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Faunal mortality on roads due to religious tourism across time and space in protected areas: A case study from south India

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ABSTRACT

The presence of roads in any landscape is known to negatively influence terrestrial and aquatic ecosystems. Many tourist destinations and religious enclaves in developing countries are inside protected areas (PA). They are well connected by roads and attract thousands of visitors. The effect of such large human congregations inside PA on biodiversity is not well understood. Here, we address the impacts of increased vehicular traffic due to religious tourism on local fauna inside the Kalakad Mundanthurai Tiger Reserve in south India. We sampled sections of surfaced roads for mortalities before and during an annual festival across three habitats in 2008 and 2009. Millipedes, anurans, insects and reptiles dominated the mortalities and mammals avoided the roads. A total of 1413 individuals belonging to 56 species were killed on roads. Nocturnal species constituted 50% of these mortalities and 64% of the species composition. There was a 299% increase in road mortalities and 648% increase in nocturnal species mortality during the festival compared to those before the festival. Mean mortalities varied across habitats and were highest in moist deciduous forests. Mortalities were influenced significantly by vehicular traffic rather than rainfall. Indications of a temporary local extinction were evident beyond certain threshold of vehicular movement. The number of vehicles plying on the roads was three times higher than the threshold level as determined in this study. The festival also had a spillover effect by causing increased mortalities on roads not connected to the temple. We discuss several strategies to minimize impacts due to large scale vehicular movement inside protected areas.

1. Introduction

Roads are both important and integral part of development. Connectivity being a priority, large areas of pristine habitats has been sacrificed for laying roads resulting in several direct and indirect negative impacts on ecosystems (Goosem, 2007). Fragmentation of habitat by roads and the frequent passage of vehicles on them act as physical barriers for species dispersal across a range of taxa (Carr and Fahrig, 2001; Goosem, 2007; Laurance, 2004; Ree et al., 2009). Animal abundance and population structure is often negatively affected by road mortalities resulting from frequent vehicular movement (Fahrig and Rytwinski, 2009). These effects of roads are not limited to the road itself but often extended to varying distances perpendicular to the road (Forman and Deblinger, 2000; Eigenbrod et al., 2009; Trombulak and Frissell, 2000).

Road mortalities are primarily influenced by habitat variability along the road corridor (Inbar and Mayer, 1999; Seshadri et al., 2009). Seasonality of climate in general and rainfall in particular is an important factor that influences mortalities of certain taxonomic groups like amphibians by timing and triggering reproductive activity and dispersal (Duellman and Trueb, 1994; Vijaykumar et al., 2001). Vehicular movements at night are considered to substantially increase the mortality in certain nocturnal animals like amphibians (Mazerolle, 2004). The possible synergistic effects of the two aforementioned factors could increase negative impacts on populations.

High densities of roads passing through protected areas (PA) often result in mortality of large bodied animals. Much attention is given to understanding and mitigating the impact of roads through PAs on these animals as roads experience some form of traffic all through the year (e.g. Grosman et al., 2009; McLellan et al., 1999; Mech, 1989). Unlike in many developed countries, relatively large proportion of the traditional religious enclaves and scenic landscapes in Asia including India are located inside PAs. These areas attract millions pilgrims and tourists to the PA which brings additional seasonal traffic; the impact of which, on fauna, is not known. Sudden surge in traffic through forest areas can push populations of large animals away from the disturbance area but, smaller organisms that do not show such quick adaptive responses are often killed (Goosem, 2007; Rao and Girish, 2007). We have no clear understanding on how additional vehicular traffic affect these

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organisms in terms of the habitat they use, behavior of the species and their populations.

Vehicular densities on Indian roads have increased from 0.3 to 30 million in the last 50 years and many of them pass through PA and non-PAs (Raman, 2009; Seshadri et al., 2009). The Western Ghats of India which is a global biodiversity hotspot is known for high endemism among reptiles and amphibians. There are few scientific studies in India on the impact of these roads inside PA's and except for three which investigate road mortalities in relation to habitat (Seshadri et al., 2009; Rao and Girish, 2007; Vijaykumar et al., 2001), others only documented species killed on roads due to vehicular movements (Baskaran and Boominathan, 2010; Chhangani, 2004; Gokula, 1997; Kumara et al., 2000). Moreover these studies are taxa specific and no attempt was made to document the wide range of taxa killed on the roads. In the hilly areas such as the Western Ghats where the diversity is high and mainly comprises of smaller animals from a variety of taxa, documenting the species and individuals killed across taxa becomes important to understand the effects of road traffic on biodiversity loss.

Current protected area management regulates the entry of vehicles into PAs but during tourist seasons such practices are relaxed, especially in developing countries due to public and political pressures. This is often due to inadequate knowledge and awareness on the impacts such high density traffic have on the native biota and ways to negate it. Even though the issues highlighted above are common across several countries it may need site specific solutions for conservation action. The aim of this study is to identify the impacts of increased vehicular movement on fauna due to religious tourism inside the Kalakad Mundanthurai Tiger Reserve a protected area in the Western Ghats. It addresses the following specific objectives:

1. Compare and contrast the diurnal and nocturnal species composition and mortality rate of fauna killed on the roads before and during the festival.
2. Identify habitats and microhabitats that are prone to high faunal mortality.
3. Quantify the impacts of and rainfall on road mortalities of vertebrate, invertebrate, diurnal and nocturnal species.

2. Study area

Kalakad Mundanthurai Tiger Reserve (KMTR), 895 km^2 (8°25′–8°53′ N and 77°10′–77°35′ E) is located in the south Indian state of Tamil Nadu. It comprises a matrix of habitats ranging from thorny scrub to the wet evergreen forests thus sustaining a high diversity of flora and fauna (Johnsingh, 2001). KMTR experiences two monsoon seasons; the southwest (June to September) and the northeast (October to January) with annual rainfall ranging from 3000 mm in the western parts to about 750 mm on the eastern parts (Ishwar et al., 2001). The elevation of the reserve ranges from 100 to over 1900 m amsl.

There are 28 enclaves in form of dam sites, waterfalls, religious sites and human settlements inside the reserve and the road network connecting these are utilized by public and private vehicles for occupation, tourism and religious and cultural activities (Ali and Pai, 2001). Among these enclaves, the religious sites attract a large influx of people and vehicles during annual temple festivals. The *Sorimuthian* temple, where one such festival celebrated annually during July to August, is situated on the banks of river *Tamiraparani* inside the tiger reserve. It attracts a regular flow of pilgrims and tourists in low numbers (ca.20 vehicles/day) all through the year. The road network (Fig. 1) leading to this enclave passes through rocky scrub and thorn forest from *Papanasam* till *lower camp* and later through moist deciduous forest to the temple. *Banatheertham*, a water cascade at *Karaiyar* located past the temple area is a tourist site and the road passes through the unique dry evergreen forests. *Servalar* is a dam site located away from the temple area and the road passes through moist deciduous forest. *Mundanthurai* is the junction where the roads meet.

Many of the pilgrims to the *Sorimuthian temple* visit *Banatheertham* during the festival but not to *Servalar*. The festival is celebrated during the new moon day and varies every year depending on the lunar calendar. Nearly 0.2 million people congregate for 10 days, construct temporary houses to reside in the forest around the temple, park vehicles in the forest and use the river water for domestic and recreational purposes. Entry of vehicles into the reserve is controlled by imposing a nominal entry fee and vehicle entry is banned during night hours for the general public. The roads are open to regular buses and bonafide users of the enclaves. However, during the festival, in order to cope up with the large influx of vehicles all restrictions are removed and vehicles are free to enter. This results in an increase in vehicular traffic on roads leading to the temple during the festival compared to the regular traffic on non-festival days (ca.70 vehicles/h and ca.5 vehicles/h, respectively). As the roads leading to Temple, *Karaiyar* and *Servalar* experience varying levels of vehicular movement (pers. obs.) and pass through different habitats; they were chosen for this study (Table 1).

2.1. Sampling

Hundred meter segments of the road were sampled for road mortalities at every 0.5 km on all road sections. The segments were permanently marked using tags on tree and white paint on roads. The number of segments sampled depended on the total length of the road in each habitat (Table 1). Sampling was done three days prior to and three days during the festival with one day gap in between. The survey was started at 06:00 h to avoid the possibility of road kills being macerated and hampering identification because of repeated vehicular movement and to reduce incidents of dead animals being picked by birds and other scavengers (Goosem, 2007).

The survey was carried out by a team of two persons walking the road segment and documenting road mortalities. Three different teams carried out the sampling simultaneously every morning in different habitats and the species and the number of individuals killed in each segment were recorded. The carcasses were photographed with a digital camera (Canon S5IS) when their identity was ambiguous. All the carcasses were removed and scraped out from the road using forceps in order to avoid recounting it during the next sampling session. The road segments passing through human settlements were not sampled as they might have influenced the species composition and mortality. Road mortalities were recorded only if they were on the surfaced part of the road and not beyond it. The mortalities were identified to the lowest possible level and classified as either nocturnal or diurnal using field guides for respective taxa (Das, 2002; Ganesh et al., 2010; Prater, 1997; Narendra and Kumar, 2006; Whitaker and Captain, 2004). Due to lack of information on invertebrates and the macerated condition of carcasses, they were identified only up to genus level or as taxonomically recognizable units. Only a few were identified to species level. The road mortalities were pooled and standardized to individuals per kilometer (ind./km) for before and during the festival for the two years of sampling.

The vehicular density data was obtained from another study conducted at the same time in the reserve (Prashanth and Ganesh, 2010). Data on animal movement was also taken from another study where two observers moved at 20 kmph on a motor bike between 21:00 h and 00:00 h on all road sections and all animals detected within 50 m of the road were recorded (Goswami et al., 2010). Daily rainfall data was obtained from the *Papanasam*,

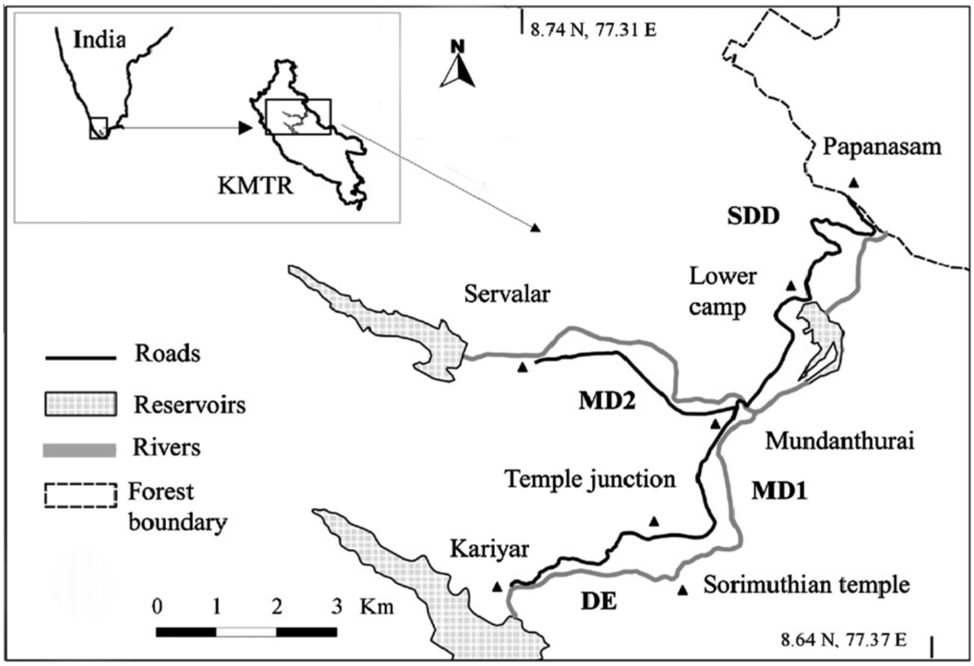

Fig. 1. Map showing the study area. SDD, MD1, MD2 and DE indicate Scrub-Dry deciduous, Moist deciduous 1, Moist deciduous 2 and Dry evergreen habitats along respective roads.

Table 1
Details of habitats on road section and sample effort in each of the four road sections comprising of 3 habitats.

No.	Location	Number of 100 m segments sampled	Sample length (m/day)	Road length (km)	Habitat type (abbreviation)
1	Papanasam to lower camp	7	700	3.5	Scrub-Dry deciduous (SDD)
2	Lower camp to Temple junction	10	1000	5	Moist deciduous-1 (MD1)
3	Mundanthurai to Servalar	7	700	3.5	Moist deciduous-2 (MD2)
4	Temple junction to Karaiyar	5	500	2.5	Dry evergreen (DE)

Servalar and *Karaiyar* weather stations of the Tamil Nadu Electricity Department located within KMTR. The previous day's vehicular density and rainfall were used to relate to current day mortalities. Data was pooled for the two years except for regression analysis. Paired '*t*' test was used to test the significance of variations between mortalities before and during festival. One way ANOVA was used for testing the significance of variations across habitats. Shanon H log 10 index was used as a measure to compare diversity of mortalities across habitats. Multiple regressions were fitted to test the relationship of vehicular density and rainfall with road mortality. A fifty point forward regression was carried out for separately for vertebrates, invertebrates, diurnal and nocturnal species with vehicular density. It was done to determine the maximum threshold of vehicular density on roads. All tests were carried out using free statistical packages PAST (Hammer et al., 2001) and GraphPad (GraphPad software, 1998).

3. Results and discussion

3.1. Diurnal and nocturnal species composition and mortalities across habitats

A total of 1413 mortalities of 56 species belonging to eight classes were recorded over the 2 year study period (Appendix A). Invertebrates comprised 53% of the mortalities followed by reptiles (25%), amphibians (15%) and small mammals (7%). The species composition varied significantly across the four habitats ($F = 3$, $p = 0.024$). The overall mean mortality rates also differed across habitats ($F = 7.94$, $p = 0.001$) and were highest in MD1 (188 ind./km) followed by the SDD (27 ind./km); DE (45 ind./km) and lowest in MD2 (14 ind./km).

The total mortality across all habitats increased by 299% during the festival (45 species, 1130 ind.) than before the festival (16sp, 283 ind.; Fig. 2). The mean mortality rate, within each habitat, varied significantly before and during the festival for SDD ($t = -5.755$, $p < 0.001$) and MD1 habitat ($t = -5.933$, $p < 0.001$) but not for the MD2 ($t = -1.926$, $p > 0.05$) and DE habitats ($t = 1.688$, $p > 0.05$). Though the mortality rates were higher in MD1 before and during the festival, the diversity of moralities was highest in DE (2.09) before and in SDD (2.95) during the festival. The diversity was lowest in SDD (1.90), followed by MD2 (0.83) and MD1 (1.29) before the festival but during the festival, diversity was lowest in DE (1.99) followed by MD1 (2.16) and MD2 (2.48).

The high mortality rate in SDD and MD1 is due to the increased number of vehicles passing through those habitats during the festival. The high diversity of mortalities in DE before the festival is due to regular tourist movement to *Karaiyar*. As some of the pilgrims also use the roads through MD2 and DE to go to *Servalar* and *Karaiyar*, a marginal increase in mortalities can be seen in both these habitats during the festival. This occurrence of increased mortalities in areas unconnected with temple, termed as a "Spillover effect" is due to two reasons; first, due to increased vehicular movement in these areas during the festival and second, due to the high diversity of species in these areas. Restrictions on vehicular traffic in such areas are important to prevent any spillover effect.

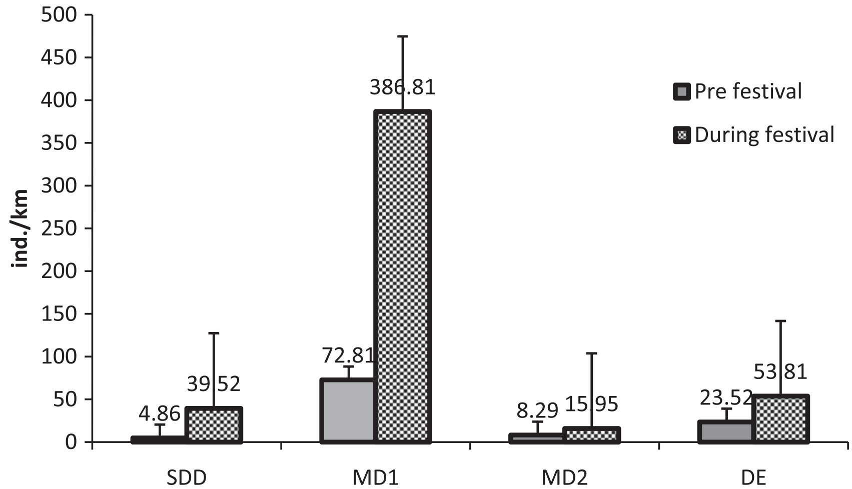

Fig. 2. Mean mortalities ($x \pm$ se) pre and during the festival across habitats.

Among the species recorded, Millipede was the most commonly killed species both before and during the festival. Forest roaches were the most common species killed before the festival and Bi-colored frog (*Clinotarsus curtipes*) during the festival. Millipedes were the most common species killed among invertebrates in all habitats both before and during the festival. These slow moving species are active by dusk but, under cloudy and wet conditions, many crossed roads and were killed even during the day. *C. curtipes*, a near threatened species, was the second most common species recorded in the study. Their mortalities were restricted to MD1 and SDD habitats (1.67 and 29.66/km, respectively) which may be due to the presence of river *Tamiraparani*. This species breeds in the river and disperses into the forest and mortalities occurred during that period which also included many gravid females.

Among mammals, only four species of small mammals were recorded. The mammal mortality rate was lower in comparison to a study by Kumara et al. (2000), where 12 species of both large and small mammals have been killed. In a parallel study at the same site and time, many mammals like Bonnet Macaque (*Macaca radiata*) and White Bellied Wood Rat (*Madromys blanfordi*) were noticed escaping from being killed by speeding vehicles (Goswami et al., 2010). Many other species have also been observed crossing and foraging along roadsides, especially at night but, are absent when the vehicular movement increases during the festival (Table 2). This evasive behavior of larger mammals towards traffic and roads could explain their absence in mortalities.

Among invertebrates, many small organisms such as ants, glow worms, forest roaches were killed (Appendix A). Their mortalities were lower as compared to larger invertebrates like scorpion spp., and centipede sp. Since this is the first study to document the mortalities across taxa, comparisons were not possible with other studies. The occurrence of House roaches (*Periplanata* sp 2) in SDD, MD1 and DE habitats in the year 2009 was another significant addition to the fauna documented in KMTR. This species being associated with human habitations (pers. obs.) could be an alien invasive species being inadvertently introduced by the annual festival. This species does not occur outside human settlements unless transported through household articles which is the case during the festival. The settlements inside the reserve have this species but it is never recorded beyond the settlements and hence not recorded as road mortalities at other times.

Table 2
Mammals observed foraging along roads before and during festival at day and at night.

Species	Common names	IUCN* category	Occurrence			
			Before festival		During festival	
			Day	Night	Day	Night
Loris tardigradus	Slender loris	EN	0	1	0	0
Semnopithecus priam	Hanuman Langur	NT	1	0	1	0
Macaca radiata	Bonnet macaque	LC	1	0	1	0
Melursus ursinus	Sloth Bear	VU	1	0	0	0
Paradoxurus hermaphrodites	Common Palm Civet	LC	0	1	0	0
Paradoxurus jerdoni	Brown palm Civet	LC	0	1	0	0
Viverricula indica	Small Indian Civet	LC	0	1	0	0
Herpestes smithii	Ruddy Mongoose	LC	1	1	0	0
Panthera paradus	Leopard	NT	1	1	0	0
Sus scrofa	Wild pig	LC	1	1	1	1
Moschiola indica	Mouse deer	LC	0	1	0	0
Axis axis	Spotted deer	LC	1	1	1	1
Rusa unicolor	Sambar deer	VU	1	1	0	1
Funambulus palmarum	Three striped squirrel	LC	1	0	1	0
Lepus nigricollis nigricollis	Black naped hare	LC	0	1	0	0
Total occurrence of species			8	11	4	3

* As per IUCN Red List of Threatened Species (www.iucnredlist.org as accessed on 07 December 2010). LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered. "0" Indicates absence and "1" indicates presence during the time period.

The overall drastic increase of mortalities by 299% during the festival lays a strong impetus for the need to undertake studies documenting the negative effects on fauna at a population level. The roads passing through MD1 and SDD habitats have highest mortality rates and thus, should be prioritized for mitigation measures.

3.2. Nocturnal species composition and mortalities across habitat

Nocturnal species alone constituted 50% of mortalities (713 mortalities, 6 classes and 34 species). The species composition varied significantly across habitats ($F = 4.32$, $p = 0.005$). Amphibians, Insects and reptiles each accounted for 26% of mortalities followed by Arachnids (9%) and Mammals (5%). Other invertebrates comprised the remaining (6%). *Periplanata* sp 1 a species of forest cockroach was the most common species before but *C. curtipes* was the most commonly killed nocturnal species during the festival. Other commonly killed species included crawling invertebrates like scorpion spp., centipede sp and mammals like bat sp (Appendix A).

Mortality rates of nocturnal species increased by 648% during the festival (25 species and 629 ind.) compared to those before the festival (6 species and 84 ind.). The mean mortality rates before and during festival (Fig. 3) were highest in MD1 (190.3 ind./km) and the least in MD2 (10.4 ind./km). The differences among mortalities before and during the festival were significant for all habitats except for MD2 ($t = -0.9457$, $p > 0.05$). The comparable mortality rate in MD2 could be a result of the restrictions imposed against the entry of vehicles towards *Servalar* by the forest authorities during the festival in 2009.

Among the nocturnal species, most amphibian mortalities occurred during night hours and comprised of four families (25 ind./km). This is high compared to a study reporting amphibian mortalities of seven families killed (2 ind./km) in a PA (Vijaykumar et al., 2001). Among reptiles, only 10 species (3.3 ind./km) were documented in this study whereas Kumara et al. (2000) report 18 species (3.5 ind./km) and Vijaykumar et al. (2001), report 24 species (0.4 ind./km) inside PAs. Even though it is evident that fewer species of reptiles are killed in our study, the mortality rates are similar to that reported by Kumara et al. (2000). It should be noted that both the studies in comparison, were carried out on highways without the surge in vehicular movement due to pilgrimages. Among arthropods, 10 species (27.5 ind./km) were recorded of which more than 20% was a cricket sp (5.9 ind./km). The behavior of certain species like scorpions and centipedes to forage on roads at night could explain their high mortalities (pers. obs.). Apart from the crawling arthropods that get killed, many of the flying insects get attracted to the lights of the constantly passing vehicles and get crushed by them. This in turn, can have a cascading effect birds like Owls and Nightjars, which hawk for insects on road by attracting and causing road mortalities by direct collision with vehicles.

It was observed that though vehicle entry was stopped within the reserve at night on non-festival days, mortality of nocturnal species continued to occur in low rates, even in the control habitats. This is due to the regular tourist vehicles leaving the reserve at night and the regular bus movement inside the reserve connecting the enclaves to the cities outside. Also, in year 2009, a ban on use of polythene bags was brought into force and all vehicles entering the reserve were screened and frisked. To avoid being frisked by the forest authorities, the pilgrims entered the reserve a week earlier when there was no frisking resulting in nocturnal species mortality even during non-festival period. The high mortality rates of nocturnal species in MD1 during the festival highlights the result of allowing vehicles into these habitats during night hours. This increased mortality also fortifies the need for prioritizing the road section passing through this habitat for impact mitigation strategies. The high mortality rates of nocturnal species and the drastic 648% increase, calls for a complete night time ban on vehicular movement. A recent legal order banning such night time traffic on a national highway passing through Bandipur National park in central Western Ghats has been passed and stringently implemented (Anonymous, 2010). It is not only an indication of the shift in focus towards including roads in management strategies but is also an example of mitigation measures that would be effective is reducing biodiversity loss.

3.3. Vehicular density, rainfall and local extinction

The multiple regression model of road mortality rate showed a strong positive relationship with increasing vehicular density and rainfall ($R^2 = 0.56$, $p < 0.0001$). But, of the two variables, only vehicular density significantly influenced the model (t-ratio = 8.806, $p < 0.0001$) and not rainfall (t-ratio = 0.1073, p = 0.914). We tried lag correlations for rainfall but these were not significant. The output model was $[M:] = 1.257 + 0.4708\ [V:] + 0.04189\ [R:]$ where M = mean road mortality/km, V = vehicular density/h and R = rainfall (mm).

The 50 point forward regression with vehicular density, in case of diurnal species and invertebrate species had a liner best fit relationship but, in case of nocturnal species and vertebrate species, the best fit curve was non-linear (Fig. 4). The curve for diurnal

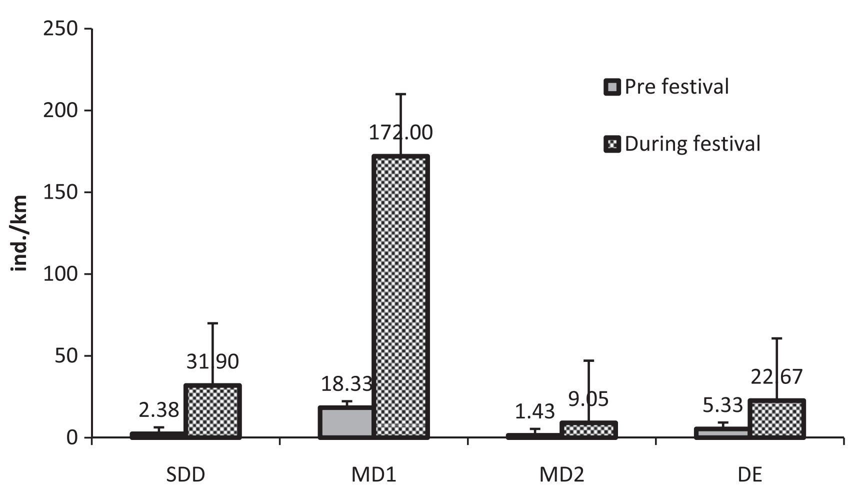

Fig. 3. Mean mortalities ($x \pm$ se) of Nocturnal species pre and during the festival across habitats.

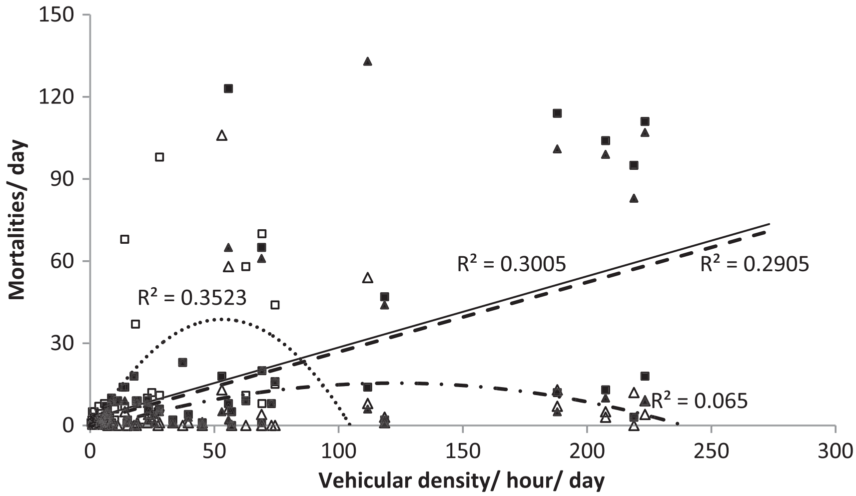

Fig. 4. Regression curves showing the effect of vehicular density on diurnal; nocturnal; vertebrate and invertebrate species (closed square with dark line: diurnal; open square with dotted line: nocturnal species; closed triangle with dashed line: invertebrates and open triangle with double dash dot line: vertebrates).

species explained 30% ($R^2 = 0.30$, $p < 0.001$) of the variation in mortalities and for nocturnal species 35% ($R^2 = 0.35$, $p < 0.001$). For invertebrates, it was 29% ($R^2 = 0.29$, $p < 0.001$) and for vertebrates it was 6% ($R^2 = 0.06$, $p > 0.5$). On examining the relationship further, the number of vertebrate mortalities increased smoothly but declined at about 150 vehicles/h before reaching zero mortality by 250 vehicles/h. The invertebrate mortalities however, increased linearly with increasing vehicular density up to 300 vehicles/h. The diurnal species mortality increased with increasing vehicular density even beyond 250 vehicles/h. But the nocturnal species mortalities increased rapidly and began to drop with about 50 vehicles/h before completely reaching zero mortality after 100 vehicles/h.

The curves of nocturnal species and of vertebrates reaching zero with increase in vehicular density indicate that these two taxa get negatively affected by high vehicular movement. The reduction of mortalities to zero after a certain vehicular density could be due to temporary local extinction of species or species actively avoiding the road during high vehicular movement. Though certain large mammal showed evasive movement (Table 2), smaller organisms like invertebrates, amphibians and reptiles did not respond to high vehicular density and thus leading to their mortalities. The vehicular density beyond which the mortalities start to decline can be considered as a threshold limit for controlling the number of vehicles entering the reserve. At present, the number of vehicles entering the reserve far exceeds the threshold levels of 50 vehicles/h for nocturnal species and 150 vehicles/h for vertebrate species. We recommend and reiterate that a complete ban on night traffic should be introduced even during the festival to reduce impact on nocturnal species and as a preventive measure, the number of vehicles should be restricted to half of the threshold level between 75 and 100 vehicles/h for diurnal species.

Studies elsewhere have documented decline in animal populations due to high vehicular movement. Cases of population isolation and dilution of gene pool due to roads acting as barriers for population dispersal have also been commonly reported (Ree et al., 2009). Langevelde and Jaarsma (2009) modeled the effect of increased traffic on animal populations. They recommend measures such as reducing traffic volume on roads or reduction in the vehicle speed to reduce mortality rate. At present, there are no such measures undertaken in our study site. Further increase in un-controlled vehicular movement will worsen the current situation leading to drastic declines in the populations, especially of nocturnal species. It may also cause a permanent local extinction of certain species which do not show evasive response to vehicular movement on roads.

The regression analysis is based on four categories viz., vertebrates (nocturnal and diurnal); invertebrates (nocturnal and diurnal); diurnal (vertebrates and invertebrates) and nocturnal (vertebrates and invertebrates). It is evident that vertebrate species and nocturnal species are the most affected by direct collision with vehicles (Fig. 4). Larger animals that show evasive movement (Table 2) do not get killed on roads but roads act as potential barriers for their movement. The smaller vertebrates and invertebrates, especially the nocturnal species, do not show such response behavior to increased vehicular densities and thus have high mortality rates compared to large mammals. It is more likely that the reduction in mortalities to zero in nocturnal species and smaller vertebrate species is a result of local extinction and not due to evasive movement. However, determining the actual reasons for the patterns was beyond the scope of this study. This finding reiterates the requirement of a night time traffic ban and lays impetus for further studies directed at understanding impacts on the fauna at a population level.

This study, for the first time, documents the variations in diversity and mortality rates across different habitat types. MD1 experiences the highest mortality but is low in diversity whereas, DE experiences relatively lower mortality but has a high diversity of mortalities. Interestingly, the mortality rates and diversity of SDD habitat, through which all vehicles invariably pass to reach the temple, are lower than MD1 or DE. This could be resulting from the terrain and restriction of vehicle speeds. The road passing through SDD between *Papanasam* and *Lower camp*, is a winding hill road along the contours and this considerably reduces the speed at which vehicles move. Hence, fewer road mortalities are documented in this habitat in-spite of vehicle densities being high. After *Lower camp*, the road passing through MD1 is a plateau. The roads are linear and flat without speed humps. This encourages the pilgrims to over-speed resulting in increased mortalities (pers. obs.). The unique case of high mortality rates in DE and MD2 could be because the habitats support high diversity and any vehicular movement causes high mortality. Further, increased mortalities in these two habitats highlight the need for implementing mitigation measures not only in MD1 but in DE and MD2 as well.

4. Management implications

There is a 299% increase in road mortalities due to increased vehicular traffic inside forested areas during the festival. Nocturnal species are the most affected showing a drastic 648% increase in mortalities during festival. The mortality rates increase across habitat type and even in control habitats. The control habitats MD2 and DE show relatively high diversity compared to SDD and MD1. These two habitats also experience unrestricted entry of vehicles and a combination of these factors like high diversity, terrain, rainfall and vehicular movement may be causing the spillover effect. In case of MD1, the highest mortality rate is recorded both before and during the festival. This could be a result of flat roads without speed humps and the unrestricted entry of vehicles. Given the high mortality rates, this road section naturally becomes a priority for undertaking mitigation measures. However, high mortalities in DE and MD2 indicate the need for habitat specific interventions apart from general amelioration measures.

The high mortality reaching zero with increased vehicular density indicates a case of temporary local extinction, as observed among nocturnal species. The current vehicular densities on roads far exceed the threshold levels. Allowing vehicles beyond the threshold is likely to cause a permanent local extinction of species such as millipedes, scorpions and centipedes.

Like in many Asian countries, the PA management has ignored the issue of roads being potential drivers for the loss of biodiversity. Symptomatic amelioration measures have been undertaken towards vehicles plying inside forest areas, largely due to the high costs involved in preventive measures like construction of over passes or underpasses which require considerable planning. In situations like in this study where biodiversity conservation overlaps with social, cultural and economic issues, it often becomes difficult to implement drastic solutions to mitigate problems.

We suggest few simple strategies like preventing traffic on certain roads which appears to help curtail impacts. Whenever possible, night time vehicular movement should be completely stopped. Banning night time traffic inside PA is possible using existing legislations in different countries and is the best option. However, in cases where it cannot be achieved or in case of day time vehicular movement, regulation of vehicular traffic well below threshold levels is essential for preventing a local extinction of species. Further, it is advisable to have more public transport vehicles like buses than allowing private cars to reduce vehicular density well below threshold. Studies by Dodd et al. (2004) and Ree et al. (2009) recommend low cost underpasses that can be retrofitted with the existing road and at specific points to suit specific taxa like areas of high amphibian dispersal (like in MD1 where *C. curtipes* disperses). Such measures can be implemented only after a detailed study in that direction is undertaken. High vehicular density causes a physical barrier effect and in such cases, we suggest that traffic calming measures like regulating vehicles such that they go together in batches with gaps of half hour between batches. We have observed mammals like Wild pig *Sus scrofa*, *Leopard Panthera paradus*, Deers, Civets and Bears cross the road when the separation time between vehicles is ca. 2 min. Increasing the time span of this gap should essentially ease the barrier effect for the larger mammals which did not have any representation in road mortality, possibly due to road evasion. Reducing vehicle speed especially in MD1 and MD2, by regular installation of speed humps and retaining road verges in blind corners of roads will further help ease the barrier effect for large mammals. Slower vehicle speeds give more response time for animals to avoid being hit and thus reduce mortality rates and natural vegetation in road verges provides shelter space to animals stunned by approaching vehicles. Further, maintaining canopy contiguity can ease barrier effect to arboreal nocturnal species like Slender Loris (*Loris tardigradus*) and Civets which show evasive movement to increased vehicular density.

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Appendix A

List of species recorded and mortality rates before and during festival.

Species	Common name	Habit	Mortality rate/km	
			Before	During
Amphibia				
Clinotarsus curtipes Jerdon (1853)	Bi colored frog	Nocturnal	0.11	21.15
Duttaphrynus melanostictus Schneider (1799)	Common Toad	Nocturnal	0.69	4.60
Euphlyctis cyanophlyctis Schneider (1799)	Skitter frog	Nocturnal	0.23	0.23
Fejervarya sp		Nocturnal	0.11	0.34
Frog sp		Nocturnal	1.38	2.30
Frog sp 1		Nocturnal	0.00	0.23
Frog sp 2		Nocturnal	0.00	0.11
Frog sp 3		Nocturnal	0.00	0.11
Frog sp 4		Nocturnal	0.00	0.11
Arachnida				
Scorpion sp 1		Nocturnal	0.34	3.91
Scorpion sp 2		Nocturnal	0.00	1.03
Spider sp		Diurnal and nocturnal	0.34	0.23

(*continued on next page*)

Appendix A (*continued*)

Species	Common name	Habit	Mortality rate/km	
			Before	During
Chilopoda				
Centipede sp		Nocturnal	0.11	6.67
Diplopoda				
Millipede sp		Diurnal	20.57	48.28
Pill Millipede sp		Diurnal	0.46	2.76
Insecta				
Ant sp		Diurnal	0.23	0.46
Acraea terpsicore Linnaeus (1758)	Tawny coaster butterfly	Diurnal	0.11	0.00
Bee sp		Diurnal	0.00	0.34
Beetle sp 1		Nocturnal	0.23	0.46
Beetle sp 2		Nocturnal	0.00	0.11
Bug sp		Diurnal	0.00	0.11
Butterfly sp		Diurnal	0.00	0.11
Caterpillar sp		Diurnal	0.11	0.11
Casemoth caterpillar sp		Diurnal	0.11	0.00
Cricket sp		Nocturnal	0.46	1.61
Euploea core Cramer (1780)	Blue tiger butterfly	Diurnal	0.11	0.00
Glow worm sp		Nocturnal	0.00	0.92
Grasshopper sp 1		Diurnal	0.80	4.02
Grasshopper sp 2		Diurnal	0.00	1.61
Hole cricket sp		Diurnal	0.00	0.11
Insect sp		Diurnal and nocturnal	0.57	1.26
Leptogenys processionalis Jerdon (1851)	Procession ant	Diurnal and nocturnal	0.11	0.00
Moth sp		Nocturnal	0.00	0.23
Periplanata sp 1	Forest roach	Nocturnal	2.99	2.64
Periplanata sp 2	Cockroach	Nocturnal	1.15	17.13
Praying Mantis sp 1		Diurnal	0.34	0.34
Praying Mantis sp 2		Diurnal	0.00	0.11
Spider Wasp sp		Diurnal	0.11	0.00
Wasp sp		Diurnal	0.11	0.11
Mammalia				
Bat sp		Diurnal	0.00	0.11
Field mouse sp		Diurnal	0.00	0.11
Gerbil sp		Crepescular	0.00	0.11
Madromys blanfordi Thomas (1881)	White bellied wood rat	Nocturnal	0.00	0.46
Mollusca				
Snail sp		Diurnal and nocturnal	0.34	0.11
Reptilia				
Calotes sp		Diurnal	0.00	1.03
Calotes versicolor Daudin (1802)	Garden calotes	Diurnal	0.00	0.57
Eryx sp	Sand boa sp	Nocturnal	0.00	0.23
Gecko sp		Nocturnal	0.00	0.57
Hemidactylus leschenaultii Duméril amd Bibron (1836)	Bark Gecko	Nocturnal	0.00	0.11
Hemidactylus triedrus Daudin (1802)	Termine hill gecko	Nocturnal	0.00	0.23
Lycodon aulicus Linnaeus (1758)	Wolf snake	Nocturnal	0.11	0.23
Macropisthodon plumbicolor Cantor (1839)	Green Keelback	Nocturnal	0.23	0.11
Oligodon arnensis Shaw (1802)	Common kukri	Nocturnal	0.00	0.23
Ramphotyphlops braminus Daudin (1803)	Brahminy worm snake	Nocturnal	0.00	0.23
Snake sp		Na	0.11	0.69
Trimeresurus spp.	Viper sp	Nocturnal	0.00	0.23

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