Using traffic flow theory to model traffic mortality in mammals

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Abstract

Traffic has a considerable effect on population and community dynamics through the disruption and fragmentation of habitat and traffic mortality. This paper deals with a systematic way to acquire knowledge about the probabilities of successful road crossing by mammals and what characteristics affect this traversability. We derive a model from traffic flow theory to estimate traffic mortality in mammals related to relevant road, traffic and species characteristics. The probability of successful road crossing is determined by the pavement width of the road, traffic volume, traversing speed of the mammals and their body length. We include the traversability model in a simple two-patch population model to explore the effects of these road, traffic and species characteristics on population dynamics. Analysis of the models show that, for our parameter ranges, traffic volume and traversing speed have the largest effect on traffic mortality. The population size is especially negatively affected when roads have to be crossed during the daily movements. These predictions could be useful to determine the expected effectiveness of mitigating measures relative to the current situation. Mitigating measures might alter the road and traffic characteristics. The effects of these changes on traffic mortality and population dynamics could be analysed by calculating the number of traffic victims before and after the mitigating measures.

Introduction

Traffic flows are principal causes of habitat fragmentation (Andrews 1990; Forman and Alexander 1998; Spellerberg 1998; Trombulak and Frissell 2000). There are at least four negative effects of traffic on animals (Van Langevelde and Jaarsma 1997): destruction or alteration of habitat due to construction, disturbance of habitat along the road or railway (noise, vibrations, car visibility, etc.), barriers created by the road or railway (increased resistance for movements), and barriers by traffic (collision risk during crossing). The first two directly affect the habitat of the species. They result in a decline of habitat area or strips along the road with lower quality of habitat. The latter two effects have an impact on individuals. These four effects may have implications for population dynamics and community structure near the road. In this paper, we investigate the mortality due to traffic on roads. We define the traversability of a road as the probability of successfully crossing that road by an individual.

Measures are applied to reduce traffic accidents (Garret and Conway 1999; Singh and Satheesan 2000) and protect biodiversity (Van Bohemen 1998; Trombulak and Frissell 2000). Mitigation measures include keeping wildlife off the road (e.g., fences: Romin and Bissonnette 1996; Putman 1997), providing alternative routes (e.g., fauna passages and ecoducts: Jackson and Griffin 1998; Keller and Pfister 1997) or reducing the risk of collisions (e.g., highway lighting or mirrors: Romin and Bissonnette 1996; Putman 1997). Most measures involve technical devices...
that change the road characteristics. However, also other measures may reduce traffic mortality, such as reduction of traffic volume or speed, and periodic closing of roads (during the night or a specific season). For effectively applying mitigating measures that reduce traffic mortality at locations where no passageways or fences are constructed, insight in the effects of road and traffic characteristics on traffic mortality is needed (Andrews 1990; Kirby 1997; Forman and Alexander 1998).

In this paper, we analyse a model based on the relevant road, traffic and species characteristics to estimate the probability of successfully road crossing. In contrast to other recent studies on traffic mortality (Van Langevelde and Jaarsma 1997; Hels and Buchwald 2001; Clevenger et al. 2003), we explicitly derive the model from traffic flow theory. A sensitivity analysis demonstrates what parameters should be estimated carefully.

Since the number of traffic victims does not directly provide insight in the effects of infrastructure on local population dynamics, we include the traversability model in a simple population model. This model consists of two patches and annual exchange of individuals between the patches. With this two-patch population model, we explore the effects of road, traffic and species characteristics on population dynamics. Therefore, we analyse the population size where traffic mortality affects the daily movements of the animals and the yearly exchange of individuals between the patches. Based on the analysis of the traversability model and the population model, we explore which characteristics make species vulnerable to traffic mortality.

Model for estimating the traversability of roads

Relevant road, traffic and species characteristics

What are the relevant road, traffic and species characteristics that have an effect on the traversability? Regarding the road characteristics, it is clear that as the road is wider, an animal needs more time to cross and the probability of a successful road crossing decreases. Moreover, wider roads carry higher traffic volumes and allow for higher speeds. A small clearance of a road, i.e., a short distance from the road to dense vegetation, has a negative impact on the traversability of the road (Oxley et al. 1974; Adams and Geis 1983; Clevenger et al. 2003). A small clearance can often be found in forested landscapes.

High traffic volumes cause high noise loads and a high collision probability since the intervals to cross between the vehicles are small. An increase of traffic volume may lead to such a flow of vehicles that individuals do not cross the road anymore. The time split of the traffic indicates the seasonal and daily fluctuations of the traffic volume. The traffic volume that largely determines traffic mortality (called the decisive traffic volume) depends on the time split of the daily traffic flow and the activity period of the animals during the day (Figure 1). During these periods, individuals are exposed to traffic mortality when roads are within their activity range. Vehicle speed seems to be important because of the better opportunities for both animal and driver to avoid a collision when the vehicle speed is lower.

Depending on the road and traffic characteristics, different animal species experience differences in traffic mortality, such as in insects (Munguira and Thomas 1992; Vermeulen 1994), reptiles and amphibians (Hels and Buchwald 2001), birds (Clevenger et al. 2003) and mammals (Mader 1984; Lankester et al. 1991; Clarke et al. 1998). Whether these species are vulnerable to traffic mortality depends on characteristics such as their home range size, the period of the day or season during which the animals are active, whether they move large distances during foraging, dispersal or migration, their traversing behaviour (velocity, reaction to approaching vehicles), their body length or the size of the group in which the individuals move.

Traffic flow theory

Central in the traversability model that estimates traffic mortality in animals, is the mathematical description of traffic flows where the probability of a successful road crossing depends on the number of vehicles passing during a certain time period. The traversability model is based on the assumption that the road crossing of an animal is successful if an ‘acceptable’ gap in the traffic flow appears at the start of the crossing. A crossing during a smaller gap results in a collision since an animal and a vehicle will be at the same location at the same moment. The model does not include ‘corrections’ by human or animal when this occurs. In traffic engineering, this gap acceptance approach has already been applied to model traffic flows (e.g., see Haight 1963, 1966; Drew 1968;