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Vertebrate road mortality estimates: Effects of sampling methods and carcass removal

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ABSTRACT

The study of road mortality rates is important to identify species in need of detailed population evaluation, to determine the effectiveness of mitigation measures or to identify road network sections or road stretches where to concentrate mitigation actions. However, the impacts of roads on vertebrate mortality are usually underestimated, since detection probability and removal rates are not considered when road-kill magnitude is evaluated. In this paper, we present differential equations to estimate road-kill mortality rates taking into account carcass detectability and removal rates. The equations presented consider the periodicity and sampling methods normally used in road mortality studies and we discuss the recommended formulae to each sampling context. To exemplify outcomes of each equation we used a data set obtained during a one-year monitoring of vertebrate road-kills in southern Brazil. Our results show that there are differences in carcass detectability and removal rates among different taxonomic and body size groups. For reptiles and birds, respectively, we estimated mortality rates two and 39 times larger when considering carcass removal and detectability. Although our mortality estimates may be affected by some possible biases in sampling detection probability and removal rates, our main goal in this study was to provide a mathematical alternative to incorporate those error sources in road-kill estimates. We believe that the proposed mathematical models, by properly estimating road-kill magnitude, represent a substantial step towards an adequate evaluation of road impacts on wildlife.

1. Introduction

Vehicle-animal collisions are considered by some authors the major direct human cause of terrestrial vertebrate mortality worldwide (Forman and Alexander, 1998). It is crucial to estimate road mortality rates for monitoring and mitigating this impact, since road-kills may have substantial effects on population's density (Fahrig and Rytwinski, 2009), have a stronger effect than road avoidance over population's persistence (Jackson and Fahrig, 2011) and – contrasting with other causes of mortality – are responsible for eliminating healthy individuals from populations (Bujoczek et al., 2011).

Road mortality rates can be used to identify species in need of detailed population studies, to identify road network sections or road stretches where to concentrate mitigation actions or to determine the effectiveness of mitigation measures (Taylor and Goldingay, 2010). This is especially important for evaluating the effectiveness of wildlife passages comparing mortality on roads with and without passages and before and after their construction (Lesbarrères and Fahrig, 2012).

As pointed out by Prosser et al. (2008), mortality estimates are affected by two main factors: the carcass removal between death time and survey time, and detectability since it is unlikely that all carcasses present at a site will be found by observers. Carcass persistence on road can be influenced by weather, scavengers activity (Slater, 2002) and traffic flow, whereas detectability can be affected by carcass size (Morrison, 2002), amount of roadside vegetation, survey method and researchers' abilities (Hobday and Minstrell, 2004). Not accounting for these limitations may significantly underestimate road-kill impact on wildlife populations, potentially affecting temporal and spatial pattern recognition, and ultimately may represent waste of lives and economic resources due to ineffective mitigation. 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 carcass removal and detectability variations.

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The incorporation of detection probabilities is becoming of great relevance on ecology literature, especially after the work of MacKenzie et al. (2002) and Wintle et al. (2004). Since animals are not always detected and detection probabilities differ trough time and space, MacKenzie and Kendall (2002) suggest that any monitoring program should estimate detection probabilities to adjust estimates accordingly.

Although evaluation of carcass removal rates and searchers detection probabilities are part of protocols adopted to estimate mortality rates of wind power plants on birds (at least since Erickson et al., 2000), this approach is still predominantly ignored in road-kill surveys (but see Gerow et al. (2010) and Guinard et al. (2012), for recent proposals). By not incorporating those factors, researchers consider that carcass persistence and detectability are homogeneous among different vertebrate taxonomic classes and among different body size groups, and that the degree of underestimation is similar among 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 body size and low carcass persistence and detectability.

Finally, we present mathematical models to estimate road-kill magnitude in different research situations, which incorporate both components of underestimation (carcass removal and searcher detectability). We start with models already proposed by Erickson et al. (2000) and Shoenfeld (2004) for avian fatalities in wind power plants and then present a more general description suitable for road-kill estimates considering the methods and periodicity of such studies. In order to test these models and discuss their outcomes and implications, we use a road-kill data set from surveys carried out during a one-year monitoring in Rota do Sol road, southern Brazil.

2. Methods

2.1. Study area

This study was developed in a 66 km section of RSC-453/ERS-486 in Rio Grande do Sul State, southern Brazil, a two-lane road called Rota do Sol (50 W 19′ 12″, 29S 15′ 58″/ 49 W 57′ 29″, 29S 36′ 59″), with a mean daily traffic of 3108 vehicles (DAER-RS, 2009). This road section crosses three protected areas: Rota do Sol Environmental Protected Area (54, 670.5 ha), Aratinga Ecological Station (5882 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). We observed three geomorphological regions (lowland, hillsides and highland), 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 high density of rural settlements and small villages and the predominance of agriculture.

2.2. Mortality rate estimation model

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

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

where $G(t)$ is the number of carcasses on the road at time t. This differential equation leads to a solution for $G(t)$ in the form:

$$G(t) = (G(0) - \lambda T_R)e^{-t/T_R} + \lambda T_R. \tag{2}$$

$G(t)$ tends exponentially to the steady state solution given by:

$$G(t \to \infty) = \lambda T_R. \tag{3}$$

The time constant characterizing this exponential evolution from the initial value $G(0)$ to the steady state (λT_R) is T_R. Considering, for example, the case where there is an initial excess of carcasses on the road ($G(0) > \lambda T_R$), at a time $t = T_R$, the excess number of carcasses on the road will be reduced by ~63%.

The number of road-kills (N) obtained from a single measurement at the steady state condition can be estimated as:

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

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 road-kill rate λ from N.

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

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

Eq. (5) is not always correct. It considers only the steady state solution: the system must not be recovering from a perturbation during any measurement. But road-kill measurements themselves do usually take the system out of the steady state (during measurements, carcasses are often removed for further analysis or to avoid double counting). Interference between subsequent measurements can be avoided if their time separation, T_S, is sufficiently larger than T_R (the percent error implied by using Eq. (5) instead of the more general relation that will be described later in the text will be less than 5% when $T_S \geqslant 4T_R$). 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:

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

$$\to N = \sum_{i=0}^{n-1} N_i = n \cdot p\lambda T_R \left(\frac{e^{\frac{T_S}{T_R}} - 1}{e^{\frac{T_S}{T_R}} - 1 + p} \right) \tag{7}$$

Although Eq. (7) is more accurate than Eq. (5) in the case of low ratio T_S/T_R, care must be taken while using it, especially if the number of measurement steps, n, is not very large. The approximation made is usually not valid for the initial measurements which can lead to overestimated road-kill rates (for example, considering $T_S = T_R$ and $p = 1$, the percent error implied by using Eq. (7) instead of the more general relation that will be described bellow will only be lower than 5% for $n \geqslant 12$). A more correct procedure would be to consider the system initially in the steady state. The first measurement, taken at time 0, will then give $N_0 = p \cdot G(0) = p\lambda T_R$ (Eq. (4)). Since measured carcasses are removed right after the first