UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

INSTITUTO DE BIOCIÊNCIAS

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

Dissertação de Mestrado

Fauna atropelada:

estimativas de mortalidade e identificação de zonas de agregação

Fernanda Zimmermann Teixeira

Porto Alegre, janeiro de 2011

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Dissertação apresentada ao Programa de Pós-Graduação em Ecologia, do Instituto de Biociências da Universidade Federal do Rio Grande do Sul, como parte dos requisitos para obtenção do título de Mestre em Ecologia.

Orientador: Prof. Dr. Andreas Kindel

Comissão Examinadora

Prof. Dr. Alex Bager
Prof. Dr. Demétrio Luis Guadagnin
Prof. Dr. Leandro da Silva Duarte

Porto Alegre, janeiro de 2011

Agradecimentos

Agradeço, primeiramente, ao Programa de Pós-Graduação em Ecologia e ao Instituto de Biociências pela formação e suporte financeiro e logístico durante as saídas de campo e a CAPES pela bolsa concedida durante estes dois anos.

À Secretaria Estadual do Meio Ambiente, pela autorização para pesquisa dentro da APA Rota do Sol e pela acolhida na sede de São Francisco de Paula. Ao Rodrigo Cambará Printes, pelo grande incentivo para o desenvolvimento do trabalho dentro da APA, pelo interesse em aplicar seus resultados e, principalmente, por ter resgatado uma página do meu caderno de campo que foi perdida no meio do acidente.

À empresa Biolaw Consultoria Ambiental Ltda, em especial ao Adriano de Souza Cunha, pela parceria que permitiu a realização das saídas de campo e o *upgrade* do Siriema.

Agradeço ao meu orientador, Prof. Andreas Kindel, pelos momentos de orientação e desorientação ao longo desse trabalho. Agradeço pela amizade, turbilhões de ideias, motivação quase sem fim e por responder os milhões de emails que eu envio!

Ao Igor Pfeifer Coelho, também conhecido por Dusma Gates, diretor da Siriema Corporation, por ter iniciado a pesquisa com rodovias por aqui e por ter se tornado um amigo. Muito obrigada pelas críticas e sugestões, muito ainda virá pela frente! Ao Artur Vicente Pfeifer Coelho, o 'Físico', pela programação do Siriema e parceria neste trabalho.

A equipe do Laboratório de Ecologia de Populações e Comunidades, pela companhia nas horas de trabalho, apoio, sugestões, piadas e risadas. Especialmente, à Prof. Sandra Hartz, ao Prof. Leandro Duarte, ao Jan Karel, ao André de Mendonça Lima, à Larissa Gonçalves, e aos três grandes colegas da turma de mestrado, Fernanda Thiesen Brum, Marcos Bergmann

Carlucci (Golden Boy) e Vinicius Bastazini (Batavinho), por terem se tornado grandes amigos nesses dois anos!

Agradeço pela ajuda na identificação das carcaças: André de Mendonça Lima, Caroline Zank, Cibele Indrusiak, Cristian Joenck, Jan Karel, Liliane Coelho, Luis Marin da Fonte, Márcio Borges Martins, Marta Fabian, Michele Abadie, Patrick Colombo, Simone Leonardi e Vinícius Bastazini. Agradeço à Isadora e ao Alan pelas tentativas de identificação de pelos de mamíferos.

Pela ajuda em campo: Vinícius, Liliane, Felipe, Diogo e em especial a Isadora, por ter topado essa empreitada comigo. Aos motoristas que nos acompanharam: Marcelo, Sandro e em especial ao Osvaldo, por ter passado por poucas e boas com a gente.

A minha família, por ser hiperbólica, mas tão cheia de carinhos. Ao meu irmão, por me questionar e me obrigar a ser forte nas minhas argumentações. A minha mãe, por ser tão mãe a ponto de me tirar do sério. Ao meu pai, por um dia ter me sugerido trabalhar com fauna atropelada e ter imprimido o primeiro artigo que li sobre o assunto. Ao Luis, por me fazer rir nas horas em que eu precisava e por acreditar em mim mais do que eu mesma. Obrigada por me aguentarem ligada em alta voltagem!

Concluo dedicando este trabalho ao meu avô Nilo Figueira Teixeira (*in memorian*), por ser a pessoa mais inteligente que eu já conheci. Agradeço a ele pelas tantas histórias contadas e por ter me ensinado a ser uma pessoa que “perde o amigo, mas não perde a piada”.

Resumo

O atropelamento de animais silvestres é considerado como o principal fator antrópico responsável diretamente pela mortalidade de vertebrados terrestres em escala global. Estimativas de mortalidade são fundamentais para avaliar o impacto de rodovias, mas para reduzir o seu viés a remoção de carcaças e a eficiência dos observadores devem ser consideradas. Medidas mitigadoras têm sido implementadas para reduzir a mortalidade da fauna e ampliar a conectividade da paisagem, mas um fator determinante para a sua efetividade é a sua correta localização. Com o objetivo de qualificar o planejamento de medidas mitigadoras, neste trabalho procuramos responder a quatro perguntas: 1) há diferença na remoção e detectabilidade de carcaças entre diferentes grupos taxonômicos? 2) qual a influência da remoção e detectabilidade de carcaças sobre as estimativas de magnitude de mortalidade? 3) a mortalidade se distribui de forma agregada ao longo da rodovia? e 4) a distribuição espacial de atropelamentos de diferentes grupos taxonômicos é similar? Nossos resultados apontam diferenças na taxa de remoção e na detectabilidade de carcaças entre os grupos, além de demonstrar que, ao desconsiderar esses fatores, a magnitude de atropelamentos é subestimada. Ademais, nossos resultados indicam que a distribuição espacial de atropelamentos de mamíferos pode ser utilizada como indicadora da ocorrência de atropelamentos de outros grupos taxonômicos apenas em escalas menos refinadas, exigindo o planejamento de medidas mitigadoras mais amplas. Os resultados aqui apresentados devem ser considerados no monitoramento de animais atropelados e no planejamento de medidas mitigadoras do impacto de rodovias.

Palavras-chave Rodovias, detectabilidade, remoção de carcaças, agregações, padrão espacial

Abstract

Vehicle-wildlife collisions are considered the main human factor responsible directly for vertebrate mortality worldwide. Roadkill estimates are elementary to evaluate road impacts, but carcass removal and searcher efficiency must be considered in order to diminish estimation bias. Mitigation measures have been implemented to reduce wildlife mortality and to increase connectivity, but their correct placement is an important factor defining the effectiveness of these measures. In order to qualify mitigation planning, in this study we aim to answer four main questions: 1) is there difference in carcass removal rates and detectability among different taxonomic groups? 2) do carcass removal and detectability influence mortality magnitude estimates? 3) are roadkills spatially aggregated? and 4) are roadkill spatial distribution of different taxonomic groups similar? Our results show differences in carcass removal and detectability among groups, and demonstrate that mortality magnitude is underestimated when these factors are not considered. Also, our results indicate that mammal roadkill aggregations may be used as a surrogate of roadkill aggregations of other taxonomic groups in larger scales. The results presented here must be considered in roadkill monitoring and in mitigation measures planning.

Key words Roads, detectability, carcass removal, aggregation, spatial pattern

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Introdução geral

As estradas são imprescindíveis no atual contexto socioeconômico em que se insere a grande maioria da população humana, oferecendo acesso a uma grande variedade de recursos (Perz et al. 2008). Entretanto, as rodovias são reconhecidas também como o principal fator direcionador de degradação das paisagens, fato plenamente documentado na recente onda de ocupação da Amazônia (Fearnside 1987, Laurance et al. 2002).

A implementação de rodovias é uma das formas mais disseminadas de modificação da paisagem. A construção de rodovias e o tráfego de veículos causam inúmeros impactos diretos e indiretos nas populações de animais silvestres do entorno, como a perda de hábitat, a morte por atropelamento e o efeito de barreira, este último causado por alterações na cobertura vegetal, ruídos e iluminação. O atropelamento e o efeito de barreira são responsáveis pela fragmentação e isolamento das populações de animais silvestres que, juntamente com a perda de hábitat, geram uma redução do tamanho populacional e, consequentemente, aumentam os riscos de extinções locais de inúmeras espécies (Forman & Alexander, 1998; Trombulak & Frissell 2000, Fahrig & Rytwinski 2009, Jaeger et al. 2006) (figura 1).

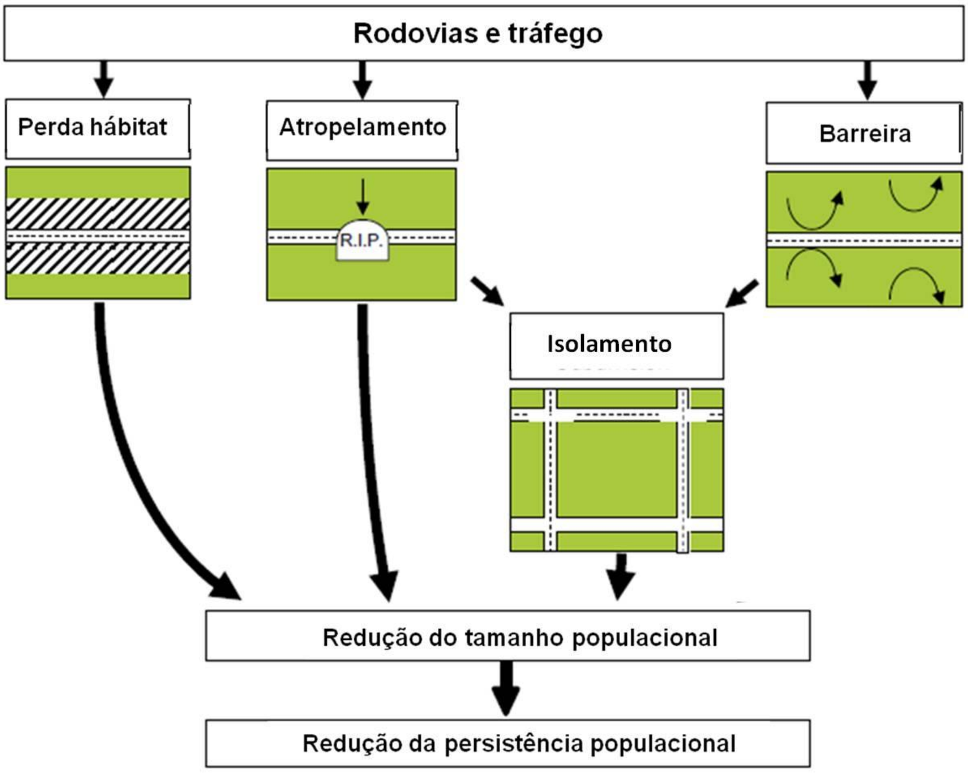

Figura 1. Impactos causados pela construção de rodovias e pelo tráfego de veículos nas populações de animais silvestres. Figura modificada de Jaeger et al. 2006.

Alguns autores sustentam que a colisão com veículos já deve ter ultrapassado a caça como o principal fator antrópico responsável diretamente pela mortalidade de vertebrados terrestres em escala global (Forman & Alexander 1998). As taxas de atropelamento, em alguns casos, podem ser muito elevadas em relação aos tamanhos populacionais, afetando a densidade das populações (Fahrig et al. 1995, Huijser & Bergers 2000). O impacto causado por rodovias atinge animais dos mais diversos grupos taxonômicos, como anfíbios (Glista et al. 2009, Hels & Buchwald 2001), répteis (Row et al. 2007), aves (Jacobson 2005), mamíferos (Huijser & Bergers 2000, Clevenger et al. 2003) e invertebrados (Koivula & Vermeulen 2005).

Os primeiros estudos sobre o impacto de rodovias sobre a fauna foram desenvolvidos na década de 1920 (e. g. Spiker 1927, Komarek & Wright 1929, Cottam 1931), com medidas sobre colisões entre veículos e a fauna, embora sem o rigor metodológico da pesquisa ecológica atual (Forman et al. 2003). A partir da década de 1980, os tópicos estudados em ecologia de rodovias foram ampliados e houve uma aceleração no esforço de pesquisa e na disseminação da informação (Forman et al. 2003). Estudos desenvolvidos recentemente têm abordado temas como: efeito de evitamento da rodovia pela fauna (Eigenbrod et al. 2009), fragmentação causada pelo sistema viário (Jaeger et al. 2007), poluição sonora e impacto do tráfego de veículos sobre a fauna (Parris & Scheinder 2008), efeitos demográficos e populacionais (Hels & Buchwald 2001), isolamento genético de populações (Clevenger & Samaya 2010), padrões espaciais e temporais de atropelamentos (Grilo et al. 2009), efetividade de medidas mitigadoras (Clevenger & Waltho 2000), entre outros.

Apesar da quantidade de estudos disponíveis, os resultados de muitas pesquisas têm sido apenas descritivos e baseados em estudos de caso, reportando monitoramentos ou contagens de animais atropelados por veículos, com padrões sazonais e características etárias e sexuais dos atropelados (Clevenger et al. 2003). Além disso, o monitoramento de animais atropelados normalmente prioriza a magnitude de mortalidade em detrimento do estudo de padrões espaciais e temporais. Mamíferos de maior porte geralmente são o grupo mais bem documentado, provavelmente devido ao seu tamanho corporal e interesse na sua demografia e conservação (Trombulak and Frissel 2000). No Brasil, os estudos de ecologia de rodovias iniciaram-se com o trabalho de Novelli et al. (1988), mas somente nos últimos anos o desenvolvimento de trabalhos sobre o tema tem se ampliado. Entretanto, apesar do aumento do número de publicações no Brasil, predominam trabalhos descritivos que apenas apresentam listas de espécies de atropelados e com pouca preocupação com os métodos empregados (Bager et al. 2007).

Em função da diversidade de impactos sobre a fauna silvestre, mostra-se necessário o planejamento e a implantação de medidas mitigadoras. Diversas ações têm sido implementadas nos últimos anos, como túneis e pontes para travessia de fauna, redutores de velocidade, placas informativas, entre outras (Glista et al. 2009). Entretanto, embora inúmeros estudos tenham registrado a funcionalidade de algumas dessas medidas (e.g. Clevenger & Whalto 2000, Goosem et al. 2005), sua efetividade depende da definição adequada do local de sua implantação. Como uma maneira de aumentar o sucesso dessas medidas, o monitoramento de fauna atropelada pode desempenhar um importante papel antes da adoção de recomendações gerais para a mitigação, como a instalação de passagens de fauna (Coelho et al. 2008).

Embora a contagem dos animais atropelados possa ser útil para avaliar a magnitude desse impacto, a simples contagem é inadequada para entender as relações entre a rodovia e a fauna silvestre (Clevenger et al. 2003). Neste sentido, a identificação de trechos de maior mortalidade através da avaliação da distribuição espacial dos atropelamentos é um passo importante para qualificar o planejamento de medidas mitigadoras (Taylor & Goldingay 2010). Com a identificação dos pontos de agregação de atropelamentos, é possível avaliar variáveis que influenciam essas agregações e adequar o planejamento das ações de mitigação. Entretanto, o estudo de animais atropelados vem sendo realizado sem considerar alguns fatores importantes como a taxa de remoção de carcaças por carniceiros e a variação na detectabilidade das carcaças em função do seu tamanho e grupo taxonômico. Esses fatores podem influenciar diretamente os resultados encontrados e esse viés influenciará o planejamento e a efetividade de medidas mitigadoras.

Com o objetivo de qualificar os estudos na área de ecologia de rodovias e contribuir para o planejamento adequado de medidas mitigadoras, neste trabalho respondemos a quatro perguntas: 1) há diferença na remoção e detectabilidade de carcaças entre diferentes grupos taxonômicos? 2) qual a influência da remoção e detectabilidade de carcaças sobre as estimativas de magnitude de mortalidade? 3) a mortalidade por colisões com veículos distribui-se de forma agregada ao longo da rodovia? e 4) a distribuição espacial de atropelamentos de diferentes grupos taxonômicos é similar?

Ao não responder estas questões pode-se implantar instrumentos de redução de impactos inadequados, tendo como consequência o desperdício de importantes recursos financeiros e o descrédito da estratégia perante empreendedores, gestores e população em geral. Entretanto, estas questões raramente são abordadas de maneira apropriada no licenciamento de rodovias ou na redução do passivo ambiental de rodovias já implantadas.

Capítulo 1: Road mortality estimates: effects of sampling methods and carcass removal

Road mortality estimates: effects of sampling methods and carcass removal[1]

Teixeira, Fernanda Zimmermann[2] · Coelho, Artur Vicente Pfeifer[3] · Esperandio, Isadora Beraldi[4] · Kindel, Andreas[2]

Abstract

Road mortality rates are important to identify species in need of detailed population studies, to determine the effectiveness of mitigation measures or to identify road network sections or road stretches where to concentrate mitigation actions. Therefore, a good estimate of road mortality magnitude must necessarily encompass carcass removal and searchers' efficiency, in order to reduce calculation bias. In this paper, we test if there are differences in carcass detectability and removal rates among different taxonomic and size groups, and we adapt a model to estimate the mortality magnitude to the context of roadkills, which incorporates both components of detectability variation (carcass removal and searcher detectability). To present this mathematical model and discuss its outcomes and implications we use a roadkill data set from a survey carried out in southern Brazil. Our results show differences in removal rates and detectability among body size and taxonomic groups of vertebrates and demonstrate the degree of underestimation of mortality that result from those error factors. Since there are differences within and among taxonomic groups due to size effects, separate estimates have to be obtained for each taxonomic group to reveal total mortality.

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[1] Artigo a ser submetido para o periódico European Journal of Wildlife Research.

[2] Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio Grande do Sul.
[3] Instituto de Física, Universidade Federal do Rio Grande do Sul.
[4] Instituto de Biociências, Universidade Federal do Rio Grande do Sul.

Key words Roadkill, detectability, scavenger, searcher efficiency

Introduction

Vehicle-animal collisions are considered by some authors the major direct human cause of vertebrate mortality worldwide (Forman and Alexander 1998). Since road mortality may have substantial effects on a population’s density (Fahrig and Rytwinski 2009), it is crucial to estimate mortality rates for monitoring and mitigating this impact.

Road mortality rates can be used to identify species in need of detailed population studies, to determine the effectiveness of mitigation measures (Taylor and Goldingay 2010) or to identify road network sections or road stretches where to concentrate mitigation actions. However, carcass detectability is often ignored in roadkill surveys (Slater 2002, Langen et al. 2007). As pointed out by Prosser et al. (2008) detection is affected by two main factors: the carcass removal between death time and survey time, and searchers’ efficiency since it is unlikely that all carcasses present at a site will be found by observers. Carcass persistence on road can be influenced by climate, scavengers activity (Slater 2002), and traffic flow, whereas searchers’ efficiency can be biased by carcass size (Morrison 2002), amount of roadside vegetation, survey method and researchers’ abilities (Hobday and Minstrell 2004).

Roadkill magnitude is critical for evaluating the effectiveness of wildlife passages comparing mortality on roads with and without passages, and before and after their construction. Additionally, not accounting for detectability limitations may significantly underestimate roadkill impact on wildlife populations, affecting temporal and spatial pattern recognition and ultimately represents waste of lives and economic resources due to ineffective mitigation.

Therefore, a good estimate of road mortality magnitude must necessarily encompass carcass removal and searchers' efficiency, in order to reduce calculation bias (Prosser et al. 2008). By ignoring these influences, one may be assuming perceived differences among roads or road stretches to be real, while they might in fact be a result of detectability variations among them.

Although evaluation of carcass removal rates and researchers detection probabilities are part of protocols adopted to survey the impact of wind power plants on birds (at least since Ericksson et al. 2000), this approach is still predominantly ignored in roadkill surveys (but see Gerow et al. 2010 for a recent proposal). By not accounting for detectability, surveys consider that carcass persistence and detectability are homogeneous among different vertebrate taxonomic classes and among different size groups. Here, we aim to test if these assumptions hold. Our hypothesis is that taxonomic groups like amphibians and birds are more heavily underestimated due to their small size and low carcass persistence and detectability.

Finally, we modified a mathematical model to estimate roadkill magnitude, which incorporates both components of detectability variation (carcass removal and searcher detectability). This model was initially proposed by Ericksson et al. (2000) and Shoenfeld (2004) for avian fatalities in wind power plants, and may be very useful for roadkill estimates. To present this mathematical model and discuss its outcomes and implications we use a roadkill data set from a survey carried out in southern Brazil.

Methods

Study area

This study was developed in a 66 kilometres section of RS-486/RST-453 in Rio Grande do Sul State, southern Brazil, a two-laned road also called Rota do Sol (50W 19' 12", 29S 15' 58"/ 49W 57' 29", 29S 36' 59"), with a mean daily traffic of 3,108 vehicles (DAER-RS, 2009). This road section crosses three protected areas: Rota do Sol Environmental Protected Area (54,670.5 hectares), Aratinga Ecological Station (5,882 ha), and Mata Paludosa Biological Reserve (113 ha), all of which recognized as core areas of Atlantic Forest Biosphere Reserve in southern Brazil (MMA, 2000). Three geomorphological regions (lowland, hillside and highland) were observed, differing in human impact on vegetation cover and landscape structure, as well as in biotic and abiotic attributes, such as vegetation cover, rainfall levels and temperature. Highland is covered with Araucaria Forest in a mosaic with grasslands, while hillside and lowland are covered with Atlantic Forest *strictu sensu* (Oliveira-Filho and Fontes 2000). Also, lowlands are much more fragmented than hillside and highlands (Ribeiro et al. 2009), with a higher density of rural settlements and small villages and the predominance of agriculture.

Mortality Rate Estimation Model

To estimate the magnitude of road mortality, we employed a mathematical model based on previous works from Ericksson et al. (2000) and Shoenfeld (2004) for avian fatalities in wind energy plants. Considering a constant roadkill or mortality rate (number of roadkills per unit time), λ, and describing carcass removal from the road by a characteristic time, T_R, one can write:

$$\frac{dG(t)}{dt} = \lambda - \frac{G(t)}{T_R} , \qquad (1)$$

where G(t) is the number of carcasses on the road at time t, and $G(t)/T_R$ is the number of carcasses removed per time unit at t. This differential equation leads to a solution for G(t) in the form:

$$G(t) = \left(G(0) - \lambda T_R\right) e^{-t/T_R} + \lambda T_R \qquad (2)$$

After a time t sufficiently larger than T_R, G(t) will tend exponentially to the steady state solution

$$G(t \to \infty) = \lambda T_R \qquad (3)$$

The number of roadkills obtained from a single measurement (N) can, then, be described as:

$$N = p \cdot G(t \to \infty) = p\lambda T_R , \qquad (4)$$

where p is the searcher efficiency, describing the fraction of carcasses on the road that are actually counted. Using appropriate values for p and T_R, one can, then, obtain the roadkill rate λ.

However, a single measurement usually does not produce a statistically significant number of roadkills, and the sum of roadkills obtained during sequential measurements is often considered. Care must be taken while using the simple approach described by equation (4) to obtain λ in this case. Equation (4) considers a single measurement only. In the simplest case, we will have, for n subsequent measurements:

$$N = \sum_{i=0}^{n-1} N_i = np\lambda T_R \ . \qquad (5)$$

But equation (5) is not always correct. It considers only the stead state solution of (2): the system must not be recovering from a perturbation during any measurement. But measurements themselves do usually take the system out of the steady state (carcass are often removed for further analysis during measurements). Interference between subsequent measurements will be avoided if their time separation, T_s, is sufficiently larger than T_R (at least a few times T_R). But one can also use correction factors in order to compensate for this kind of interference: Shoenfeld (2004) considered the effect of a series of periodic measurements at times 0, T_s, $2T_s$, etc… Approximating that every measured carcass is removed and that the number of carcasses on the road right before each measurement is always the same ($\lim_{t\to 0^-} G(t) = \lim_{t\to T_s^-} G(t) = \lim_{t\to 2T_s^-} G(t) = \ldots$), he showed that:

$$N_i = p\lambda T_R \left(\frac{e^{\frac{T_S}{T_R}} - 1}{e^{\frac{T_S}{T_R}} - 1 + p} \right) \qquad (6)$$

Although equation (6) is more accurate than (5) for the case of low ratio T_s/T_R, care must be taken while using it, especially if the number of measurement steps is not very large. The approximation made is usually not valid for the initial measurements which can lead to overestimated roadkill taxes. A more correct procedure should be to consider the system initially in the steady state. The first measurement, taken at time 0, will then give $N_0 = p \cdot G(0) = p\lambda T_R$ (equation 4). Since measured carcasses are removed, right after the first measurement ($t = 0^+$), we will have $G(0^+) = (1-p)\lambda T_R$. Using this value as G(0) in equation (2), one can calculate the number of carcasses on the road right before the second measurement at T_S: $G(T_S^-) = \lambda T_R (1 - pe^{-T_S/T_R})$. The second measurement expected value will then be $N_1 = pG(T_S^-) = p\lambda T_R \left(1 - pe^{-T_S/T_R}\right)$. This procedure can be repeated in order to calculate the expected number of carcasses found at all subsequent measurements:

$$N_i = \lambda T_R p \left(1 - \sum_{j=1}^{i} e^{-\frac{jT_s}{T_R}} p(1-p)^{j-1}\right). \quad (7)$$

If "k" measurements are taken, the expected total number of carcasses will be:

$$N = \sum_{i=0}^{k-1} N_i = \lambda T_R p \sum_{i=0}^{k-1} \left(1 - \sum_{j=1}^{i} e^{-\frac{jT_S}{T_R}} p(1-p)^{j-1}\right) \quad (8)$$

Usually, T_R is in the order of a day, and monthly or even weakly taken measurements can be individually well described by equation (4). Nonetheless, it is very important to determine the value of T_R to ensure that the simple steady state description can actually be applied on a set of measurements temporally separated by T_s. The magnitude of T_R is also important if one is considering a time varying roadkill rate $\lambda(t)$. If λ changes in a time scale sufficiently greater than T_R, equation (4) can still be used to determine $\bar{\lambda}$ at t. Table 1 synthesises when each equation must be used for estimating roadkill mortality.

Data collection and analysis

To evaluate carcass persistence, we surveyed the road for four consecutive days per month in 10 field trips between July 2009 and June 2010. The surveys were conducted with a vehicle at about 40 to 50 km/h, with two observers (besides the driver). We considered only carcasses killed in the last 24 hours, thus ignoring carcasses observed in the first day, which could have been killed more than 24 hours earlier. In the following days, we recorded the persistence of the carcasses found on the second day until the fourth day (0-2 days of persistence). All animals were classified by body size (small ≤ 500g; large > 500g) and taxonomic group (amphibian, reptile, bird, and mammal).

To test for differences in carcass persistence among groups delimited by body size or taxonomic classes, we performed univariate analysis of variance (ANOVA) with randomization test (Manly 1997), being the persistence time (0-2 days) the response variable, the body size or taxonomic class the factor, and the carcasses the sample units. When the results indicated a significant difference on carcass persistence between groups defined by taxonomic classes, we performed contrast analyses through randomization to verify which taxonomic groups differed from others (Pillar and Orlóci 1996).

To evaluate the detection probability due to sampling method (searcher efficiency), we compared the number of carcasses (response variable) found in 45 sections of 500 m (reaching 22.5 km monitored with two observers) using two survey methods: by vehicle (at speed of 40 to 50 km/h) and by foot. We sampled six or seven sections per day during seven days (in February, May and June 2010). In each day of our sampling session, we monitored a 500 m section every 10 km of the road, and the initial position was chosen randomly within the first 10 km of the road. Since Slater (2002) observed maximum removal rate at dawn and just after dusk, the same selected sections were monitored by car in the morning and again by foot in the afternoon to minimize confounding effect of carcass removal. All roadkills detected by any survey methods were classified into the same categories adopted before.

In order to estimate searcher efficiency, we considered that survey by foot detected 100% of carcasses on the road and then we calculated the proportion of detectable carcasses (p) found by searchers in a moving vehicle. This proportion was calculated as an average by road section for each survey method. For estimating carcass removal time (T_R), we first determined roadkills that occurred in a time interval of 24 hours by performing two measurements spaced by this time interval and considering only carcasses found in the second measurement but not in the first. The presence of these carcasses on the road during the subsequent days was, then, monitored and the percentage of the initial carcasses that remained on the road was determined for each of these days. Since we did not consider new carcasses, we can use equation (2) with $\lambda = 0$:

$$G(t) = G(0)e^{-t/T_R}. \qquad (9)$$

Considering G(0) = 100% and performing a simple exponential fitting to the obtained data, we estimated T_R values. T_R represents carcass removal characteristic time, that is, the time needed for 1/*e* (approximately 63%) of carcasses to be removed. For both searcher efficiency and carcass removal we considered the carcasses that were roadkilled and found on the road, instead of experimentally placing carcasses along the road. We made this choice in order to consider the natural variation in size and other differences among carcasses, what would not be possible by experimentally placing carcasses along the road.

To test for differences in searcher efficiency between the two methods, we performed univariate ANOVA with randomization test (Manly 1997) for each one of the two body sizes and the four taxonomic groups considering the carcass number in each road section (response variable). Road sections were defined as blocks, restricting permutation within each block

(Pillar 2006). To reduce the probability of type I error due to the number of tests performed, we adopted Bonferroni corrections (Legendre e Legendre 1998; $\alpha' = \alpha/k$, were k corresponds to the number of independent tests and α to the initial significance criterion, which in our case equals 0.05). Thus, we adopted $\alpha'=0.025$ and $\alpha'=0.012$ for the two body size and four taxonomic class ANOVA, respectively. For each ANOVA test, we used Euclidean distance as the dissimilarity measure and the sum of squares between groups of sampling units as the test criterion (Q_b statistic, Pillar e Orlóci 1996). We performed all analyses with 1000 randomizations in MULTIV 2.4 (Pillar 2006).

Finally, to obtain roadkill rates (λ) for reptiles, birds and mammals, we used equation (8) and the total number of measured carcasses ($N = N_0 + N_1 + N_2 + N_3$) in each month. We calculated values of λ for each month and then obtained mean roadkill rate ($\bar{\lambda}$) per day.

Results

Carcass removal

To evaluate carcass persistence on the road we used 242 roadkills, of which 113 were amphibians, 24 reptiles, 62 birds, and 43 mammals. Of these, 195 were classified as small-sized and 47 as large-sized. Small carcasses remained significantly less time than large carcasses on the road (P=0.001; Fig. 1a). When carcass persistence is evaluated with regard to taxonomic group, amphibians and birds persisted significantly less time than reptiles and mammals, whereas there were no differences within each of these two pairs of taxonomic categories (table 2; Fig. 1b). Removal rates within 24 hours are, in general, very high, with more than 80% of small body-sized animals and between 47.26 to 85.56% of animals from different taxonomic groups disappearing within this time period.

Searchers' efficiency

When monitoring by foot we found 207 roadkills, of which 152 were amphibians, 15 reptiles, 21 birds, and 17 mammals. They were classified as small-sized (190 individuals) and large-sized animals (17 individuals). Of all animals recorded, only 12 were recorded by car, of which three were reptiles, a bird, and eight mammals, classified as small (one) and large-sized (11 individuals). Differences in detectability between those methods were significant for all groups tested except large body size (Fig. 2a-f).

Estimation of mortality rate

Since we identified differences in carcass removal and searchers' efficiency due to survey method among taxonomic and size groups, we made separated estimations of mortality rates for reptiles, birds and mammals (table 3). We did not estimate roadkill rates for amphibians because we did not recorded any amphibian carcass by car when estimating searcher efficiency. Equation (8) allows considering subsequent measurements with searcher's influence (like carcass removal for further analysis). So, for each group, we used four subsequent measurements ($N = N_0 + N_1 + N_2 + N_3$) in each month, with a time interval $T_S = 1$ day. Mean roadkill rates obtained using equation (8) with $k = 4$, $T_S = 1$ day and the values of p and T_R are presented in table 3.

Discussion

Most authors that estimate roadkill magnitude considered only carcasses counted during surveys and extrapolated the numbers counted to a period of time (like a year), without including corrections for detectability and carcass removal. In another way, some authors estimate roadkill mortality considering a time of carcass persistence a priori, like Vieira (1996), who assumed that carcasses remained for a week on the road, and Pinowski (2005), who considered two days of persistence for estimating caiman roadkill magnitude. Nevertheless, Hels and Buchwald (2001) estimated amphibian roadkill mortality including corrections for animals not observed, calculating the efficiency of the monitoring by mark-recapture theory. They estimated searcher efficiency by marking carcasses on control surveys and then calculating how many carcasses were "recaptured".

As an alternative to correct this estimation bias, we modified a mathematical function from Shoenfeld (2004) to estimate total roadkill mortality considering the observer detectability and carcass removal. All taxonomic groups were underestimated, but this bias was stronger for birds, which have very low detection and high removal rates. Using this function we can extrapolate roadkill data and determine the expected number of animals actually killed from that found by the searchers.

Gerow et al. (2010) estimated total roadkill magnitude by modifying the equation proposed by Shoenfeld (2004), multiplying it by an extra factor, which considers the number of days, the number of measures and mean time between surveys. However, this extra factor does not fit in Shoenfeld (2004) model. The formula used by Gerow et al. (2010) assumes that time between surveys follows a Poisson distribution, but surveys are usually planned to take place in systematic intervals. In these sense, we should use a model that considers that surveys are conducted periodically, like equation (8).

Our results clearly show how strong can be the underestimation of roadkill rate if one disregards the effects of searcher efficiency and carcass removal characteristic time. It is also interesting to compare these relations with the ones obtained via equation (5), considering always a steady state situation, and with equation (6), considering Shoenfeld`s approximation. For the case of reptiles, for example (similar conclusions can be obtained for the other groups), one would obtain $\lambda$=9.69 using equation (5), which would also lead to an underestimation of the roadkill rate. On the other hand, using Shoenfeld`s approximation one would get λ=12.75, which leads to a larger roadkill rate compared to the result from equation (8).

Besides the underestimation on roadkill estimates due to carcasses that are not detected or that are removed, some animals hit by a car die away from the road, never being detected by searchers. Baker et al. (2004) estimated, during seven years of monitoring, that 31.48% of roadkill carcasses were found away from a road. This factor of bias is still not included and remains a challenge for accurate mortality estimates.

Carcass removal rates were very high in the first 24 hours. Similar results were found by Antworth et al. (2005), with 60-97% of carcasses disappearing in 36 hours. Carcass removal, however, is not homogeneous among taxonomic and size groups. Amphibians and birds, predominantly small body-sized animals, were removed faster than reptiles and mammals, which usually are of larger size. The same pattern was found by other authors on road surveys (e.g. Slater 2002, Langen et al. 2007, Hels and Buchwald 2001), and cited by Morrison (2002) for wind power plants.

Detectability also differed among taxonomic and size groups and was much lower for amphibians and birds than for reptiles and mammals. Langen et al. (2007) also found a bias on amphibian monitoring by car when they compared it with the results obtained by foot. Also, it must be considered that taxonomic and size groups are associated factors, since amphibians and birds often have small body sizes and mammals are usually of larger size. Thus, some authors have suggested that amphibian roadkills should be monitored by foot in order to diminish the bias and favour the detectability of small and thin-skinned amphibians (e.g. Hels and Buchwald 2001, Orłowski et al. 2008).

The most direct effect of roadkill removal and detectability biases is the underestimation of mortality magnitude within each taxonomic group and among them due to body size. This was pointed out previously by Slater (2002), who estimated that mortality rates can be 12 to 16 times that recorded by a moving vehicle when not considering removal rates and detectability. The evaluation of roadkill magnitude without the incorporation of these factors, considering only the mean number of roadkills detected per survey, results in similar mortality rates among groups, what do not correspond to reality. Incorporating these sources of mortality estimating error is elementary for the evaluation of roadkill impacts on each taxonomic group. Indeed, birds are the group with the highest mortality underestimation by car surveys and the most impacted group from vehicle-wildlife collisions, since they have lower detectability and higher removal rates.

Our results show differences in removal rates and detectability among size and taxonomic groups of vertebrates and we demonstrate the degree of mortality underestimation that result from those error factors. Since there are differences within and among taxonomic groups due to size effects, separate estimates have to be obtained for each taxonomic group to reveal total mortality.

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Table 1 Equations modified from Ericksson et al. (2000) and Shoenfeld (2004) to estimate roadkill mortality using carcass removal time and searcher's detectability.

Equation	Nº	When it must be used
$N = p \cdot G(t \to \infty) = p\lambda T_R$	4	Roadkill estimation obtained from a single measurement.
$N = \sum_{i=0}^{n-1} N_i = np\lambda T_R$	5	Roadkill estimation obtained from n subsequent measurements. It only must be used if time between measurements is larger than carcass removal time, due to searchers influence when removing carcasses.
$N_i = p\lambda T_R \left(\frac{e^{\frac{T_S}{T_R}} - 1}{e^{\frac{T_S}{T_R}} - 1 + p} \right)$	6	Roadkill estimation obtained from cases with low ratio T_S/T_R. However, it must be avoided when there are only a few measurements.
$N = \sum_{i=0}^{k-1} N_i = \lambda T_R p \sum_{i=0}^{k-1} \left(1 - \sum_{j=1}^{i} e^{-\frac{jT_S}{T_R}} p(1-p)^{j-1} \right)$	8	Roadkill estimation obtained from K measurements. It must be used when carcasses are removed by searchers while monitoring.

Table 2 Differences in carcass persistence between taxonomic classes (results from univariate ANOVA, Qb=22.612, P=0.001). In bold, significant contrast P values.

Contrasts	P(Qbº≥Qb)
Amphibian x Reptiles	**0.001**
Amphibian x Birds	0.673
Amphibian X Mammals	**0.001**
Reptiles x Birds	**0.002**

Contrasts	P(Qb°≥Qb)
Reptiles x Mammals	1
Birds x Mammals	**0.002**

Table 3 Estimates of total roadkills per day (λ) corrected for detectability biases introduced by carcass removal and survey method using equation (8). "T_R" is the estimated carcass removal characteristic time, "p" is the estimated searcher efficiency and $\bar{N}/4$ represents the mean number of carcasses observed in each measurement, without considering correction factors for removal rates and searcher efficiency. Since N represents number of carcasses measured in four consecutive days, it must be divided per four to obtain mean number measured per day.

	p	T_R (days)	$\bar{N}/4$	λ (day^{-1})
Reptiles	0.23	1.85	4.12	**11.22449**
Birds	0.06	0.7	4.25	**102.4096**
Mammals	0.47	1.75	3.85	**6.209677**

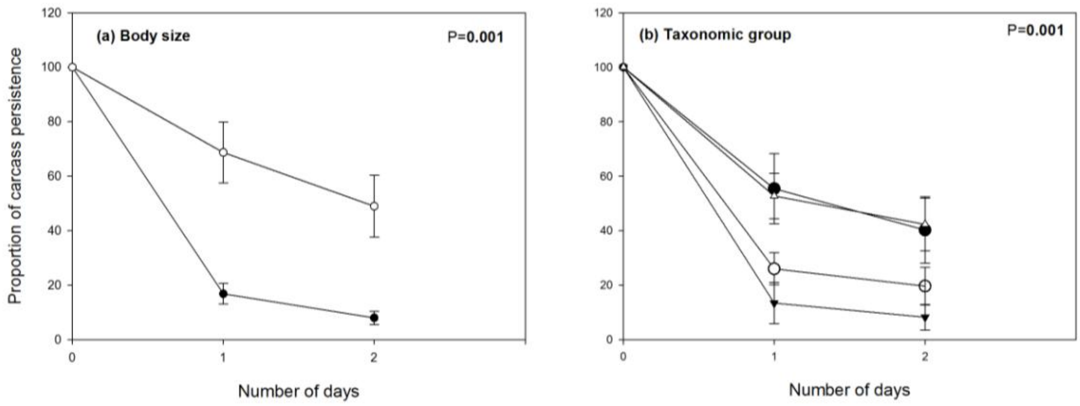

Fig. 1 Proportion of persisting carcasses after three consecutive survey days. a) Small animals (n=195; black circles) and large animals (n=47; open circles); b) amphibians (n=113; open circles), reptiles (n=24; black circles), birds (n=62; black triangles) and mammals (n= 43; open triangles). Probability values (p) obtained by ANOVA with randomization tests.

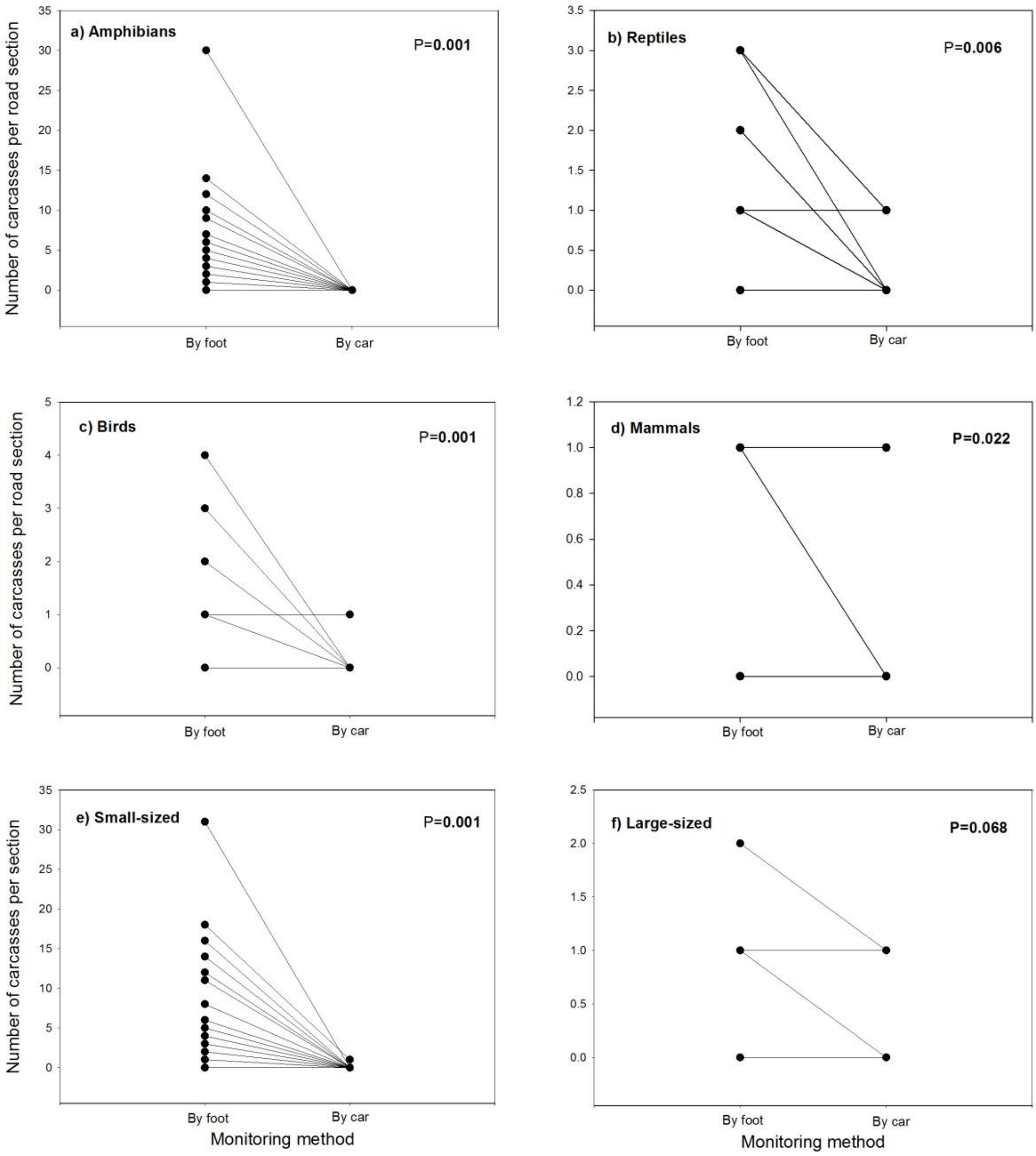

Fig. 2 Carcass number recorded in 45 road sections of 500 m using two survey methods; points connected by lines represent the same road section (block) monitored by both methods (vehicle and foot); number of road sections represented is lower than monitored due to superimposed results.

Capítulo 2: Are mammal roadkill hotspots coincident with those detected for other vertebrate groups?

Are mammal roadkill hotspots coincident with those detected for other vertebrate groups?

Fernanda Z. Teixeira, Isadora B. Esperandio, Andreas Kindel

Abstract

Many mitigation measures have been implemented to reduce wildlife mortality on roads and increase connectivity, like under and overpasses, reduced speed limits, lights and warning signs. An important factor defining the effectiveness of these measures is their correct placement. In order to plan mitigation measures, it is important to identify roadkill aggregation peaks and the scales in which more intense hotspots are formed. In this paper, we used a data set from a roadkill survey in southern Brazil to test the presence of roadkill aggregations in different scales and evaluate if mammal roadkill hotspots can be a surrogate of roadkill aggregations of other taxonomic groups. Our hypothesis is that spatial patterns of mammal roadkills do not overlap with hotspots of other taxonomic groups. The Ripley's K test indicated roadkill aggregations in all scales evaluated with similar radius amplitude for all groups evaluated. The largest number of hotspots was concentrated in lowland road stretch, with lower roadkill intensity in hillside and highlands. Sørensen resemblance measure indicated that, in small scales, mammal roadkill hotspots are not a surrogate for hotspots of other taxonomic classes, although in a larger scale similarity in hotspots location increased, indicating a scale-dependent pattern. In these sense, punctual mitigation measures, like wildlife passages, when implemented based on survey results of mammal roadkills, would not

be functional for other taxonomic groups. Nevertheless, more extensive mitigation measures could be implemented and reach a larger spectrum of species even if based solely on a mammal roadkill survey. Our results are relevant in the evaluation of impacts caused by roads already implemented, when planning of mitigation measures is needed after road construction.

Keywords Roads, vehicle-wildlife collision, aggregation, spatial pattern

Introduction

Wildlife populations can be isolated directly by roadkills and indirectly by barrier effects (Forman and Alexander 1998; Trombulak and Frissell 2000; Jaeger et al. 2006) and many mitigation measures have been implemented to reduce wildlife mortality and increase connectivity, like under and overpasses (Clevenger and Whalto 2000; Goosem et al. 2005), reduced speed limits, lights and warning signs (Glista et al. 2009). In the next decades, the implementation of such measures to enhance landscape connectivity will be challenging, especially in a scenario of climate change, where species may adapt their ranges and distributions by moving through landscape (Clevenger and Samaya 2010).

An important factor defining the effectiveness of these punctual measures is their correct placement (Glista et al. 2009). To optimize mitigation planning, it is necessary to evaluate roadkill spatial distribution and detect roadkill hotspots. Mortality patterns usually are not random, since animals commonly use the same crossing routes (Malo et al. 2004, Seiler 2005, Ramp et al. 2006). The survey of roadkills is a way to identify wildlife crossing routes and propose mitigation measures where wildlife populations will be more benefited

(Sillero 2008; Taylor and Goldingay 2010). In these sense, ecologists usually search for evidence of non-randomness to infer about underlying processes, like answers to environmental heterogeneity (Perry et al. 2002). Since the knowledge about spatial patterns has consequences on roadkill mitigation planning, we must answer two main questions: (1) are roadkills aggregated? and (2) where are roadkill hotspots located?

Roadkill surveys often address mortality magnitude and specific taxonomic groups. Large mammals are the best-documented roadkills, probably due to their size and to interest in their demography (Trombulak and Frissel 2000). Other taxonomic groups are often neglected in roadkill surveys, so it's elementary to know if roadkill spatial pattern of one taxonomic group can be a surrogate of the spatial patterns of others. In environmental assessment of road expansions or in monitoring of pre-existing roads, the results obtained when monitoring one taxonomic group are often used to plan mitigation measures that should reach all groups. By doing this, they assume that spatial patterns of mortality (e.g. roadkill hotspots) are similar for animals from different taxonomic classes. To our knowledge, the similarity in roadkill spatial patterns among animals from different taxonomic classes has not been tested until now.

In order to plan mitigation measures, it is important to identify aggregation peaks and the scales in which more intense hotspots are formed. According to a revision done by Taylor and Goldingay (2010), spatial explicit models to evaluate roadkills have been developed only recently (e. g. Jaeger et al. 2005; Litvaitis and Tash 2008). Roadkill spatial patterns may have different causes, like traffic flow and speed, road design, presence of landscape corridors, habitat availability, and others. These different factors may operate in different spatial scales. Most authors analyze roadkill hotspots by choosing arbitrary scales of analysis, not considering the effects of different scales. Nevertheless, many data sets present different spatial patterns when evaluated in different scales, which is known as scale effect (Perry et al. 2002).

In this paper, we used a data set from a roadkill survey in southern Brazil to test the presence of roadkill aggregations in different scales and evaluate if mammal roadkill hotspots can be a surrogate of roadkill aggregations of other taxonomic groups. Our hypothesis is that spatial patterns of mammal roadkills do not overlap with hotspots of other taxonomic groups. If we confirm this hypothesis, care must be taken when extrapolating the results from roadkill surveys.

Methods

Study area

This study was performed in a 66 km road section of Rota do Sol road (RS-486/RST-453), located in northeastern of Rio Grande do Sul state, Brazil (50W 19' 12'', 29S 15' 58''/ 49W 57' 29'', 29S 36' 59''). The selected road stretch crosses core zones of Atlantic Forest Biosphere Reserve and was chosen due to its landscape heterogeneity, encompassing three geomorphological regions (lowland, hillside and highland), ranging from 2 m to 925 m of altitude, with differences in antropic occupation, landscape structure and biotic and abiotic attributes and thus expected to have a great heterogeneity in roadkill distribution at a fine scale. Highland is covered with Araucaria Forest in a mosaic with grasslands, while hillside and lowland are covered with Atlantic Forest *strictu sensu* (Oliveira-Filho and Fontes 2000). Also, lowlands are much more fragmented than hillside and highlands (Ribeiro et al. 2009), with a higher density of rural settlements and small villages and the predominance of agriculture.

Data collection

Roadkill surveys were performed during four to five consecutive days per month, between July 2009 and July 2010. Two observers in a moving vehicle (40-50 km/h) recorded all vertebrate carcasses found, including amphibians, reptiles, birds and mammals.

Data analysis

In order to evaluate the randomness of roadkill spatial distribution, we performed an adapted bidimensional Ripley's K statistic for each taxonomic group (Coelho et al. 2008). Ripley's K is used to test for non-randomness of spatial distribution of any set of events across multiple scales (Ripley 1981; Cressie 1993; Levine 2000). For the interpretation of the test we used *L* function, which evaluates the aggregation intensity at different scales (Ripley 1981; Levine 2000).

In K test, a circle with a certain radius is centred in a roadkill event, summing all roadkill events inside the circle area. Since the road is not transformed to be linear, the road extension inside each circle may vary, so the sum of all events in the circle is multiplied by a correction factor, which considers the road length inside the circle. This correction also allows for further comparisons among different scales. After all events are evaluated, there is a general sum that corresponds to the aggregation intensity at the initial scale. To allow the comparison of different roads or data sets, this sum is standardized by total road length and total number of roadkills. This analysis is repeated for different radius sizes, from the initial radius set by the user to the total road length. In these sense, aggregations occurrence is evaluated in a multi-scale approach, which corresponds to the radius size (Coelho et al. 2010).

This analysis can be described by

$$K(r) = \frac{D}{n(n-1)} \sum_{i=1}^{n} 2r / Ci(r) \sum_{j \neq i} fij$$

where: *K(r)* = value of K statistic for spatial scale *r*; *D* = road length; *n* = number of events; *r* = radius; *i* = roadkill event; *j* = another roadkill event; *Ci(r)* = road length inside the circle with *r* radius centred in roadkill event *i*; *fij* = index equal to 0 if *j* is outside the circle *r* radius centred in *i*, or equal to 1 if *j* is inside this area.

For the interpretation of different scales used and to evaluate aggregations significance we used

$$L(r) = K(r) - Ks(r)$$

where: *L(r)* = difference between value of K statistic for radius *r* and value of simulated K for the same radius; *Ks(r)* = the mean of all *K* values obtained trough Monte Carlo simulations. When *L(r)* is higher than confidence limits (90%), it means that there are roadkill aggregations with statistical significance. The presence of roadkills aggregations means that some places are more susceptible to the occurrence of roadkill than others. We carried out Ripley's K test for amphibians, reptiles, birds and mammals, considering an initial radius of 100 m and repeated for incrementally larger scale distances (with a radius increment of 100 m at each new step) to total road length. This initial radius size was chosen because we considered that it corresponds to a scale where mitigation measures like underpasses and speed limiters can be effective.

To identify roadkill hotspots location, we performed a bidimensional hotspot analysis. In this analysis, the road is divided in *n* stretches with the same size. An evaluation scale is chosen according to the results obtained in Ripley's K test. A circle with *r* radius is now centred in the first road stretch, summing all roadkill events inside this area. This number is then multiplied by a correction factor that considers the road length inside the circle. The circle is then centred in the next road section and again all events are summed and multiplied by the correction factor. This procedure is done for all road stretches (Coelho et al. 2010).

This analysis can be described by:

$$H_i(r) = 2r / C_i(r) \sum_{j=1}^{n} f_{ij}$$

where: *Hi(r)* = aggregation value for the ith road division for a chosen *r*; *i* goes from 1 to *m* (number of road stretches); *n* = number of roadkill events; *r* = chosen radius; *Ci(r)* = total road length inside the circle with *r* radius centered in ith road division; *fij* = 1 if the distance between event *j* and the center of ith road division is lower than *r* and *fij* = 0 otherwise.

To evaluate hotspots statistical significance we calculated confidence limits with Monte Carlo simulations by randomization of roadkill events. *H(r)* values higher than 90% confidence limits indicate significant hotspots, that is, road stretches with high mortality.

For the identification of aggregation locations and to evaluate aggregations significance along the road we used

$$N(strech) = H(r) - Hs(r)$$

where: *N(strech)* = difference between the *H* value observed for *r* scale and the simulated *H* value for *r* scale; *Hs(r)* = mean simulated *H* values in Monte Carlo randomizations.

All Ripley's K analyses and hotspots analyses were performed in Siriema software (Coelho et al. 2010), considering 90% confidence limits to calculate statistical significance. These confidence limits were chosen in an attempt to minimize Type II error probabilities based on the precautionary principle, since environmental decision-making requires that β is kept small (Underwood and Chapman 2003) and it is worse not to identify roadkill hotspots when they in fact exist than to identify hotspots when they do not exist.

To test if hotspots of different taxonomic groups overlap, we transformed aggregation intensity data in a binary variable for roadkill hotspot presence. We performed this data transformation in order to control for random intensity variation (i.e. intensity values inside confidence intervals). With this binary matrix, we performed an association test using Sørensen resemblance measure between variables. Significance values were obtained using randomizations (Manly 1997). Road stretches were considered as sampling units and roadkill aggregation presence in road stretches for each taxonomic group as variables. These analyses were carried out in two different scales, with a 100 m radius and with a 1000 m radius, to test if overlapping is a scale-dependent pattern, and performed in MULTIV 2.4 (Pillar 2006).

Results

We recorded 150 birds, 136 wild mammals, 75 reptiles and 291 amphibians. The Ripley's K test indicated roadkill aggregations in all scales evaluated with similar radius amplitude for all groups evaluated, from zero to 46-51 kilometres (Fig. 1). Considering the 800 road stretches obtained from Hotspot Analysis with 100 m radius, aggregations were concentrated in 4-11% of the road. The largest number of hotspots was concentrated in lowland road stretch (the last 30 kilometres), with lower roadkill intensity in hillside and highlands (the first 30 kilometres) (Fig. 2 and Fig.3).

The association test indicated low overlapping in roadkill aggregations among different taxonomic groups, but indicated that this pattern is scale-dependent, since similarity in the location of roadkill aggregations enhanced with increasing scale (Table 1).

Discussion

Vertebrate roadkills were nonrandomly distributed and significantly clustered. Our results showed that roadkill hotspots locations were similar among different taxonomic groups in larger scales, but not in a refined scale. To our knowledge, this is the first time that the similarity among roadkill spatial patterns of different taxonomic groups is evaluated. Sørensen resemblance measure indicated that, in small scales, mammal roadkill hotspots are not a surrogate for hotspots of other taxonomic classes, although in a larger scale similarity in hotspots location increased, indicating a scale-dependent pattern. A hypothesis to explain this pattern is that, in a refined scale, differences in behaviour and habitat selection among species become more evident than in larger scales, where the influence of macrohabitat availability is possibly the most important factor. In this sense, punctual mitigation measures, like wildlife passages, when implemented based in survey results of mammal roadkills, would not be functional for other taxonomic groups. Nevertheless, more extensive mitigation measures – as the reduction of speed limits in a larger road stretch or multiple wildlife passages implemented near each other – could be implemented and reach a larger spectrum of species even if based solely on a mammal roadkill survey.

Although our results show that aggregation zones of different taxonomic groups do overlap when evaluated in an appropriate scale, some authors question the success of multi-taxa mitigation measures and suggest that mitigation should be addressed to specific target species, arguing that only species-specific measures can be effective. There are some evidences that each type of wildlife passages, for example, will benefit some particular species due to differences in behaviour (Glista et al. 2009). Indeed, the fact that aggregations occur in the same zone does not mean that all organisms will be benefited by common mitigation measures. Wildlife passages benefit cursorial animals and even among them only a few will use similar types of passages. Our results only show that mammal hotspots can be a surrogate for hotspots zones of other animals in larger scales, whereas, in order to mitigate road impacts for multiple taxa one must adopt a set of mitigation measures that should include over and underpasses (e.g. Aresco, 2005, for amphibians and reptiles; Jacobson, 2005, for birds; and Clevenger and Waltho, 2000 and Goosem et al., 2005, for mammals), speed limitation, signalling and habitat protection.

These results are very important in the context of mitigating road impact, since monitoring roadkill of all taxonomic groups is difficult, due to influences of detectability and survey method (Slater 2002, Langen et al. 2007, Hels and Buchwald 2001, Teixeira et al. this volume). For example, amphibian monitoring by car is inadequate, but monitoring by foot cannot be applied to regional or national conservation plans. Also, monitoring by car allows detecting a larger number of carcasses in less time (Sillero 2008), increasing sample size. Many authors assume that every victim is detected in roadkill surveys, which may be true only for large conspicuous mammals (Hels and Buchwald 2001). However, we must be aware that the effect of sample size caused by detectability problems on hotspot detection has not been evaluated, and we could expect that it influences recognition of roadkill spatial patterns. Detectability affects estimates of mortality magnitude (Teixeira et al. this volume), but its effect (especially carcass removal component) over spatial patterns is not known.

Our results are relevant in the sense of impacts caused by roads already implemented, when planning of mitigation measures is needed after road construction. In Brazil this is happening in a network of thousands of kilometres and we believe the same is observed in other developing countries. Mammal roadkill hotspots used as a surrogate to identify roadkill spatial patterns of other taxa can be an advantage due to its easiest monitoring, with higher detectability and lower removal rates. However, we must be careful since we do not know how general this pattern is and how it is affected by variation in detectability among taxonomic or ecological groups.

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Table 1. Sørensen similarities of roadkill aggregations among taxonomic groups.

	Sørensen (100 m radius)	P	Sørensen (1000 m radius)	P
Amphibians x Reptiles	0.10853	0.099	0.27119	0.008
Amphibians x Birds	0.20988	0.003	0.44604	0.001
Amphibians x Mammals	0.18182	0.541	0.56489	0.001
Reptiles x Birds	0.059406	0.004	0.53012	0.001
Reptiles x Mammals	0.097561	0.126	0.24	0.027
Birds x Mammals	0.17391	0.003	0.4375	0.001

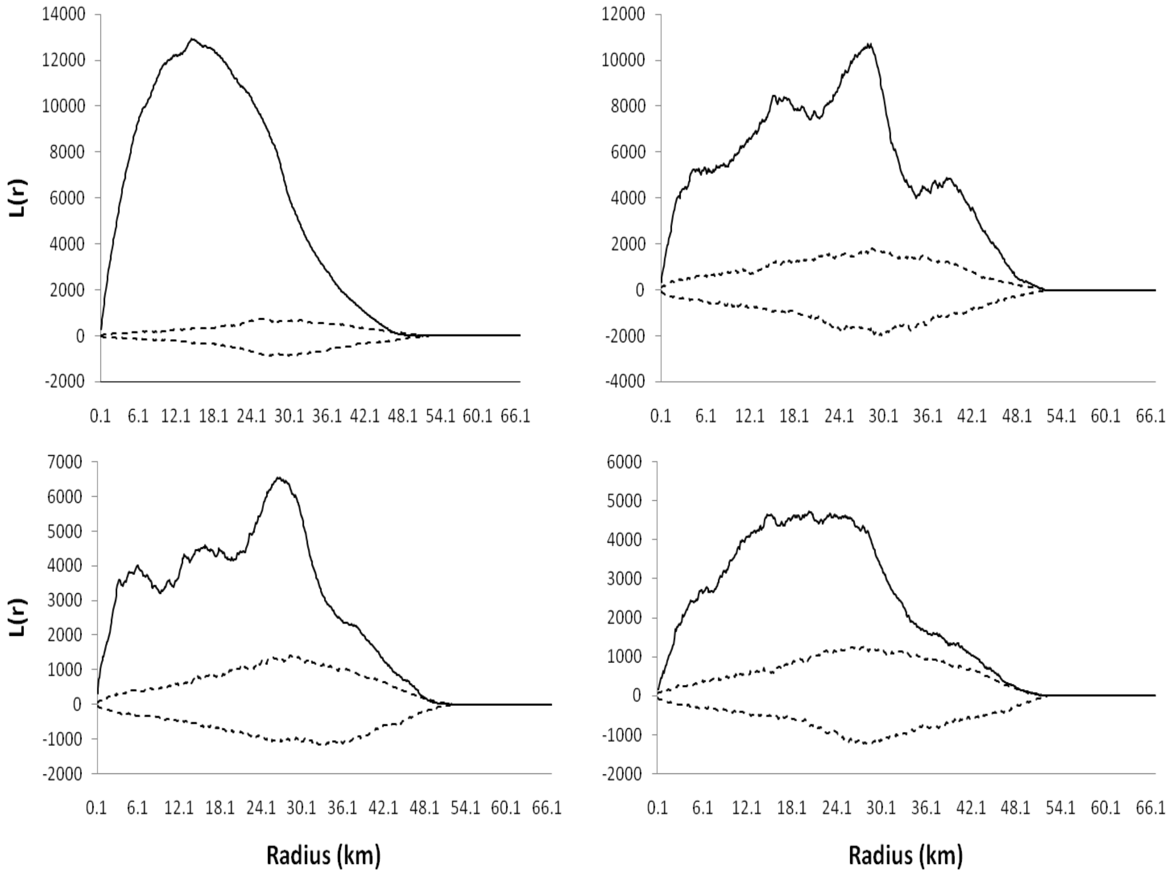

Fig. 1. Results of Ripley's K test for multiple scales at Rota do Sol, southern Brazil. The continuous line represents observed L(r) values and the dotted lines represent confidence limits. a) Amphibians. b) Reptiles. c) Birds. d) Mammals.

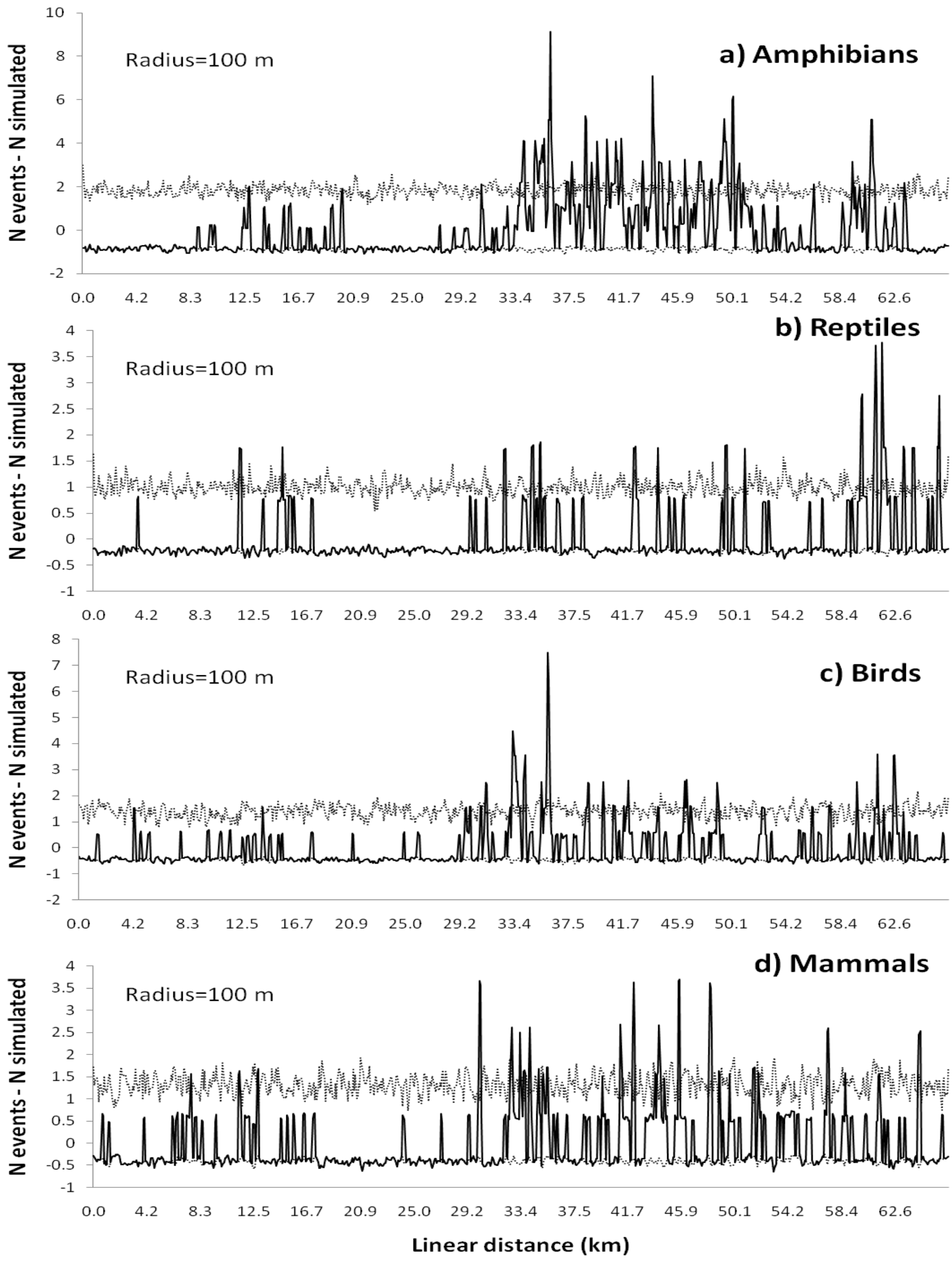

Fig. 2. Results of hotspots analyses at Rota do Sol with a 100 m radius. The black line represents observed intensity of roadkill aggregation and the grey lines represent confidence limits. The first 30 kilometres are in highland and hillside and the last 30 kilometres are in lowland. a) Amphibians. b) Reptiles. c) Birds. d) Mammals.

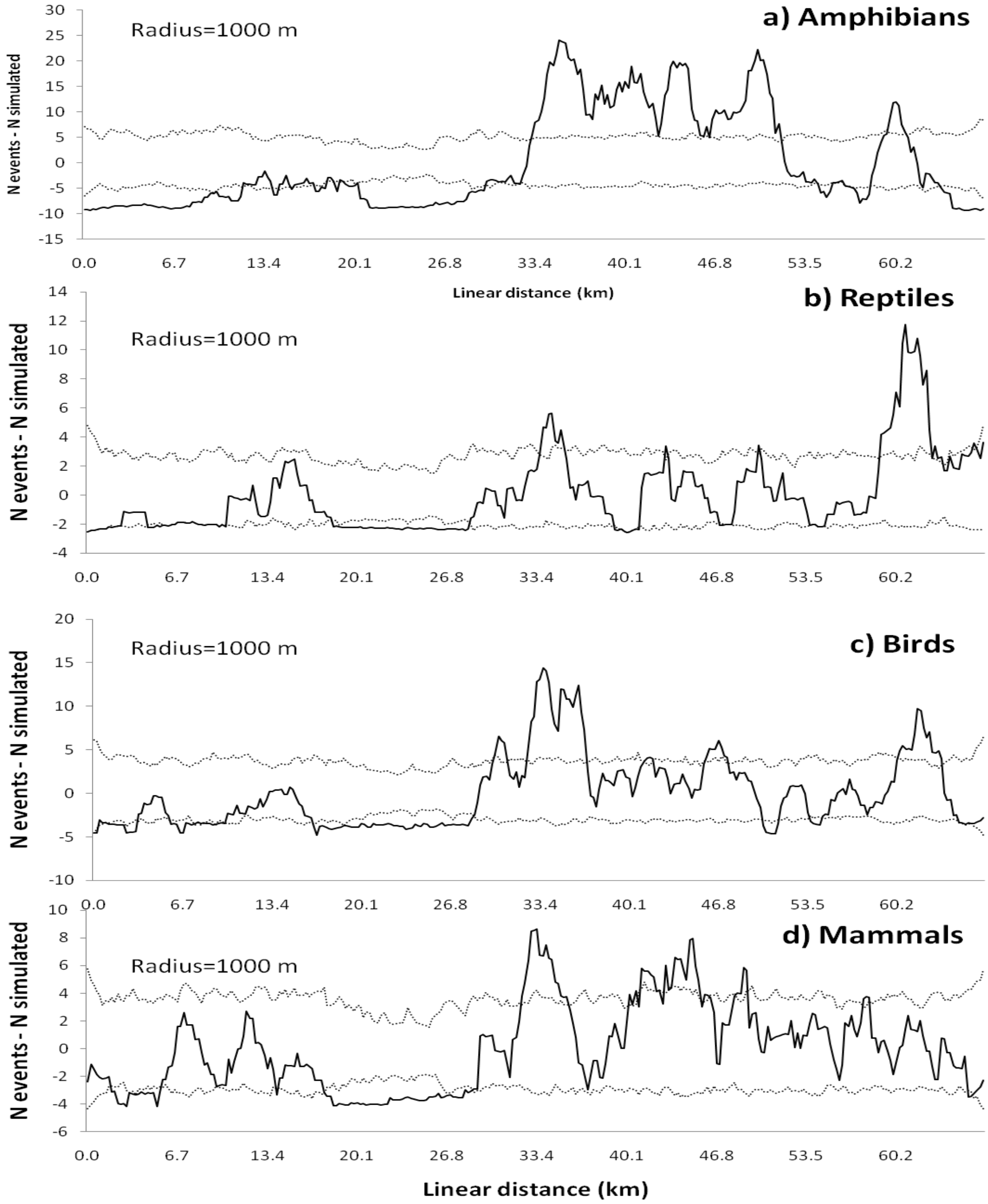

Fig. 3. Results of hotspots analyses at Rota do Sol with a 1000 m radius. The black line represents observed intensity of roadkill aggregation and the grey lines represent confidence limits. The first 30 kilometres are in highland and hillside and the last 30 kilometres are in lowland. a) Amphibians. b) Reptiles. c) Birds. d) Mammals.

Considerações finais

O estudo aqui apresentado traz importantes contribuições à ecologia de rodovias. As perguntas que norteiam este trabalho foram investigadas de forma a contribuir no desenho amostral de estudos futuros de fauna atropelada e no monitoramento e planejamento de medidas mitigadoras.

As análises apresentadas demonstram que a remoção de carcaças é alta nas primeiras 24 horas em que a carcaça está na rodovia e que as taxas de remoção não são homogêneas entre grupos taxonômicos e classes de tamanho. Anfíbios e aves, animais normalmente de menor tamanho, foram removidos mais rapidamente do que répteis e mamíferos.

Da mesma forma, a detecção dos pesquisadores diferiu para grupos taxonômicos e classes de tamanho diferentes, sendo muito menor para anfíbios e aves. Entretanto, deve ser considerado que grupos taxonômicos e classes de tamanho são fatores associados, já que anfíbios e aves normalmente possuem corpo de menor tamanho, enquanto mamíferos são maiores.

O efeito direto gerado pela remoção de carcaças e detecção é a subestimativa da magnitude de mortalidade de animais atropelados em cada grupo taxonômico. A avaliação da magnitude de atropelamentos sem a incorporação desses fatores, considerando apenas o número de carcaças medidas no monitoramento, resulta em taxas similares de mortalidade para cada grupo, o que não corresponde à realidade. Incorporar essas fontes de erro nas estimativas é de fundamental importância para a avaliação dos impactos de rodovias. Ainda, as aves são os animais com maiores subestimativas em monitoramentos de carro e possivelmente um dos grupos mais afetados pelos atropelamentos, já que possuem baixa detecção e altas taxas de remoção.

Como uma alternativa para corrigir esse viés, adaptamos um modelo matemático que incorpora esses fatores (detecção e taxas de remoção) na estimativa da taxa de mortalidade. Essa função considera que os monitoramentos de fauna atropelada normalmente são realizados periodicamente e com a retirada das carcaças pelos pesquisadores, permitindo sua ampla aplicação nos monitoramentos. A partir dos resultados aqui apresentados, mostramos diferenças nas taxas de remoção e detecção entre grupos taxonômicos e classes de tamanho, indicando que esses fatores geram subestimativas da taxa de atropelamentos. Considerando que há diferenças na remoção e detecção entre os grupos avaliados, é importante que as taxas de atropelamento de cada grupo taxonômico sejam calculadas separadamente.

Ao avaliarmos o padrão espacial e a similaridade entre as agregações de atropelamentos entre diferentes grupos taxonômicos, identificamos que a localização das agregações de atropelamentos de mamíferos pode ser utilizada como indicadora da localização de agregações de outros grupos taxonômicos, mas apenas em escalas mais amplas. Em escalas refinadas, há grandes diferenças nos padrões espaciais entre os grupos, provavelmente devido a diferenças no comportamento e uso do hábitat entre os grupos. Assim, em escalas mais amplas (como a escala avaliada de 1 km), um mosaico de medidas mitigadoras pode ser implementado e atingir maior diversidade de espécies. Entretanto, deve-se considerar que o simples uso de um grupo como indicador dos padrões espaciais de outros não significa que todos os organismos serão beneficiados com a implementação das medidas mitigadoras. Portanto, para mitigar os impactos de rodovias para diversos táxons ao mesmo tempo, deve-se planejar e implementar medidas diferenciadas para os grupos-alvo.

Os resultados aqui apresentados são muito importantes no contexto da mitigação do impacto de rodovias, já que o monitoramento de todos os grupos taxonômicos impactos mostra-se difícil, principalmente devido a diferenças nas taxas de detecção de acordo com o método utilizado. Sabe-se que a detecção e a remoção afetam as estimativas de mortalidade, mas deve-se ainda avaliar qual o seu efeito sobre a identificação de padrões espaciais. Desta forma, é importante a aplicação dos resultados aqui apresentados no monitoramento de rodovias já implementadas e no planejamento de medidas mitigadoras.

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