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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 causalities, 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 linear 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, Trocmé *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 (21º 49' N, 79º 30' E) and Gandatola village (21º 53' N, 79º 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

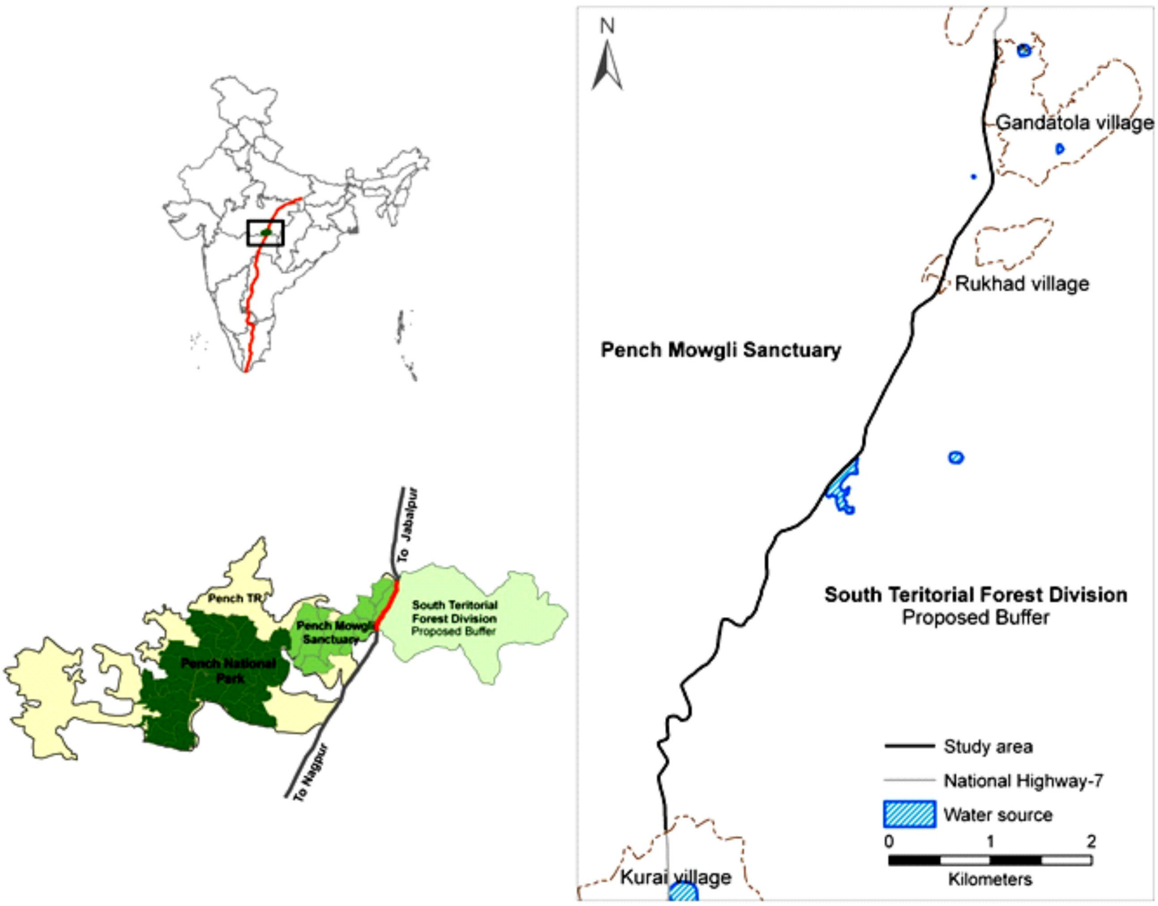

Figure 1. Study area and the Pench Tiger Reserve.

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 0º C in winter and maximum of 45º 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 snakes kills were recorded by two observers. Whenever the snake kills were encountered on the road, the vehicle was stopped to enable the team to identity 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 Landset 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.

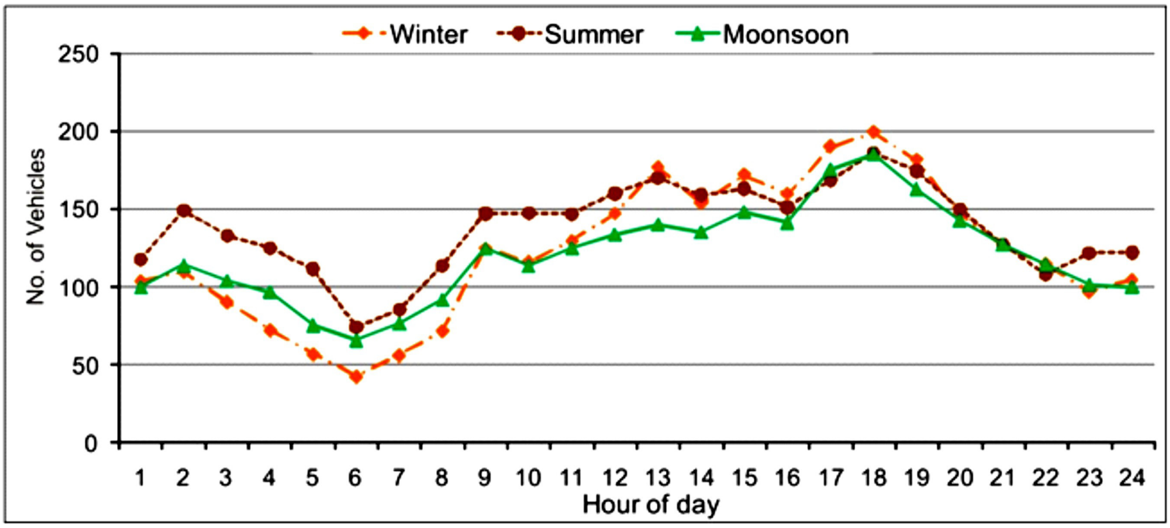

Figure 2. Average traffic volume on the National Highway - 7

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	*Trimeresurus gramineus*	Viperidae	1	Schedule IV	not listed
Barred wolf snake	*Lycodon striatus*	Colubridae	22	Schedule IV	not listed
Beaked worm snake	*Grypotyphlops acutus*	Typhlopidae	3	Schedule IV	not listed
Checkered keelback	*Xenochrophis piscator*	Colubridae	3	Schedule II	Appendix III

Continuation Table 2

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

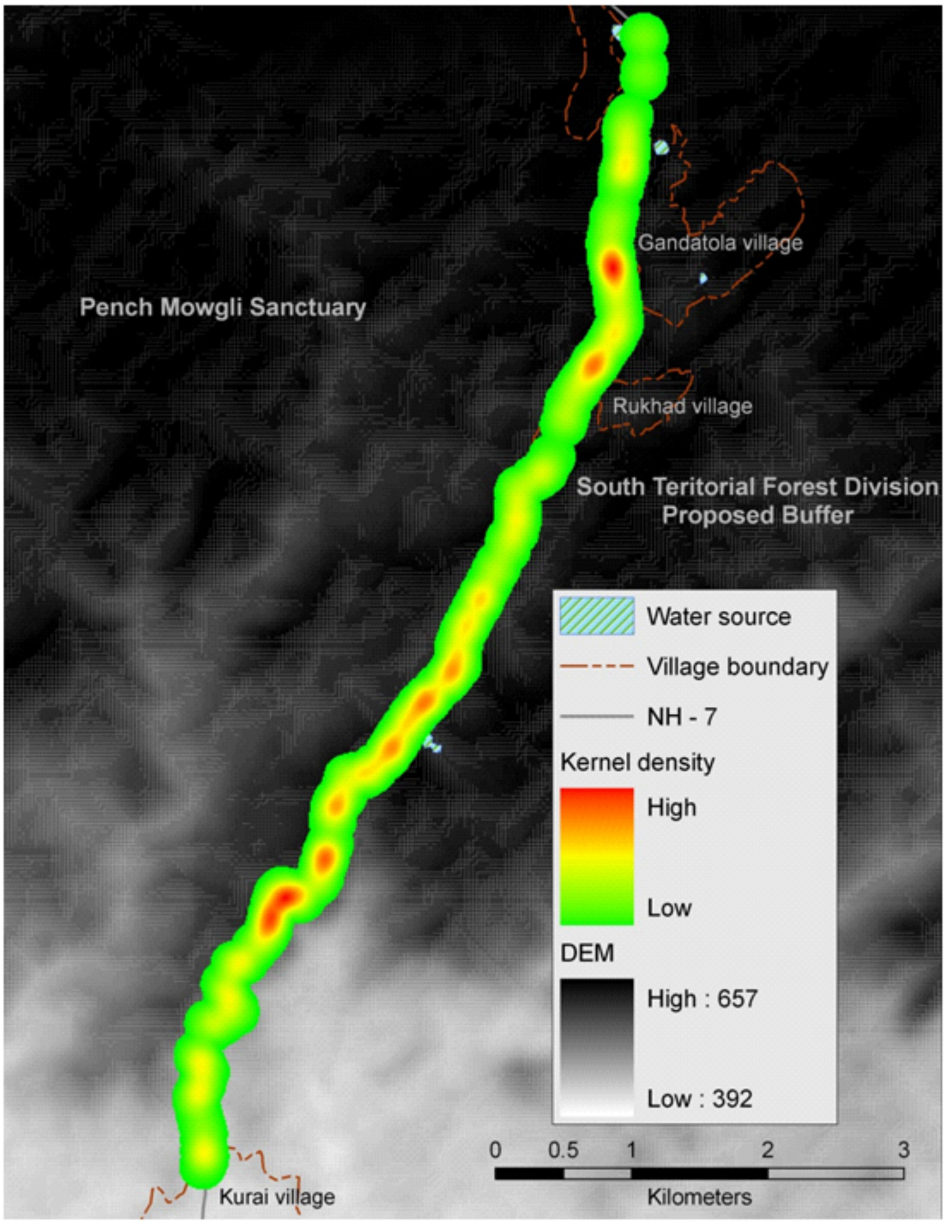

Figure 3. Kernel density estimation of snake fatalities.

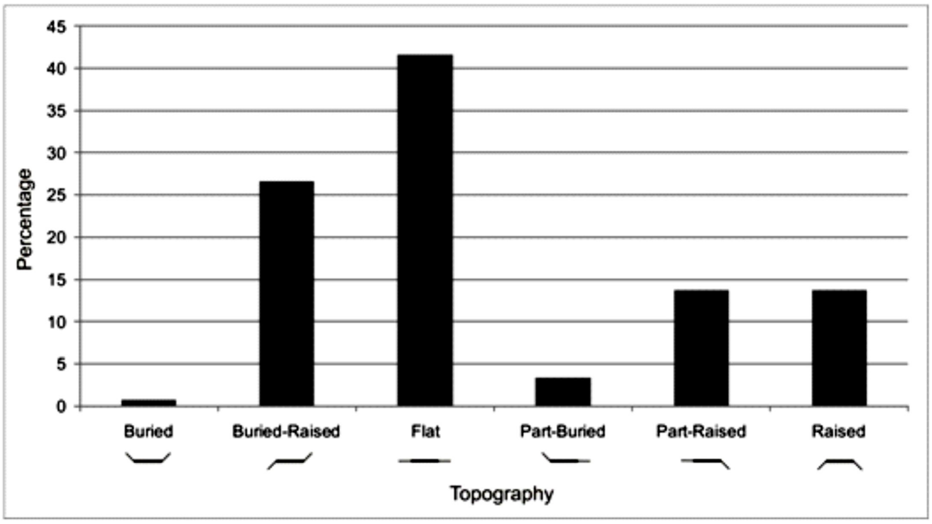

Figure 4. Percentage of snake kills in different topography.

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.

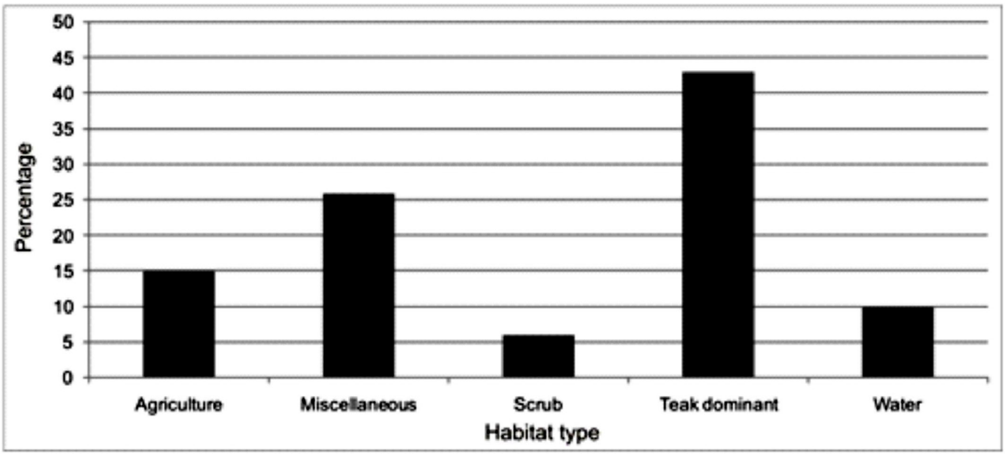

Figure 5. Mortality rate in different habitat type.

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, β - 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).

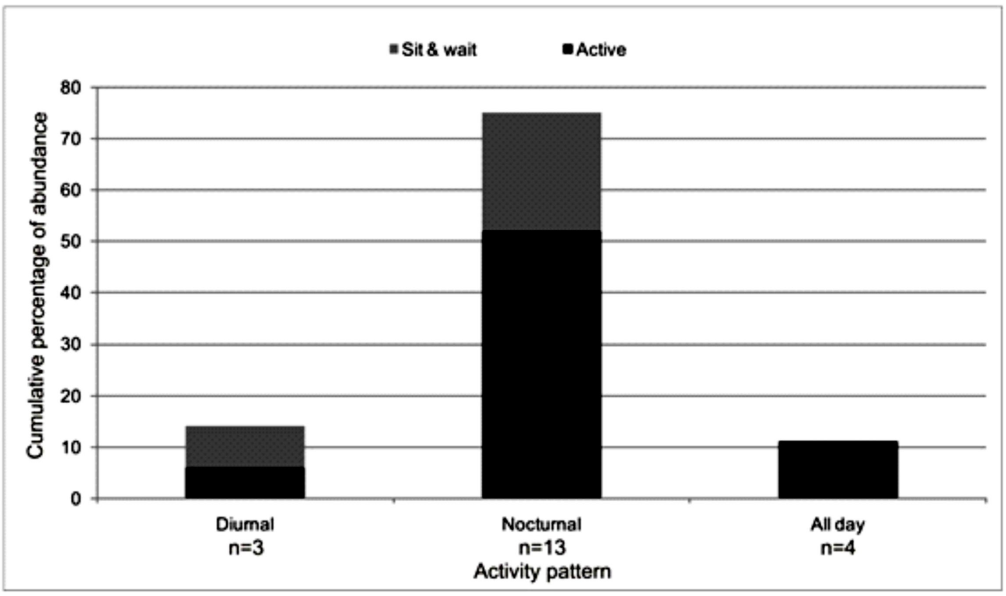

Figure 6. Activity pattern and foraging habit of the snake kills.

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.

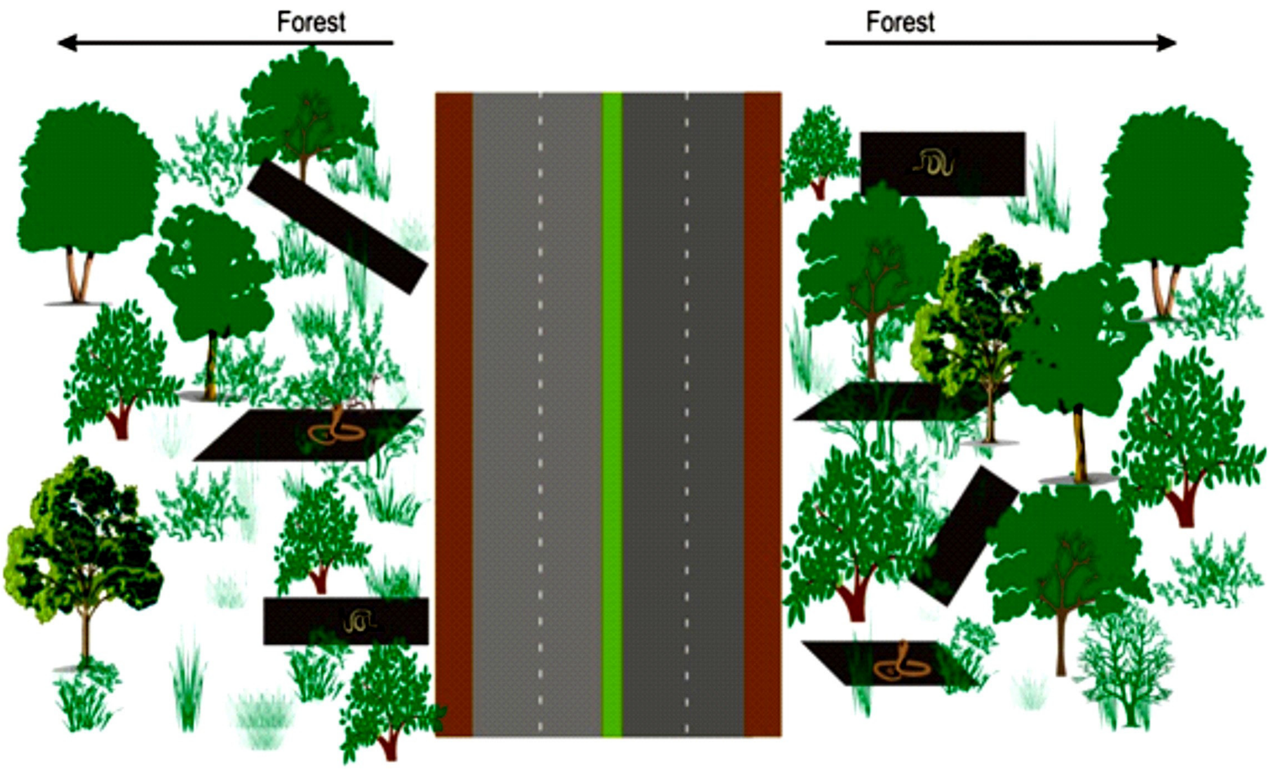

Figure 7. Creation of alternative sites for thermoregulation of snakes**.**

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