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Predicting wildlife road-crossing probability from roadkill data using occupancy-detection models

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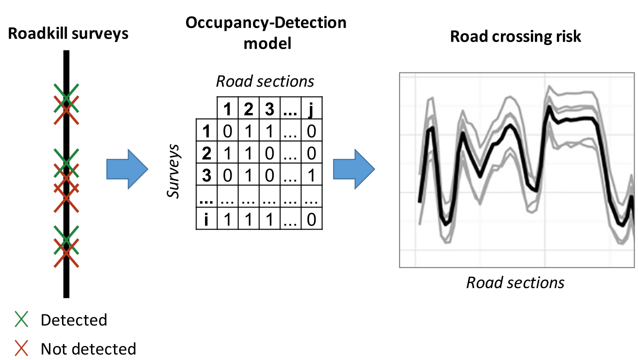
HIGHLIGHTS

- Occupancy-detection models (ODMs) could overcome roadkill surveys biases.
- Bayesian ODMs were developed for six *taxa*, found road-killed in 114 km, Brazil.
- ODMs assessed the influence of explanatory variables in road crossing risk.
- We found a higher road crossing risk near agriculture areas and open habitat.
- ODMs improve the assessment of roadkill risk along transportation infrastructures.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildlife-vehicle collisions (WVC) represent a major threat for wildlife and understanding how WVC spatial patterns relate to surrounding land cover can provide valuable information for deciding where to implement mitigation measures. However, these relations may be heavily biased as many casualties are undetected in roadkill surveys, e.g. due to scavenger activity, which may ultimately jeopardize conservation actions. We suggest using occupancy models to overcome imperfect detection issues, assuming that 'occupancy' represents the preference for crossing the road in a given site, i.e. is a proxy for the roadkill risk; and that the 'detectability' is the joint probability of an animal being hit in the crossing site and its carcass being detected afterwards. Our main objective was to assess the roadkill risk along roads while accounting for imperfect detection issues and relate it to land cover information. We conducted roadkill surveys over 114 km in nine different roads, biweekly, for five years (total of 484 surveys), and developed a Bayesian hierarchical occupancy model to assess the roadkill risk for the six most road-killed taxa for each road section and season (WET and DRY). Overall, we estimated a higher roadkill risk in road sections surrounded by agriculture, open habitats; and a higher detectability within the 4-lane road sections. Our modeling framework has a great potential to overcome the limitations related to imperfect detection when assessing the roadkill risk and may become an important tool to predict which road sections have a higher mortality risk.

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1. Introduction

Roads are known to promote numerous negative impacts on natural populations and habitats worldwide (Forman et al., 2003; Trombulak and Frissell, 2000; van der Ree et al., 2015). Perhaps the most important of such impacts is wildlife-vehicle collisions (WVC), which often represent a significant contributor to population depletion in the vicinity of roads, as reported for insects (Baxter-Gilbert et al., 2015), amphibians (Gibbs and Shriver, 2002), reptiles (Beaudry et al., 2010), birds (Borda-De-Água et al., 2014), and mammals (Ramp and Ben-Ami, 2006). Additionally, WVC may exacerbate the road barrier effect by blocking potential crossings, therefore restricting gene flow between roadside populations (Ascensão et al., 2016; Jackson and Fahrig, 2011). Combined, population depletion and barrier effects may accelerate the loss of genetic variation due to random drift and increase inbreeding, which may result in local extinctions (Reed et al., 2007; Westemeier, 1998). Hence, it is crucial to understand where WVC are more likely to occur, i.e. the roadkill risk, in order to implement mitigation measures, such as road passages and fencing (Ascensão et al., 2013; Lesbarreres and Fahrig, 2012).

Accurate assessments of the roadkill risk, however, can be strongly biased as observers may fail to detect roadkills along the surveys, either because carcasses are removed from the road, e.g. by scavengers, or are hidden to observers, e.g. tossed to the road verges (Santos et al., 2016, 2011; Slater, 2002). Such false absences may in turn lead to biased conclusions on collision patterns that ultimately may result in incorrect biodiversity management decisions (Eberhardt et al., 2013). Remarkably, there is a vast body of literature aimed at understanding the main drivers of WVC and predicting where WVC are more likely to occur (Beaudry et al., 2010; Clevenger et al., 2002; Crawford et al., 2014; Malo et al., 2004; Ramp and Ben-Ami, 2006), yet to our knowledge, such approaches have never integrated the false absence issues. Ignoring imperfect detection in biological surveys is dangerous and affects our ability to truly identify factors that are important for species occupancy (Guillera-Arroita et al., 2014; Mackenzie et al., 2006).

We suggest using occupancy-detection models (ODMs) (Mackenzie et al., 2002) to analyze WVC data, therefore integrating the detectability issues. ODMs require repeated sampling to account for false absences, conducted at spatially-replicated sites, i.e. surveys made by visiting sites more than once, to simultaneously estimate occupancy and detection probability, thereby correcting for imperfect detection (Mackenzie et al., 2006; Mackenzie et al., 2002). Observed absences are integrated in the model as a mixture of non-detections and true absences (Hanks et al., 2011). Conveniently, the requisite of repeated surveys in time and space is also the typical sampling protocol employed in road mortality surveys, where observers drive the same road repeatedly searching for WVC.

Within this approach, we suggest that ‘occupancy’ represents the preference of a species to use a given road section for crossing or foraging — road crossing risk, which can be regarded as a proxy of the roadkill risk. Note that we are considering the usage probability and not the roadkill rate as the main parameter to assess the road crossing risk. On the other hand, ‘detection’ is the collision event per se, i.e. a moving vehicle detects (hit) an animal crossing the road. Because not all carcasses are found afterwards in roadkill surveys, we considered that the detection component of ODMs is the joint probability of an animal being hit while crossing the road, and the carcass being found in subsequent roadkill surveys. Hence, road sections with higher occupancy rates (i.e. higher road crossing risk) may indicate best locations to implement mitigation measures.

We developed a Bayesian hierarchical occupancy model to assess the road crossing risk and relate it with land cover and road-related information. This approach allows researchers and road managers to account for false absence issues and therefore improves the estimation of the roadkill risk along surveyed roads, thereby providing more robust information to delineate and implement management practices (e.g. crossing structures).

2. Materials and methods

2.1. Study area

We conducted the study in Brasília (Federal District), located in the Cerrado biome of Central Brazil (Fig. 1). The vegetation in the study area is dominated by savannah forest (‘Cerradão’ and ‘Mata de Galeria’), open savannah (‘Cerrado *sensu stricto*’) and grasslands (Ribeiro and Walter, 2008). Surveys were conducted along nine roads (total 114 km), including four-lane (BR-020 and DF-001; 16 km), two-lane (DF-001, DF-345 and DF-128; 74 km), and dirt roads (DF-205 and DF-001; 24 km) (Fig. 1). Both the four-lane and two-lane roads were paved (with shoulders). The four-lane roads

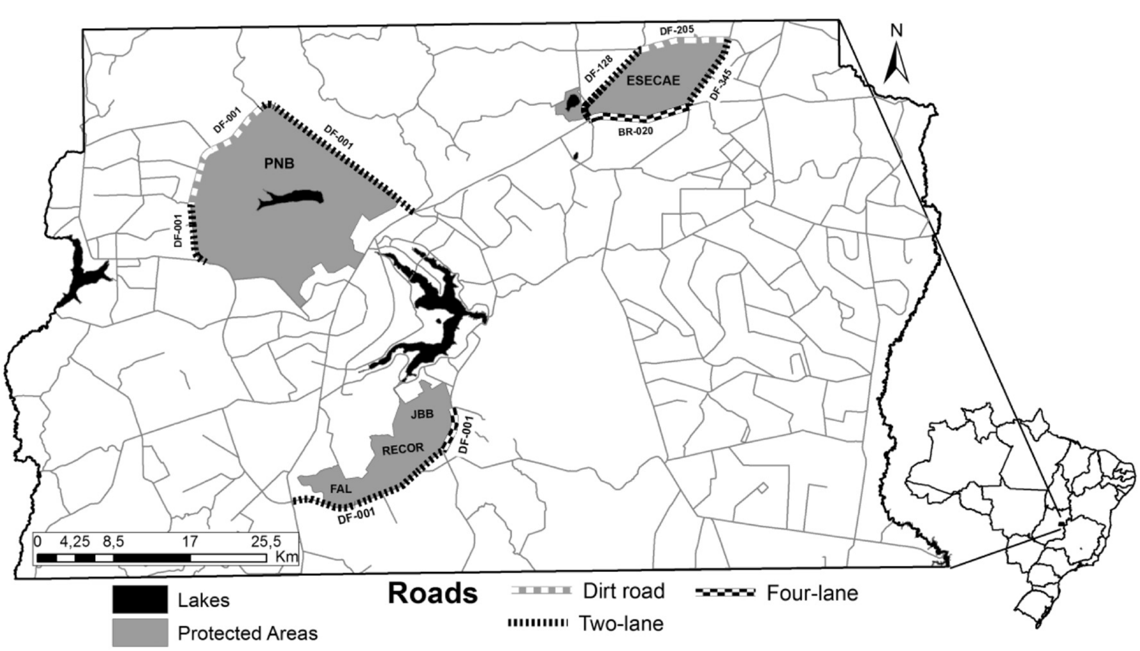

Fig. 1. Study area with location of monitored roads and protected areas.