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SNAKE ROAD MORTALITY IN A PROTECTED AREA IN THE ATLANTIC FOREST OF SOUTHEASTERN BRAZIL

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Abstract. Roads that cross natural areas may exert negative effects on the local fauna. Among them, the most obvious negative effect is vehicular run over. For snakes, the risk of roadkill seems to be higher in habitat generalists, locally abundant or highly mobile species. High snake mortality by roadkill occurs mainly when animals cross roads during terrestrial movements to breeding, wintering, foraging or summering habitats. We here describe snake road mortality at Núcleo Picinguaba, Parque Estadual da Serra do Mar, a protected rainforest area located on the northern coast of the State of São Paulo, Brazil. We sampled a 16 km tract of a paved road from October, 2001 to December, 2002, totalling 5,173 km. We found 60 roadkilled snakes, belonging to 15 species, representing around 58% of the species recorded for the region. More mobile species seemed to be more vulnerable to road mortality than sedentary species. Snake species encountered dead on the road tended to have great mobility, to be active foragers, and to show plasticity in microhabitat use. Road mortality seemed to coincide with age and sex specific seasonal activities. The higher number of juveniles found in May could reflect juvenile recruitment, mainly for more active species and for those with greater dispersion ability. The increased road mortality in October may be a consequence of males searching females during the mating period. Although the density of roadkilled species in the area is poorly known, the relative low rate of snake mortality we found at Núcleo Picinguaba, associated with the small length of the highway inside the park and the relatively low traffic volume, indicate that the actual negative effect of the BR-101 highway on local snake populations is negligible for the most common and abundant species. However, given that the Serra do Mar State Park is a type II park in the IUCN Protected Area Management Categories, measures which result in decrease of snake mortality should be implemented by the park managers.

Keywords. Snakes, Atlantic Forest, Vehicular mortality, Road ecology, Protected area.

Introduction

Roads are among the most evident environmental manmade changes and can cause diverse negative ecological effects for the fauna (Forman and Alexander, 1998; Trombulak and Frissell, 2000; Clevenger *et al.,* 2003; Forman *et al.,* 2003; Andrews and Gibbons, 2005). These effects include habitat loss, habitat degradation or fragmentation, road avoidance behaviors and direct wildlife mortality (Andrews, 1990; Bennett, 1991; Forman and Alexander, 1998). Wildlife populations using areas adjacent to roads face increased mortality risk due to collisions with vehicles (Mumme *et al.,* 2000). This form of mortality can have substantial effects on a population's demography (Trombulak and Frissell, 2000), since it can affect density and demographic structure of wild populations (Fahrig *et al.,* 1995; Huijser and Bergers, 2000; Gibbs and Steen, 2005).

Vehicle collision is an important source of mortality to many species of reptiles (Case, 1978; Bernadino and Dalrymple, 1992; Rosen and Lowe, 1994; Ashley and Robinson, 1996; Gokula, 1997; Klingenbock *et al.,* 2000; Clevenger *et al.,* 2003; Andrews and Gibbons, 2005; Richardson *et al.,* 2006). For snakes, on-road mortality is frequent (Klingenbock *et al.,* 2000; Koenig *et al.,* 2001; Andrews and Gibbons, 2005; Richardson *et al.,* 2006), and some factors seem to increase vulnerability to roadkills. The risk of roadkill seems to be higher in habitat generalists, locally abundant, and more mobile species (Forman *et al.,* 2003; Jochimsen *et al.,* 2004). In addition, high snake mortalities occur mainly when animals cross roads during terrestrial movements to breeding, wintering or summering habitat (Ashley and Robinson, 1996; Smith and Dodd, 2003; Aresco 2005). Ecological differences among species, sex and age classes can reflect in movement patterns (Gibbs, 1998; Semlitsch, 2000; Carr and Fahrig, 2001; Blouin-Demers and Weatherhead, 2002; Andrews and Gibbons, 2005; Steen and Smith, 2006), which in turn can affect road mortality (Bonnet *et al.,* 1999).

Roads can represent barriers or filters to snake movements along the landscape (Andrews and Gibbons, 2005). Thus, understanding patterns related to snake road mortality makes it possible to infer its impact over populations and eventually to propose actions to reduce them. The objective of this study was to examine snake road mortality at Núcleo Picinguaba, Parque Estadual da Serra do Mar, a protected rainforest area located on the northern coast of the State of São Paulo, Brazil. We documented the diversity of species affected by road mortality, explored differences in road mortality relative to assemblage diversity, seasons and ecological traits of the species, and discuss the importance of roadkills on local snake populations.

Material and Methods

Study site

The study was carried out at Núcleo Picinguaba (47,000 ha), a portion of the Parque Estadual da Serra do Mar (315,000 ha), located on the northern coast of the State of São Paulo (SP), southeastern Brazil (23°23'S, 44°50'W). Snake roadkill searches were conducted along a 16 km stretch of the BR-101 highway which crosses the park near the coast (Fig. 1). The Núcleo Picinguaba area is dominated by escarpments that reach the sea in the bay of Picinguaba. The sampled area encompasses the following vegetation types: dense rainforest, restinga forest (rainforest on coastal sandy soils) and transitional vegetation between dense rainforest and restinga forest (Rizzini, 1973). The climate is tropical-wet (Köeppen, 1948). The Núcleo Picinguaba covers an area of coastal zone, seasonally controlled by equatorial and tropical weather systems, under the influence of the Tropical Atlantic air mass. Mean monthly rainfall is generally above 200 mm from October to April and between 80 and 160 mm from May to September. Highest precipitation occurs from December to March (about 380 mm/month). Mean relative humidity above 85% throughout the year. Mean annual temperature is 21.9°C. Lower temperatures occur in the drier season, resulting in a rainier/warmer season from October to April and a drier/colder season from May to September. Climatic data were obtained from the Instituto Nacional de Metereologia, for the meteorological station of the Instituto Agronômico de Campinas, at Ubatuba (SP) (23°27'S, 45°04'W), located about 60 km from our study area.

Data on roadkills were obtained by regular road sampling, through the help of local people, and also by accidental encounters. During regular road samplings, we drove slowly, about 30-40 km/h, searching for snake roadkills. Every sampling day we covered a 16 km tract of the highway that crosses the park, in both directions. Additionally we drove through secondary, unpaved roads that cross the park. Search for roadkills was always made by two people. Samplings were made from 16:00 to 19:00 h. We performed regular road samplings during 9 to 12 days per month. From October 2001 to December 2002, we drove about 300 to 415 km each month, totaling 5,173 km during 15 months.

To get information from local people about snakes found dead on road, we distributed four 20 L containers with 15% formaldehyde at the headquarters of the Núcleo Picinguaba and to the neighboring villagers to deposit snakes roadkills. Cards were also given to the villagers in order to record information such as time and site of collection.

Roadkills found by us during activities that were not part of the regular sampling sessions were considered as accidental encounters.

When specimen conditions allowed, snakes were fixed and housed in the collection of the Instituto Butantan (IB). We used the following categories in relation to microhabitat use by the snakes: fossorial, terrestrial, arboreal, and aquatic (*e.g.* Duellman, 1989). Snakes which use both the ground and the vegetation while active were considered as semi-arboreals. The activity period and substrate use were characterized using published data for the Atlantic Forest (see Sazima and Haddad, 1992; Marques, 1998; Marques and Sazima, 2004; Marques *et al.,* 2004; Hartmann *et al.,* 2009). The taxonomy at the level of subfamily and family used herein follows Zaher *et al.* (2009).

To explore the importance of roadkills on local snake populations, we estimated a relative road mortality (RRM) for each species by dividing the number of roadkills by the number of individuals found in a parallel study of the snake fauna (Hartmann *et al.,* 2009). Species found dead on road but rare ($N \leq 2$) at Hartmann *et al.* (2009) were excluded of the RRM analyses. We also calculated a road mortality rate as the number of roadkills per kilometer per year, for year 2002. To detect possible differences between juveniles and adults, sexual maturity was assessed through the examination of gonads (see Hartmann *et al.,* 2009). The snout-vent length of the smallest mature male and smallest mature female of each species was used to differentiate immature from adult individuals (see criteria in Shine, 1977, and Marques, 1996).

Results

A total of 60 roadkilled snakes were obtained during this study, belonging to 15 species, representing around 58% of the species recorded for the region (Table 1). Out of the 60 snakes (all found in the paved road), 46 were found by sampling by car, nine by accidental encounters and five by local collectors. The number of individuals found as roadkills was positively correlated with their abundance in the area obtained in a parallel study ($r_s = 0.744$, $p < 0.05$; Table 1). The four most common species in roadkills in the study area ($N \geq 5$, Table 1), were common (19-29 individuals) or of intermediate abundance (3-18 individuals), in the study of Hartmann *et al.* (2009). Together, these species represent more than half of the roadkills (N = 32). However, the dominant species in the assemblage (*Bothropoides jararaca* and *Bothrops jararacussu,* with abundances of 71 and 47 individuals, respectively) in the study of Hartmann *et al.*

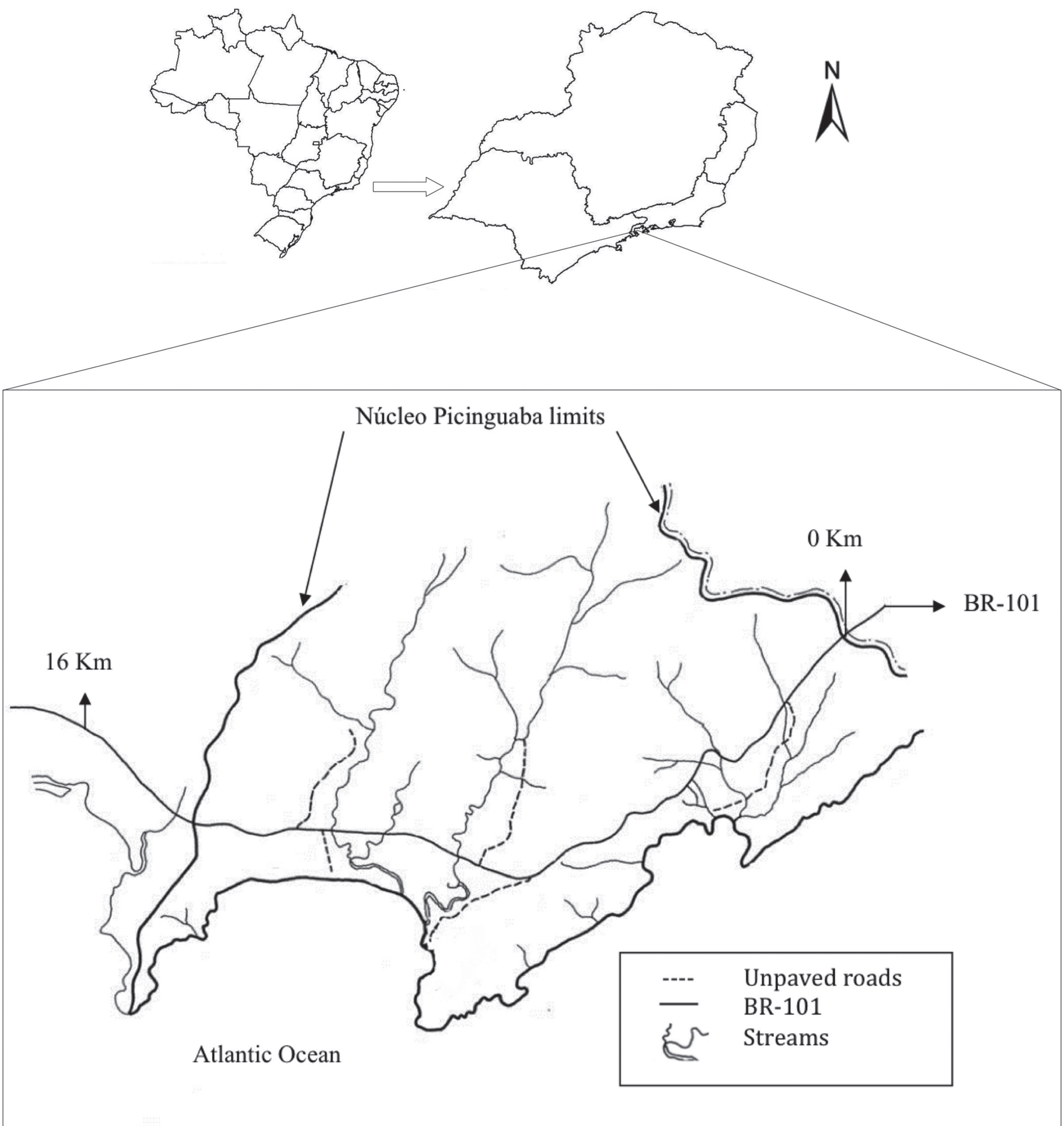

Figure 1. Map of the study area with the sampled road (BR-101 highway), Núcleo Picinguaba, Parque Estadual da Serra do Mar, southeastern Brazil.

Table 1. Diversity and number of snake roadkills at Núcleo Picinguaba, Parque Estadual da Serra do Mar, southeastern Brazil, from October 2001 to December 2002. Numbers in parentheses indicate the relative rod mortality (RRM). In italics the most roadkilled species ($N \geq 05$), with higher road mortality rate (for year 2002), or with high relative road mortality ($RRM \geq 0.50$). Note that *Bothropoides jararaca* and *Bothrops jararacussu* were dominant in the assemblage ($N \geq 30$), but with low number of roadkills. Ar, arboreal; Aq, aquatic; Fo, fossorial; Sa, semi-arboreal; Te, terrestrial.

Species	Snakes on Assemblage	Snakes roadkills (RRM)	Road mortality rate	Habitat use
Chironius exoletus (Linnaeus, 1758)	19	*12 (0.63)*	*1.8*	Sa
Chironius bicarinatus (Wied, 1820)	12	*08 (0.67)*	*0.8*	Sa
Oxyrhopus clathratus Duméril, Bribon and Duméril, 1854	10	*06 (0.60)*	*1.0*	Te
Chironius fuscus (Linnaeus, 1758)	29	*06* (0.21)	*1.0*	Sa
Chironius laevicollis (Wied, 1824)	09	04 (0.44)	0.6	Te
Spilotes pullatus (Linnaeus, 1758)	13	04 (0.31)	*0.8*	Sa
Philodryas olfersii (Lichtenstein, 1823)	04	03 *(0.75)*	0.4	Sa
Chironius foveatus (Bailey, 1955)	12	03 (0.25)	0.4	Sa
Liophis miliaris (Linnaeus, 1758)	20	03 (0.15)	0.6	Aq, Te
Bothropoides jararaca (Wied,1824)	71	03 (0.06)	0.6	Te
Bothrops jararacussu Lacerda, 1884	47	03 (0.04)	0.2	Te
Micrurus corallinus (Merren, 1820)	07	02 (0.29)	—	Te, Fo
Clelia plumbea (Wied, 1820)	01	01	0.4	Te
Dipsas sp.	02	01	0.2	Ar
Sibynomorphus neuwiedi (Ihering, 1911)	02	01	—	Sa
Thamnodynastes cf. *nattereri* Mikan, 1828	05	—	—	Sa
Imantodes cenchoa (Linnaeus, 1758)	04	—	—	Ar
Taeniophallus affinis (Günther, 1858)	04	—	—	Te
Echinanthera cephalostriata (Di-Bernardo, 1996)	03	—	—	Te
Dipsas indica Laurenti, 1768	02	—	—	Ar
Taeniophallus bilineatus (Fischer, 1885)	02	—	—	Te
Xenodon neuwiedii Günther, 1863	02	—	—	Te
Helicops carinicaudus (Wied, 1825)	01	—	—	Aq
Uromacerina ricardinii (Peracca, 1897)	01	—	—	Ar
Echinanthera undulata (Wied, 1824)[1]	—	—	—	Te
Siphlophis pulcher (Raddi, 1820)[2]	—	—	—	Sa
Number of snakes	282	60	44	—
Number of species	26	15	13	—

(1) Species found after the fieldwork.
(2) Species not found in this study, but with confirmed occurrence in the region (*see* Marques *et al.,* 2001).

(2009) were rarely found dead on the road (three roadkills in each species; Table 1). From January to December 2002, we found 44 individual snakes dead on the paved road which cross the Núcleo Picinguaba, in 116 days of regular road sampling. Based on this number, we estimated a loss of about 140 snakes per year. Considering the length of the highway inside the park, the rate of snake mortality was 8.6 snakes/km/year.

Adults were more frequently found as roadkills ($N = 45$) than juveniles ($N = 13$). For two individuals, it was not possible to determine maturity stage. Males were more frequently found as roadkills ($N = 30$) than females ($N = 18$). For 12 individuals, it was not possible to determine the sex. Out of the 15 species found dead on road, 12 show terrestrial or semi-arboreal habits (Table 1). The relative road mortality was high ($RRM \geq 0.5$) in four species: *Philodryas olfersii, Chironius exoletus, C. bicarinatus* and *Oxyrhopus clathratus* (Table 1). The species found more frequently as roadkills, with higher road mortality rate, and/or those with higher RRM were terrestrial or semi-arboreal (Table 1). Strictly arboreal and fossorial species were less often found as roadkills in the overall sample. In addition, the ambush-foraging and most sedentary species were less often found as roadkills (Table 1).

There was no difference in the frequency of roadkills among seasons (one snake at every 101 km during the raining season and one snake at every 111 km during the dry season ($\chi^2 = 1.4$, $DF = 1$, $p = 0.26$). However, there seems to be two peaks: (1) in April

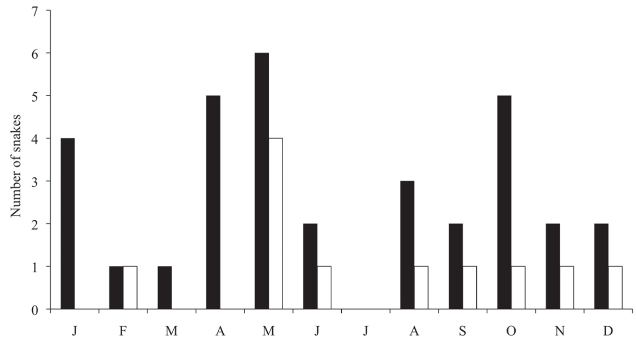

FIGURE 2. Number of adult (N = 33, black columns) and juvenile snake roadkills (N = 11, white columns) from January to December 2002 at Núcleo Picinguaba, Parque Estadual da Serra do Mar, southeastern Brazil.

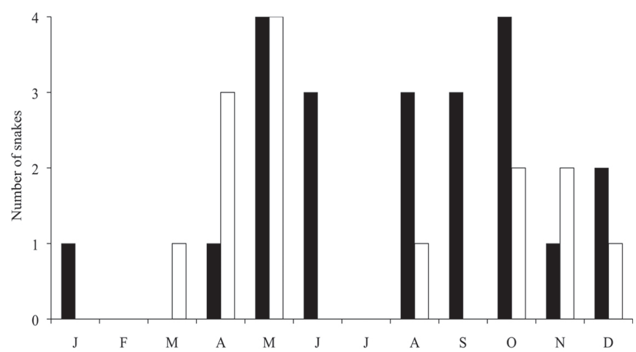

FIGURE 3. Number of male (N = 22, black columns) and female snake roadkills (N = 14, white columns) from January to December 2002 at Núcleo Picinguaba, Parque Estadual da Serra do Mar, southeastern Brazil.

and May, when 15 snakes were found, with four juveniles in May (Fig. 2); and (2) between August and October, when 13 snakes were found, with a higher number of males (N = 10, Fig. 3).

DISCUSSION

In general, road mortality is concentrated on one or few species, usually habitat generalists, locally abundant, highly mobile, and/or attracted by the resources or favorable environmental characteristics of roads (Forman *et al.,* 2003). Although more than half of the species registered for the region are subject to vehicular mortality, this was more frequent in four species. These species are active foragers, all show plasticity in the use of microhabitats and, more importantly, they are highly mobile. Thus, the main determinant factor of road mortality risk at our study area seems to be snake mobility.

The semi-arboreal *Philodryas olfersii* and species of *Chironius* (mainly *C. bicarinatus* and *C. exoletus*) are slender, agile species which move quickly in forests or open areas (Dixon *et al.,* 1993; Marques and Sazima, 2004; Hartmann and Marques, 2005; Hartmann *et al.,* 2009). *Oxyrhopus clathratus* is a terrestrial species (Marques and Sazima, 2004), which may explore altered areas and has high capacity for moving among areas (Hartmann *et al.,* 2009). For species with high plasticity in microhabitat use and more mobile, the BR-101 road was not a significant barrier for displacement. However, for species which are exclusively arboreal or fossorial, the road may represent an actual barrier, preventing movements between forests located in each side of the road. Irrespective of the preferential habitat use, roads may interfere in the patterns of snake mobility (Row *et al.,* 2007), no matter if it leads to death or if it limits the living area.

The two ambush and nocturnal foragers (*Bothropoides jararaca* and *Bothrops jararacussu,* Sazima, 1992; Marques and Sazima, 2004), although dominant in the assemblage (Hartmann *et al.,* 2009), were rarely found dead on the roads. Lower mobility and activity mainly at night, when the traffic volume is smaller, can lead to lower exposition to vehicular mortality (Bonnet *et al.,* 1999). On the other hand, sampling in the afternoon can result in lower detection of nocturnal species. Scavengers may have more time to remove snakes dead during the night, whereas diurnal snakes remain less time dead on the road.

Coelho *et al.* (2008), working in another area at the Atlantic Forest, found the primarily nocturnal viper *Rhinocerophis alternatus* as the most frequent species dead on road. However, the road sampled by these authors presents heavy nighttime traffic, what may explain the high number of roadkills of a primarily nocturnal species. As in other studies in Brazil (see Coelho *et al.,* 2008, Prada, 2004; Kunz e Ghizoni-Jr., 2009; Turci and Bernarde, 2009), we found mainly larger or middle-sized snakes dead on road. This seems to be a common result in studies that use vehicular surveys as the main method (Enge and Wood, 2002; Coleman *et al.,* 2008; Taylor and Goldingay, 2004), indicating that vehicular surveys may provide biased results towards large snakes.

Snake road mortality may be correlated with traffic volume (Bernardino and Dalrymple, 1992) if the greatest snake activity occurs in periods of high vehicle traffic. The sampled road in this study had a relatively low traffic volume (< 1000 vehicles/day), characterized mainly by the traffic of local people from small communities around the Park. The traffic volume in the study area is relatively homogenous during the year, although it increases in summer, or on holiday eves (information obtained in the Federal Highway Police station near the park). Although this variation occurs, we failed to find higher numbers of snake roadkills in the periods of higher vehicle traffic.

As ectotherms, snakes are strongly influenced by environmental conditions (Lillywhite, 1987; Zug *et al.,* 2001). Mainly during colder temperatures, snakes can reduce their activity (Gibbons and Semlitsch, 1987), with lower exposition to road mortality. However, temperatures low enough to limit snake activity do not occur in our study area (Hartmann *et al.,* 2009). On the other hand, there may be times when some species are more active (*i.e.,* move more), what would result in an increase in the rate of road mortality (Jochimsen, 2005). For instance, snakes may be more susceptible to road mortality during post-natal dispersal, migration, and mate search (Marques *et al.,* 2000; Jochimsen, 2005; Shepard *et al.,* 2008). Thus, sex and age classes may differ in their succeptibility to road mortality at some periods of the year (Case, 1978; Brown *et al.,* 1986; Gibbs, 1998; Semlitsch, 2000; Carr and Fahrig, 2001; Andrews and Gibbons, 2005; Steen and Smith, 2006). This seems to be the case for the two periods of the year when we found higher numbers of roadkills. The high number of roadkills in May could reflect juvenile recruitment, mainly of more active and mobile species (*Chironius bicarinatus* and *C. laevicollis*). On the other hand, the high number of roadkills in October may be due to mate searching by males, especially in *Chironius exoletus.* In situations of extremely high road mortality, a population could decline as a result of biased removal of adult males (Jochimsen, 2005). However, given the low rate of roadkills observed during this study, this seems not to be the case of the snake populations which inhabit our study area.

An increase of the tourism, which seems to be occurring in the region, may lead to an increased traffic volume. As a consequence, the rate of snake mortality in the region may increase in the future, since the number of roadkills may be related to traffic volume (Rosen and Lowe, 1994; Drews, 1995). Our mortality estimate (8.6 snakes/km/yr) is smaller than those found in other studies: 12.8 snakes/km/yr in Florida (Enge and Wood, 2002), 22.5 snakes/km/yr in Arizona (Rosen and Lowe, 1994) and 48.6 snakes/km/yr in Poland (Borczik, 2004), but higher to that found by Jochimsen (2005) in Idaho (2.8 snakes/km/yr). However, these numbers could be underestimates because some snakes are presumably too small to be detected or are removed from the road by scavengers before detection (Rosen and Lowe, 1994).

Even low road mortality rates can reduce snake populations, because local populations may have already been depressed from decades of cumulative roadkills (Enge and Wood, 2002; Clevenger *et al.,* 2003). Snake mortality in roads, associated with fragmentation effects, can result in population declines, inbreeding, and local extinctions (Forman *et al.* 2003; Row *et al.,* 2007). However, the relative low rate of snake mortality we found at Núcleo Picinguaba (8.6 snakes/km/yr), associated with the small length of the highway inside the park and the relatively low traffic volume, indicate that the actual negative effect of the BR-101 highway on local snake populations is negligible for the most common and abundant species. However, given that the Serra do Mar State Park is a type II park in the IUCN Protected Area Management Categories (Dudley, 2008), and thus was "set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area", measures which result in decrease of snake (and other animals) mortality (e. g., wildlife passages) should be implemented by the park managers.

Resumo

Rodovias que cruzam áreas naturais podem acarretar diversos efeitos negativos sobre a fauna local. O mais óbvio destes efeitos é a morte por atropelamento. Para serpentes, o risco de atropelamentos parece ser maior nas espécies que apresentam hábitos generalistas, localmente abundantes ou altamente móveis. Altas taxas de atropelamentos podem ocorrer quando os animais cruzam a rodovia durante movimentos para forrageamento, acasalamento, reprodução ou migração. Neste estudo descrevemos a mortalidade de serpentes por atropelamentos na rodovia BR-101, na altura do Núcleo Picinguaba do Parque Estadual da Serra do Mar, uma área protegida localizada no litoral norte do estado de São Paulo. Para tal foram amostrados os 16 km da rodovia que cortam o Núcleo, de outubro de 2001 a dezembro de 2002, totalizando 5173 km. Neste período foram encontradas 60 serpentes atropeladas, pertencendo a 15 espécies e representando 58% da riqueza de serpentes registrada para região. Os atropelamentos parecem coincidir com o estágio de vida e com as atividades sazonais de cada sexo. O maior número de filhotes em maio pode ser reflexo do recrutamento, principalmente para as

espécies mais ativas e que apresentam grande mobilidade. O aumento de atropelamentos em outubro pode ser consequência da procura de fêmeas pelos machos durante a época de acasalamento. Embora a densidade populacional das espécies de serpentes atropeladas na área seja pouco conhecida, a taxa de atropelamentos relativamente baixa encontrada, associada com o pequeno comprimento da rodovia dentro dos limites do Núcleo Picinguaba, indicam que os efeitos negativos atuais da BR-101 sobre as populações locais de serpentes são pouco relevantes para as espécies mais comuns e abundantes. Entretanto, como o Parque Estadual da Serra do Mar é uma Unidade de Conservação de Proteção Integral, medidas que resultem em um decréscimo na mortalidade de serpentes (e. g., passagens de fauna), devem ser implementadas pelos gestores do parque.

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