview of transportation-related wildlife problems. Pp 1-4. *In*: G.L. Evink *et al.* (eds.). *Proceedings of the Third International Conference on Wildlife Ecology and Transportation (ICOWET)*. FL-ER- 73-99. Florida Dept. of Transportation, Tallahassee, Florida. 330p.
- JOCHIMSEN, D.; PETERSON C.R.; ANDREWS, K.M. & GIBBONS, J.W. 2004. A Literature Review of the Effects on Roads the Measures used to Mitigate those Effects. Final Report to Idaho Fish and Game Department and the USDA Forest Service. 78p.
- JOCHIMSEN, D.M. 2005. Factors influencing the road mortality of snakes on the upper Snake River Plain, Idaho. Pp. 351-365. *In*:

- C.L. Irwin, P. Garret & K.P. McDermott (eds.). *Wildlife Impacts and Conservation Solutions*. North Carolina State University, North Carolina.
- JOYCE, T.L. & MAHONEY, S.P. 2001. Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. *Wildlife Society Bulletin*, 29: 281-291.
- KANNAN, P. 2007. Mortality of reptiles due to vehicular traffic in Mudumalai Wildlife Sanctuary, Western Ghats, Tamil Nadu, India. *Cobra*, 1:1-3.
- KRIVDA, W. 1993. Road kills of migrating garter snakes at the Pas, Manitoba. *Blue Jay*, 51:197-198.
- LANGEN, T.A.; MACHNIAK, A.; CROWE, E.K.; MANGAN, C.; MARKER, D.F.; LIDDLE, N. & RODEN, B. 2007. Methodologies for surveying Herpetofauna mortality on rural highways. *Journal of Wildlife Management*, 71: 1361-1368, <http://dx.doi.org/10.2193/2006-385>
- LODE, T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. *Ambio*, 29: 163-166.
- MADER, H.J. 1987. Animal Habitat Isolation by Roads and Agricultural Fields. *Biological Conservation*, 29: 81-96, [http://dx.doi.org/10.1016/0006-3207\(84\)90015-6](http://dx.doi.org/10.1016/0006-3207(84)90015-6)
- McDONALD, P.J. 2012. Snakes on roads: An arid Australian perspective. *Journal of Arid Environments*, 1-4.
- MCKENNA, D.; MCKENNA, K.; MALCOM, S. & BERENBAUM, M. 2001. Mortality of Lepidoptera along roadways in central Illinois. *Journal of the Lepidopterists Society*, 55: 63-68.
- MECH, L.D. 1989. Wolf population survival in an area of high road density. *American Midland Naturalist*, 121: 387-389, <http://dx.doi.org/10.2307/2426043>
- MOORE, R.G. 1978. Seasonal and daily activity patterns and thermoregulation in the southwestern speckled rattlesnake (*Crotalus mitchelli pyrrhus*) and the Colorado desert sidewinder (*Crotalus cerastes laterorepens*). *Copeia*, 439-442, <http://dx.doi.org/10.2307/1443608>
- MUKHERJEE, D. 2007. Resource utilization patterns of reptiles in the tropical dry mixed deciduous forest of Anaikatty Hills, Western Ghats, India. *PhD Thesis*. Bharathiar University, Coimbatore, India. 150p.
- OXLEY, D.J.; FENTON, M.B. & CARMODY, G.R. 1974. The effects of roads on populations of small mammals. *Journal of Applied Ecology*, 11: 51-59, <http://dx.doi.org/10.2307/2402004>
- PASHA, M.K.S.; AREENDRAN, G.; SANKAR, K. & QURESHI, Q. 2000. A preliminary checklist of snakes of Pench Tiger Reserve, Madhya Pradesh, *Cobra*, 40: 5-8.
- PUGLISI, M.J.; LINDZEY, J.S. & BELLIS, E.D. 1974. Factors Associated with Highway Mortality of White-tailed Deer. *Journal of Wildlife Management*, 38: 799-807, <http://dx.doi.org/10.2307/3800048>
- RAMP, D.; CALDWELL, J.; KATHRYN, A.E.; WARTON, D. & CROFT, D.B. 2005. Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. *Biological Conservation*, 126: 474-490, <http://dx.doi.org/10.1016/j.biocon.2005.07.001>
- RAMP, D.; WILSON, V.K. & CROFT, D.B. 2006. Assessing the impact of roads in peri-urban reserves: Road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biological conservation*, 129: 348-359, <http://dx.doi.org/10.1016/j.biocon.2005.11.002>
- REIJNEN, R.; FOPPEN, R.; TERBRAAK, C. & THISSEN, J. 1995. The effects of car traffic on breeding bird populations in woodland Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology*, 32: 187-202, <http://dx.doi.org/10.2307/2404428>
- RICHARDSON, J.H.; SHORE, R.F. & TREWEEK, J.R. 1997. Are major roads a barrier to small mammals? *Journal of Zoology London*, 243: 840-846, <http://dx.doi.org/10.1111/j.1469-7998.1997.tb01982.x>
- ROE, J.H.; GIBSON, J. & KINGSBURY, B.A. 2006. Beyond the wetland border: estimating the impact of roads on two species of water snakes. *Biological Conservation*, 130: 161-168, <http://dx.doi.org/10.1016/j.biocon.2005.12.010>
- ROEDENBECK, I.A. & VOSER, P. 2008. Effects of roads on spatial distribution, abundance and mortality of brown hare (*Lepus europaeus*) in Switzerland. *European Journal of Wildlife Research*, 54: 425 -437, <http://dx.doi.org/10.1007/s10344-007-0166-3>
- ROSEN, P.C. & LOWE, C.H. 1994. Highway mortality of snakes in the Sonoran Desert of Southern Arizona. *Biological Conservation*, 68: 143-148, [http://dx.doi.org/10.1016/0006-3207\(94\)90345-X](http://dx.doi.org/10.1016/0006-3207(94)90345-X)
- ROW, J.R.; BLOUIN-DEMERS, G. & WEATHERHEAD, P.J. 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). *Biological Conservation*, 137: 117-124, <http://dx.doi.org/10.1016/j.biocon.2007.01.020>

- RUDOLPH, D.C.; BURGDORF, S.; CONNER, R.N. & SCHAEFER, R. 1999. Preliminary evaluation of the impact of roads and associated vehicular traffic on snake populations in eastern Texas. Pp 129-136. In: G.L. Evink, P. Garrett, D. Zeigler & J. Berry (eds.). Proceedings of the International Conference on Wildlife Ecology and Transportation. Florida Department of Transportation, Tallahassee, Florida, USA. 1 CD-ROM.
- SEILER, A. 2001. Ecological Effects of Roads A review. Swedish University. *Introductory Research Essay*. Uppsala, Swedish. 40p.
- SEILER, S.; HELLDIN, J.-O. & SEILER, C. 2004. Road mortality in Swedish mammals: results of a drivers' questionnaire. *Wildlife Biology*, 10: 225-233.
- SESHADRI, K.S. & GANESH, T. 2011. Faunal mortality on roads due to religious tourism across time and space in protected areas: A case study from south India. *Forest Ecology and Management*, 262: 1713-1721, <http://dx.doi.org/10.1016/j.foreco.2011.07.017>
- SHEPARD, D.B.; KUHN, A.R.; DRESLIK, M.J. & PHILLIPS, C.A. 2008. Roads as barriers to animal movement in fragmented landscapes. *Animal Conservation*, 11: 288-296, <http://dx.doi.org/10.1111/j.1469-1795.2008.00183.x>
- SHINE, R.; LEMASTER, M.; WALL, M.; LANGKILDE, T. & MASON, R. 2004. Why did the snake cross the road? Effects of roads on movement and location of mates by garter snakes (*Thamnophis sirtalis parietalis*). *Ecology and Society*, 9: 9.
- SILVERMAN, B.W. 1986. Density Estimation for Statistics and Data Analysis. Chapman & Hall, London. 175p.
- SMITH, D.J. 2003. Ecological Effects of Roads: Theory, Analysis, Management and Planning Considerations. *PhD Thesis*. University of the State of Florida. Gainesville, USA.
- SMITH, L.L. & DODD, C.J. 2003. Wildlife mortality on highway US 441 across Payne's Prairie, Alachua County, Florida. *Florida Naturalist*, 66: 128-140.
- SPELLERBERG, I.F. 2002. Ecological effects of roads. Science Publishers, Enfield, New Hampshire, USA. 251p.
- SPSS 15.0. 2006. Command Syntax Reference, SPSS Inc., Chicago.
- SULLIVAN, B. K. 1981. Observed differences in body temperature and associated behavior of four snake species. *Journal of Herpetology*, 15: 245-246, <http://dx.doi.org/10.2307/1563390>
- SUNDAR, G.K.S. 2004. Mortality of herpetofauna, birds and mammals due to vehicular traffic in Etawah District, Uttar Pradesh, India. *Journal of the Bombay Natural History Society*, 101: 392-398.
- SZERLAG, S. & MCROBERT, S.P. 2006. Road occurrence and mortality of the northern diamondback terrapin. *Applied Herpetology*, 3: 27-37, <http://dx.doi.org/10.1163/157075406775247058>
- TREMBATH, D.F. & FEARN, S. 2008. Body sizes, activity times, food habits and reproduction of brown tree snakes (*Boiga irregularis*) (Serpentes: Colubridae) from tropical north Queensland, Australia. *Australian Journal of Zoology*, 56: 173-178, <http://dx.doi.org/10.1071/ZO08008>
- TREWEEK, J.S.; THOMPSON, N.V. & JAPP, C. 1993. Ecological assessment of road developments. A review of environmental statements. *Journal of Environmental Planning and Management*, 36: 295-308, <http://dx.doi.org/10.1080/09640569308711948>
- TROCMÉ, M.; CAHILL, S.; DE VRIES, H.J.G.; FARRALL, H.; FOLKESON, L.; FRY, G.; HICKS, C. & PEYMEN, J. (eds.). 2002. *COST 341. Habitat Fragmentation due to transportation infrastructure: The European Review*. Office for Official Publications of the European Communities, Luxembourg. 253p.
- TROMBULAK, S.C. & FRISSELL, C.A. 2002. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*. 14: 18-30, <http://dx.doi.org/10.1046/j.1523-1739.2000.99084.x>
- VAN GELDER, J.J. 1973. A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo* L. *Oecologia*, 13: 93-95
- VIEIRA, E.M. 1996. Highway mortality of mammals in central Brazil. *Journal of the Brazilian Association for the Advancement of Science*, 48: 270-271.
- VIJAYAKUMAR, S.P.; VASUDEVAN, K.; ISHWAR, N.M. 2001. Herpetofaunal mortality of Roads in the Anamalai Hills. Southern Western Ghats. *Hamadryad*, 26: 253-260.
- WHITAKER, R. & CAPTAIN, A. 2004. Snakes of India: The Field Guide. Draco Books, India. 494p.
- WPA. 1972. Wildlife (Protection) Act 1972. Ministry of Environment & Forests. Government of India.
- YAHNER, R. 1988. Changes in wildlife communities near edges. *Conservation Biology*, 4: 333-339, <http://dx.doi.org/10.1111/j.1523-1739.1988.tb00197.x>

Submetido em 30/08/2012.

Aceito em 14/02/2013.

Acknowledgement

Undertaking this research has been a truly thrilling and challenging experience for me. Little did I that a stretch of road can attract my academic interest and would offer so much to learn. My research work could not have been accomplished without the invaluable support and guidance provided by many people.

I take this opportunity to express my sincere gratitude to my supervisor Dr. Asha Rajvanshi, Former Head, EIA Cell. Her own enthusiasm in the subject fostered my interest in road ecology and provided the foundations for this research and Ph.D. She not only provided continuous support in my research work but also encouraged me to present my work in the international conference in USA very early in my capacity as a young researcher. I cannot really thank her enough for her encouragement, motivation and willingly sharing her vast knowledge to enrichen me intellectually. I could not have had a better advisor; mentor and a friend for helping me undertake this first study in India in the area of road ecology.

I would like to express my deep sense of gratitude to my co-supervisor Dr. V.B. Mathur, Director, Wildlife Institute of India, who has been a source of inspiration and guidance for me in all these years. In him, I found someone who always had a ready and a perfect solution for all academic and administrative queries that I posed to him from time to time.

I owe a deep sense of respect to Late Dr. S. Bhupathy, Principal Scientist & Head, SACON, who inspired me to make a carrier in Wildlife Science. I wish he had lived to see this work.

I could not have accomplished this work without the enabling support of the officials of Madhya Pradesh Forest Department. I am grateful to Dr. H.S. Pabla, IFS (Former Principal Chief Conservator of Forests and Chief Wildlife Warden for granting the permission to undertake fieldwork for my study in Pench Tiger Reserve. I owe my special gratitude to Field Directors- Shri H.S. Negi and Dr. Khageshwar Nayak; Shri O.P. Tiwari, Deputy Field Director, Pench Tiger Reserve. These officials have not only providing the much needed logistic support for conducting the study but also provided the insight that greatly helped in refining the objectives of the study. Discussions with all the above officials greatly helped in finalising the methodology adopted for achieving the different objectives of this study and provided me the insight to explore a range of impacts of a road-widening project in one of the important tiger landscapes in central India.

I am extremely thankful to Dr. S.P. Goyal, Emeritus Scientist, Wildlife Institute of India who persuaded me to conclude my research work especially when my job demanded more time and I delayed the submission of this work. He helped me resolve the conflict in my mind to my responsibility as a wildlife inspector or a researcher who must also do justice to science through contributions from my study.

I am grateful to Mr. P.R. Sinha, Former Director, Wildlife Institute of India for providing me the opportunity to undertake this work as a researcher under the project funded by the Wildlife Institute of India.

I express my sincere gratitude to Dr.V.P Uniyal, Research Coordinator for his valuable guidance, cooperation and support that helped me muster enough confidence in me to submit this work for the award of a doctoral degree.

I am sincerely grateful to all the faculty members of WII who provided very valuable inputs and insights during the presentation of different components of my work in the annual research seminars of WII over three years and subsequently, also during the Pres Thesis presentation.

I acknowledge the support extended to me by my field assistants-Shri. Shivanand and Shri. Dhanalal during the time of arduous fieldwork. Without their support in field, it would not have been easy for me to make the most out of my effort in collecting the field-based data.

I am indebted to Shri. Narinder Singh Bist, Sr. Technical Officer at EIA cell, WII for his valuable assistance in presenting this work in its present form. Shri. Surinder Singh Negi, Attendant in, EIA Cell, willingly and merrily provided the enabling support in my work at all times.

I thank all researchers at WII for their encouragement and, comradery during my stay at WII.

Last but not the least I thank my family, my parents, my beloved wife Menaka and my two little angels (Kavinyaa Shri and Naviyaa) for supporting me spiritually during the writing of this thesis and for providing the much-needed emotional support through different stages of life.

A. Pragatheesh

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Publications

Chapter 1: Introduction

Roads: Implication for biodiversity

Roads, across the globe, have become physically most distinct linear corridors imposed on the environment by humans for the transportation of people and materials. Globally, at least 25 million km new roads are anticipated by 2050 – a 60% increase in the total length of roads over that in 2010. Nine-tenths of all road construction is expected to occur in developing nations (Dulac 2013).

There is an estimate of one billion vehicles (http://wardsauto.com/ar/world_vehicle_population_110815) travelling on approximately 50 million km of public roads (van der Ree *et al.* 2011, based on his personal communication with T. Langton) and the road network and traffic volumes are still increasing, particularly in eastern Europe, China, India, and Latin America. The United States of America has the largest road network with over 6 million km public roads followed by India representing the second largest road system in the world with ca 5.2 million km. China is third with ca 5.8 million km of roads and Brazil with ca 1.75 million km of roads has the fourth largest road system in the world.

To date, very few landscapes are bereft of roads, and as human populations continue to increase, road density is likely to increase further whether it be by new developments, road improvements, or road upgrade schemes.

As roads extend pervasively throughout most terrestrial landscapes and habitats, impacts associated with roads through wildlife areas have really become a global problem. Many ecologists have singled out roads as the factor posing the greatest threats to biodiversity (Noss 2002; Leblond *et al.* 2007; Grilo *et al.* 2011;

Bennett 2017; Lechner *et al.* 2018; Mehri *et al.* 2018) and leading to the widest form of modifications of natural landscapes (Diamondback 1990; Bennett 1991; Noss & Cooperrider 1994; Trombulak & Frissell 2000; Liu *et al.* 2008; Shi *et al.* 2018). According to Forman and Alexander (1998), by the end of the 20th century, vehicle collisions with wildlife have replaced hunting as the leading direct cause of mortality in terrestrial vertebrates. Others argue that the severity of negative ecological impacts of roads and threats to biodiversity can offset the benefits of facilitated linkage, enhanced mobility, and improved accessibility (Forman & Alexander 1998; Spellerberg 1998; Byron 2000).

Although in terms of proportion of area under road, most countries may have about only 1–2% of their land area under roads and roadsides (Forman 1998), their linear nature make them conspicuous features in most landscapes and even more prominent in otherwise roadless areas of large contiguous forested tracts and natural habitats in the wilderness areas. The impacts of roads can be ecologically most significant or incredibly subtle depending on the natural characteristics of the road corridors (road surface plus its maintained roadsides and any parallel vegetated strips). Another important factor that can influence the nature of road-related ecological impacts is whether the development involves widening or upgrading existing roads or planning of a new road, highway, or an expressway in a roadless area that is an important habitat for species commanding high conservation priority.

Impacts of roads and other linear clearings that traverse through large areas of natural habitats have been demonstrated in many areas of the world and are well documented by Adams and Geis (1983); Foreman and Alexander (1998); Spellerberg (1998); Seiler (2001); Van der Ree *et al.* (2011); Clement *et al.* (2015); Laurance *et*

al. (2009), Laurance and Burgués-Arrea (2017), Laurance (2018) and in over 20,000 additional citations from around the globe. Such studies show that roads and highways can threaten biodiversity in many ways.

Summary of ecological threats

The negative impacts of roads on wildlife no longer spring a surprise. There is a growing recognition of their deleterious impacts on the natural environment and the need to quantify and mitigate these impacts (Andrews 1990; Spellerberg 1998; Forman 2002; Donaldson & Bennett 2004; Goosem 2004; Davenport & Davenport 2006; Roedenbeck *et al.* 2007; Laurence *et al.* 2014). The effects of roads are varied and include many direct and indirect effects (Figure 1.1) that have been clearly defined and also schematically represented (Van der Zande *et al.* 1980; Forman 1995; Seiler 2001).

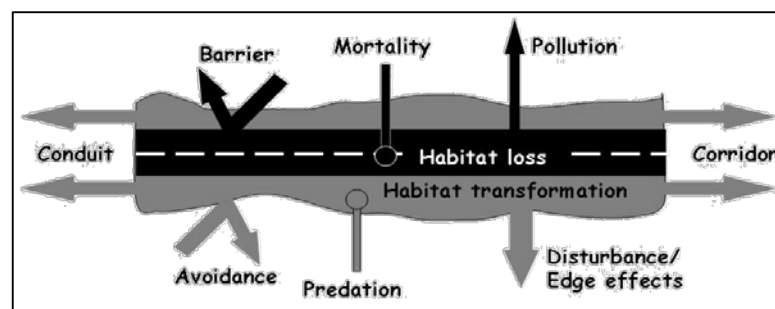


Figure 1.1 Ecological effects of road (modified from Van der Zande *et al.* 1980).

Habitat loss and transformation

The construction of roads and railways change the natural landscape along the entire length of the road, or railway line, apart from fragmenting the landscape. Compared to national highways, narrow country roads have more intense network and its penetration into the wild habitat is deeper and the adverse effect is therefore manifold as compared to a single national highway (Bartlett *et al.* 2016; Pardini *et al.*

2017; Veach *et al.* 2017; Symes *et al.* 2018). When considering the roadside embankments, slope cuttings, parking and other travellers' amenities like petrol pumps, food outlets, rest stops, pedestrian view points and walkways, the effect of the fragmentation becomes more pronounced (Seiler 2001).

The construction of new roads and railroads inevitably transforms large areas into linearly defined, insulated, and highly disturbed habitats. Although it will be impossible to evaluate total loss of habitat in terms of size and functions due to road construction and its subsequent operations, it can at least be based on assessment of habitat loss physically occupied by roads. Experience shows that associated features, such as roadsides, embankments and slope cuttings, and the ensuing physical infrastructure development (parking places, gas stations, or pedestrians walkway) occupy several times larger area than the paved surface of the road. The combined effects of habitat loss and roads together thereby influence the "accessible habitat" (Eigenbrod *et al.* 2008).

Areas associated with highway and roadway alignments represent verge habitats that often serve as conduits facilitating the movement of animals (Merriam 1991; Saunders *et al.* 1991; Iuell *et al.* 2003) and may become altered by spread of undesirable plants and animals (Seabrook & Dettmann 1996; Parendes & Jones 2000). This may further restrict functional use of the roadside habitats. Storm water discharges, alterations in stream hydrology, air emissions, and exotic plants can degrade habitats ranging up to several hundred meters from railways and highways (Transportation Research Board 1997; Trombulak & Frissell 2000).

Habitat fragmentation and modification

While mobility of people and transportation of goods is an integral component of globalization and economic opportunity, road infrastructure that enhances connectivity among people also results in increased habitat fragmentation which is recognized as the largest single threat to biological diversity worldwide (Brahmdstedt & Barsch 1993; Meffe *et al.* 1997; Prillewitz 1997; Auestad *et al.* 1999; Forman 2000). Literature review (Fleiter & Watson 2006) and an impressive amount of empirical studies (Andren 1994; Canters & Cuperus 1997; Evink *et al.* 1998; Spellerberg 1998; Evink *et al.* 1999; Debinski & Holt 2000; Forman 2000; van der Ree *et al.* 2010) illustrate the widespread impact of possible effects of fragmentation on wildlife species and ecosystems.

The fragmentation process initiates the loss of habitat that results in progressive reduction in species diversity in the landscape (Figure 1.2). The final outcome can be the isolation effects which becomes more important (Harris 1984). Empirical studies indicate that the number of species drops significantly when more than 80% of the original habitat is lost and as habitat remnants become isolated (Andren 1994).

The consequences of habitat fragmentation to wildlife can be variable and complex. By opening of core areas fragmentation of contiguous habitat patches takes place that may lead to a dramatic increase in edges and this may result in the geographic isolation of “islands” of habitat among a matrix of urban or agricultural land-uses, thereby restricting the mobility of certain organisms (Andreassen *et al.* 1996). Inability of individuals to cross roads can ultimately lead to population isolation (Epps *et al.* 2005; Riley *et al.* 2006) and reduced population viability.

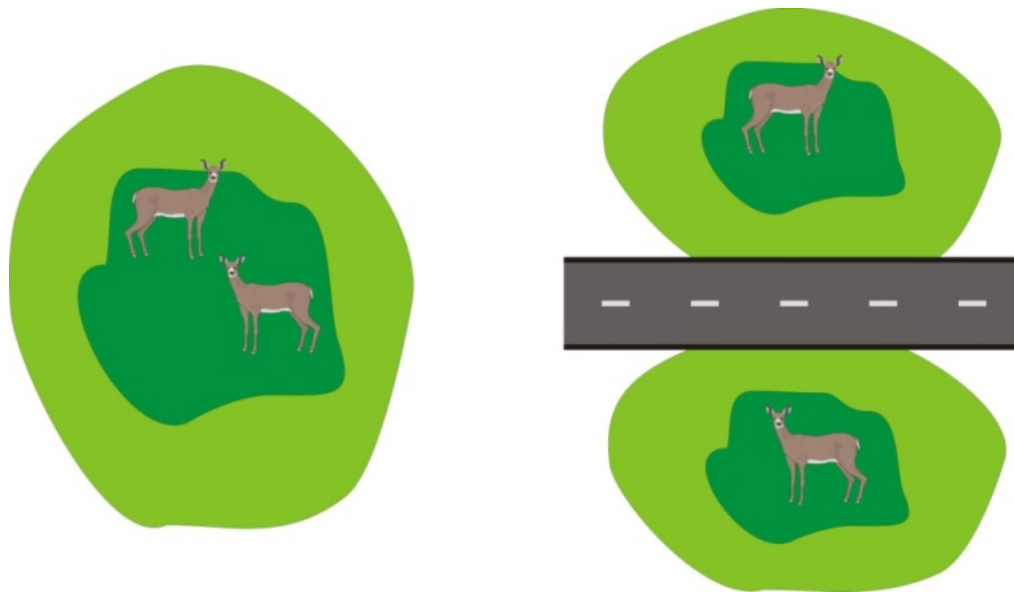


Figure 1.2 The core habitat lost due to the increased edge effect along the route of the road results in far greater reduction in area of available habitat than that taken by road.

Road avoidance and barrier effect

Unlike the habitat lost under the footprint of the road which is a direct and most obvious environmental impact, the ecological effects of road avoidance caused by traffic disturbance is not so obvious. Yet, the implications of road avoidance by animals is far more significant than other forms of ecological impacts of roads (Lovallo & Anderson 1996; Whittington *et al.* 2004; Jaeger *et al.* 2005; Benítez-López *et al.* 2009).

Many species such as elk (*Cervus elaphus*), moose (*Alces alces*), grizzly bear (*Ursus arctos*), gray wolves (*Canis lupus*), mountain lions (*Puma concolor*), and Canada lynx (*Lynx canadensis*) are known to avoid roads (Frederick 1991; Dickson *et al.* 2005; Dussault *et al.* 2007). Carnivores that are especially sensitive to presence of roads and human development can present wider implications for the ecosystem. Being

top predators, effects on them would have a bearing on regulation of prey species that may become overpopulated in their absence (Weaver 2001). Road avoidance has been also demonstrated by small mammals (Oxley Fenton & Carmody 1974; Mader 1984; Swihart & Slade 1984), gliding mammals (van der Ree *et al.* (2010), birds (Illner 1992; Reijnen *et al.* 1995) salamanders (DeMaynadier & Hunter 2000), snakes (Row *et al.* 2007) and even ground-foraging arthropods (Mader *et al.* 1990). Such avoidance can lead to changes in species composition and population structure. Biodiversity of a native habitat can increase or decrease with the introduction of the road (National Cooperative Highway Research Program Transportation (NCHRPT) 2002).

When highways and roads deny access to species to fulfil important requirements of animal's lifecycles, they become formidable barriers. The barrier effect on wildlife results from a combination of disturbance and avoidance effects. Disturbances due to high traffic volume contributing to unabated movement of vehicle on roads (Figure 1.3), noise pollution, and human activity may repel many species from approaching infrastructure corridors.



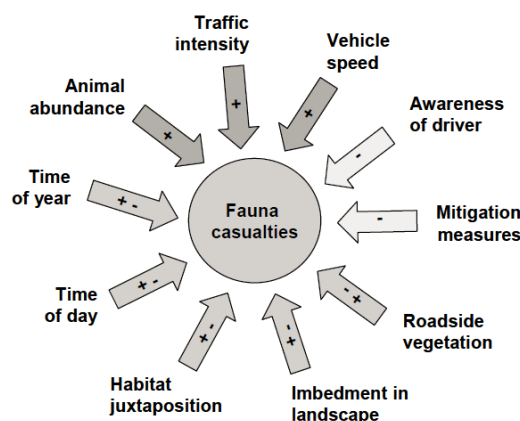
Figure 1.3 Barrier effects.

Most infrastructure barriers do not completely block animals' movements, but reduce the number of crossings quantitatively (e.g. Merriam *et al.* 1989). The intensity of the barrier is dependent on the intrinsic nature of the highway and verges (Mader 1984; Bennett 1991; Bright 1993; Vermeulen 1993; Penny Anderson Associates 1994; Slater 1995; English Nature 1996).

Disruption of dispersal and movement processes that maintain gene flow, supplement small or declining populations, and re-colonize local populations lost to extinction can be the most serious threat from a wildlife conservation standpoint.

Mortality of wildlife species

Road-induced mortality of animals is the most visible and universally acknowledged impacts that have been a concern to biologists (Stoner 1925). Carcasses of dead animals have become such a common view in road corridors that Knutson (1987) published a field guide for animals on roads and streets. The numbers of casualties appear to be constantly growing as traffic increases and infrastructure expands.



Factors influencing the number of road kills (Seiler 2001)

With the increase in traffic along the duration of the day, a shift in the animal mortality is observed. The species activity is a major contributor to this, namely its foraging and breeding seasons, seasonal migration, food requirement, especially when there are young ones to take care of (e.g. Van Gelder 1973; Bergmann 1974; Göransson *et al.* 1978; Aaris-Sorensen 1995; Groot Bruinderink & Hazebroek 1996; Lesbarrères & Fahrig 2012; Dwyer *et al.* 2016; Jacobson *et al.* 2016; Williams *et al.* 2018). Climatic conditions like temperature, rainfall, snow can also influence the mortality rates (e.g. Jaren *et al.* 1991; Belant 1995; Gundersen & Andreassen 1998).

For decades road mortality of animals has been a prime ecological concern as it is the most common effect of road through any natural habitat (e.g. Stoner 1925; Trombulak & Frissell 2000; Seiler & Helldin 2006; Kazemi *et al.* 2016; Pandey 2016; Visintin *et al.* 2016; Winton *et al.* 2018). The increase in traffic has seen a direct correlation to the increase in animal mortality due to vehicular collision, and expansion of the infrastructure. Forman and Alexander (1998) concluded that: “sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land”.

The larger home ranges of animals and long migratory movements make the animals more vulnerable to road mortality. The frequency of these animals to encounter a road is much higher compared to animals with small home ranges. Traffic is considered as an important cause of mortality especially for endangered mammalian species (e.g. Harris & Gallagher 1989; Madsen *et al.* 2002; Jaarsma *et al.* 2006; Kioko *et al.* 2015; Bartonička *et al.* 2018; Ashem 2019).

Most road kills occur in hotspots or are clustered along roads. Spatial patterns in wildlife mortality near roads clearly depend on animal population density; suitable habitat (Gomes *et al.* 2009; Grilo *et al.* 2009) and landscape structure (Beaudry *et al.* 2008); animal behaviour (Grilo *et al.* 2009); and road and traffic characteristics (Clevenger & Waltho 2004; Malo *et al.* 2004).

Amphibians may be particularly vulnerable to effects of roads (Eigenbrod *et al.* 2009) because they are slow-moving organisms that access multiple habitats seasonally to complete their life cycle. For snakes, which are generally slow moving and tend to get attracted to the paved surfaces for thermoregulation, roads are a significant source of mortality (Row *et al.* 2007). Similarly, turtles are particularly sensitive to mortality because of their need to use uplands to lay eggs, often bringing them in conflict with vehicular traffic (Beaudry *et al.* 2010). Bird species with low flight paths are vulnerable to vehicle hits (Ault 1982; Svensson 1998). Mammalian species are especially vulnerable to road network because they have large spatial requirements, small populations, tend to live at low densities, and occupy small geographic range or exhibit migratory behaviour (Ball *et al.* 2001; Gittleman *et al.* 2001).

Road-induced human colonization and disturbance

Road-induced human expansion is indeed an important consideration as a driving force in ecology because human presence both inadvertently and directly shapes the ecological character of the natural environment. At least three major ecological effects – hunting and fishing, recreation, and changes in use of land and water – have been associated with road developments the world over (Trombulak &

Frissell 2000). These may not be often captured in community perceptions. According to Richard Forman, the father of road ecology, “Degraded habitat surrounding roads is a bigger problem, ironically nearly invisible to the driver speeding along the highway”.

New roads may often increase the rate with which natural resources are exploited due to increased ease of access by humans into formerly remote areas (WII 1997). Cutting of snags for firewood along the roadsides can decimate cavity-nesting bird populations (Noss 1995). Roads can lead to large-carnivore-vehicle collisions, poaching, and indirectly providing greater hunting access, resulting in reduced prey availability (Brody 1984; Thiel 1985; Mattson *et al.* 1987; McLellan & Shackleton 1988; Mech *et al.* 1988; Noss *et al.* 1996; Kerley *et al.* 2002). The most common secondary impact of roads is the increasing potential for hunting of wildlife populations (Trombulak & Frissell 2000) and consequent reduction in population sizes of many game species. Earth movement and traffic have resulted in den losses of foxes (Koopman *et al.* 2001).

Similarly, roads lead to increased predation and increase in human wildlife conflicts and retaliatory killings. Road induced human presence in wilderness areas can disturb animals, causing them to unnecessarily expend energy avoiding people, thereby potentially reducing reproductive success (Manville 1983; van Dyke *et al.* 1986; Goodrich & Berger 1994; Primm 1996). Human induced feeding of animals on road side offer yet another major risk of mortality of some species of primates which get adapted to human facilitated feeding (Southwick *et al.* 1976; Chhangani 2004a; Pragatheesh 2011).

The construction of roads through native vegetation favours the movement of pest animals (Schmidt 1989; Gelbard & Belnap 2003). They act as dispersal corridors for invasive species (Parendes & Jones 2000). In some cases, these species spread from roadsides into adjacent native communities (Noss 1995). As a consequence, the functional habitat within road corridor gets degraded and highly modified and permanently disturbed corridor. Since ecological impacts of road developments may not be immediate, time lags between landscape change and ecosystem response (Tilman *et al.* 1994) often limit the recognition of such impacts.

With roads, follow the ribbon development along major highways (Rujopakarn 2003) that may have impacts on use and quality of road side habitats (Forman & Alexander 1998; Treweek 1999). While the trade economists have written extensively about the link between major road and market access, and national economies (Eberts 1989), the link between roads, landscape disturbance and loss of biodiversity largely remain a matter of concern only (Chomitz & Gray 1996; Wilkie *et al.* 2000).

Environmental pollution

The paradox of socio-economic benefits from transportation and the deterioration of environmental systems at the same pace compound the complexities of issues for road planners and environmental managers. The environmental dimensions of transportation are associated with each of the stages from alignment, to construction to implementation and even much beyond the foreseeable future. Transportation sector is becoming increasingly linked to environmental problems (Hamilton 1991; Tsunokawa & Hoban 1997; Rodrigue 2012). The most important impacts of transport on the environment relate to climate change, air quality, noise,

water quality, soil quality, land take and associated loss of habitat and decline in biodiversity (Rodrigue 2012).

The activities of the transport industry release several million tons of gases and particulate matter each year into the atmosphere. These include lead (Pb), carbon monoxide (CO), carbon dioxide (CO₂; not a pollutant), methane (CH₄), nitrogen oxides (NO_x), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), silicon tetrafluoride (SF₆), benzene and volatile components (BTX), heavy metals (zinc, chrome, copper and cadmium) and particulate matters (ash, dust). These emissions contribute to climate change, environmental contamination and resource degradation. Heavy metals, such as zinc, cadmium, nickel from motor oil and tyres are washed off the road sides. This road run-off often carries organic and inorganic pollutants and other suspended matter (Gjessing *et al.* 1984) that contaminate water bodies enter the soil and may accumulate in plant and animal tissues, with the consequent effect on reproduction and survival (Scanlon 1987). Many studies have documented increasing levels of lead in plants with proximity to roads, and with increases in traffic volume. This lead moves up the food chain, with sometimes severe toxic effects on animals (Harrison & Dyer 1984).

The removal of earth's surface for highway construction or lowering surface grades have led to loss of fertile and productive soils. Roads that are likely to boost the growth of transport industry also bring an element of risk from spilling of hazardous chemical and industrial products along the highway (Figure 1.4)



Figure: 1.4 Paint spilling from the toppled truck on NH-7 along Pench Tiger Reserve.

An immediate impact is noise from heavy traffic along highways. Increasing noise levels have a negative impact on the urban environment reflected in falling land values and loss of productive land uses. Noise and artificial lighting have shown to affect some wildlife. Animal responses to noise pollution are as varied as the animals themselves. Some of the established responses include alteration in activity patterns, increase in heart rate and production of stress hormones (Noss 2002), abandonment of habitats, changes in singing behaviour of bird and breeding success (Reijnen *et al.* 1995; Parris & Schneider 2008) changes in anuran calls and signal masking (Bee & Swanson 2007). Noise pollution is also known to impact pollination and seed dispersal (Francis *et al.* 2012).

Ecological impact of road sector in India

Road sector in India

Historic perspective

In India, roads have come a long way starting from the trails of earlier times used by our ancestors to travel through woods on hunting sprees. Although first reference to road system in India was made when the Aryans migrated 5000 years ago (Ghaswala 1965), the evidence of road development in the Indian subcontinent can be traced back to approximately 4000 BC from the ancient cities of Harrapa and Mohenjodaro of the Indus Valley Civilization.

Around the 1st Century AD, the ancient Silk Road came into being, which passed through northern India and China. Development of roads took a new turn during the Mauryan rule in the 4th century. The Mughal period was the golden era for roads as the whole of India was effectively connected by roads to rule the vast empire (Figure 1.5). One of the famous highways of medieval India is the Grand Trunk Road that originated in Sonargaon near Dhaka in Bangladesh and ended at Peshawar in modern-day Pakistan and linked several important Indian cities from Kolkata in the east to Amritsar in the west. During the colonial period in the 19th century, the British upgraded the existing highway network and built roads in many inaccessible areas such as the Western Ghats. Progress in road building continued in independent India for boosting economic growth.

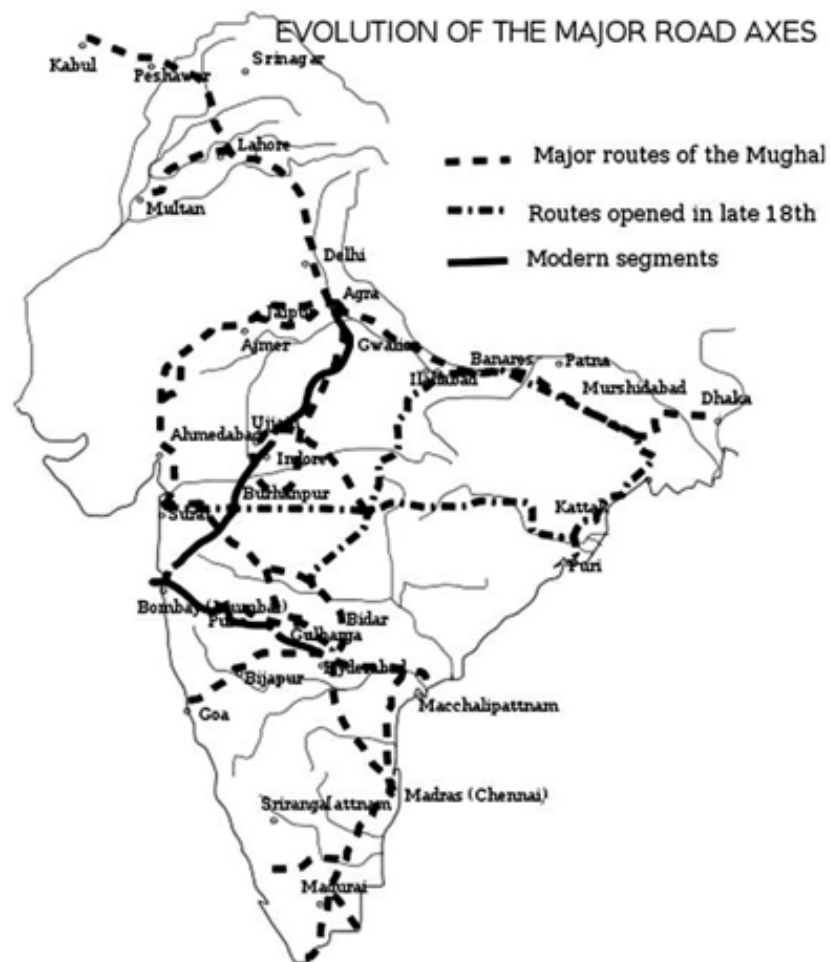


Figure: 1.5 Evolution of Indian road network showing the evolution of routes since the Mughal times (Source: <http://en.wikipedia.org/wiki/File:Roadevol.svg>)

Current status of developments in road sector

Transportation has been noted to be a critical infrastructure requirement for economic growth in India (Raghuram & Babu 2001). It has assumed a pivotal role in the movement of passengers and goods across the country. India with its present road network of over 56.03 lakh km. (Ministry of Road Transport and Highways) is the second largest road network in the world. Currently India's road density at 1.7 km of roads per sq km was higher than that of Japan (0.91 km/sq km), USA (0.68 km/ sq km), China (0.47 km/ sq. km), Brazil (0.18 km/sq.km) and Russian Federation (0.08

km/ sq km). Adjusted for its large population, India has approximately 4.63 km of roads per 1000 people (Census 2011).

The paved/surfaced road length in India was 62.5 per cent of the total road length which was lower as compared to United Kingdom (100%), Korea (84.9%) and Russian Federation (70.60%). National Highways (NHs) in India, which accounted for 1.76 % of the total length as on 31st March 2016 was much lower than that of some of the developed countries of the world such as Japan, Korea Republic, UK and Brazil.

This network consists of National Highways, Expressways, State Highways, Major District Roads, other District Roads and Village Roads of varying lengths (Table 1.1).

Table: 1.1 Existing Road Network of India.

Category of Road	Length of Roads (km)
National Highways (NHs)	1,01,011
State Highways (SHs)	1,76,166
District Roads	5,61,940
Rural Roads	39,35,337
Urban Roads	5,09,730
Project Roads	3,19,109
Total	56,03,293

Source: Basic Road Statistics of India 2015-16 Ministry of Road Transport and Highways, Govt. of India, 2018

Although National Highways constitute only about 1.80 percent of the total road network, they carry 40 percent of the total road traffic (Ministry of Road Transport and Highways, Govt. of India 2018). The rapid expansion and strengthening of the road network, is therefore a national priority to provide for both, present and future traffic and for improved accessibility to the hinterland.

Roads through sensitive habitats

As per the National Highway Authority of India, the country has the second largest road system in the world, which covers over 5.6 million km including 26,697 km passing through wildlife habitats and forests (Rajvanshi *et al.* 2001). Less than 4.99% of India's geographical area is demarcated as protected for wildlife preservation (WII 2016) with most endangered species being found in higher densities within these protected areas. Roads cut across many of India's protected areas, fragmenting the wild habitats and endangering many of the species that are already getting the beating from the anthropogenic pressures. Some examples are the National Highway 72 and 74 crossing Rajaji National Park; State highway passing through Balram Ambaji Sanctuary; seven State Highways through Gir National Park and Sanctuary; Poily-Ranjitpura approach road passing through Jambughoda Wildlife Sanctuary (Rajvanshi *et al.* 1998; WII 2007; Joshi & Dixit 2012).

As per the National Highway Authority of India, the country has the second largest road system in the world, which covers over 5.6 million km including 26,697 km passing through wildlife habitats and forests (Rajvanshi *et al.* 2001). In India PA network cover less than 4.99 % of the geographical area of the country, presently India has a network of 103 National Parks, 536 Wildlife Sanctuaries, 67 Conservation Reserves and 26 Community Reserves (WII 2016) many endangered species being found in higher densities within these protected areas. Roads cut across many of India's Protected Areas, fragmenting the wild habitats and endangering many of the species that are already getting the beating from the anthropogenic pressures. Some of the prominent examples of these negative effects include the National Highway (NH)

72 and 74 crossing Rajaji National Park; NH 67 and 212 passing through Bandipur National Park; NH 209 bisecting Sathyamangalam Wildlife Sanctuary in Tamil Nadu; NH 6 and 7 intersecting at least 6 tiger corridors in the Vidarbha region of Maharashtra; State Highway (SH) 54 passing through Balram Ambaji Sanctuary; seven state highways and the railway lines through Gir National Park and Sanctuary; NH 37 through Kaziranga National Park; NH 54 through Borail Wildlife Sanctuary in Assam; NH 54E passing through Lumding Reserve Forest in Assam and the Poily-Ranjitpura approach road passing through Jambughoda Wildlife Sanctuary (Rajvanshi *et al.* 2001; WII 2007; Joshi & Dixit 2012; Habib *et al.* 2015).

Roads passing through Tiger Reserves

Of the 50 Protected Areas declared as a Tiger Reserve in the country, major roads including National Highways, State Highways and roads of the Public Works Department traverse through as many as 26 Tiger Reserves (Rajvanshi *et al.* 2013) for varying lengths (Table 1.2).

Table: 1.2 Road passing the Tiger Reserves in India.

Sl.No	State	Name of the Tiger Reserve (TR)	Road			Remark
			NH	SH	PWD	
1.	Andhra Pradesh	Nagarjunsagar-Srisailem TR		SH		140 km
				SH		50 km
2.	Arunachal Pradesh	Namdapha TR	NH-153			13 km
3.	Assam	Kaziranga TR	NH-37			60 km
4.	Assam	Manas TR	NH-31			22 km
5.	Assam	Nameri TR	NH-69			
6.	Chhattishgarh	Achanakmar TR			PWD	30 km
7.	Jharkhand	Palamau TR		SH		
8.	Karnataka	Bandipur TR	NH-212			65 km
			NH-67			80 km
9.	Karnataka	Bhadra TR		SH-65		12 km
10.	Karnataka	Dandeli-Anshi TR		SH-95		
11.	Karnataka	Nagarhole TR		SH-33		19 km
12.	Kerala	Parambikulam TR			PWD	40km
13.	Kerala	Periyar TR			PWD	
14.	Madhya Pradesh	Bandhavgarh TR		SH-11		6 km
				SH-10		7 km
15.	Madhya Pradesh	Kanha TR			PWD	28 km
					PWD	20 km
16.	Madhya Pradesh	Panna TR		SH-6		10 km
17.	Madhya Pradesh	Pench TR	NH-7			9 km
18.	Maharashtra	Pench TR	NH-7			39 km
19.	Maharashtra	Melghat TR		SH-6		30 km
				SH		25 km
20.	Orissa	Satkosia TR			PWD	
21.	Rajasthan	Sariska TR		SH-13		12km
22.	Tamil Nadu	Annamalai TR		SH-17		12 km
				SH-78		30 km
23.	Tamil Nadu	Kalakad-Mundathurai TR			PWD	50 km
24.	Tamil Nadu	Mudumalai TR	NH-67			30 km
25.	Uttar Pradesh	Dudhwa TR			PWD	
26.	Uttarakhand	Corbett TR		SH- 4		35 km

India's pursuit for developments in the road sector cannot ensure sustainable economic growth and human development without mainstreaming ecological concerns in the planning of developments in the road sector.

Present study

Rationale

The assessment of biodiversity impacts of road networks represents an important and rapidly progressing frontier area of ecology that can substantially enhance much needed scientific knowledge for reducing the ecological footprints of roads. Much of the research on the ecological effects of roads and traffic on wildlife has been conducted in North America, Canada, Europe, Australia (Forman *et al.* 2003; van der Ree *et al.* 2003; Trombulak & Frissell 2004; van der Ree 2006; Backmann *et al.* 2010; Clevanger *et al.* 2010, van der Ree *et al.* 2011, 2015). The experience from these has been successfully employed in application of best practice designs and solutions for safeguarding species in peril (Forman *et al.* 2003; Clevenger & Huijser 2009).

Further, many of these countries do not face the challenges of conserving plants and animals in mega diverse habitats that are also dominated by humans in roaded landscapes to complicate the assessment of ecological impacts of road schemes (Rao & Girish 2007). Such studies are indeed useful in laying the principles and approaches to influence where roads are built, how they are designed and how effectively transportation agencies avoid, reduce and manage impacts. It may be however difficult to strategize actions for addressing impacts of roads based on experience from different continents and regions; taxa and habitats and diversity of threats. Studies that assess impacts on wildlife in the tropical forests are inadequate and even fewer in the Indian context. Only a handful of studies in the area of road ecology have been conducted in India (Table 1.3).

Table: 1.3 Studies on road related impacts on protected area.

Reference of the Study	Location	Target species (or group) and habitats
Jeganathan <i>et al.</i> (2018)	Anamalai Tiger Reserve	Mammals, birds, reptiles and amphibians
Gajera <i>et al.</i> (2018)	Aravalli Mountain Range of North Gujarat	Mammals, birds and reptiles
Saraf and Jadesh (2017)	Kalaburagi district, Karnataka	Butterflies
Chittaragi and Hosetti (2014)	Mid-Western Ghats, Karnataka	Snakes
Pragatheesh and Rajvanshi (2013)	Pench Tiger Reserve	Snakes
Joshi and Dixit (2012)	Rajaji National Park	Elephant
Prakash (2012)	Bandipur Tiger Reserve, Karnataka	Large mammals and birds
Gubbi <i>et al.</i> (2012)	Nagarahole Tiger Reserve, Karnataka	Large mammals
Pragatheesh (2011)	Pench Tiger Reserve	Rhesus Macaque
Bhupathy <i>et al.</i> (2011)	Portion of Western Ghats between Kumuly and Sabarimala, Tamil Nadu	Herpetofaunal
Seshadri and Ganesh (2011)	Kalakad Mundanthurai Tiger Reserve, Tamil Nadu	Mammals, reptiles, amphibians and invertebrates
Pragatheesh (2011)	Pench Tiger Reserve	Rhesus macaque
Baskaran and Boominathan (2010)	Mudumalai Tiger Reserve, Tamil Nadu	Mammals, birds, reptiles and amphibians
Behera and Borah (2010)	Nagarjunasagar-Srisailam Tiger Reserve, Andhra Pradesh	Mammal
Behera and Jena (2010)	Nagarjunasagar-Srisailam Tiger Reserve, Andhra Pradesh	Birds
Seshadri <i>et al.</i> (2009)	Sharavathi river basin, Central Western Ghats, Karnataka	Amphibians
Das <i>et al.</i> (2007)	Kaziranga National Park, Assam	Reptiles
Rao and Girish (2007)	Bandipur N.P, Nagarahole N.P and Ring road, Mysore	Butterflies
Parasharya and Tere (2007)	Anand-Ahmedabad highway, Gujarat	Monitor lizard
Sunder (2004)	Etawah district, Uttar Pradesh in an agriculture dominated area	Herpetofauna, birds and Mammals
Chhangani (2004a)	Kumbhalgarh Wildlife Sanctuary, Rajasthan	Birds
Chhangani (2004b)	Kumbhalgarh Wildlife Sanctuary, Rajasthan	Hanuman langur
Rajvanshi <i>et al.</i> (2001)	Gundla Bhrameshwaram Wildlife Sanctuary	Giant Squirrel / habitat fragmentation
Vijaykumar <i>et al.</i> (2001)	Anamalai Tiger Reserve, Tamil Nadu	Herpetofaunal
Kumar <i>et al.</i> (2000)	Anamalai Tiger Reserve, Tamil Nadu	Reptiles and mammals
Dhinda <i>et al.</i> (1988)	Punjab, India	Birds
WII (2007)	Ambaji Sanctuary	Wildlife habitats and species in road corridor
WII (1999)	Amba valley and Rajmachi	Western Ghat ecosystem

Majority of these studies are however limited in their attempts to assess number and distribution of road kills largely based on one-time survey or opportunistic counts (Table 1.4).

Table: 1.4 Selected studies from India that focus on road related mortalities of wildlife.

Period	Location	Target taxa
2011–2012	Anamalai Tiger Reserve	Mammals, birds, reptiles and amphibians (Jeganathan <i>et al.</i> 2018)
2015–2016	Kalaburagi district, Karnataka	Butterflies (Saraf & Jadesh 2017)
2012–2013	Mid-Western Ghats, Karnataka	Snakes (Chittaragi & Hosetti 2014)
2010	Mudumalai Tiger Reserve	Birds, reptiles, amphibians and mammals (Selvi 2010)
2009–2010	Kanha-Pench corridor	Rhesus macaque (Pragatheesh 2011)
2006–2010	Kacchh district, Gujarat	Small mammals (Maurya <i>et al.</i> 2011)
2008–2009	Kalakkad Mundanthurai Tiger Reserve	Arthropods, molluscs, mammals and reptiles (Seshadri & Ganesh 2011)
2008	Sharavathi river basin	Amphibians (Seshadri <i>et al.</i> 2009)
2007–2008	Nagarjunsagar-Srisailam Tiger Reserve	Mammals (Behera & Borah 2010)
2006–2007	Etawah district, Uttar Pradesh	Reptiles, amphibians, birds and mammals (Sunder 2004)
2006	Anand-Ahmedabad highway, Gujarat	Monitor lizard (Parasharya & Tere 2007)
2005–2006	Bandipur and Nagarhole National Parks	Insects (Rao & Girish 2007)
2004–2005	Kaziranga National Park	Reptiles (Das <i>et al.</i> 2007)
1995–2000	Kumbalgarh Wildlife Sanctuary	Hanuman langur (Chhangani 2004a)
1998–1999	Mudumalai Wildlife Sanctuary	Vertebrates (Baskaran & Boominathan 2010)
1995–1999	Kumbalgarh Wildlife Sanctuary	Birds (Chhangani 2004b)
1998–1999	Anamalai Tiger Reserve	Reptiles (Vijayakumar & Vasudevan 2001)
1995–1998	Anamalai Tiger Reserve	Reptiles and mammals (Kumara <i>et al.</i> 2000)

Studies on behavioural response of animals to vehicular traffic or on the use of road side habitats are limited to Gubbi *et al.* (2012), Joshi and Dixit (2012), Prakash (2012) Vidya and Thuppil (2010). It therefore becomes even more important to assess ecological impacts of roads in India where linking road planning with biodiversity offers far greater challenges and opportunities.

Such studies that contribute to the knowledge on the magnitude of the impacts of major roads such as highways and expressways would be a step towards planning modern, energy efficient, biodiversity friendly and sustainable developments in the road transportation sector. Further, such studies would provide an insight about species and habitat that are most vulnerable to the negative impact of roads to consolidate our efforts on evolving effective mitigation strategies.

Objectives

Environmental Impact Assessment is being widely adopted as a process for environmental planning that provides a basis for resource management to achieve the fundamental goals of sustainability. This study aims to review the ecological implications and conservation challenges posed by the existing National highway 7 passing through Pench Tiger Reserve and to adopt EIA as an assessment tool to mainstream ecological considerations and conservation concerns in the assessment of the impacts of the proposed up-gradation of the highway in the section passing through Pench Tiger Reserve.

The following are the specific objectives of the proposed study:

- (i) Assess the nature of ecological impacts of existing road section of National Highway-7 passing through Pench Tiger Reserve.

- (ii) Predict the changes on habitat integrity, quality and use by wild animals in response to proposed up-gradation of the NH-7 road from two lane to four lane.
- (iii) Assess the impacts of existing road on wild animal movement and the efficacy of design and dimensions of movement passages across the road.
- (iv) Assess the potential threats of mortality and injury associated with existing and proposed traffic density/ volume.
- (v) Propose effective measures for preventing road induced impacts that can better ensure harmonization of conservation and development.

Chapter 2: Review of literature

The first documented study on impacts of roads and vehicular traffic dates back to 1925 when Dayton Stoner documented 225 traffic killed vertebrates from 29 species during a 632 mile trip in Iowa, USA (Ree *et al.* 2011). Marshall became the first campaigner against the construction of roads in the last undeveloped areas of the United States of America (Marshall 1935). Over the years, transportation ecology has advanced and shaped our current understanding of the ecological implications of the transportation infrastructure.

For a little over three decades, efforts have been made to understand, quantify, and where possible, offset the impacts of transportation projects. These efforts spawned a field of science known as road ecology (Forman 1998; Forman *et al.* 2003; Roedenbeck *et al.* 2007). Among the most noted compilation of existing knowledge and research about the interaction of transportation infrastructure and ecosystem elements and processes is the Road Ecology; Science and Solutions (Forman *et al.* 2003).

Road ecology is gradually maturing as a discipline as transportation planners, and conservation community strive to implement road schemes that work in harmony with conservation to deliver optimum economic benefits. Literature on the ecological effects of roads and traffic is growing by every hour from around the world. This range from some excellent literature databases such as Transportation Research Board Publications and ROAD-RIP Roads Bibliographic database, bibliographies (Nietvelt 2002) to reviews and reports on the ecology of roads and traffic (Leedy 1978; Watkins 1981; Gilbert 1989; Andrews 1990; Bennett 1991; Atkinson & Cairns

1992; Ramsay 1994; Forman 1995; Noss 1995; Spellerberg 1998; Trombulak & Frissell 2000; Underhill & Angold 2000; Seiler 2001; Watson 2005; Rodney van der Ree *et al.* 2015) and published papers in journals, guidance manuals and best management practices.

Thematic coverage of studies

Habitat fragmentation	
While roads connect humans, they fragment the landscape, and with it, ecosystems and habitats for all species. The expanding knowledge greatly improves the understanding of the many different implications for wildlife species, habitats and pose serious challenges to conserve biodiversity in highly dissected areas by roads.	
Key Reference	Important lessons and findings
Andrews 1990; Brothers & Spinyarn 1992; Faaborg <i>et al.</i> 1993; Andre 1994; Van Bohemen 1995; Reed <i>et al.</i> 1996; Forman 1997; Vos & Chardon 1998; Crooks 2002; Fahrig 2002; Franklin <i>et al.</i> 2002; Goosem 2002; Keller & Largiadèr 2003; Seiler 2003; Foresman 2004; Epps <i>et al.</i> 2005; Watson 2005; Cushman 2006; Forman 2006; Culley <i>et al.</i> 2007; Cullen 2016; Crooks <i>et al.</i> 2017; Fletcher <i>et al.</i> 2018; Rogan, Jordan & Lacher, Thomas 2018	<p><i>'Unable to cross overhead using the overlapping branches of intact forest canopies, the animals now face a permanent problem—a serious, life-threatening challenge—of a gap caused by the break in tree cover over the road'. That crossing, even if takes only a few seconds or minutes, can be an agonisingly long and threatening one for an animal trying to cross even a moderately busy road' (Shankar Raman 2009).</i></p> <p><i>Habitat fragmentation by roads is usually abrupt and often severe and there is frequently a simultaneous reduction in habitat quality and population size. If new constructions fragment an area in such a way as to leave habitat 'islands' distant, disconnected and small then the remaining populations may not be able to recover (Soule 1987).</i></p> <p><i>'The fragmentation of a forest may disrupt some ecological processes and wildlife habitat, and affect its capacity to maintain species and processes usually found in those habitats. Forest fragments may be too small to maintain viable breeding populations of species and excessive fragmentation can contribute to the loss of plant and animal species that are unable to adapt to fragmented forest conditions' (Ontario State of the Forest Report 2001 Section 1.1.4).</i></p> <p><i>The home range of each individual in the fragmented landscape may include multiple fragments, forcing the individual to move among them through the human-modified landscape. Depending on the characteristics of the non-habitat (i.e., "matrix") areas of the</i></p>

	<i>landscape, this may result in higher levels of human-wildlife conflict and higher mortality due to hunting, poaching and collisions with vehicles (Vynne2011)</i>
Highway permeability	
The negative effects of road including the fragmentation of natural habitats and mortality of animals that are hit by vehicles can be partially mitigated through improvements in existing infrastructure to enhance permeability for wildlife (Kintsch & Cramer 2011).	
Key Reference	Important lessons and findings
Canada: Alexander <i>et al.</i> 2005; Adam T. Ford, Anthony P. Clevenger 2018	<i>'Landscapes cannot be reconnected and more permeable. Responsible agencies and organisations need to be aggressive about promoting mitigation and conservation ethic into road planning. By embracing the Cinderella Principle of making the virtual shoe fit more closely to the actual physical footprint of roads, we will be able to achieve a closer connection with ecological harmony with its resultant effect of abundant wildlife (Bissonetet 2002).</i>
Czech Republic: Hlavac & Andel 2002	
Spain: Yanes <i>et al.</i> 1995;Gurrutxaga <i>et al.</i> 2010	
USA: Kintch & Crammer 2011; Brehme C.S. <i>et al.</i> 2013	
Animal mortality	
Perhaps more than any other impact, road kill has been very well documented for many different Species (Sundar 2004; Barthelmess & Brooks 2010; Benitez & Verweij 2010; Attademo <i>et al.</i> 2011; Kambourova-ivanova <i>et al.</i> 2012) Vehicle collisions claim individual animals regardless of age, sex or condition of the individual animal	
Key Reference	Important lessons and findings
Large and medium mammals Dreyer 1937; Bellis & Graves 1971; Puglisi <i>et al.</i> 1974; Bashore <i>et al.</i> 1985; Ferreras <i>et al.</i> 1992; Drews, C. 1995; Huber <i>et al.</i> 1998; Ramp <i>et al.</i> 2005; Kristiansen <i>et al.</i> 2007; Grovenburg 2008; Patten & Patten 2008; Colino-Rabanal <i>et al.</i> 2011; Pragatheesh 2011; Marcis Saklaurs & Raivis Baltmanis 2015; Fernando Ascensão <i>et al.</i> 2017	<i>'Sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land' (Forman & Alexander 1998)</i> <i>'Flattened fauna' (carcasses on the road) is a macabre illustration of the most visible negative impact of roads and their traffic flows on nature: traffic mortality among animals traversing the road" (Jaarsma et al. 2006)</i>

<p>Small mammals</p> <p>Oxley <i>et al.</i> 1974; Adams 1984; Davies <i>et al.</i> 1987; Orłowski & Nowak 2004; Lesinski 2007; Bissonette & Rosa 2009; Gaisler <i>et al.</i> 2009; Marcis Saklaurs and Raivis Baltmanis 2015; Rytwinski, T. & Fahrig, L. 2015</p>	<p><i>'There were over 24,000 vertebrate collisions including reptiles and amphibians on a 31 km stretch of road on the Thousand Islands Parkway in only a 5 month study period ' (Eberhardt 2008).</i></p> <p><i>'An estimated 4,500 ducks are killed on highway rights-of-way each year in the prairie pothole region of North Dakota because about a third of nesting ducks have not hatched by the early July mowing' (Cook & Daggett 1995).</i></p>
<p>Birds</p> <p>Dunthorn & Errington 1964; Dhindsa <i>et al.</i> 1988; Bencke & Bencke 1999; Erritzoe <i>et al.</i> 2003; Orłowski 2005; Boves 2007; Bujoczek <i>et al.</i> 2011; Borda-de-Água, <i>et al.</i> 2014; Victoria J. Bennett. 2017</p>	<p><i>'Scavengers such as corvids and raptors are at risk of being hit by vehicles as they forage on other road killed carcasses' (Mumme 2000).</i></p> <p><i>'Peak mortality of snakes (all species included) occur during May and October when individuals were frequently observed basking on road surfaces during cooler temperatures' (McClure 1951).</i></p>
<p>Reptiles</p> <p>Campbell 1956; Dodd <i>et al.</i> 1989; Bernardino & Dalrymple 1992; Rosen Lowe 1994; Ferreira, R. B., & Silva-Soares, T. 2012; Pragatheesh & Rajvanshi 2013; McCardle, L. D., & Fontenot, C. L. 2015; Monica Rincon-Aranguri <i>et al.</i> 2019</p>	<p><i>'Road-kill counts along a 3.6 km section of a two-lane paved causeway in Ontario, Canada over two seasons yielded >32,000 individual amphibians' (Ashley & Robinson 1996).</i></p> <p><i>Behavioral avoidance may restrict animal movement across roads, as might the actual physical barrier that the roads form' (Donaldson & Bennett 2004)</i></p>
<p>Amphibians</p> <p>Ballasina 1989; Cooke 1995; Ashley & Robinson 1996; Boarman & Sazaki 1996; Kumara <i>et al.</i> 2000; Carr & Fahrig 2001; Hels & Buchwald 2001; Kobylarz 2001; Gibbs & Shriver 2002; Smith & Dod 2003; Cooke & Sparks 2004; Mazerolle 2004; Aresco 2005; Gibbs & Shriver 2005; Puky 2006; Orłowski 2007; Santo <i>et al.</i> 2007; Beaudry <i>et al.</i> 2008; Andrews <i>et al.</i></p>	<p><i>Rates of mortality on roads, including those of reptiles, vary by species and also by type of road, season, weather, individual age-or stage class, sex, and many other factors (Andrews <i>et al.</i> 2008);</i></p>

<p>2008; Coelho <i>et al.</i> 2008; Elzanowski <i>et al.</i> 2009; Glista <i>et al.</i> 2009; Bhupathy <i>et al.</i> 2011; Coelho Rabanal <i>et al.</i> 2012; Jarvis <i>et al.</i> 2019</p>	
<p>Invertebrates Baur & Baur 1989; Rao & Girish 2007; Skórka <i>et al.</i> 2013; Pilar Tamayo <i>et al.</i> 2014; Baxter-Gilbert <i>et al.</i> 2015; Munoz <i>et al.</i> 2015; Skórka, <i>et al.</i> 2018.</p>	
Avoidance	
Key Reference	Important lessons and findings
<p><i>Avoidance of roads by large and medium mammals</i> Singer 1978; Mace <i>et al.</i> 1996; Leblond <i>et al.</i> 2011; Leblond <i>et al.</i> 2013; Marcis Saklaurs and Raivis Baltmanis 2015; Fernando Ascensão <i>et al.</i> 2017</p> <p><i>Avoidance of roads by small mammals</i> Wilkins 1982; McGregor <i>et al.</i> 2008; Schaub <i>et al.</i> 2008; Marcis Saklaurs and Raivis Baltmanis 2015; Rytwinski, T. & Fahrig, L. 2015</p> <p><i>Avoidance of traffic by birds</i> Reijnen & Foppen 2006; Magne Husby. 2017</p> <p><i>Avoidance of roads by reptiles</i> Koenig <i>et al.</i> 2001; Cheryl S. Brehme <i>et al.</i> 2018</p>	<p><i>'In southeastern British Columbia, researchers calculated that 8.5% of the total grizzly bear study area was abandoned by bears as a result of road avoidanc'. (Mace et al. 1996)</i></p>
<p>Barrier effect and isolation Of all primary effects of infrastructure, it is the barrier effect that contributes most to the overall fragmentation of habitat (e.g. Reck & Kaule 1993; Forman & Alexander 1998).</p>	

Key Reference	Important lessons and findings
<p>Mader 1984; McLellan & Shackleton 1988; Richardson <i>et al.</i> 1997; Lode 2000; Anderson 2002; Dyer <i>et al.</i> 2002; Rondinini & Doncaster 2002; Marsh <i>et al.</i> 2004; Riley <i>et al.</i> 2006; Dussault <i>et al.</i> 2007; Gagnon <i>et al.</i> 2007; Rico <i>et al.</i> 2007; Shepard <i>et al.</i> 2008; Leblond <i>et al.</i> 2013 ; Hsiang Ling Chen, John L. Koprowski. 2016</p>	<p><i>'Species of animals most at risk of population fragmentation due to roads and traffic include species that are unwilling to travel across cleared areas' (Forman et al. 2002).</i></p> <p><i>'The barrier effect of roads on wildlife populations can pose more problems for a wider variety of species than the impacts of road kill or habitat avoidance and has the potential to cause the most severe ecological impacts' (Foreman & Alexander 1998).</i></p> <p><i>Roads can act as barriers to animal movement through mortality during crossing attempts or behavioral avoidance. This barrier effect has negative demographic and genetic consequences that can ultimately result in local or regional extinction (Shepard et al. 2008)</i></p>
<p>Environmental contamination The alteration of the chemical environment by roads results in a number of consequences for living organisms. Goldsmith <i>et al.</i> 1976; Gjessing <i>et al.</i> 1984.</p>	
Key Reference	Important lessons and findings
<p><i>Traffic born pollution affects</i> Backstrom <i>et al.</i> 2003; Bohemen 1998; Benedict & Billeter 2004; Bernhardt-Romermann & Fischer 2007; Signal <i>et al.</i> 2007; Jones <i>et al.</i> 2000; Addo & Sanders 1995; Spellerberg 1998; Gustafsson <i>et al.</i> 2005; Bernhardt-Romermann <i>et al.</i> 2007; Signal <i>et al.</i> 2007; Matthes <i>et al.</i> 2007; Thenoux <i>et al.</i> 2007; Wang <i>et al.</i> 2007; ECO 2008; Barber <i>et al.</i> 2009; Parris & Schneider 2009; van der Ree <i>et al.</i> 2011; Lesbarrères and Fahrig 2012; Dwyer <i>et al.</i> 2016; Jacobson <i>et al.</i> 2016; Williams <i>et al.</i> 2018;</p>	<p><i>'We walked 4.34 km of moderately to heavily traveled highways and interstate interchanges near Newport News, VA, and counted discarded bottles and vertebrates trapped inside Of all bottles found, 429 contained remains of vertebrates. Seven hundred ninety-five vertebrates were found trapped in bottles during this study - an average of 1.85 individuals per bottle and 183.2 animals per km of roadway' (Benedict & Billeter 2004)</i></p>

<i>Noise impacts</i>	
Barrass 1985; Dooling & Popper 2007; Lengagne 2008; Barber, Crooks, & Fristrup 2009; Parris & Schneider 2008; Kociolek <i>et al.</i> 2015	<i>'Traffic noise may interfere with breeding birds 'ability to hear birdsong, which they rely on to attract mates and establish breeding territories. Because noise travels farther in open habitats, a decrease in population density adjacent to roads has been found to be greatest for grassland birds, less for birds in deciduous woods, and least for birds in coniferous woods' (Maine Department of Transportation, 2007)</i>
Human colonization-induced disturbances	
Key Reference	Important lessons and findings
<i>Plant invasion:</i> McLellan & Shackleton 1988; Milton & Dean 1998; Harrison <i>et al.</i> 2002; Gelbard & Belnap 2003; Hansen & Clevenger 2005; Christen & Matlack 2006; Flory & Clay 2006; Jodoin <i>et al.</i> 2008 Mcintyre & Lavorel 1994 Manville 1983; Brody & Pelton 1989; Fuller 1989; Camarra & Parde 1990; Ferreras <i>et al.</i> 1992; Palomares & Delibes 1992; Trombulak & Frissell 2000 ; Sheng-Lan Zeng <i>et al.</i> 2010	<i>'Although the direct effects of roads are serious, they pale in comparison to the indirect impacts. In tropical frontier regions, new roads often open up a Pandora's box of unplanned environmental maladies, including illegal land colonization, fires, hunting, gold mining, and forest clearing' ...William Laurence (Environment OPINION 360 dated 19 JAN 2012)</i> <i>'Eight of the grizzly bears marked in the study were killed by humans between 1988 and 1994. Improved road access resulted in illegal killings as well as management removal of bears conditioned to human food' (McLellan & Shackleton 1988).</i> <i>The linear development itself typically does not cause a disturbance response; it is the human presence that causes the problems (Lyon <i>et al.</i> 1985).</i>

Studies across regions

Region	Key Reference
Africa	Newmark <i>et al.</i> 1996; Milton & Dean, 1998; Higgins <i>et al.</i> 1999; Dean & Milton 2003; Kioko <i>et al.</i> 2015
Asia	Baofa <i>et al.</i> 2006; Kalansuriya <i>et al.</i> 2009; Zeng <i>et al.</i> 2011; Gu <i>et al.</i> 2011; Sathish-Narayanan <i>et al.</i> , 2016; Solanki <i>et al.</i> , 2016; Özcan and Özkazanç, 2017; Rawankar and Wagh 2018; Toyran <i>et al.</i> , 2018; Monge Nájera 2018; Akrim <i>et al.</i> , 2019
Australia and	Taylor & Mooney 1991; Lonsdale & Lane 1994; McIntyre & Lavorel 1994; Webb 2002; Clancy 2004; Taylor & Goldingay 2004; Ramp <i>et al.</i> 2005; Ramp

Oceania	<i>et al.</i> 2005, 2006; Ramp <i>et al.</i> 2006; Ben-Ami & Ramp 2006; Kofron & Chapman 2006; Freeman & Bruce 2007; Fulton <i>et al.</i> 2008; Parris & Schneider 2008; Roedenbeck <i>et al.</i> 2008; Trembath & Fearn, 2008; Parris & Schneider 2009; Parris <i>et al.</i> 2009; Roger & Ramp 2009; Spooner & Smallbone 2009; Van der Ree <i>et al.</i> 2009
Europe	Dunthorn & Errington 1964; Hernandez 1988; Foppen & Reijnen 1994; Reijnen <i>et al.</i> 1995; Groot Bruinderink & Hazebroek 1996; Reijnen <i>et al.</i> 1996; Angold 1997; Clark <i>et al.</i> 1998; Pons 2000; Underhill & Angold 2000; Rondinini & Doncaster 2002; Deutschewitz <i>et al.</i> 2003; Erritzoe <i>et al.</i> 2003; Keller & Largiader 2003; Filho <i>et al.</i> 2004; Ising & Kruppa 2004; Keller <i>et al.</i> 2004; Seiler 2004; Ascensao & Mira 2005; Malo <i>et al.</i> 2005; Orłowski 2005; Seiler 2005; Coulon <i>et al.</i> 2006; Cousins 2006; Reijnen & Foppen 2006; Varga <i>et al.</i> 2006; Jaarsma <i>et al.</i> 2007; Kuehn <i>et al.</i> 2007; Rico <i>et al.</i> 2007; Zachos <i>et al.</i> 2007; Bozena 2008; Gryz & Krause 2008; Hanson 2008; Lengagne 2008; Mata <i>et al.</i> 2008; Olsson & Widen 2008; Roedenbeck & Voser 2008; Schaub <i>et al.</i> 2008; Balkenhol & Waits 2009; Barrientos & Bolonio 2009; Elzanowski <i>et al.</i> 2009; Gomes <i>et al.</i> 2009; Grilo <i>et al.</i> 2009; Holderegger & Giulio 2010; Bujoczek <i>et al.</i> 2011; Colino-Rabanal <i>et al.</i> 2011; Garcia-Gonzaleza <i>et al.</i> 2012; Lee <i>et al.</i> 2012; Neumann <i>et al.</i> 2012; Renterghem & Botteldooren 2012; Le Viol <i>et al.</i> 2012; Collinson <i>et al.</i> , 2014; Husby 2016; Husby 2017; Vidal-Vallés <i>et al.</i> , 2018; Tejera e al., 2018.
Latin America and North America	Bellis & Graves 1971; Puglisi <i>et al.</i> 1974; Barry & Regan 1978; Rost & Bailey 1979; Bashore <i>et al.</i> 1985; Dodd <i>et al.</i> 1989; Langley <i>et al.</i> 1989; Bernardino & Dalrymple 1992; Brothers & Spingarn 1992; Tyser & Worley 1992; Loos & Kerlinger 1993; Rosen & Lowe 1994; Ogden 1996; Romin & Bissonette 1996; Auerbach <i>et al.</i> 1997; Bencke & Bencke 1999; Brooks 1999; Mumme <i>et al.</i> 2000; Parendes & Jones 2000; Clevenger <i>et al.</i> 2001; Develey & Stouffer 2001; Joyce & Mahoney 2001; Bard <i>et al.</i> 2002; Harrison <i>et al.</i> 2002; Cain <i>et al.</i> 2003; Clevenger <i>et al.</i> 2003; Erritzoe <i>et al.</i> 2003; Gelbard & Belnap 2003; Watkins <i>et al.</i> 2003; Lohr <i>et al.</i> 2003; Gibson & Merkle 2004; McDonald & St. Clair 2004; Shine <i>et al.</i> 2004; Aresco 2005; Erickson <i>et al.</i> 2005; Epps <i>et al.</i> 2005; Hansen & Clevenger 2005; Jacobson 2005; Jochimsen 2005; Rentch <i>et al.</i> 2005; Boarman & Sazaki 2006; Christen & Matlack 2006; Cushman <i>et al.</i> 2006; Flory & Clay 2006; Jochimsen 2006; Kaseloo 2006; Andrews <i>et al.</i> 2007; Boves 2007; Dooling & Popper 2007; Epps <i>et al.</i> 2007; Bee & Swanson 2007; Huijser <i>et al.</i> 2007; Theoharides & Dukes 2007; Coelho <i>et al.</i> 2008; Jodoin <i>et al.</i> 2008; Eigenbrod <i>et al.</i> 2008; McGregor <i>et al.</i> 2008; Marsh <i>et al.</i> 2008; Ng <i>et al.</i> 2008; Bissonette & Rosa 2009; Barber <i>et al.</i> 2009; Eberhardt 2009; Flory & Clay 2009; Gonser 2009; Bowman <i>et al.</i> 2010; Clevenger & Sawaya 2010; Danks & Porter 2010; Found & Boyce 2011; Kapfer <i>et al.</i> 2010; Schwab & Zandbergen 2011; Shanley & Pyare 2011; Summers <i>et al.</i> 2011;

	Jackson & Fahrig 2011; Rosa & Bager 2012; Loss <i>et al.</i> , 2014; González-Suárez <i>et al.</i> , 2018; Monge Nájera 2018.
Canada	Ogden 1996; Eberhardt 2009; Summers <i>et al.</i> 2011; Bishop and Brogan 2013.

Studies on different animal groups

Species	Key Reference
Large mammals	Rost & Bailey 1979; Newmark <i>et al.</i> 1996; Hubbard <i>et al.</i> 2000; Underhill 2002; Gibbs & Shriver 2002; Seiler 2004; Malo <i>et al.</i> 2005; Ramp <i>et al.</i> 2005; Seiler 2005; Ramp <i>et al.</i> 2006; Baofa <i>et al.</i> 2006; Dussault <i>et al.</i> 2006; McGregor <i>et al.</i> 2008; Barrientos & Bolonio 2009; Grilo <i>et al.</i> 2009; Huijser <i>et al.</i> 2009; Laurance 2009; Roger & Ramp 2009; Bowman <i>et al.</i> 2010; Clevenger & Sawaya 2010; Danks & Porter 2010; Colino-Rabanal <i>et al.</i> 2011; Shanley & Pyare 2011; Gubbi <i>et al.</i> 2012; Neumann <i>et al.</i> 2012; Marcis Saklaurs and Raivis Baltmanis 2015; Fernando Ascensão <i>et al.</i> 2017
Medium and small mammals	Grant & French 1980; Adams & Geis 1983; Fitzgibbon 1997; Bellamy <i>et al.</i> 2000; Huijser & Bergers 2000; Hanski <i>et al.</i> 2001; Clevenger <i>et al.</i> 2003; McGregor <i>et al.</i> 2003; Rico <i>et al.</i> 2007; McGregor <i>et al.</i> 2008; Smith-Patten & Patten 2008; Barrientos & Bolonio 2009; Bissonette & Rosa 2009; Kuykendall & Keller 2011; McLaren <i>et al.</i> 2011; Sabino-Marques & Mira 2011; Ascensao <i>et al.</i> 2012; Gonzalez-Gallina <i>et al.</i> 2013; Ruiz-Capillas <i>et al.</i> 2013; Marcis Saklaurs and Raivis Baltmanis 2015; Rytwinski, T. & Fahrig, L. 2015
Birds	Raty 1979; Bennett 1991; Loos & Kerlinger 1993; Reijnen & Foppen 1994; Reijnen <i>et al.</i> 1995; Forman & Alexander 1998; Kuitunen <i>et al.</i> 1998; Spellerberg 1998; Mumme <i>et al.</i> 2000; Ford <i>et al.</i> 2001; Gutzwillera & Barrow 2003; Ramsden 2003; Peris & Pescador 2004; Jacobson 2005; Gryz & Krauze 2008; Orłowski 2008; Parris & Schneider 2008; Glista <i>et al.</i> 2009; Gomes <i>et al.</i> 2009; Parris & Schneider 2009; Hoskin & Goosem 2010; Bujoczek <i>et al.</i> 2011; Kociolek <i>et al.</i> 2011; Butler <i>et al.</i> 2013; Borda-de-Água, <i>et al.</i> 2014; Victoria J. Bennett. 2017; Magne Husby. 2017
Herpetofauna	Hodson 1962; van Gelder 1973; Laursen 1981; Dodd <i>et al.</i> 1989; Bernardino & Dalrymple 1992; Rosen & Lowe 1994; Cooke 1995; Fahrig <i>et al.</i> 1995; Reijne <i>et al.</i> 1995; Ashley & Robinson 1996; Bonnet <i>et al.</i> 1999; Hels & Buchwald 2001; Erritzoe <i>et al.</i> 2003; Mazerolle 2004; Sundar 2004; Andrews & Gibbons 2005; Aresco 2005; Jochimsen 2005; Cushman 2006; Ciesiolkiewicz <i>et al.</i> 2006; Szerlag & McRobert 2006; Roe <i>et al.</i> 2006; Row <i>et al.</i> 2007; Coelho <i>et al.</i> 2008; Fulton <i>et al.</i> 2008; Shepard <i>et al.</i> 2008; Trembath & Fearn 2008; Woltza <i>et al.</i> 2008; Bouchard <i>et al.</i> 2009; Elzanowski <i>et al.</i> 2009; Parris <i>et al.</i> 2009; Benitez-Lopez <i>et al.</i> 2010; Hoskin & Goosem 2010; Le Viol <i>et al.</i> 2012; Jarvis <i>et al.</i> 2019

Fish	Belford & Gould 1989; Warren & Pardew 1998; O’Hanley & Tomberlin 2005; Vander Pluym <i>et al.</i> 2008; Bouska & Paukert 2009; Bouska & Paukert 2010; Bouska <i>et al.</i> 2010; Doehring <i>et al.</i> 2011; MacPherson <i>et al.</i> 2012; Pepino <i>et al.</i> 2012
Invertebrates	Mungaira & Thomas 1992; King <i>et al.</i> 2000; Mckenna <i>et al.</i> 2001; Rao & Girish 2007; Pilar Tamayo <i>et al.</i> 2014; Baxter-Gilbert <i>et al.</i> 2015; Munoz <i>et al.</i> 2015; Skórka, <i>et al.</i> 2018

Mitigation measures

Given the range ecological of direct and secondary impacts of roads as understood from foregone literature, no more roads would be ever built until solutions to mitigate these threats exist. An overview of some of the most useful and recent literature Table 3.1 a range of mitigation options for addressing many roads induced ecological impacts provide a convincingly large resource base.

<p><i>Mitigation measures for reducing impacts on wildlife species</i></p> <p>Putman, 1997; Jackson <i>et al.</i> 2000; Jochimsen <i>et al.</i> 2004; Malo <i>et al.</i> 2004; Putman <i>et al.</i> 2004; Jacobson 2005; Jaarsma <i>et al.</i> 2007; Glista <i>et al.</i> 2009; Clara Grilo <i>et al.</i> 2010</p> <p><i>Mitigation of barrier effects and fragmentation</i></p> <p>Janssen <i>et al.</i> 1997; Opdam 1997; Rosell <i>et al.</i> 1997; Jackson & Griffin 2000; Rajvanshi <i>et al.</i> 2001; Mitchell <i>et al.</i> 2006; Van der Ree <i>et al.</i> 2008; Brendan D. Taylor and Ross L. Goldingay. 2010; David Lesbarreres and Lenore Fahrig. 2012</p> <p><i>Improving the high permeability and connectivity</i></p> <p>Marshall <i>et al.</i> 1995; Federal Highway Administration 2002; Hlavac & Andel 2002; Mata <i>et al.</i> 2005; Adam T. Ford, Anthony P. Clevenger 2018</p> <p><i>Effectiveness of Highway Lighting</i></p> <p>Reed & Woodard 1981; John M. Sullivan. 2009</p> <p><i>Safe crossing passages for Wildlife:</i></p> <p>Jackson 1996; Land & Lotz 1996; Barnum 2003; Hartmann 2003; Lapoint <i>et al.</i> 2003; Lesbarreres <i>et al.</i> 2004; McDonald & Clair 2004; Ng <i>et al.</i> 2004; Ruediger 2007; Veage & Jones 2007; Bissonette & Cramer 2008; Mata <i>et al.</i> 2008; Olsson <i>et al.</i> 2008; Van der Ree <i>et al.</i> 2009; Jansen <i>et al.</i> 2010; Sawyer & LeBeau 2011; Rytwinski T <i>et al.</i> 2016</p> <p><i>Fencing designs:</i></p> <p>Clevenger & Huijser 2011; Rytwinski <i>et al.</i> (2016)</p>

If the road construction projects are to be planned, responsible design and best practices must be implemented for the ecological impacts of these roads to be minimized. Guidance is building up and is becoming available in the form of best practices, design manuals and handbooks (Messmer & West 2000; Forman *et al.* 2003; White & Ernst 2003; Reijnen & Foppen (2006). These can provide a useful guidance and prescriptions to address and even avoid road related ecological impacts through the design of ecologically -friendly highways (Jackson & Griffin 2000; Dolan & Whelan 2004; Garrett & Bank 1995).

Best Practice guidance
<p><i>Wildlife Crossing Structures and design solutions</i> Iuell <i>et al.</i> 2003; Meese <i>et al.</i> 2007; Woltz <i>et al.</i> 2008; Clevenger & Huijser 2011; Fairbank 2012; Ministry of Transportation. 2015</p>
<p><i>Culvert Design:</i> Yanes <i>et al.</i> 1995; Smith 2003; Arizona Game & Fish Department 2006; Patrick <i>et al.</i> 2010; State of Queensland 2015</p>
<p><i>Best Practice Guidelines species conservation in road impacted habitats</i> Penny Anderson Associates 1994; Bats: NRA 2005; Badgers: NRA 2005; Amphibians and reptiles : Mitchell <i>et al.</i> 2006. Ontario Ministry of Natural Resources and Forestry. 2016</p>
<p><i>Habitat and road side vegetation Management Guidelines</i> Johnson 2008; Native Vegetation Council. 2012</p>
<p>Leedy <i>et al.</i> 1982; National Roads Authority 2004</p>
<p><i>Advanced technological options for mitigating Animal Vehicle Collisions:</i> D'Angelo <i>et al.</i> 2006; Huijser <i>et al.</i> 2009; Bridget M. Donaldson. 2017</p>

Chapter 3. Study area

The structure and functioning of a road varies according to its design, use, width, type of surface and location. The ecological impacts of road system therefore will vary with the type of road being considered and the landscape features in its alignment. For understanding the ecological impacts of a road, it is therefore necessary to review both the road features and the ecological setting of the area. The environmental gradients (temperature, rainfall, drainage, slope etc) are also equally important in describing the ecological space in which roads functions and influence the use by animals. The following sections aim to provide an understanding of the road features and description of the environmental and ecological setting of the area.

National Highway-7

National Highway-7 is the major North-South National Highway in India that runs through the states of Uttar Pradesh, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu (Figure: 3.1). The highway connects several important Indian cities such as Varanasi, Rewa, Jabalpur, Nagpur, Hyderabad, Bangalore, Dharmapuri, Salem, Dindigul, Madurai, Virudhunagar, Tirunelveli and Kanyakumari. A major part of NH-7 covers the North-South Corridor of NHDP and it is officially listed as running over 2,369 km from Varanasi to Kanyakumari. It is the longest national highway in India. As per the recent rationalization of Highway numbers this has been renamed as NH 44 (GOI 2010). Out of 2369 km of total length, 128 km is in Uttar Pradesh, 504 km is in Madhya Pradesh, 232 km is in Maharashtra, 753 km is in Andhra Pradesh, 125 km is in Karnataka and 627 km is in Tamil Nadu.

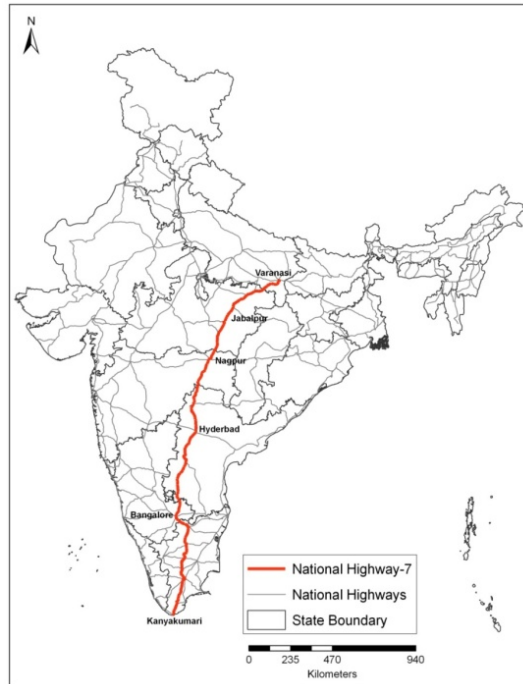


Figure: 3.1 National Highway-7 running through North-South part of India.

The Indian Government has set ambitious plans for upgrading of the National Highways in a phased manner in the years to come. The National Highway Authority of India (NHAI) an autonomous agency of the Government of India, responsible for management of a network of over 60,000 km of National Highways in India is implementing the National Highways Development Project to upgrade, rehabilitate and widen major highways in India to a higher standard. As part of the phased upgradation of different National Highways, the NHAI has also proposed the 4 laning of the National Highway-7

The stretch of NH-7 between 627.000 and 636.000 km, aligned in the state of Madhya Pradesh, passes through one of the most important forest corridors which connect Kanha and Pench Tiger Reserves in central India. This study was conducted on a 9 km stretch of this National Highway (NH-7) between Kurai village (21° 49' N,

79° 30' E) and Gandatola village (21° 53' N, 79° 32' E) aligned along on the Pench Mowgli Sanctuary forming the Eastern boundary of Pench Tiger Reserve (Figure: 3.2). The existing highway with an overall mean width of 7m has a single lane in either direction without a median strip. The 9 km linear road section in the study area has 36 culverts. Of these, 27 are pipe and box culverts (1x1m) and 9 are medium sized culverts that vary in size (3x2 to 5x3 m). This road has been in existence for several hundred years and therefore, no precise historical information is available about this road.

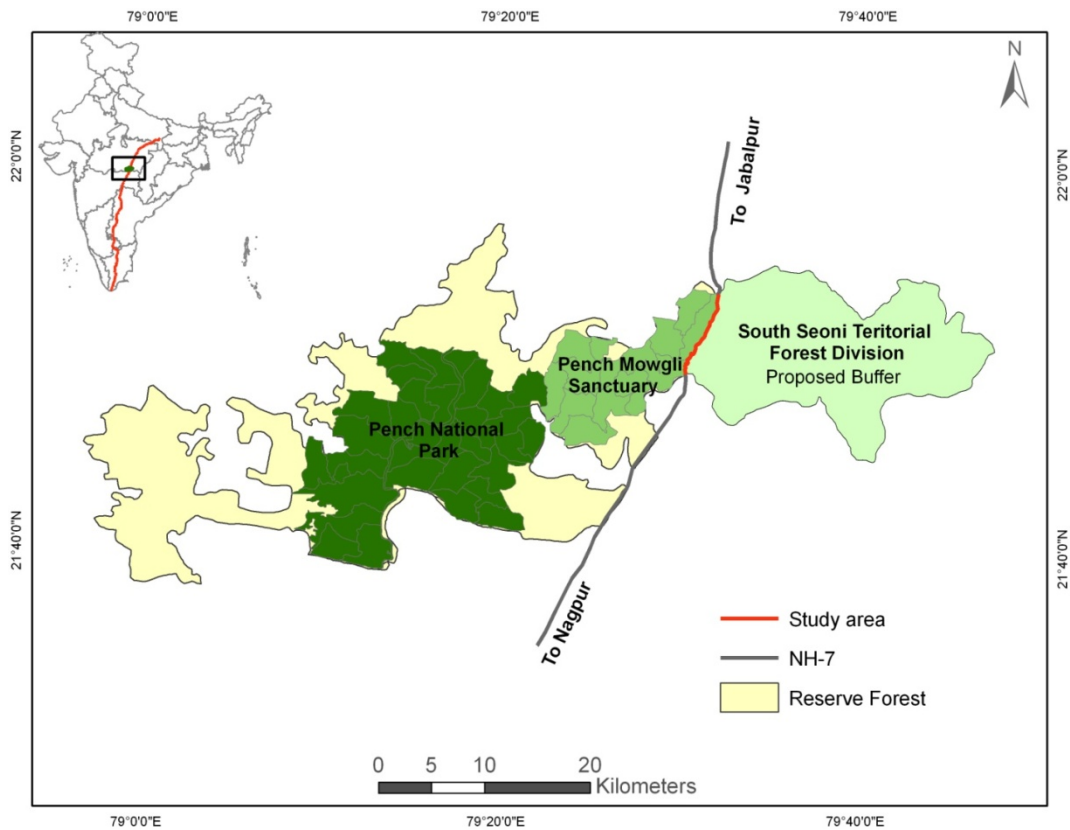


Figure: 3.2 Alignment of National Highway - 7 showing the 9 km stretch aligned along the Tiger Reserve on the left and through the forested tract of South Seoni Territorial Forest Division.

Terrain

The terrain of the area is mostly undulating, characterized by small ridges. Based on the topographical features, the 9 km road section through forest can be divided into two segments hilly and flat sections. The road section falling between 627.000 to 632.000 km, is aligned through flat terrain gently undulating and criss-crossed by seasonal streams and *nallahs*. In the remaining stretch between 632.000 and 636.000 km the road is aligned through hills and intercepted by some seasonal drainage. The elevation range from 450 m to 630 m above M.S.L. (Figure: 3.3)

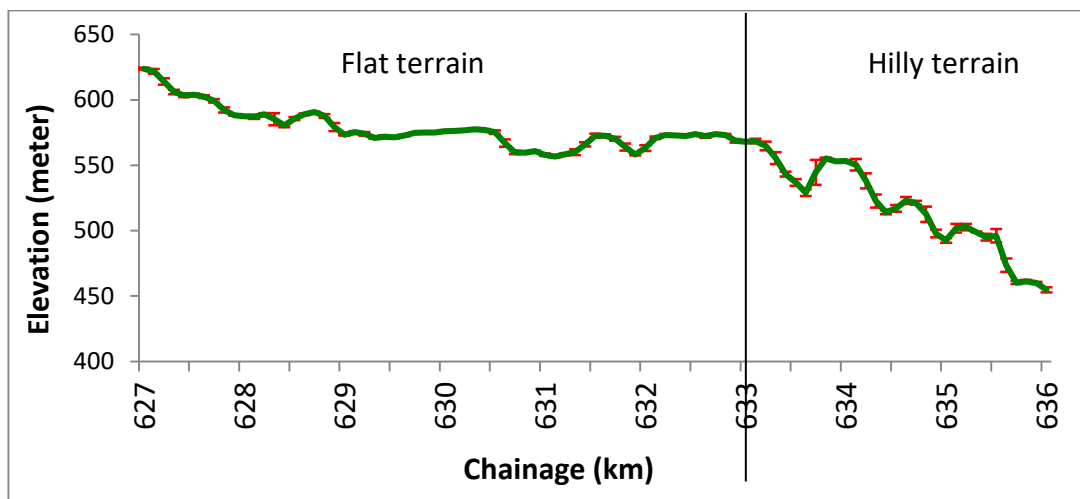


Figure: 3.3 Elevation of the NH-7 passing along Pench Tiger Reserve.

Climate

The Central Indian Highlands have a monsoonal continental climate with a distinct monsoon (July to September), summer (April to June) and winter (November to February). The mean annual rainfall is around 1400mm with the South-West monsoon accounting for most of the rainfall in the region. During the dry season (November to May), the mean rainfall is 59.5mm. The annual range of temperature varies between 2°C in peak winter to 49°C in peak summer. The average monthly

temperature varies from a minimum of 1.5°C in winter to a maximum of 35°C in summer.

Drainage pattern

The area is mostly undulating with numerous seasonal streams and *nallahs* traversing the road corridor. In the first segment from 627.000 to 632.000 km, seasonal streams are flowing towards Pench Mowgli Sanctuary (western side of the road). Streams in the remaining section (632.000 to 636.000 km) are oriented to flow towards forested area under South Territorial Division (eastern side of the road). Most of these seasonal streams remain dry through the year except in, monsoon when water flows through these. During summer, when the water becomes a limiting factor for most animals, *Dhudia* pond located on the edge of the road becomes the main source of water for the wild animals of this area. To further overcome the water scarcity, the park management has constructed several artificial water holes along the road and within the reserve (Figure: 3.4).

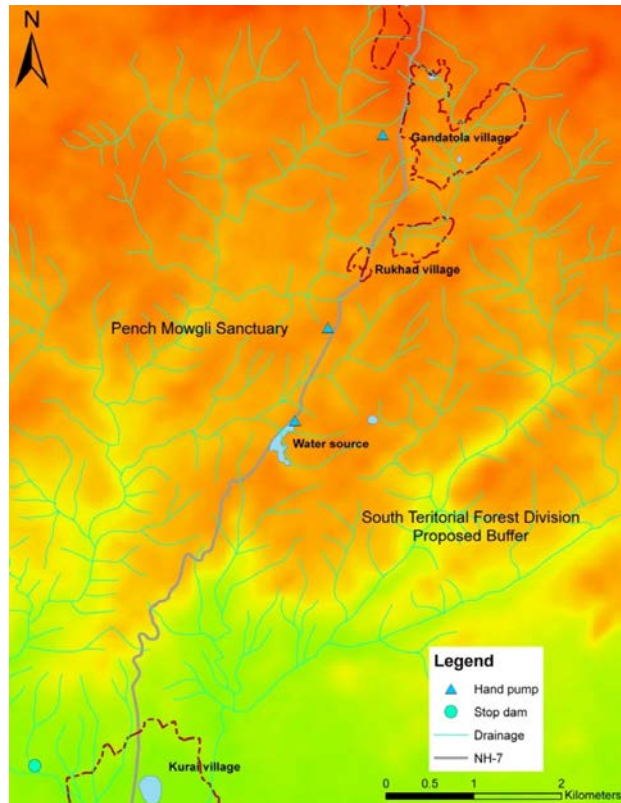


Figure: 3.4 Seasonal drainages and artificial water holes along the NH-7.

Conservation values of the area

The road section between 627.000 and 636.000 km borders Pench Mowgli Sanctuary of the Pench Tiger Reserve and traverses the forests of South Territorial Division which represent the area proposed for inclusion within the proposed buffer of the Pench Tiger Reserve. The forest along the road section under study holds significant place in the natural history of Central India and commands high conservation significance as a forested corridor between Kanha and Pench Tiger Reserves. The National Highway-7 cuts this corridor near the Rukhad forest patch. The forest within the road corridor that is managed as different administrative units (Pench Tiger Reserve and South Territorial Forest Division) by the Madhya Pradesh Forest is similar in structure and biodiversity values.

These forests represent elements of South Indian Tropical Moist Deciduous Forest (slightly moist), Southern Tropical Dry Deciduous Teak bearing forest and Southern Dry Deciduous Mixed Forests (Champion & Seth 1968).

Flora

The characteristic flora of the study area is represented by Teak (*Tectona grandis*) associated with *Madhuca indica*, *Diospyros melanoxylon*, *Terminalia tomentosa*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Ougeinia dalbergoides*, *Miliusa velutina* and *Lannea coromandelica* in more or less flat terrain (Figure:3.5). The undulating terrain and hill slopes have patches of mixed forest dominated by *Boswellia serrata* and *Anogeissus latifolia*. Species like *Sterculia urens* and *Gardenia latifolia* are found scattered on rocky slopes. Bamboo (*Dendrocalamus strictus*) patches occur in the hill slopes and along the streams. Some of the open patches of the park are covered with tall grasses interspersed with *Butea monosperma* and *Zizyphus mauritiana*. Evergreen tree species like *Terminalia arjuna*, *Syzygium cumini* and *Ixora parviflora* are found in riparian vegetation along the nallahs and river banks. *Cleistanthus collinus* occurs as dense dominant patches in some parts. The major shrub found in this area is *Lantana camara*. Dominant climber species are *Bauhinia vahlii* and *Butea superba*.

Fauna

The forest along the road corridor is a home to the rich and diverse fauna (Harshey & Chandra 2001; Biswas & sankar 2002). The major carnivores species of the area include tiger (*Panthera tigris*), leopard (*Panthera pardus*), sloth bear (*Melursus ursinus*), wild dog (*Cuon alpinus*), Wolf (*Canis lupus*), Indian fox (*Vulpes bengalensis*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), leopard cat (*Felis*

benghalensis), small Indian civet (*Viverricula indica*), common palm civet (*Paradoxurus hermaphroditus*), ratel (*Mellivora capensis*), common mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*) are present in this area (Figure: 3.6.). Chital (*Axis axis*), Sambar (*Rusa unicolor*), Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*), Chowsingha (*Tetraceros quadricornis*), barking deer (*Muntiacus muntjac*) and wild pig (*Sus scrofa*) are the major ungulate species found in the study area (Figure: 3.7). Common langur (*Presbytis entellus*) and rhesus macaque (*Macaca mulatta*) represent the primate fauna of the area. Pench Tiger Reserve which borders the road on one side supports more than 262 species of birds (Pasha *et al.* 2003). Among the lower vertebrates, Python (*Python molurus*), Indian Cobra (*Naja naja*), Russell's Viper (*Vipera russeli*), Indian Krait (*Bungarus caeruleus*), Common Rat Snake (*Ptyas mucosus*) represent the species of snakes occurring in the area. Many of these animals use National Highway-7 for frequenting between their habitats in Pench Tiger Reserve and the South Seoni Territorial Forest Division.



Figure: 3.5 Habitat along the National Highway-7.

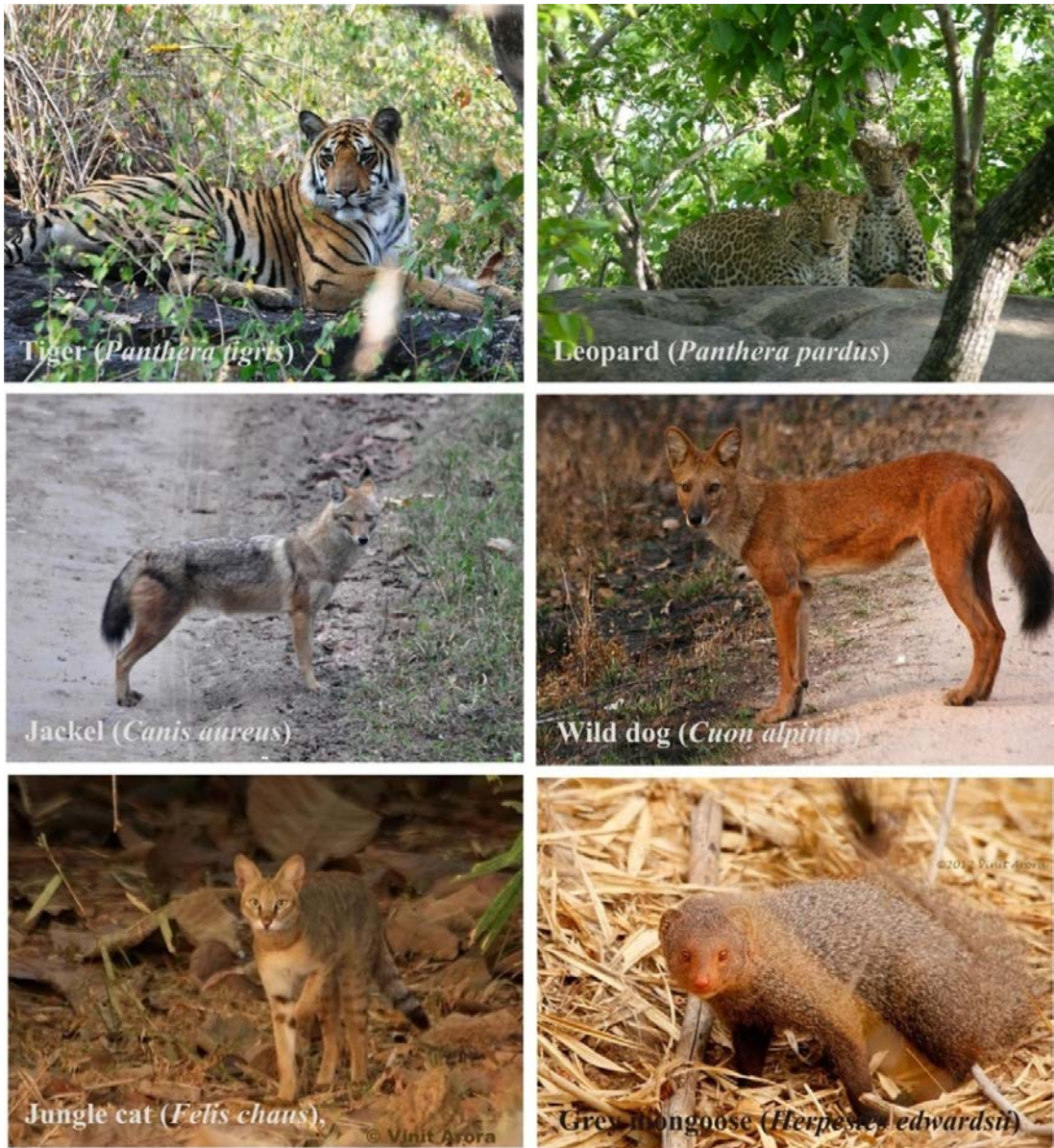


Figure: 3.6 Major carnivores in habitats along the National Highway-7



Figure: 3.7 Major ungulates in habitats along the National Highway-7.

Challenges for wildlife conservation

Challenges of conserving wildlife in natural areas are ever increasing. These become even more complex when multiple factors including those linked to sustenance of local communities and rampant urban infrastructure development together compound the biodiversity loss and decimate the natural habitats supporting the endangered species.

Anthropogenic factors operating in the area

There are 3 village located along the road namely Kurai (636.300 km), Gandatolo (629.500) and Rukhad (627.600). These villages are highly dependent on nearby forest for livestock grazing and collection of fodder, NTFP and fire wood. These sustenance based activities are beginning to result in greater demands on resources with increasing cattle and human population. The National Highway-7 has created easy access to resource sites for removal of larger quantities of biomass and has accelerated the transportation of removed resources from the forests (Figure: 3.8).



Figure: 3.8 Biotic pressures along the National Highway-7.

Traffic related disturbance

During the course of this study, effort was made to collect the traffic related information on the 9 km section of the National Highway-7 aligned through wildlife habitat. Continuous monitoring was conducted for three days per season to determine the total number vehicles moving on the road per day. Data on number of two wheelers, four wheelers (cargo vans, buses trucks) passing through this road was recorded. Traffic count was conducted on a Tuesday, Friday and Saturdays or Sunday to capture variations in traffic volume on busy week days, market days and weekends that may have higher number of tourists visiting the Tiger Reserve.

During the study period, vehicular speed was monitored at two locations each in hilly and flat sections of the road four different times in a day: (i) early morning (3 to 5 am), (ii) morning (8 to 10am), (iii) evening (4 to 6 pm) and night (10 to 12).

Assessment of traffic on NH-7

The average annual daily traffic recorded on the 9 km long road was 3035 ± 274 vehicle/day (Mean \pm SD) and varied in different seasons. The average daily traffic flow was relatively higher (3269 vehicle/day) during summer season than in winter (2952 vehicle/day) and monsoon (2884 vehicle/day). Maximum average daily traffic was high on Sundays (3382 vehicle/day) during summer. The minimum traffic was recorded on Tuesday (2620 vehicle/day) during monsoon (Figure: 3.9).

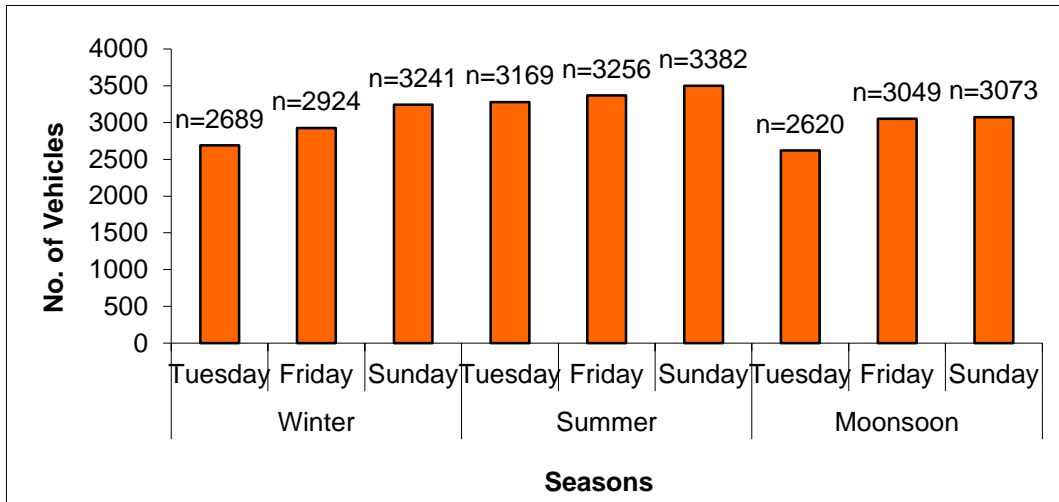


Figure: 3.9 Traffic volume at different day.

The heavy vehicles traffic, largely comprising of freight trucks remained the highest in all the three seasons. This was followed by the passenger vehicle traffic during night time (Figure: 3.10). The tourist travelling between Kanha and Pench Tiger Reserve during summer and winter and the regular movement of travellers between Nagpur and Jabalpur may be contributing to the high volume of passenger vehicles traffic.

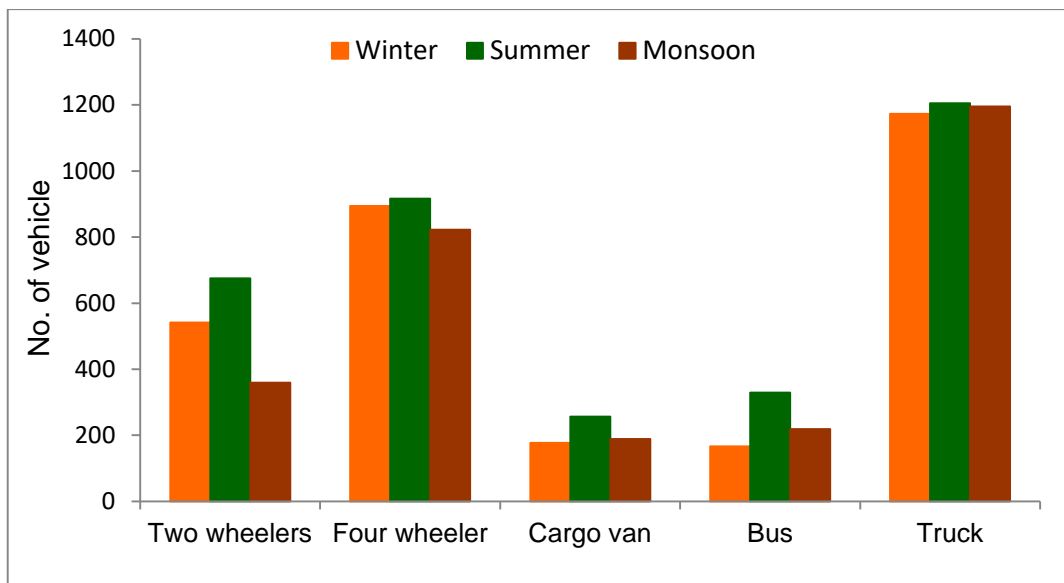


Figure: 3.10 Number of vehicle flow on NH-7.

The traffic flow during late night and early morning hours was recorded to be the lowest (80 vehicles/hr/day) in all seasons. The traffic peaked (180 vehicles/hr/day) during evening (1600 hr and 1700 hr) in all seasons (Figure: 3.11). Heavy vehicle traffic was highest during the late night (1000 hr and 1200 hr) and early morning hours (0200 hr and 0400 hr).

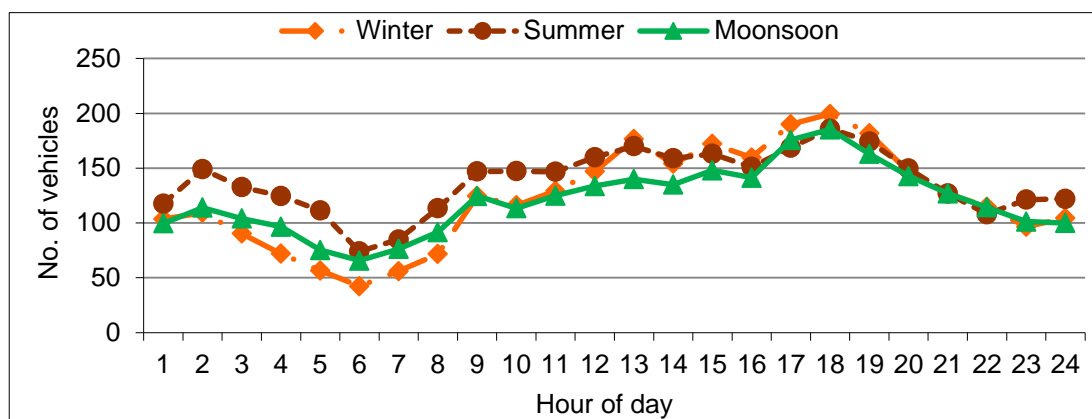


Figure: 3.11 Volume of vehicular traffic on NH-7 in different hours of the day.

Vehicle speed

Average speed varied for different vehicles. Higher speed (69 km/hr \pm 13 - 45 km/hr \pm 7) was recorded of cars both, in the flat and hilly terrain (Figure: 3.12). Paired sample T-Test showed that the vehicle speed varied in different terrain. Significant difference was recorded between speed of vehicle in flat terrain and hilly terrain (Two wheeler: $t= 5.546$, $df = 32$, $P<0.001$), Four wheeler: $t=15.819$, $df = 114$, $p<0.001$), Cargo van: ($t=8.983$, $df = 19$, $p<0.001$), Bus: ($t=10.363$, $df = 27$, $p<0.001$), Light truck: ($t=7.343$, $df =27$, $p<0.001$), Heavy truck: ($t=18.160$, $df =131$, $p<0.001$)

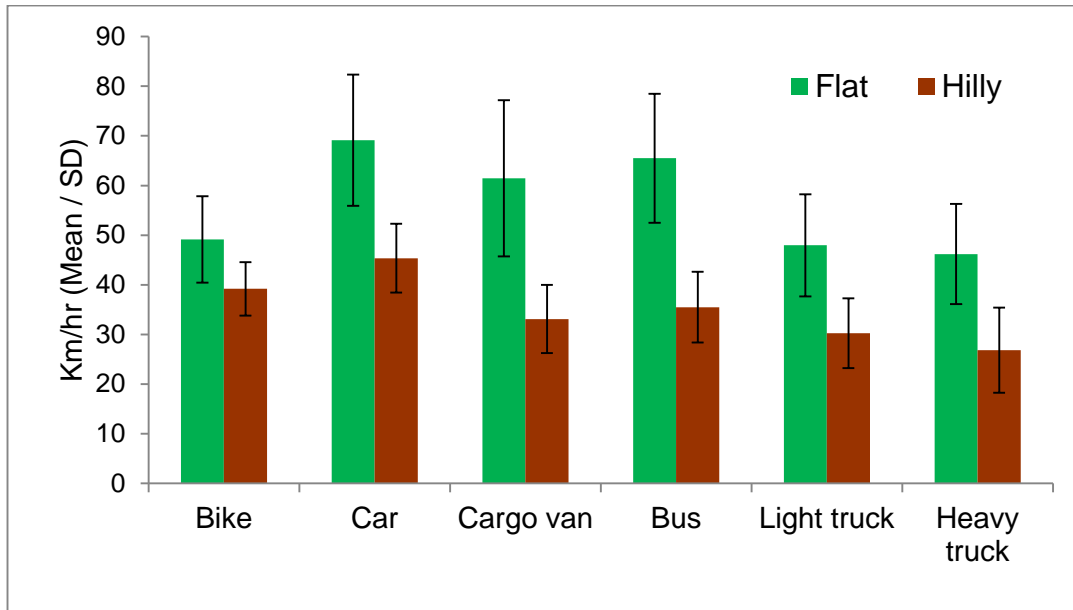


Figure: 3.12 Speed of vehicles monitored in road sections with different topography.

Chapter 4. Impact of road on habitat use by mammals

Introduction

The earliest studies on the effects of roads on wildlife populations date back to early 1970s (Bellis & Graves 1971; Oxley *et al.* 1974; Rost & Bailey 1979). The subject of road ecology continued to draw the interest of several workers even subsequently. This has generated a wealth of knowledge about the specific impacts of roads on different groups of animals living in different ecosystems and landscapes across different regions of the world.

Impact of roads on mammal populations have been studied in **Asia** (Baofa *et al.* 2006), **Africa** (Newmark *et al.* 1996; Laurance *et al.* 2006), **Australia and Oceania** (Ramp *et al.* 2005; Ramp *et al.* 2006; Roger & Ramp 2009), **Europe** (Seiler & Sjørusen 2004; Malo *et al.* 2005; Seiler & Høtelleid 2005; Barrientos & Bolonio 2009; Grilo *et al.* 2009; Colino Rabanal 2011; Neumann *et al.* 2012) **Latin America and North America** (Rost & Bailey 1979; McGregor *et al.* 2008; Bowman *et al.* 2010; Danks & Porter 2010; Shanley & Pyare 2011; Cullen *et al.* 2016; González-Gallina *et al.* 2018).

The potential ecological impacts of the expanding roadway infrastructure on the use of adjacent wildlife habitats has drawn the attention of biologists, natural resource managers and researchers in recent decades. Studies have revealed that linear infrastructures that cut across wildlife habitats have significant negative effects on adjacent habitats, wildlife populations, communities and even ecosystems (Laurance 2009; Gubbi *et al.* 2012). The use of the roadside habitats by animals is often highly correlated with spatial and temporal components like topographic features, proximity

to resources, road features, curvature, traffic volume, proximity to human habitation, season and time of the day (Ramp *et al.* 2006). Studies have also been done using species-distribution models, satellite imagery and animal-sign surveys to provide quantitative evidence of roads causing impacts by (1) cutting through habitats where endangered mammals are likely to occur, (2) intensifying forest conversion, and (3) contributing to illegal hunting and wildlife trade (Clements *et al.* 2014).

Studies have also confirmed that ecology and behaviour of animals also influence their use of roadside habitat (McLellan & Shackleton 1988; Schaik & Griffiths 1996; Tigas *et al.* 2002; McDonald & St. Clair 2004; Ditchkoff *et al.* 2006; Lehndal 2008). Large mammals are sensitive to habitat fragmentation because of their low numbers and large home ranges (Gibbs & Shriver 2002). While some species are attracted to roadside habitats, others completely avoid them (Forman & Alexander 1998; Forman *et al.* 2003). Generally, ungulates are attracted to road verges because these may offer better foraging ground than the interior areas along the road (Bennett 1991). Forestry was the most relevant parameter to explain road-kill, followed by water bodies, both in the large scale, and proximity of river, highlighting the importance of water source (De Freitas *et al.* 2014).

In India, where the science of road ecology is still in its infancy, only a few disparate studies (e.g. Gubbi *et al.* 2012; Prakash 2012) have attempted to evaluate the use of highway edges as habitat by large mammals in wildlife reserves in South India and the behavioural response of elephants to vehicular traffic (Vidya & Thuppil 2010). Very little is currently known about how mammals use habitats affected by roads in India and the factors that influence vulnerability of species to road effects.

More focused studies such as this should provide a useful insight for understanding different dimensions of impact sources and ecological effects of highways in India.

Background

The physical presence of a road generally brings about significant modification in the forested landscape.

This has been also true for sections of NH-7 routed through the forest areas abutting the Pench Mowgli Sanctuary. The most obvious modifications that have been brought about in the otherwise historically contiguous landscape of the region are:

- i. Creation of a road corridor that includes the linear surface used by vehicles and the area of land immediately influenced by the road in terms of noise, visual, hydrological and atmospheric impacts;
- ii. The road verge, representing the strip of vegetated land, 5 to 8 m wide beyond the edge of surfaced road but within the road corridor that screens the road from the surrounding landscape;
- iii. Fractured habitats resulting from the split in the contiguous patch of forest created by the physical presence of the NH-7 that may extend up to several km from the road edge.

The disturbance created by such a linear infrastructure needs to be more widely studied in the fragmented habitats and the road verges to be able to aid road-planners and civil engineers in the establishment of ecologically adapted, safe and sustainable highway development projects.

This chapter presents the results of the studies undertaken to evaluate the impacts of NH-7 on modifications in availability and the suitability of habitats of the fragmented forests and of the road verges as reflected from habitat use studies conducted in the context of mammalian species of the area.

Distribution of mammals in the fractured habitats along the road

Methodological approach

Direct sightings

Line transect method has been widely used to assess habitat use by wild animals the world over (Buckland *et al.* 2001, 2004; Thomas *et al.* 2010). Line transects have been used in assessing habitat use by wild ungulates in Indian subcontinent (Karanth & Sunquist 1995; Khan *et al.* 1996; Biswas & Sankar 2002; Bagchi *et al.* 2003). Clearings were made to lay 17 straight line transects (Figure 4.1). These transects were laid in different habitat types and were permanently marked using paint. Each of the transect was 2 km long and was laid perpendicular to the road covering a total linear stretch of 9 km. This sampling design facilitated the detection of animals without investing too much effort in locating or creating pathways through the forest while making observation on animal presence. Each transect was walked 3 to 4 times. Effort was replicated in all the three seasons-monsoon (July to October), winter (November to February) and summer (March to June) to assess the year round use of the habitats by wild animals. All transects were walked in the early morning between 6.00 am and 8.00 am after sunrise and information on the number of animal sighted, species, sighting angle, perpendicular distance, group size, and age structure was collected. Data on transects was collected for two years between August 2008 to

July 2010. This involved covering total distance of 748 km on foot. In order to avoid disturbance and to ensure that animal sighting are not missed out, each transects was walked by two persons (an observer and a recorder). Based on direct sighting, presence of animals, was recorded at every 100 m mark on the line transect assuming that each observation at every 100 m interval was an independent record. The data was pooled for transects on both sides of the road. Encounter rate was generated to assess the distribution status and trends at varying distance (0 to 2.0 km) from the road to the forest interior.

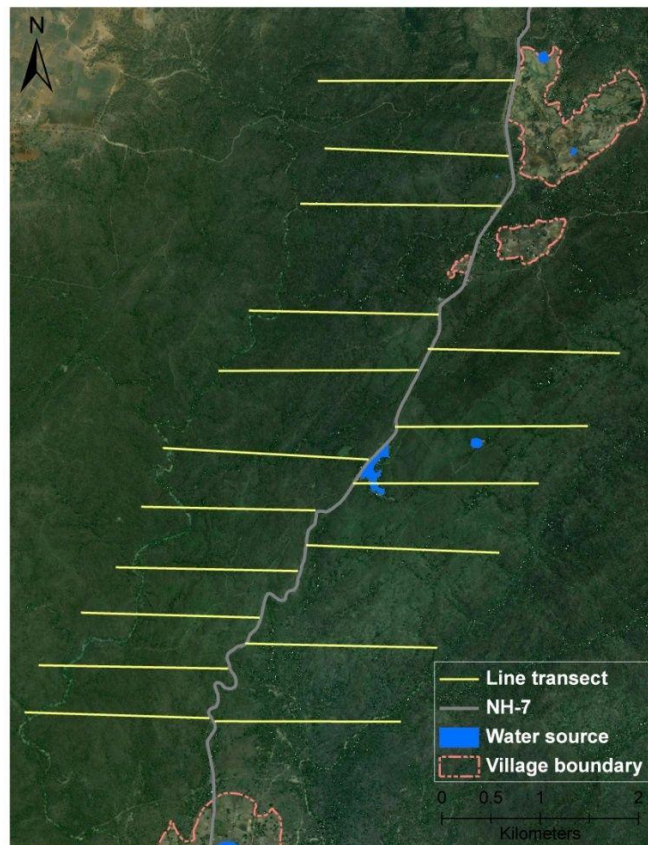


Figure: 4.1. Location of the line transects along the NH-7.

Indirect evidences

Use of faecal pellet count method for assessing use of road verge by animals was first described by Bennett *et al.* (1940). Presence of pellet groups was taken as indirect evidence of habitat use by the species but was not used for estimating absolute number of animals. Systematically at every 100 m mark on the permanent line transect, 2x20 m plot was laid. A total of 20 such permanent plots on each transect (total 340 plots) were established in the fragmented habitats on each side of the road (Figure 4.2). Pellets of different species were identified by their size and shape following Rivero *et al.* (2005) in each plot during August 2008 to July 2010. All the plots were visited once in every season. To prevent recounting of the pellets, all the counted pellet groups were removed from the plots prior to enumerations in the next season. The number of pellet groups for each species in each plot was used to calculate pellet group density per hectare. All the observations and records are based on studies conducted over a period of two years.



Figure: 4.2. Location of the pellet plot on line transect along the National Highway-7.

Results

Assessment of habitat use by mammals based on encounter rate

The results of animal distribution in fragmented habitats are based on the efforts of covering a total of 864 km over a two-year period between August 2008 and July 2010. During summer, 9 species that were encountered on the line transect included gaur (*Bos gaurus*), Indian hare (*Lepus nigricolli*), Indian muntjac (*Muntiacus muntjak*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), cheetal (*Axis axis*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*) and Hanuman langur (*Semnopithecus entellus*).

During winter, 7 species were encountered. These included: chital (*Axis axis*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*) and hanuman langur (*Semnopithecus entellus*). During monsoon, 6 species that were encountered were chital (*Axis axis*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), Hanuman langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*). It is apparent from Figure 4.3 that encounter rate varied between different seasons.

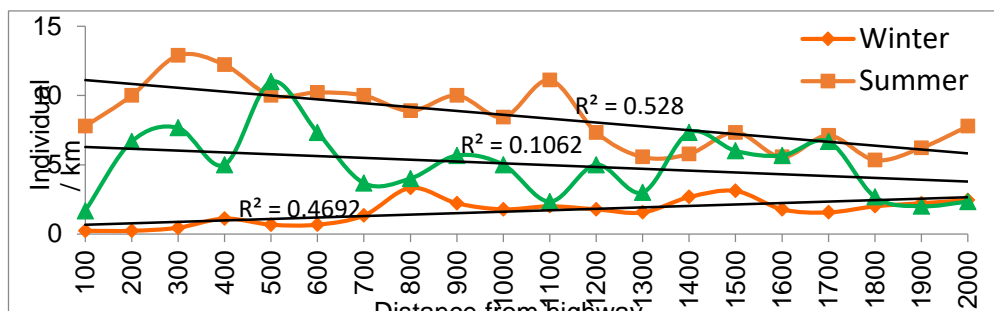


Figure: 4.3. Variation in distribution of mammals from road edge to forest interior.

The species that were encountered in all seasons are chital (*Axis axis*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), gaur (*Bos gaurus*), rhesus macaque (*Macaca mulatta*) and Hanuman langur (*Semnopithecus entellus*). In summer, the use of the forest fragments was relatively high (8.47 ± 0.50 individuals/km) when compared to the use of these habitats during monsoon (5.03 ± 0.53 individuals/km) and winter (1.65 ± 0.20 individuals/km) seasons.

Animal encounters during summer were more in areas between 300 and 500 meter from the road and gradually decreased in the forest interior ($R^2=0.528$, $F=20.136$, $P=0.001$, $df=19$). The artificial water sources (created by the Madhya Pradesh Forest Department) in most locations that were close to the road probably attracted animal to use the road verges during summer when the water availability becomes limited in the forest interior (Figure 4.4). Similar observations by Western (1975) and Newmark *et al.* (1996) also confirmed positive relationship between water availability along road and the use of roadside habitat by animals.

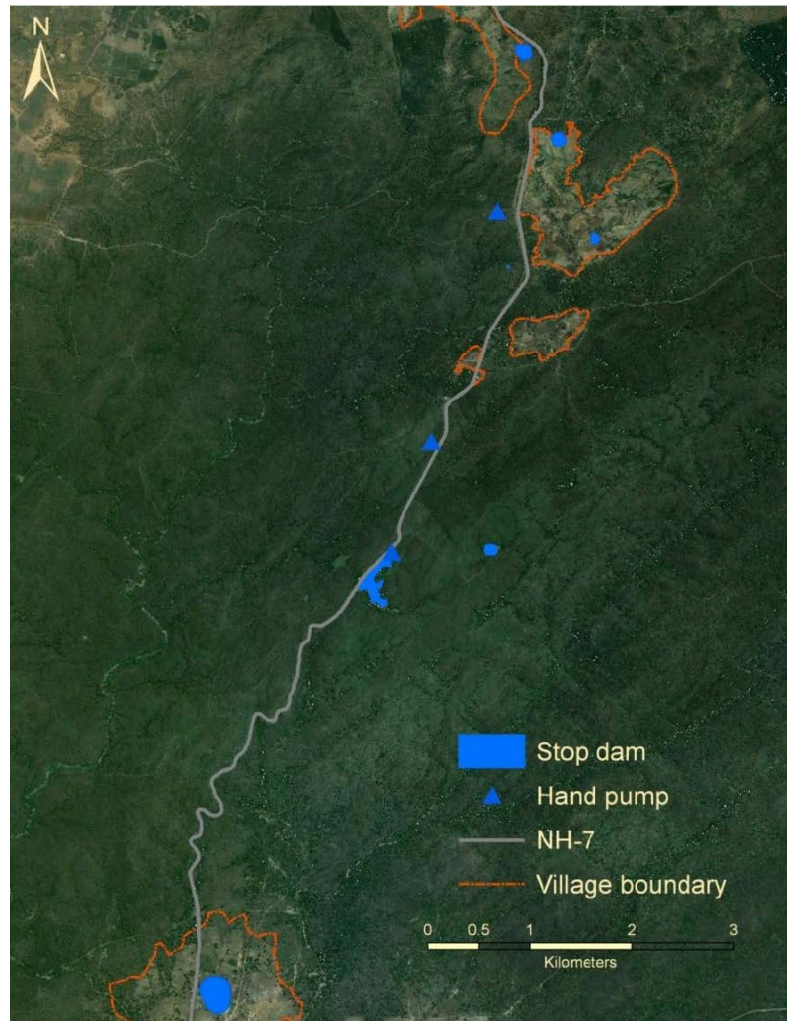


Figure: 4.4. Location of stop dam and hand pump along NH-7.

During summer period, relatively more number of species (8.47 ± 0.50 individuals /km) used the roadside habitat when compared to use patterns in other seasons. Even species like gaur (*Bos gaurus*) which is a naturally shy animal (Gopala 2007) used road verges for grazing to meet their requirement of water despite the high level of disturbance from vehicular traffic.

In contrast to this, the encounter rate of animals during winter improved beyond 800m and further increased progressively towards forest interior ($R^2=0.469$, $F= 15.914$, $P=0.001$, $df=19$). The animals that were encountered more often included

gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), chital (*Axis axis*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*) and Hanuman langur (*Semnopithecus entellus*). The avoidance of the roadside habitat by most animals during winter could be attributed to the availability of adequate amount of water in the streams and ponds in the forest interiors. During monsoon, encounter rate of mammals increased from the road edge to forest interior ($R^2=0.106$, $F= 2.139$, $P=.161$, $df=19$). The encounter rates of different species in different seasons varied and are presented in Table 4.1.

Table 4.1. List of animals encountered in line transects.

Common name	Scientific name	Encounter (individuals/km) \pm S.E		
		Summer	Winter	Monsoon
Chital	<i>Axis axis</i>	3.87 \pm 0.82	0.60 \pm 0.20	2.30 \pm 0.76
Gaur	<i>Bos gaurus</i>	0.40 \pm 0.18	0.08 \pm 0.05	-
Indian hare	<i>Lepus nigricolli</i>	0.01 \pm 0.01	-	-
Indian muntjac	<i>Muntiacus muntjak</i>	0.01 \pm 0.01	-	-
Nilgai	<i>Boselaphus tragocamelus</i>	0.02 \pm 0.02	0.02 \pm 0.02	0.02 \pm 0.02
Sambar	<i>Rusa unicolor</i>	0.82 \pm 0.20	0.33 \pm 0.09	0.67 \pm 0.23
Wild pig	<i>Sus scrofa</i>	1.26 \pm 0.39	0.04 \pm 0.04	1.48 \pm 0.48
Hanuman langur	<i>Semnopithecus entellus</i>	3.50 \pm 0.69	0.77 \pm 0.23	2.48 \pm 0.73
Rhesus macaque	<i>Macaca mulatta</i>	1.18 \pm 0.60	1.08 \pm 0.50	2.30 \pm 0.80

In summer, species like chital and wild pig are more attracted to the roadside habitats that become more open and offer abundant sprouts of grass after the first shower. The artificial waterholes present close to the road also attract these animals. More wild pigs (1.48 \pm 0.48 individuals/km) were encountered in line transect between 800 m and 1600 m from the road during monsoon. During this season, the adults accompanied by young ones avoided the roadside and actively foraged food in the

interior forest. The encounter rate of sambar (0.82 ± 0.20 individuals/km) was more during summer as the artificial waterholes close to the road may facilitate the use of roadside. The encounter rate of gaur was highest (0.40 ± 0.17 individuals/km) within 1000 m from the road edge and gradually decreased in the forest interior. The presence of artificial waterholes along the road perhaps offered the greatest attraction for these otherwise shy species to use the roadside habitat.

During summer and winter, maximum number of rhesus macaques (*Macaca mulatta*) was encountered close to the road and the encounter rate gradually decreased towards the forest interior. The use of roadside habitat by rhesus macaque is highly influenced by the artificial feeding by passers-by (Pragatheesh 2011). During monsoon, rhesus macaques are distributed throughout the road verge and the forest interior (Pragatheesh 2011). Hanuman langur (*Semnopithecus entellus*) generally avoided the roadside habitat (Table 4.1).

Assessment of habitat use by mammals based on indirect evidence

The pellet encounter rate (13.24 pellet group/hectare) also indicated that the use of roadside habitats by most animals was relatively higher in summer when compared to the use in monsoon (6.55 pellet group/hectare) and winter season, (4.94 pellet group/ hectare respectively). During summer, pellets of 6 species: gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), chital (*Axis axis*), wild pig (*Sus scrofa*), Indian muntjac (*Muntiacus muntjak*) and Indian hare (*Lepus nigricollis*) were encountered in the plots. During monsoon, pellets of 4 species: nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), chital (*Axis axis*) and wild pig

(*Sus scrofa*) were encountered. In winter, pellets of 4 species: gaur (*Bos gaurus*), sambar (*Rusa unicolor*), chital (*Axis axis*) and wild pig (*Sus scrofa*) were encountered.

Distribution of pellet groups on the roadside habitat also varied with seasons (Figure 4.5). During summer, highest number of pellet groups (13.24 pellet group/hectare) was observed within 0 to 500 m of the road. This encounter rate decreased significantly ($R^2=0.673$, $F= 37.075$, $P=0.001$, $df=19$) as the distance to forest interior increased. During monsoon, the decline in the pellet group encounter was significant ($R^2=0.775$, $F= 62.300$, $P=0.001$, $df=19$) as the distance from the road verge to forest interior increased. During winter season, the encounters rates of pellet group did not vary significantly ($R^2=0.488$, $F= 17.161$, $P=0.001$, $df=19$) in the roadside habitat and the forest interior.

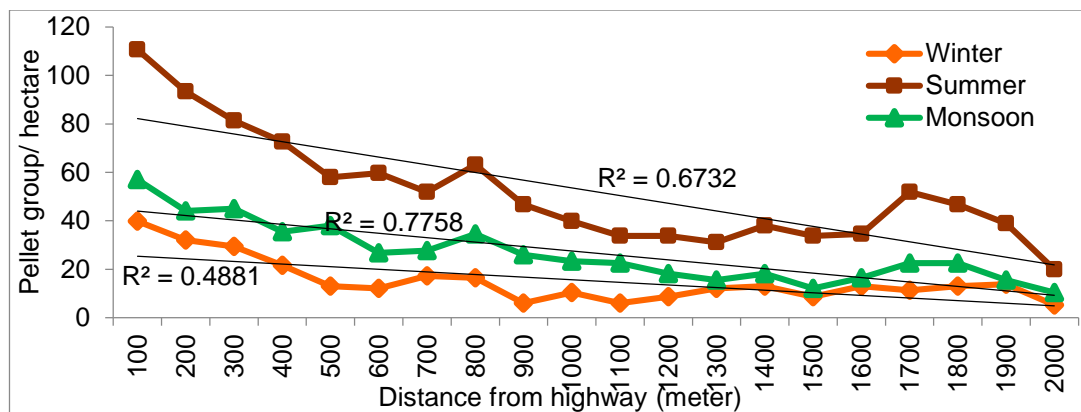


Figure: 4.5. Seasonal distribution of pellet groups of mammals from road verge to forest interior.

Key findings

Based on the assessment of use of fragmented habitats along the road by animals, the salient findings are:

1. The use of the forest fragments along the road was relatively high (8.47 ± 0.50 individuals/km) in summer when compared to use of these habitats during monsoon (5.03 ± 0.53 individuals/km), and winter (1.65 ± 0.20 individuals/km) seasons
2. Animal encounters during summer were more at a distance between 300 and 500m from the road and gradually decreased towards the forest interior
3. During winter, the encounter rates was more beyond 800 m and increased progressively towards forest interior.
4. During monsoon, the encounter rates of mammals was randomly distributed.

Use of road verges by mammals

The importance of road verges as natural habitats in urban landscapes and as vital corridors, linking habitats is well acknowledged (Yanes *et al.* 1995; Hlavac & Andel 2002; Alexander *et al.* 2005; Gurrutxaga *et al.* 2010). Roads and road verges do provide habitat for some animals, particularly small mammals and insects (Oxley *et al.* 1974; Getz *et al.* 1978; Vermeulen 1993; Brock & Kelt 2004), and serve as a source of food for carrion-feeders (Bennett 1988).

Road construction, widening and upgrades have invariably affected the enormous areas of linear habitats representing the road verges (Brody & Pelton 1989; Richardson *et al.* 1997; Clarke *et al.* 1998; Goosem 2002; Rondinini & Doncaster 2002; Saeki & Macdonald 2004; Jaeger *et al.* 2005; Ramp *et al.* 2006; Dussault *et al.* 2007; Gagnon *et al.* 2007; McGregor *et al.* 2008; Shepard *et al.* 2008; Leblond *et al.* 2013).

If the biodiversity in fragmented habitats on each side of the NH-7 has to be conserved, it is important to assess the habitat potential and use of the road verges by wild animals because animals from verges may have better opportunity to re-establish themselves in the fragmented habitats.

Methodology

(i) Surveying for mammals in the road verge

Presence of mammals in the road verge was estimated following standard methods (Hirst 1969; Varman & Sukumar 1995; Gese 2004). Roadside counts were made using a four-wheel vehicle driven at a speed of <20 km/h. Continuous monitoring was done for 24 hrs on 3 days in each season: monsoon (July to October), winter (November to February) and summer (March to June). During the daytime, direct observations were made of the animals present within 50 m from the road. During night time, animals were spotlighted by vehicle and detected by the eye-shine or by movement of animal on the road. When animals were spotted, geographic coordinates were recorded using Global Positioning System (GPS; Garmin 72 unit) and information on species, group size and habitat type was recorded. Encounter rates were calculated for all observed mammals. Time of animal sighting on the road verge was used to create 24 hour activity patterns and all independent sightings of species were pooled on an hourly basis for 2 years. The activity pattern of the mammals was calculated using Circular statistics using the Oriana version 3 software to assess the variations in activity pattern around the clock.

Generally, the animal sighting in the road verge can be difficult, due to either less abundance of the species, low visibility due to terrain or because of the vehicle and human disturbance on the road. Considering that the use of indirect methods such as the quantification of tracks and faeces (pellet groups) can be more appropriate in such circumstances (Campbell *et al.* 2004; Mandujano 2005), indirect evidences

(pellet) were collected within 10 m of the entire 9 km linear stretch bordering the Pench Tiger Reserve.

(ii) *Determining the factors influencing the use of road verges by mammals*

Spatial and temporal variables were chosen to describe the site-specific attributes for each animal sighting and mean pellet group. The road was categorized into one of the six categories following Clevenger *et al.* (2003) as (1) road surface raised compared to surrounding landscape, (2) no slope, (3) road surface buried relative to surrounding landscape, (4) one side flat, one buried, (5) one side flat, one side raised and (6) one side buried, one raised (Table 4.2). The highway was divided into 100 m segments (n=90) for this study and on each of these segments, spatial data on landscape related variables such as the distance of animal sightings from agriculture, water sources, drainage and animal crossing structures was generated using the Euclidean Distance Method in Arc Info. Assessment of average altitude (meter) and slope (degree) was derived from 30m resolution Digital Elevation Model (ASTER Global Digital Elevation Model) and proportion of Normalized Difference Vegetation Index (NDVI) was extracted using Global Land Cover Facility (GLCF). For each linear segment, information on nearest distance to vegetation cover was recorded. For assessing visibility, the nearest distance between the road segment and the unobstructed view of the approaching vehicle from either side of the highway was measured (Table 4.3). For vegetation cover and visibility, observations were made at every 25 m intervals on a 9 km long highway and the results were presented as an average for every 100 m segment.

Table 4.2 Road topography categories


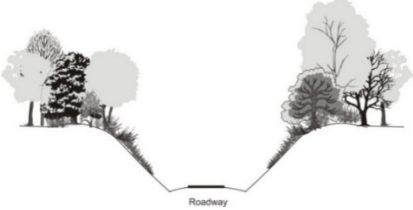

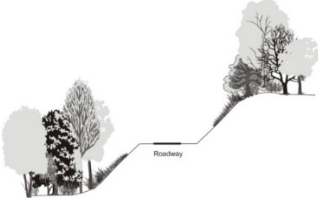



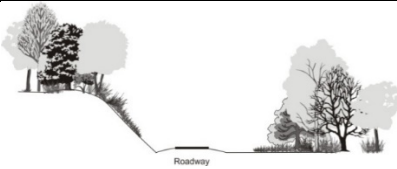

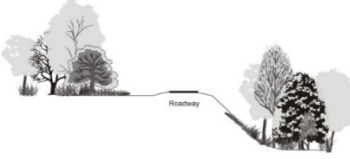


	Road topography category	Graphic representation	
1.	<p>Buried (road surface relatively lower than the surrounding landscape which has higher elevation)</p>		
2.	<p>Buried- Raised (valley on one side of the road and raised elevation on the other side)</p>		
3.	<p>Flat (road surface and roadside features on the same plane)</p>		
4.	<p>Part-Raised (road surface is elevated or raised on one side and flat on the other side)</p>		
5.	<p>Part-Buried (one side of the road has flat topography and the other side has a dip)</p>		
6	<p>Raised (road surface is significantly raised in comparison to the surrounding landscape)</p>		

Table 4.3. Variables and their description used in the analysis

Variable name	Description	Unit	Source
Visibility	Distance from point where from any approaching vehicle is first seen	Meter	Field sampling
Distance to cover	Distance to vegetation cover taken from both sides of road	Meter	Field sampling
NDVI	Proportion of forest cover	Value	GLCF
Distance to water	Distance to nearest water source (lake)	Meter	Euclidean distance(Arc Info)
Distance to underpass	Distance to nearest wildlife crossing structure	Meter	Euclidean distance(Arc Info)
Distance to drainage	Distance to nearest seasonal drainage	Meter	Euclidean distance(Arc Info)
Distance to agriculture	Distance to nearest human settlements	Meter	Euclidean distance(Arc Info)
Altitude	Mean ground altitude of the road (segments)	Meter	Digital elevation model
Slope	Mean ground slope of the road (segment)	Degree	Digital elevation model

Linear regression model was developed to relate the habitat use by animals use with landscape features and road attributes. In each segment, use varied between 0 (no animal sighted) to 12 (maximum animal sighted). We used the SPSS Statistical Package (version 15.0, SPSS 2006) for statistical analysis, Arc GIS 9.2 (ESRI 2004) and Microsoft Excel for all other analysis.

Result

Distribution of mammals on the road verge

Data on roadside counts (Table 4.4) indicate that average encounter rate was 8.24 ± 0.12 individuals/day based on observations of as many as 13 species of mammals recorded in the road verge during the survey. The use of road verges by rhesus macaques (*Macaca mulatta*) was relatively more (61 ± 19 individuals/10 km/day) when

compared to use by other species – Hanuman langur (*Semnopithecus entellus*): 23±14 individuals/10 km/day; chital (*Axis axis*): 4.44±1.48 individuals/10 km/day; wild pig (*Sus scrofa*): 0.96±0.31; Indian hare (*Lepus nigricollis*): 0.59±0.03; sambar (*Rusa unicolor*) : 0.52±0.17; gaur (*Bos gaurus*): 0.46±0.15; jungle cat (*Felis chaus*): 0.40±0.13 individual/10 km/day; nilgai (*Boselaphus tragocamelus*): 0.28±0.09 individual/10 km/day; grey mongoose (*Herpestes edwardsii*): 0.25±0.08 individual/10 km/day; common palm civet (*Paradoxurus hermaphroditus*): 0.25±0.08 individual/10 km/day and wild dog (*Cuon alpinus*): 0.09±0.03 individual/10 km/day). More number of animals used road verge habitat during summer as was determined from encounter rates (6.79±0.11 individuals/10 km/day) when compared to encounters in winter (0.90±0.01 individuals/10 km/day) and monsoon (0.56±0.005 individuals/10 km/day).

Table 4.4. List of animals and their encounter rates along NH-7 section passing through PTR

No	Species		Wild animal use along highway	
	Common name	Scientific name	Encounter/ 10 km/day ± S.E	Percentage
1	Common palm civet	<i>Paradoxurus hermaphroditus</i>	0.25±0.05	0.27
2	Gaur	<i>Bos gaurus</i>	0.46±0.09	0.49
3	Grey mongoose	<i>Herpestes edwardsii</i>	0.25±0.02	0.27
4	Indian giant flying squirrel	<i>Petaurista philippensis</i>	1.00±0.11	1.07
5	Indian hare	<i>Lepus nigricollis</i>	0.59±0.03	0.63
6	Jungle cat	<i>Felis chaus</i>	0.40±0.05	0.43
7	Nilgai	<i>Boselaphus tragocamelus</i>	0.28±0.04	0.30
8	Sambar	<i>Rusa unicolor</i>	0.52±0.08	0.56
9	Chital	<i>Axis axis</i>	4.44±0.68	4.76
10	Wild dog	<i>Cuon alpinus</i>	0.09±0.02	0.10
11	Wild pig	<i>Sus scrofa</i>	0.96±0.12	1.03
12	Rhesus macaques	<i>Macaca mulatta</i>	61.00±19.00	65.42
13	Hanuman langur	<i>Semnopithecus entellus</i>	23.00±14.00	24.67

The use of the road verge habitat by mammals appeared to be clustered. During the survey, maximum numbers of animals were sighted between 628.400 to 629.300

km which is in close proximity of the human habitations (629.700 to 631.700 km) and water sources (634.400 to 635.500 km) (Figure 4.6 and 4.7).

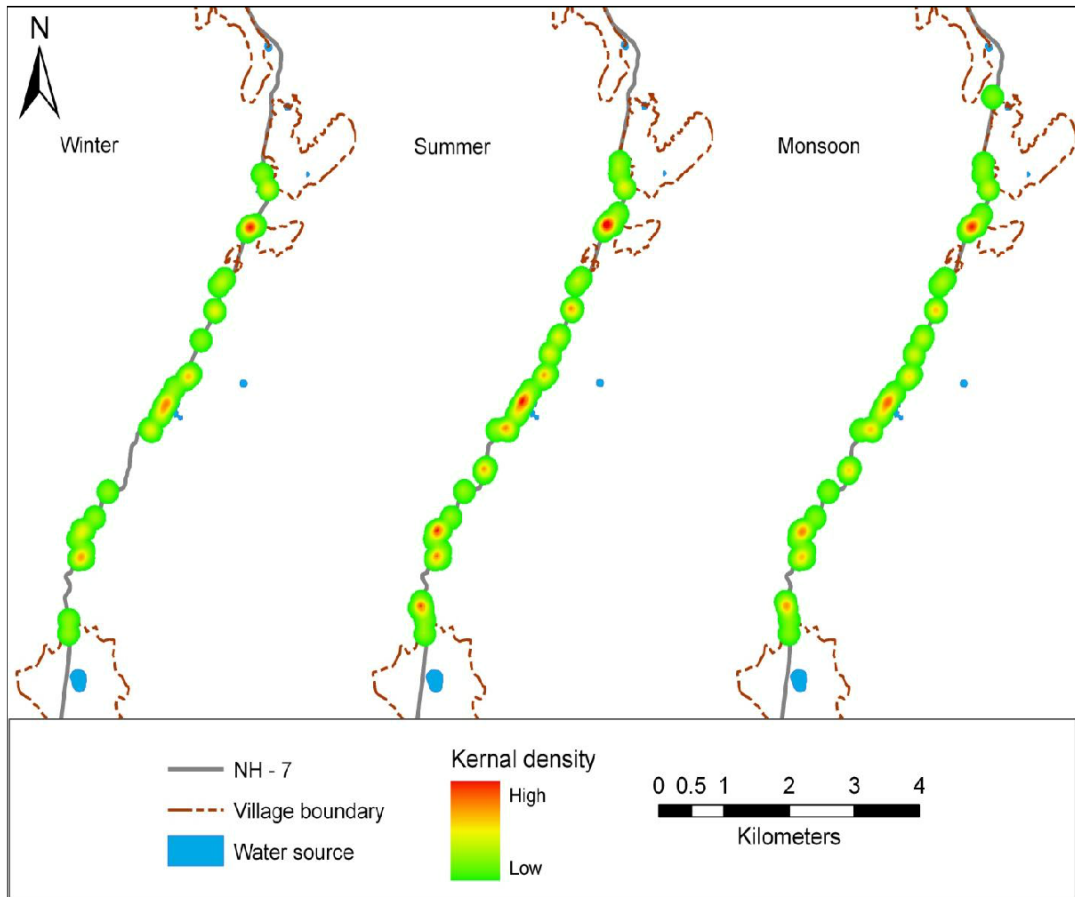


Figure: 4.6. Kernel density of the animals sighted on NH-7 passing through PTR.

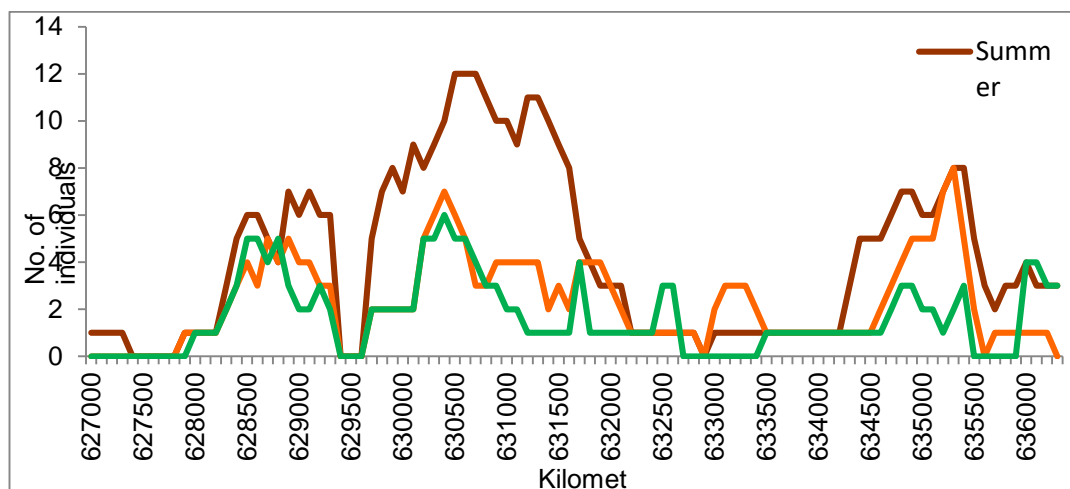


Figure: 4.7. Number of animals sighted in each 100 m section of NH-7.

From the Pearson correlation performed to see the relationship between traffic volume and habitat use, it becomes evident that the animal use of the roadside habitat was positively correlated to the average number of vehicle on the road ($r=0.998$, $p=0.001$) in all seasons. Further, the animal avoided the road verge habitat during daytime when the traffic volume is high on the road ($r=-0.448$, $p=0.05$) (Figure. 4.8).

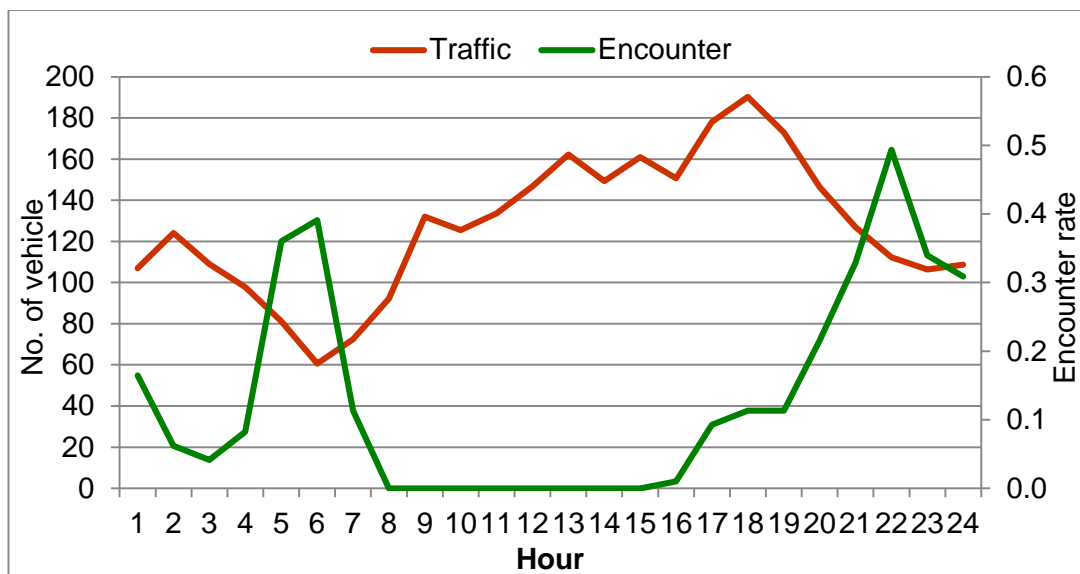


Figure: 4.8. Animal activity in different hours of the day against average traffic volume for the same time.

Road verge habitat use by mammals

Based on pellet counts (22.44 ± 19.7 pellet group/100 m), the roadside habitat was relatively more used by ungulates during summer than during winter (6.65 ± 4.9 pellet group/100 m) and monsoon (2.35 ± 1.5 pellet group/100 m) in the entire 9 km stretch. The indirect evidence shows that the linear habitat in the entire length of the road verge has been used by the ungulates. The pellet groups were, however more concentrated in sections between 628.000 km to 629.400 km and between 630.400 km

to 632.700 km that are aligned close to agricultural areas and in close proximity of water sources (Figure 4.9 and 4.10).

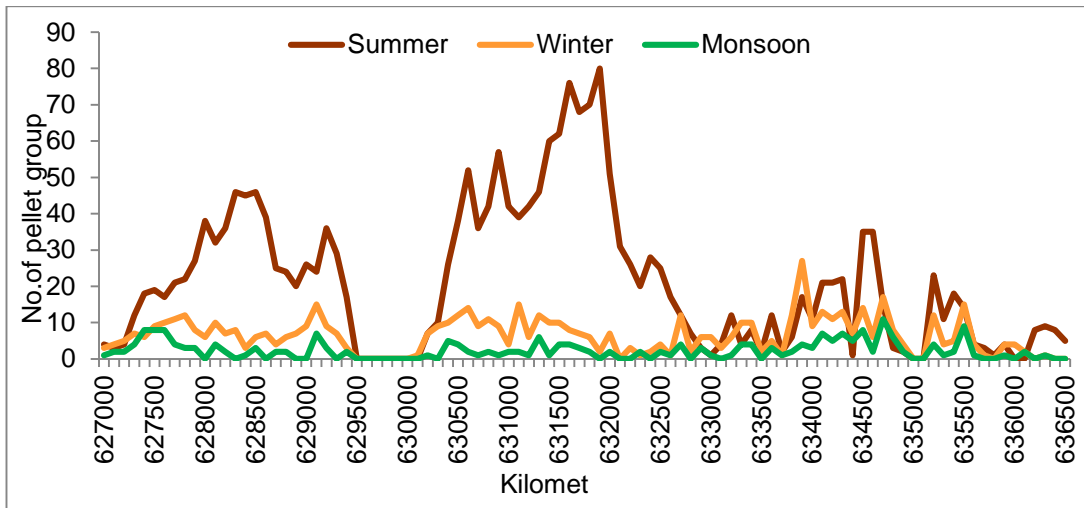


Figure: 4.9. Pellet group counts for mammals along the road edge in a 9 km stretch.

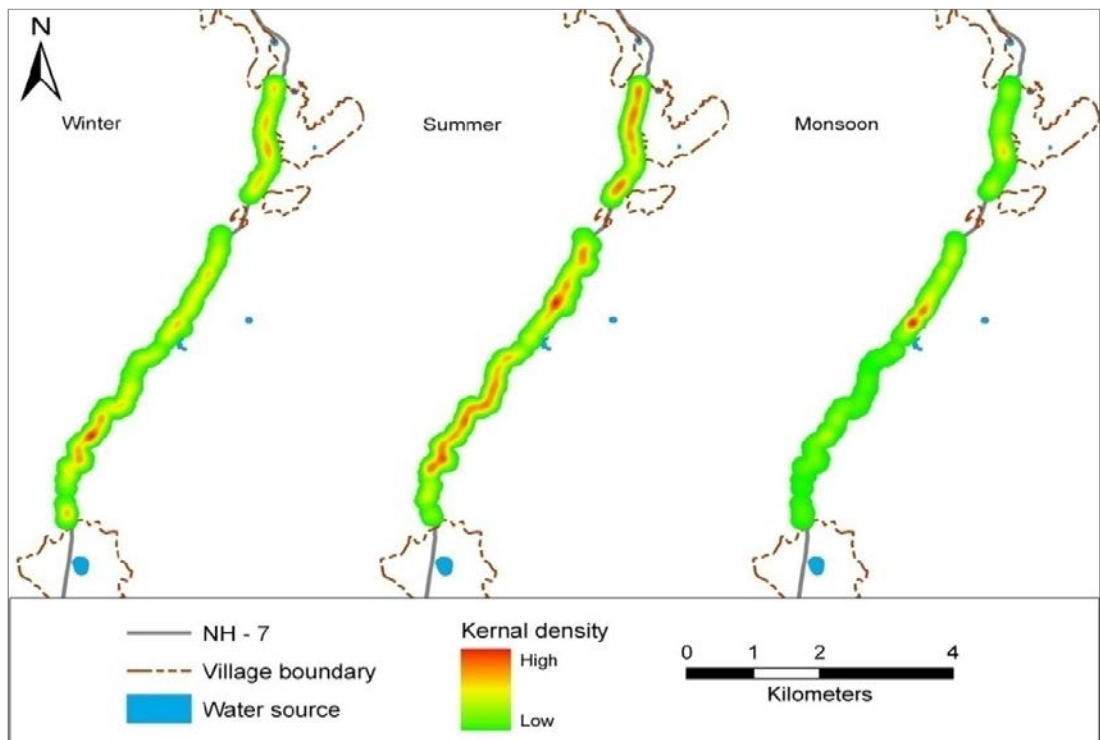


Figure: 4.10. Kernel density estimation of pellet groups of mammals along the road.

Activity pattern of animal using roadside habitat

Based on roadside surveys conducted in all seasons over a two-year period, a total of 689 individuals of wild animals were recorded (Figure 4.11). The activity pattern of the animals sighted that was calculated using Oriana, software package indicates that primates (Rhesus macaques and Hanuman langur) were the two most sighted animals in the roadside habitat. The activity peak of rhesus macaques was observed at 9:57 h \pm 4:45 SD and for Hanuman langur at 10:19h \pm 4:33SD. Both the animals were more active during daytime between 9:00 h and 11:00 h (Figure 4.12 and Table 4.5). The activity pattern of chital shows that 86% of animals were sighted during night, 14% of chital were sighted during the daytime along the road and the peak activity time was 00:01 h \pm 04:03 SD. In case of sambar, 83 % of sightings occurred during night, only 17 % of animals were sighted during daytime and the peak activity time was 19:25 h \pm 01:39 SD. For wild boar, 70% of animals were sighted during night time, 30% during daytime and the peak activity time was 01:29 h \pm 07:44 SD. In case of gaur 100% of animals were sighted during night time and the activity peaked at 00:15 h \pm 03:56 SD. For animals such as common palm civet, grey mongoose, Indian giant flying squirrel, Indian hare, nilgai, jungle cat and wild dog, activity patterns could not be established because of very low encounter rates (Figure 4.12).

Table 4.5. Circular statistics of temporal activity patterns of major ungulates and the average vehicular traffic on NH-7 along the Pench Tiger Reserve.

Variables	Chital	Sambar	Wild boar	Gaur	Rhesus Macaque	Hanuman langur	Average vehicle traffic
Number of Observations	149	29	61	43	235	109	3047
Mean Vector (μ)	0:01	19:25	1:29	0:15	9:57	10:19	16:29
Length of Mean Vector (r)	0.569	0.911	0.129	0.587	0.461	0.49	0.163
Median	23:00	19:00	5:00	23:00	9:00	9:00	17:00
Concentration	1.389	5.895	0.259	1.458	1.037	1.122	0.331
Circular Variance	0.431	0.089	0.871	0.413	0.539	0.51	0.837
Circular Standard Deviation	4:03	1:39	7:44	3:56	4:45	4:33	7:16



Figure: 4.11. Animals encountered on the road and in the roadside habitat

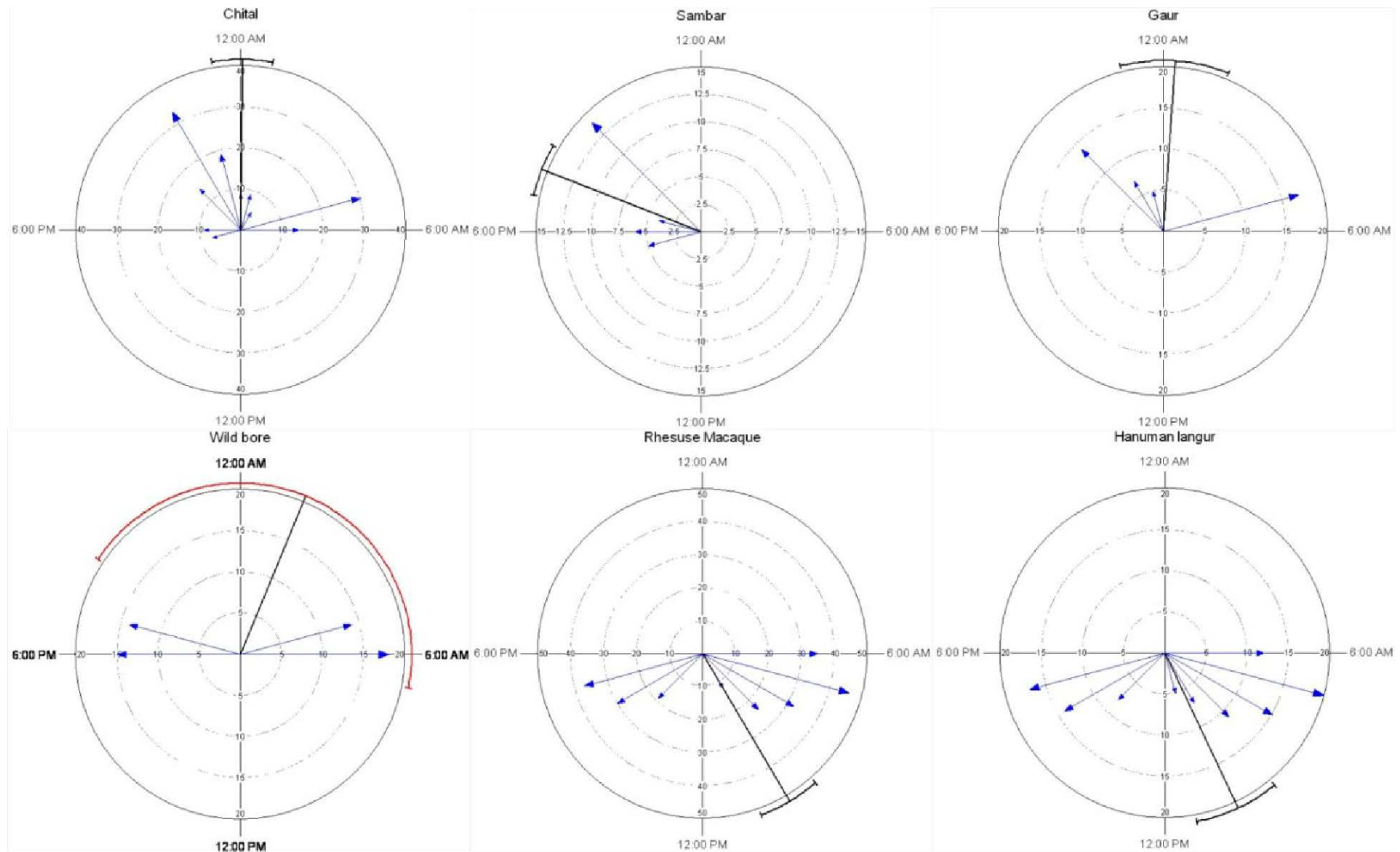


Figure: 4.12. Temporal activity patterns of ungulate species using the roadside habitat along the edge of Pench Tiger Reserve.

Factors influencing the roadside habitat use

Use of roadside habitat by the wild animals is generally associated with specific habitat, terrain and adjacent land use types. Those species that have distinct movement corridors to access resources, disperse to maintain their social structure, or seasonally migrate, the presence of a road network within the landscape may have consequences. If roads act as barriers to movement, individuals may not be able to access critical food resources, breeding grounds, hibernacula, or avoid inbreeding. Predictive models may, therefore, be essential in identifying and providing insights into such issues (Bennett 2017). In this study, it was found that most of the ungulates used the flat terrain (levelled road) compared to other topographic categories (Figure 4.13). A linear regression model was built for animal sighting and location. The animal sighting in the roadside habitat was positively related to the NDVI ($p=0.001$) and negatively related to proximity to village ($p=0.001$) and altitude (DEM) of the road ($p=0.001$). Other variables such as distance to vegetation cover, drainage, underpass, water source, visibility on the road and slope did not influence the use of roadside habitat by animals (Table 4.6).

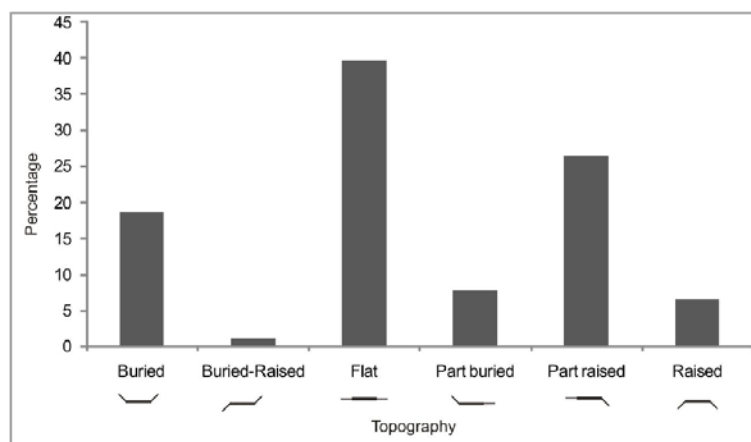


Figure: 4.13. Percentage of mammals sighted in road section with varying topography.

Table 4.6. Linear regression of animal use of road verge habitat with the selected variables, (β – Regression coefficient, S.E. – standard error of the regression coefficient, df- Degrees of freedom P – significance level).

Variables	β	S.E	df	P
Distance to cover	.119	.197	.607	.545
Distance to drainage	.009	.010	.846	.400
Distance to underpass	-.007	.004	-1.706	.092
Distance to village	-.003	.001	-3.658	.001
Distance to water source	-.001	.001	-.387	.700
NDVI	62.367	15.816	3.943	.001
Elevation	-.080	.020	-3.946	.001
Slope	-.398	.233	-1.709	.091
Visibility	.005	.018	.266	.791

Key findings

- 13 species of mammals used the road verge habitat but the use was spatially clustered. Maximum numbers of animal encounters based on direct and indirect evidences were clustered near waterholes created by the Madhya Pradesh Forest Department.
- Average encounter rate of mammals recorded in the road verge habitat was 8.24 ± 0.12 individuals/day.
- The use of road verge indicated diurnal variations as is reflected from 84% of mammals encountered during night time and only 16% animals encountered during daytime.
- The use of habitats in the road verge varied with different seasons with highest use (6.79 ± 0.11 individuals/10km/day) observed during summer

when compared to use of these habitats during winter (0.90 ± 0.01 individuals/10km/day), and monsoon (0.56 ± 0.005 individuals/10km/day).

- Encounter rates of animals both, diurnally and seasonally, were also influenced by traffic.
- The use of the road verges was relatively more by primates like rhesus macaques and Hanuman *langur* based on their encounter rates (61 ± 19 individuals/10km/day and 23 ± 14 individuals/10km/day respectively).

Discussion

According to Cramer and Bisonette (2005), a permeable landscape feature is one that allows free daily movement of a species across its home range. While road-verges can provide a good linking mechanism between habitats for both common and uncommon species, for range expansion or travel between fragmented habitats, they may fail to serve as routes of connectivity because of highway-related factors (Underhill 2002).

Based on the findings of NH-7, it becomes evident that as many as thirteen species of mammals used the road verge (Table 4.7). In addition to this, indirect evidences (scats and pugmark) of tiger and informal discussions with the staff of the State Forest Department and local people confirmed the use of roadside habitat by tigers.

In observations made by Downes *et al.* (1997), all fourteen species of native mammals recorded during the study were present in remnant forested strips (15–32 m wide) along roadsides, and one species, the common brush tail possum, was detected in roadside vegetation but not in forests. The mean species richness

per site did not differ significantly between forests and near roadsides, but distant roadsides had lower species richness than either of the former.

The use of roadside habitat by mammals where the road forms an edge of the protected area may however differ as most animals would rarely move out of the protected habitats into roaded areas with a lower habitat potential unless such areas provide specific benefits of dispersing freely, moving between alternative habitats and re-colonizing areas to be part of viable populations. Based on the density ranges of major ungulate species (2 ± 0.4 to 55 ± 8.4) of Pench Tiger Reserve provided by Majumder *et al.* (2012) and the results of the present study, it becomes evident that the use of the road verge bordering the Tiger Reserve by most mammals was fairly restricted.

Table 4.7. Density and encounter rate of ungulates in Pench Tiger Reserve and in road verge.

Common name	Scientific name	Density of ungulates in PTR (Majumder <i>et al.</i> 2012)	Encounter rate of animals in the road verge (Present study)
Chital	<i>Axis axis</i>	55 ± 8.4	4.44 ± 0.68
Gaur	<i>Bos gaurus</i>	2 ± 0.6	0.46 ± 0.09
Nilgai	<i>Boselaphus tragocamelus</i>	2 ± 0.4	0.28 ± 0.04
Sambar	<i>Rusa unicolor</i>	5.4 ± 0.6	0.52 ± 0.08
Wild pig	<i>Sus scrofa</i>	7 ± 1.5	0.96 ± 0.12

Movement of animals is also expected to be influenced by environmental, ecological, and behavioural variables (Wiens 1995; Phillips *et al.* 2004). The probability of many large animals using road is also influenced by their agility and use of large home ranges (Gibbs & Shriver 2002). As the average home range for major

herbivore and carnivore species using the road verges varies from 7 to 16 km² and 41 to 202 km² respectively (Sankar 1994; Sankar *et al.* 2000; Acharya *et al.* 2006; Sharma & Jhala 2011) some of the animals may be interacting more with the roads.

The use of road verge habitat by primates like rhesus macaques and Hanuman langur was relatively more when compared to other mammals as evident from the activity pattern of rhesus macaques (9:57 h \pm 4:45 SD) and Hanuman langur (10:19 h \pm 4:33 SD). The earlier study conducted by Pragatheesh (2011) concluded that the use of road verge habitat by rhesus macaques could be highly influenced by hand feeding by passersby. He observed a positive correlation (Pearson- product moment $r = 0.968$, $p = 0.01$) between the number of people feeding the primates and the number of animals encountered in the road verge.

Southwick *et al.* (1964) considered that readily available water in roadside ditches and ponds, and adjacent agricultural crops was important for supporting primate populations. As most of the water sources are located along the section of the road that was studied, this could be one of the contributing factors for use of road verges by the primate species of the area.

The activity pattern of wild ungulates varied between day and night time. Maximum number of ungulates were encountered during night time (84%) followed by daytime (16%). The mean activity time of ungulates varied as is indicated by the activity patterns of chital (00:01 h \pm 04:03 SD), sambar (19:25 h \pm 01:39 SD), gaur (00:15 h \pm 03:56 SD) and wild boar (01:29h \pm 07:44 SD). This variation based on observations during daytime when high traffic and human activities (e.g. wood cutting, grazing and lopping) were at the peak is in contrast to patterns that were observed by Ramesh *et al.* (2012) based on his studies in Mudumalai Tiger Reserve which

represented an undisturbed habitat for most ungulates. Earlier studies (Kuck *et al.* 1985; Cassirer *et al.* 1992; Cote 1996; Papouchis *et al.* 2001; Fortin & Andruskiw 2003) also explain that anthropogenic disturbance could be one of the factors that may be limiting the roadside habitat use. Further, it is possible that the animals which are using the roadside habitat may have become adapted to use road during night time because of greater crossing opportunities than at daytime (Jeffrey *et al.* 2007).

Use of the road verge habitat was observed to be typically species specific, with some animals completely avoiding the roads and others being attracted to it (Forman & Alexander 1998; Forman *et al.* 2003). Among the ungulates, chital (*Axis axis*) were attracted to open habitats created alongside roads when compared to areas with dense vegetation (Zwartjes *et al.* 2005; Ramesh *et al.* 2009). A study by Sartaj *et al.* (2010) found that occurrence of chital groups was more in open area compared to close forest for vigilance purpose. During summer, the road verges (approximately 5 - 7 m) on the either side of the road are generally control burned by the State Forest Department as part of the management practices for preventing forest fire. With the first monsoonal shower, these burnt patches that also receive additional runoff from the highway are covered with spurts of green grass that attract the chital (*Axis axis*) to browse the tender blades of grasses and other herbaceous growth along the road.

According to Newmark *et al.* (1996) darkness may be providing the cover for many of the species. This could be one of the factors influencing number of mammals using the roadside habitat during night time. In the present study, the higher number of roadside counts of chital during night time (n=6) and more number of animal mortalities on road during night time (97%) reflect greater use of road verges during the night time. Becker *et al.* (2011) also observed moose avoiding highway during high

traffic volume in Buffalo Fork Valley. Gagnon *et al.* (2007) reported that elk (*Cervus elaphus*) shifted use away from a highway in Arizona when diurnal traffic volume was high and yet returned at night when traffic volume declined. Similarly, Brandenburg (1996) and Brody and Pelton (1989) observed that highway crossings by black bears occurred at night when traffic volume was low. These findings were also applicable to Grizzly bears that tend to cross highways more at night when the traffic volume is low (Waller & Servheen 2005). Complete avoidance of roads where traffic volumes had significantly increased was reported in bears and badgers (*Meles meles*) by Brandenburg (1996) and Clarke *et al.* (1998) respectively. Early studies (Perry & Overly 1977; Witmer & deCalesta 1985; Rowland *et al.* 2000; Wisdom *et al.* 2005) reported elk (*Cervus elaphus*) avoiding areas near forest roads with higher traffic levels.

The use of road verges by mammals was spatially clustered. This may be because of the suitable habitat or spatio-temporal factors such as water, forest cover and terrain, which attract the animal to use the habitats across the road. Maximum number of animals were encountered nearer the waterholes (locally referred as *dhubia talab*) constructed by the Madhya Pradesh Forest Department. The linear regression model showed that the animal sighting locations were directly correlated to the NDVI (forest cover), reflecting that animals preferred the locations where the forest cover is high and their sightings are negatively correlated to the proximity to village. This clearly shows that wild animals prefer locations where disturbance is low.

During the survey, maximum number of animals were frequently sighted in flat terrain roads. This shows that animals preferred to cross roads in flat terrain compared to other types of terrain, because of the ease of crossing. The design

characteristics of the road, including the topography and the surface may sometime determine the habitat characteristics for species that might use the road verge. This has been true for kangaroo rats (*Dipodomys stephensi*) that were more active in using dirt roads than gravel roads (Brock & Kelt 2004) and grizzly bears (*Ursus arctos*) that avoided unpaved roads (Mace & Waller 1996). For some small mammals, road verges constitute a ‘‘long, ribbon-like habitat’’ along which they can move and disperse (Vermeulen 1993).

Recommendation

This study suggests the species using the roadside habitat were highly influenced by the water availability in the dry season. The artificial waterhole created by the forest department which is present along the road attracts the animal to use the roadside habitat during the high dry season (summer). It may be responsible for the high wildlife mortality on the road during the dry season. Similar type of results confirm the changes in wildlife population in the proximity of infrastructure for larger mammals (Cameron *et al.* 1992; Newmark *et al.* 1996; Nellemann *et al.* 2003; Joly *et al.* 2006). At several places in India, major road projects are constructed or aligned close to water sources (wetland or waterfalls) for improving aesthetic values of highway corridor. Infrastructure-mediated impacts are expected to be most damaging in species-rich ecosystems, such as tropical forests, where few roads currently exist (Laurence *et al.* 2009, 2014). Our approach can be used in those areas for regulating the expansion of new infrastructure, supporting regional planning and road development schemes, and increasing the efforts to mitigate their detrimental effects (Torres *et al.* 2016). This study recommends better water source planning to

reduce/minimize the number of animals using the roadside habitat by removing waterholes (hand pump) existing close to the roadside and creating more waterholes away from the road. More extensively, existing drainage culverts can be used as faunal underpasses for improved permeability for animals (Clevenger *et al.* 2001). Fences are necessary to culverts in order to reduce road-kill and increase connectivity between populations possibly fragmented by the highway. Culverts can function as faunal underpasses when their entry is wider than their overall length because the animal should see the end of the tunnel.

Chapter 5: Impact of road on mortality of mammals and proposed mitigation measures

Introduction

Globally, 25% of mammalian species for which data are available are threatened with extinction and decline in their populations due to degradation and loss of habitats, hunting and harvesting (Laurance *et al.* 2006; Schipper *et al.* 2008). In addition to these factors, infrastructure developments such as railways, power lines, pipelines, hydroelectric developments, oil wells, seismic lines impacts are also known to influence the long-term viability of populations and, eventually, biodiversity (Nellemann & Cameron 1996; Mahoney & Schaefer 2002; Nellemann *et al.* 2003; Noel *et al.* 2004; Barrios & Rodriguez 2004).

Roads have been recognized to be yet another human induced factor that has significant potential to negatively impact animal populations owing to the risks of mortality associated with roads (Lode 2000). The extent to which road construction contributes to direct mortality has not been estimated in as much details as has direct mortality from other forms of habitat destruction (Petranka *et al.* 1993). The changes in the landscape in terms of fragmentation of the continuous patch, isolation of habitats due to road network, would have a negative impact on the animals killed while moving on and off the roads (Coffin 2007).

A growing literature in the field of road ecology suggests that vehicle/wildlife collisions can be major sources of vertebrate mortality and thus potentially limit wildlife populations (Aresco 2005). Many studies support that mammals are often the most common vertebrate taxon to be killed by vehicles (Warren 1936; Dreyer 1937; Scott 1938; McClure 1951; Oxley *et al.* 1974; Adams 1984; Glista *et al.* 2009;

Barthelmess & Brooks 2010; Thomas *et al.* 2013). They are especially more vulnerable to road network because they have large spatial requirements, small populations, tend to live at low densities and occupy small geographic ranges or exhibit migratory behaviour (Ball *et al.* 2001; Gittleman *et al.* 2001).

Considerable numbers of studies have evaluated the impact of road on mammals in different parts of the world. In the Canada and United States, road kill has surpassed hunting in its effect on vertebrate mortality (Forman & Alexander 1998). Mortality of a range of species including moose (Bangs *et al.* 1989; Grosman *et al.* 2009), badgers (Clarke *et al.* 1998), Iberian lynx (Ferrerias *et al.* 1992) panther and black bear (Harris & Scheck 1991) caribou, elk, grizzly bear in Canada (EDI 2015; Groot Bruinderink & Hazebroek 1996; Romin & Bissonette 1996; Conover 1997) have been reported.

Approximately one million wild animals are killed on roads each year in the UK alone (Underhill & Angold 2000). Mortality of wolves (Colino-Rabanal *et al.* 2011) collision of ungulates (Groot & Hazebroek 1996; Seiler 2005) brown hare (Roedenbeck & Voser 2008), badgers (Clarke *et al.* 1998; Jaarsma *et al.* 2007) represent significant impact of roads in Europe. In Australia, long-nosed bandicoots and Swamp wallabies (Ben-Ami & Ramp 2006; Ramp *et al.* 2005, 2006) hare (Roedenbeck & Voser 2008), possums, hedgehogs and rabbits (Brockie *et al.* 2009) are well document. Deer-vehicle collision (Bellis & Graves 1971; Puglisi *et al.* 1974; Bashore *et al.* 1985; Romin & Bissonette 1996; Joyce & Mahoney 2001; Christie 2003; Myers *et al.* 2008; Ng *et al.* 2008; Gonser *et al.* 2009; Danks & Porter 2010; Found & Boyce 2011) and bobcats (Cain *et al.* 2003), Florida panther (Schwab & Zandbergen 2011) are reported from Latin America and North America. Carcass

study of mammals included black backed jackal and spotted hyena in Ethiopia (Kiros *et al.* 2016), mongooses and olive baboons, wildebeest, zebra in Tarangire-Manyara-Ecosystem Tanzania (Kioko *et al.* 2015).

With roads attracting large-scale investments and with huge negative impacts on wildlife and their habitats, road ecology has been identified as an important discipline in conservation biology (Van der Ree *et al.* 2011). Both the terrestrial and aquatic ecosystems are prone to the effects of roads by the way of vehicular collision and collision while road construction 2) Changes in the animal behaviour and home range 3) modifications in the surrounding environment 4) dispersal of the species, 5) alteration in the habitat with reference to human interference (Trombulak & Frissell 2000). As the number and extent of road networks are predicted to expand dramatically in developing countries (Fahrig & Rytwinski 2009).

This is especially true for most tropical developing countries including India that ranks second in the world in terms of total road length (56.03 lakh km) with 26,697 km aligned through wildlife habitats (Rajvanshi *et al.* 2001). Information on the road-induced mortality of mammal in India is very limited (Kumara *et al.* 2000; Sunder 2004; Baskaran & Boominathan 2010; Behera & Borah 2010; Seshadri & Ganesh 2011; Gubbi *et al.* 2012; Prakash 2012; Joshi & Dixit 2012; Gajera *et al.* 2018; Jeganathan *et al.* 2018). Most of these studies provide information based on anecdotal records and seasonal data and have been largely limited to Western Ghat region. More serious scientific endeavours are needed to determine the most probable locations and causes of traffic induced mortality and injury.

This study is a more focussed attempt to estimate road-induced mortality of mammals based on exhaustive field based observations collected over a two year

period on a 9 km section of National Highway (NH)-7 passing through Pench Tiger Reserve. The following are the key objectives this study:

- Estimate road-induced mortality of mammals based on exhaustive field based observations collected over a two-year period
- Identify the group of mammals that is most vulnerable to road-induced mortality
- Define the spatial distribution of road kills and evaluate the factors influencing the mortality of mammals.
- Determine factors that influence road-induced mortality
- Proposed strategies for reducing mammal casualties on NH-7

Based on the results of this study, appropriate options to avoid and reduce road-induced mortality of mammals have been discussed to long term conservation of the mammals in this landscape.

Methodology

Estimating road kills

Standard road cruising methods (Ashley & Robinson 1996; Clevenger *et al.* 2003; Langen *et al.* 2007) were adopted for estimating vertebrates and also methods that were specific for estimating mammals (Gryz & Krauze 2008). The 9 km road section running along the Pench Tiger Reserve and separating the Reserve from the South Seoni Territorial Forest Division was monitored for a total of 430 road cruising days spread across three seasons monsoon (n=147), winter (n=143) and summer (n=140) between August 2008 to July 2010. This resulted in a total effort of

monitoring 3870 km of road length. The timing of the survey was decided to ensure that this did not coincide with the activity time of scavenging animals so that kill records were not lost. The road was surveyed in the morning (0530–0630 hrs) and in the evening (1730–1830 hrs) at a speed of 10–20 km. The time invested in conducting each vehicular transect usually extended from 1.5–2 hrs but largely depended on the number of road kills encountered and the weather conditions. When road kill was encountered, the team stopped to record observations about the state of the road kill, roadside habitat features, road segment and location using Garmin 72 GPS. Whenever possible, the road victims were identified to species level with the help of field guide (Prater 1971; Menon 2003) and segregated into age categories (juvenile and adult) and sex classes. If the corpse's disintegration made species identification impossible, they were pooled into broad categories (large and small sized mammals, primates, rodents, bats). During each survey, two spotters scanned the road and the verge area on either side for recording vertebrate fatalities.

The survey resulted in a total effort of 3870 km. All road kills spotted during the morning survey were assumed to be killed during the previous night. All dead carcasses were removed from the road to ensure that there was no double count during subsequent survey. In addition, staff of the forest department and local people were requested to leave the carcass untouched and to communicate the information about the kill and its location to the research team as soon as possible. The entire road was surveyed during all the three seasons (Summer, monsoon and winter) as mentioned above.

Data on average traffic volume on the road section passing along the Pench Tiger Reserve that was generated based on continuous recording of the number of

vehicles over a period of twenty four hours for three days per season (refer to section I for details) was used in evaluation of the impacts. Pearson correlation coefficients were calculated to test the relationship between seasonal traffic volume and the number of road-kill carcasses found for mammal species.

For better outcome of data analysis, road kills were grouped into (i) large/medium sized mammals (chital (*Axis axis*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), Indian fox (*Vulpes bengalensis*), jackal (*Canis aureus*), jungle cat (*Felis chaus*); (ii) small sized mammals (common palm civet (*Paradoxurus hermaphroditus*), grey mongoose (*Herpestes edwardsii*), Indian hare (*Lepus nigricollis*), Indian porcupine (*Hystrix indica*), striped palm squirrels (*Funambulus palmarum*); (iii) primates (Hanuman langur (*Semnopithecus entellus*), rhesus macaque (*Macaca mulatta*); (iv) rodents and (v) arboreal mammal (Bats). This grouping was based on body size, weight and habitat utilized.

Prediction of fatality hotspots

Kernel Density method (Gitman & Levine 1970) was used to identify the fatality hotspots on the 9 km section of the road as this is recognized to be one of the most popular methods for analyzing the point event distribution data (Silverman 1986; Bailey & Gatrell 1995). This method generates a smooth surface map showing point data (kill location) on the basis of which the density of events (road kills per unit area) is determined to provide an estimate of kill concentration. The clustering and dispersion of traffic accidents are well illustrated by the Kernel Density Analysis, along with showing the location of the hotspots for the road kills (Bill *et al.* 2013). The area of influence or a bandwidth chosen for this study was 200 m. The Kernel

Density estimation for species fatalities was done using the spatial analyst toolbox of ArcGIS (ESRI 2004). Zero values were omitted to avoid confusion between zero density and no data. This approach that help identify fatality hotspots provides useful inputs in planning mitigating measures to address the impacts of road-induced mortality in hotspots (Ramp *et al.* 2005, 2006; Gomes *et al.* 2009).

Factors influencing the road kills

The spatio-temporal pattern of road casualties is influenced by various factors, such as the species' biology, traffic and road characteristics, and landscape and habitat composition (Seiler 2001). Spatial and temporal variables were chosen to describe the site-specific attributes for each road kill. The road was categorized into one of the six road topography categories following Clevenger *et al.* (2003) as (1) Buried (road surface buried relative to surrounding landscape), (2) Buried- Raised (one side buried, one raised), (3) Flat (no slope), (4) Part-Raised (one side flat, one side raised) and (5) Part-Buried (one side flat, one buried), (5) Raised (road surface raised compared to surrounding landscape). Land use land cover classified maps were generated using Landsat 7 Thematic Mapper (30 m resolution image taken on November 2009 (Path: 144, row: 52) downloaded from the USGS archive Global Visualization Viewer (<http://glovis.usgs.gov>). The image was classified into five major cover Teak dominant, (2) Miscellaneous, (3) Scrub forest and (5) Water sources. A 50 m buffer created around each road kill location was treated as a point in the GIS domain for extracting information on habitat features relevant to location of each kill. For this study, the 9 km stretch of highway was divided into 100 m segments (n=90). On each of these segments, spatial data on landscape related

variables such as the distance between mammal kill and agriculture, water sources, drainage and animal crossing structures was generated using the Euclidean Distance Method in Arc Info. Assessment of average altitude (meter) and slope (degree) was derived from 30 m resolution Digital Elevation Model (ASTER Global Digital Elevation Model). For each linear segment, information on nearest distance to vegetation cover was recorded. For assessing visibility, the nearest distance between the road segment and the unobstructed view of the approaching vehicle from either side of the highway was measured. For vegetation cover and visibility, observations were made at every 25 m intervals on a 9 km long highway and the results were presented as an average for every 100 m segment. Pearson rank correlations were run to test for relationships among variables (Quinn & Witmer 2003) that have been described in Table 5.1. In each segment, road kill data varied from 0 (without road kills) to 6 (maximum kill). We used the SPSS statistical package (SPSS 2006) for statistical analysis, ArcMap 9.2 (ESRI 2009) Hawth's Tools extension (Beyer, H.L. 2004) and Microsoft Excel for all other statistical analysis.

Table: 5.1 Variables and their description used in the analysis of factors influencing road-induced mortality of mammals.

Variable name	Description	Unit	Source
Visibility	Distance from place to mammals hit to the point where from any approaching vehicle is first seen	Metre	Field
Distance to cover	Distance to vegetation cover taken from both sides of road	Metre	Field
Distance to water	Distance to nearest water source (lake)	Metre	Euclidean distance(Arc Info)
Distance to underpass	Distance to nearest wildlife crossing structure	Metre	Euclidean distance(Arc Info)
Distance to drainage	Distance to nearest seasonal drainage	Metre	Euclidean distance(Arc Info)
Distance to agriculture	Distance to nearest human settlements	Metre	Euclidean distance(Arc Info)
Altitude	Mean ground altitude of the road (segments)	Metre	Digital elevation model
Slope	Mean ground slope of the road (segment)	Degree	Digital elevation model

Result

A total of 272 of road-induced kills of mammals were recorded in 430 days during August 2008 to July 2010 and included 15 species. On an average, 0.70 mammals/10 km/day road kills were observed. The most vulnerable animal group was rodent which accounted for 51% of the total kills of mammals (Figure 5.1) followed by primates (28%) which include rhesus macaque (n=54,) and hanuman langur (n=23). The large/medium size mammals predominantly including jungle cat (n=9) and chital (n=6) along with other species such as wild pig (n=2), jackal (n=2), sambar (n=1) and Indian Fox (n=1) together accounted for 8% road kills. This was comparable with the percentage kill of small mammals (8%) represented by striped

palm squirrels (n=9), common palm civet (n=5), grey mongoose (n=1), Indian hare (n=5), Indian porcupine (n=1) and Bat (n=15) (Figure 5.2.a & b.).

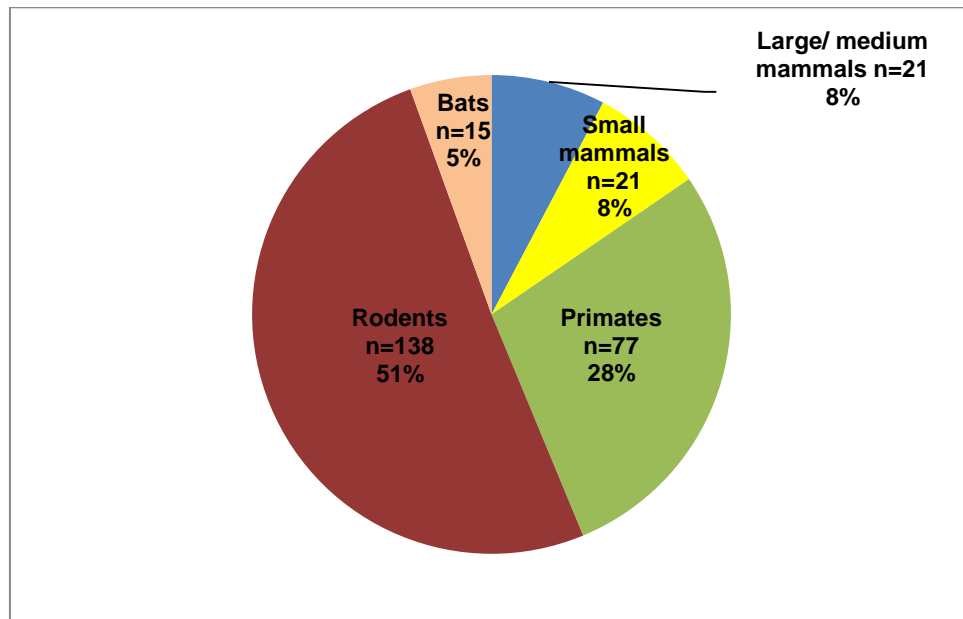


Figure: 5.1 Percentage kills of different groups of mammals on a 9 km section of NH-7.



Figure: 5.2a Road kills of large and small mammals on NH-7 along Pench Tiger Reserve.



Figure: 5.2b Road kills of medium and small mammals on NH-7 along Pench Tiger Reserve.

Most of the species killed are listed as protected species under Wild Life Protection Act, 1972 and command high conservation importance (Table 5.2). According to IUCN (2008), sambar (*Rusa unicolor*) is already listed under the

category 'Vulnerable' because of current threats of wild meat and antler marketing in South East Asia.

Table: 5.2 List of mammal species killed on National Highway -7.

Common name	Scientific name	Family	Percentage of taxa	WPA status	IUCN status
Chital	<i>Axis axis</i>	Cervidae	2.21	Schedule III	Least Concern
Common palm civet	<i>Paradoxurus hermaphroditus</i>	Viverridae	1.84	Schedule II	Least Concern
Grey mongoose	<i>Herpestes edwardsii</i>	Herpestidae	0.37	Schedule II	Least Concern
Hanuman langur	<i>Semnopithecus entellus</i>	Cercopithecidae	8.46	Schedule II	Least Concern
India hare	<i>Lepus nigricollis</i>	Leporidae	1.84	Schedule IV	Least Concern
Indian Fox	<i>Vulpes bengalensis</i>	Canidae	0.37	Schedule II	Least Concern
Indian Porcupine	<i>Hystrix indica</i>	Hystricidae	0.37	Schedule IV	Least Concern
Jackal	<i>Canis aureus</i>	Canidae	0.74	Schedule II	Least Concern
Jungle cat	<i>Felis chaus</i>	Felidae	3.31	Schedule II	Least Concern
Rhesus macaque	<i>Macaca mulatta</i>	Cercopithecidae	19.85	Schedule II	Least Concern
Sambar	<i>Rusa unicolor</i>	Cervidae	0.37	Schedule III	Vulnerable
Striped palm squirrels	<i>Funambulus palmarum</i>	Sciuridae	3.31	Schedule IV	Least Concern
Wild pig	<i>Sus scrofa</i>	Suidae	0.74	Schedule III	Least Concern
Unidentified bat	-	-	5.51	Schedule V	-
Unidentified rodent	-	-	50.74	Schedule V	-

The number of mammal kills varied across seasons as is evident from percentage of road kill during summer (47%), monsoon (31%) and winter (22%). This variation in road kill numbers in the three seasons is positively correlated (Pearson-product moment $r = 0.852$, $p = 0.01$) with variations in traffic volume in summer (3269/day), winter (2951/day), and monsoon (2884/day) Figure 5.3.

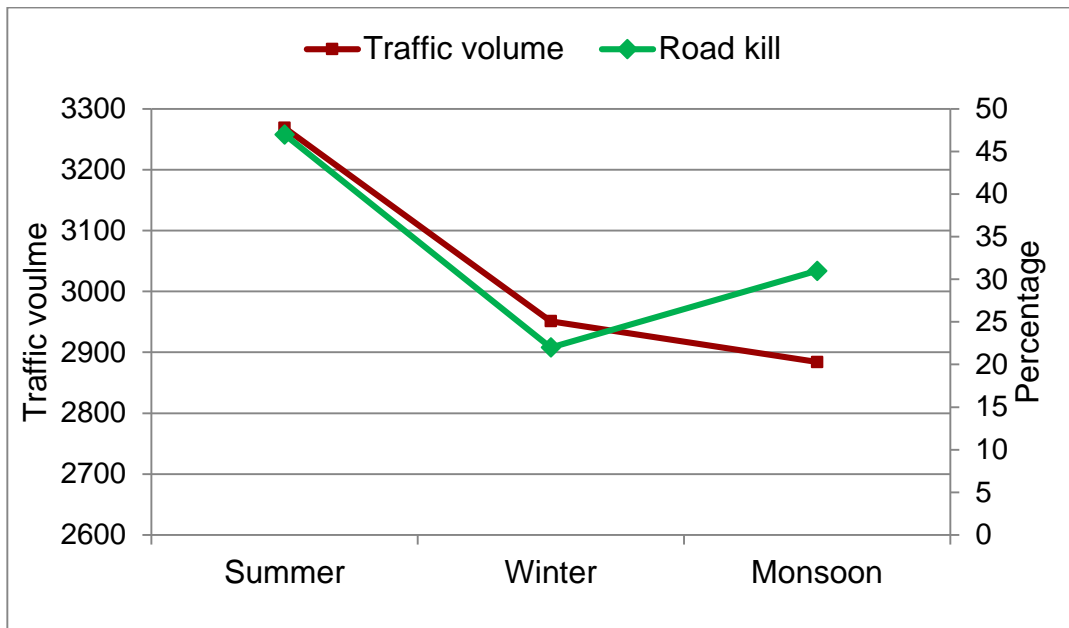


Figure: 5.3 Number of vehicle and percentage of kill on NH-7.

The percentage kill of adult mammals was significantly higher (90%) than other age classes (Chi-square test, $X^2=26.0$, d.f.=14, $P<0.026$). The number of kills of males (41 %) was also significantly higher than the percentage (32%) of females killed (Chi-square test, $X^2=26.0$, d.f.=18, $P<0.009$) (Figure 5.4 & 5.5).

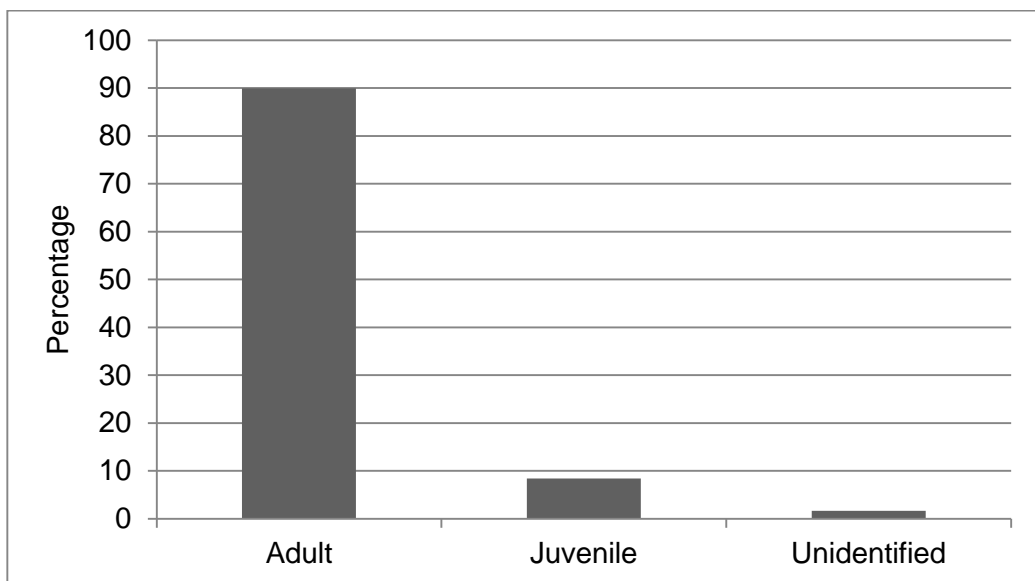


Figure: 5.4 Age of mammals killed on NH-7.

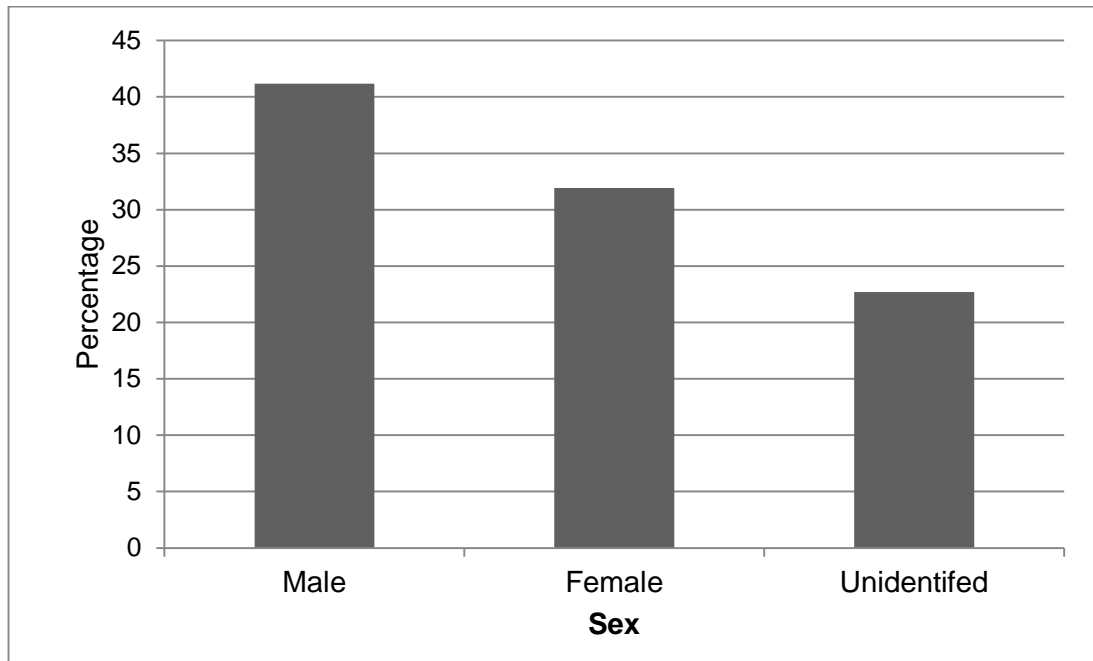


Figure: 5.5 Percentage of sex group of mammals got killed on NH-7.

Prediction of fatality hotspots

The Kernel Density analysis identified the locations of high mortality on different segments of the road (Figure 5.6). Road kill of mammals did not have a random pattern of occurrence, but was spatially clustered on the road. High abundance of fatalities of large and medium sized mammals killed on the road section close to water body. For small sized mammals, fatality clusters occurred nearer to agricultural land (628.900 to 628.700 km) and water source (631.700 to 637.500 km). Fatality cluster of primates also occurred close to agricultural land (636.300 to 635.900 and 627.300 to 627.400 km) and water sources (631.900 to 631.500 km). Mortality of rodents occurred almost on the entire 9 km stretch of road but more clusters occurred in the hill segment (636.300 to 631.400 km). Kills of bats were clustered close to a water source (632.200 to 631.800 km).

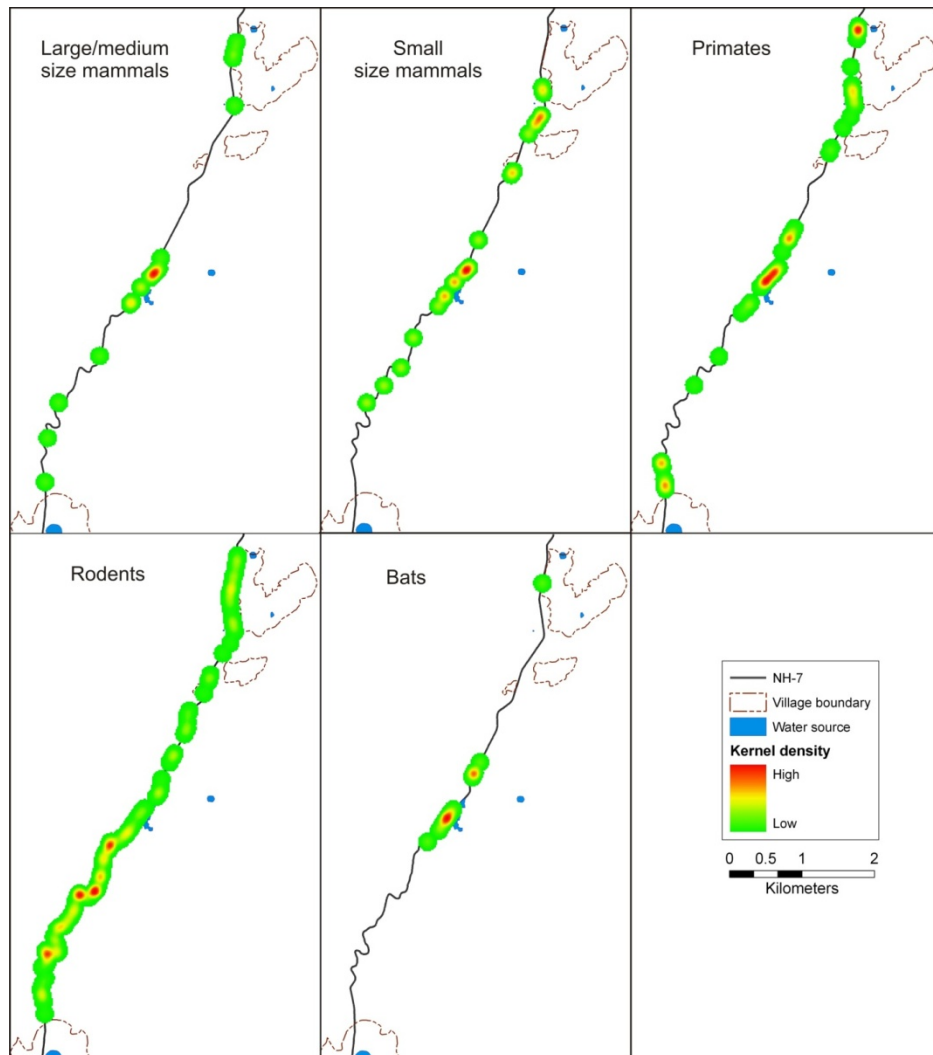


Figure: 5.6 Location of road-induced kills of mammals based on Kernel Density estimation.

Factors influencing the road kills

It can be inferred from the results of this study that road-side topography influence road use by different groups of mammals. In road topography class defined as 'Part Raised' highest number of road-induced kills was recorded of bats (67%), primates (52%), large/medium size mammals (48%) and small size mammals (29%). In the topographic class referred as 'Buried-Raised' the percentage kills of rodents (56%) was highest. In the road section referred to as 'Buried' where the road surface

was lower than the surrounding areas, the overall percentage of road kills of mammals was lowest (Figure 5.7).

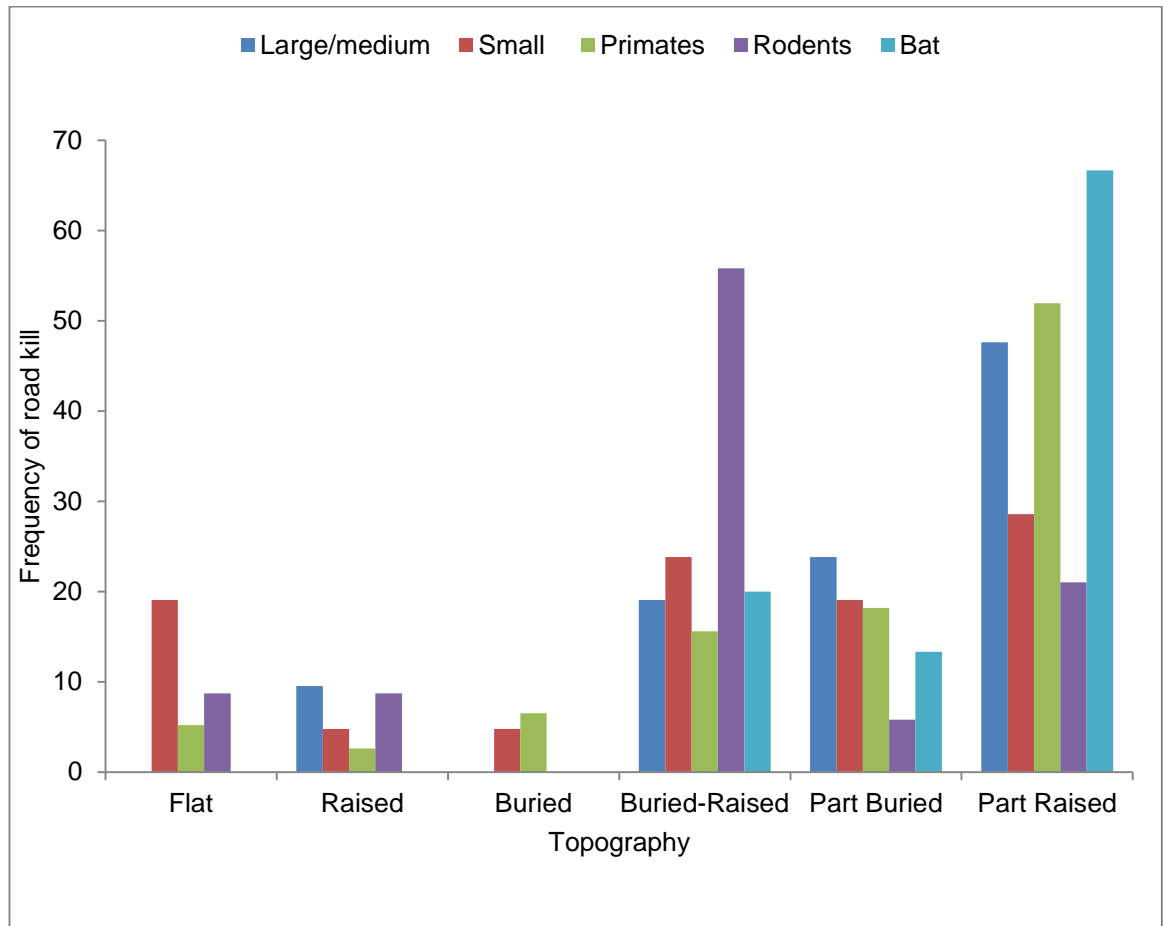


Figure: 5.7 Mortality of mammals groups in different topography.

Road-induced kills based on forest type along the road (Figure 5.8) varied in percentage of large/medium sized mammals (43%), small mammals (52%), primates (39%) and bats (53%) in teak dominant forest. In the road section along the miscellaneous forests, percentage kill of rodents was relatively higher (49%). The lowest number of kills was recorded on road sections passing through scrub forest that represented fairly degraded habitat.

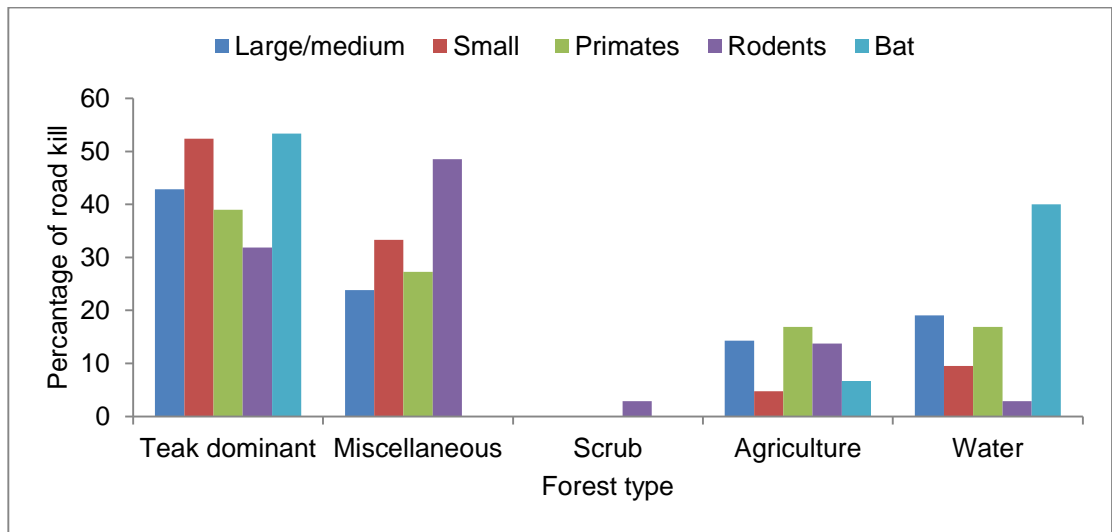


Figure: 5.8 Percentage kill of mammals in different habitat type.

Considering that a range of ecological drivers factors and site characteristics influence the use of roadside habitat and use of road by mammals (Seiler 2001; Clevenger *et al.* 2003; William *et al.* 2018), an attempt was made in this study to identify environmental and road related variables that influenced the road kills of mammals in the 9 km stretch of NH-7. Based on Pearson correlation matrix (Table 5.3), kills of primate are negatively influenced by proximity to water ($r = -0.367$, $P < 0.01$). *Dhudia* pond, the only water source which is located on the edge of the road (632.200 to 631.800) and the human feeding of primates that is encouraged by travellers are the major attractions for primates using the road. Unsuccessful attempts to flee off the busy highway eventually lead to frequent hits of Rhesus macaque by the speeding vehicles (Pragatheesh 2011).

Mortality of bats is negatively influenced by the proximity to water sources ($r = -0.238$, $P < 0.05$). Fruiting trees like Jamun (*Syzygium cumini*) located adjacent to the *Dudhia* pond attracted these animals to fly over the road. Consequently, as many as $n = 10$ bats representing nearly 70% of the total bats collision occurred while flying

across the road. While the road kills of rodents are positively correlated with water and proximity to agriculture area ($r=0.309, 0.400, P < 0.01$ respectively), they are negatively correlated ($r= -0.246, P < 0.05$) to the distance from crossing structures particularly the pipe and box culverts.

Distribution of road-induced kills of large/medium sized mammals and small mammals was largely random as the Pearson Correlation Coefficient of mammal road kill animals did not show any significant correlation with altitude, slope, visibility and distance of kill location from nearest cover, water sources, cultivated areas, drainages and animal passages.

Table: 5.3 Pearson Correlation Coefficient of mammal road kill animals (groups) with the selected variables.

Groups	Variables							
	Altitude	Slope	Visibility	Distance to agriculture	Distance to animal crossing structure	Distance to cover	Distance to drainage	Distance to water
Large / Medium size mammals	0.084	0.033	-0.052	0.110	-0.109	0.070	-0.125	-0.179
Small mammals	-0.019	-0.148	-0.064	0.085	-0.111	-0.031	0.037	-0.172
Primates	0.107	-0.080	-0.014	-0.077	0.016	0.061	-0.036	-.367**
Rodents	0.088	0.151	-0.081	.400**	-.246*	0.139	0.028	.309**
Bats	0.107	-0.122	0.175	0.203	-0.103	-0.046	-0.069	-.238*

*. Correlation is significant at the 0.05 level (2-tailed).

** . Correlation is significant at the 0.01 level (2-tailed).

Key findings

The results of this study lead to the following salient finding:

- A total of 272 road-induced kills of mammals were recorded in 430 days between August 2008 and July 2010 and included 15 species.
- The most vulnerable animal group was rodent accounting for 51% of the total kills of mammals
- The number of mammals kills varied across seasons and is positively correlated with seasonal variations in traffic volume
- The percentage kills of adult mammals was significantly higher (90%) than other age classes and more males are killed when compared to females
- The road kills were spatially clustered
- Factors such as road topography, nearness to water sources and agriculture, volume of traffic and forest type in road corridor influenced the location of kills

Discussion

A total of 272 road-induced kills of mammals were recorded in 430 days between August 2008 and July 2010 and represented 15 species. This translated to 0.70 mammals/10 km/day and illustrates potential magnitude of road related mortality on declining populations of mammals. Estimates of road mortality indicate more mammals being killed than birds. Similar findings were also reported by Burgin and Brainwood (2008) on the highway in New South Wales. According to Barthelmeß (2014) the presence of an ecotone, distance to forest, road width are the primary

factors influence mammalian mortality on roads. The results of the present study emphasize that proportion of a road-kill may not pose serious threats to a variety of species but this may be a significant factor in the overall decline of rodents and primates in the area. The present study highlight taxonomic differences in road kills, with rodents and primates together accounting for nearly 80 % of road-induced kills of mammals on the road section that was studied. Such species specific variation in response to a road have also been recognised by Fahrig and Rytwinski (2009); Benitez-Lopez *et al.* (2010).

This variation in groups of animals experiencing higher percentage of mortality both directly as a result of collision or indirectly while feeding, predating or scavenging could be relative to their body size, reproductive rates, mobility, diet and feeding behaviour (habitat generalists or specialists (Forman *et al.* 2003; Orłowski & Nowak 2004; Camphuysen *et al.* 2010; Rytwinski & Fahrig 2011). Presence of higher number of juveniles and greater abundance of the fauna in some groups could be other factors that may influence percentage of road-induced mortality across seasons (Coelho *et al.* 2008; Smith-Patten & Patten 2008).

Sometimes the behavioural response such as attraction to road for a resource (food water, den sites etc.) which attracts animals onto road irrespective of the traffic makes them more strongly susceptible to road mortality (Morgantini 1996). Many researchers have also discovered that roadkill depends on varying resources, such as standing water during wet cycles, and life history, such as dispersal, hibernation or foraging patterns (Davies *et al.* 1987; Main & Allen 2002; Saeki & Macdonald 2004). These observations suggest that the reasons that animals are killed by vehicles are driven mostly by the spatial arrangement of resources. Animals die

when they are struck while trying to reach resources. As heavy traffic volume near habitats influence the probability of the roadkills, the adjacent trees, landscape, slope along the road are also probable factors for road kill (Shyh-Chyang 2016).

In the present study, primates constitute 28% of total kills of mammals (n =77). Collisions of Rhesus macaque (*Macaca mulatta*) and Hanuman langur (*Semnopithecus entellus*) to the order of 20 % and 8% respectively occurred because of human feeding associated with passersby travelling on the road attracting the animals onto the road and collision with large number of vehicles (2884 to 3269 vehicles/day) moving in that stretch (Pragatheesh 2011). From our study, it becomes evident that rodents being nocturnal animals are active during night time and because of poor visibility are often run over by vehicles. These animals with low body mass and feeding behaviour that attracts them to road make them most vulnerable. Ford and Fahrig (2007) also found that mammals of about 1.06 kg body mass were more frequently encountered in road-kill surveys. Although vehicular traffic intensity and speed of vehicles particularly in the night traffic are known to influence road kills, Seiler (2003); Lesinski (2007); and Coelho *et al.* (2008) recognise that relationship between traffic volume and road kill may not be always be linear as higher traffic may also increase barrier effect and reduce the attempts by the animals to cross the road.

In the present study, the number of road kills do not coincide with traffic volume peaks on a daily basis because many of the species may tend to either avoid roads when the traffic volume is high (Waller & Servheen 2005; Dodd *et al.* 2006) or because some species would have crossed the road successfully. The study however illustrates a positive relationship between wildlife collisions and traffic volume across

seasons as is clearly reflected in seasonal fluctuation in road kills and traffic volume in different seasons (Pearson-product moment $r = 0.852$, $p = 0.01$). Similar observations have been also reported from other studies on mammals (Clarke *et al.* 1998; Alexander *et al.* 2005; Orłowski & Nowak 2006). During summer, when the highest number of vehicle ($n=3269/\text{day}$) were observed on the road, 47% of the road kills were recorded. Breeding and dispersal activities of mammals during summer season make them susceptible to road mortality (Clevenger *et al.* 2003). Further, during summer, when the water becomes a limited resource in the forest interior, the artificial waterholes close to the roadside attract mammals to use the roadside habitat, thereby, making them more prone to the collisions with the speeding vehicles.

The relationship between traffic volume and the number of recorded road-kills could be also affected by population dynamics, distribution and animal abundance (Groot & Hazebroek 1996; Messmer & West 2000; Putman *et al.* 2004; Bright *et al.* 2015; Santos *et al.* 2018). The higher percentage of rodent kills could be associated with their greater abundance in the area when compared to other animals groups such as large ungulate species (e.g. Sambar, Chital and Gaur) or small mammals (e.g. porcupine).

On the other hand, the road mortality of some animals may not be necessarily linked to their abundance (Lesinski 2007). For bats in particular, the kills may not be influenced by their actual abundance in the habitat, but on the flight path and height above the ground level and on where the animal may have landed after the collision with the vehicle. Gaisler *et al.* (2009) based on the study of bat casualties on the highway in Austria, believed that the bats knocked down on the road and thrown off

the road into adjacent vegetation may not have been included in the count of casualties.

Most large mammals (sambar, chital, gaur) in this stretch of NH-7 are confined within the Pench Tiger Reserve and the Reserved Forest of the South Seoni Territorial Division that adequately meet habitat requirements in terms of food, cover, space and water. Only few species (eg. chital, wild pig) that are attracted to use road verges because of light, openness of cover, forage and browse availability become victims of speeding vehicles. This explains 2.2% of road kills contributed by chital (n=6) to the overall low percentage of road-induced kills on the NH-7 in the stretch studied. This argument also draws support from the study by Morgantini (1996) which explains that the thriving plant communities resulting from the increased sunlight can provide valuable food resources for herbivores which take advantage of shrub species that proliferate along the edges of linear features.

Significant cause of Jungle cat road kills (3.3%, n=9) could be their movements on and across road for hunting rodents. Carnivores and predators are attracted to the abundant prey found along the edges of linear features. The road or trail becomes a sink when the predators are also exposed to higher levels of mortality as a result of both direct and indirect causes (Forman *et al.* 2003; Barrientos & Bolonio 2009) also observed that polecat road mortality was influenced by the presence of prey next to the road.

Road mortality is undoubtedly the most conspicuous impact of roads upon wildlife (Litvaitis & Tash 2008; Santos *et al.* 2011) and has been well studied (Clevenger *et al.* 2001, 2003). When selecting the best places to locate mitigation measures, a description of the patterns and covariates of road-induced mortality

becomes relevant factors (Gunson *et al.* 2011; Markolt *et al.* 2012). There is enough evidence in support of the argument that topographical features of the road, landscape and habitat characteristics of the surrounding area are important determinants of spatial and temporal patterns of road kills (Clevenger *et al.* 2003; Jaarsma *et al.* 2007; Beaudry *et al.* 2008; Barrientos & Bolonio 2009; Gomes *et al.* 2009; Grilo *et al.* 2009). In addition, road characteristics have been reported to directly influence rates of animal– vehicle collisions (Forman & Alexander 1998; Grovenburg *et al.* 2008; McShea *et al.* 2008; Ng *et al.* 2008) reported that topographic and vegetative features in proximity to a road influenced habitat use and movement patterns of deer. According to Clevenger *et al.* (2003), cover near the road can impede a driver’s ability to see wildlife and an animal’s ability to see the roadway and therefore cover distance is considered as an important determinant of vehicular collisions of mammals in general. Smith (1999, 2003) carried out an extensive spatial analysis of road kill in Florida and provided planning and design options for mitigating vehicle-wildlife collisions patterns based on assessment of animals distribution and movement patterns and road ownership issues.

In this study, kernel Density estimates highlight that road kills of the mammals are spatially clustered. Other variables such as road topography, roadside habitat features, terrain, water availability, distance to culverts and distance at which the kill location is visible also influenced spatial distribution of road kills. The findings of the present study illustrate that mortality hot spots could be clearly identified for different groups of mammals on the 9 km stretch of the road. High abundance of fatalities of large and medium sized mammals occurred on the road section closer to water body. Kernel Density estimates (Figure 5.6) indicate that

mortality clusters of large/medium and small sized mammals occur in proximity of water source and agriculture area. Several other studies have highlighted that mammals that are attracted to water and food source along the road are more susceptible to road-induced direct and indirect mortality (Newmark *et al.* 1996; Taylor & Goldingay 2004). According to Barthelmess (2014), two landscape variables, distance to cover and the presence of an ecotone, as well as one road variable, road width, appeared as broadly important predictors of mammalian road mortality, though there was also species specific variation in factors that increased the risk of MVCs.

Our observation support that in the road sections where the road surface that is partly raised (one side flat, one buried) is a death trap for large/medium size mammals with total kills accounting for as much as 70% of mortality. The partly raised topography provides easy access for the animals from Pench Tiger Reserve that are then unable to move down slope after crossing the road because of the steep slope. Fatality clusters of primates occurred close to water body and agricultural land. Road kills of primates are negatively influenced by the proximity to water source ($r = -0.367$, $P < 0.01$). Rhesus macaque and Hanuman langur were often killed on the road section close to *dhudia* lake and the temple (*Banjarimai*) where large number of devotees visiting the temple offer food to the primates (Pragatheesh 2011).

Several other studies support that road-induced mortalities are not random in their occurrence but are spatially clustered (Puglisi *et al.* 1974; Hubbard *et al.* 2000; Joyce & Mahoney 2001; Clevenger *et al.* 2003; Ramp *et al.* 2006; Markolt *et al.* 2012). Mortality of rodents occurred almost on the entire 9 km stretch of road but more fatality clusters occurred in the hill segment. More mortality clusters of rodents

occurred in the hilly section of the road. In the section characterized by Buried-Raised topography, the highest percentage of road kills (56%) was recorded. The higher incline of the road on one side perhaps limited the ability of the rodents to get onto the road surface and once they get there, it became difficult to get off the road because of the elevated surface on the hill side of the road. Lambert *et al.* (2006) also observed in tropical Amazonia that rodent abundance was related to the roadside habitat features. While the road kills of rodents were positively correlated with water and proximity to agriculture area ($r=0.309$, 0.400 , $P < 0.01$ respectively), they were negatively correlated ($r = -0.246$, $P < 0.05$) to the distance from crossing structures particularly the pipe and box culverts. The mortality of some rodents (mouse, shrews and porcupines, moles) on road along agricultural areas can sometimes also be a result of the seasonal increase in farming activities and the movement of rodents on roads when they are flushed out from agricultural areas or granaries (Rolley & Lehman 1992; Jacob & Hempel 2003). In similar studies in Portugal (Grilo *et al.* 2015), observed that the traffic volume is not the significant factor for road kills as compared to other animal movement parameters.

It is inferred from our study that bats are negatively correlated to the water source ($r=-0.238$, $P < 0.05$). The mortality clusters of bats were limited to specific segments of the road nearer to the location of the water body. As bats generally tend to orient themselves in the landscape with the aid of tall vegetation cover, they often fly along linear elements of the landscape such as roads (NRA 2004) and collide with vehicles when they move from one roosting or feeding area to another. Bats prefer moist and deciduous forests with old trees and water streams (Niermann *et al.* 2007; Luean *et al.* 2009) especially during night time (Gaisler *et al.* 2009). Fruit trees and

other food resources such as insects on the road near the water body (*Dudhia* pond) mostly attracted bats to fly above the road to utilize the roadside habitat resulting in their collision with vehicles. Other studies also supports that roads built through or near wetlands, water courses and ponds are especially significant source of mortality for mammals. Roads through or adjacent to wetlands, ponds, and other waterways have some of the highest road-kill rates (Forman & Alexander 1998; Guter *et al.* 2005).

The influence of habitat cover and movement corridors in proximity of the roadside is known to influence the rates of direct collisions with vehicles (Hodson 1962; Forman *et al.* 2003; Bellis & Graves 1971; Bennett 1991; Clevenger *et al.* 2003). In the present study, significant mortality of large/medium (43%), small (52%), primates (39%) and bats (53%) occurred in the road section along teak dominated forest while higher percentage mortality of rodent (49%) occurred in miscellaneous forest. Early studies by Hodson (1962); Bellis and Graves (1971); Clevenger *et al.* (2003) also recorded higher number of road kill in the wooded area or dense cover adjoins both sides of a road. Based on another study (Forman & Alexander 1998), the vicinity of a large natural-vegetation patch and the area between two such patches are the factors that can influence the road kill locations for foraging or dispersing animals. In a multi-scale spatial analysis where the spatial and temporal parameters are analyzed it is observed that 1) higher vehicular mortality of a particular species may result in the decline of its population, 2) a decrease of the functional role of these native species, 3) the importance of the study of the spatial and temporal scales to conserve the wildlife from vehicular collisions (Kazemi *et al.* 2016).

Recommendations for mitigation of impacts

Ideally, mitigation measures must be designed to deliver results that ensure mitigation success based on criteria that are convincing, well recognized and are measurable. The criteria to achieve ecological goals for securing long term conservation benefits require comprehensive approach to address both, barrier and mortality effects (Figure 5.9).

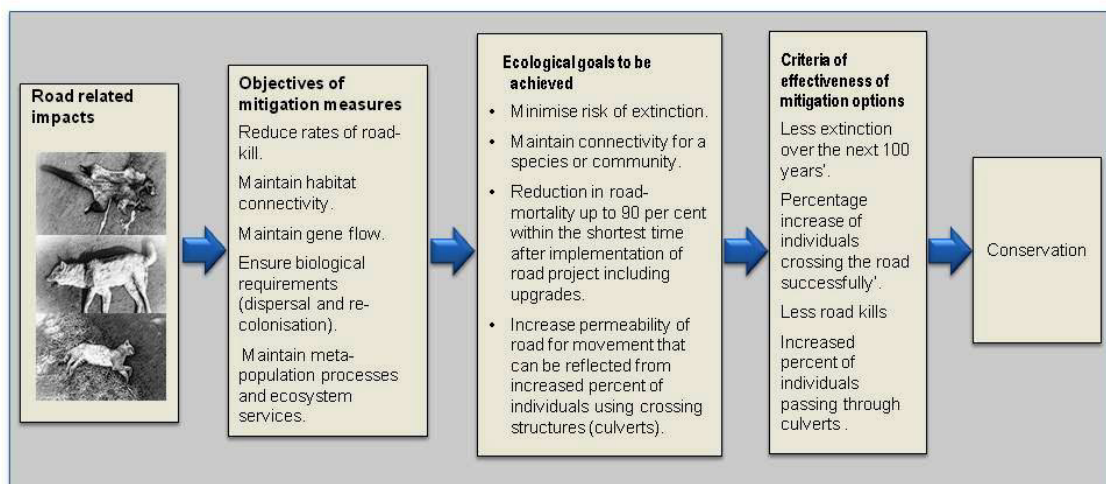
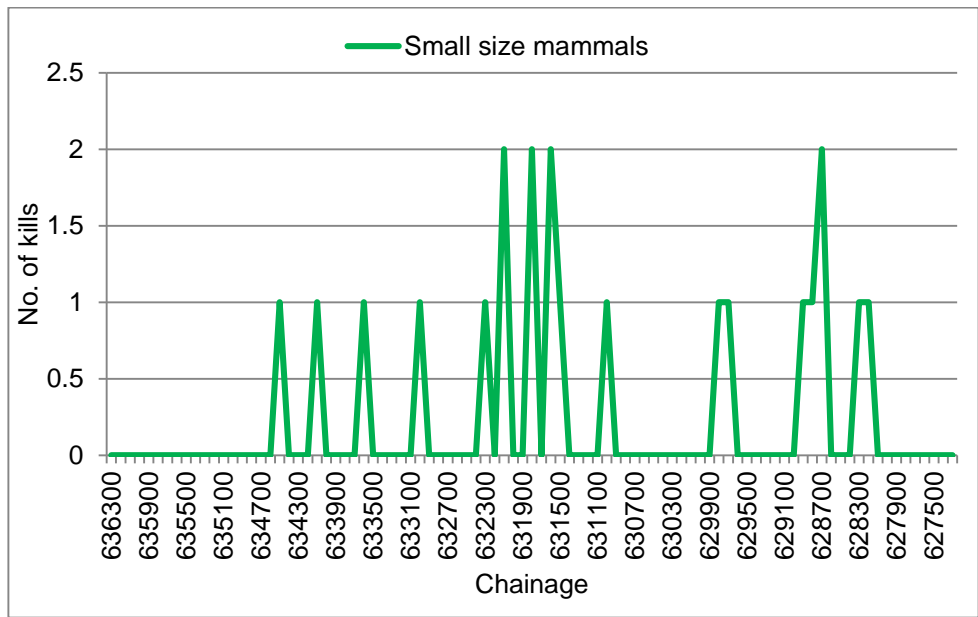
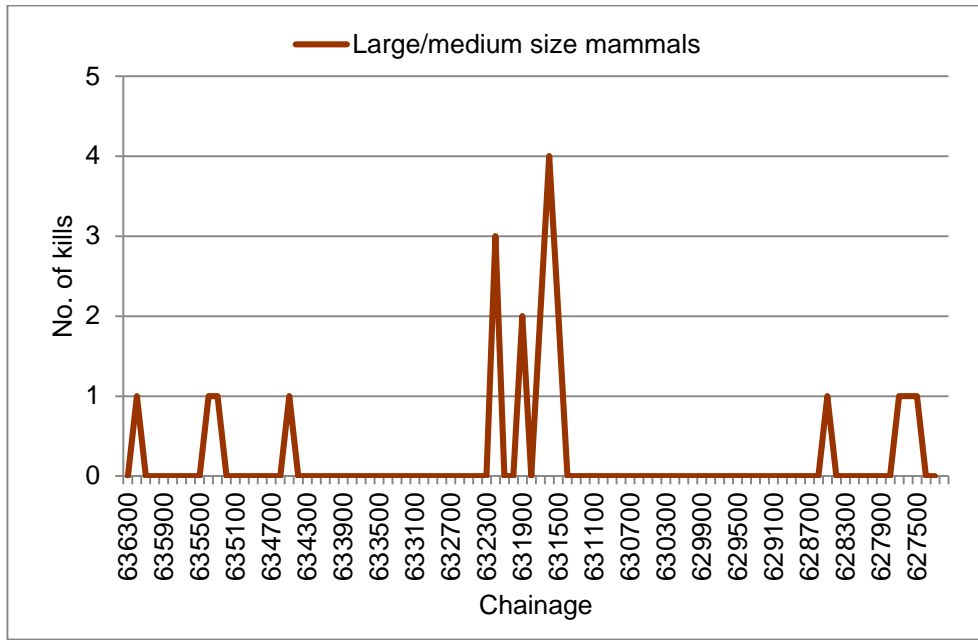
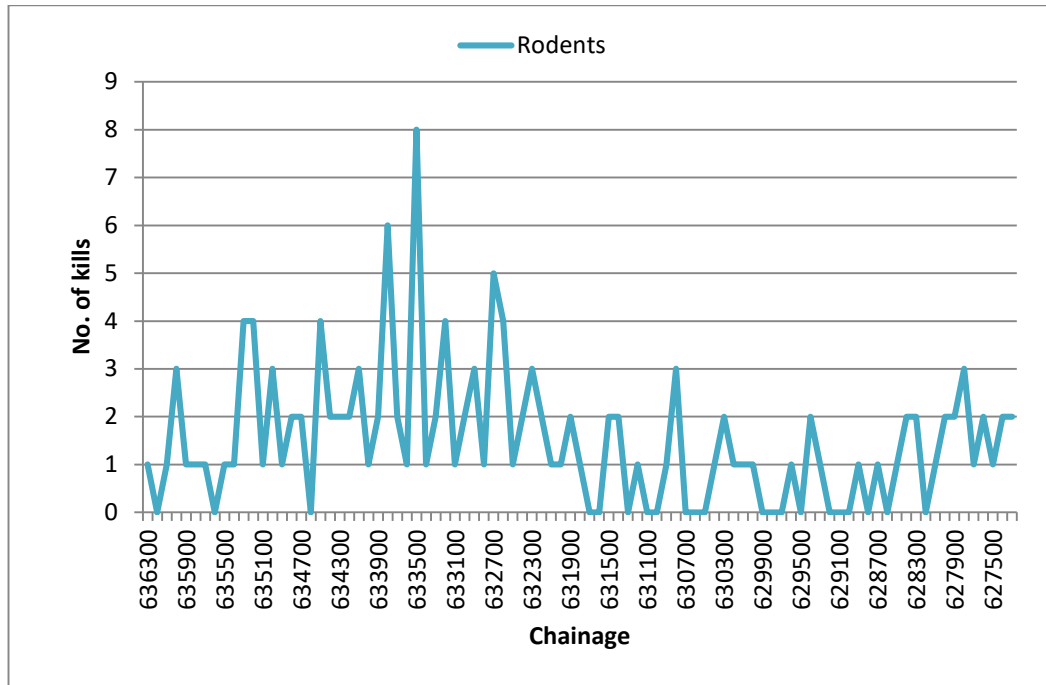
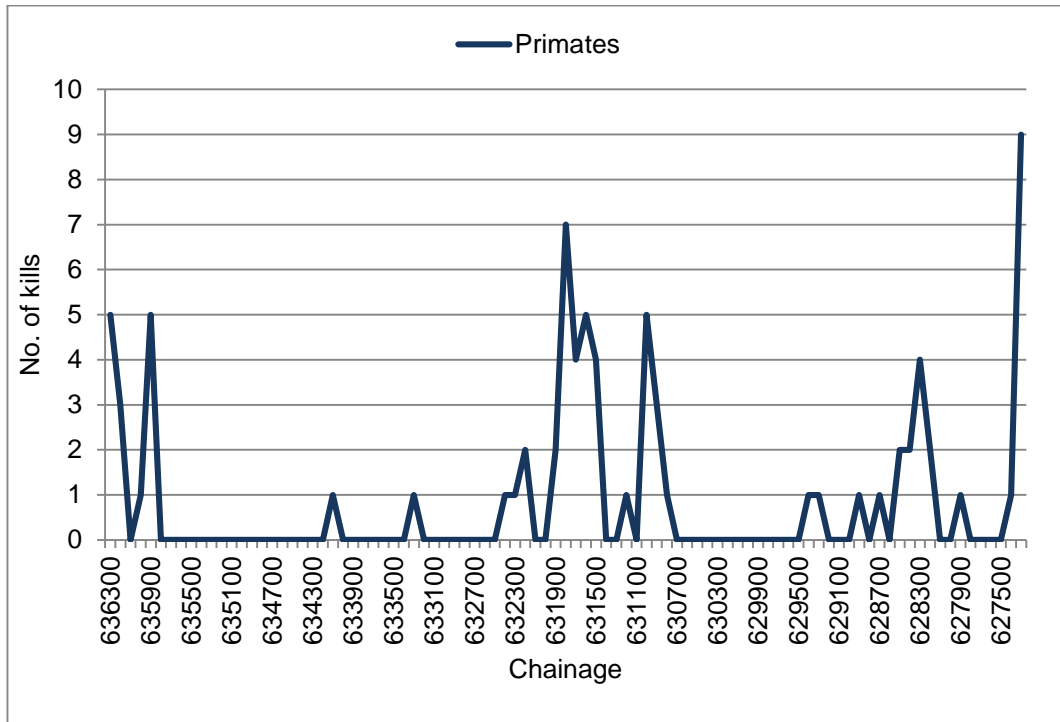


Figure: 5.9 Criteria to achieve ecological goals for securing long term conservation benefits.

The present study clearly illustrates that road related direct and indirect mortality of NH-7 can be a major source of impacts on a wide variety of mammal species even in its present state of a two-lane road (Figure: 5.10). The focus of this section of the chapter is therefore restricted to proposing measures to reduce road-induced mortality of animals on NH-7 based.





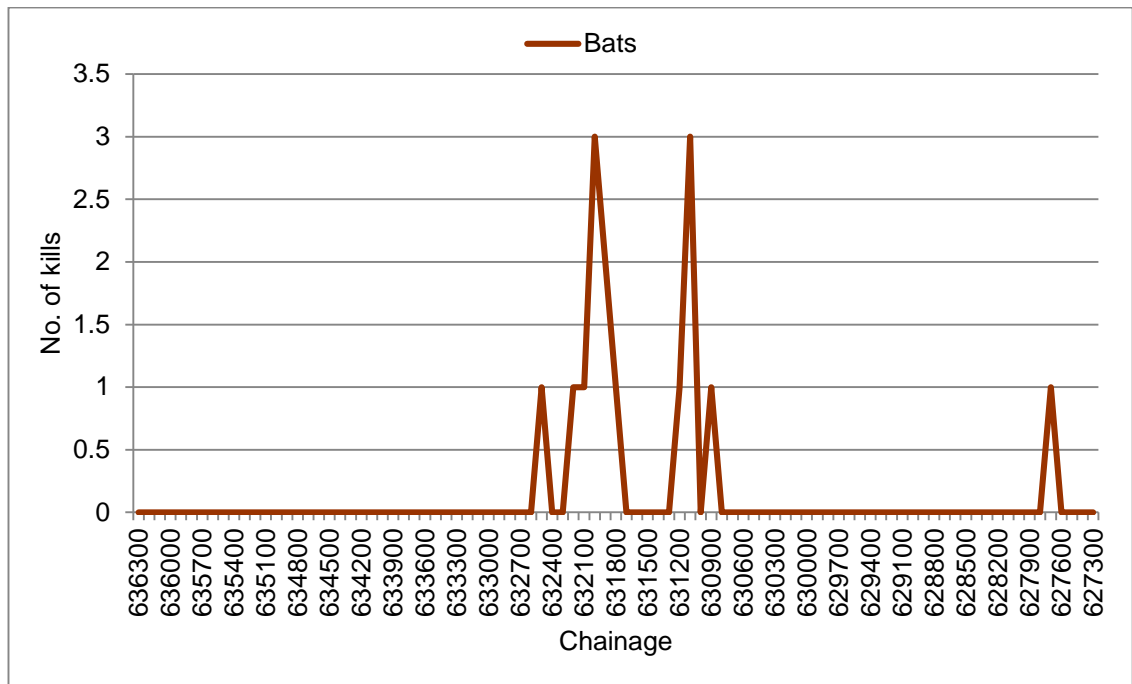


Figure: 5.10 Assessment of road related mortality of different groups of animal on NH-7 based on the count.

These mitigation measures are being proposed with an objective to achieve at least two important and measurable conservation outcomes- increased population viability and significant reduction in road-induced mortality of animals to prevent consequent decline in their populations in the long term. The effectiveness of the constructed structures like crossing pathways or fencing remains inconclusive due to the lack of analysis before and after the construction (Rytwinski *et al.* 2016). The evaluation of traffic volume with relation to animal behaviour and landscape connectivity needs to be understood before investing in the appropriate construction (Jacobson *et al.* 2016). The recommended options would essentially fall in one of the two categories: (i) regulatory or prescriptive measures that are like to alter human behaviour and (ii) on- site habitat management (Figure 5.11) that are likely to influence animal adaptations.

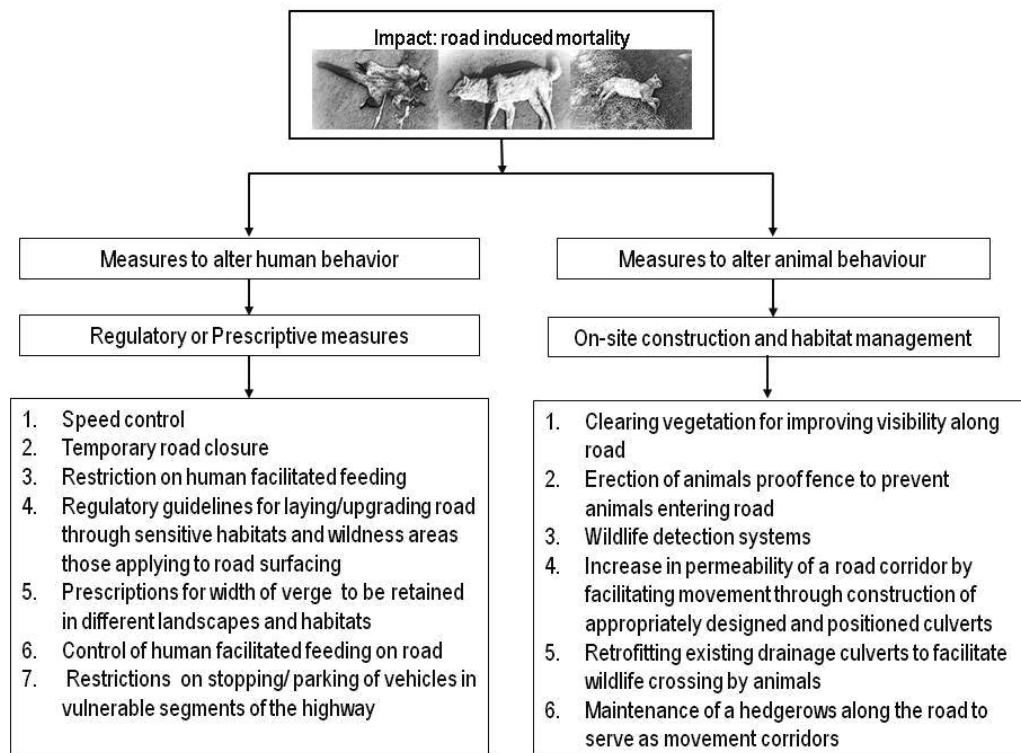


Figure: 5.11 Mitigation approaches recommended for addressing road related mortality of animals.

The specificity of the animal groups, details of actions proposed and the sections of road where these would be applied is presented in Table 5.4. The ultimate success of these mitigation measures will however depend on compliance by road building agencies, monitoring by and decision makers and validation of the long term benefits for conservation by the conservation community.

Table: 5.4 Mitigation option suggested for different group of mammals.

Animals group	Vulnerable sections of road (km)	Factor influencing mortality	Mitigation option
<p>Large and medium sized mammals (e.g. Chital, Sambar, Wild pig, Indian fox, Jackal, Jungle cat)</p>	<p>631.700 to 637.500</p>	<p>Water sources, forage and browse availability along the road, prey availability and topography</p>	<ul style="list-style-type: none"> • Speed calming measures along with regulatory controls on traffic movement on the highway • Clearing vegetation for improving visibility along road. • Managing road verges to provide adequate resources to distract animals from crossing roads. • Managing roadside vegetation for optimum benefits of unobstructed view of animal along the road for the drivers • Fencing, designed to keep ungulates and carnivore species off roads • Wildlife detection systems • Increase in permeability of a road corridor by facilitating movement through construction of appropriately designed and positioned under passages
<p>Small mammals (e.g. common palm civet, Grey mongoose, Indian hare, Indian porcupine, Striped palm squirrels)</p>	<p>628.900 to 628.700; 631.700 to 637.500</p>	<p>Food resources, proximity to agricultural areas that provide food</p>	<ul style="list-style-type: none"> • Speed breakers for calming speed. • Clearing of vegetation. • Erection of animals proof fence to prevent animals like civet and mongoose to get onto the road and placement of tunnels

			<p>to facilitate movement of hare and squirrel.</p> <ul style="list-style-type: none"> • Retrofitting existing drainage culverts to facilitate wildlife crossing by animals
Primates	<p>636.300 to 635.900</p> <p>627.300 to 627.400</p> <p>631.900 to 631.500</p>	<p>Food resources</p> <p>Fruits, and insects around water point</p>	<ul style="list-style-type: none"> • Speed break • Control of human facilitated feeding on road • Restrictions on stoppages/ parking of vehicles in vulnerable segments of the highway.
Rodents (e.g. Mouse, moles and shrews)	<p>631.900 to 631.500</p>	<p>Resources such as water and proximity to agricultural areas that provide food (grains and seeds).</p>	<ul style="list-style-type: none"> • Increase in permeability of a road corridor by facilitating movement through construction of appropriately designed and positioned under passages
Bats	<p>632.200 to 631.800</p>	<p>Food resources such as fruits, and insects around water point,</p> <p>Connectivity of habitats</p>	<ul style="list-style-type: none"> • Use of close planting of tall vegetation to encourage a higher flight line • Use of lighting to inhibit bat entry onto vulnerable sections of the road • Maintenance of a hedgerows along the road to serve as movement corridors • A green bridge planted with trees may be useful in guiding bats over roads to cross close to well-established commuting points.

Chapter 6. Impact of road on mortality of birds and proposed mitigation measures

Introduction

Birds are excellent flagships and vitally sensitive indicators of environmental pollution in terrestrial and aquatic ecosystems (Gaston 1974) and play a significant role in biodiversity conservation. Birds are very significant denizens of both aquatic and terrestrial ecosystem as they play a vital role at various trophic levels of the food chain. They also play a significant role in maintaining the floral species composition of a given habitat by means of dispersion (Pejchara *et al.* 2008). The places that are rich in bird species are also rich in other forms of biodiversity. For conserving the avian community their habitats needs to be conserved. Hence, an integrated approach is required towards conserving them which would yield better results.

Expansion and upgrades (single lane to multiple lanes) of roads is being increasingly recognized as a national priority for improving connectivity and economic development in most countries including India (Pradhan & Bagchi 2012). At the same time, such developments are often inimical to biodiversity conservation as habitat reduction and animal mortality associated with roads together pose the greatest threats for conservation of many wildlife species in linearly fragmented habitats.

The landscapes traversed by roads significantly affects the biology of birds (Raty 1979; Reijnen & Foppen 1994; Reijnen *et al.* 1995; Ramsden 2003). Many studies demonstrate that roads can induce diverse negative impacts on bird communities (Bennett 1991; Forman & Alexander 1998; Spellerberg 1998). More specific impacts include high mortality of birds due to road hits (Mumme *et al.* 2000), changes in distribution patterns of breeding birds due to persistently high noise of

vehicular movement on busy road sections (Reijnen *et al.* 1995; Kuitunen *et al.* 1998; Peris & Pescador 2004; Hoskin & Goosem 2010), barrier-effects preventing the normal movements of birds across habitats that become disconnected by roads (Bélisle & St. Clair 2001) and lower reproductive success generally associated with disturbance due to increased human access (Trombulak & Frissell 2000).

Road hits of birds affect a greater number of individuals in the population when compared to other factors such as predation (Bujoczek *et al.* 2011) and hunting (Forman & Alexander 1998). Studies on road hit birds have been conducted in **Africa** (Dean & Milton 2003; Kioko *et al.* 2015); **Australia** (Taylor & Mooney 1991; Clancy 2004; Taylor & Goldingay 2004; Kofron & Chapman 2006; Ramp *et al.* 2006; Fulton *et al.* 2008; Parris & Schneider 2009); **South America** (Cuyckens *et al.* 2016; Monge Nájera 2018); **Brazil** (Bencke & Bencke 1999; Develey & Stouffer 2001; Coelho *et al.* 2008; Rosa & Bager 2012; Costa *et al.* 2015; González-Suárez *et al.* 2018). **Canada** (Ogden 1996; Eberhardt 2009; Summers *et al.* 2011; Bishop and Brogan 2013). **Europe** (Dunthorn & Errington 1964; Hernandez 1988; Pons 2000; Erritzoe *et al.* 2003; Helldin and Seiler 2003; Ascensao & Mira 2005; Orłowski 2005; Varga *et al.* 2006; Gryz & Krauze 2008; Gomes *et al.* 2009; Bujoczek *et al.* 2011; Collinson *et al.* 2014; Husby 2016, 2017; Schwartz *et al.* 2018; Tejera *et al.* 2018; Vidal-Vallés *et al.* 2018). **North America** (Loos & Kerlinger 1993; Bencke & Bencke 1999; Mumme *et al.* 2000; Develey & Stouffer 2001; Bard *et al.* 2002; Clevenger *et al.* 2003; Erritzoe *et al.* 2003; Erickson *et al.* 2005; Jacobson 2005; Boves 2007; Huijser *et al.* 2007; Loss *et al.* 2014); **Asia** (Özcan and Özkazanç 2017; Monge Nájera 2018; Toyran *et al.* 2018; Lake Van Akrim *et al.* 2019).

In India bird hits on road was first reported by Dhindsa *et al.* (1988), which was subsequently followed by studies conducted by Chhangani (2004); Sundar (2004); Baskaran and Boominathan (2010); Prakash (2012); Sathish-Narayanan *et al.* (2016); Solanki *et al.* (2016); Rawankar and Wagh (2018). Most of these studies are however limited to the study of road kills and inventorising the number of species killed.

This study attempts to assess the road-related mortality of birds in the 9 km section of National Highway (NH)-7 along Pench Tiger Reserve. The study aims to (i) Determine the spatial distribution of road kills. (ii) Evaluate the factors influencing the mortality of birds. (iii) Explore measures to prevent and reduce the road induced mortality of birds to ensure the long term conservation of the birds in this landscape.

Methodology

Road kill data collection

The 9 km length road was surveyed for a total of 430 road cruising days spread across three seasons: monsoon (n=147), winter (n=143) and summer (n=140) between August 2008 to July 2010 following the standard road cruising methods adopted for vertebrates (Ashley & Robinson 1996; Clevenger *et al.* 2003; Langen *et al.* 2007). On each day of the survey, vehicular transect was conducted both, at dawn (0530–0630 hrs) and dusk (1730–1830 hrs) at a speed between 10 and 20 km/hr with two observers. The time spent during the single transect depended on the road kill number and weather conditions. It lasted normally from 1.5 to over 2 h. The survey resulted in a total effort of 3870 km. On encountering a road kill, carcass were identified to species level and information regarding the state of the road kill, location (Universal Transverse coordinates with a Global Positioning System receiver), roadside habitat feature and

the road segment were recorded. All dead carcasses were removed from the road to ensure that there was no double count during subsequent survey. As explanatory factors of road-kills vary widely between feeding habit and body size of birds (Sundar 2004; Gunson *et al.* 2011), it was important to understand such factors to be able to describe the spatial pattern of road-kill aggregations. Accordingly, provisional division of the bird fauna killed on road was made into five feeding guilds: (i) carnivore, (ii) frugivore, (iii) granivore, (iv) insectivore, (v) omnivore, as per Ali and Ripley (1989). The bird kills were also grouped based on body size.

Data on average traffic volume on the road section passing along the Pench Tiger Reserve was generated based on continuous recording of the number of vehicles over a period of twenty four hours for three days per season. Total number of two wheelers, passenger cars, heavy vehicles, trucks and lorries moving on the road was recorded. Data on traffic was collected on week and non-week days and market days to capture any variations in traffic volume on different days.

Prediction of fatality hotspots

We used Kernel Density Method to identify the fatality hotspots on the 9 km section of the road (Gitman & Levine 1970). Kernel method is one of the most popular methods for analyzing the point event distribution data (Silverman 1986; Bailey & Gatrell 1995; Özcan and Özkazanç 2017). This method generates a smooth surface map showing point data (kill location) on the basis of which the density of events (road kills per unit area) is determined to provide an estimate of kill concentration. This approach of identifying fatality hotspots provides a useful insight for addressing impacts in such hotspots by various mitigation strategies (Ramp *et al.* 2005, 2006;

Gomes *et al.* 2009). The area of influence or a bandwidth chosen for this study was 200 m. The kernel estimation for species fatalities was done using the Spatial Analyst Toolbox of ArcGIS 9 version (ESRI 2004). Zero values were omitted to avoid confusion between zero density and no data.

Factors influencing the road hit

When a vehicle approaches, the birds can fly away, although this is not always applicable. Some of the species are at higher risk to vehicular collision, like the owls who hunt for prey near the roads, (Boves & Belthoff 2012), their low flight pattern which brings them to height of the vehicle wind screen (Grilo *et al.* 2012). Some species use the road side water bodies and bushes for food and also the scavenger birds get on to the roads. Grassland birds and ground dwelling birds often have their nests and eggs destroyed from roadside clearing methods, like before the fire seasons (Kociolek *et al.* 2015).

We observed habitat features and land use in areas surrounding all the road kills. Based on the topographical features, the road was categorized into six topographical classes following Clevenger *et al.* (2003). These were (i) road surface raised compared to surrounding landscape, (ii) no slope, (iii) road surface buried relative to surrounding landscape, (iv) one side flat, one buried, (v) one side flat, one side raised and (vi) one side buried, one raised. We created land use land cover classified map were generated using Landsat 7 Thematic Mapper (30 m resolution) acquired on November 2009 (Path: 144, row: 52) downloaded from the USGS archive Global Visualization Viewer (<http://glovis.usgs.gov>). The image was classified into five major cover types spanning across both the sides of the road as (1) Teak dominant,

(2) Miscellaneous, (3) Scrub forest, (4) Agriculture and (5) Water sources. A 50 m buffer was created around each road kill location that was treated as a point in the GIS domain. Information was extracted from classified image on habitat type.

The road was divided into 100 m segment (n=90) for this study and on each segment, spatial data on landscape related variables such as the distance of the kill from the habitation, water body, and drainages were generated using the Euclidean distance method in Arc Info. Average Altitude (meter) and slope (degree) was derived from 30 m resolution Digital Elevation Model (ASTER Global Digital Elevation Model). The distance from the bird kill to the nearest forest cover on both sides of the road was recorded during the survey using a range finder. The optimum distance from where the bird can be best visible to the driver on road was assessed by measuring the nearest distance between the road kill location and an unobstructed view of the approaching vehicle from either side of the highway. Proportion of Normalized Difference Vegetation Index (NDVI) was extracted using Landsat 7 Thematic Mapper. (Table 6.1). Linear regression model was developed to relate the occurrence of road-kills with landscape attributes. In each segment, road hit varied from 0 to 6 road kills. We chose 7 variables to describe site-specific attributes of each road-kill site. We used the SPSS 15.0 version statistical package (SPSS 2006) for all statistical analysis, Arc GIS 9.2 (ESRI 2004) and Microsoft Excel for all other analysis.

Table 6.1 Landscape and site variables and their description used in the analysis.

Variable name	Description	Source
Distance to cover (m)	Distance of the forest edge from the location of the road kill	Field sampling
Distance to drainage (m)	Distance of the road kill from nearest seasonal stream	Euclidean distance(Arc Info)
Distance to habitation (m)	Distance of the road kill from nearest human settlements	Euclidean distance(Arc Info)
Distance to water (m)	Distance of the road kill from the nearest water source (lake)	Euclidean distance(Arc Info)
Elevation (m)	Mean ground altitude of the road (100 m segments)	Digital elevation model
NDVI (value)	Proportion of forest cover	GLCF
Slope (Degree)	Mean ground slope of the road (100 m segment)	Digital elevation model
Visibility (m)	Farthest distance from which the driver can locate a bird on the road vice-versa	Field sampling

Result

Species composition and temporal pattern

A total of 143 bird kills representing 16 species were recorded between August 2008 and July 2010 (430 days) with 3870 km of sampling effort (Figure 6.1a to 6.1b). Most of these bird species provide important ecosystem functions such as pollination, seed dispersal, biological control of pests, regulation of population of invertebrates, reptiles and small mammals (Table 6.2). Maximum number of road kills represented insectivorous birds (35%). These were followed by omnivores 30%, carnivores 21%, frugivores 8% and graminivores birds 6% (Figure 6.2). The number of bird kills varied seasonally, the highest mortality was recorded during summer (52%), followed by 35% of birds killed in monsoon and 13% bird killed in winter. Common myna (*Acridotheres ginginianus*) had the highest number of mortality (n=29) representing 20 % of the total birds killed. This trend was followed by Jungle babbler (*Turdoides striatus*) (n=18) and Indian roller (*Coracias benghalensis*) (n=11) representing 13 % and 11% of the total road kills respectively.



Figure 6.1a Road kills of birds on NH-7 along Pench Tiger Reserve.

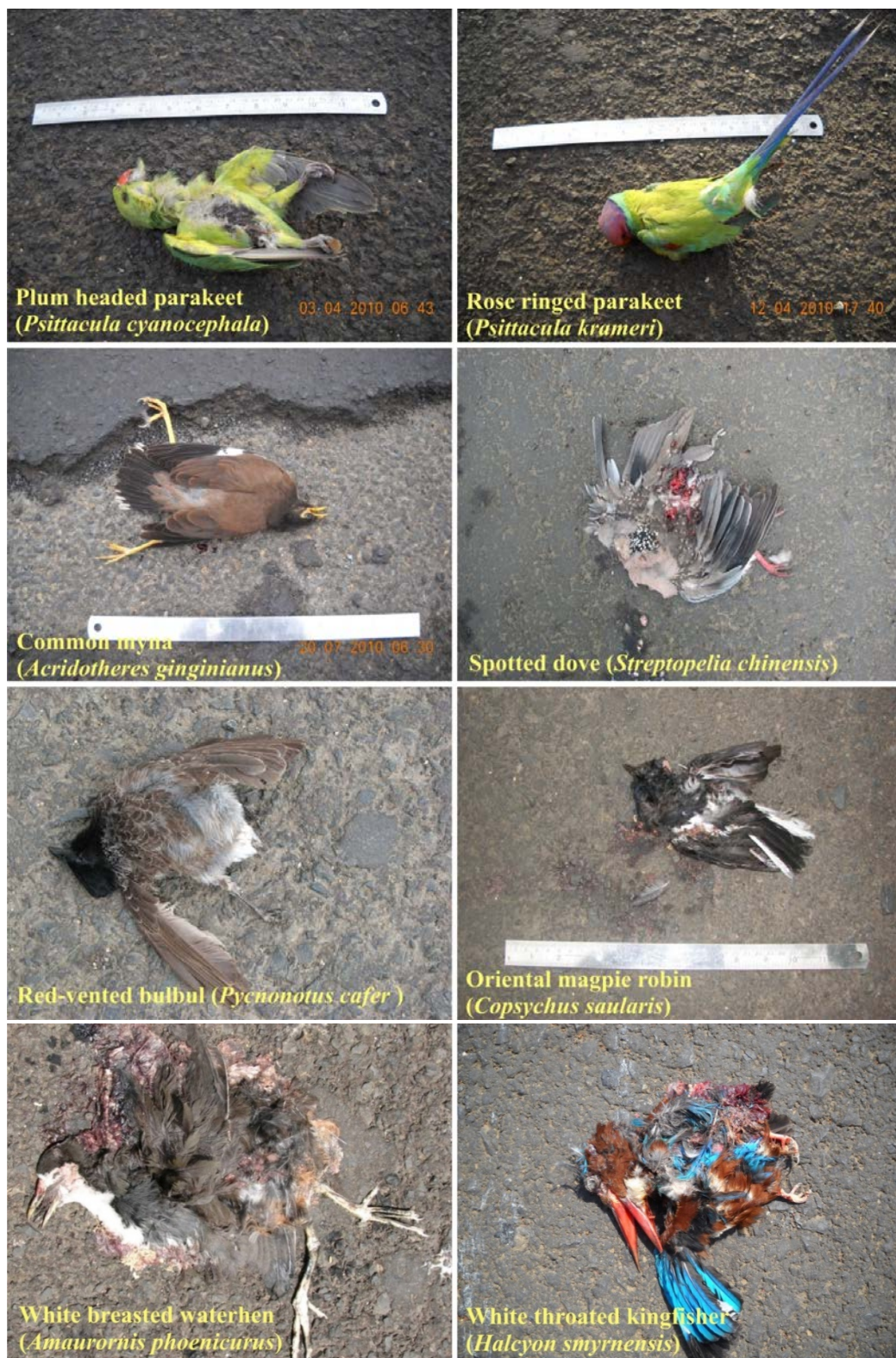


Figure 6.1b Road kills of birds on NH-7 along Pench Tiger Reserve.

Table 6.2 List of bird species killed on National Highway -7 along Pench Tiger Reserve.

Common name	Scientific name	Percentage of taxa	Habitat	Frequency	Status
Asian pied starling	<i>Sturnus contra</i>	3	Tk	U	R
Common myna	<i>Acridotheres ginginianus</i>	20	Tk, Ms, Cc, Os, Cs	C	R
Gray nightjar	<i>Caprimulgus indicus</i>	3	Tk, Ms, Os, Cs	C	R
Greater racket tailed drango	<i>Dicrurus paradiseus</i>	1	Tk, Ms, Bm	C	R
Indian roller	<i>Coracias benghalensis</i>	11	Tk, Ms, Cs	C	R
Jungle babbler	<i>Turdoides striatus</i>	13	Tk, Ms, Bm, Cc, Os	C	R
Jungle owlet	<i>Glaucidium radiatum</i>	10	Tk, Ms, Bm, Cc, Os	C	R
Large billed crow	<i>Corvus macrorhynchos</i>	2	Tk, Ms, Bm, Gr, Os, Cs	C	R
Oriental magpie robin	<i>Copsychus saularis</i>	3	Tk, Cc, Os	C	R
Plum headed parakeet	<i>Psittacula cyanocephala</i>	2	Tk, Ms, Bm, Cc	C	R
Red-vented bulbul	<i>Pycnonotus cafer</i>	3	Tk, Ms, Bm, Cc, Os	C	R
Rose ringed parakeet	<i>Psittacula krameri</i>	2	Tk, Ms, Bm, Cc, Gr, Cs	C	R
Spotted dove	<i>Streptopelia chinensis</i>	6	Tk, Ms, Cc, Cs	C	R
Spotted owlet	<i>Athene brama</i>	9	Os, Cs	U	R
White breasted waterhen	<i>Amaurornis phoenicurus</i>	1	Wl	C	R
White throated kingfisher	<i>Halcyon smyrnensis</i>	1	Ms, Cc, Cs, Wl	C	R
Unidentified		8			

Habitat codes: **Tk** – Teak forest; **Ms** – Miscellaneous forest (teak mixed, *Anogeissus-Boswellia* stand, hill forest, and *zizyphus* stand)

Bm Bamboo dominant forest; **Cc** – *Cleistanthus collinus* woodland; **Gr** – Grassland – Savannah; **Os** – Open scrub jungle (dominated by *Lantana*); **Cs** – Countryside / Cultivation; **Wl** – Wetlands (river, streams, ponds, and reservoir)

Frequency codes: **C**- Common; **U**- Uncommon

Status codes: **R** – Resident

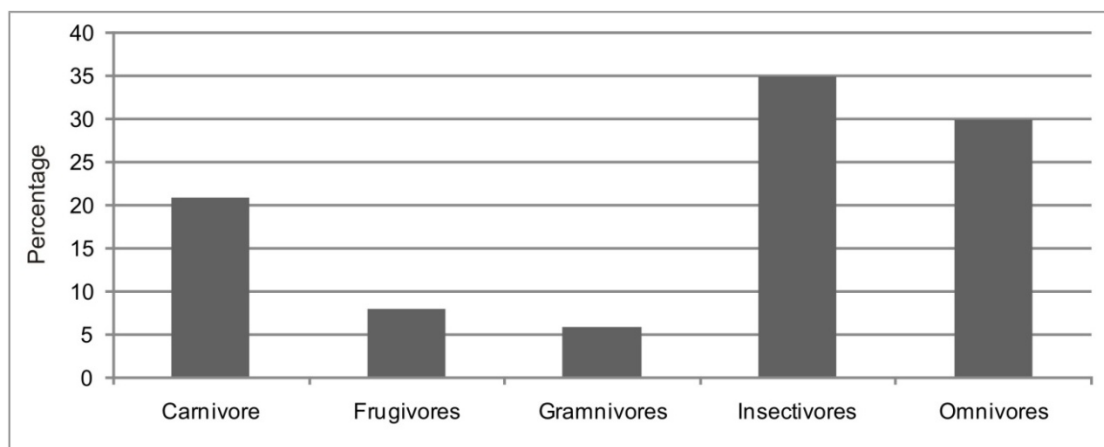


Figure 6.2 Representation of bird hits in different feeding guilds.

Seasonal variation in frequency of road kills

During the field study, average traffic flow recorded on the 9 km road was 3035 ± 274 vehicles/day. The average traffic volume varied between season with maximum number of vehicles recorded during summer (3269 vehicles/day) followed by 2952 vehicles/day in winter and 2884 vehicles/day in monsoon. The traffic flow during late night and early morning hours was recorded to be the lowest (80 vehicles/hr/day) in all seasons. The traffic peaked (180 vehicles/hr/day) during evening (1600 hr and 1700 hr) in all seasons. Road kills of bird have a positive correlation with the number of vehicles plying on the road ($r = 0.724$, $p < 0.01$).

Variation in road kills based on body size

Most of the birds killed represent resident birds commonly occurring in the Pench Tiger Reserve with Asian pied starling (*Sturnus contra*) and Spotted owlet (*Athene brama*) being the exceptions. During the study, percentage kill of small size birds was relatively higher (69%), followed by very small birds (19%) and medium

sized birds (13%). No kills of large bodied birds was reported during our study (Figure 6.3).

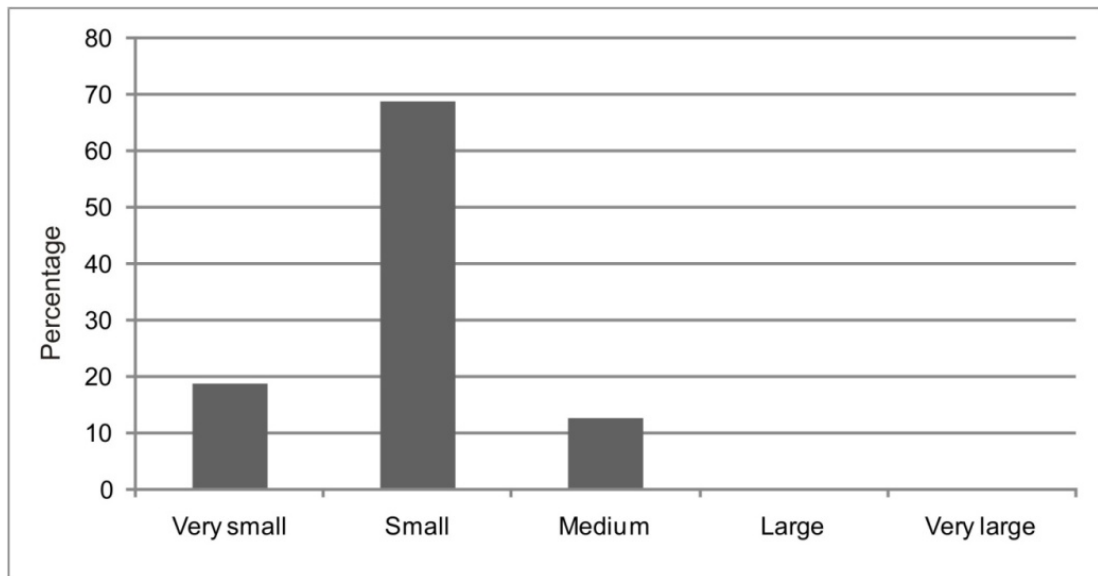


Figure 6.3 Variation in bird mortality based on body size.

Prediction of fatality hotspots

Mortality of birds occurred almost along the entire length of the road through the rich tracts of wildlife habitats and dispersal corridors of many endangered species ranging from mammals, birds, reptiles and amphibians. The Kernel Density Estimates of birds (Figure 6.4), reflects that the high abundance of fatalities of birds occur on the road section aligned through the flatter topography (chainage 627.800 km to 630.800 km). In the hilly area, kills were mostly concentrated in the road bends (chainage 633.500 km and 634.200 km).

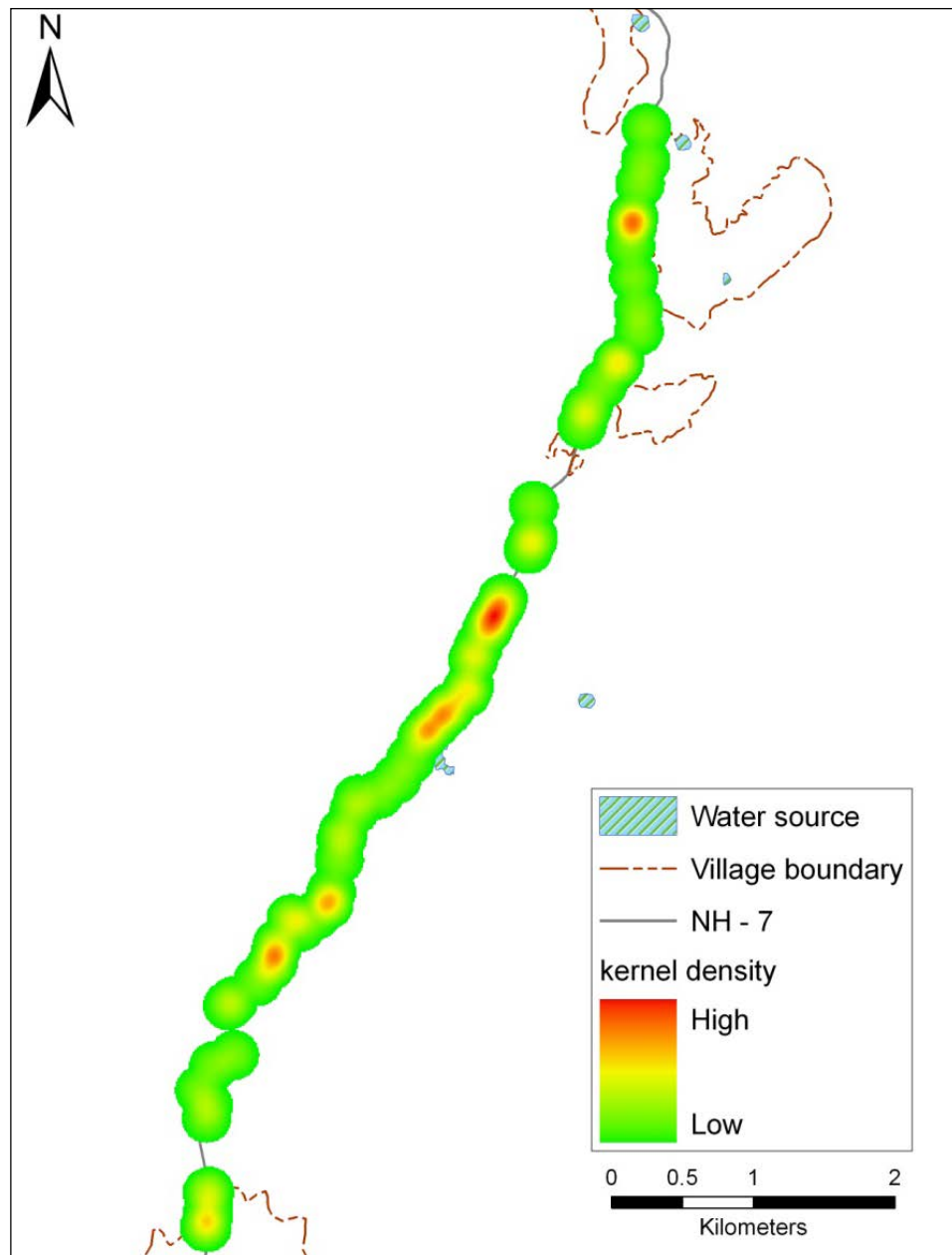


Figure 6.4 Kernel Density Estimation of bird hits.

Factors influencing the road hit

Road-side topography, habitat type, terrain and land-use influenced the habitat use by birds. The lowest mortality (1%) of bird hits was recorded in buried topography where road level was lower than the surrounding areas (Figure 6.5).

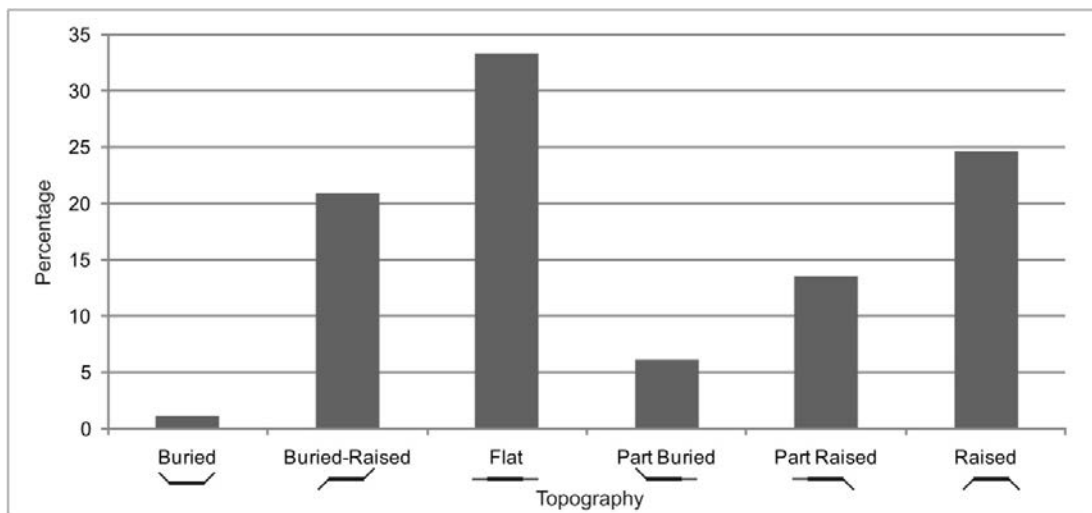


Figure 6.5 Percentage of bird kills in different topography.

Maximum number of bird hits (40%) occurred in road section passing through miscellaneous forest, followed by 25% of road hits in the teak dominant forest (Figure 6.6). Bird hits were recorded to be relatively lower in road sections passing through agricultural and scrub forest (15% and 13% respectively) indicating that these were fairly degraded habitat for use by bird species.

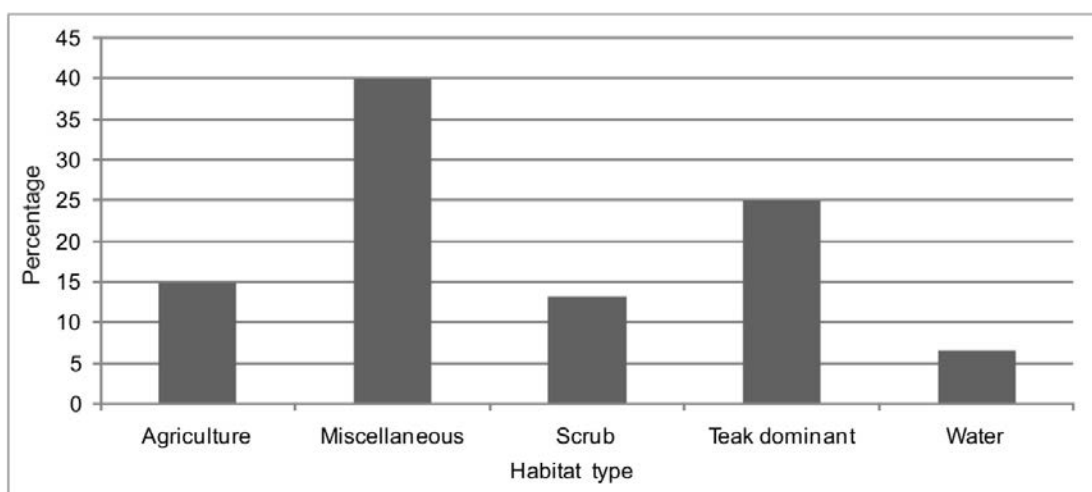


Figure 6.6 Percentage mortality in different habitat types.

The linear regression model showed that the bird hit is negatively related to the distance at which the bird is visible to the driver on the road ($p=0.001$) and elevation. Other variables such as NDVI, distances to drainage, agriculture, water, to cover and the slope class did not influence the probability of the road hit birds (Table 6.3).

Table 6.3 Linear regression of bird kills with the selected variables, β – Regression coefficient, S.E. – standard error of the regression coefficient, P – significance level

Variables	β	S.E.	df	P
Distance to cover	-0.030	0.050	-0.292	0.771
Distance to drainage	0.136	0.003	1.379	0.172
Distance to habitation	0.077	0.000	0.716	0.476
Distance to water	-0.207	0.000	-1.905	0.060
Elevation	-0.345	0.002	-3.167	0.002
NDVI	-0.090	4.249	-0.813	0.419
Slope	-0.076	0.047	-0.765	0.447
Visibility	-0.345	0.005	-3.409	0.001

Key findings

- A total of 143 bird kills were recorded during the study. These belong to 16 different species of the nearly 262 species of birds reported from Pench Tiger Reserve (Pasha *et al.* 2004).
- Many of these birds perform ecologically important function of seed dispersal and pollination.
- Maximum number of bird hits was recorded in miscellaneous forest followed by teak dominant forest.
- Fatalities did not follow a random trend along the entire 9 km length of the roads. Instead, these were spatially clustered.

- Kernel density indicated that higher bird mortality 33% occurred more in flat areas at 630.8 km

Discussion

The major ecological effects of roads are opening up of forest habitats, creating virtual boundaries in the landscape, along with bringing in vehicular traffic and its common problems like noise, pollution, dust and also mortality to the wild animals (Helldin & Seiler 2003). Maximum number of bird hits was recorded in miscellaneous forest followed by teak dominant forest (Figure 6.5). A total of 143 bird kills were recorded during the study. These belong to 16 different species of the nearly 262 species of birds reported from Pench Tiger Reserve (Pasha *et al.* 2004). Many of these birds perform ecologically important function of seed dispersal and pollination. Birds like Common myna (*Acridotheres ginginianus*), Red-vented bulbul (*Pycnonotus cafer*), Plum headed parakeet (*Psittacula cyanocephala*), Rose ringed parakeet (*Psittacula krameri*) and Jungle babblers (*Turdoides striatus*) are mainly frugivores birds which play an important role in seed dispersal and pollination, Continuous removal of these birds will have negative impacts on regeneration of the vegetation. Species like Indian roller (*Coracias benghalensis*), Jungle owlet, (*Glaucidium radiatum*) and Spotted owlet (*Athene brama*) that are fairly widespread control pests and regulate the number of large crustaceans, insects, earthworms, rodents, snakes, fishes and frogs in the forested ecosystems.

The results of our studies are similar to other studies (Hodson 1962; Bellis & Graves 1971; Bennett 1991; Clevenger *et al.* 2003) that also indicate that concentrations of road-killed animals generally occurred in wooded areas along the

road. The average bird mortality rate was 0.36 birds/10 km/day. This value is relatively high when compared to the reported mortality of birds (0.05 individuals/10 km/day) by Sundar (2004) on a two lane road measuring 20 km connecting the towns of Etawah and Mainpuri in Uttar Pradesh State of India. The International Union for Conservation of Nature (IUCN 2008) listed roads and railroads as the greatest threats to birds and other wildlife. Recent study by Bujoczek *et al.* (2011) conclude that frequent road kills of birds can randomly eliminate healthy individuals of the population around the road, which may leads to consequent decline in their population.

This study, we observed that most of the birds that were killed represented small sized birds that were common. Common species, especially those that are specialized on widespread environmental conditions may rapidly become rare (Lindenmayer *et al.* 2011). Our study indicated that insectivore birds were found to be most vulnerable to hits (35%) during their attempt to feed on insects on the road followed by omnivore birds (30%). Sundar (2004) also observed that omnivore and insectivore species were relatively more vulnerable to road kills compared to birds in other guilds based on his studies in northern India. A study by Jaeger *et al.* (2005) and Fulton *et al.* (2008) suggest that species which are abundant along roads are most vulnerable to road kills. Jackson (2003) explained higher vulnerability of insectivore birds because of their attempts to feeding on insects on the road surface. Some times aesthetically pleasing road side vegetation, provides food source to the birds, thereby increasing their risk to vehicle collision (Kociolek *et al.* 2015).

Bird hits have seasonal variation, corresponding with certain life cycle periods (Loos & Kerlinger 1993; Gryz & Krauze 2008). We observed highest mortality (52%) of birds during summer followed by 35% kills in monsoon. This could be because most

of birds in the dry deciduous woodland become very active in search of food during peak breeding time that corresponds with summer (March-May) and monsoon (July-September). According to Gaston (1981) and Dhindsa *et al.* (1988), variations in mortality rate in woodland birds occupying dry deciduous forests across seasons could be due to their association with breeding activities and corresponding increase in foraging. These birds might also be attracted to spillage of grains on the road.

During the study period, maximum traffic was recorded during summer (3269 vehicles/day). Bird kills have a strong positive correlation with traffic volume ($r=0.724$, $p<0.01$). The traffic volume has been recognized as the source of disturbance affecting the population of breeding birds near road (Reijnen & Foppen 2006).

As this study did not aim to assess the total bird species diversity in the range of habitats along the road, it is difficult to assess the proportion of species killed. The overall disturbance effect of roads on wildlife would therefore be underrepresented by road kills and birds are possibly also affected due to stress from traffic noise. Parris and Schneider (2009) observed that traffic noise could obstruct detection of song by conspecific. Noise may hinder birds in establishing and maintaining territories and in attracting mates that may possibly lead to reduced breeding success in noisy roadside habitats. Consequently, unmated males may disperse to new territories away from the road and inexperienced males may take their place through immigration, which might result in the roadside areas acting as 'habitat sink' (Foppen & Reijnen 1994). Reijnen *et al.* (1996) observed lower population densities of birds in the habitat close to roads because of the traffic noise. These negative trends in population may also be operating in this study area but needs to be further explored.

It was observed that fatalities did not follow a random trend along the entire 9 km length of the roads. Instead, these were spatially clustered. Kernel density indicated that higher bird mortality 33% occurred more in flat areas at 630.8 km (Figure 6.4). We believe that this could be because of the flat topography providing easy path for birds to fly low. This may lead to higher incidences of hits by vehicles that move at a higher speed in flatter sections of the road. Similar explanations have also been provided by Hernandez (1988); Clevenger *et al.* (2003); Ascensao and Mira (2005); Ramp *et al.* (2006) based on their studies. The linear regression model predicts bird hit was negatively correlated with visibility on the road. When visibility is less between bird and vehicle drivers or vice versa, the probability of getting hit by the speeding vehicle may increase.

Mitigation

The conservation importance of birds is well established. They are valued for critical ecological functions they perform. They control populations of insects and rodent, reduce damage to crops and forests, help limit the transmission of diseases such as, dengue fever, and malaria and play a vital role in regenerating habitats by pollinating plants and dispersing seeds. At the same time, bird populations are declining around the world (BirdLife International 2004; Kociolek *et al.* 2011) as a result of increasing human activity. One of the potential sources of threats to bird population is the, expansion of road network through development of new roads and up-gradation of existing roads in natural areas.

Considering that developments in road sector are essential for economic development and that conservation of bird diversity is of paramount priority for

sustaining life and ecosystem benefits, planning mitigation options must aim to harmonize these apparently conflicting goals. Merits of employing diverse mitigation approaches to address road induced mortality of birds have been well accepted by many workers (Jacobson 2005; Glista *et al.* 2009; Gomes *et al.* 2009; Kociolek *et al.* 2011).

The present study has provided useful insight about the impacts of roads on birds for planning effective mitigation measures that can best address the specific impacts of roads on bird species. During migration seasons, birds are more susceptible to vehicular injuries and mortality, when they stopover or use the road habitat for food source. During breeding season their movement is restricted to their nest and nurturing the eggs and the young (Kociolek *et al.* 2015). While the movement of the bird species across the road is dependent on the attractiveness of habitats on or along either side of the roads, collisions with vehicles represent the unsuccessful attempts of crossing over the roadway. This attractiveness is generally enhanced because of the availability of sites for roosting and perching; availability of edible fruits and seeds from trees along the roads and the high abundance of invertebrates, reptiles and small mammals in the road verges.

Since birds can fly, they often do not have a definitive path, hence the conventional mitigation measures are aimed at minimising roadkill, through creation of passages and erection of fences may not be applicable for addressing impact of birds hits. Studies have also indicated that some bird species with small home ranges and small body size with high flight path are less prone to vehicular collisions (Rytwinski & Fahrig 2012). Mitigation measures should be best employed during the planning stage.

Strategies for mitigating mortalities therefore focus on (i) managing road side habitat to reduce attractiveness for birds (ii) encourage birds to fly higher above the roadway to reduce risk of collisions, (iii) maintaining a clear zone, devoid of trees and shrubs to prevent reptiles and rodents become easy prey for many bird species that get attracted to use road corridor for patrolling for food. Removal of resources for the birds along the roads would encourage them to move away their foraging and roosting sites away from the road boundary. (iv). Clearing the road side vegetation (shrubs and bushes) within 5 m wide area along the road and trimming of branches of tree species for maintaining a 3 m high clearing should be part of prescription for road side habitat management (Figure 6.7). (v). Planting of trees with non edible fruits and species such as Teak (*Tectona grandis*) that discourage undergrowth along the roadside would be effective in reducing the use of road side habitat /verges by most birds. (vi) Installation of light reflectors to reflect light away from the road surface can be effective in reducing the blinding effects of vehicular lights for nocturnal insectivorous birds that invariably get hit while feeding on insects along the road.

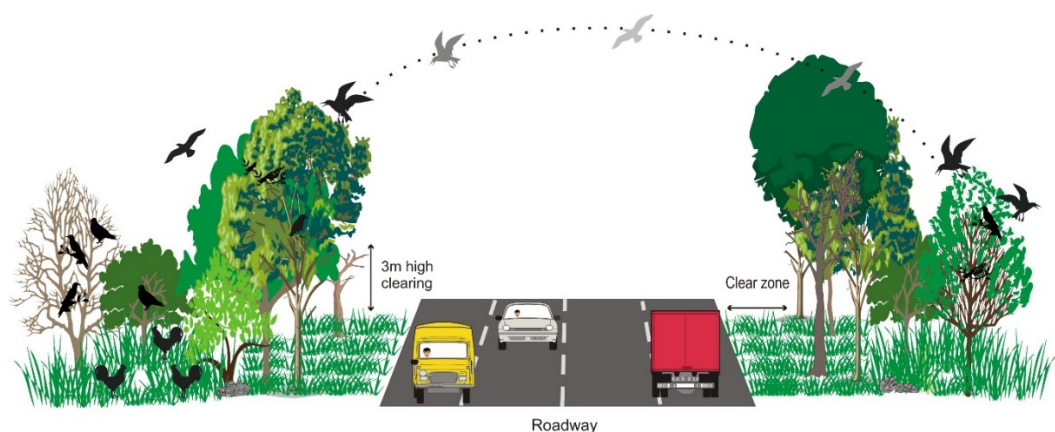


Figure 6.7 provides an illustration of the above suggested measures to reduce bird collisions on and along road.

Chapter 7. Impact of road on mortality of snakes and proposed mitigation measures

Introduction

India, with more than 56.03 lakh km existing road length, has the world's second largest road network. Approximately 26,000 km of road length traversing through wilderness areas are routed through as many as 26 tiger reserves spread across the country. The National Highway Authority of India proposes to further expand this network by adding new road links and also by widening existing roads to four lane roadway.

Roads represent one of the most widespread forms of modification of the natural landscape associated with expansion in transportation infrastructure that is often justified for facilitating linkages, enhancing mobility and improving accessibility. Several independent studies and comprehensive reviews of ecological impacts specific to roads have singled out roads as the largest factor posing the greatest threats to biodiversity (Treweek *et al.* 1993; Forman & Alexander 1998; Spellerberg 2002; Trombulak & Frissell 2002; Smith 2003; Seiler *et al.* 2004; Eigenbrod *et al.* 2008; Fahrig & Rytwinski 2009; Beckmann *et al.* 2010; Clevenger & Sawaya 2010).

These studies have demonstrated that roads increase fragmentation of habitats and populations; lead to isolation and obstruction of animal movements; result in road induced mortality of animals and extinction of rare and endemic species (Oxley *et al.* 1974; Mader 1987; Mech 1989; Ashley & Robinson 1996; Richardson *et al.* 1997; Forman & Alexander 1998; Jackson 1999; Lode 2000; Goosem 2007; Hicks &

Peymen 2008; Quintero *et al.* 2012; Secco *et al.* 2014; Machado *et al.* 2015; Cuyckens *et al.* 2016; Jacobson *et al.* 2016; Maschio *et al.* 2016; Sosa & Schalk 2016; Heigl *et al.* 2017; Fischer *et al.* 2018; Monge Nájera 2018; Yue *et al.* 2018).

Road related mortality has been widely documented for different taxa – butterflies (Mckenna *et al.* 2001); amphibians (van Gelder 1973; Hels & Buchwald 2001); snakes (Rosen & Lowe 1994; Andrews & Gibbons 2005; Row *et al.* 2007), birds (Reijnen *et al.* 1995; Erritzoe *et al.* 2003; Sundar 2004; Benitez-Lopez *et al.* 2010; Bujoczek *et al.* 2011) and mammals (Oxley *et al.* 1974; Vieira 1996; Clevenger *et al.* 2003; Roedenbeck & Voser 2008).

As snakes play an important ecological role both as predators and prey in the different ecosystems, they command high significance for conservation. Snakes represent an ideal target group for studying direct and indirect impacts of roads (Andrews & Gibbons 2005) not only because road related mortality has been documented for over half a century (e.g., Krivda 1993; Smith & Dodd 2003; Gibson & Merkle 2004; Row *et al.* 2007), but also because of the breadth of ecological niches represented among snake species (Ernst & Ernst 2003) and their greater vulnerability to roads. The tendency of snakes to thermo regulate on road surfaces, their relatively slow locomotion, life history characteristics, low reproductive rates and seasonal variability in habitat use are factors that increase their vulnerability to roads (Rosen & Lowe 1994; Rudolph *et al.* 1999; Jochimsen *et al.* 2004).

Although knowledge about the ecological impacts of road on snakes is rapidly accumulating from many parts of the world (Bernardino & Dalrymple 1992; Rosen & Lowe 1994; Gibson & Merkle 2004; Shine *et al.* 2004; Jochimsen 2005; Andrews *et al.* 2007; Freeman & Bruce 2007; McDonald 2012), studies on impacts

of roads on snakes are scarce in India. Also, most of the studies are limited to a few disparate records of road induced mortality of snakes in tropical evergreen and moist deciduous forests (Gokula 1997; Vijayakumar *et al.* 2001; Das *et al.* 2007; Kannan 2007; Baskaran & Boominathan 2010; Bhupathy *et al.* 2011; Seshadri & Ganesh 2011; Chittaragi & Hosetti 2014; Santhoshkumar *et al.* 2017; Jadhav *et al.* 2018). No studies on road related impacts on snakes have been conducted in the forested landscapes in central India. The present study was undertaken to fill the void of such studies in the tropical dry deciduous forests of central India. The objective of our study was to

- (i) estimate the road related mortality of snakes in the 9 km section of National Highway (NH)-7 passing through Pench Tiger Reserve,
- (ii) define the spatial distribution of road kills
- (iii) evaluate the factors influencing the mortality of snakes and
- (iv) propose mitigation options to prevent and reduce the road induced mortality of snakes for ensuring the long term conservation of snakes in this landscape.

Methods

Road-kill data collection

Road cruising and collecting method that has been widely used to determine species negatively impacted by roads was adopted (Ashley & Robinson 1996; Clevenger *et al.* 2003; Langen *et al.* 2007). The entire 9 km stretch of highway was surveyed for a total of 430 road cruising days spread equally across three seasons:

monsoon/July to October (n=147), winter/November to February (n=143) and summer/March to June (n=140) between August 2008 to July 2010. On all cruising days, the vehicular survey was conducted in the morning (0530–0630 hrs) and in the evening (1730–1830 hrs) at a speed of 10–20 km/hr. Observations about snake kills were recorded by two observers. Whenever the snake kills were encountered on the road, the vehicle was stopped to enable the team to identify the species (Whitaker & Captain 2004). Additionally, information on the state of the road kills, geo-coordinates of the road kills (using Garmin 72 GPS) and roadside habitat features were recorded. After recording the information, the dead snakes were removed from the road to avoid repeat count during subsequent surveys. The 430 days of vehicular survey resulted in a total effort of surveying 3870 km. Information on average traffic volume per day and peak traffic was collected through continuous monitoring based on manual counts for three days per season in a two year period.

Data on average traffic volume on the road section passing along the Pench Tiger Reserve was generated based on continuous recording of the number of vehicles over a period of twenty four hours for three days per season. Total number of two wheelers, passenger cars, heavy vehicles, trucks and lorries moving on the road was recorded. Data on traffic was collected on week and non-week days and market days to capture any variations in traffic volume on different days.

Prediction of fatality hotspots

Fatality hotspots were determined on the 9 km section of the road, using Kernel Density Estimation method (Gitman & Levine 1970) which is one of the common methods for analyzing the point event distribution data (Silverman 1986;

Bailey & Gatrell 1995). This method generates a smooth surface map showing point data (kill location) on the basis of which the density of events (road kills per unit area) is determined to provide an estimate of kill concentration. This approach of identifying fatality hotspots provides a useful insight for planning mitigation strategies to avoid and reduce road kills in high mortality zones (Ramp *et al.* 2005, 2006; Gomes *et al.* 2009). The area of influence or a bandwidth chosen for this study was 200 m. The Kernel Density Estimation for species fatalities was done using the Spatial Analyst Toolbox of ArcGIS Version-9 (ESRI 2004). Zero values were omitted to avoid confusion between zero density and no data.

Factors influencing the road kill

The road area was also typified to assess the road features that may have influence on the frequency and abundance of snake mortality. The road was categorized into six categories following (Clevenger *et al.* 2003): (i) road surface raised compared to surrounding landscape, (ii) no slope, (iii) road surface buried relative to surrounding landscape, (iv) one side flat, one buried, (v) one side flat, one side raised and (vi) one side buried, one raised.

We created land use, land cover classified map using Landsat 7 Thematic Mapper (30 m resolution) acquired on November 2009 (Path: 144, row: 52) and downloaded from the US Geological Survey archive Global Visualization Viewer (<http://glovis.usgs.gov>). The image was classified into five major cover types spanning across both the sides of the road as (1) Teak dominant, (2) Miscellaneous, (3) Scrub forest, (4) Agriculture and (5) Water sources. A 50 m buffer was created

around each road kill location that was treated as a point in the GIS domain. Information was extracted from classified image on habitat type.

On encountering a snake kills on the road, the distance from the snake kill to the closest vegetation cover on both sides of the road was recorded using a range finder. The nearest distance at which the kill could have been visible to a driver of the vehicle was assessed by measuring the nearest distance between the point of road and an unobstructed view of the approaching vehicle from either side of the highway. Spatial data (Table 7.1) on landscape related variables: distance of the kill from the agriculture, water sources, drainage and animal crossing structures was generated in GIS laboratory using the Euclidean distance method in Arc Info. Altitude (meter) and slope (degree) was derived from 30 m resolution Digital Elevation Model (ASTER Global Digital Elevation Model).

A linear regression model was developed to relate the occurrence of road-kills to the landscape and road attributes. The 9 km road was divided into 100 m segments (n=90) and the road kill data was segregated for each of these segments. In each segment, number varied from 0 to 15 road kills. We chose 8 variables to describe site-specific attributes of each road-kill site (Table 7.1). We used the SPSS statistical package (version 15.0, SPSS 2006) for all statistical analysis, Arc GIS 9 (ESRI 2004) and Microsoft Excel for all other analysis.

Table 7.1 Landscape and site variables and their description used in the analysis.

Variable name	Description	Source
Visibility (m)	Farthest distance from which the driver can locate a snake on the road	Field
Distance to cover (m)	Distance of vegetation cover from the location of the road kill	Field
Distance to water (m)	Distance of the road kill from the nearest water source (lake)	Euclidean distance (Arc Info)
Distance to animal crossing structure (m)	Distance of the road kill from the nearest animal crossing structure	Euclidean distance (Arc Info)
Distance to drainage (m)	Distance of the road kill to nearest seasonal drainage	Euclidean distance (Arc Info)
Distance to agriculture (m)	Distance of the road kill to nearest human settlements	Euclidean distance (Arc Info)
Altitude (m)	Mean ground altitude of the road (100 m segments)	Digital elevation model
Slope (Degree)	Mean ground slope of the road (100 m segment)	Digital elevation model

Results

Traffic volume

From the data we collected (Figure 7.1) during the study, average traffic flow recorded on the 9 km road was 3035 ± 274 vehicles/day. The average traffic volume varied between summer (3269 vehicles/day), winter (2884 vehicles/day) and monsoon (2884 vehicles/day). The highest average daily traffic was recorded on Sundays (3382 vehicles/day) during summer and minimum traffic was recorded on Tuesdays (2620 vehicles/day) during monsoon. Number of heavy vehicles (trucks) remained highest in the overall total traffic volume in all of the three seasons. The traffic flow during late night and early morning hours was recorded to be the lowest (80 vehicles/hr/day) in all seasons. The traffic peaked (180 vehicles/hr/day) during evening (1600 hr and 1700 hr) in all seasons. Road kills of snakes has a strong positive correlation with the number of vehicles plying on the road ($r= 0.99, p<0.001$) in all seasons.

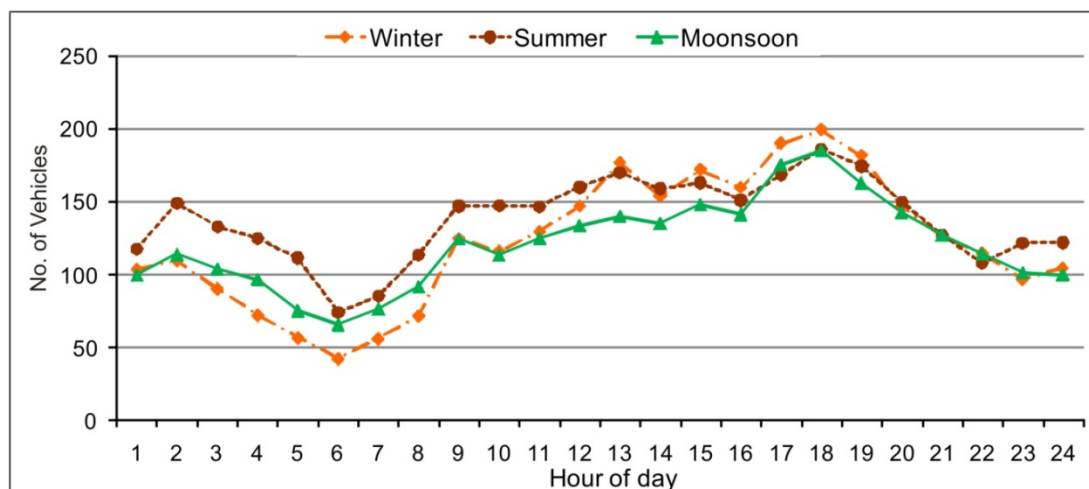


Figure: 7.1 Average traffic volume on the National Highway – 7.

Species composition and temporal pattern of road kills

Based on 430 days of observations and 3870 km of effort between August 2008 to July 2010, 490 road kills of snakes were recorded (Table 7.2). These together represented 20 different species. Many of the species that have contributed to the road kills command high conservation importance. The Indian rock python is listed under Schedule I and 4 species (Checkered keelback, Indian rat snake Russell's viper and Spectacled cobra are listed under Schedule II of Indian Wild Life Protection Act (WPA), 1972. The Indian python is also listed in Appendix I of the CITES.

The snakes were killed at the rate of 1.13 animal/10 km/day. The number of snake kills varied seasonally. The highest mortality was recorded during monsoon (50%), followed by 37% of snakes killed in summer and 13% snakes killed in winter. Of the total count of 490 snakes kills recorded during the study, Barred wolf snake (*Lycodon striatus*) had the highest number of mortality (n=99) representing 22 % of the total snakes killed. This was followed by Common cat snake, *Boiga trigonata* (n=49) and Striped keelback, *Amphiesma stolatum* (n=38) representing 11% and 8 % of the total road kill respectively.

Table 7.2 List of snake species killed on National Highway -7.

Common name	Scientific name	Family	Percentage of taxa	WPA status*	CITES**
Bamboo pit viper	<i>Trimeresurus gramineus</i>	Viperidae	1	Schedule IV	not listed
Barred wolf snake	<i>Lycodon striatus</i>	Colubridae	22	Schedule IV	not listed
Beaked worm snake	<i>Grypotyphlops acutus</i>	Typhlopidae	3	Schedule IV	not listed
Checkered keelback	<i>Xenochrophis piscator</i>	Colubridae	3	Schedule II	Appendix III
Common bronzeback tree snake	<i>Dendrelaphis tristis</i>	Colubridae	3	Schedule IV	not listed
Common cat snake	<i>Boiga trigonata</i>	Colubridae	11	Schedule IV	not listed
Common krait	<i>Bungarus caeruleus</i>	Elapidae	3	Schedule IV	not listed
Common kukri snake	<i>Oligodon arnesis</i>	Colubridae	2	Schedule IV	not listed
Common sand boa	<i>Gongylophis conicus</i>	Boidae	2	Schedule IV	Appendix II
Common trinket snake	<i>Coelognathus helena helena</i>	Colubridae	5	Schedule IV	not listed
Common wolf snake	<i>Lycodon aulicus</i>	Colubridae	3	Schedule IV	not listed
Forstens cat snake	<i>Boiga forsteni</i>	Colubridae	2	Schedule IV	not listed
Green keelback	<i>Macropisthodon plumbicolor</i>	Colubridae	4	Schedule IV	not listed
Indian rat snake	<i>Ptyas mucosa</i>	Colubridae	2	Schedule II	Appendix II
Indian rock python	<i>Python molurus molurus</i>	Pythonidae	3	Schedule I	Appendix I
Russell's kukri snake	<i>Oligodon taeniolatus</i>	Colubridae	2	Schedule IV	not listed
Russell's viper	<i>Daboia russelii</i>	Viperidae	4	Schedule II	Appendix III
Saw scaled viper	<i>Echis carinatus</i>	Viperidae	4	Schedule IV	not listed
Spectacled cobra	<i>Naja naja</i>	Elapidae	1	Schedule II	Appendix II
Striped keelback	<i>Amphiesma stolatum</i>	Colubridae	8	Schedule IV	not listed
Unidentified	—	—	12	—	—

*WPA-Wildlife Protection Act, 1972 ** CITES – Convention on International Trade in Endangered Species of Wild Fauna and Flora

Prediction of fatality hotspots

Mortality of snakes occurred almost on the entire length of the road which traversed through rich tracts of wildlife habitats and cut across dispersal corridors of many endangered species. The Kernel Density Estimates of snakes (Figure 7.2), reflects that the high abundance of fatalities of snake occur on the road section aligned through the flatter areas and in locations nearer to villages that have agriculture fields. In the hilly area, kills were mostly concentrated in the road bends.

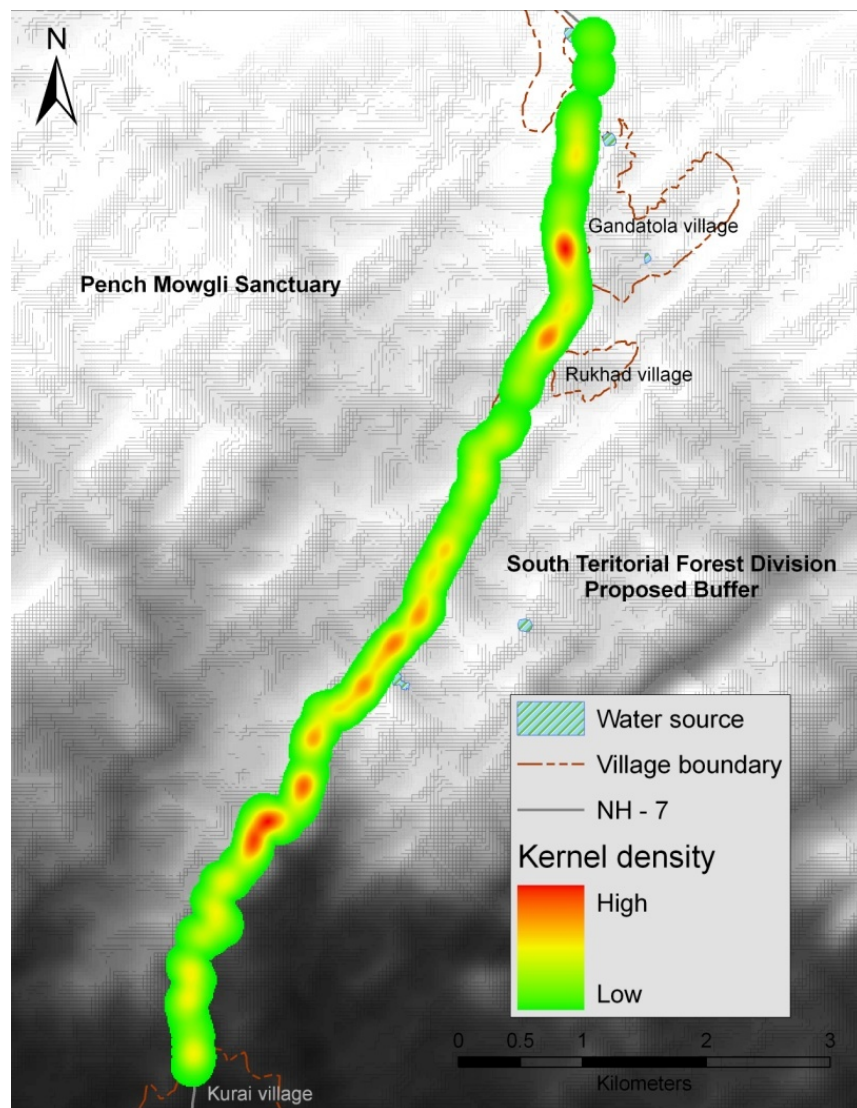


Figure 7.2 Kernel density estimation of snake fatalities.

Factors influencing the road kill

In general, the movement of snakes is likely to be influenced by habitat type, terrain and land-use. In our study, we also attempted to associate snake kills with road topography that is differentiated into six categories (buried, buried-raised, flat, part buried, part raised and raised) for the purpose of this study. Percentage of snake kills recorded in the flat section of the road (Figure 7.3) is highest (42%) when compared to 27% of road kills recorded in the hilly area where the road is partly buried and partly raised.

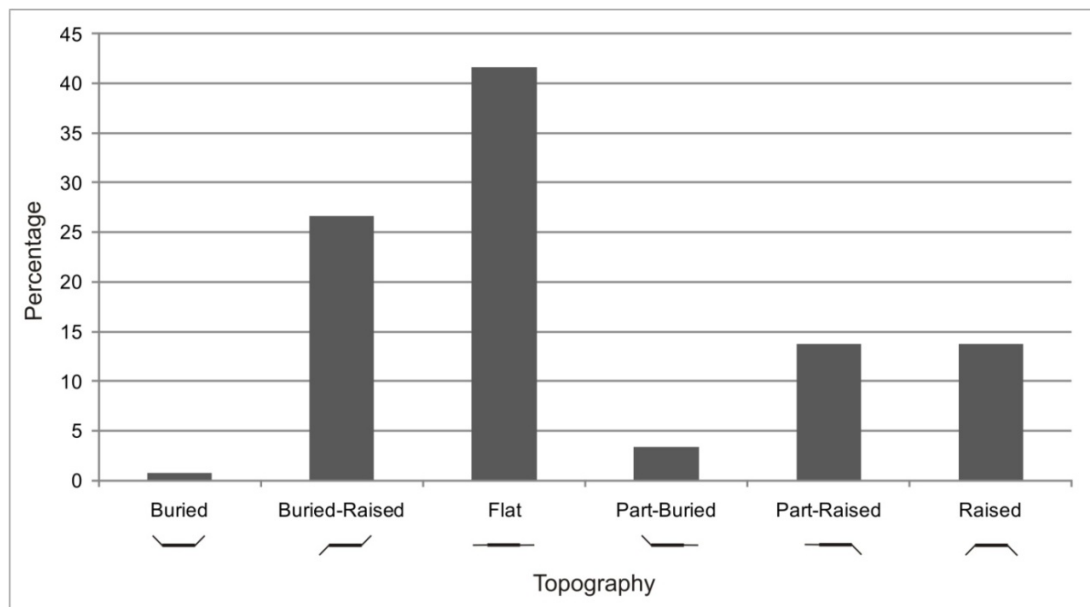


Figure 7.3 Percentage of snake kills in different topography.

Our data shows that the highest percentage of snake mortality (43%) occurred in road sections passing through Teak dominated forest (Figure 7.4). These forest tracts on either side of the road offer excellent habitat for varied species of animal ranging from large carnivores (e.g. tiger, leopard and wild dog) and herbivores (e.g. chital, sambar and nilgai) to smaller creeping animals (snakes) that frequently use the

road as a conduit for movement across the two habitats. The results of this study are similar to other studies that indicate that concentrations of road-killed animals generally occur where wooded areas or cover is found on both sides of a road (Hodson 1962; Bellis & Graves 1971; Bennett 1991; Clevenger *et al.* 2003). The lowest mortality (6%) of snakes occurred in road sections passing through Scrub forest which is a fairly degraded habitat. As the large water body forms the aquatic habitat just abutting the road in the hilly section, it is mostly avoided by snakes. This explains the low percentage of snake kills on the road segment near the water body.

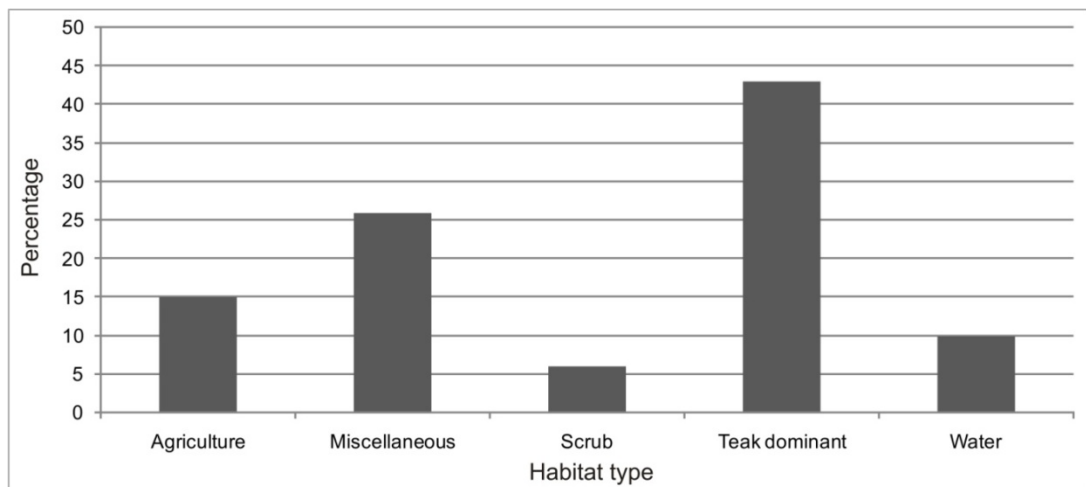


Figure 7.4 Mortality rate in different habitat types.

The linear regression ($R^2= 0.79$) shows that the snake kill is positively correlated with the elevation and negatively correlated with the distance to agricultural fields, water and the animal crossings. Other variables such as distance to vegetation cover, visibility distance, distance to drainage and slope did not influence the probability of the road kill (Table 7.3). Most of the flatter segment of the road where highest number of snake kills has been recorded is aligned through the elevated areas in the landscape.

Table 7.3 Linear regression of snake kills with the selected variables, β – Regression coefficient, S.E. – Standard Error of the regression coefficient, P – Significance Level

<i>Variables</i>	β	<i>S.E.</i>	<i>P</i>
Distance to cover	0.035	0.045	0.556
Distance to drainage	0.021	0.002	0.730
Distance to animal crossings	-0.127	0.001	0.098
Distance to agriculture	-0.432	0.000	0.001
Distance to water	-0.126	0.000	0.058
Elevation	0.780	0.003	0.001
slope	0.071	0.044	0.295
Visibility	-0.050	0.004	0.417

Key findings

- (i) A total of 490 snake kills were recorded during the study. These belong to 20 different species of the nearly 40 species of snakes reported from central Indian landscape (Chandra & Gajbe 2005) and of these, 19 species have been reported from Pench Tiger Reserve, by Pasha *et al.* (2000).
- (ii) The snakes were killed at the rate of 1.13 animal/10km/day
- (iii) The highest mortality was recorded during monsoon (50%), followed by 37% of snakes killed in summer and 13% snakes killed in winter
- (iv) Kernel Density Estimate indicated that higher abundance of fatalities of snake occur on the road section aligned through the flatter areas and in locations nearer to villages that have agriculture fields. In the hilly area, kills were mostly concentrated in the road bends.

Discussion

A total of 490 snake kills representing 20 different species were recorded during the study (Figure 7.5a to 7.5c). Of the nearly 270 species of snakes reported (Whitaker & Captain 2004) from different parts of the country, approximately 40 species have been reported from the central Indian landscape (Chandra & Gajbe 2005) and of these, 19 species have been reported from Pench Tiger Reserve, by Pasha *et al.* (2000). The present study supports the occurrence of as many as 20 species in this area. It is an already acknowledged fact that snake kills serve as a good indicators of the herpetofaunal species of the area (Hels & Buchwald 2001) and the road cruising and collecting methods are valuable tools for studying snakes (Gibson & Merkle 2004; Mukherjee 2007). We suspect that there may be more species of snakes occurring in this area. Subsequent road cruising and collection efforts may thus be useful in the inventorying of snake species of this area.

The average mortality rate (1.13 animal/10 km/day) of snakes varied seasonally. Coelho *et al.* (2008) also observed seasonal variation in the road kill pattern. This variability may be associated with changes in movement patterns of snakes during breeding and dispersal seasons. This variability could also be a reflection of spatial and temporal variations in environmental characteristics and availability of resources. The high mortality during monsoon can be explained by the fact that snakes are cold blooded animal and they tend to rest on road surfaces during cooler nights (Dodd *et al.* 1989; Rosen & Lowe 1994; Shine *et al.* 2004).

Road kills of snakes have a strong positive correlation with traffic on the road ($r= 0.99$, $p<0.001$). Szerlag and McRobert (2006) also reported positive relationship between traffic volume and mortality of herpetofauna. Compared to

other herpetofauna, snakes are at the highest risk of mortality as their movement is relatively slower on a smooth road as compared to other surfaces (Bonnet *et al.* 1999). Row *et al.* (2007) observed that some drivers deliberately run the vehicles over snakes because they dislike snakes. In the present study also, one of the authors observed the drivers attempting to kill the snakes moving on the road.



Figure 7.5a Mortality of snakes on NH-7 along Pench Tiger Reserve.



Figure 7.5b Mortality of snakes on NH-7 along Pench Tiger Reserve.



Figure 7.5c Mortality of snakes on NH-7 along Pench Tiger Reserve.

Nearly 72% of the snakes that get killed are nocturnal. Some species of snakes that actively forage during night time are relatively more vulnerable to the vehicles when compared to snakes that are active throughout the day. In the present study, high mortality of snakes could be explained because 52 % of the snakes were nocturnal and actively feeding during night (Figure 7.6), 23% of the snakes sit and wait for the prey and are therefore less vulnerable to traffic. Of the total count of 490 snakes kills recorded during the study, Barred wolf snake and Common cat snakes which accounted for nearly 22% and 11% of road kills respectively are both nocturnal and active feeders (Whitaker & Captain 2004).

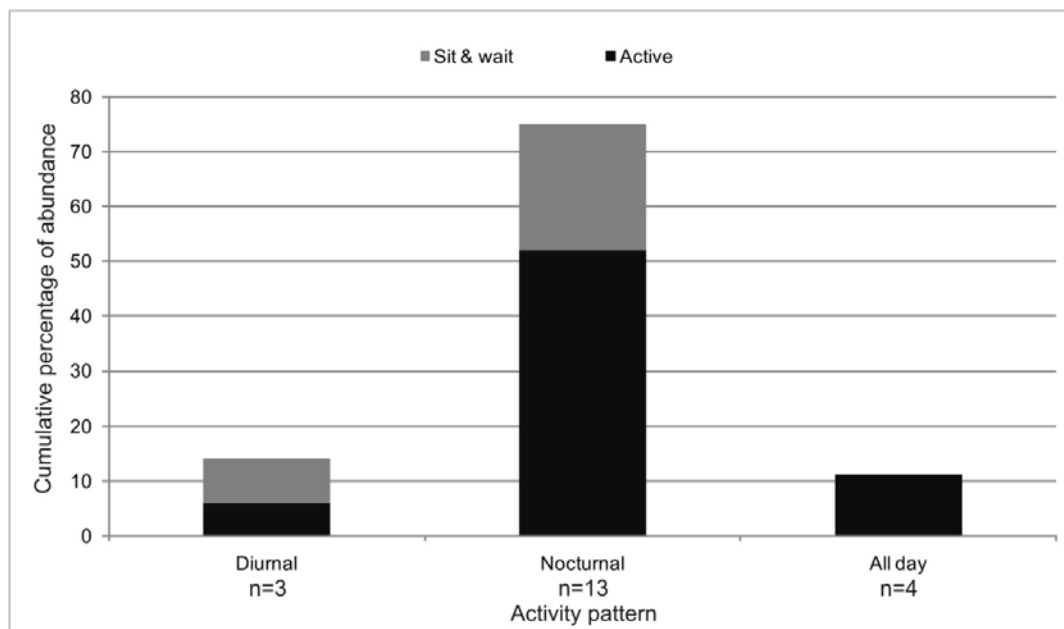


Figure 7.6 Activity pattern and foraging habit of the snake killed.

Our study indicates that fatalities of snakes occur throughout the entire length of the road. This observation renders support to the fact that snakes continue to attempt to use habitat that has been dissected by the road which poses a major barrier for their movement. Similar conclusions that road act as barrier for snakes especially

for smaller species were also drawn from studies by Andrews and Gibbons (2005), Aresco (2005), Row *et al.* (2007), Shepard *et al.* (2008).

Although fatalities were recorded throughout the road, kills did not occur randomly along the entire 9 km length of the roads but were spatially clustered. Kernel density and linear regression analysis indicates higher snake mortalities near areas of anthropogenic influence including human settlements and agricultural fields in flat areas. Prey availability in the agricultural area tends to attract nocturnal snakes on the road during night that are more often killed by speeding vehicles in flat areas. Our findings support the observations of Puglisi *et al.* (1974), Clevenger *et al.* (2001), Joyce and Mahoney (2001), Huijser *et al.* (2006) that wildlife-vehicle collisions do not occur randomly along roads but are spatially clustered.

Several factors including specific habitats, terrain and adjacent land-use types that influence wildlife movements also play an important role in determining locations of higher probability of road mortality compared to other locations (Forman & Alexander 1998). We attempted to relate road kills with landscape and site variables within the road corridor (Table 7.1). Higher moisture, lower temperature and presence of leaf litter that modify the micro habitat conditions in culverts and the prey availability in agricultural fields both improve the prospects of use by active feeders. More kills therefore occurred at locations that were closer to drainage channels and near agricultural areas. Similarly, in sections of road that were closer to water bodies, more kills were recorded. This is perhaps because many of the snake species that get attracted to the prey species occurring near water sources attempt to cross the road and get killed in the process.

Implications for conservation

Road induced mortality plays a significant role in the decline of snake populations. This poses significant conservation challenges for species that are already endangered or species that are at risk on account of alteration of their habitat conditions. During our study, we recorded 12 kills of Indian rock python which is listed in schedule-I under the Wild Life (Protection) Act, 1972, Government of India. Of these, 9 individuals were juvenile. The road induced loss of dispersing juveniles and consequent isolation is likely to impact upon the gene flow across the landscape. Ciesiolkiewicz *et al.* (2006) also recorded that juvenile snakes appear to be most susceptible to road mortality, especially during hatching and dispersal.

Common bronzeback tree snake, constituting 3 % (n=14) of species killed by the vehicle during this study, is an arboreal species that is threatened by the reduction of canopy connectivity and by the road induced fragmentation of connectivity between the road side habitat. The threat to snake species may vary with differential mortality of animals that cross more slowly (e.g. Russell's viper) than with snakes that immobilize, or freeze in response to a passing vehicle.

Drawing population estimates for the various species of snakes based on the present study of snakes killed on road alone could be misleading as the relative kill rates by species may not correspond to their relative abundance locally. It is important to consider that low mortality percentages of some species of snakes (Green keelback, Beaked worm snakes and Russell's kukri snakes) could be a function of a smaller population of uncommon snakes (Whitaker & Captain 2004) found in the forested habitat outside protected areas.

Mitigation

Habitat fragmentation of wildlife habitats by roads is globally recognised as one of the biggest threats to conservation of biodiversity (Andrews 1990; Seiler 2001; Bekker *et al.* 2003; Andrews & Gibbons 2005; Shepard *et al.* 2008).

In the application of the mitigation measures, its often observed, that precautions drawn for one species may not be suitable measure for other wildlife species of the same area. For example, fences may be helpful in safekeeping animals off the roads, while it might stop animal movement totally for some other species (Jacobson *et al.* 2016). Rudolph *et al.* (1999) observed that some snake species may be entirely removed due to vehicular collision, as they are more attracted to the roads. Some snake species need to be studied in detail, and require more intense mitigation measures. The vehicle speed and the response of snake species to the traffic needs to be understood to develop and design mitigation measure (Hels & Buchwald 2001; van Langevelde & Jaarsma 2004).

This study serves as a useful template for assessing the nature and magnitude of vehicle induced mortality of snakes based on observations on a section of National Highway-7 aligned along an important protected area in central India. Understanding these impacts is critical for determining appropriate conservation strategy because of the importance of snakes as trophic components of terrestrial ecosystems (Rosen & Lowe 1994). Mitigation approaches to address road induced mortality of snakes have been well discussed by many workers (Jochimsen *et al.* 2004; Aresco 2005; Coelho *et al.* 2008; Trembath & Fearn 2008). These approaches have focused largely on improving the permeability of roads as passage for wildlife, managing traffic to

reduce barrier effect of moving vehicles and managing wildlife areas to prevent snakes frequenting on roads.

In the present context, construction of speed breakers in fatality hotspots, and use of fences specifically engineered for snakes are some of the conventional approaches that can be effective in reducing road induced mortality. Most of these post-construction mitigation measures would however serve only as second best option because they are not targeted to avoid the effects of roads in first place. Further, planning of retrofitting measures is often more costly. Developing ecologically sensitive approaches and innovative design that can be applied both at the planning stage and also subsequently as a retrofit would be most effective in controlling road kills. One such measure of constructing 1 m high wall with a lip on the high end along the road length through forest stretches is recommended by Dodd *et al.* (2004) for preventing snakes from getting on to the road. The feasibility and success of such measures will however depend on the characteristics of the road corridor.

The author reviewed (Brattstrom 1965; Moore 1978; Sullivan 1981; Bernardino & Dalrymple 1992; Ashley & Robinson 1996) of proposing a mitigation measure to address the ecological requirement of thermoregulation that may be the primary factor influencing the number of individual snakes on roads or the time spent on the road surface during any foray to a road. The author recommend placing strips of individual surfaces that are attractive from a thermoregulatory perspective along the road in high mortality zones determined in this study (Figure 7.7).

Such measures can be initially implemented on the experimental basis and once tested for their effectiveness, can be subsequently replicated in other road

schemes. Results and practical guidance from this research should significantly reduce the mortality of Indian rock python and Russell's viper that command high conservation importance.

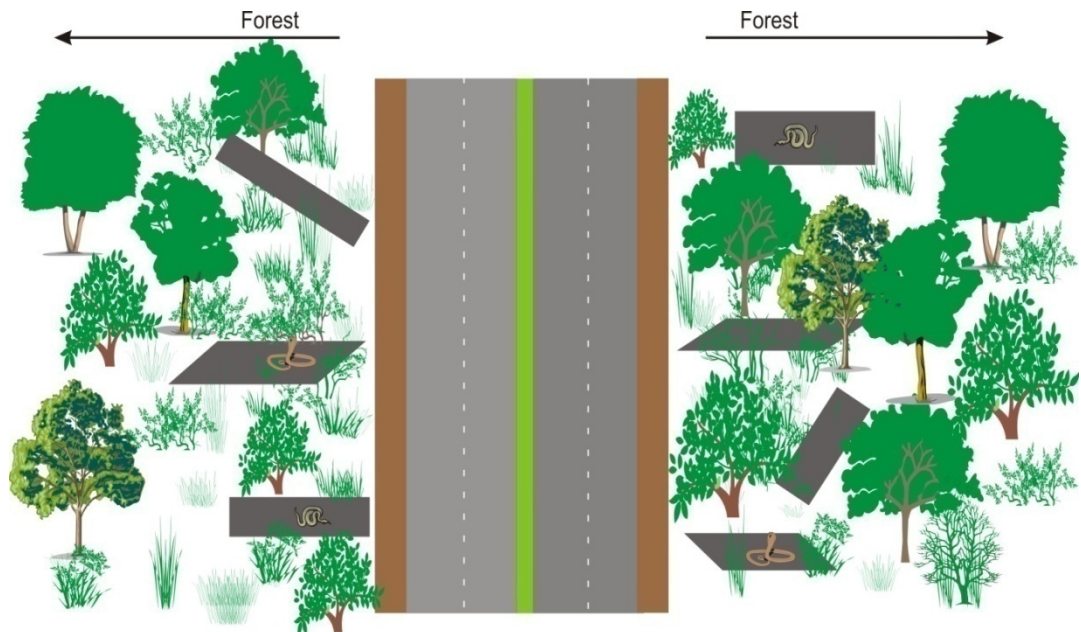


Figure: 7.7 Creation of alternative sites for thermoregulation of snakes.

Chapter 8. Evaluation of effectiveness of existing culverts and proposed design option

Introduction

The habitat of the small mammals are significantly fragmented by roads and highways, more so when the water sources are also cut across (Theobald *et al.* 1997; Forman & Alexander 1998; Trombulak & Frissell 2000). The culverts allowing water passage under the road are effective option of mitigating barrier effects of roads animal crossing (Hunt *et al.* 1987; Yanes *et al.* 1995; Rodriguez *et al.* 1996; Clevenger *et al.* 2001; Cain *et al.* 2003; Mata *et al.* 2005; Corlatti *et al.* 2009). While the species become adaptive to change on roads for crossing the roads the presence of culverts and passages reduce the effect of fragmentation and can make this adaptation feasible to avoid vehicular collisions. The road corridors however may impose limitations for the dispersal or migration of local fauna (Meaney *et al.* 2007).

Culverts under the road with ledges can provide passageways for small mammals, with dry culvert sections for crossing of larger mammals. The importance of such road culverts and under passages has been well appreciated for their three functional benefits: (i) increasing the permeability for wildlife movement (ii) reducing the road related mortality (Clevenger & Waltho 2000; Cramer & Bissonette 2006) and (iii) minimizing the risks to both humans and wildlife populations (Bond & Jones 2008; Fairbank 2012). The role of such culverts becomes even more significant where the likely increase in the road width would decrease the rate of successful crossings (Lovallo & Anderson 1996; Philcox *et al.* 1999; LaPoint *et al.* 2003) and make small and medium sized mammals more vulnerable to road kills and predation (Korpimaki & Norrdahl 1989; Rodriguez *et al.* 1996).

Experience about the efficacy of culverts for increasing road permeability and habitat connectivity for terrestrial wildlife is accumulating from studies around the world. Considerable numbers of studies have evaluated the effectiveness of existing wildlife crossing structure in Canada (Clevenger *et al.* 2001; McDonald & St. Clair 2004; McGregor *et al.* 2008; Clevenger & Sawaya 2010); Spain (Grilo *et al.* 2008; Mata *et al.* 2008), Sweden (Olsson *et al.* 2008; Neumann *et al.* 2012), The Netherlands (Reijnen *et al.* 1996), Czech Republic (Rico *et al.* 2007), United Kingdom (Rondinini & Doncaster 2002), Australia (Van der Ree *et al.* 2009), and USA (Boarman & Sazaki 2006).

Many of these studies have been able to establish that drainage culverts can mitigate the potentially harmful effects of road by providing a vital habitat linkage for large to medium-sized and small mammals (Ascensao & Mira 2007; Grilo *et al.* 2008; Mateus *et al.* 2011). These studies also demonstrate that the effectiveness of culverts in ensuring wild animal movements across the roads depend on a number of variables, including: size, proximity to natural wildlife corridors, noise levels, substrate, vegetative cover, moisture, temperature, light, and human disturbance (Jackson & Griffin 2000; Sparks & Gates 2012). Species specific structural requirement for movement across roads may however pose the risk of such structures become barriers for most other species (Barnum 2003).

Among the factors affecting use of culverts by small and medium-sized terrestrial vertebrates, proximity to cover and culvert dimensions have been reported to be important determinants (Hunt *et al.* 1987; Yanes *et al.* 1995; Rodriguez *et al.* 1996). Openness and the potential for animals to see the habitat on the other side of

the underpass are other important factors that have been cited by many workers (Reed & Woodard 1981; Foster & Humphrey 1995; Clevenger & Waltho 2000).

The benefits of safe crossing structure for wildlife in the improved transportation corridors are (1) habitat connectivity (2) reduced animal vehicular collisions and (3) increased safety of the motorists and pedestrian. The successful usage of the culverts as passageways for wildlife depends on the location of the culvert, its topography, adjacent habitat characteristics, dimension, its construction materials and also its seasonality of dryness and water passage (Brudin 2003). Appropriate and well maintained fences in the adjoining areas can also funnel the animals towards the underpass and encourage their use (Jackson & Griffin 1998).

Several factors can influence the use of culverts by mammals there include: dimensions (width and length) of the underpass, its proximity to natural corridors, noise levels from anthropogenic disturbance, illumination of the passage, type and density of the adjoining vegetative cover, material used for construction of underpass, micro climate, nearness to the water source, its accessibility during monsoon and anthropogenic use (Wang 2014). The ecological and behavioural patterns of animals are known to influence the adaptation of these passages a much complex process (Hartmann 2002). The study of these factors can help in design and construction of passages that become most effective for use by animals (Jackson & Griffin 2000).

This study was undertaken to evaluate the effectiveness of thirty six culverts that exist in the route corridor of NH-7 aligned along the wildlife habitats extending to Pench Tiger Reserve on one side of the road and to the South Seoni Territorial Forest Division on the other side.

This study had the following key objectives:

- i. Monitor the use of existing drainage culverts by mammals using the habitats in the road corridor
- ii. Assess permeability of culverts for mammals
- iii. Identify the factors influencing the use of culverts as movement corridors
- iv. Provide recommendations for retrofitting design of existing drainage culverts for small and medium-size mammal requirements
- v. Provide best practice guidance for planning crossing structures in future road corridor.

Methods

Although the road underpasses are used by wildlife for their movement, this may vary with species preference, culvert design, topography, water source, landuse of the culvert sites along with seasonal and regional local changes, like the passageway becoming too warm, or getting submerged in water during monsoon (Sparks *et al.* 2017). The various types of species using the passageway should be taken into consideration to provide an understanding of the use of culverts of various forms and dimensions. Thirty six culverts were monitored within a 9 km road corridor. These culverts can be broadly classified into: (i) Pipe culverts (n=27) with diameter ranging between 0.5 m to 1.0 m and (ii) Slab culverts including box

culverts (n=3) and Arch culverts (n=6) ranging in dimensions (height × width) from 2×2 to 5×10.

The passages in box and arch culverts (n=9) were monitored from August 2008 to July 2010 using (i) track plots to detect animal footprints inside the culverts and (ii) camera traps to obtain spatio-temporal evidences of use by animals (Figure 8.1). For assessing the permeability of pipe culverts, attempts were made to track direct and indirect evidence of mammals at the entry/exits. Footprints of mammals were collected on a Pugmark Impression Pads (PIP). For this, soft sand was spread across the entire width of each of the large box culverts on either end up to a depth of 3 m to monitor animal use (Figure 8.2). Observations were made (total 540 days) during three seasons (winter, summer and monsoon) during 2008–2010. Each time, a passage was visited, the animal species was identified based on tracks and the direction and the size of the footprints was noted. Afterwards, the bed was levelled into a smooth surface to determine the use of different types of culverts by animals. In case of smaller culverts, largely the pipe culverts, the entrances were inspected for animal evidence in all the seasons for over a two year (2008–2010) period.

A passive sensor camera trap (WILDVIEW xtreme 2, Grand Prairie, Texas, USA) was placed at the centre of each culvert. Due to high risk of theft in the area, the passages were chosen according to their provision of suitable mounting, securing and camouflaging possibilities while ensuring that they were positioned along a path, which captured most movements of most animals either to or from the culverts. Camera traps were fixed for 270 operative days in three seasons (winter, summer and monsoon) and checked every alternative day to collect the photographs. These photographs that provided information on the date and hour of the capture of the

animal were used to monitor the daily activity patterns of animals using the culvert. The capture time was used to create a 24 hour activity pattern of all species using the different culverts to characterize them as nocturnal or diurnal. On a rare occasions, when an individual was captured more than once at a camera station during a short period of time (<1 minute), only the first capture of that animal was taken to avoid pseudo-replication. The crossing rate was calculated based on the number of times the given species used the passage (as per data from PIP and camera traps) and divided by the number of operative days of sampling in each season.

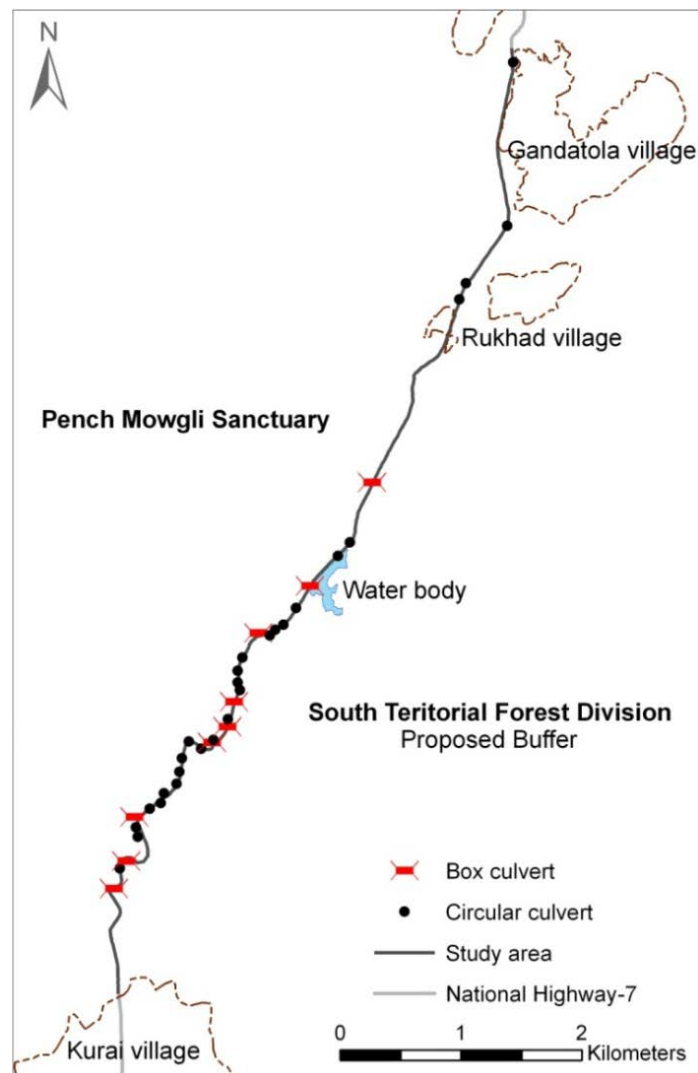


Figure 8.1 Location of box and circular culverts located in NH-7 along Pench Tiger reserve.



Figure 8.2 Preparing for collecting Pugmark Impression Pads (PIP) and fixing cameras traps for photo documenting the use of culverts.

Nine independent variables encompassing structural, landscape and disturbance in each culvert were selected for conducting use analysis (Table 8.1) under this study. The animal use and structural variables (height, depth and width) of all culverts were measured to calculate their openness ratio = $\text{width} \times \text{height} / \text{depth}$ following Reed and Ward (1985). Noise level (db) mean of A-weighted decibel was recorded at the centre point of the culverts. Landscape variables such as distance from the village (m), water body (m) and drainage (m) were obtained using the Euclidean distance method in Arc Info. Altitude (m) and slope (degree) was derived

from ASTER 30 m resolution Digital Elevation Model (DEM). Structural variables such as openness of culvert, distance to forest cover (m) and disturbance (human and domestic animals) were recorded. Pearson’s Correlation Test was used to check if there was any correlation between the use of culvert by different mammal species and the landscape and structural variables.

Table 8.1 Variables and their description used in the analysis.

Variable name	Description	Unit	Source
Openness of culvert	Width(m) x length(m) / height(m) of the culvert	index	Field sampling
Noise level	Mean noise level in culverts	decibel (dbl)	Field sampling
Biotic disturbance	Number of human and domestic animals recorded in culvert	count	Field sampling
Distance to cover	Distance to vegetation cover taken from both sides of culvert	metre	Field sampling
Distance to drainage	Distance to nearest seasonal drainage	metre	Euclidean distance(Arc Info)
Distance to water body	Distance to nearest water source (lake)	metre	Euclidean distance(Arc Info)
Distance to village	Distance to nearest human settlements	metre	Euclidean distance(Arc Info)
Elevation	Mean ground altitude of the culvert	metre	Digital elevation model
Slope	Mean ground slope of the culvert	degree	Digital elevation model

Results

Use of culverts based on field based monitoring

216 complete tracks in PIPs were recorded in different culverts and seasons. Presence of tracks varied from 2 to 46 tracks per culvert in the total duration of the study.

Of the thirteen species of mammals that use the habitat (refer Chapter. 3) in the corridor of NH-7, only 7 species were observed to be using the slab culverts (including both, the box and the arch culverts) as is evident from PIP observations and camera traps data. Species use of individual culvert varied from 1 to 7 species

per culvert. An average of 0.36 animal crossing/culvert/days was recorded based on the total monitoring (540 days) effort under this study.

It becomes evident from the PIP and camera traps data that large herbivores species such as sambar and chital did not use any of the slab culverts. Rhesus macaque (*Macaca mulatta*) and Hanuman langur (*Semnopithecus entellus*) very sparingly used the culverts because the human facilitated feeding tends to attract these animals to use the road and roadside habitats (Pragatheesh 2011).

The animals that were recorded to be using culverts in all seasons were small mammals such as wild pig, palm civet, jungle cat, porcupine and mongoose. The relative use of the culverts based on observations in all seasons reflected variability in the use by different animal species: wild pig: 0.230 ± 4.82 crossing/day; common palm civet: 0.067 ± 0.67 crossing/day; Indian porcupine: 0.022 ± 0.51 crossing/day; jungle cat: 0.007 ± 0.69 crossing/day; grey mongoose: 0.007 ± 0.19 crossing/day (Table 8.2, Figure 8.5a and b). These figures suggest very limited use of culverts. The relative use of culverts across seasons is however highest during summer (0.23 crossings/culvert during) when compared to use in winter (0.08 crossings/culvert) and in monsoon (0.04 crossings/culvert). This supports that culverts may function as refreshing spots for temperature regulation and this may thereby increase their attractiveness for animals during the hottest periods of the year (Ascensao & Mira 2007).

Table 8.2 List of species using the slab culverts.

No	Species		Use of slab culvert to cross the highway	
	Common name	Scientific name	Crossing/day	S.E.
1.	Common palm civet	<i>Paradoxurus hermaphroditus</i>	0.067	0.67
2.	Grey mongoose	<i>Herpestes edwardsii</i>	0.007	0.19
3.	Hanuman langur	<i>Semnopithecus entellus</i>	0.020	1.35
4.	Indian porcupine	<i>Hystrix indica</i>	0.022	0.51
5.	Jungle cat	<i>Felis chaus</i>	0.007	0.69
6.	Rhesus macaques	<i>Macaca mulatta</i>	0.003	0.19
7.	Wild pig	<i>Sus scrofa</i>	0.230	4.82

Maximum numbers of animals were captured during early morning and late night (Figure 8.3). Use of a culvert was positively related to the number of mammals using the roadside (Pearson-Product Moment $r = 0.819$, $p = 0.001$), and negatively correlated to disturbance caused by biotic factors (human and domestic animals) within the culverts (Pearson-Product Moment $r = -0.830$, $p = 0.001$).

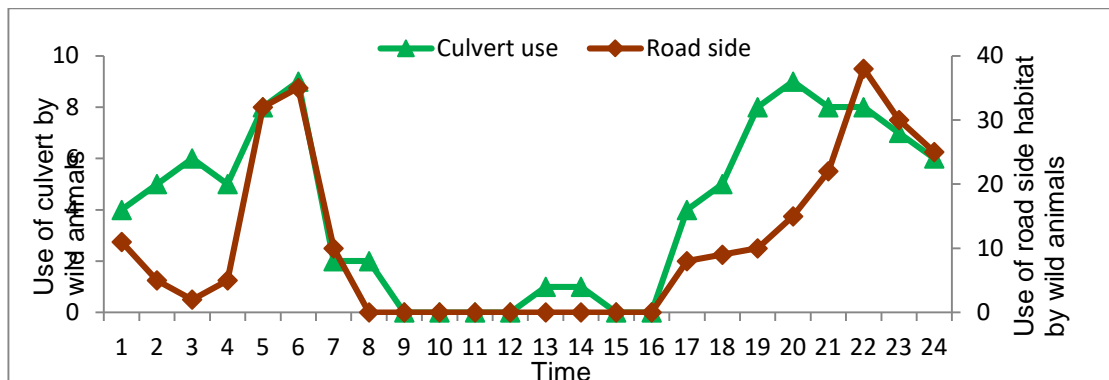


Figure 8.3 Temporal patterns showing the use of the roadside habitats and the culverts by animals.

There is an evidence of temporal variations in the use of culverts by wild animals and biotic elements (livestock and people). This may be one of the ways to combat the impacts of biotic pressures on the use of crossing structure (Figures 8.4

and 8.6). No evidence (direct or indirect) of use of any of the pipe culverts (n= 27) by wild mammals was observed during the study.

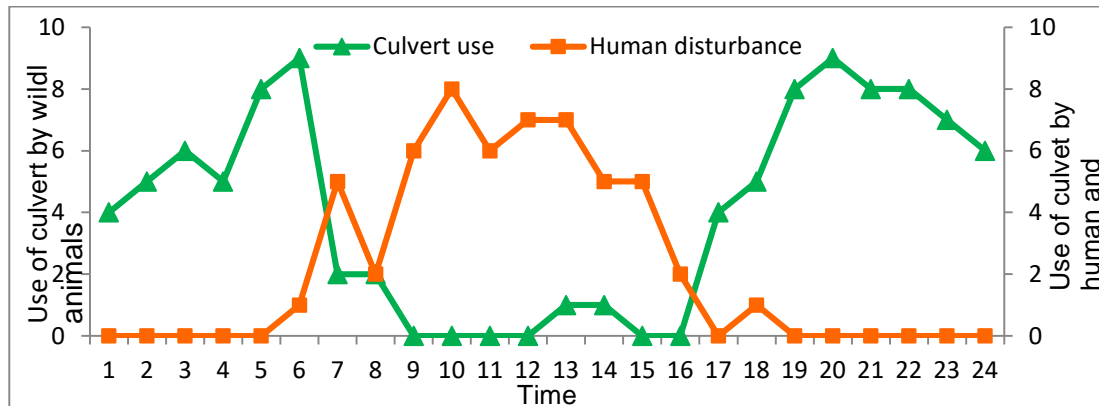


Figure 8.4 Temporal differentiation of culvert use by wild animals and biotic elements.



Figure 8.5 a Drainage culvert used by wild animals in Pench Tiger Reserve.

A: Wild pig (*Sus scrofa*). **B:** Indian porcupine (*Hystrix indica*). **C:** Jungle cat (*Felis chaus*). **D:** Grey mongoose (*Herpestes edwardsii*). **E:** Hanuman langur (*Semnopithecus entellus*). **F:** Rhesus macaques (*Macaca mulatta*)



Figure 8.5 b Biotic pressure on drainage culvert. **A:** Domestic dog. **B:** Cattle. **C:** Human

Factor influencing use of culvert by mammals

In the present study, mammals varied in their use of the slab culverts including both box and arc type culverts. These culverts which varied in location, dimension, neighbourhood characteristics (e.g. proximity to vegetation, water bodies and villages) degree of openness and level of biotic pressures influenced the responses of different animal species to use these as movement corridors.

Pearson's Correlation Test shows that animal use was positively correlated ($r = .602$, $P < 0.01$) with the openness of culvert and disturbance in the culvert while species use was negatively correlated ($r = .583$, $P < 0.01$ and $r = .438$, $P < 0.01$) to the noise level in the culvert and proximity to the forest (Table 8.3). The openness of the culvert is directly proportional to the number of species using the culvert, i.e., species richness ($n=7$). Other variables such as disturbance in the culvert, distance to village, and distance to drainage, elevation and slope did not influence the culvert use.

Table 8.3 Pearson's Correlation Coefficient between species and explanatory variables.

	Species use	Openness of culvert	Noise level	Disturbance	Distance to cover	Distance to drainage	Distance to water body	Distance to village	Elevation	Slope
Species use	1									
Openness of culvert	.602**	1								
Noise level	-.583**	-.519**	1							
Disturbance	-.776**	.857**	-.461**	1						
Distance to cover	-.438**	-.302	.414*	-.205	1					
Distance to drainage	-.086	-.090	.277	-.071	.191	1				
Distance to water body	-.028	-.160	-.107	-.140	-.126	.201	1			
Distance to village	-.217	-.300	.354*	-.372*	-.081	.165	-.152	1		
Elevation	-.134	.097	.216	-.004	.217	-.136	-.811**	.172	1	
Slope	-.228	-.277	.135	-.188	.210	.132	.509**	-.262	-.405*	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

An attempt was made to review locational attributes of culverts in the road corridor as these can make or mar the prospects of successful wildlife crossing. It was observed that the location of most of the culverts corresponded with high mortality zones on the road. Figure 8.6 illustrates that all of the culverts are ideally located in sections of the road which correspond with high animal mortality locations. This is suggestive of animal's preference for road over culverts for moving across the road even if such attempts resulted in threats of collisions with moving vehicles.

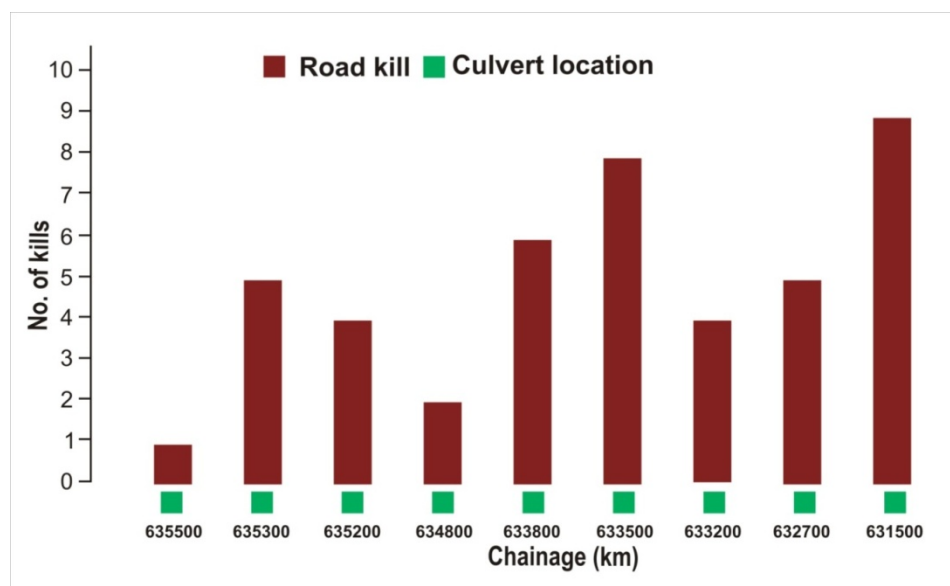


Figure 8.6 Location of culvert and road kill around the culvert.

With this, the ineffectiveness of culverts in terms of facilitating the animal movement can be now more convincingly explained in context of the limitations associated with design and dimensions of all the 9 culverts in the NH-7 corridor. This reiterates the need for improved planning and designing of culverts to ensure their

benefit in facilitating the linkage between the wildlife habitats on either side of the NH-7.

I. Evaluation of the suitability of existing culverts for movement of mammals based on their design and dimensions






The 9 km stretch (Chainage 627.000 to 635.900 km) of NH- 7 crossing through Pench Tiger Reserve has 36 culverts in which 27 are pipe and box culvert and 9 are medium sized culvert. Each of these culverts was evaluated for their suitability as passages for movement of wildlife across NH-7. Goals and criteria for evaluating the suitability of structures to facilitate terrestrial wildlife movement from one side of a highway to the other were developed. Current body of knowledge and globally available guidance for reviewing the permeability of crossing structures for wildlife for evaluating animal passages was used for this (Beier & Loe 1992; Smith 2003; Ruediger & DiGiorgio 2007; Kintsch & Cramer 2011). The information was compiled on suitability of structural features and other passage attributes (landscape, slope, animal preferences for different structures) for ensuring their efficacy as passages (Tables 8.4 and 8.5)






Table 8.4 Passage attributes preferred by different sized mammals.

Category	Type/shape	Height (m)	Width (m)	Length (m)	Animal class		Preferred passage attributes	Reference
					Group	Size		
Culvert	Circular	0.5 – 1.0	0.5 – 1.0		Mammal	Small	Structure which provides enclosed protection from small animals that require cover.	Foster & Humphrey (1995), Land & Lotz (1996), Rodriguez <i>et al.</i> (1997), Clevenger & Waltho (1999), Clevenger <i>et al.</i> (2002), Servheen <i>et al.</i> (2003), Foresman (2004).
	Circular	1.0 – 1.7	1.0 – 1.7		Mammal	Medium	Functional crossing structure including a variety of structure types and sizes. A non-submerged pathway is almost always preferred and usually required by species.	Clevenger & Waltho (1999), Mata <i>et al.</i> (2005).
	Arch	2-4.6	2- 4.7	35–50	Mammal	Small	Crossings providing species-specific habitat and conditions throughout the entire structure, including natural substrate, light, temperature and moisture.	Ng <i>et al.</i> (2004), Mata <i>et al.</i> (2005).
Bridge culverts	Small Bridge (box culvert)	1.5	3.6	30	Mammal	Medium	Species in this groups use a variety of structure types and prefer to have suitable habitat directly adjacent to the entrance of the structure	Reed <i>et al.</i> (1975), Donaldson (2005), Ehinger <i>et al.</i> (2006), Hardy <i>et al.</i> (2006), Singer <i>et al.</i> (2011).
	Medium bridge	4.8	8.8	37	Mammal	Large	Passages that have good visibility within and around the structure and clear line of sight from one end of a crossing structure are wider than they are tall	Ehinger <i>et al.</i> (2006), Kintsch & Cramer (2011), Sawyer & LeBeau (2011).
	Spanning bridge underpasses for wildlife	5-10	6-30	27-84	Mammal	Large	Open structure that provide good visibility but can be tolerant of longer structure. Species in this group then to prefer more open structure.	Brown <i>et al.</i> (1999), Ng <i>et al.</i> (2004), Tritsis (2011).

The results of the evaluation are presented in Table 8.5.

Table 8.5 Suitability of the different type of existing culverts in NH-7 corridor.

Sl. No	Existing structure	Dimension (height × width) meter	Suitability
1.		0.5×0.5	Appropriate for use by species of snakes and other small reptiles and mammals such as rodents, hair and mongoose. The use is likely to become restricted with progressive accumulation of silt load in the passages.
2.		1×1 or 2×1	Suitable for movement of amphibian, lizards and snakes and small mammals such as mongoose, civets that are shy and require some cover.
3.		1×2	Not suitable as crossing structure for large bodied animals such as tiger, gaur, sambar and chital that critically require a movement passage in the road corridor
4.		2×2 or 2×3	Appropriate for use by small mammals that prefer some cover and openness in their passages for better visibility. The structure will have limited suitability in the long term as such structures are likely to have a reduced opening because of gradual silt load accumulation as these are planned on streams.
5.		2×4	More wide then high structures reduce openness and become unsuitable for movement of large carnivores and large ungulates.

6.		3×2	More wide then high structures reduce openness and become unsuitable as underpass for use by large carnivores and ungulates but can be used by smaller mammals such as jungle cat, palm civet, jackals.
7.		3×3	Not suitable for use by large carnivores like tiger wild dog and ungulates such as gaur which require large and more open areas, good light and some cover in crossing zones.
8.		3×9	Dimensions are not appropriate for use by species such as tiger, leopard, wild dog and large ungulates like gaur, sambar, nilgai and chital. Wider, higher, and more open underpass would improve permeability for these species.
9.		5×6 or 5×7	Proposed height of the piers is not suitable for use by leopards, tigers and gaur, sambar, chital which need more open passages openness and good visibility in the passage.
10.		5×10	Location and dimensions are not suitable for use by large carnivore and large ungulates. This underpass is located very close to human settlement and too the site of the proposed underpass. It receives high biotic pressures which may discourage animals from using the proposed underpass effectively.

Key findings

The following are the silent finding:

- Out of 13 species using the habitat in the road corridor, only 7 species used the culverts.
- Species use of individual culvert varied from 1 to 7 species per culvert.
- The use of culverts by the mammals of the area is very limited. An average of 0.36 animal crossing/culvert/days was recorded based on the total monitoring (540 days) effort under this study.
- Use of culverts was not influenced by location in the present context.
- Use of culverts was strongly influenced by openness ratio, dimension and design features and not by location in the present context.
- Use of the culvert by animals was positively correlated with the openness of culvert and negatively correlated to the forest and biotic disturbance.
- Alternative structures are needed to address the connectivity issues for animal movement across the road.

Discussion

Number of species using the crossing structure for movement across roads is an important evaluation criterion for evaluating the effectiveness of culverts (Alexander & Waters 1999; Veage & Jones 2007). Out of 13 species using the habitat in the NH-7 corridor, only 7 species used the culverts. These observations are in conformity with Kinhill Pty Limited (1996) and AMBS Consulting (1997) who

estimated that half of the number of species recorded from the surrounding area use culverts.

Frequency of crossings at each structure is another important factor that determines the level of permeability of such structures (Alexander & Waters 1999). The usefulness of these constructed structures are effected by their vegetation cover, the animal behavioural and movement patterns, human use of / near the structures, and the size and type of the structures (Lesbarrères *et al.* 2004; Clevenger & Waltho 2005; Lesbarrères & Fahrig 2012). Barrier fencing with proper length and sturdiness, appropriate line of sight to the crossing structures are also supplementary factors to effect the rate of usage of the passageways by wild animals (Clevenger *et al.* 2001; Clevenger & Huisjer 2011; Huijser *et al.* 2016). Based on the present study, 0.36 animals/culvert/day are using the culvert to cross the NH-7 road, indicating that the animals using the culverts are comparatively lower than those occurring in the roaded habitat.

The primary aim of wildlife-friendly structures is to minimize the influence of roads on wildlife populations. This includes reducing direct effects such as road-kill and increasing the permeability of such structures for safe crossings. Evaluation of the effectiveness of crossing structures has therefore been the focus of several studies around the globe (Corlatti *et al.* 2009; Glista *et al.* 2009; Huijser *et al.* 2009; Mata *et al.* 2009; Van der Ree *et al.* 2009; Clevenger & Sawaya 2010; Mateus *et al.* 2011; Sparks & Gates 2012, 2017) but the outcomes are complex to form a basis for arriving at consensus about the ‘ideal fit’ for crossing structure that can be universally adopted. Some studies have argued that the location of a crossing structure, particularly in the relation to habitat quality, is the most important factor

predicting the effectiveness feature (Podlucky 1989; Foster & Humphrey 1995; Yanes *et al.* 1995; Rodriguez *et al.* 1996; Clevenger & Waltho 2000; Glista *et al.* 2009).

The use of the underpasses by ungulates may vary between location and the type of underpass, including its line of sight, vegetation and its accessibility (Dodd *et al.* 2007; Gagnon *et al.* 2011). Underpasses like bridge-type structures can also be favourable to ungulates, when combined with the suitable vegetation in the nearby areas. The adaptation to the underpass also varies from residential to migratory wild animals. These crossing structures are effective in reducing fragmentation of habitats, conserving migratory corridors and enhancing the safety of both the animals crossing the roads and the vehicular traffics (Simpson *et al.* 2016). Ungulate studies have shown that placement of crossing structures near existing game paths can possibly improve the structure's success (Groot & Hazebroek 1996). Road ecologists and engineers have used historical road kill data and crossing points (Scheick & Jones 1999; Buchanan 2005) for choosing locations for crossing structures that can best address connectivity issues meaningfully.

The experience from the present study however completely flouts the logic that culvert located in animal crossing zones on the road will perform better as movement conduits. In the 9 km section of NH-7, all the culvert (n=9) locations corresponded with zones of high road kills. Behavioural response of species could be another aspect that needs to be considered in understanding the avoidance of culverts by some animals. Many ungulates avoid underpasses unless there is no other way to cross a road (Ward 1982) Evidence in support of several species avoiding the crossing structures altogether is reflected from elk in Canada, avoiding confining

structures (Ng *et al.* 2004; Clevenger & Waltho 2005), black bear (*Ursus americanus*), bobcat (*Lynx rufus*) and coyote (*Canis latrans*) not using any of the surveyed culverts in the state of Maryland Sparks and Gates (2012) and bighorn sheep not using any of the crossing structures along the more recently twinned section of Trans Canada (Bristow & Crabb 2008).

Studies reporting increase in use of crossing structures over time, suggest that there is an initial acclimation period (Land & Lotz 1996; Opdam 1997; Clevenger & Waltho 2004; Baofa *et al.* 2006) which limits the use of culverts. Clevenger and Waltho (2004) observed more than fivefold increase in subsequent use of such structures by ungulates over a 5-year period. In the present context, many of the existing culverts do not appear to be the conduits for movement of mammals despite the fact that the road constructed several decades ago provided ample time for acclimatization of animals to such structures.

Clevenger *et al.* (2001) found that as traffic volume increase, small mammals tend to increase their use of culverts for crossing roads. The present study however does not support this to be true either as most species that preferred road over culverts for their movement continued to use the roads intermittently between the traffic peaks. The failure to cross the road successfully resulted in a total of 272 of road induced kills of mammals (comprising 15 species) in 430 days during August 2008 to July 2010 (refer Chapter 4).

Researches have shown that the design of the structure can be the most influential factor for influencing use (Reed *et al.* 1975; Ballon 1985; Cain *et al.* 2003; Clevenger & Waltho 2005). Study conducted in Trans-Canada Highway (Clevenger & Waltho 2005) found that the most often herbivores and carnivores

were using the crossing structure which had high openness ratios. From the study in Northwest Spain (Mata *et al.* 2003) it was observed variation animals varied in that choice and preferences for crossing structure. Structures used by humans were avoided by the wild animals; who preferred crossing the roads.

The evaluation of the culverts in the NH-7 corridor indicates that none of these culverts appeared to have sufficient structural and surrounding characteristics (openness, low biotic influences and suitable habitats around the structures). Some of the culverts with low openness ratio (width \times height/depth) were sparingly used (0.36 animal crossing/culvert/day) by some species. Some compelling factors (cover, resources, mates, and high peaking traffic) may be sometimes forcing the animals to use culverts for movement across the road.

In addition to this, the functional approaches that have been reviewed in the context of underpass use by mammals illustrate that corridor value for animals is also determined by many factors, such as its length, the topography and vegetation cover of the corridor, conservation importance of species, and adjacent human activities (Reed *et al.* 1975; Harris 1984; Henein & Merriam 1990; Ng *et al.* 2004; Ascensao & Mira 2007). The influence of biotic disturbance on use of culverts is also reflected from the present study where the culvert located close to Rukhad village (chainage 627.600) that experienced high biotic influence was not used by animals as the use of these culverts overlapped with use by the domestic cattle and dogs. Culverts located away from the village were sparingly used by several species (Rukhad village). Although there is evidence of carnivore species presence in the road corridor (e.g. tiger, leopard, sloth bear and wild dog), only jungle cat was recorded in the drainage culverts. This is perhaps sensitivity of the animals on the distribution and structure of

the culverts. Clevenger and Waltho (2000) even found that carnivore use was more influenced by human activities than by structure variables. Rodriguez *et al.* (1996) observed that the crossing structures placed near continual disturbance area were less frequently used by large animals (e.g., carnivores and ungulates), Small mammals likewise, avoided crossing structures located in disturbed areas (McDonald & St Clair 2004; Mata *et al.* 2005).

Almost all of the culverts in the stretch of NH-7 are located in wildlife habitats. Culverts surrounded with adequate cover had relatively higher number of animal tracks. The presence or amount of cover (shrubs or trees) at passage entrances has been considered an essential component for designing effective crossing structures (Hunt *et al.* 1987; Rodriguez *et al.* 1996; Rosell *et al.* 1997). The habitat attributes of the area surrounding the entrance to other passages discouraged use of such culverts. It is quite likely site that of limited the use of crossing structures by specific species. This is in conformity with the studies (Pede villano & Wright 1987; Clevenger & Waltho 2000) that highlighted that vegetation cover present on the either end of the crossing structures can also obstruct the view of ungulates, some culverts were such that they obscure visibility through the culvert and leave prey species more vulnerable to predators (AZGFD 2006).

This study concludes that all of the existing culvert structure had low permeability for mammals especially for large mammals present in the area. Based on road kills/hits, indirect evidences of animal presence during all three seasons (summer, winter and monsoon) over two years and the monitoring of the culverts, it is an accepted fact that the animals use the road more often than the crossing structures.

Mitigation

Although Mitigation measures are best applied at the planning stage of road construction, results from our study of an operation highway provide a useful insight for the design and placement of future wildlife underpasses, as well as retrofitting existing structures.

Keeping in view the proposed expansion of this road into a four lane highway, it is vital to ensure connectivity of the habitats across the roads in these zones for ensuring long term conservation of carnivore and herbivore species many of which are important from conservation perspective. One of the important considerations in enhancing the efficacy of the passages in this road stretch is to secure that underpasses must have sufficient width to maintain interior habitat qualities that would enhance use by sensitive species. This has invariably been the guiding principle for promoting both, 'functional' connectivity and structural connectivity between fragmented wildlife habitats (Noss 1983; Noss & Cooperider 1994; Hilty *et al.* 2006; Beier *et al.* 2008; Kadoya 2009; Clevenger & Huijser 2011). The following two specific approaches are recommending for mitigating the impacts of existing NH-7 and its proposed widening to a four lane road:

i. Retrofitting measures

The culverts located in the corridor of NH-7 along the Pench Tiger Reserve have to be retrofitted where there is need for ensuring the animals crossing location to prevent animal-vehicle collisions. Culverts of appropriate should be used to accommodate different faunal groups rather than be targeted for specific species. Exception can be made when targeting the development of crossing structures for conservation reasons. In addition to the features that improve design and openness

ratio, continuous fencing towards the crossing structure would help reduce the mortality and help funnelling the animal towards crossing. A general guidance on suitability of different structures for wild animals using the habitats along the National Highway is provided in Table 8.6.

ii. New constructions

In order to increase the intended use of the wildlife habitats across NH-7 by the mammals, construction of 5 large passages is recommended for inclusion in the road widening plan of NH-7. The specification of size and, location along with justifications for these structures is provided in Table 8.7. The location of the existing structures (Figure 8.7) and additional structures (Figure 8.8a to 8.8e) proposed by Wildlife Institutes of India are shown on Google Imagery.

Based on the study additional structures are proposed on road section passing through PENCH Tiger Reserve (Chainage 627.000 To 635.900 Km):

Table 8.6 General guidance on planning suitable passages for animals using the habitats along National Highway-7.

Species	Large underpass			Culverts			Canopy crossing
	Open span bridge / flyover > 90 m wide × 7 m high	60 m wide × 7 m high	30 m wide × 7 m high	Slab culvert 3 to 5 m wide × 4 m high	Box culvert <3 m wide × 2 m high	Pipe culvert 1 to 2 m diameter	
Tiger	R	P	NR	NR	NA	NA	NA
Leopard	R	R	P	NR	NA	NA	NA
Sloth bear	R	R	P	NR	NA	NA	NA
Wild dog	R	R	P	NR	NA	NA	NA
Jackal	R	R	R	P	NR	NA	NA
Hyena	R	R	R	P	NR	NA	NA
Wolf	R	R	R	P	NR	NA	NA
Fox	R	R	R	P	NR	NA	NA
Jungle cat	R	R	R	P	NR	NA	NA
Rusty spotted cat	R	R	R	P	NR	NA	NA
Civet	R	R	R	R	NR	NA	NA
Mongoose	R	R	R	R	P	P	NA
Gaur	R	P	NR	NR	NA	NA	NA
Sambar	R	R	P	NR	NA	NA	NA
Nilgai	R	R	P	NR	NA	NA	NA
Chital	R	R	R	P	NA	NA	NA
Blackbuck	R	R	R	P	NR	NA	NA
Indian Muntjac	R	R	R	P	NR	NA	NA
Mouse deer	R	R	R	P	NR	NA	NA
Four horned antelope	R	R	R	P	NR	NA	NA
Indian gazelle	R	R	R	P	NR	NA	NA
Wild pig	R	R	R	R	NR	NA	NA
Porcupine	R	R	R	R	NR	NR	NA
Hare	R	R	R	R	P	NR	NA
Squirrels	R	R	R	R	R	P	R
Primates	R	R	R	R	NR	NA	R
Rodents	R	R	R	R	R	R	NA
Monitor lizard	R	R	R	R	R	R	NA
Snakes	R	R	R	R	R	R	NA
Turtles	R	R	R	R	R	R	NA
Frog and toad	R	R	R	R	R	R	NA
Lizards	R	R	R	R	R	R	NA
Invertebrates (creeping animals)	R	R	R	R	R	R	NA

R- Recommended, P-Possible if adapted to local condition, NR- Not recommended, NA- Not applicable

Table 8.7 Details of additional structures proposed.

Sl. No.	Chainage Km	Structure Type	Dimension (m)		Justification
			Width	Height	
1.	Mid Point: 628.500 Start: 628.100 End: 629.100	Underpass for Animals	1000	5	This section of the road is a well established crossing zone for herbivore species such as gaur, sambar, chital and wild pig. These species are using this section of the road to cross over. Other animals that are using this section are jackals, Indian Fox, jungle cat, palm civet and hare. Earlier studies have confirmed mortality of many of these species in this section. Considering this as a crossing zone for many species, an underpass in this section will greatly facilitate animal movement for optimum utilization of road side habitats. The underpass in this section will essentially have to be wide enough to provide adequate passage, light and openness.
2.	Mid Point: 630.600 Start: 630.000 End: 631.200	Underpass for Animals	1200	5	Large number of carnivores such as tiger, leopard and wilddog and herbivore such as gaur, sambar, nilgai, chital and wild pig cross over in this section. Based on the earlier studies conducted by WII, on this section, road kills of many of these mammals have been recorded. It would be necessary to construct a flyover for vehicles in this section to secure an undisturbed movement corridor for animals. Some of which are highly endangered. Such a passage will also require habitat improvement and management for encouraging use by animals
3.	Mid Point: 632.350	Underpass for Animals	90	5	This section is crossing zone for carnivore such as tiger and wild dog and for herbivore such as gaur, sambar, nilgai and chital. There are reports of road kills of chital, sambar, wild pig, jackal, jungle cat and civets from this area.
4.	633.550	Underpass for Animals	60	5	Carnivores such as tiger and wild dog and herbivore such as chital, sambar and wild pig cross in this section
5.	635.050	Underpass for Animals	60	5	Large carnivore such as tiger, leopard and wild dog and herbivore such as gaur, sambar, chital and wild pig frequently cross in this section. Maximum number of road kills especially of small mammals like jungle cat, palm civet and hare have been reported from this section.

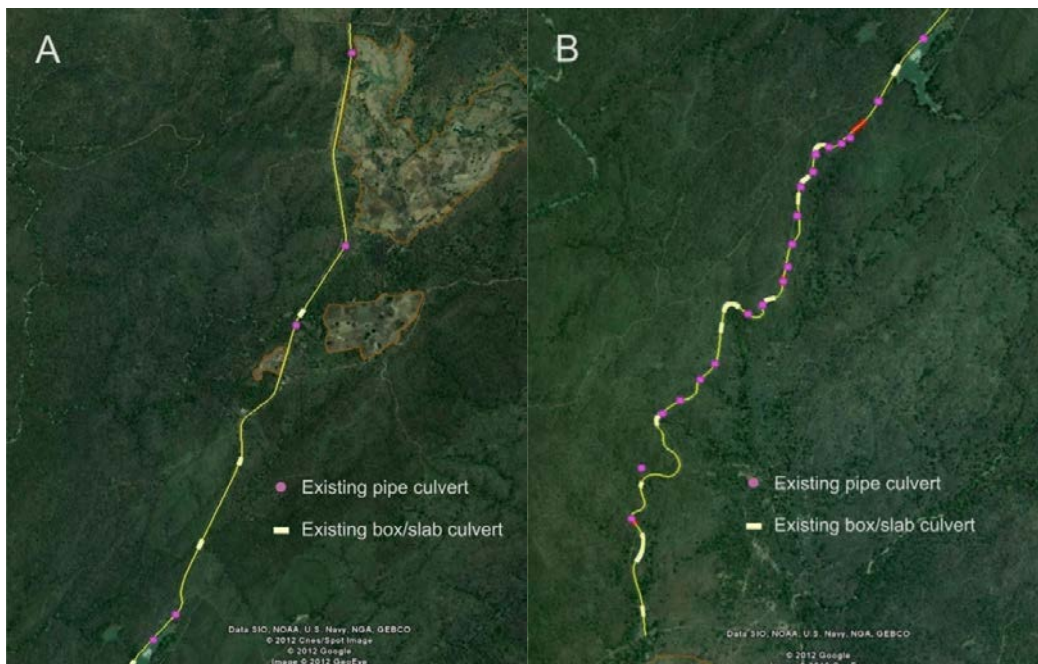


Figure 8.7 Location of the existing structures on NH-7 along the PENCH Tiger Reserve (A: Flat section of NH-7, B: Hilly section of NH-7).

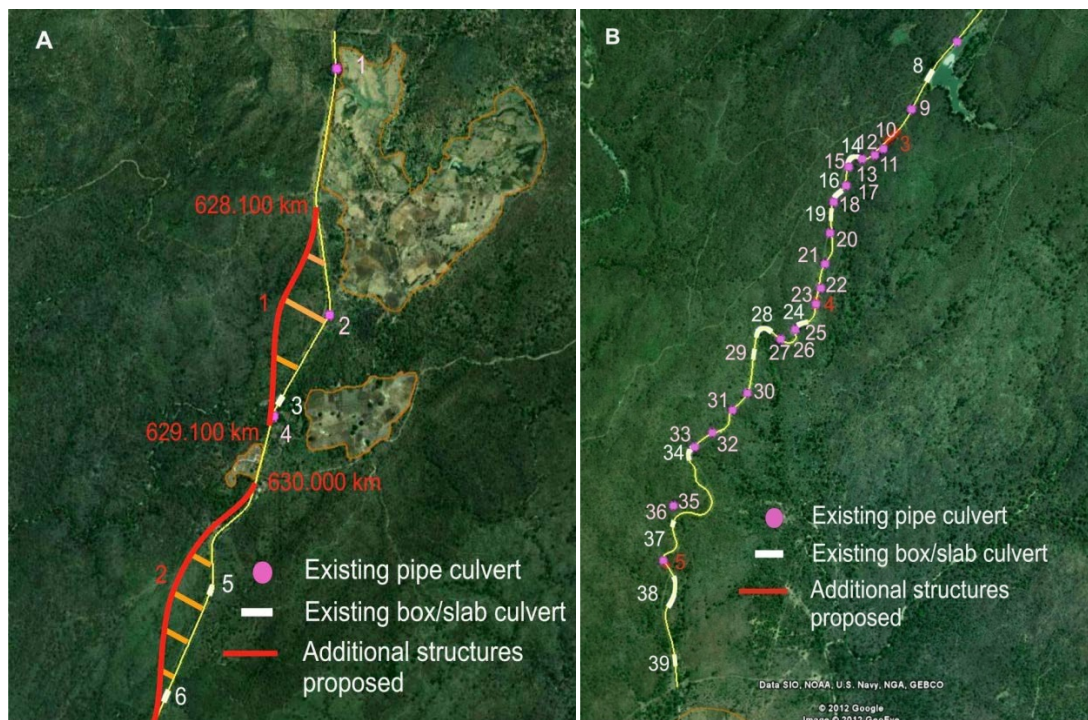


Figure 8.8a Location of additional structures proposed in this study on NH-7 along the PENCH Tiger Reserve (A: Flat section of NH – 7, B: Hilly section of NH-7).

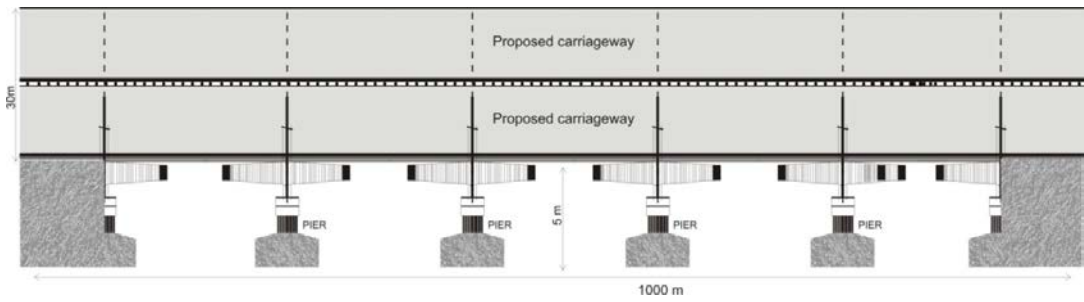


Figure 8.8b Proposed 1000 m underpass to fauna crossing at 630.600 (Start: 630.000 End: 631.200).

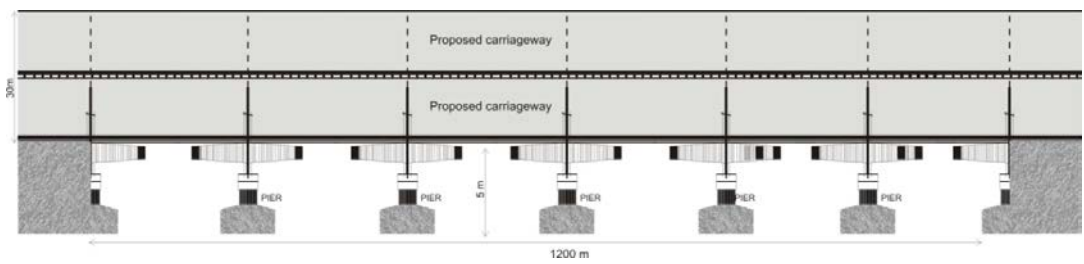


Figure 8.8c Proposed 1200 m underpass to fauna crossing at 628.500 (Start: 628.100 End: 629.100).

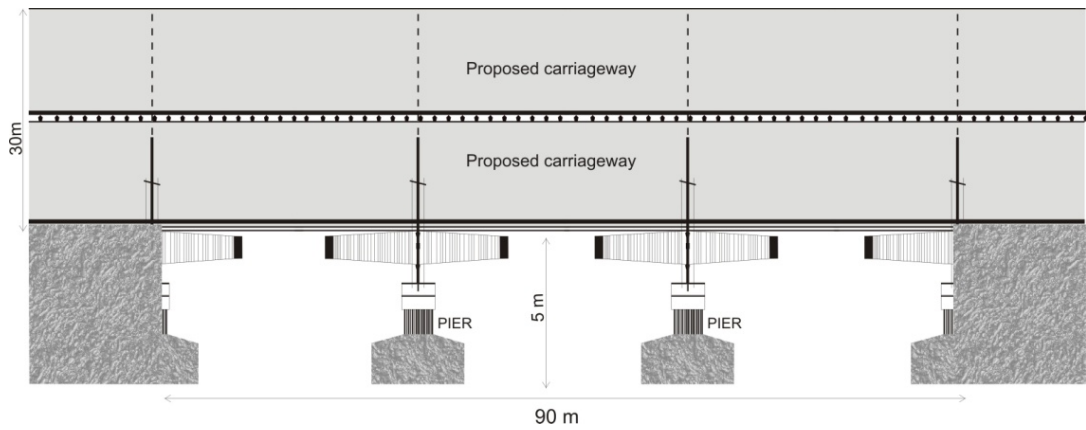


Figure 8.8d Proposed 90 m underpass to fauna crossing at 632.350.

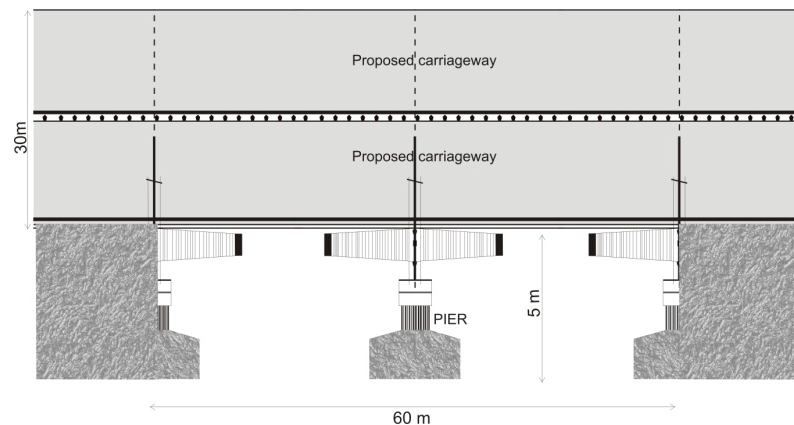


Figure 8.8e Proposed 60 m underpass to fauna crossing at 633.550 and 635.050.

9. References

- Aaris-Sorensen, J. (1995) Road-kills of badgers (*Meles meles*) in Denmark. *Annales Zoologici Fennici*, **32**, 31-36.
- Acharya, B.B., Sankar, K. & Johnsingh, A.J.T. (2006) *Ecology of the dhole (Cuon alpinus Pallas) in Central India*. Final Report, Wildlife Institute of India, Dehradun.
- Adam T.F. & Clevenger, A.P. 2018. Factors affecting the permeability of road mitigation measures to the movement of small mammals. *Canadian Journal of Zoology*, 1-6.
- Adams, L. & Geis, A. (1983) Effects of roads on small mammals. *Journal of Applied Ecology*, **20**, 403-415.
- Adams, L.W. (1984) Small mammal use of an interstate highway median strip. *Journal of Applied Ecology*, **21**, 175-178.
- Addo, J.Q. & Sanders, T.G. (1995) *Effectiveness and Environmental Impact of Road Dust Suppressants*. Mountain-Plains Consortium. U.S. Department of Commerce, Colorado [PB95-236543].
- Akrim, F., Mahmood, T., Andleeb, S., Hussain, R. & Collinson, W.J. (2019) Spatiotemporal patterns of wildlife road mortality in the Pothwar Plateau, Pakistan. *Mammalia*. doi:10.1515/mammalia-2017-0101.
- Alexander, S. & Waters, N.M. (1999) *Decision Support Applications for Evaluating Placement Requisites & Effectiveness of Wildlife Crossing Structures*. Proceedings of the Third International Conference on Wildlife Ecology & Transportation (ICOWET), FL-ER-73-99) (ed G.L. Evink *et al.*), pp. 237-252. Florida Department of Transportation, Tallahassee, FL.
- Alexander, S.M., Waters, N.M. & Paquet, P.C. (2005) Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains, *The Canadian Geographer*, **49**, 321-331.

- Ali, S. & Ripley, S.D. (1989) *Concise Handbook of the Birds of India and Pakistan*. Oxford University Press, Delhi.
- Anderson, P. (2002). Roads as barriers. *Wildlife and Roads: The Ecological Impact* (eds B. Sherwood, D. Cutler & J.A. Burton), pp. 169-184. Imperial College Press, London.
- Andre, N.H. (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos*, **71**, 355-366.
- Andreassen, H.P., Ims, R.A. & Steinset, O.K. (1996) Discontinuous habitat corridors: effects on male root vole movements. *Journal of Applied Ecology*, **33**, 555-560.
- Andren, H. (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat – a review. *Oikos*, **71**, 355-366.
- Andrews, A. (1990) Fragmentation of habitat by road and utility corridors: a review. *Australian Zoologist*, **26**, 130-142.
- Andrews, K.M. & Gibbons, J.W. (2005) How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia*, **4**, 772-782.
- Andrews, K.M., Gibbons, J.W. & Jochimsen, M. (2007) Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation*, **3**, 121-143.
- Angold, P.G. (1997). The impact of a road upon adjacent heath land vegetation: effects on plant species composition. *Journal of Applied Ecology*, **34**(2), 409-417.
- Aresco, M.J. (2005) Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida lake. *The Journal of Wildlife Management*, **69**(2), 549-560.

- Arizona Game & Fish Department (AZGFD) (2006) *Guidelines for Culvert Construction to Accommodate Fish and Wildlife Movement and Passage*. Arizona Game and Fish Department, Habitat Branch, Phoenix, Arizona, USA.
- Ascensao, F. & Mira, A. (2005) Spatial Patterns of Road Kills: A Case Study in Southern Portugal. *Proceedings of the 2005 International Conference on Ecology and Transportation*, (eds C. L. Irwin, P. Garrett, & K. P. McDermott), pp. 641-646. Center for Transportation and the Environment, North Carolina State University, Raleigh, N. C, USA.
- Ascensao, F. & Mira, A. (2007) Factors affecting culvert use by vertebrates along two stretches of road in Southern Portugal. *Ecological Research*, **22**, 57-66.
- Ascensao, F., Clevenger, A.P., Grilo, C., Filipe, J. & Santos-Reis, M. (2012) Highway verges as habitat providers for small mammals in agro-silvopastoral environments. *Biodiversity Conservation*, **21**, 3681-3697.
- Ascensão, F., Desbiez, A.L.J., Medici, E.P. & Bager, A. 2017. Spatial patterns of road mortality of medium-large mammals in Mato Grosso do Sul, Brazil. *Wildlife Research*, **44**(2), 135-146.
- Ashem, R. (2019) Road kills: sequestering animal mortality on the roadways http://e-pao.net/epSubPageExtractor.asp?src=education.Science and Technology.Road_kills_Sequestering_animal_mortality_on_the_roadways_By_Rahul_Ashem
- Ashley, E. & Robinson, J. (1996) Road mortality of amphibians, reptiles and other wildlife on the long point causeway, Lake Erie, Ontario. *Canadian Field-Naturalist*, **110**(3), 403-412.
- Atkinson, R.B. & Cairns, J. (1992) Ecological risks of highways. Advances in modern environmental toxicology. *Predicting ecosystem risk*, **20**, 237-262.
- Attademo, A.M., Peltzer, P.M., Lajmanovich, R.C., Elberg, G., Junges, C., Sanchez, L.C. & Basso, A. (2011) Wildlife vertebrate mortality in roads from Santa Fe Province, Argentina. *Revista Mexicana de Biodiversidad*, **82**, 915-925.

- Auerbach, N.A., Walker, M.D. & Walker, D.A. (1997) Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. *Ecological Applications*, **7**(1), 218-235.
- Auestad, I., Norderhaug, A. & Austad, I. (1999) Road verges—species-rich habitats. *Aspects of Applied Biology*, **54**, 269-274.
- Ault, J.W.I. (1982) *A quantitative estimate of barn owl nesting habitat quality*. M.S. Thesis, Oklahoma State University, Stillwater, OK, USA.
- Australian Museum Business Services (AMBS) Consulting (1997) *Fauna Usage of Three Underpasses Beneath the F3 Freeway Between Sydney and Newcastle*. For NSW roads and traffic authority.
- Backstrom, M., Nilsson, U., Hakansson, K., Allard, B., Karlsson, S. (2003) Speciation of heavy metals in road runoff and roadside total deposition. *Water Air and Soil Pollution*, **147**, 343-366.
- Bagchi, S., Goyal, S.P. & Sarkar, K. (2003) Niche relationships of an ungulate assemblage in a dry tropical forest. *Journal of Mammalogy*, **84**, 981-988.
- Bailey, T.C. & Gatrell, A.C. (1995) *Interactive Spatial Data Analysis*. Longman, New York.
- Balkenhol, N. & Waits, L.P. (2009) Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. *Molecular Ecology*, **18**, 4151-4164.
- Ball, J.P., Nordengren, C. & Wallian, K. (2001) Partial migration by large ungulates: characteristics of seasonal moose *Alces alces* ranges in northern Sweden. *Wildlife Biology*, **7**, 39-47.
- Ballasina, D. (1989) Toads on roads in Belgium. *Amphibians and Roads*, (ed T.E.S Langton), 83-86. ACO Polimer Products Ltd., London.
- Ballon, P. (1985) Premierès observations sur l'efficacité des passages à gibier sur l'autoroute A36, pp. 311-316. Routes et Faune Sauvage. Actes du colloque. Ministère de l'Équipement, du Logement, de l'Aménagement du Territoire et des Transports, Bagneux-Cedex, France.

- Bangs, E.E., Bailey, T.N. & Portner, M.F. (1989) Survival rates of adult female moose on the Kenai Peninsula, Alaska. *Journal of Wildlife Management*, **53**(3), 557-563.
- Baofa, Y., Huyin, H., Yili, Z., Le, Z. & Wanhong, W. (2006) Influence of the Qinghai-Tibetan railway and highway on the activities of wild animals. *Acta Ecologica Sinica*, **26**(12), 3917-3923.
- Barber, J.R., Crooks, K.R. & Fristrup, K.M. (2009) The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution*, **25**(3), 180-89.
- Bard, A.M., Smith, H.T., Egensteiner, E.D., Mulholland, R., Harber, T.V., Heath, G.W., Miller, W.J.B. & Weske, J.S. (2002) A simple structural method to reduce road-kills of Royal Terns at bridge sites. *Wildlife Society Bulletin*, **30**, 603-605.
- Barnum, S.A. (2003) *Identifying the Best Locations along Highways to Provide Safe Crossing Opportunities for Wildlife*. Report Number CDOTDTD-UCD-2003-9. Colorado Department of Transportation Research Branch, Denver.
- Barrass, A.N. (1985) *The effects of highway traffic noise on the phonotactic and associated reproductive behavior of selected anurans*. PhD Thesis, Vanderbilt University.
- Barrientos, R. & Bolonio, L. (2009) The presence of rabbits adjacent to roads increases polecat road mortality. *Biodiversity Conservation*, **18**, 405-418.
- Barrios, L. & Rodriguez, A. (2004) Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. *Journal of Applied Ecology*, **41**, 72-81.
- Barry, T. M. & Regan, J.A. (1978) *FHWA Highway Traffic Noise Prediction Model*. FHWA-RD-77-108, Federal Highway Administration, Washington, DC.
- Barthelmess, E.L & Brooks, M.S. (2010) The influence of body-size and diet on road-kill trends in mammals. *Biodiversity Conservation*, **19**, 1611-1629.

- Barthelmess, E.L. (2014) Spatial distribution of road-kills and factors influencing road mortality for mammals in Northern New York State. *Biodiversity and Conservation*, **23**(10), 2491-2514.
- Bartlett, L.J., Newbold, T., Purves, D.W., Tittensor, D.P. & Harfoot, M.B. (2016) Synergistic impacts of habitat loss and fragmentation on model ecosystems. *Proceedings of the Royal Society B: Biological Sciences*, **283**(1839), 20161027.
- Bartonička, T., Andrášik, R., Duřa, M., Sedoník, J. & Bíl, M. (2018) Identification of local factors causing clustering of animal-vehicle collisions. <https://doi.org/10.1002/jwmg.21467>
- Bashore, T.L., Tzilkowski, W.M. & Bellis, E.D. (1985) Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management*, **49**, 769-774.
- Basic Road Statistics of India 2015-16. Ministry of Road Transport and Highways. Retrieved 15 January 2018.
- Baskaran, N. & Boominathan, D. (2010) Road kill of animals by highway traffic in the tropical forests of Mudumalai Tiger Reserve, southern India. *Journal of Threatened Taxa*, **2**(3), 753-759.
- Baur, A. & Baur, B. (1989) Are roads barriers too dispersed in the land snail *Arianta arbustorum*? *Canadian Journal of Zoology*, **68**, 613-617.
- Baxter-Gilbert, J.H., Riley, J.L., Neufeld, C.J.H., Litzgus, J.D. & Lesbarrères D. 2015. Road mortality potentially responsible for billions of pollinating insect deaths annually. *Journal of Insect Conservation*, **19**, 1029–1035.
- Beaudry, F., Demaynadier, P.G. & Hunter, M.L. (2008) Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. *Biological Conservation*, **141**, 2550-2563.
- Beaudry, F., Demaynadier, P.G. & Hunter, M.L. (2010) Identifying hot moments in road-mortality risk for freshwater turtles. *Journal of Wildlife Management*, **74**, 152-159.

- Becker, S.A., Nielson, R.M., Brimeyer, D.G. & Kauffman, M.J. (2011) Spatial and temporal characteristics of moose highway crossings during winter in the buffalo fork valley, Wyoming. *Alces*, **47**, 69-81.
- Beckmann, J.P., Clevenger, A.P., Huijser, M.P. & Hilty, J.A. (2010) *Safe Passages: Highways, Wildlife and Habitat Connectivity*. Island Press, Washington, DC, USA.
- Bee, M.A & Swanson, E.M. 2007. Auditory masking of anuran advertisement calls by road traffic noise. *Animal Behaviour*, **74**, 1765-1776.
- Behera, S. & Borah, J. (2010) Mammal mortality due to road vehicles in Nagarjunasagar-Srisailam Tiger Reserve, Andhra Pradesh, India. *Mammalia*, **74**, 427-430.
- Beier, P. & Loe, A.S. (1992) Checklist for evaluating impacts to wildlife movement corridors. *Wildlife Society Bulletin*, **20**, 434-440.
- Beier, P., Majka, D.R. & Spencer, W.D. (2008) Forks in the road: choices and procedures for designing wildland linkages. *Conservation Biology*, **22**(4), 836-851.
- Bekker, L.B., Cuperus, G.J., Dufek, R., Hicks, F.G., Keller, H.V., Rosell, C., Sangwine, T., Wandall & Maire, B.L. (2003) *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solution*. European Cooperation in the Field of Scientific and Technical Research, Rue de la Loi 200, B -1049 Brussels
- Belant, J.L. (1995) Moose collisions with vehicles and trains in northeastern Minnesota. *Alces*, **31**, 45-52.
- Belford, D.A. & Gould, W.R. (1989) An evaluation of trout passage through six highway culverts in Montana. *North American Journal of Fisheries Management*, **9**, 437-445.
- Bélisle, M. & St. Clair, C.C. (2001) Cumulative effects of barriers on the movement of forest birds. *Conservation Ecology*, **5**(2), 9.

- Bellamy, P.E., Shore, R.F., Ardeshir, D., Treweek, J.R. & Sparks, T.H. (2000) Road verges as habitat for small mammals in Britain. *Mammal Review*, **30**(2), 131-139.
- Bellis, E.D. & Graves, H.B. (1971) Deer mortality on a Pennsylvania interstate highway. *Journal of Wildlife Management*, **35**(2), 232-237.
- Bellis, E.D. & Graves, H.B. (1971) Deer mortality on a Pennsylvania interstate highway. *Journal of Wildlife Management*, **35**, 232-237.
- Ben-Ami, D. & Ramp, D. (2006) Modeling the effect of roads and other disturbances on wildlife populations in the peri-urban environment to facilitate long-term viability. *Proceedings of the 2005 International Conference on Ecology and Transportation*, (eds C.L. Irwin, P. Garrett, K.P. McDermott), pp. 317-322. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
- Bencke, G.A. & Bencke, C.S.C. (1999) The potential importance of road deaths as a cause of mortality for large forest owls in southern Brazil. *Cotinga*, **11**, 17-18.
- Benedict & Billeter (2004) Discarded Bottles as a Cause of Mortality in Small Vertebrates *Southeastern Naturalist*, **3**(2), 371-377.
- Benítez-López, A., Alkemade, R. & Verweij, P.A. (2009) *Are mammal and bird populations declining in the proximity of roads and other infrastructure?* Systematic Review No. 68. Collaboration for Environmental Evidence.
- Benitez-Lopez, A., Alkemade, R. & Verweij, P.A. (2010) The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. *Biological Conservation*, **143**, 1307-1316.
- Bennett, A.F. (1988) Roadside vegetation: a habitat for mammals at Naringal, southwestern Victoria. *Victoria National*, **105**, 106-113.
- Bennett, A.F. (1991) Roads, roadsides and wildlife conservation: a review. *Nature conservation 2 - The role of corridors*, (eds D.A. Saunders and R.J. Hobbs), pp 99-118. Surrey Beatty & Sons Pty Limited, Western Australia.

- Bennett, A.F. (1991) Roads, roadsides and wildlife conservation: a review. *Nature Conservation 2: The Role of Corridors* (eds D.A. Saunders & R.J. Hobbs), pp. 99-117. R.J. Surrey Beatty, Chipping Norton, Australia.
- Bennett, L.J., English, P.F. & McCain, R. (1940). A study of deer populations by use of pellet- group counts. *Journal of Wildlife Management*, **4**, 398-403.
- Bennett, V.J. (2017) Effects of road density and pattern on the conservation of species and biodiversity. *Current Landscape Ecology Reports*, **2**, 1. <https://doi.org/10.1007/s40823-017-0020-6>.
- Bergmann, H.H. (1974) Zur Phänologie und Ökologie des Strassentods der Vögel. *Vogelwelt*, **95**, 1-21.
- Bernardino, J. & Dalrymple, G.H. (1992) Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. *Biological Conservation*, **61**, 71-75.
- Bernhardt-Romermann, M., Kudernatsch, T. & Fischer, A. (2007) Traffic born pollution affects vegetation composition of coniferous forests. *Forstarchiv*, **78**, 46-54.
- Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available at <http://www.spatial ecology.com/htools>.
- Bhupathy, S., Srinivas, G., Sathish, N., Karthik, T. & Madhivanan, A. (2011) Herpetofaunal mortality due to vehicular traffic in the western ghats, India: A case study. *Herpetotropicos*, **5**(2), 119-126.
- Bigal, K.L., Ashmore, M.R., Headley, A.D., Stewart, K. & Weigert, K. (2007) Ecological impacts of air pollution from road transport on local vegetation. *Applied Geochemistry*, **22**, 1265-1271.
- Bil, M., Andra, R. & Janoska, Z. (2013) Identification of hazardous road locations of traffic accidents by means of kernel density. Estimation and cluster significance evaluation. *Accident Analysis and Prevention*, **55**, 265-273.
- BirdLife International (2004) *State of the World's Birds 2004: Indicators for Our Changing World*. Cambridge, UK.

- Bishop, C.A. & Brogan, J.M. (2013) Estimates of avian mortality attributed to vehicle collisions in Canada. *Avian Conservation and Ecology*, **8**(2), 2.
- Bissonette, J.A. & Rosa, S.A. (2009) Road zone effects in small-mammal communities. *Ecology and Society*, **14**(1), 27.
- Bissonette, J.A. (2002) Scaling roads and wildlife: the Cinderella principle. *Z Jagdwiss*, **48** supplement 208-214.
- Bissonette, J.A., & Cramer, P.C. (2008) *NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings*. Transportation Research Board of the National Academies. Washington, D.C. www.trb.org/news/blurb_detail.asp?id=9369.
- Biswas, S. & Sankar, K. (2002) Prey abundance and food habits of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. *Journal of Zoology, London*, **256**, 411-420.
- Boarman, W. & Sazaki, M. (1996) Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. *Highways and movement across wildlife: improving habitat connection and wildlife passageways across highway corridors*, (eds G. Evink, D. Ziegler, P. Garrett, & J. Berry), pp. 169-173. Proceedings of the Florida Department of Transportation, Federal Highway Administration transportation-related wildlife mortality seminar. Orlando, Florida, May 1996.
- Boarman, W.I. & Sazaki, M. (2006) A highway's road-effect zone for desert tortoises (*Gopherus agassizii*). *Journal of Arid Environments*, **65**, 94-101.
- Bohemen, H.D. (1998) Habitat Fragmentation, infrastructure and Ecological Engineering. *Ecological Engineering*, **11**, 199-207.
- Bond, A.R. & Jones, D.N. (2008) Temporal trends in use of fauna-friendly underpasses and overpasses. *Wildlife Research*, **35**, 103-112.
- Bonnet, X., Naulleau, G. & Shine, R. (1999) The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation*, **89**, 39-50.

- Borda-de-Água, L., Grilo, C. & Pereira, H.M. (2014). Modeling the impact of road mortality on barn owl (*Tyto alba*) populations using age-structured models. *Ecological Modelling*, **276**, 29–37.
- Bouchard, J., Ford, A.T., Eigenbrod, F.E., & Fahrig, L. (2009) Behavioral responses of northern leopard frogs (*Rana pipiens*) to roads and traffic: implications for population persistence. *Ecology and Society*, **14**(2), 23.
- Bouska, W.W. & Paukert, C.P. (2010) *Road Crossing Designs, their Effect on Prairie Stream Fishes, and an Update on the Topeka Shiner*. Dakota Chapter of the American Fisheries Society annual meeting, Spearfish, SD.
- Bouska, W.W., Keane, T. & Paukert, C.P. (2010) The effects of road crossing design on geomorphology and classification of prairie streams. *Journal of Freshwater Ecology*, **25**, 499-506.
- Bouska, W. & Paukert, C. (2009) Road Crossing Designs and Their Impact on Fish Assemblages of Great Plains Streams. *Transactions of the American Fisheries Society* **139**, 214-222.
- Boves, T. (2007) *The effects of roadway mortality on Barn Owls in Southern Idaho and a study of ornamentation in North America Barn Owls*. Master's thesis. Boise State University, Idaho, USA. pp. 108.
- Boves, T.J. & Belthoff, J.R. (2012) Roadway mortality of barn owls in Idaho, USA. *The Journal of Wildlife Management*, **76**, 1381-1392.
- Bowman, J., Ray, J.C., Magoun, A.J., Johnson, D.S. & Dawson, F.N. (2010) Roads, logging, and the large-mammal community of an eastern Canadian boreal forest. *Canadian Journal of Zoology*, **88**, 454-467.
- Bozena S. 2008. Road vegetation in Central Europe - an example from the Czech Republic. *Biologia*, **63**(6), 1085-1088.
- Brahmdstedt, J. & Barsch, B. (1993) *Roadways and Wildlife. An Annotated Bibliography*. Arizona Game and Fish Department Region II, Flagstaff, AZ.

- Brandenburg, D.M. (1996) *Effects of roads on behavior and survival of black bears in coastal North Carolina*. Thesis, University of Tennessee, Knoxville, Tennessee, USA.
- Brattstrom, B.H. (1965) Body temperatures of reptiles. *American Midland Naturalist*, **73**, 376-422.
- Brehme, C.S., Hathaway, S.A. & Fisher, R.N. 2018. An objective road risk assessment method for multiple species: ranking 166 reptiles and amphibians in California. *Landscape Ecology*, **33**, 911-935.
- Brehme, C.S., Tracey, J.A., McClenaghan, L.R. & Fisher, R.N. (2013) Permeability of roads to movement of scrubland lizards and small mammals. *Conservation Biology*, **27**(4), 710-720.
- Bridget, M. & Donaldson. 2017. Improving Animal-Vehicle Collision Data for the Strategic Application of Mitigation. Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903. FHWA/VTRC 18-R16.
- Bright, P., Balmforth, Z. & Macpherson, J. (2015) The effect of changes in traffic flow on mammal road kill counts. *Applied Ecology and Environmental Research*, **13**, 171-179.
- Bright, P.W. (1993) Habitat fragmentation – problems and predictions for British mammals. *Mammal Review*, **23**, 101-111.
- Bristow, K. & Crabb, M. (2008) *Evaluation of Distribution and Trans-Highway Movement of Desert Bighorn Sheep: Arizona Highway 68*. Final Report 588. Arizona Game and Fish Department, Phoenix, Arizona.
- Brock, R.E. & Kelt, D.A. (2004) Influence of roads on the endangered Stephens' kangaroo rat (*Dipodomys stephensi*): are dirt and gravel roads different? *Biological Conservation*, **118**, 633-640.
- Brockie, R.E., Sadleir, R.M.F.S. & Linklater, W.L. (2009) Long-term wildlife road-kill counts in New Zealand. *New Zealand Journal of Zoology*, **36**(2), 123-134.
- Brody, A.J. & Pelton, M.R. (1989) Effects of roads on black bear movements in western North Carolina. *Wildlife Society Bulletin*, **17**, 5-10.

- Brody, A.J. (1984) *Habitat use by black bears in relation to forest management in Pisgah National Forest, North Carolina*. M.S. Thesis. University of Tennessee, Knoxville.
- Brooks, M. L. (1999) Habitat invisibility and dominance by alien annual plants in the western Mojave Desert. *Biological Invasions*, **1**, 325-337.
- Brothers, T. S. & Spingarn, A. 1992. Forest fragmentation and alien plant invasion of central Indiana old-growth forests. *Conservation Biology*, **6**, 91-100.
- Brown, D.L., Laird, J., Sommers, W. & Hamilton, A. (1999) *Methods used by the Arizona Department of Transportation to Reduce Wildlife Mortality and Improve Highway Safety*. Proceedings of the Transportation Related Wildlife Mortality Seminar (eds G.L. Evink, P. Garrett & D. Ziegler), pp. 181-182. Florida Department of Transportation. Report No. FL-ER-73-99. Tallahassee, FL.
- Brudin, C.O. (2003) Wildlife use of existing culverts and bridges in North Central Pennsylvania. *UC Davis: Road Ecology Center*. Retrieved from <https://escholarship.org/uc/item/67f406>
- Bruinderink, G.W.T.A. & Hazebroek, E. (1996) Ungulate traffic collisions in Europe. *Conservation Biology*, **10**, 1059-1067.
- Buchanan, K. (2005) *Sharing the Way with Wildlife: Macropod Mortality on Roads in Redland Bay*. Master of Science Thesis, Griffith University, Brisbane.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D. & Thomas, L. (2004) *Advanced Distance Sampling*. Oxford University Press, Oxford.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., & Thomas, L. (2001) *Introduction to Distance Sampling – Estimating Abundance of Biological Populations*. Oxford University Press, Oxford.
- Bujoczek, M., Ciach, M. & Yosef, R. (2011) Road-kills affect avian population quality. *Biological Conservation*, **144**, 1036-1039.

- Burgin, S. & Brainwood, M. (2008) Comparison of road kills in peri-urban and regional areas of New South Wales (Australia) and factors influencing deaths. *Australian Zoologist*, **8**, 137-144
- Byron, H. (2000) *Biodiversity and Environmental Impact Assessment: A Good Practice Guide for Road Schemes*. The RSPB, WWF-UK, English Nature and the Wildlife Trusts, Sandy.
- Cain, A.T., Tuovila, V.R., Hewitt, D.G. & Tewes, M.E. (2003) Effects of a highway and mitigation projects on bobcats in Southern Texas. *Biological Conservation*, **114**, 189-197.
- Camarra, J.J. & Parde, J.M. (1990) The brown bear in France-status and management in 1985. *Aquilo, Serie Zoologica*, **27**, 93-96.
- Cameron, R.D., Reed, D.J., Dau, J.R. & Smith, W.T. (1992) Redistribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. *Arctic*, **45**, 338-342.
- Campbell, D., Swanson, G.M. & Sales, J. (2004) Comparing the precision and cost-effectiveness of faecal pellet group count methods. *Journal of Applied Ecology*, **41**, 1185-1196.
- Campbell, H. (1956) Snakes found dead on the roads of New Mexico. *Copeia*, 124-125.
- Camphuysen, K., Boer, P.D., Bouten, W., Gronert, A. & Baranes, J.S. (2010) Mammalian prey in Laridae: increased predation pressure on mammal populations expected. *Lutra*, **53**(1), 5-20.
- Canters, K.J. & Cuperus, R. (1997) *Fragmentation of Bird and Mammal Habitats by Roads and Traffic in Transport Regions*. Proceedings of the sixth annual IALE (UK) Species Dispersal and Landuse Processes. IALE, London, UK.
- Carr, L. & Fahrig, L. (2001) Effect of road traffic on two amphibian species of differing viability. *Conservation Biology*, **15**, 1071-1078.

- Cassirer, E.F., Freddy, D.J. & Ables, E.D. (1992) Elk responses to disturbance by cross-country skiers in Yellowstone National Park. *Wildlife Society Bulletin*, **20**, 375-381.
- Champion, H.G. & Seth, S.K. (1968) *A Revised Survey of the Forest Types of India*. Govt of India Press, Delhi. 404 pp.
- Chandra, K. & Gajbe, P.U. (2005) An inventory of herpetofauna of Madhya Pradesh and Chhattisgarh. *Zoos' Print Journal*, **20**(3), 1812-1819.
- Chen, H.L. & Koprowski, J.L. 2016. Barrier effects of roads on an endangered forest obligate: influences of traffic, road edges, and gaps. *Biological Conservation*, **199**, 33-40
- Chhangani, A.K. (2004) Frequency of avian road-kills in Kumbhalgarh Wildlife Sanctuary, Rajasthan, India. *Forktail*, **20**, 110-111.
- Chhangani, A.K. (2004a) Killing of hanuman langur in road accident. *Primate Report*, **69**, 49-57.
- Chittaragi, J.B. & Hosetti, B.B. (2014) Road kill mortality of snakes (Squamata: Serpentes) in different land cover areas of Semi-Malnad region, Mid Western Ghats, Shimoga, India. *Current Biotica*, **8**(1), 57-65.
- Chomitz, K.M. & Gray, D.A. (1996) Roads, land use and deforestation: a spatial model applied to Belize. *The World Bank Economic Review*, **10**, 487-512.
- Christen, D. & Matlack, G. (2006). The role of roadsides in plant invasions: a demographic approach. *Conservation Biology*, **20**, 385-391.
- Christie, J.S. & Nason, S. (2003) Analysis of vehicle collisions with moose and deer on New Brunswick arterial highways. The 31st Annual Conference of the Canadian Society for Civil Engineering, Moncton, New Brunswick. 11p.
- Ciesiolkiewicz, J., Orłowski, G. & Elzanowski, A. (2006) High juvenile mortality of grass snakes *Natrix natrix* (L.) on a suburban road. *Polish Journal of Ecology*, **54**(3), 465-472.

- Ciesiołkiewicz, J., Orłowski, G. & Elżanowski, A. (2006) High juvenile mortality of grass snakes *Natrix natrix* (L.) on a suburban road. *Polish Journal of Ecology*, **54**(3), 465-472.
- CITES (2012) *Convention on International Trade in Endangered species of Wild Fauna and Flora*. Reservations Entered by Parties. <www.cites.org>. (Accessed on 26/08/2012).
- Clancy, G.P. (2004) A survey of road-killed owls in north-eastern New South Wales. *Corella*, **28**, 89-92.
- Clarke, G.P., White, P.C.L. & Harris, S. (1998) Effects of roads on badger *Meles meles* populations in south-west England. *Biological Conservation*, **86**, 117-124.
- Clements, G.R., Lynam, A., Gaveau, D., Lim Yap, W., Lhota, S., Goosem, M., Laurance, S. & Laurance, W. (2014) Where and how are roads endangering mammals in Southeast Asia's forests? *PloS One*, 9. e115376. 10.1371/journal.pone.0115376.
- Clevenger, A. & Huijser, M. (2011) *Wildlife Crossing Structure Handbook: Design and Evaluation in North America*. US Department of Transportation: Lakewood, Colorado.
- Clevenger, A. P. & Sawaya, M.A. (2010) Piloting a non-invasive genetic sampling method for evaluating population-level benefits of wildlife crossing structures. *Ecology and Society*, **15**(1), 7.
- Clevenger, A.P. & Huijser, M.P. (2009) *Handbook for design and evaluation of wildlife crossing structures in North America*. Department of Transportation, Federal Highway Administration, Washington, D.C., USA.
- Clevenger, A.P. & Waltho, N. (1999) *Dry Drainage Culvert use and Design Considerations for Small and Medium Sized Mammal Movement across a Major Transportation Corridor*. Proceedings of the Transportation Related Wildlife Mortality Seminar (eds G.L. Evink, P. Garrett & D. Ziegler), pp. 263-278. Florida Department of Transportation. Report No. FL-ER-73-99.

- Clevenger, A.P. & Waltho, N. (2000) Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology*, **14**, 47-56.
- Clevenger, A.P. & Waltho, N. (2004) *Long-term, Year-Round Monitoring of Wildlife Crossing Structures and the Importance of Temporal and Spatial Variability in Performance Studies*. Proceedings of the 2003 International Conference on Ecology and Transportation, pp. 293-302, Center for Transportation and the Environment, 24-29 August 2003, Lake Placid, NY, USA.
- Clevenger, A.P. & Waltho, N. (2005) Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*, **121**, 453-464.
- Clevenger, A.P., Chruszcz, B. & Gunson K. (2001) Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology*, **38**(6), 1340-1349.
- Clevenger, A.P., Chruszcz, B. & Gunson, K.E. (2001) Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin*, **29**, 646-653.
- Clevenger, A.P., Chruszcz, B. & Gunson, K.E. (2001) Highway mitigation fencing reduces wildlife vehicle collisions. *Wildlife Society Bulletin*, **29**, 646-653.
- Clevenger, A.P., Chruszcz, B. & Gunson, K.E. (2003) Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological Conservation*, **109**, 15-26.
- Clevenger, A.P., Chruszcz, B., Gunson, K. & Wierzchowski, J. (2002) *Roads and Wildlife in the Canadian Rocky Mountain Parks – Movements, Mortality and Mitigation*. Final report to Parks Canada, Banff, Alberta, 432 pp.
- Coelho, I.P., Kindeland, A. & Coelho, A.V.P. (2008) Road kills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. *European Journal Wildlife Research*, **54**, 689-699.
- Coffin, A. (2007). From road kill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography*, **15**, 396-406.

- Colino Rabanal, V.J. (2011) *Contributions to the analysis of vertebrate road mortality*. Ph.D Thesis, Salamanca University.
- Colino–Rabanal, V.J. (2011) *Contributions to the analysis of vertebrate road mortality*. Ph.D. Thesis, Salamanca University.
- Colino-Rabanal, V.J., Bosch, J., Munoz, M.J. & Peris, S.J. (2012) Influence of new irrigated croplands on wild boar (*Sus scrofa*) road kills in NW Spain. *Animal Biodiversity and Conservation*, **35**, 247-252.
- Colino-Rabanal, V.J., Lizana, M. & Peris, S.J. (2011) Factors influencing wolf *Canis lupus* road kills in Northwest Spain. *European Journal of Wildlife Research*, **57**, 399-409.
- Collinson, W.J., Parker, D.M., Reilly, B.K., Bernard, R.T.F. & Davies-Mostert, H.T. (2014) Wildlife road traffic accidents: a new technique for counting flattened fauna Infra Eco Network Europe 2014 (Sweden). *Ecology and Evolution*, **4**(15), 3060-3071.
- Conover, M.R. (1997) Monetary and intangible valuation of deer in the United States. *Wildlife Society Bulletin*, **25**(2), 298-305.
- Cook, K.E. & Daggett, P.M. (1995). *Highway Road kill, Safety, and Associated Issues of Safety and Impact on Highway Ecotones. Un reviewed report for Task Force on Natural Resources, (AIF52)*. Transportation Research Board, National Research Council.
- Cooke, A. (1995) Road mortality of common toads (*Bufo bufo*) near a breeding site, 1974-1994. *Amphibia-Reptilia*, **16**, 87-90.
- Cooke, A.S. & Sparks, T.H. (2004). Population declines of the common toad (*Bufo bufo*): the contribution of road traffic and monitoring value of casualty counts. *Herpetological Bulletin*, **88**, 13-26.
- Corlatti, L., Hackländer, K. & Frey-Roos, F. (2009) Ability of wildlife overpasses to provide connectivity and prevent isolation. *Conservation Biology*, **23**, 548-556.

- Costa, A.S., Ascensão, F. & Bager, A. (2015) Mixed sampling protocols improve the cost-effectiveness of road kill surveys. *Biodiversity and Conservation*, **24**, 2953.
- Cote, S.D. (1996) Mountain goat responses to helicopter disturbance. *Wildlife Society Bulletin*, **24**, 681-685.
- Coulon, A., Guillot, G., Cosson, J.-F., Angibault, J. M.A., Aulagnier, S., Cargnelutti, B., *et al.* (2006). Genetic structure is influenced by landscape features: Empirical evidence from a roe deer population. *Molecular Ecology*, **15**, 1669-1679.
- Cousins, S.A.O. (2006) Plant species richness in midfield islets and road verges. The effect of landscape fragmentation. *Biological Conservation*, **127**, 500-509.
- Cramer, P.C. & Bisonette, J.A. (2005) *NHCHRP 25-27 update: Wildlife crossing in North America*. Deer-vehicle crash reduction: setting a strategic agenda workshop. University of Wisconsin-Madison.
- Cramer, P.C. & Bissonette, J.A. (2006) *Wildlife Crossings in North America: The State of the Science and Practice*. Proceedings of the 2005 International Conference on Ecology and Transportation, San Diego, California (eds C.L. Irwin, P. Garrett, & K.P. McDermott), pp. 442-447. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.
- Crooks, K.R. (2002) Relative sensitivities of mammalian carnivores to habitat fragmentation. *Conservation Biology*, **16**, 488-502.
- Crooks, K.R., Burdett, C.L., Theobald, D.M., King, S.R.B., Marco, M.D., Rondinini, C. & Boitani, L. 2017. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *Proceedings of the National Academy of Sciences* July 2017, 114 (29) 7635-7640
- Cullen, L., Stanton, J.C., Lima, F., Uezu, A., Perilli, M.L.L. & Akçakaya, H.R. (2016) Implications of fine-grained habitat fragmentation and road mortality for jaguar conservation in the Atlantic forest, Brazil. *PLoS One*, **11**(12), e0167372.

- Culley, T.M., Sbita, S.J. & Wick, A. (2007) Population genetic effects of urban habitat fragmentation in the perennial herb *Viola pubescens* (Violaceae) using ISSR markers. *Annals of Botany*, **100**, 91-100.
- Cushman, S.A. (2006) Effects of habitat loss and Fragmentation on amphibians: A review and prospectus. *Biological Conservation*, **128**, 231-240.
- Cushman, S.A., McKelvey, K.S., Hayden, J. & Schwartz, M.K. (2006) Gene flow in complex landscapes: Testing multiple hypotheses with causal modeling. *American Naturalist*, **168**, 486-499.
- Cuyckens, G., Mochi, L., Vallejos, M., Gastón Perovic, P. & Biganzoli, F. (2016) Patterns and composition of road-killed wildlife in Northwest Argentina. *Environmental Management*, **58**(5), 810-820.
- D'Angelo, G.J., D'Angelo, J.G., Gallagher, G.R., Osborn, D.A. & Miller, R.J. (2006) Warren Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. *Wildlife Society Bulletin*, **34**, 1175-1183.
- Danks, Z.D. & Porter, W.F. (2010) Temporal, spatial and landscape habitat characteristics of moose-vehicle collisions in Western Maine. *Journal of Wildlife Management*, **74**, 1229-1241.
- Danks, Z.D. & Porter, W.F. (2010) Temporal, spatial, and landscape habitat characteristics of moose-vehicle collisions in Western Maine. *Journal of Wildlife Management* **74**, 1229-1241.
- Das, A., Ahmed, M.F., Lahkar, B.P. & Sharma, P. (2007) A preliminary report of reptilian mortality on road due to vehicular movement near Kaziranga National Park, Assam, India. *Zoos' Print Journal*, **22**(7), 2742-2744.
- Davenport, J. & Davenport, J.L. (eds) (2006) *The Ecology of Transportation: Managing Mobility for The Environment*. Environmental Pollution. Springer, Dordrecht, The Netherlands.
- Davies, J.M., Roper, T.J. & Shepherdson, D.J. (1987) Seasonal distribution of road kills in the European badger. *The Journal of Zoology*, **211**, 525-529.

- De Freitas, S.R., Nepomuceno De Oliveira, A., Ciocheti, G., Vieira, M.V., Maria, D., & Matos, S. (2014). How landscape features influence road-kill of three species of mammals in the Brazilian savanna? *Oecologia Australis*, **18**, 35-45.
- Dean, W.R.J. & Milton, S.J. (2003) The importance of roads and road verges for raptors and crows in the Succulent and Nama-Karoo, South Africa. *Ostrich*, **74**, 181-186.
- Debinski, D.M. & Holt, R.D. (2000) Habitat fragmentation experiments: a global survey and overview. *Conservation Biology*, **14**, 342-355.
- DeMaynadier, P. & Hunter, M. (2000) Road effects on amphibians movements in a forested landscape. *Natural Areas Journal*, **20**, 56-65.
- Deutschewitz, K., Lausch, A., Kühn, I. & Klotz, S. (2003) Native and alien plant species richness in relation to spatial heterogeneity on a regional scale in Germany. *Global Ecology Biogeography*, **12**, 299-311.
- Develey, P.F. & Stouffer, P.C. (2001) Effects of roads on movements by understory birds in mixed-species flocks in central Amazonian Brazil. *Conservation Biology*, **15**, 1416-1422.
- Dhindsa, M.S., Sandhu, J.S., Sandhu, P.S. & Toor, H.S. (1988) Roadside birds in Punjab (India): relation to mortality from vehicles. *Environmental Conservation*, **15**, 303-310.
- Diamondback (1990) Ecological effects of roads. *Killing Roads: A Citizens Primer on the Effects and Removal of Roads* (ed. Davis). Earthfirst Biodiversity Project Special Publication, United States.
- Dickson, B.G., Jenness, J.S. & Beier, P. (2005) Influence of vegetation, topography, and roads on cougar movement in southern California. *Journal of Wildlife Management*, **69**, 264-276.
- Ditchkoff, S.S., Saalfeld, S.T. & Gibson, C.J. (2006) Animal behavior in urban ecosystems, Modifications due to human-induced stress. *Urban Ecosystem*, **9**, 5-12.

- Dodd, C. Jr., Enge, K. & Stuart, J. 1989. Reptiles on highways in north-central Alabama, USA. *Journal of Herpetology* **23**,197-200.
- Dodd, C.K., Barichivich, W.J. & Smith, L.L. (2004) Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. *Biological Conservation*, **118**, 619-631.
- Dodd, N.L., Gagnon, J.W. Manzo, A.L. & Schweinsburg, R.E. (2007) Video surveillance to assess highway underpass use by elk in Arizona. *Journal of Wildlife Management*, **71**, 637-645.
- Dodd, N.L., Gagnon, J.W., Boe, S. & Schweinsburg, R.E. (2006) Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Proceedings of the 2005 International Conference on Wildlife Ecology and Transportation (eds C.L. Irwin, P. Garrett & K.P. McDermott), pp. 461-477. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.
- Doehring, K., Young, R.G. & Quarterman, A.J. (2011) Suitability of Dual - frequency Identification Sonar (DIDSON) to monitor juvenile fish movement at floodgates. *New Zealand Journal of Marine and Freshwater Research*, **45**(3), 413-422.
- Dolan, L.M.J. & Whelan, P. (2004) Ecologically Friendly Highways. *The Engineers Journal*, **54**(1), 43-49. The Institution of Engineers of Ireland, Dublin.
- Donaldson, A. & Bennett, A.F. (2004) *Ecological Effects of Roads*. Implications for the Internal Fragmentation of Australian Parks and Reserves. Parks Victoria Technical Series. Parks Victoria, Melbourne.
- Donaldson, B.M. (2005) *Use of Highway Underpasses by Large Mammals and Other Wildlife in Virginia and Factors Influencing Their Effectiveness*. Final Report for the Virginia Department of Transportation.

- Dooling R.J. & Popper, A.N. (2007) *The effects of highway noise on birds*. Report to the California Department of Transportation, contract 43A0139. California Department of Transportation, Division of Environmental Analysis, Sacramento, California, USA.
- Downes, G.M., Hudson, I.L., Raymond, C.A., Dean, G.H., Michell, A.J., Schimleck, L.S., Evans, R. & Muneri, A. (1997) *Sampling Plantation Eucalypts for Wood and Fiber Properties*. CSIRO Publishing, Melbourne, Australia.
- Drews, C. (1995) Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. *African Journal of Ecology*, **33**, 89-100.
- Dreyer, W. (1937) The question of wildlife destruction by the automobile. *Science*, **82**, 439-440.
- Dulac, J. (2013) Global Land Transport Infrastructure Requirements: Estimating Road and Railway Infrastructure Capacity and Costs to 2050. International Energy Agency.
- Dunthorn, A.A. & Errington, F.P. (1964) Casualties among birds along a selected road in Wiltshire. *Bird Study*, **11**, 168-182.
- Dussault, C., Ouellet, J., Laurian, C., Courtois, R., Poulin, M. & Breton, L. (2007) Moose movement rates along highways and crossing probability models. *Journal of Wildlife Management*, **71**, 2338-2345.
- Dussault, C., Roulin, M., Courtois, R. & Ouellet, J.P. (2006) Temporal and spatial distribution of moose-vehicle accidents in the Laurentides Wildlife Reserve, Quebec, Canada. *Wildlife Biology* **12**, 415-426.
- Dwyer, R.G., Carpenter-Bundhoo, L., Franklin, C.E. & Campbell, H.A. (2016) Using citizen-collected wildlife sightings to predict traffic strike hot spots for threatened species: a case study on the southern cassowary. *Journal of Applied Ecology*, **53**, 973-982.

- Dyer, S.J., O'Neill, J.P., Wasel, S.M. & Boutin, S. (2002) Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern. *Alberta Canadian Journal of Zoology*, **80**, 839-845.
- Eberhardt, E. (2008) *Current and potential wildlife fatality hotspots along the Thousand Islands Parkway in eastern Ontario, Canada*. M.Sc. Thesis, Department of Geography and Environmental Studies, Carleton University. A Guide to Landscape Treatments for National Road Schemes in Ireland, National Roads Authority.
- Eberhardt, E. (2009) *Current and potential wildlife fatality hotspots along the Thousand Islands Parkway in Eastern Ontario, Canada*. M.Sc. thesis, Carleton University, Ottawa, Canada.
- Eberts, R. (1989) *Some empirical evidence on the linkage between public infrastructure and local economic development*. Federal Reserve Bank of Cleveland, Cleveland, Ohio.
- EDI Environmental Dynamics Inc. (2015) Large mammal-vehicle collisions: review of mitigations and analysis of collisions in Yukon. Prepared for Government of Yukon. Yukon Fish and Wildlife Branch Report MRC-15-02, Whitehorse, Yukon, Canada.
- Ehinger, W., Garvey-Darda, P., Gersib, R., Halupka, K., McQueary, P., Meyer, W., Schanz, R. & Wagner, P. (2006) *Interstate 90 Snoqualmie Pass East Mitigation Development Team: Recommendation Package*. Submitted to: U.S. Department of Transportation, Federal Highway Administration and Washington State Department of Transportation.
- Eigenbrod, F., Hecnar, J.S. & Fahrig, L. (2008) Accessible habitat: an improved measure of the effects of habitat loss and roads on wildlife populations. *Landscape Ecology*, **23**, 159-168.
- Eigenbrod, F., Hecnar, J.S. & Fahrig, L. (2009) Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. *Ecology and Society*, **14**, 24.

- Eigenbrod, F., Hecnar, S. J. & Fahrig, L. (2008) The relative effects of road traffic and forest cover on anuran populations. *Biological Conservation*, **141**, 35-46.
- Elzanowski, A., Ciesiołkiewicz, J., Kaczor, M., Radwańska, J. & Urban, R. (2009) Amphibian road mortality in Europe: a meta-analysis with new data from Poland. *European Journal of Wildlife Research*, **55**, 33-43.
- English Nature. (1996) *The Significance of Secondary Effects From Roads and Road Transport on Nature Conservation*. English Nature Research Report No. 178. English Nature, Peterborough, UK.
- Environmental Commissioner of Ontario (ECO) (2008) *Roads - Pathways for Humans, Barriers for Functioning Ecosystems*. Getting to K(No)w, ECO Annual Report, 2007-08. Toronto, ON : Environmental Commissioner of Ontario. 192-197.
- Epps, C.W., Palsboll, P.J., Wehausen, J.D., Roderick, G.K., Ramey, R.R. & McCullough, D.R. (2005) Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. *Ecology Letters*, **8**, 1029-1038.
- Epps, C.W., Wehausen, J.D., Bleich, V.C., Torres, S.G. & Brashares, J.S. (2007) Optimizing dispersal and corridor models using landscape genetics. *Journal of Applied Ecology*, **44**, 714-724.
- Erickson, W.P., Johnson, G.D. & Young, D.P. (2005) A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions. *General technical report PSWGTR- 191*, (eds C.J. Ralph & T.D. Rich), pp. 1029-1042. U.S. Department of Agriculture, Forest Service, Albany, California.
- Ernst, C.H. & Ernst, E.M. (2003) *Snakes of the United States and Canada*. Smithsonian Press, Washington, DC.
- Erritzoe, J., Mazgajski, T.D. & Rejt, L. (2003) Bird casualties on European roads a review. *Acta Ornithologica*, **38**, 77-93.
- ESRI (2004) *ArcGIS 9*. Environmental Systems Research Institute, New York.

- Evink, G.L., Garrett, P. & Zeigler, D. (eds) (1999) *Florida Department of Transportation, Report No. FL-ER-73-99, Tallahassee*. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. September 13-16, 1999, Florida, 330 pp.
- Evink, G.L., Garrett, P., Zeigler, D. & Berry, J. (eds) (1998) *Florida Department of Transportation, Report No. FL-ER-69-98, Tallahassee*. Proceedings of the International Conference on Wildlife Ecology and Transportation. February 10-12, 1998. Ft. Myers, Florida., Florida, 263 pp.
- Faaborg, J.M., Brittingham, T.D. & Blake, J. (1993) Habitat fragmentation in the temperate zone: A perspective for managers. *Status and Management of Neotropical Migratory Birds* (eds D.M. Finch & P.W. Stangel), pp. 331-38. US Forest Service General Technical Report RM-229.
- Fahrig, L. & Rytwinski, T. (2009) Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society*, **14**(1), 21.
- Fahrig, L., 2002. Effect of habitat fragmentation on the extinction threshold: A synthesis, *Ecological Application*, **12**, 346-353.
- Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D. & Wegner, J.F. (1995) Effect of road traffic on amphibian density. *Biological Conservation*, **73**, 177-182.
- Fairbank, L. (2012) *The Value of Wildlife Crossing Structures*. The Road Ripoter, spring equinox. 10-14.
- Federal Highway Administration (2002) *Critter crossings: Linking habitats and reducing road kill*.
<http://www.fhwa.dot.gov/environment/wildlifecrossings/main.htm>
- Ferreira, R. B. & Silva-Soares, T. (2012). Road mortality of snakes at the Parque Estadual da Fonte Grande, an urban forest of southeastern Brazil. *Boletim Do Museu de Biologia Mello Leitao*, **29**, 5–15
- Ferreras, P., Aldama, J.J., Beltran, J.F. & Delibes, M. (1992) Rates and causes of mortality in a fragmented population of Iberian lynx *Felis Pardina Temminck*. *Biological Conservation*, **61**, 197-202.

- Filho, J.M.A., Lenzi, A., Zannin, P.H.T. (2004) Effects of traffic composition on road noise: a case study. *Transportation Research Part D*, **9**, 75-80.
- Fischer, W., Godoi, R.F. & Filho, A.C.P. (2018) Road kill records of reptiles and birds in Cerrado and Pantanal landscapes. *Check List*, **14**(5), 845-876.
- Fitzgibbon, C.D. (1997) Small mammals in farm woodlands: the effects of habitat, isolation and surrounding land-use patterns. *Journal of Applied Ecology*, **34**(2), 530-539.
- Fleiter, J. & Watson, B. (2006) The speed paradox: The misalignment between driver attitudes and speeding behaviour. *Journal of the Australasian College of Road Safety*, **172**, 23-30.
- Fletcher, R.J., Didham, R.K., Cristina, B.L., Barlow, J., Ewers, R.M., Rosindell, J., Holt, R.D., Gonzalez, A., Pardini, R., Damschen, E.I., Melo, F.P.L., Ries, L., Prevedello, J.A., Tschamtker, T., Laurance, W.F., Lovejoy, T. & Haddad, N.M. (2018). Is habitat fragmentation good for biodiversity?. *Biological Conservation*, **226**, 9-15.
- Flory, S.L. & Clay, K. (2009) Effects of roads and forest successional age on experimental plant invasions. *Biological Conservation*, **142**, 2531-2537.
- Flory, S.L., & Clay, K. (2006) Invasive shrub distribution varies with distance to roads and stand age in eastern deciduous forests in Indiana, USA. *Plant Ecology*, **184**, 131-141.
- Foppen, R. & Reijnen, R. (1994) The effects of car traffic on breeding bird populations in woodland. II. Breeding dispersal of male Willow Warblers *Phylloscopus trochilus* in relation to the proximity of a highway. *Journal of Applied Ecology*, **31**, 95-101.
- Ford, A.T. & Fahrig, L. (2007) Diet and body size of North American mammal road mortalities. *Transportation Research Part D*, **12**, 498-505.
- Ford, H.A., Barrett, G.W., Saunders, D.A. & Recher, H.F. (2001) Why have birds in the woodlands of Southern Australia declined? *Biological Conservation*, **97**, 71-88.

- Foresman, K.R. (2004) *The Effects of Highways on Fragmentation of Small Mammal Populations and Modifications of Crossing Structures to Mitigate Such Impacts*. Montana Department of Transportation Research Section, Helena, MT.
- Foresman, K.R. (2004) *The Effects of Highways on Fragmentation of Small Mammal Populations and Modifications of Crossing Structures to Mitigate such Impacts*. Final Report. FHWA/MT-04-005/8161.
- Forman, R. (2000) Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*, **14**, 31-35.
- Forman, R.T.T. & Alexander, L.E. (1998) Roads and their major ecological effects, *Annual Review of Ecology and Systematics*, **29**, 207-231.
- Forman, R.T.T. (1995) *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge.
- Forman, R.T.T. (1997) *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge.
- Forman, R.T.T. (1998) Road ecology: a solution for the giant embracing us. *Landscape Ecology*, **13**, III-V.
- Forman, R.T.T. (2002) Foreword. *Applying Landscape Ecology in Biological Conservation*, pp. vii-x (ed. K. J. Gutzwiller). Springer, New York, USA.
- Forman, R.T.T. (2006) Good and bad places for roads: effects of varying road and natural pattern on habitat loss, degradation, and fragmentation. *Proceedings of the 2005 International Conf. on Ecology & Transportation*, (eds By C.L. Irwin, P. Garrett, & K.P. McDermott). Raleigh, NC : Center for Transportation & the Environment, NC State U.
- Forman, R.T.T., Sperling, D., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T. & Winter, T. (2003) *Road Ecology: Science and Solutions*. Island Press, Washington, DC.

- Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T. & Winter, T.C. (2002) *Road Ecology: Science and Solutions*. Island Press, Washington.
- Fortin, D. & Andruskiw, M. (2003) Behavioral response of free-ranging bison to human disturbance. *Wildlife Society Bulletin*, **31**, 804-813.
- Foster, L.R. & Humphrey, S.R. (1995) Use of highway underpasses by Florida panther and other wildlife. *Wildlife Society Bulletin*, **23**(1), 95-100.
- Found, R. & Boyce, M.S. (2011) Predicting deer-vehicle collisions in an urban area. *Journal of Environmental Management*, **92**, 2486-2493.
- Found, R. & Boyce, M.S. (2011) Predicting deer-vehicle collisions in an urban area. *Journal of Environmental Management*, **92**, 2486-2493.
- Francis, C.D., Kleist, N.J., Cruz, A. & Ortega, C.P. (2012) Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. *Proceedings of the Royal Society B: Biological Sciences*. <https://doi.org/10.1098/rspb.2012.0230>
- Franklin, A.B., Noon, B.R & George, T.L. (2002) What is Habitat Fragmentation?. *Studies in Avian Biology*, **25**, 20-29.
- Frederick, G.P. (1991) *Effects of forest roads on grizzly bears, elk, and gray wolves: a literature review*. USDA Forest Service, Kootenai National Forest, Montana, p. 49.
- Freeman, A. & Bruce, C. (2007) The things you find on the road: road-kill and incidental data as an indicator of habitat use in two species of tropical pythons. *Biology of the Boas and Pythons* (eds R. Henderson, R. Powell), pp. 152-165. Eagle Mountain Publishing, Eagle Mountain.
- Freeman, A. & Bruce, C. (2007) The things you find on the road: road-kill and incidental data as an indicator of habitat use in two species of tropical pythons. *Biology of the Boas and Pythons* (eds R. Henderson, R. Powell), pp. 152-165. Eagle Mountain Publishing, Eagle Mountain.

- Fuller, T. (1989) Population dynamics of wolves in north-central Minnesota. *Wildlife Monographs*, **105**, 1-41.
- Fulton, G.R., Smith, M., Choi, M.N. & Takahashi, S. (2008) Road ecology from a road-side assemblage of forest birds in south-western Australia. *Ornithological Science*, **7**, 47-57.
- Gagnon, J.W., Dodd, N.L., Ogren, K.S. & Schweinsburg, R.E. (2011) Factors associated with the use of wildlife underpasses and importance of long-term monitoring. *Journal of Wildlife Management*, **75**, 1477-1487.
- Gagnon, J.W., Theimer, T.C., Dodd, N.L., Boe, S. & Schweinsburg, R.E. (2007) Traffic volume alters elk distribution and highway crossings in Arizona. *Journal of Wildlife Management*, **71**, 2318-2323.
- Gaisler, J., Oehak, Z. & Bartonieka, T. (2009) Bat casualties by road traffic (Brno-Vienna) *Acta Theriologica*, **54**(2), 147-155.
- Gajera, N.B., Joshi, P. & Dharaiya, N. (2018) Highway mortality of vertebrate species in the Aravalli mountain range of north Gujarat, India. *Indian Journal of Research*, **7**(10), 106-108.
- Garcia-Gonzalez, C., Campo, D., Pola, I.G. & Garcia-Vazquez, E. (2012) Rural road networks as barriers to gene flow for amphibians: species-dependent mitigation by traffic calming. *Landscape and Urban Planning*, **104**, 171-180.
- Garrett, P.A. & Bank, F.G. (1995) *The Ecosystem Approach to Transportation Development*. U.S. Department of Transportation. Federal Highway Administration.
- Gaston, A.J. (1974) Methods for estimating bird population. *Journal of the Bombay Natural History Society*, **72**(2), 271-283.
- Gaston, A.J. (1981) Seasonal breeding, moulting and weight changes in birds of dry deciduous forest in North India. *Journal of Zoology*, **194**(2), 219-243.
- Gelbard J. L. & Belnap, J. (2003) Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology*, **17**(2), 420-432.

- Gese, E.M. (2004) *Survey and Census Techniques for Canids*. USDA National Wildlife Research Center – Staff Publications, Paper 337.
- Getz, L.L., Cole, F.R. & Gates, D.L. (1978) Interstate roadsides as dispersal routes for *Microtus pennsylvanicus*. *Journal of Mammalogy*, **59**, 208-212.
- Ghaswala, S.K. (1965) *History of Road Development in India by Central Road Research Institute*. Society for the History of Technology Publication.
- Gibbs, J.P. & Shriver, G. (2002) Estimating the Effects of Road Mortality on Turtle Populations. *Conservation Biology* **16**, 1647-1651.
- Gibbs, J.P., Shriver, W.G. (2005) Can road mortality limit populations of pool-breeding amphibians? *Wetlands Ecology and Management*, **13**, 281-289.
- Gibson, J.D. & Merkle, D.A. (2004) Road mortality of snakes in Central Virginia. *Banisteria*, **24**, 8-14.
- Gilbert, O.L. (1989) *Roads. The Ecology of Urban Habitats*, pp. 145-164. Chapman and Hall Ltd., New York.
- Gitman, I. & Levine, M.D. (1970) An algorithm for detecting unimodal fuzzy sets and its application as a clustering technique. *IEEE Trans Computer*, **19**, 583-593.
- Gitman, I. & Levine, M.D. (1970) An algorithm for detecting unimodal fuzzy sets and its application as a clustering technique. *IEEE Transactions on Computers*, **19**, 583-593.
- Gittleman, J.L., Funk, S. M., Macdonald, D.W. & Wayne, R.K. (2001) Carnivore conservation. *Conservation Biology*, p. 5. Cambridge University Press, Cambridge.
- Gjessing, E., Lygren, E., Berglind, L., Gulbrandsen, T. & Skanne, R. (1984) Effect of highway runoff on lake water quality. *Science of the Total Environment*, **33**, 247-257.

- Glista D., Devault, T. & DeWoody, J. (2009) A review of mitigation measures for reducing wildlife mortality on roadways. *Landscape and Urban Planning*, **91**, 1-7.
- Glista, D.J., DeVault, T.L. & DeWoody, J.A. (2009) A review of mitigation measures for reducing wildlife mortality on roadways. *USDA National Wildlife Research Center - Staff Publications*, 846 pp.
- Glista, D.J., Devault, T.L. & DeWoody, J.A. (2009) A review of mitigation measures for reducing wildlife mortality on roadways. *Landscape and Urban Planning*, **91**, 1-17.
- GOI (2010) Government of India, Ministry of Road Transport and Highway (P&M Section)
<http://dorth.gov.in/writereaddata/sublinkimages/finaldoc6143316640.pdf>
 assessed on 20/10/2012
- Gokula, V. (1997) Impact of vehicular traffic on snakes in Mudumalai Wildlife Sanctuary. *Cobra*, **27**, 26-30.
- Goldsmith, C.D., Scanlon, P.F., & Pirie, W.R. (1976) Lead concentrations in soil and vegetation associated with highways of different traffic densities. *Bulletin of Environmental Contamination and Toxicology*, **16**, 66-70.
- Gomes, L., Grilo, C., Silva C. & Mira A. (2009) Identification methods and deterministic factors of owl road kill hotspot locations in Mediterranean landscapes. *Ecological Research*, **24**, 355-370.
- Gonser, R.A., Jensen, R.R. & Wolf, S.E. (2009) The spatial ecology of deer-vehicle collisions. *Applied Geography*, **29**, 527-532.
- González-Gallina A., Hidalgo-Mihart, M.G. & Castelazo-Calva, V. (2018) Conservation implications for jaguars and other neotropical mammals using highway underpasses. *PLoS One*, **13**(11), e0206614.

- Gonzalez-Gallina, A., Benitez-Badillo, G., Rojas-Soto, O.R., Hidalgo-Mihart, M.G. (2013) The small, the forgotten and the dead: highway impact on vertebrates and its implications for mitigation strategies. *Biodiversity and Conservation*, **22**(2), 325-342.
- González-Suárez, M., Zanchetta Ferreira, F. & Grilo, C. (2018) Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography*, 1-12. 10.1111/geb.12769.
- González-Suárez, M., Zanchetta, F. and Grilo, C. (2018) Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography*. **27**, 1093-1105.
- Goodrich, J.M. & Berger, J. (1994) Winter recreation and hibernating blank bear *Uesus americanus*. *Biological Conservation*, **67**, 105-110.
- Goosem, M. (2002) Effects of tropical rainforest roads on small mammals: fragmentation, edge effects and traffic disturbance. *Wildlife Research*, **29**, 277-289.
- Goosem, M. (2004) Linear infrastructure in tropical rainforests: mitigating impacts on fauna of roads and powerline clearings. *Conservation of Australia's Forest Fauna* (ed D. Lunney), pp. 418-434. Royal Zoological Society of NSW, Mosman, NSW.
- Goosem, M. (2007) Fragmentation impacts caused by roads through rainforests. *Current Science*, **93**, 1587-1595.
- Gopala, A. (2007) *A Study on vegetation ecology in Pench Tiger Reserve, Madhya Pradesh with reference to Gaur (Bosgaurus)*. PhD Thesis. University of Saurashtra, India.
- Göransson, G., Karlsson, J. & Lindgren, A. (1978) *Influence of Roads on the Surrounding Nature. II. Fauna*. Stockholm, Sweden: Swedish Environmental Protection Agency, SNV PM 1069.
- Grant, W.E & French, N.R. (1980) Evaluation of the role of small mammals in grassland ecosystems: a modeling approach. *Ecological Modeling*, **8**, 15–37.

- Grilo, C., Bissonette J.A. & Santos-Reis, M. (2009) Spatial-temporal patterns in Mediterranean carnivore road casualties: consequences for mitigation. *Biological Conservation*, **142**, 301-313.
- Grilo, C., Bissonette, J. & Cramer, P. (2011) Mitigation measures to reduce impacts on biodiversity. <https://www.researchgate.net/publication/233759909> Mitigation measures to reduce impacts on biodiversity
- Grilo, C., Bissonette, J.A. & Cramer, P.C. 2010. Mitigation measures to reduce impacts on biodiversity. In: Highways: Construction, Management, and Maintenance 73-114
- Grilo, C., Bissonette, J.A. & Santos-Reis, M. (2008) Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. *Biodiversity and Conservation*, **17**, 1685-1699.
- Grilo, C., Bissonette, J.A. & Santos-Reis, M. (2009) Spatial-temporal patterns in Mediterranean carnivore road casualties: consequences for mitigation. *Biological Conservation*, **142**, 301-313.
- Grilo, C., Ferreira, F.Z., Revilla, E. (2015) No evidence of a threshold in traffic volume affecting road-kill mortality at a large spatio-temporal scale. *Environmental Impact Assessment Review*, **55**, 54-58.
- Grilo, C., Sousa, J., Ascensão, F., Matos, H., Leitão, I., Pinheiro, P., Costa, M., Bernardo, J., Reto, D., Lourenço, R., Santos-Reis, M. & Revilla, E. (2012) Individual spatial responses towards roads: implications for mortality risk. *PLoS One*, **7**, 43811.
- Groot, B. & Hazebroek, E. (1996) Ungulate traffic collisions in Europe. *Conservation Biology*, **10**(4), 1059-1067.
- Grosman, P.D., Jaeger, J.A.G., Biron, P.M., Dussault, C. & Ouellet, J.P. (2009) Reducing moose–vehicle collisions through salt pool removal and displacement: an agent-based modeling approach. *Ecology and Society*, **14**(2), 17.

- Grovenburg, T., Jenks, J.A., Klaver, R.W., Monteith, K.L., Galster, D.H., Schauer, R.J., Morlock, W.W. & Delger, J.A. (2008) Factors affecting road mortality of white-tailed deer in eastern South Dakota. *Human–Wildlife Conflict*, **2**, 48-59.
- Gryz, J. & Krauze, D. (2008) Mortality of vertebrates on a road crossing the Biebrza Valley (NE Poland). *European Journal of Wildlife Research*, **54**, 709-714.
- Gu. H., Dai. Q., & Wangi, Q. & Wang. Y. (2011). Factors contributing to amphibian road mortality in a wetland. *Current Zoology*, **57**, 768-774.
- Gubbi, S., Poornesha, H.C. & Madhusudan, M.D. (2012) Impact of Vehicular Traffic on the Use of Highway Edges by Large Mammals in a South Indian Wildlife Reserve. *Current Science*, **102**, 1047-1051.
- Gundersen, H. & Andreassen, H.P. (1998) The risk of moose *Alces alces* collision: a predictive logistic model for moose-train accidents. *Wildlife Biology*, **4**(2), 103-110.
- Gunson, K.E., Mountrakis, G. & Quackenbush, L.J. (2011) Spatial wildlife-vehicle collision models: a review of current work and its application to transportation mitigation projects. *Journal of Environmental Management*, **92**, 1074-1082.
- Gurrutxaga, M., Lozano, P.J. & Barrio, G.D. (2010) Assessing highway permeability for the restoration of landscape connectivity between protected areas in the Basque Country, Northern Spain. *Landscape Research*, **35**(5), 529-550.
- Gustafsson, M., Blomqvist, G., Dahl, A., Gudmundsson, A., Ljungman, A., Lindbom, J., Rudell, B. and Swietlicki, E. (2005) Inandningsbara partiklar från dubbdaäckslitage avvaägbana - egenskaper och inflammatoriska effekter i mänskliga luftvägsceller. [Inhalable particles from studded tyre-induced wear of paved road surfaces - characteristics and inflammatory effects in human respiratory cells. Utdrag ur WearTox-projektet. VTI rapport 521. Linköping, Sweden.
- Guter, A., Dolev, A., Saltz, D. & Kronfeld-Schor, N. (2005) Temporal and spatial influences on road mortality in otters: conservation implication. *Israel Journal of Zoology*, **51**, 199-207.

- Gutzwiller, K.J. & Barrow, W.C. (2003) Influences of roads and development on bird communities in protected Chihuahuan Desert landscapes. *Biological Conservation*, **113**, 225-237.
- Hamilton, R.S. & Harrison, R.M. (eds) (1991) *Highway Pollution*. Elsevier, Amsterdam.
- Hanski, I., Henttonen, H., Korpimäki, E., Oksanen, L., Turchin, P. 2001. Small-rodent dynamics and predation. *Ecology* **82**(6), 1505-1520.
- Hanson, C.E. (2008) High Speed Train Noise Effects on Wildlife and Domestic Livestock. *Noise and Vibration Mitigation, NNF 99*, (eds B. Schulte-Werning *et al.*), pp. 26–32.
- Hardy, A.R., Fuller, J., Huijser, M.P., Kociolek, A. & Evans, M. (2006) *Evaluation of Wildlife Crossing Structures and Fencing on US Highway 93, Evaro to Polson*. Phase I: Preconstruction data collection and finalization of evaluation plan. Final report. Western Transportation Institute, College of Engineering, Montana State University. Prepared for Montana Department of Transportation.
- Harris, L.D. & Gallagher, P.B. (1989) New initiatives for wildlife conservation. The need for movement corridors. *In Defense of Wildlife: Preserving Communities and Corridors*, pp. 11-34 (Anonymous). Washington.
- Harris, L.D. & Scheck, J. (1991) From implications to applications: the dispersal corridor principle applied to the conservation of biological diversity. *Nature Conservation 2: The Role of Corridors* (eds D.A. Saunders & R.J. Hobbs), pp. 189-220. Surrey Beatty & Sons, Chipping Norton, New South Wales, Australia.
- Harris, L.D. (1984) *The Fragmented Forest*. University of Chicago Press, California, pp. 722.
- Harrison, P.D. & Dyer, M.I. (1984) Lead in mule deer forage in Rocky Mountain National Park, Colorado. *Journal of Wildlife Management*, **48**, 510-517.

- Harrison, S., Hohn, C. & Ratay, S. (2002) Distribution of exotic plants along roads in a peninsular nature reserve. *Biological Invasions*, **4**, 425-430.
- Hartmann, M. (2002) Evaluation of wildlife crossing structures: their use and effectiveness. *Road Ripporter*, 7.
- Hartmann, M. (2003). *Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness*.
- Heigl, F., Horvath, K., Laaha, G. & Zaller, J.G. (2017) Amphibian and reptile road-kills on tertiary roads in relation to landscape structure: using a citizen science approach with open-access land cover data. *BMC Ecology*, **17**(1), 24. doi:10.1186/s12898-017-0134-z.
- Helldin, J.O. & Seiler, A. (2003) Effects of roads on the abundance of birds in Swedish forest and farmland. IENE Conference 2003 Proceedings, Infra Eco Network Europe, Brussels, Belgium.
- Hels, T. & Buchwald, E. (2001) The effect of road kills on amphibian populations. *Biological Conservation*, **99**, 331-340.
- Henein, K. & Merriam, G. (1990) The elements of connectivity where corridor quality is variable. *Landscape Ecology*, **4**(2-3), 157-170.
- Hernande, Z.M. (1988) Road mortality of the Little Owl (*Athene noctua*) in Spain. *Journal of Raptor Research*, **22**, 81-84.
- Hicks, C. & Peymen, J. (2008) *COST 341, Habitat Fragmentation due to Transportation Infrastructure: The European Review*, pp. 129-174. Office for Official Publications of the European Communities, Luxembourg.
- Higgins, S. I., Richardson, D.M., Cowling, R.M. & Trinder-Smith, T.H. (1999) Predicting the landscape-scale distribution of alien plants and their threat to plant diversity. *Conservation Biology*, **13**, 303-313.
- Hilty, J., Lidicker Jr, W.Z. & Merenlender, A.M. (2006) *Corridor Ecology*. Island Press, Washington, DC.

- Hirst, S.M. (1969) Road-strip census techniques for wild ungulates in African woodlands. *Journal of Wildlife Management*, **33**, 40-48.
- Hlavac, V. & Andel, P. (2002) *On the Permeability of Roads for Wildlife: A Handbook (Prague, Czech Republic: Agency for Nature Conservation and Landscape Protection of the Czech Republic)*.
- Hodson, N.L. (1962) Some notes on the causes of bird casualties. *Bird Study*, **9**, 168-173.
- Holderegger, R. & Giulio, M.D. (2010) The genetic effects of roads: A review of empirical evidence. *Basic and Applied Ecology*, **11**, 522-531.
- Hoskin, C.J. & Goosem, M.W. (2010) Road impacts on abundance, call traits, and body size of rainforest frogs in northeast Australia. *Ecology and Society*, **15**(3), 15.
- Hubbard, M.W., Danielson, B.J. & Schmitz, R.A. (2000) Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management*, **64**, 707-712.
- Huber D., Kusak J. & Frkovic A. (1998) Traffic kills of brown bear in Gorski Kotar, Croatia. *Ursus*, **10**, 167-171.
- Huijser, M.P. & Bergers, P.J.M. (2000) The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. *Biological Conservation*, **95**, 111–116.
- Huijser, M.P., Duffield, J.W., Clevenger, A.P., Ament, R.J. & XMcGowen, J.W. (2009) Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool. *Ecology and Society*, **14**(2), 15.
- Huijser, M.P., Fairbank, E.R., Camel-Means, W., Graham, J., Watson, V., Basting, P. & Becker, D. (2016) Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife-vehicle collisions and providing safe crossing opportunities for large mammals. *Biological Conservation*, **197**, 61-68.

- Huijser, M.P., Gunson, K.E. & Abrams, C. (2006) *Wildlife-vehicle collisions and Habitat Connectivity Along Montana Highway 83 in the Seeley-Swan Valley, Montana: A Reconnaissance*. Western Transportation Institute Report No. FHWA/MT-05-009/8177, Montana State University, Bozeman, MT. 160p.
- Huijser, M.P., Holland, T.D., Kociolek, A.V., Barkdoll, A.M. & Schwalm, J.D. (2009) Animal-vehicle crash mitigation using advanced technology phase ii: system effectiveness and system acceptance Report No FHWA-OR-TPF-09-14 http://www.oregon.gov/ODOT/TD/TP_RES/
- Huijser, M.P., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A.P., Smith, D. & Ament, R. (2007) *Wildlife-vehicle collision reduction study*. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.
- Hunt, A.H., Dickens, J. & Whelan, R.J. (1987) Movement of mammals through tunnels under railway lines. *Australian Zoologist*, **24**, 89-93.
- Husby, M. (2016) Factors affecting road mortality in birds. *Ornis Fennica*, **93**, 212-224.
- Husby, M. (2017) Traffic influence on roadside bird abundance and behaviour. *Acta Ornithologica*, **52**(1), 93-103.
- Illner, H. (1992) Road deaths of Westphalian owls: methodological problems, influence of road type and possible effects on population levels. *The Ecology and Conservation of European Owls* (eds C.A. Glabraith et al.), pp. 94-110. JNCCP.
- Ising, H. & Kruppa, B. (2004) Health effects caused by noise: Evidence in the literature from the past 25 years. *Noise and Health*, **6**, 5-13.
- IUCN (International Union for Conservation of Nature), (2008) *The IUCN Red List of Threatened Species*. IUCN, Cambridge.
- IUCN (International Union for Conservation of Nature). (2008) *The IUCN Red List of Threatened Species*. IUCN, Cambridge, United Kingdom.

- Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavac, V., Keller, V.B., Rosell, C., Sangwine, T., Tørsløv, N., & Wandall, B.I.M. (eds) (2003) *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. Office for Official Publications of the European Communities, Luxembourg.
- Iuell, B., Hans, B., Ruud, C., Jiri, D., Gary, F., Claire, H., Vaclav, H., Verena, K., Carme, R. Tony, S., Niels, T. & Barbara le Maire, W. (2003) *COST 341 - Habitat Fragmentation due to Transportation Infrastructure*. Wildlife and Traffic - A European Handbook for Identifying Conflicts and Designing Solutions.
- Jaarsma C.F., Van Langevelde F. & Botma, H. (2006) Flattened faune and mitigation: traffic victims related to road, traffic, vehicle, and species characteristics. *Transportation Research Part D-Transport and Environment*, **11**, 264-276.
- Jaarsma, C.F., Van Langevelde, F., Baveco, J.M., van Tupen, M. & Arisz, J. (2007) Model for rural transportation planning considering simulating mobility and traffic kills in the badger *Meles meles*. *Ecological Informatics*, **2**, 73-82.
- Jaarsma, R., Langevelde, F. & Botma, H. (2006) Flattened fauna and mitigation: traffic victims related to road, traffic, vehicle, and species characteristics. *Transportation Research Part D: Transport and Environment*, **11**, 264-276.
- Jackson, H.D. (2003) Another reason for nightjars being attracted to roads at night. *Ostrich*, **74**, 228-230.
- Jackson, N.D. & Fahrig, L. (2011) Relative effects of road mortality and decreased connectivity on population genetic diversity. *Biological Conservation*, **144**, 3143–3148.
- Jackson, S. (1996) Underpass systems for amphibians. *Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar*, (eds G.L. Evink, P. Garrett, D. Zeigler & J. Berry), pp. 4. State of Florida Department of Transportation. Tallahassee, FL, 1996. FL-ER-58-96.

- Jackson, S. (1999) *Overview of Transportation-related Wildlife Problems*. Proceedings of the Third International Conference on Wildlife Ecology and Transportation (ICOWET) (eds G.L. Evink *et al.*), pp. 1-4. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, Florida, 330p.
- Jackson, S.D. & Griffin, C.R. (1998) *Towards a Practical Strategy for Mitigating Highway Impacts on Wildlife*. International Conference on Wildlife Ecology and Transportation, FL-ER-69-98, Florida Department of Transportation, Tallahassee, pp. 17-22.
- Jackson, S.D. & Griffin, C.R. (2000) *A Strategy for Mitigating Highway Impacts on Wildlife. Wildlife and Highways: Seeking Solutions to an Ecological and Socioeconomic Dilemma*. The Wildlife Society, Bethesda, MD.
- Jacob, J. & Hempel, N. (2003) Effects of farming practices on spatial behaviour of common voles. *Journal of Ethology*, **21**, 45-50.
- Jacobson, S.L. (2005) Mitigation measures for highway-caused impacts to birds. *General technical report PSWGTR-191*, (eds C.J. Ralph & T.D. Rich), pp. 1043-1050. U.S. Department of Agriculture, Forest Service, Albany, California.
- Jacobson, S.L., Bliss-Ketchum, L.L., Catherine, E., de Rivera, C.E. & Smith, W.P. (2016) A behavior-based framework for assessing barrier effects to wildlife from vehicle traffic volume. *Ecosphere*, **7**(4), 1345.
- Jacobson, S.L., Bliss-Ketchum, L.L., de Rivera, C.E. & Smith, W.P. (2016) A behavior-based framework for assessing barrier effects to wildlife from vehicle traffic volume 1. *7*(4), e01345.
- Jadhav, P.L., Chavan, S.P. & Trimukhe, H.S. (2018) Snake species diversity and their distribution in and around Nanded city, Maharashtra, India. *Journal of Entomology and Zoology Studies*, **6**(4), 1855-1860.

- Jaeger, J.A.G., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., Charbonneau, N., Frank, K., Gruber, B. & von Toschanowitz, K.T. (2005) Predicting when animal populations are at risk from roads: an interactive model of road avoidance behaviour. *Ecological Modeling*, **185**, 329-348.
- Jansen, Deborah, Sherwood, Krista & Fleming, Elizabeth (2010) The I-75 project: lessons for the Florida Panther. *Safe Passages* (eds Jon P. Beckmanna, Anthony P. Clevenger, Marcel R. Huijser, & Jodi A. Hilty), pp. 205-221. Island Press, Washington DC.
- Janssen, A.A., Lenders, W.A. & Leuven, R.S.E.W. (1997) *Measures combating the effect of habitat fragmentation on the badger (meles meles) in the Netherlands: ecological corridors or pitfalls? Proceedings of the International Conference on Habitat Fragmentation and Infrastructure*, (eds K. Canters, A. Piepers & D. Hendriks-Heersma). Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management, Road and Hydraulic Engineering Division, Delft, Netherlands.
- Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P.H. & Wiseth, B. (1991) Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces*, **27**, 93-99.
- Jarvis, L.E., Hartup, M. & Petrovan, S.O. 2019. Road mitigation using tunnels and fences promotes site connectivity and population expansion for a protected amphibian. *European Journal of Wildlife Research*, **65**, 27.
- Jeganathan, P., Divya, M., Kumar, A.M. & Raman, S.T.R. (2018) Seasonal variation in wildlife road kills in plantations and tropical rainforest in the Anamalai Hills, Western Ghats, India. *Current Science*, **114**(3), 619-626.
- Jochimsen, D., Peterson C.R., Andrews, K.M. & Gibbons, J.W. (2004) *A Literature Review of the Effects on Roads the Measures used to Mitigate those Effects*. Final Report to Idaho Fish and Game Department and the USDA Forest Service. 78p.

- Jochimsen, D.M. (2005) Factors influencing the road mortality of snakes on the upper Snake River Plain, Idaho. *Wildlife Impacts and Conservation Solutions* (eds C.L. Irwin, P. Garret, K.P. McDermott), pp. 351-365. North Carolina State University, North Carolina.
- Jochimsen, D.M. (2006) *Factors Influencing the Road Mortality of Snakes on the upper Snake River Plain, Idaho*. Proceedings of the 2005 International Conference on Ecology and Transportation (eds C.L. Irwin, P. Garrett & K.P. McDermott), pp. 351-365. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
- Jochimsen, D.M., Peterson, R.C., Andrews, M.K. & Gibbons, W.J. (2004) COST 341. *A literature review of the effects of roads on amphibians and reptiles and the measures used to mitigate those effects*. Final Report to Idaho Fish and Game Department and the USDA Forest Service. 79 pp.
- Jodoin, Y., Lavoie, C., Villeneuve, P., Theriault, M., Beaulieu, J. & Belzile, F. (2008) Highways as corridors and habitats for the invasive common reed *Phragmites australis* in Quebec, Canada. *Journal of Applied Ecology*, **45**(2), 459-466.
- Johnson, A.P.E. (2008) *Best Practices Handbook for Roadside Vegetation Management*, Minnesota Department of Transportation.
- Joly, K., Nellemann, C. & Vistnes, I. (2006) A reevaluation of caribou distribution near an oilfield road on Alaska's North Slope. *Wildlife Society Bulletin*, **34**, 866-869.
- Jones, J.A., Swanson, F.J., Wemple, B.C. & Snyder, K.U. (2000) Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology*, **14**, 76-85.
- Jordan, R. & Lacher, T. (2018) Impacts of habitat loss and fragmentation on terrestrial biodiversity, Reference Module in Earth Systems and Environmental Sciences, 1-18.

- Joshi, R. & Dixit, A. (2012) Wildlife mortality on National Highway 72 and 74 across the Rajaji National Park and the Haridwar conservation area, North India. *International Journal of Conservation Science*, **3**(2), 127-139.
- Joyce, T.L. & Mahoney, S.P. (2001) Spatial and temporal distributions of moose-vehicle collisions in New found land. *Wildlife Society Bulletin*, **29**, 281-29.
- Joyce, T.L. & Mahoney, S.P. (2001) Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. *Wildlife Society Bulletin*, **29**, 281-291.
- Kadoya, T. (2009) Assessing functional connectivity using empirical data. *Population Ecology*, **51**, 5-515.
- Kalansuriya, C.M., Pannila, A.S. & Sonnadara, D.U.J. (2009) *Effect of roadside vegetation on the reduction of traffic noise levels*. Proceedings of the Technical Sessions, 25, 1-6.
- Kambourova-ivanova, N., Koshev, Y., Popgeorgiev, G., Ragyov, D., Pavlova, M., Mollov, I. & Nedialkov, N. (2012) Effect of traffic on mortality of amphibians, reptiles, birds and mammals on two types of roads between Pazardzhik and Plovdiv Region (Bulgaria) - preliminary results materials and methods. *Acta Zoologica Bulgarica*, **64**, 57-67.
- Kannan, P. (2007) Mortality of reptiles due to vehicular traffic in Mudumalai Wildlife Sanctuary, Western Ghats, Tamil Nadu, India. *Cobra*, **1**(3), 1-3.
- Kapfer, J.M., Pekar, C.W., Reineke, D.M., Coggins, J.R. & Hay, R. (2010) Modeling the relationship between habitat preferences and home-range size: A case study on a large mobile colubrid snake for North America. *Journal of Zoology*, **282**, 13-20.
- Karanth, K.U. & Sunquist, M.E. (1995). Prey selection by tiger, leopard and dhole in tropical forests. *Journal of Animal Ecology*, **64**, 439-450.
- Kaseloo, P.A. (2006) Synthesis of noise effects on wildlife populations. *Proceedings of the 2005 International Conference on Ecology and Transportation*, (eds C.L. Irwin, P Garrett, K.P. McDermott), pp. 33-35. Center for Transportation and the Environment, North Carolina State University, NC, Raleigh.

- Kazemi, V., Jafari, H. & Yavari, A. (2016) Spatio-temporal patterns of wildlife road mortality in Golestan National Park-North East of Iran. *Open Journal of Ecology*, **6**, 312-324.
- Keller, I. & Largiadèr, C.R. (2003) Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. *Proceedings of the Royal Society B*, **270**, 417-423.
- Keller, I., Nentwig, W. & Largiader, C.R. (2004) Recent habitat fragmentation due to roads can lead to significant genetic differentiation in an abundant flightless ground beetle. *Molecular Ecology*, **13**, 2983-2994.
- Kerley, L.L., Goodrich, J.M., Miquelle, D.G., Smirnov, E.N., Quigley, H.B. & Hornocker, M.G. (2002) Effects of roads and human disturbance on Amur tigers. *Conservation Biology*, **16**(1), 97-108.
- Khan, J.A., Chellam, R., Rodgers, W.A. & Johnsingh, A.J.T. (1996). Ungulate densities and biomass in the tropical dry deciduous forests of Gir, Gujrat, India. *Journal of Tropical Ecology*, **12**, 149-162.
- Kiffner, C.K.J., Jenkins, N. & Collinson, W.J. (2015): Wildlife road kill patterns on a major highway in northern Tanzania, *African Zoology*. **50**(1), 1-6.
- King, R.S., Nunnery, K.T. & Richardson, C.J. (2000) Macro-invertebrate assemblage response to highway crossings in forested wetlands: implications for biological assessment. *Wetlands Ecology and Management*, **8**, 243-256.
- Kinhill Pty Limited. (1996) *Impact of Highways on Australian Fauna*. Field surveys and a review relevant literature review
- Kintsch, J. & Cramer, P.C. (2011) *Permeability of Existing Structures for Terrestrial Wildlife: A Passage Assessment System*. Research Report No.WA-RD 777.1 Washington State Department of Transportation, Olympia, WA. (<http://www.wsdot.wa.gov/research/reports/fullreports/777.1.pdf>)
- Kintsch, J. & Patricia, C. (2011) *Permeability of Existing Structures for Wildlife: Developing a Passage Assessment System*. Report to the Washington State Department of Transportation Research Report No. WA-RD 777.1.

- Kioko, J., Kiffner, C., Jenkins, N. & Collinson, W. (2015) Wildlife road kill patterns on a major highway in Northern Tanzania. *African Zoology*, **50**, 1-6.
- Kioko, J., Kiffner, C., Phillips, P., Patterson-Abrolat, C., Collinson, W. & Katers, S. (2015) Driver knowledge and attitudes on animal vehicle collisions in Northern Tanzania. *Tropical Conservation Science*, **8**(2), 352-366.
- Kiros, W., Kibrom, F.G., Raman, V., Teferi, M., Solomon, K. & Yonas, M. (2016) Vehicle-wild vertebrate collision mortality on the highways of Tigray, Ethiopia, implications for conservation. *African Journal of Ecology*, **54**(4), 442-449.
- Knutson, R. (1987) *A Field Guide to Common Animals of Roads, Streets, and Highways*. Ten Speed Press, Berkeley, USA, p. 88.
- Kobylarz, B. (2001) The effect of road type and traffic intensity on amphibian road mortality. *Journal of Service Learning in Conservation Biology*, **1**, 10-15.
- Kociolek, A., Grilo, C. & Jacobson, S. (2015). Flight Doesn't Solve Everything: Mitigation of Road Impacts on Birds. Handbook of Road Ecology, 1st Edn. Chichester: John Wiley & Sons.
- Kociolek, A.V., Clevenger, A.P., Clair., C.C. & Proppe, D.S. (2011) Effects of Road Networks on Bird Populations. *Conservation Biology*, **25**(2), 241-249.
- Kociolek, A.V., Grilo, C. & Jacobson, S. (2015) Flight doesn't solve everything: mitigation of road impacts on birds. *Handbook of Road Ecology*. (eds van der Ree, R., Smith, D. & Grilo, C.). Wiley, Oxford.
- Koenig, J., Shine, R. & Shea, G. (2001) The ecology of an Australian reptile icon: how do bluetongue lizards (*Tiliqua scincoides*) survive in suburbia? *Wildlife Research*, **28**, 215-227.
- Kofron, C.P. & Chapman, A. (2006) Causes of mortality to the endangered Southern Cassowary *Casuarius casuarius johnsonii* in Queensland, Australia. *Pacific Conservation Biology*, **12**, 175-179.

- Koopman, M.E., Cypher, B.L. & McCullough, D.R. (2001) Factors influencing space and prey use by San Joaquin kit foxes. *Transactions of the Western Section of the Wildlife Society*, **37**, 77-83.
- Koopman, M.E., Scrivner, J.H. & Kato, T.T. (2001) Patterns of den use by San Joaquin kit foxes. *Journal of Wildlife Management*, **62**, 373-379.
- Korpimäki, E. & Norrdahl, K. (1989) Avian predation on mustelids in Europe 1: occurrence and effects on body size variation and life traits. *Oikos*, **55**, 205-215.
- Kristiansen L.V., Sunde, P., Nachman, G. & Madsen, A.B. (2007) Mortality and reproductive patterns of wild European polecats *Mustela putorius* in Denmark. *Acta Theriol (Warsz)*, **52**, 871-878.
- Krivda, W. (1993) Road kills of migrating garter snakes at the Pas, Manitoba. *Blue Jay*, **51**, 197-198.
- Kuck, L., Hompland, G.L. & Merrill, E.H. (1985) Elk calf response to simulated mine disturbance in southeast Idaho. *Journal of Wildlife Management*, **49**, 751-757.
- Kuehn, R., Hindenlang, K.E., Holzgang, O., Senn, J., Stoeckle, B., & Sperisen, C. (2007) Genetic effect of transportation infrastructure on roe deer populations (*Capreolus capreolus*). *Journal of Heredity*, **98**, 13-22.
- Kuitunen, M., Rossi, E. & Stenroos, A. (1998) Do highways influence density of land birds? *Environmental Management*, **22**, 297-302.
- Kumara, H.N., Sharma, A.K., Kumar, A. & Singh, M. (2000) Road kills of Wild Fauna in Indira Gandhi Wildlife Sanctuary, Western Ghats, India: Implications for Management. *Biosphere Conservation* **3**, 41-47.
- Kuykendall, M.T & Keller, G.S. (2011) Impacts of roads and corridors on abundance and movement of small mammals on the llano estacado of Texas. *The Southwestern Naturalist*, **56**(1), 9-16.

- Lambert, T.D., Malcolm, J.R. & Zimmerman, B.L. (2006) Amazonian small mammal abundances in relation to habitat structure and resource abundance. *Journal of Mammal*, **87**, 766-776.
- Land, E.D. & Lotz, M. (1996) Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. *Trends in Addressing Transportation Related Wildlife Mortality* (eds G.L. Evink, P. Garrett, D. Zeigler & J. Berry), pp. 350-355. Proceedings of the Transportation Related Wildlife Mortality Seminar. State of Florida, Department of Transportation, Tallahassee, USA.
- Langen, T.A., Machniak, A., Crowe, E.K., Mangan, C., Marker, D.F., Liddle, N. & Roden, B. (2007) Methodologies for surveying Herpetofauna mortality on rural highways. *Journal of Wildlife Management*, **71**, 1361-1368.
- Langley, W.M., Lipps, H.W. & Theis, J.F. (1989) Responses of Kansas motorists to snake models on a rural highway. *Transactions of the Kansas Academy of Science*, **92**, 43-48.
- Lapoint, S.D., Kays, R.W. & Ray, J.C. (2003) Animal crossing the Northway: Are existing culverts usefull?. *Adirondack Journal of Environmental Studies*, **11**.
- Laurance, W. (2018) If you can't build well, then build nothing at all. *Nature*, **563**, 295.
- Laurance, W.F. & Burgués-Arrea, I. (2017) Roads to riches or ruin? *Science*, **358**, 442-444.
- Laurance, W.F. (2009) Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, **24**, 659-669.
- Laurance, W.F. (2009) Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, **24**, 659-669.
- Laurance, W.F., Clements, G.R., Sloan, S.P., O'Connell, C.S., Mueller, N.D., Goosem, M., Oscar Venter O., Edwards. D.P., Phalan, B., Balmford, A., Ree. R.V.D., & Arrea. I.B. (2014) A global strategy for road building. *Nature*, **513**, 229-232.

- Laurance, W.F., Croes, B.M., Tchgnoumba, L., Lahm, S.A., Alonso, A., Lee, M.E., Campbell, P. & Ondzeano, C. (2006) Impacts of roads and hunting on Central African rainforest mammals. *Conservation Biology*, **20**(4), 1251-1261.
- Laurance, W.F., Goosem, M. & Laurance, S.G.W. (2009) Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution*, **24**, 659-669.
- Laurance, W.F., Goosem, M. & Laurance, S.G.W. 2009. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, **24**, 12, 159-169.
- Laursen, K. (1981) Birds on roadside verges and the effect of moving on frequency and distribution. *Biological Conservation*, **8**, 61-72.
- Le Viol, I., Chiron, F., Julliard, R. & Kerbiriou, C. (2012) More amphibians than expected in highway storm water ponds. *Ecological Engineering*, **47**, 146-154.
- Leblond, M., Dussault, C & Ouellet, J.P. (2013) Avoidance of roads by large herbivores and its relation to disturbance intensity. *Journal of Zoology*, **289**(1), 32-40.
- Leblond, M., Dussault, C., Ouellet, J.P., Poulin, M., Courtois, R. & Fortin, J. (2007) Electric fencing as a measure to reduce moose–vehicle collisions. *Journal of Wildlife Management*, **71**, 1695-1703.
- Leblond, M., Frair, J., Fortin, D., Dussault, C., Ouellet, J.-P. & Courtois, R. (2011). Assessing the influence of resource covariates at multiple spatial scales: an application to forest-dwelling caribou faced with intensive human activity. *Landscape Ecology*, **26**, 1433–1446.
- Lechner, A., Chan, F. & Campos-Arceiz, A. (2018) Biodiversity conservation should be a core value of China’s Belt and Road Initiative. *Nature Ecology & Evolution*, **2**, 408-409.
- Lee, A.M., Davies, L. & Power, S.A. (2012) Effects of roads on adjacent plant community composition and ecosystem function: An example from three calcareous ecosystems. *Environmental Pollution*, **163**, 273-280.

- Leedy, D.L. & Adams, L.W. (1982) *Wildlife Considerations in Planning and Managing Highway Corridors*. Report No. FHWA-TS-82-212, National Technical Information Service, Springfield, Va. 93pp.
- Leedy, D.L. (1978) *Highways and Wildlife: Implications for Management. Classification, Inventory, and Analysis of Fish and Wildlife Habitat*. The Proceedings of a National Symposium, pp.363-383. Fish and Wildlife Service, US Department of the Interior, Maryland.
- Lehndal, L. (2008) *Activity Patterns, Diurnal and Nocturnal Behaviour of the Marsh Deer (*Blastocerus dichotomus*) in the Jataí Ecological Station, Brazil*. Degree project. SLU, Sweden.
- Lengagne, T. 2008. Traffic noise affects communication behavior in a breeding anuran, *Hyla arborea*. *Biological Conservation*, **141**, 2023–2031.
- Lesbarrères, D. & Fahrig, L. (2012) Measures to reduce population fragmentation by roads: what has worked and how do we know? *Trends in Ecology and Evolution*, **27**, 374-380.
- Lesbarrères, D., Lodé, T. & Merilä, J. (2004) What type of amphibian tunnel could reduce road kills? *Oryx*, **38**, 220-223.
- Lesinski G, Kowalski M, Wojtowicz B, Gulatowska J. & Lisowska A. (2007) Bats on forest islands of different size in an agricultural landscape. *Folia Zoologica*, **56**, 153-161.
- Lesinski, G. (2007) Bat road casualties and factors determining their number. *Mammalia*, **71**(3), 138-142.
- Lindenmayer, D.B., Wood, J.T., McBurney, L., MacGregor, C., Youngentob, K. & Banks, S.C. (2011) How to make a common species rare: A case against conservation complacency. *Biological Conservation*, **144**, 1663-1672.
- Litvaitis, J.A. & Tash, J.P. (2008) An approach toward understanding wildlife-vehicle collisions. *Environmental Management*, **42**, 688-697.
- Liu, S., Cui, B., Dong, S., Yang, Z.F., Yang, M & Holt, K. (2008) Evaluating the influence of road networks on landscape and regional ecological risk – a case

- study in Lancang River Valley of Southwest China. *Ecological Engineering*, **34**, 91-99.
- Lode, T. (2000) Effect of a motorway on mortality and isolation of wildlife populations. *Ambio*, **29**, 163–166.
- Lohr, B., Wright, T.F. & Dooling, R.J. (2003) Detection and discrimination of natural calls in masking noise by birds: estimating the active space of a signal. *Animal Behavior*, **65**, 763-777.
- Lonsdale, W.M. & Lane, A.M. (1994) Tourist vehicles as vectors of weed seeds in Kakadu-National-Park, Northern Australia. *Biological Conservation*, **69**(3), 277-283.
- Loos, G. & Kerlinger, P. (1993) Road mortality of Saw-whet and Screech Owls on the Cape May peninsula. *Journal of Raptor Research*, **27**, 210-213.
- Loss, S., Will, T. & Marra, P. (2014) Estimation of bird-vehicle collision mortality on U.S. roads. *The Journal of Wildlife Management*, **78**, 763-771.
- Loss, S.R., Will, T., Loss, S. S. & Marra, P.P. 2014. Bird-building collisions in the United States: estimates of annual mortality and species vulnerability. *Condor: Ornithological Applications* 116, 8-23.
- Lovallo, M.J. & Anderson, E.M. (1996) Bobcat movements and home ranges relative to roads in Wisconsin. *Wildlife Society Bulletin*, **24**, 71-76.
- Luean, R.K., Benda, P., Horaek, I., Reiter, A., Hoffmannova, A., Hulova, S., Neckaoova, J., Svaeina, T. & Hulva, P. (2009) First data on distribution, ecology and behavior of Alcathe bat (*Myotis alcathoe*) in the Czech Republic. *Acta Chiropterologica*, **11**(1), 61-69.
- Lyon, L.J., Lonner, T.N., Weigand, J.P., Marcum, C.L., Edge, W.D., Jones, J.D. & McCleerey, D.W. (1985) *Coordinating Elk and Timber Management: Final Report of the Montana Cooperative Elk-Logging Study 1970-1985*. Montana Department of Fish, Wildlife and Parks, Helena. 53 pp.

- Mace, R.D. & Waller, J.S. (1996) Grizzly bear distribution and human conflicts within Jewel Basin Hiking Area: Swan Mountains, Montana. *Wildlife Society Bulletin*, **24**, 461-467.
- Mace, R.D., Waller, J.S., Manley, T.L., Lyon, L.J. & Zurring, H. (1996) Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana. *Journal of Applied Ecology*, **33**, 1395-1404.
- Machado, F.S., Fontes, M.A.L., Mendes, P.B., Moura A.S. & dos S. Romão, B. (2015) Road kill on vertebrates in Brazil: seasonal variation and road type comparison. *North-western Journal of Zoology*, **11**(2), 247-252.
- MacPherson, L.M., Sullivan, M.G., Foote, A. L. & Cameron, E.S. (2012) Effects of Culverts on Stream Fish Assemblages in the Alberta Foothills. *North American Journal of Fisheries Management*, **32**, 480-490.
- Mader, H. (1984) Animal habitat isolation by roads and agricultural fields. *Biological Conservation*, **29**, 81-96.
- Mader, H.J. (1987) Animal habitat isolation by roads and agricultural fields. *Biological Conservation*, **29**, 81-96.
- Mader, H.J., Schell, C. & Kornacker, P. (1990) Linear barriers to arthropod movements in the landscape. *Biological Conservation*, **54**, 209-222.
- Madsen, A., Strandgaard, H. & Prang, A. (2002) Factors causing traffic killings of roe deer *Capreolus capreolus* in Denmark. *Wildlife Biology*, **8**, 55-61.
- Mahoney, S.P. & Schaefer, J.A. (2002) Hydroelectric development and the disruption of migration in caribou. *Biological Conservation*, **107**, 147-153.
- Main, M.B. & Allen, G.M. (2002) Landscape and seasonal influences on road kill of wildlife in Southwest Florida. *Florida Scientist*, **65**(3), 149-158.
- Maine Department of Transportation (2007) *Beginning with Habitat* <http://www.beginningwithhabitat.org/pdf/MARoadsWildlife-FINAL.pdf>.

- Majumder, A., Basu, S., Sankar, K., Qureshi, Q., Jhala, Y.V. & Gopal, R. (2012) Prey selection, food habits and temporal activity patterns of sympatric carnivores in Pench Tiger Reserve, Madhya Pradesh, Central India. *Journal of Scientific Transactions in Environment and Technovation*, **5**(3), 110-120.
- Malo, J.E., Hervás, I., Herranz, J., Mata, C. & Suárez, F. (2005) *How many days to monitor a wildlife passage? Species detection patterns and the estimation of the vertebrate fauna using crossing structures at a motorway*. The 2007 International Conference on Ecology and Transportation: 406-413.
- Malo, J.E., Suarez, F. & Diez, A. (2004) Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology*, **41**, 701-710.
- Mandujano, S. (2005) Calibration of tracks count to estimate population density of white-tailed deer (*Odocoileus virginianus*) in a Mexican tropical forest. *The Southwestern Naturalist*, **50**, 223-229.
- Manville, A.M. (1983) Human impact on the black bear in Michigan's lower peninsula. *International Association for Bear Research Management*, **5**, 20-33.
- Mark, L.W. (2005) Background and Literature Review, Conservation Services Division New Mexico Department of Game and Fish.
- Markolt, F., Szemethy, L., Lehoczki, R. & Heltai, M. (2012) Spatial and temporal evaluation of wildlife-vehicle collisions along the M3 Highway in Hungary. *North-Western Journal of Zoology*, **8**(2), 414-425.
- Marsh, D.M., Milam, G.S., Gorham, N.P. & Noelle G.B. (2004) Forest roads as partial barriers to terrestrial Salamander movement. *Conservation Biology*, **19**, 2004-2008.
- Marsh, D.M., Page, R.B., Hanlon, T.J., Corritone, R., Little, E.C., Seifert, D.E., *et al.* (2008) Effects of roads on patterns of genetic differentiation in red-backed salamanders, *Plethodon cinereus*. *Conservation Genetics*, **9**, 603-613.
- Marshall, I. C., Corner, A. & Tattersfield, P. (1995). An amphibian mitigation scheme for the A34 Wilmslow and Handforth Bypass, Chesire, United Kingdom. *Habitat Fragmentation and Infrastructure: Proceedings of the*

International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering (eds K. Canters, A. Piepers & D. Hendriks–Heersma), pp. 227-237. Maastricht and The Hague, The Netherlands, Delft.

Marshall, R. 1935. Immediate problems of wilderness preservation Quoted in Nash, R, 1982. *Wilderness and the American ad*. Yale University Press: New Haven. 3rd Edition: P. 204.

Maschio, G.F., Santos-Costa, M.C. & Prudente, A.L.C. (2016) Road-kills of snakes in a tropical rainforest in the Central Amazon Basin, Brazil. *South American Journal of Herpetology*, **11**(1). <https://doi.org/10.2994/SAJH-D-15-00026.1>

Mata Estacio, C., Hervás, I., Herranz Barrera, J., Suárez Cardona, F. & Malo, J. (2003) *Effectiveness of Wildlife Crossing Structures and Adapted Culverts in a Highway in Northwest Spain*. Proceedings of the International Conference on Ecology and Transportation (eds C. Leroy Irwin, Paul Garrett, & K.P. MacDermott).

Mata, C., Hervás, I., Herranz, J., Malo, J.E. & Suárez, F. (2009) Seasonal changes in wildlife use of motorway crossing structures and their implication for monitoring programmes. *Transportation Research Part D*, **14**, 447-452.

Mata, C., Hervas, I., Herranz, J., Sua´ rez, F. & Malo, J.E. (2005) Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. *Biological Conservation*, **124**(3), 397-405.

Mata, C., Hervás, I., Herranz, J., Suárez, F. & Malo, J. (2008) Are motorway wildlife passages worth building? Vertebrate use of road-crossing structures on a Spanish motorway. *Journal of Environmental Management*, **88**, 407-415.

Mata, C., Hervas, I., Herranz, J., Suárez, F. & Malo, J.E. (2005) Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. *Biological Conservation*, **124**(3), 397-405.

- Mateus, A.R., Grilo, C. & Santos-Reis, M. (2011) Surveying drainage culvert use by carnivores: Sampling design and cost–benefit analyzes of track-pads vs. video-surveillance methods. *Environmental Monitoring and Assessment*, **181**(1), 101-109.
- Matthes, S., Grewe, V., Sausen, R. & Roelofs, G.J. (2007) Global impact of road traffic emissions on tropospheric ozone. *Atmospheric Chemistry and Physics*, **7**, 1707-1718.
- Mattson, D.J., Knight, R.R. & Blanchard, B.M. (1987) The effects of developments and primary roads on grizzly bear habitat use in Yellowstone National Park, Wyoming. *International Conference on Bear Research and Management*, **7**, 259-273.
- Maurya, K.K., Bopanna, I.P., Dutta, S. & Jhala, Y.V. (2011) *Impacts of roads on small mammals in the agro-pastoral landscape of Kachchh, Gujarat*. Proceedings of Second Seminar on Small Mammals Conservation Issues, 2, pp. 40-45.
- Mazerolle, M.J. (2004) Amphibian road mortality in response to nightly variations in traffic intensity. *Herpetologica*, **60**, 45-53.
- McCardle, L.D. & Fontenot, C.L. (2015). The influence of thermal biology on road mortality risk in snakes. *Journal of Thermal Biology*, **56**, 39–49.
- McClure, H.E. (1951) An analysis of animal victims on Nebraska’s highways. *Journal of Wildlife Management*, **15**, 410-420.
- McDonald, P.J. (2012) Snakes on roads: an arid Australian perspective. *Journal of Arid Environments*, **79**, 116-119.
- McDonald, W. & Clair, C.C. (2004) Elements that promote highway crossing structure use by small mammals in Banff National Park. *Journal of Applied Ecology*, **41**(1), 82-93.
- McGregor, R.L., Bender, D.J. & Fahrig, L. (2008) Do small mammals avoid roads because of the traffic?. *Journal of Applied Ecology*, **45**, 117-123.

- McGregor., Rachele., Derrane, S., Bender, D. & Fahrig, L. (2003) The effect of traffic volume on translocated small mammal movement. *Proceedings of the International Conference on Ecology and Transportation*, (eds C. Leroy Irwin, Paul Garrett, and K.P. McDermott), pp. 394-396. Center for Transportation and the Environment, North Carolina State University, NC, Raleigh.
- Mcintyre, S. & Lavorel, S. (1994) Predicting richness of native, rare, and exotic plants in response to habitat and disturbance variables across a variegated landscape. *Conservation Biology*, **8**, 521-531.
- Mckenna, D., Mckenna, K., Malcom, S. & Berenbaum, M. (2001) Mortality of Lepidoptera along roadways in central Illinois. *Journal of the Lepidopterists Society*, **55**(2), 63-68.
- McLaren., Ashley, L., Fahrig & Waltho, N. (2011) Movement of small mammals across divided highways with vegetated medians. *Canadian Journal of Zoology*, **89**, 1214-1222.
- McLellan, B.N. & Shackleton, D.M. (1988) Grizzly bears and resource-extraction industries: Effects of roads on behaviour, habitat use and demography. *Journal of Applied Ecology* **25**, 451-460.
- McShea, W.J., Stewart, C.M., Kearns, L.J., Liccioli, S. & Kocka, D. (2008) Factors affecting autumn deer-vehicle collisions in a rural Virginia county. *Human-Wildlife Conflicts*, **2**, 110-121.
- Meaney, C., Bakeman, M., Reed-Eckert, M. & Wostl, E. (2007) Effectiveness of ledges in culverts for small mammal passage. <https://www.codot.gov/programs/research/pdfs/2007/smallmammal.pdf>
- Mech, L.D. (1989) Wolf population survival in an area of high road density. *American Midland Naturalist*, **121**, 387-389.
- Mech, L.D., Harris, S.H., Radde, G.L. & Paul, W.J. (1988) Wolf distribution and road density in Minnesota. *Wildlife Society Bulletin*, **16**, 85-87.
- Meffe, G.K., Carroll, C.R. & contributors (1997) *Principles of Conservation Biology*. Second edition. Sinauer and Associates Inc., Sunderland, MA, 729 pp.

- Mehri, A., Salmanmahiny, A., Tabrizi, A.R.M., Mirkarimi, S.H. & Sadoddin, A. (2018) Integration of anthropogenic threats and biodiversity value to identify critical sites for biodiversity conservation. *Geocarto International*, **2018**, 1-16.
- Menon, V. (2003) *Mammals of India*. Princeton Field Guides, D.K. Delhi.
- Merriam, G. (1991) Corridors and connectivity: animal population in heterogeneous environments. *Nature Conservation 2: The Role of Corridors* (eds D.A. Saunders & R.J. Hobbs). Surrey Beatty and Sons, Chipping Campden.
- Merriam, G., Kozakiewicz, M., Tsuchiya, E. & Hawley, K. (1989) Barriers as boundaries for metapopulations and demes of *Peromyscus leucopus* in farm landscapes. *Landscape Ecology*, **2**, 227-235.
- Messmer, T.A. & West, B. (eds.) (2000) *Wildlife and highways: seeking solutions to an ecological and socio-economic dilemma*. 7th Annual Meeting of The Wildlife Society, Nashville, Tennessee, USA.
- Milton, S.J. & Dean, W.R.J. (1998) Alien plant assemblages near roads in arid and semi-arid South Africa. *Diversity and Distributions*, **4**(4), 175-187.
- Ministry of Transportation. 2015. Environmental Guide for Wildlife Mitigation. Updated final report submitted by Eco-Kare International to the Ministry of Transportation, St. Catharines, Ontario, 107 pages
- Mitchell, J.C., Breisch, A.R. & Buhlmann, K.A. (2006) *Habitat Management Guidelines for Amphibians and Reptiles of the Northeastern United States*. Partners in Amphibian and Reptile Conservation, Technical Publication HMG-3, Montgomery, Alabama. 108 pages.
- Monge, N.J. (2018) Road kills in tropical ecosystems: a review with recommendations for mitigation and for new research. *Revista de Biología Tropical*, **66**, 722-738.
- Monica Rincon-Aranguri, Nicola´s Urbina-Cardona, Sandra P. Galeano, Brian C. Bock, & Vivian P. Pa´ez1. 2019. *Tropical Conservation Science*, **12**, 1–18

- Moore, R.G. (1978) Seasonal and daily activity patterns and thermoregulation in the southwestern speckled rattlesnake (*Crotalus mitchelli pyrrhus*) and the Colorado desert sidewinder (*Crotalus cerastes laterorepens*). *Copeia*, **1978**, 449-432.
- Morgantini, L.E. (1996) *Elk and Access Relationships in the Pincher Creek and Castle-Carbondale Subareas*. ASPB Annual Meeting: Access Management in Alberta; 1996 Apr 10-1996 Apr 11, Calgary, Alberta.
- Mukherjee, D. (2007) *Resource utilization patterns of reptiles in the tropical dry mixed deciduous forest of Anaikatty Hills, Western Ghats, India*, p. 150. PhD Thesis. Bharathiar University, Coimbatore, India.
- Mumme, R.L., Schoech, S.J., Woolfenden, G.E. & Fitzpatrick, J.W. (2000) Life and death in the fast lane: Demographic consequences of road mortality in the Florida Scrub-Jay. *Conservation Biology*, **14**(2), 501-512.
- Mumme, R.L., Schoech, S.J., Woolfenden, G.E. & Fitzpatrick, W. (2000) Life and death in the fast lane: demographic consequences of road mortality in the Florida Scrub-Jay. *Conservation Biology*, **14**, 501-512.
- Munguira, M.L. & Thomas, J.A. (1992). Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology*, **29**, 316-329.
- Munoz, T. & Megias, G., Munoz, P.T., Torres, F.P. & Gonzalez-Megias, A. Effect of roads on insects: a review. *Biodiversity and Conservation*, **24**, 659–682.
- Myers, W.L., Chang, W.Y., Germaine, S.S., Vander Haegen, W.M. & Owens, T.E. (2008) An analysis of deer and elk-vehicle collision sites along state highways in Washington State. Completion Report, Washington Department of Fish and Wildlife. Olympia, WA, 40p.
- Narayanan, S.S., Pradeep, V., Venkatesh, A., Kanchana, R. 2016. Effect of road kills on wildlife populations in Kalakad Mundanthurai Tiger Reserve, India. *International Journal of Advanced Research*, **4**(3), 193-204

- National Roads Authority (2004). *Guidelines for Assessment of Ecological Impacts of National Road Schemes*. National Roads Authority.
- National Roads Authority (2005). *Guidelines for the Treatment of Badgers During the Construction of National Road Schemes*.
- Native Vegetation Council. 2012. Guidelines for the Management of Roadside Vegetation. 1-30
- NCHRPT (2002) *Interactions between Roadways and Wildlife Ecology: A Synthesis of Highway Practice*. National Cooperative Highway Research Program Transportation. Research Board, Washington DC.
- Nellemann, C. & Cameron, R.D. (1996) Effects of petroleum development on terrain preferences of calving caribou. *Arctic*, **49**, 23-28.
- Nellemann, C., Jordhøy, P., Vistnes, I., Strand, O. & Newton, A. (2003) Progressive impacts of piecemeal development. *Biological Conservation*, **113**, 307-317.
- Neumann, W., Ericsson, G., Dettki, H., Bunnefeld, N., Keuler, N.S., Helmers, D.P. & Radloff, V.C. (2012) Difference in spatiotemporal patterns of wildlife road-crossings and wildlife-vehicle collisions. *Biological Conservation*, **145**, 70-78.
- Newmark, W.D., Boshe, J.I., Sariko, H.I. & Mahumbule, G.K. (1996) Effects of highway on large mammals in Mikumi National Park, Tanzania. *African Journal of Ecology*, **34**, 15-31.
- Ng, J.W., Nielsen, C. & Clair, C.C. (2008) Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. *Human-Wildlife Conflicts*, **2**(1), 34-47.
- Ng, S.J., Dole, J.W., Sauvajot, R.M., Riley, S.P.D. & Valone, T.J. (2004) Use of highway under crossings by wildlife in southern California. *Biological Conservation*, **115**, 499-507.

- Niermann, I., Biedermann, M., Bogdanowicz, W., Brinkmann, R., Le Bris, Y., Ciechanowski, M., Dietz, C., Dietz, I., Estók, P., von Helversen, O., Le Houédec, A., Paksuz, S., Petrov, B., Özkan, B., Piksa, K., Rachwald, A., Roué, S.Y., Sachanowicz, K., Schorcht, W., Tereba, A. & Mayer, F. (2007) Biogeography of the recently described *Myotis alcathoe* von Helversen and Heller, 2001. *Acta Chiropterol*, **9**(2), 361-378.
- Nietvelt, C.G. (2002) *The Effects of Roads on Wildlife: Bibliography*. Montane Wildlife Consulting, Jackson, Wyoming.
- Noel, L.E., Parker, F.R. & Cronin, M.A. (2004) Caribou distribution near an oilfield road on Alaska's North Slope, 1978-2001. *Wildlife Society Bulletin*, **32**, 757-771.
- Noss, R. (1995) *Ecological Impacts of Roads: A Bibliographic Database*. Wildlands Center for Preventing Roads, Missoula, MT.
- Noss, R. (2002) *The Ecological Effects of Roads*. Wildlands Center for Preventing Roads. <http://www.eco-action.org/dt/roads.html>.
- Noss, R.F. & Cooperrider, A.Y. (1994) *Saving Nature's Legacy: Protecting and Restoring Biodiversity*. Island Press.
- Noss, R.F. (1983) A regional landscape approach to maintain diversity. *BioScience*, **33**, 700-706.
- Noss, R.F. (1995) The ecological effects of roads, or the road to destruction, pp. 11-21. Unpublished Report. Wildlands CPR, U.S.A.
- Noss, R.F., Quigley, H.B., Hornocker, M.G., Merrill, T. & Paquet, P.C. (1996) Conservation biology and carnivore conservation in the Rocky Mountains. *Conservation Biology*, **10**, 949-963.
- NRA (2005) *National Roads Authority - Guidelines for the Treatment of Bats during the Construction of National Road Schemes*.
- NRA. (2004) *Best Practice Guidelines for the Conservation of Bats in the Planning of National Road Schemes*. National Roads Authority.

- O'Hanley, J.R. & Tomberlin, D. (2005) Optimizing the removal of small fish passage barriers. *Environmental Modeling and Assessment*, **10**, 85-88.
- Ogden, J.L.E. (1996) *Collision Course: The Hazards of Lighted Structures and Windows to Migration Birds*. Report. World Wildlife Fund (WWF) Canada and the Fatal Light Awareness Program, Ontario.
- Ogden, J.L.E. (1996) *Collision course: the hazards of lighted structures and windows to migration birds*. Report. World Wildlife Fund (WWF) Canada and the Fatal Light Awareness Program, Ontario.
- Olsson, M.P.O., Widen, P. & Larkin, J.L. (2008) Effectiveness of a highway overpass to promote landscape connectivity and movement of moose and roe deer in Sweden. *Landscape and Urban Planning*, **85**, 133-139.
- Ontario Ministry of Natural Resources and Forestry. April 2016. Best management practices for mitigating the effects of roads on amphibians and reptile species at risk in Ontario. Queen's Printer for Ontario. pp 112.
- Opdam, P. (1997) How to choose the right solution for the right fragmentation problem?. *Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of Ecological Engineering*, (ed K. Canters), pp. 55-60. Maastricht and the Hague, the Netherlands.
- Orlowski, G. & Nowak, L. (2004) Road mortality of hedgehogs *erinaceus* spp. In farmland in lower Silesia (South-Western Poland). *Polish Journal of Ecology*, **52**(3), 377-382.
- Orlowski, G. & Nowak, L. (2006). Factors influencing mammal road kill in the agricultural landscape of south-western Poland. *Polish Journal of Ecology*, **54**, 283-294.
- Orlowski, G. (2005) Factors affecting road mortality of the Barn Swallows (*Hirundo rustica*) in farmland. *Acta Ornithologica*, **40**, 117-125.
- Orlowski, G. (2007) Spatial distribution and seasonal pattern in road mortality of the common toad *Bufo bufo* in agricultural landscape of south-western Poland. *Amphibia-Reptilia*, **28**, 24-31.

- Orlowski, G. (2008) Roadside hedgerows and trees as factors increasing road mortality of birds: Implications for management of roadside vegetation in rural landscapes. *Landscape and Urban Planning*, **86**, 153-161.
- Oxford University Press USA. *Researchers may be underestimating road kill numbers.* ScienceDaily.
www.sciencedaily.com/releases/2018/05/180514083920.htm (accessed February 17, 2019).
- Oxley, D.J., Fenton, M.B. & Carmody, G.R. (1974) The effects of roads on populations of small mammals. *Journal of Applied Ecology*, **11**, 51-59.
- Özcan, A.U. & Özkazanç, N.K. (2017) Identifying the hotspots of wildlife-vehicle collision on the Çankırı-Kırıkkale highway during summer. *Turkish Journal of Zoology*, **41**, 722-730.
- Palomares, F. & Delibes, M. (1992) Some physical and population characteristics of Egyptian mongooses (*Herpestes ichneumon* L., 1758) in south-western Spain. *Z. Säugetierk*, **57**, 94-99.
- Pandey, S.K. (2016) Loss of wild species in road side accident: an alarming issues in India. *ESAIJ*, **12**(6), 224-226. ISSN: 0974-7451.
- Papouchis, C.M., Singer, F.J. & Sloan, W.B. (2001) Responses of desert bighorn sheep to increased human recreation. *Journal of Wildlife Management*, **65**, 573-582.
- Parasharya, B.M. & Tere, A. (2007) An observation of common Indian Monitor Lizard *Varanus Bengalensis* Schneider mortality on Anand–Ahmedabad Highway, Gujarat, India. *Zoos Print Journal*, **22**, 2872.
- Pardini, R., Nichols, L. & Püttker, T. (2017) Biodiversity response to habitat loss and fragmentation. 10.1016/B978-0-12-409548-9.09824-9.
- Parendes, L. A. & Jones, J.A. (2000) Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology*, **14**, 64-75.

- Parris, K. M., Velik-Lord, M. & North, J.M.A. (2009) Frogs call at a higher pitch in traffic noise. *Ecology and Society*, **14**(1), 25.
- Parris, K.M. & Schneider, A. (2008) Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and Society*, **14**(1), 29.
- Pasha, M.K.S., Areendran, G., Sankar, K. & Qureshi, Q. (2000) A preliminary checklist of snakes of Pench Tiger Reserve, Madhya Pradesh, *Cobra*, **40**, 5-8.
- Pasha, M.K.S., Jaypal, R., Areendran, A., Qureshi, A. & Sankar, K. (2004) Birds of Pench Tiger Reserve, Madhya Pradesh, Central India. *Newsletter for Ornithologist*, **1**, 1-2.
- Patrick, D.A., Schalk, C.M., Gibbs, J.P. & Woltz, H.W. (2010) Effective Culvert Placement and Design to Facilitate Passage of Amphibians across Roads. *Journal of Herpetology*, **44**(4), 618-626.
- Pedevillano, C. & Wright, R.G. (1987) The influence of visitors on mountain goat activities in Glacier National Park. *Montana Biological Conservation*, **39**, 1-11.
- Pejchara, L., Pringlea, R.M., Ranganathana, J., Zookb, J.R., Duranc, G., Oviedoc, F. & Dailya, G.C. (2008) Birds as agents of seed dispersal in a human-dominated landscape in southern Costa Rica. *Biological Conservation*, **141**, 536-544.
- Penny Anderson Associates (1994) *Roads and nature conservation guidance on impacts, mitigation and enhancements*. English Nature, Peterborough.
- Pepino, M., Rodriguez, M.A. & Magnan, P. (2012) Impacts of highway crossings on density of brook charr in streams. *Journal of Applied Ecology*, **49**, 395-403.
- Peris, S.J. & Pescador, M. (2004) Effects of traffic noise on passerine populations in Mediterranean wooded pastures. *Applied Acoustics*, **65**, 357-366.
- Perry, C. & Overly, R. (1977) *Impact of roads on big game distribution in portions of the Blue Mountains of Washington, 1972-1973*. Applied Research Bulletin No. 11. Washington Game Department, Olympia, WA, 38pp.
- Petranka, J.W., Eldridge, M.E. & Haley, K.E. (1993) Effects of timber harvesting on Southern Appalachian salamanders. *Conservation Biology*, **7**, 363-370.

- Philcox, C.K., Grogan, A.L. & Macdonald, D.W. (1999) Patterns of otter *Lutra lutra* road mortality in Britain. *Journal of Applied Ecology*, **36**(5), 748-762.
- Phillips, S.J., Dudík, M. & Schapire, R.E. (2004) *A maximum entropy approach to species distribution modeling*. Proceedings of the 21st International Conference on Machine Learning, ACM Press, New York, pp. 655-662.
- Podlucky, R. (1989) Protection of amphibians on roads: examples and experiences from Lower Saxony. *Trends in Addressing Transportation Related Wildlife Mortality*, Proceedings of the Transportation Related Wildlife Mortality Seminar (eds GL Evink *et al.*) pp. 15-28. State of Florida Department of Transportation, Tallahassee, FL. FL-ER-58-96.
- Pons, P. (2000) Height of the road embankment affects probability of traffic collision by birds. *Bird Study*, **47**, 122-125.
- Pradhan, R.P. & Bagchi, T.P. (2012) Effect of transportation infrastructure on economic growth in India: The VECM approach. *Research in Transportation Economics*, **38**(1), 1-10.
- Pragatheesh, A. & Rajvanshi, A. (2013) Spatial patterns and factors influencing the mortality of snakes on the National Highway-7 along Pench Tiger Reserve, Madhya Pradesh, India. *Oecologia Australis*, **17**(1), 20-35.
- Pragatheesh, A. (2011) Effect of human feeding on the road mortality of Rhesus macaques on National Highway-7 routed along Pench Tiger Reserve, Madhya Pradesh, India. *Journal of Threatened Taxa*, **3**(4), 1656-1662.
- Prakash, A. (2012) *A study on the impacts of highways on wildlife in Bandipur Tiger Reserve*. Master's Thesis submitted to the Tata Institute of Fundamental Research, Mumbai for the degree of Master of Science in Wildlife Biology and Conservation, National Centre for Biological Sciences, Tata Institute of Fundamental Research Bangalore, India.
- Prakash, A.B. (2012) *A study on the impacts of highways on wildlife in Bandipur Tiger Reserve*. A Thesis submitted to the Tata Institute of Fundamental Research, Mumbai.

- Prater, S.H. (1971) *The Book of Indian Animals*. Oxford University Press, Bombay.
- Prillewitz, F.C. (1997) *Fragmentation, not forever*. Proceedings of the international conference on "*Habitat Fragmentation, Infrastructure and the role of Ecological Engineering*" Maastricht and The Hague 1995 (eds K. Canters, A. Piepers & A. Hendriks-Heersma), pp. 26-29. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.
- Primm, S.A. (1996) A pragmatic approach to grizzly bear conservation. *Conservation Biology*, **10**, 1026-1035.
- Puglisi, M.J., Lindzey, J.S. & Bellis, E.D. (1974) Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management*, **38**, 799-807.
- Puky, M. (2006) Amphibian road kills: a global perspective. *Proceedings of the 2005 International Conference on Ecology and Transportation*, (eds CL Irwin, P Garrett, KP McDermott), pp. 325-338. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC:
- Putman, R.J. (1997) Deer and road traffic accidents: options for management. *Journal of Environmental Management*, **51**, 43-57.
- Putman, R.J., Langbein, J. & Staines, B.W. (2004) *Deer and road traffic accidents: A review of mitigation measures: costs and cost-effectiveness*. Report for the Deer Commission for Scotland; Contract RP23A, UK.
- Quinn, G. & Witmer, J. (2003) *Statistics for the Life Science*. Third Edition. Pearson Education, USA, p. 724.
- Quintero Angel, A., Osorio, D., Vargas-Salinas, F. & Saavedra-Rodríguez, C. (2012) Road kill rate of snakes in a disturbed landscape of Central Andes of Colombia. *Herpetology Notes*, **5**, 99-105.
- Raghuram, G. & Babu, R. (2001) Alternative means of financing railways. *Infrastructure development and financing: Towards a public-private partnership* (eds G. Raghuram, R. Jain, S. Sinha, P. Pangotra & S. Morris). Macmillan, New Delhi.

- Rajvanshi, A., Mathur, V.B. & Pragatheesh, A. 2013. Ecological effects of roads through sensitive habitats: implications for wildlife conservation. Wildlife Institute of India. Dehradun, India.
- Rajvanshi, A., Mathur, V.B., Teleki, G.C. & Mukherjee, S.K. (2001) *Roads, Sensitive Habitats and Wildlife: Environmental Guideline for India and South Asia*. Wildlife Institute of India, Dehradun and Canadian Environmental Collaborative Ltd., Toronto.
- Raleigh, N.C. (2003) Center for Transportation and the Environment, North Carolina State University, pp. 265-276.
- Ramesh, T., Kalle, R., Sankar, K. & Qureshi, Q. (2012) Spatio-temporal partitioning among large carnivores in relation to major prey species in Western Ghats. *Journal of Zoology*, **287**(4), 269-275.
- Ramesh, T., Snehalatha, V., Sankar, K. & Qureshi, Q. (2009) Food habits and prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu, India. *Journal of Scientific Transactions in Environment and Technovation*, **2**, 170-181.
- Ramp, D., Caldwell, J., Edwards, K.A., Warton, D. & Croft, D.B. (2005). Modelling of wildlife fatality hotspots along the snowy mountain highway in new south Wales, Australia. *Biological Conservation*, **126**, 474-490.
- Ramp, D., Wilson, V.K. & Croft, D.B. (2006) Assessing the impact of roads in peri-urban reserves: road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biological Conservation*, **129**, 348-359.
- Ramsay, D. (ed.) (1994) *Roads and Nature Conservation*. Guidance on impacts, mitigation and enhancement, 81 pp. English Nature, Peterborough.
- Ramsden, D.J. (2003) *Barn Owls and Major Roads: Results and Recommendations from a 15-Year Research Project*. Barn Owl Trust, Ashburton, Devon, UK.
- Rao, R. S.P & Girish. M.K.S. (2007) Road kills: Assessing insect casualties using flagship taxon. *Current Science*, **92**(6), 25.

- Raty, M. (1979) Effect of highway traffic on tetraonid densities. *Ornis Fennica*, **56**, 169-170.
- Rawankar, A. & Wagh, G. (2018) Surveillance of avian mortality on the road passing through Pohra – Malkhed reserve forest district Amravati, Maharashtra. *International Journal of Zoology Studies*, **3**(2), 135-139.
- Reck, H. & Kaule, G. (1993) Strassen und Lebensraume: Ermittlung und Beurteilung strassenbedingter Auswirkungen auf Pflanzen, Tiere und ihre Lebensraume. - Forschung Strassenbau und Strassenverkehrstechnik, Heft 654, Herausgegeben vom Bundesminister für Verkehr, Bonn-Bad Godesberg, Germany.
- Ree, R.V.D., Jaeger, J.A.G., Grift, E.A.V.D. & Clevenger, A.P. (2011) Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving toward larger scales. *Ecology and Society*, **16**, 48.
- Reed, D.F. & Ward, A.L. (1985) *Efficacy of methods advocated to reduce deer-vehicle accidents: research and rationale in the IJSA*. Pages 285-293 in Routes et faune sauvage. Service d'Etudes Techniques de Routes et Autoroutes, Bagneaux, France.
- Reed, D.F. & Woodard, T.N. (1981) Effectiveness of Highway Lighting in Reducing Deer-Vehicle Accidents. *Journal of Wildlife Management*, **45**(2), 721-726.
- Reed, D.F., Woodard, T.N. & Pojar, T.M. (1975) Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management*, **39**, 361-367.
- Reed, R., Johnson-Barnard, J., & Baker, W. (1996) Contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology*, **10**, 1098-1106.
- Reijnen R. & Foppen, R. (2006) Impact of road traffic on breeding bird populations. *The Ecology of Transportation: Managing Mobility for the Environment* (eds J. Davenport & J.L. Davenport), pp. 255-274. Springer, London.

- Reijnen, R. & Foppen, R. (1994) The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warblers breeding close to a highway. *Journal of Applied Ecology*, **32**, 187-202.
- Reijnen, R. & Foppen, R. (1994) The effects of car traffic on breeding bird populations in woodland: 1. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. *Journal of Applied Ecology*, **31**, 85-94.
- Reijnen, R., & Foppen, R. (1995) The effects of car traffic on breeding bird populations in woodland. III. Influence of population-size on the reduction of density close to a highway. *Journal of Applied Ecology*, **32**, 481-491.
- Reijnen, R., Foppen, R. & Meeuwsen, H. (1996) The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biological Conservation*, **75**, 255-260.
- Reijnen, R., Foppen, R., ter Braak, C. & Thissen, J. (1995) The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology*, **32**, 187-202.
- Rentch J.S., Fortney R.H., Stephenson S.L., Adams H.S., Grafton W.N. & Anderson J.T. 2005. Vegetation-site relationships of roadside plant communities in West Virginia, USA. *Journal Applied Ecology*, **42**, 129-138.
- Renterghem, T.V. & Botteldooren, D. (2012) On the choice between walls and berms for road traffic noise shielding including wind effects. *Landscape and Urban Planning*, **105**, 199-210.
- Richardson, J.H., Shore, R.F. & Treweek, J.R. (1997) Are major roads a barrier to small mammals? *Journal of Zoology London*, **243**, 840-846.
- Richardson, J.H., Shore, R.F., Treweek, J.R. & Larkin, S.B.C. (1997) Are major roads a barrier to small mammals? *Journal of Zoology*, **243**, 840-846.
- Rico, A., Kindlmann, P. & Sedlacek, F. (2007) Barrier effects of roads on movements of small mammals. *Folia Zoology*, **56**, 1-12.

- Rico, A., Kindlmann, P. & Sedlacek, F. (2007) Road crossing in bank voles and yellow-necked mice. *Acta Theriologica*, **52**, 85-94.
- Riley, S.P., Pollinger, J.P., Sauvajot, R.M., York, E.C., Bromley, C., Fuller, T.K. & Wayne, R.K. (2006) A southern California freeway is a physical and social barrier to gene flow in carnivores. *Molecular Ecology*, **15**, 1733-1741.
- Rivero, K., Rumiz, D.I. & Taber, A.B. (2005). Differential habitat use by two sympatric brocket deer species (*Mazama americana* and *M. gouazoubira*) in a seasonal Chiquitano forest of *Bolivia*. *Mammalia*, **69**, 169-183.
- Road Kill of Snakes on a Highway in an Orinoco Ecosystem: Landscape Factors and Species Traits Related to Their Mortality
- Robert J.M, Fraser M.S. & James F.Q. (2007) *Wildlife Crossings Guidance Manual*, California Department of Transportation.
- Rodrigue, J.-P., Comtois, C. & Slack, B. (2012) *The Geography of Transport Systems*, Hofstra University, Department of Global Studies & Geography, <http://people.hofstra.edu/geotrans>.
- Rodriguez, A., Crema, G. & Delibes, M. (1996) Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology*, **33**, 1527-1540.
- Rodriguez, A., Crema, G. & Delibes, M. (1997) Factors affecting crossing of red foxes and wildcats through non-wildlife passages across a high-speed roadway. *Ecography*, **20**, 287-294.
- Roe, J. H., Gibson, J. & Kingsbury, B.A. (2006) Beyond the wetland border: estimating the impact of roads for two species of water snakes. *Biological Conservation*, **130**, 161-168.
- Roedenbeck, I.A. & Voser, P. (2008) Effects of roads on spatial distribution, abundance and mortality of brown hare (*Lepus europaeus*) in Switzerland. *European Journal of Wildlife Research*, **54**, 425-437.

- Roedenbeck, I.A., Fahrig, L., Findlay, C.S., Houlahan, J.E., Jaeger, J.A.G., Klar, N., Kramer-Schadt, S. & Van der Grift, E.A. (2007) The Rauschholzhausen agenda for road ecology. *Ecology and Society*, **12**(1), 11. <http://www.ecologyandsociety.org/vol12/iss1/art11/>
- Roedenbeck, I.A., Voser, P. (2008) Effects of roads on spatial distribution, abundance and mortality of brown hare (*Lepus europaeus*) in Switzerland. *European Journal of Wildlife Research*, **54**, 425-437.
- Roger, E. & Ramp, D. (2009). Incorporating habitat use in models of fauna fatalities on roads. *Diversity Distribution*, **15**, 222-231.
- Rolley, R.E. & Lehman, L.E. (1992) Relationships among raccoon road-kill surveys, harvests, and traffic. *Wildlife Society Bulletin*, **20**, 313-318.
- Romin, L.A. & Bissonette, J.A. (1996) Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin*, **24**, 276-283.
- Rondinini, C. & Doncaster, C.P. (2002) Roads as barrier to movement for redgehogs. *Functional Ecology*, **16**, 504-509.
- Rondinini, C. & Doncaster, C.P. (2002) Roads as barriers to movement for hedgehogs. *Functional Ecology*, **16**, 504-509.
- Rosa, C.A. & Bager, A. (2012) Seasonality and habitat types affect road kill of neotropical birds. *Journal of Environmental Management*, **97**, 1-5
- Rosell, C., Parpal, J., Campeny, R., Jove, S., Pasquina, A. & Velasco, J.M. (1997) Mitigation of barrier effect of linear infrastructures on wildlife. *Habitat Fragmentation and Infrastructure*, (ed K Canters). Ministry of Transport, Public Works and Water Management, Delft, Netherlands
- Rosen, P. & Lowe, C. (1994) Highway mortality of snakes in the Sonoran desert of southern Arizona. *Biological Conservation*, **68**, 143-148.
- Rost G.R. & Bailey J.A. (1979) Distribution of Mule Deer and Elk in relation to roads. *Journal of Wildlife Management*, **43**, 634-641.

- Row, J.R., Blouin-Demers, G. & Weatherhead, P.J. (2007) Demographic effects of road mortality in black rat snakes (*Elaphe obsoleta*). *Biological Conservation*, **137**, 117-124.
- Rowland, M.M., Wisdom, M.J., Johnson, B.K. & Kie, J.G. (2000) Elk distribution and modeling in relation to roads. *Journal of Wildlife Management*, **64**, 672-684.
- Rudolph, D.C., Burgdorf, S.J., Conner, R.N. & Schaefer, R.R. (1999) *Preliminary Evaluation of the Impact of Roads and Associated Vehicular Traffic on Snake Populations in Eastern Texas*. Proceedings of the International Conference on Wildlife Ecology and Transportation. (eds G.L. Evink, P. Garrett, D. Zeigler & J. Berry), pp. 129-136. Florida Department of Transportation, Tallahassee, Florida. FI-ER-73-99.
- Ruediger, B. & DiGiorgio, M. (2007) *Safe Passages*. The Southern Rockies Ecosystem Project.
- Ruediger, D. (2007) *Safe Passages*. The Southern Rockies Ecosystem Project.
- Ruiz-Capillas, P., Mata, C. & Malo, J.E. (2013) Road verges are refuges for small mammal populations in extensively managed Mediterranean landscapes. *Biological Conservation*, **158**, 223-229.
- Rujopakarn, W. (2003) Bangkok transport system development: what went wrong? *Journal of the Eastern Asia Society for Transportation Studies*, **5**, 3302-3315.
- Rytwinski, T. & Fahrig, L. (2011) Reproductive rate and body size predict road impacts on mammal abundance. *Ecological Applications*, **21**(2), 589-600.
- Rytwinski, T. & Fahrig, L. (2012) Do species life history traits explain population responses to roads? A meta-analysis. *Biological Conservation*, **147**, 87-98.
- Rytwinski, T. & Fahrig, L. (2015). The impacts of roads and traffic on terrestrial animal populations. *In Handbook for road ecology*, 237–246.
- Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., van der Ree, R. & van der Grift, E.A. (2016) How Effective Is Road Mitigation at Reducing Road-Kill? A Meta-Analysis. *PLoS ONE*, **11**(11).

- Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., van der Ree, R., van der Grift, E.A. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis.
- Sabino-Marques, H. & Mira, A. (2011) Living on the verge: are roads a more suitable refuge for small mammals than streams in Mediterranean pastureland?. *Ecological Restoration*, **26**, 277-287.
- Saeki, M. & Macdonald, D.W. (2004) The effects of traffic on the raccoon dog (*Nyctereutes procyonoides viverrinus*) and other mammals in Japan. *Biological Conservation*, **118**, 559-571.
- Saklaurs, M. & Baltmanis, R. 2015. The Effect of Roads on the Movement of Large and Mid-sized Mammals. *Environmental and Climate Technologies*, **14**(1), 23–29
- Sankar, K. (1994) *The ecology of three large sympatric herbivores (chital, sambar and nilgai) with special reference for reserve management in Sariska Tiger Reserve, Rajasthan*. PhD Thesis. University of Rajasthan, Jaipur, India.
- Sankar, K., Qureshi, Q., Pasha, M.K.S. & Areendran, G. (2000). *Ecology of Gaur Bos Gaurus in Pench Tiger Reserve, Madhya Pradesh*. Final Report, p. 27. Wildlife Institute of India, Dehra Dun.
- Santhoshkumar, S., Kannan, P., Veeramani, A., Samson, A., Karthick, S. & Leonaprinicy, J. (2017) A preliminary report on the impact of road kills on the herpetofauna species in Nilgiris, Tamil Nadu, India. *Journal of Threatened Taxa*, **9**(3), 10004–10010.
- Santos, R.A.L., Mota-Ferreira, M. & Aguiar, L.M.S. (2018) Predicting wildlife road-crossing probability from road kill data using occupancy-detection models. *Science of the Total Environment*, **642**, 629-637.
- Santos, S.M., Carvalho, F. & Mira, A. (2011) How long do the dead survive on the road? Carcass persistence probability and implications for road-kill monitoring surveys. *PLoS One*, **6**(9), 25383.

- Santos, X., Llorente, G. A., Montori, A., Carretero, M.A., Franch, M., Garriga, N. & Richter-Boix, A. (2007) Evaluating factors affecting amphibian mortality on roads: the case of the Common Toad *Bufo bufo*, near a breeding place. *Animal Biodiversity and Conservation*, **30**, 97-104.
- Saraf, K.K. & Jadesh, M. (2017) A preliminary study on road killed butterflies at National Highway- 50, Kalaburagi district, Karnataka, India. *International Journal of Entomology Research*, **2**(1), 42-50.
- Sartaj, G., Sankar, K. & Jhala, Y.V. (2010) *A Study of Vigilance Behaviour of Chital (Axis axis): Examining the Determinants of Individual and Group Vigilance for Chital in Pench Tiger Reserve, India*. LAMBERT Academic Publishing, UK.
- Sathish-Narayanan, S., Pradeepa, V., Venkatesh, A. & Kanchana, R. (2016) Effect of road kills on wildlife populations in Kalakad Mundanthurai Tiger Reserve, India. *International Journal of Advanced Research*, **4**, 193-204.
- Saunders, D., Hobbs, R. & Margules, C. (1991) Biological consequences of ecosystem fragmentation: are view. *Conservation Biology*, **5**, 18-32.
- Sawyer, H. & LeBeau, C. (2011) *Evaluation of mule deer crossing structures in Nugget Canyon, Wyoming*. Wyoming Department of Transportation FHWA-WY-11/02F, Cheyenne, USA.
- Schaik, C.P.V. & Griffiths, M. (1996) Activity periods of Indonesian rain forest mammals. *Biotropica*, **28**(1), 105-112.
- Schaub, A., Ostwald, J. & Siemers, B.M. (2008) Foraging bats avoid noise. *Journal of Experimental Biology*, **211**, 3174-3180.
- Scheick, B.K. & Jones, M.D. (1999) *Locating Wildlife Underpasses Prior to Expansion of Highway 64 in North Carolina*. North Carolina Wildlife Resources Commission. Proceedings of the 1999 International Conference on Wildlife Ecology and Transportation, Missoula, Montana.
- Schipper, J., Chanson, J.S. & Chiozza, F. (2008) The status of the world's land and marine mammals: diversity, threat and knowledge. *Science*, **322**, 225-230.
- Schmidt, W. (1989) Plant dispersal by motor cars. *Vegetatio*, **80**, 147-152.

- Schwab, A.C & Zandbergen, P.A. (2011) Vehicle-related mortality and road crossing behavior of the Florida panther. *Applied Geography*, **31**, 859-870.
- Schwartz, A.L.W., Williams, H.F., Chadwick, E., Thomas, R.J. & Perkins, S.E. (2018) Road kill scavenging behaviour in an urban environment. *Journal of Urban Ecology*, **4**(1), 1-7.
- Scott, T.G. (1938) Wildlife mortality on Iowa highways. *American Midland Naturalist*, **20**, 527-539.
- Seabrook, W.A. & Dettmann, E.B. (1996) Roads as activity corridors for cane toads in Australia. *Journal of Wildlife Management*, **60**, 363-368.
- Secco, H., Ratton, P., Castro, E., Lucas, P. & Bager, A. (2014) Intentional snake road-kill: a case study using fake snakes on a Brazilian road Introduction. *Tropical Conservation Science*, **7**, 561-571.
- Seiler, A. & Helldin, J.O. (2006) Mortality in wildlife due to transportation. 10.1007/1-4020-4504-2_8.
- Seiler, A. (2001) *Ecological Effects of Roads – A Review*. Swedish University of Agricultural Sciences, Department of Conservation Biology, Introductory Research Essay No. 9. Uppsala.
- Seiler, A. (2003) Effects of infrastructure on nature. *COST 341 - Habitat Fragmentation due to transportation infrastructure: The European Review* (eds M. Trocmé, S. Cahill, J.G. De Vries, H. Farall, L. Folkesson, G.L. Fry, C. Hicks, & J. Peymen), pp. 31-50. Office for Official Publications of the European Communities, Luxembourg,
- Seiler, A. (2004) Trends and spatial patterns in ungulate-vehicle collisions in Sweden. *Wildlife Biology*, **10**, 301-313.
- Seiler, A. (2005) Predicting locations of moose-vehicle collisions in Sweden. *Journal of Applied Ecology*, **42**, 371-382.
- Seiler, S. & Hetlelid, K.J. (2005). The impact of rest duration on work intensity and RPE during interval training. *Medicine and Science in Sports and Exercise*, **37**, 1601-1607.

- Seiler, S. & Sjurgen, J.E. (2004) Effect of work duration on physiological and rating scale of perceived exertion responses during self-paced interval training. *Scandinavian Journal of Medicine and Science in Sports*, **14**, 318-325.
- Seiler, S., Helldin, J.O. & Seiler, C. (2004) Road mortality in Swedish mammals: results of a drivers' questionnaire. *Wildlife Biology*, **10**, 225-233.
- Selvi, J.T. (2010) *Dynamics of Road Kills of Wild Animals in Mudumalai Tiger Reserve*.
- Servheen, C., Shoemaker, R. & Lawrence, L. (2003) *A Sampling of Wildlife Use in Relation to Structure Variables for Bridges and Culverts under I-90 between Alberton & St. Regis, Montana*. Proceedings of the International Conference on Ecology and Transportation, (eds C.L. Irwin, P. Garrett, & K.P. McDermott), pp. 331-341. Center for Transportation and the Environment, North Carolina State University, Raleigh.
- Seshadri, K.S. & Ganesh, T. (2011) Faunal mortality on roads due to religious tourism across time and space in protected areas: a case study from south India. *Forest Ecology and Management*, **261**, 1713-1721.
- Seshadri, K.S., Yadav, A. & Gururaja, K.V. (2009) Road kills of amphibians in different land use areas from Sharavathi river basin, Central Western Ghats, India. *Journal of Threatened Taxa*, **1**, 549-552.
- Shanley, C.S. & Pyare, S. (2011) Evaluating the road-effect zone on wildlife distribution in a rural landscape. *Ecosphere*, **2**, 1-16.
- Sharma, R.K. & Jhala, Y.V. (2011) Monitoring tiger populations using intensive search in a capture-recapture framework. *Population Ecology*, **53**, 373-381.
- Shepard D.B., Kuhns A.R., Dreslik. M.J. & Phillips. C.A. 2008. Roads as barriers to animal movement in fragmented landscapes. *Animal Conservation*, **11**, 288-296.
- Shi, H., Shi, T., Yang, Z., Wang, Z., Han, F. & Cuirong, W. (2018). Effect of roads on ecological corridors used for wildlife movement in a natural heritage site. *Sustainability*, **10**, 2725.

- Shine, R., Lemaster, M., Wall, M., Langkilde, T. & Mason, R. (2004) Why did the snake cross the road? Effects of roads on movement and location of mates by garter snakes (*Thamnophis sirtalis parietalis*). *Ecology and Society*, **9**(1), 9.
- Shyh-Chyang, L. (2016) Landscape and traffic factors affecting animal road mortality. *Journal of Environmental Engineering and Landscape Management*, **24**(1), 10-20.
- Silverman, B.W. (1986) *Density Estimation for Statistics and Data Analysis*. Chapman and Hall, London.
- Simpson, O.N., Stewart, K., Schroeder, C., Cox, M., Huebner, K. & Wasley, T. (2016) Overpasses and underpasses: effectiveness of crossing structures for migratory ungulates: crossing structures and migratory ungulates. *The Journal of Wildlife Management*. 10.1002/jwmg.21132.
- Singer, F.J. (1978). Behaviour of mountain goats in relation to U.S. Highway 2, Glacier National Park Montana. *Journal of Wildlife Management*. **42**, 591-597.
- Singer, P., Huyett, A., Kintsch, J. & Huijser, M. (2011) *Interstate 70 Eco-Logical Monitoring Report*. Report to the Colorado Department of Transportation, Denver, CO.
- Skórka, P., Lenda, M., & Moroń, D. (2018). Roads affect the spatial structure of butterfly communities in grassland patches. *Peer Journal*, **6**, 5413.
- Slater, F. (1995) Wildlife road casualties. *British Wildlife*, **5**, 214-215.
- Smith, D.J. (1999) *Identification and Prioritization of Ecological Interface Zones on State Highways in Florida*. Proceedings of the Third International Conference on Wildlife Ecology and Transportation (eds G.L. Evink, P. Garrett & D. Zeigler). Florida Department of Transportation, Tallahassee.
- Smith, D.J. (2003) *Ecological Effects of Roads: Theory, Analysis, Management and Planning Considerations*. University of Florida.
- Smith, D.J. (2003) *Ecological Effects of Roads: Theory, Analysis, Management and Planning Considerations*. University of Florida.

- Smith, D.J. (2003) *Monitoring Wildlife Use and Determining Standards for Culvert Design. Report BC354-34*. Florida Department of Transportation, Tallahassee.
- Smith, L.L. & Dodd, C.J. (2003) Wildlife mortality on highway US 441 across Payne's Prairie, Alachua County, Florida. *Florida Naturalist*, **66**, 128-140.
- Smith, L.L., & Dod, C.K., (2003) Wildlife mortality on highway US 441 across Paynes Prairie, Alachua County, Florida. *Florida Scientist*, **66**, 128-140.
- Smith-Patten, B.D. & Patten, M.A. (2008) Diversity, seasonality, and context of mammalian road kills in the southern great plains. *Environmental Management*, **41**, 844-852.
- Solanki, D., Beleem, I., Kanejiya, J. & Gohil, B. (2016) A study on animal-vehicle collision in Bhavnagar city and nearby area, Gujarat, India. *Journal of Entomology and Zoology Studies*, **5**, 622-625.
- Sosa, R. & Schalk, C.M. (2016) Seasonal activity and species habitat guilds influence road-kill patterns of neotropical snakes. *Tropical Conservation Science*, <https://doi.org/10.1177/1940082916679662>.
- Soulé, M.E. (1987) *Viable Populations for Conservation*. Cambridge: Cambridge University Press.
- Southwick, C.H., Ghosh, A. & Louch, C. (1964) A roadside survey of rhesus monkeys in Bengal. *Journal of Mammal*, **45**, 443-448.
- Southwick, C.H., Sidiqi, M.F., Farooqui, M.Y. & Pal, B.C. (1976) Effects of artificial feeding on aggressive behaviour of Rhesus monkeys in India. *Animal Behavior*, **24**(1), 11-15.
- Sparks, J.L. & Gates, J.E. (2017) Seasonal and regional animal use of drainage structures to cross under roadways. *Human–Wildlife Interactions*, **11**(2), Article 9. <https://digitalcommons.usu.edu/hwi/vol11/iss2/9>
- Sparks, J.R. & Gates, J.E. (2012) An investigation into the use of road drainage structures by wildlife in Maryland, USA. *Human–Wildlife Interactions*, **6**(2), 311-326.

- Spellerberg, I.F. (1998) Ecological Effects of Roads and Traffic: A Literature Review. *Global Ecology and Biogeography Letters*, **7**(5), 317-333.
- Spellerberg, I.F. (2002) *Ecological Effects of Roads*. Science Publishers, Enfield, New Hampshire, USA.
- Spooner, P.G & Smallbone, L. (2009) Effects of road age on the structure of roadside vegetation in south-eastern Australia. *Agriculture Ecosystems & Environment*, **129**(1-3), 57-64.
- SPSS 15.0. (2006) Command Syntax Reference, SPSS Inc., Chicago.
- State of Queensland (Department of Transport and Main Roads) 2015. Road Drainage Manual, Transport and Main Roads. 1-36
- Stoner, D. (1925) The toll of the automobile. *Science*, **61**, 56-57.
- Sullivan, B.K. (1981) Observed differences in body temperature and associated behavior of four snake species. *Journal of Herpetology*, **15**, 245-246.
- Sullivan, J.M. 2009. Relationships between Lighting and Animal-Vehicle Collisions. The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A. Report No. UMTRI-2009-35
- Summers, P.D., Cunnington, G.M. & Fahrig, L. (2011) Are the negative effects of roads on breeding birds caused by traffic noise. *Journal of Applied Ecology*, **48**, 1527-1534.
- Sundar, G.K.S. (2004) Mortality of herpetofauna, birds and mammals due to vehicular traffic in Etawah District, Uttar Pradesh, India. *Journal of the Bombay Natural History Society*, **101**(3), 392-398.
- Svensson, S. (1998) Birds kills on roads: is this mortality factor seriously underestimated? *Ornis Svecica*, **8**, 183-187.
- Swihart, R. & Slade, N. (1984) Road crossing in *Sigmodon hisidus* and *Microtus ochrogaster*. *Journal of Mammalogy*, **65**, 357-360.

- Symes, W.S., Edwards, D.P., Miettinen, J., Rheindt, F.E. & Carrasco, L.R. (2018) Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nature Communications*, **9**(1), 4052.
- Szerlag, S. & McRobert, S.P. (2006) Road occurrence and mortality of the northern diamond back terrapin. *Applied Herpetology*, **3**, 27-37.
- Tamayo, P., Pascual, F. & Megías, A.G. 2014. Effects of roads on insects: a review. *Biodiversity and Conservation*, **24**(3), 659-682.
- Taylor, B.D. & Goldingay, R.L. (2004) Wildlife road kills on three major roads in north eastern New South Wales. *Wildlife Research*, **31**, 83-91.
- Taylor, B.D. & Goldingay, R.L. (2010) Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. *Wildlife Research*, **37**, 320e331. <https://doi.org/10.1071/WR09171>.
- Taylor, B.D. & Goldingay, R.L. 2010. Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. *Wildlife Research*, **37**, 320-331.
- Taylor, R.J. & Mooney, N.J. (1991) Increased mortality of birds on an elevated section of highway in northern Tasmania. *Emu*, **91**, 186-188.
- Tejera G, Rodri'guez B, Armas C, Rodri'guez A (2018) Wildlife-vehicle collisions in Lanzarote Biosphere Reserve, Canary Islands. *PLoS ONE*, **13**(3), e0192731
- Thenoux, G., Bellolio, J.P. & Halles, F. (2007) Development of a methodology for measurement of vehicle dust generation on unpaved roads. *Transportation Research Record: Journal of Transportation Research Board*, **1989**, 299-304.
- Theobald, D.M., Miller, J.R. & Hobbs, N.T. (1997) Estimating the cumulative effects of development on wildlife habitat. *Landscape and Urban Planning*, **39**, 25-36.
- Theoharides, K.A & Dukes, J.S. (2007) Plant invasion across space and time: factors affecting nonindigenous species success during four stages of invasion. *New Phytologist*, **176**, 256-273.

- Thiel, R.P. (1985) Relationship between road densities and wolf habitat suitability in Wisconsin. *American Midland Naturalist*, **113**, 404-407.
- Thomas, A.M., Kaphegyi, T.A., Dees, M., Zlatanova, D., Ueffing, C., Dutsov, A. & Kaphegyi, U. (2013) Rapid assessment of linear transport infrastructure in relation to the impact on landscape continuity for large ranging mammals. *Biodiversity Conservation*, **22**, 153-168.
- Thomas, J.M., Strauss, D.C. & Hayes, A.J. (2010) Some of the 2009 American Joint Committee on Cancer melanoma staging and classification is not evidence based. *Journal of Clinical Oncology*, **28**, e479.
- Tigas, L.A., Van Vuren, D.H. & Sauvajot, R.M. (2002) Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation*, **108**, 299-306.
- Tilman, D., May, R.M., Lehman, C.L. & Nowak, M.A. (1994) Habitat destruction and the extinction debt. *Nature*, **371**, 65-66.
- Torres, A., Jaeger, J.A.G. & Alonso, J.C. (2016) Assessing large-scale wildlife responses to human infrastructure development. *Proceedings of the National Academy of Sciences USA*, **113**, 8472-8477.
- Toyran, K., Özdemir, A. & Erkan, A. (2018) Road kills of mammal species in the Van Lake Basin (Turkey). *Biological Diversity and Conservation*, **11**(1), 40-44.
- Transportation Research Board (1997) *Toward a Sustainable Future: Addressing the Long-term Effects of Motor Vehicle Transportation on Climate and Ecology. Special Report 251*. National Academy Press, Washington, DC.
- Trembath, D.F. & Fearn, S. (2008) Body sizes, activity times, food habits and reproduction of brown tree snakes (*Boiga irregularis*) (Serpentes: Colubridae) from tropical north Queensland, Australia. *Australian Journal of Zoology*, **56**, 173-178.

- Trembath, D.F. & Fearn, S. (2008) Body sizes, activity times, food habits and reproduction of brown tree snakes (*Boiga irregularis*) (Serpentes: Colubridae) from tropical north Queensland, Australia. *Australian Journal of Zoology*, **56**, 173-178.
- Treweek, J. (1999) *Ecological Impact Assessment*. Blackwell Science Limited Pub, UK.
- Treweek, J.S., Thompson, N.V. & Japp, C. (1993) Ecological assessment of road developments. A review of environmental statements. *Journal of Environmental Planning and Management*, **36**, 295-308.
- Tritsis, K.M. (2011) *Assessment of the use of Crossing Structures by Mammals along Egnatia Motorway in Northern Greece*. Institute for Nature and Resources Conservation. Christian-Albrecht-Universität zu Kie.
- Trombulak, S. & Frissell, C. (2000) Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, **14**, 18-30.
- Tsunokawa, K. & Hoban, Ch. (eds) (1997) *Roads and the Environment: A Handbook*. World Bank Technical Paper No. 376, World Bank, Washington, DC.
- Tyser, R.W & Worley, C.A. (1992) Alien flora in grasslands adjacent to roads and trail corridors in Glacier National Park, Montana (U.S.A.). *Conservation Biology*, **6**, 251-262.
- Underhill, E. (2002) *Extending Knowledge on Occupational Health & Safety and Labor Hire Employment: A Literature Review and Analysis of Victorian Workers' Compensation Claims*. Melbourne: Work Safe Victoria.
- Underhill, E.J & Angold, G.P (2000) Effects of roads on wildlife in an intensively modified landscape. *Environmental Review*, **8**, 21-39.
- Van Bohemen, H.D. (1995) Mitigation and compensation of habitat fragmentation caused by roads: strategy, objectives and practical measures. *Transportation Research Record*, **1475**, 133-137.

- van der Ree, R. (2006) Road upgrade in Victoria a filter to the movement of the endangered squirrel glider *Petaurus norfolcensis*: results of a pilot study. *Ecological Management and Restoration*, **7**, 226-228.
- van der Ree, R., Bennett, A.F. & Gilmore, D.C. (2003) Gap-crossing by gliding marsupials: thresholds for use of isolated woodland patches in an agricultural landscape. *Biological Conservation*, **115**, 241-249.
- van der Ree, R., Cesarini, S., Sunnucks, P., Moore, J.L. & Taylor, A.C. (2010) Large gaps in canopy reduce road crossing by a gliding mammal. *Ecology and Society*, **15**(4), 35.
- van der Ree, R., Clarkson, D.T., Holland, K., Gulle, N. & Budden, M. (2008) *Review of Mitigation Measures used to deal with the Issue of Habitat Fragmentation by Major Linear Infrastructure*. Report for Department of Environment, Water, Heritage and the Arts (DEWHA), Contract No. 025/2006, Published by DEWHA.
- van der Ree, R., Heinze, D., McCarthy, M. & Mansergh, I. (2009) Wildlife tunnel enhances population viability. *Ecology and Society*, **14**(2), 7.
- van der Ree, R., Heinze, D., McCarthy, M., & Mansergh, I. (2009) Wildlife tunnel enhances population viability. *Ecology and Society*, **14**(2), 7.
- van der Ree, R., Jaeger, J.A.G., Rytwinski, T. & van der Grift, E.A. (2015) Good science and experimentation are needed in road ecology. *Handbook of Road Ecology*, pp. 71-81 (eds R. van der Ree, D.J. Smith, C. Grilo), John Wiley & Sons, Ltd.
- van der Ree, R., Jaeger, J.A.G., van der Grift, E.A. & Clevenger, A.P. (2011) Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving towards larger scales. *Ecology and Society*, **16**(1), 48.
- Van der Zande, A.N., ter Keurs, W.J. & Van der Weijden, W.J. (1980) The impact of roads on the densities of four bird species in an open field habitat – evidence of a long-distance effect. *Biological Conservation*, **18**, 299-321.

- Van Dyke, F.B., Brocke, R.H., Shaw, H.G., Ackerman, B.B., Hemker, T.P. & Lindzey, F.G. (1986) Reactions of mountain lions to logging and human activity. *Journal of Wildlife Management*, **50**, 95-102.
- van Gelder, J. (1973) A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo* L. *Oecologia*, Berlin **13**, 93-95.
- van Langevelde, F. & Jaarsma, C.F. (2004) Using traffic flow theory to model traffic mortality in mammals. *Landscape Ecology*, **19**, 895-907.
- Vander Pluym, J.L., Eggleston, D.B. & Levine, J.F. (2008) Impacts of road crossings on fish movement and community structure. *Journal of Freshwater Ecology*, **23**, 565-574.
- Varga, C., Monoki, A. & Barsony, B. (2006) Bird-protection walls: an innovative way to prevent bird strikes? *Proceedings of the 2005 International Conference on Ecology and Transportation* (eds C.L. Irwin, P. Garrett & K.P. McDermott), pp. 565-568. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, USA.
- Varman, K.S. & Sukumar, R. (1995) The line transect method for estimating densities of large mammals in a tropical deciduous forest: an evaluation of models and field experiments. *Journal of Bioscience*, **20**, 273-287.
- Veach, V., Moilanen, A. & Di Minin, E. (2017) Threats from urban expansion, agricultural transformation and forest loss on global conservation priority areas. <https://doi.org/10.1371/journal.pone.0188397>
- Veage, L. & Jones, D.N. (2007) *Breaking the Barrier: Assessing the Value of Fauna-friendly Crossing Structures at Compton Road*. Report for Brisbane City Council. Centre of Innovative Conservation Strategies, Griffith University, Brisbane, Qld, Australia.
- Veage, L. & Jones, D.N. (2007) *Breaking the Barrier: Assessing the Value of Fauna-friendly Crossing Structures at Compton Road*. Report for Brisbane City Council. Centre of Innovative Conservation Strategies, Griffith University, Brisbane, QLD, Australia.

- Vermeulen, H.J.W. (1993) The composition of the carabid fauna on poor sandy road-side verges in relation with comparable open areas. *Biodiversity and Conservation*, **2**, 331-350.
- Victoria, J.B. 2017. Effects of Road Density and Pattern on the Conservation of Species and Biodiversity. *Current Landscape Ecology Reports*, **2**(2), 1-11
- Vidal-Vallés, D., Rodríguez, A. & Pérez-Collazos, E. (2018) Bird road kill occurrences in Aragon, Spain. *Animal Biodiversity and Conservation*, **41**(2), 379-388.
- Vidya, T.N.C. & Thuppil, V. (2010) Immediate behavioural responses of humans and Asian elephants in the context of road traffic in southern India. *Biological Conservation*, **143**, 1891-1900.
- Vieira, E.M. (1996) Highway mortality of mammals in central Brazil. *Journal of the Brazilian Association for the Advancement of Science*, **48**(4), 270-271.
- Vijayakumar, S.P. & Vasudevan, K. (2001) Herpetofaunal mortality on roads in the Anamalai Hills, Southern Western Ghats. *Hamadryad*, **26**, 265-272.
- Vijayakumar, S.P., Vasudeven, K. & Ishwar, N.M. (2001) Herpetofaunal mortality of roads in the Anamalai Hills. Southern Western Ghats. *Hamadryad*, **26**(2), 253-260.
- Visintin, C., van der Ree, R. & McCarthy, M.A. (2016) A simple framework for a complex problem? Predicting wildlife-vehicle collisions. *Ecology and Evolution*, **6**(17), 6409-6421.
- Vos, C.C. & Chardon, J.P. (1998) Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. *Journal of Applied Ecology*, **35**, 44-56.
- Waller, J.S. & Servheen, C. (2005) Effects of transportation infrastructure on grizzly bears in northwestern Montana. *Journal of Wildlife Management*, **69**(3), 985-1000.

- Wang, C., Chen, Z.L., Wang, J., Zhou, N.S., Xu, S.Y. (2007) Heavy metal pollution of soils and vegetables on roadsides in Chongming Island. *Journal of Ecology and Rural Environment*, **23**: 89-93.
- Ward, A.L. (1982) Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record*, **859**, 8-13.
- Warren, E. (1936) Casualties among animals on mountain roads. *Science*, **83**, 14.
- Warren, M.L. & Pardew, M.G. (1998) Road crossings as barriers to small-stream fish movement. *Transactions of the American Fisheries Society*, **127**, 637-644.
- Watkins, L.H. (1981) *Environmental Impact of Roads and Traffic*. Applied Science Publishers Ltd, London.
- Watkins, R.Z., Chen, J.Q., Pickens J. & Brososke K.D. (2003) Effects of forest roads on understory plants in a managed hardwood landscape. *Conservation Biology*, **17**(2), 411-419.
- Weaver, J.L. (2001) *The Transboundary Flathead: A Critical Landscape for Carnivores in the Rocky Mountains*. WCS Working Papers No. 18, July 2001.
- Webb, R.H. (2002) Recovery of severely compacted soils in the Mojave Desert. *Arid Land Research and Management*, **16**, 291-305.
- Western, D. 1975. Water availability and its influence on the structure and dynamics of a savannah large mammal community. *East African Wildlife Journal*, **13**(3/4), 265-286.
- Whitaker, R. & Captain, A. (2004) *Snakes of India: The Field Guide*. Draco Books, India. 494p.
- White, P. & Ernst, M. (2003) *Second Nature: Improving Transportation Without Putting Nature Second*. Defenders of Wildlife and Surface Transportation Policy Partnership, Washington, DC.
- Whittington, J., Clair, C.C. & Mercer, G. (2004) Path tortuosity and the permeability of roads and trails to wolf movement. *Ecology and Society*, **9**(1), 4.

- Wiens, J.A. (1995) Recovery of seabirds following the Exxon Valdez oil spill: an overview. *Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters* (eds P.G. Wells, J.N. Butler & J.S. Hughes), pp. 854-893. STP 1219. American Society for Testing and Materials, Philadelphia, Pennsylvania, USA.
- WII (1997) *Ecological Assessment of the Proposed Airport Site at Lengpui, Mizoram*. WII-EIA Technical Report 20. Wildlife Institute of India, Dehradun, Uttarakhand.
- WII (1998) *Ecological Assessment of the Proposed Mumbai–Pune Expressway*. WII-EIA Technical Report 22. Wildlife Institute of India, Dehradun, Uttarakhand.
- WII (2007) *Review of the mitigation measures proposed for the widening of NH-14 through Balaram-Ambaji Wildlife Sanctuary, Gujarat State*. WII-EIA Technical Report 33. Wildlife Institute of India, Dehradun.
- Wilkie, D., Shaw, E., Rotberg, F., Morelli, G. & Auzel, P. (2000) Roads, development, and conservation in the Congo basin. *Conservation Biology*, **14**(6), 1614-1622.
- Wilkins, K. (1982) Highways as barriers to rodent dispersal. Southwest. *Nature*, **37**, 459-460.
- Williams, S., Collinson, W., Patterson-Abrolat, C., Marneweck, D.G. & Swanepoel, L.H. (2018) Using road patrol data to identify factors associated with carnivore road kill counts. e27114v1 <https://doi.org/10.7287/peerj.preprints.27114v1>.
- Winton, S.A., Taylor, R., Bishop, C.A. & Larsen, K.W. (2018) Estimating actual versus detected road mortality rates for a northern viper. <https://doi.org/10.1016/j.gecco.2018.e00476>.

- Wisdom, M.J., Cimon, N.J., Johnson, B.K., Garton, E.O. & Thomas, J.W. (2005) Spatial partitioning by mule deer and elk in relation to traffic. *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer* (ed M.J. Wisdom), pp. 53-66. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA.
- Witmer, G. & deCalesta, D. (1985) Effect of forest roads on habitat use by Roosevelt elk. *Northwest Science*, **59**(2), 122-125.
- Woltz, H.W., Gibbs, J.P. & Ducey, P.K. (2008) Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis. *Biological Conservation*, **141**, 2745-2750.
- WPA (1972) *Wildlife (Protection) Act 1972*. Ministry of Environment & Forests, Government of India.
- Yanes, M., Velasco, J. & Suárez, F. (1995) Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation*, **71**, 217-222.
- Yanes, M., Velasco, J.M. & Suarez, F. (1995) Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation*, **71**, 217-222.
- Yue, S., Bonebrake, T. & Gibson, L. (2018) Informing snake road kill mitigation strategies in Taiwan using citizen science: snake road kill mitigation using citizen science. *The Journal of Wildlife Management*, **83**, 10.
- Zachos, F.E., Althoff, C., von Steynitz, Y., Eckert, I., & Hartl, G.B. (2007) Genetic analysis of an isolated red deer (*Cervus elaphus*) population showing signs of inbreeding depression. *European Journal of Wildlife Research*, **53**, 61-67.
- Zeng, S-L., Zhang, T-T., Gao, Y., Ouyang, Z.T., Chen, J.K., Li, B. & Zhao, B. 2010. Effects of Road Disturbance on Plant Biodiversity. *International Journal of Environmental and Ecological Engineering*. **4**, 6.

- Zeng, S.L., Zhang, T.T., Gao, Y., Ouyang, Z.T., Chen, J.K., Li, B. & Zhao, B. (2011) Effects of road age and distance on plant biodiversity: a case study in the Yellow River Delta of China. *Plant Ecology*, **212**, 1213-1229.
- Zwartjes, P.W., Cartron, J.E., Stoleson, P.L.L., Haussamen, W.C. & Crane, T.E. (2005) *Assessment of native species and ungulate grazing in the southwest: terrestrial wildlife*. USDA Forest Service General Technical Report RMRS-GTR-142, Dated September 2005. Attachment 30.