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Research article

Consistent patterns of vehicle collision risk for six mammal species

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ABSTRACT

The occurrence and rate of wildlife-vehicle collisions are related to both anthropocentric and environmental variables, however, few studies compare collision risks for multiple species within a model framework that is adaptable and transferable. Our research compares collision risk for multiple species across a large geographic area using a conceptually simple risk framework.

We used six species of native terrestrial mammal often involved with wildlife-vehicle collisions in south-east Australia. We related collisions reported to a wildlife organisation to the co-occurrence of each species and a threatening process (presence and movement of road vehicles). For each species, we constructed statistical models from wildlife atlas data to predict occurrence across geographic space. Traffic volume and speed on road segments (also modelled) characterised the magnitude of threatening processes.

The species occurrence models made plausible spatial predictions. Each model reduced the unexplained variation in patterns and distributions of species between 29.5% (black wallaby) and 34.3% (koala). The collision models reduced the unexplained variation in collision event data between 7.4% (koala) and 19.4% (common ringtail possum) with predictor variables correlating similarly with collision risk across species.

Road authorities and environmental managers need simple and flexible tools to inform projects. Our model framework is useful for directing mitigation efforts (e.g. on road effects or species presence), predicting risk across differing spatial and temporal scales and target species, inferring patterns of threat, and identifying areas warranting additional data collection, analysis, and study.

1. Introduction

Roads have considerable negative ecological impacts, prompting numerous scientific studies and mitigation projects over the past five decades (Forman and Alexander, 1998; Spellerberg, 1998; van der Ree et al., 2015). The mortality of wildlife from collisions with vehicles is a significant problem throughout most of the developed world, and will likely become more so in the next few decades in the developing world (van der Ree et al., 2015). Wildlife-vehicle collisions (WVC) are estimated to kill billions of fauna annually on transportation networks (Seiler and Helldin, 2006), fostering an interdisciplinary management problem. To address this problem, studies seek to understand the frequency, magnitude and distribution of WVC. Through this understanding, managers can identify and apply appropriate mitigation strategies.

WVC are financially costly (Bissonette et al., 2008; Huijser et al., 2009; Rowden et al., 2008) and thus knowing where and how to mitigate is important. If mitigation measures are not appropriately specified or located in the landscape, costs arise from both wasted installation labour, materials and time, and on-going collisions resulting from the omission. Moreover, some forms of mitigation, such as fencing, also create “barrier-effects” - a direct impediment to the movement of many species which affects movement and gene flow (Epps et al., 2005). Thus, strategic, informed use of mitigation is important for both conservation and road safety objectives.

The literature contains many studies on WVC with several papers utilising statistical modelling methods. Quantitative models are a useful way to support decision-making for managers by helping to clearly organise problems, test inputs, and make

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inferences (Anderson et al., 2015). By determining the factors that contribute to collisions with quantitative analysis, managers can begin to understand relationships and optimise mitigation strategies.

We view two challenges in current WVC modelling and management practices. First, methods that generalise to multiple species and across taxonomic groups are under-represented in scientific studies (see Farmer and Brooks, 2012). This is likely due to the complexity in resource requirements for different taxa. Another challenge is identifying relationships between predictors and collisions that are able to be mitigated. Although management implications are highlighted in many studies, it is not always clear how the results of the analyses could be easily applied due to variable interactions and confounding effects in the model predictors (Gunson et al., 2011). Some studies explicitly suggest mitigation that relates directly to environmental variables based on model results (see Grilo et al., 2009). Although these recommendations are useful in the specific contexts of the studies, they may not generalise to varying spatial scales - specifically large areas. We argue that generality in methods is useful and it is important to create analytical tools that help managers identify risk to both individual species and taxonomic groups, across large areas, and with predictors that are within the scope of management.

In this study we have two objectives: testing a conceptual risk model framework and analysing patterns of WVC for multiple species. We first model wildlife-vehicle collisions by expanding upon a formerly developed conceptual analytical framework by Visintin et al. (2016) that relates risk to exposure (species occurrence) and hazard (traffic volume and speed). As this model framework is able to quantify risk over large spatial scales (demonstrated on a large region of south-east Australia as a case study), we apply it to six Australian terrestrial mammal species commonly involved in WVC to test its flexibility and potential to support management decision-making. We analyse model outputs to determine the relationships of common factors contributing to wildlife-vehicle collisions and make predictions of risk to identify/prioritise areas requiring mitigation. As the need for and location of WVC mitigation is often derived using species characteristics and movements (e.g. Clevenger et al., 2002), we use the model framework to determine the importance of species occurrence in collision risks on road segments. Ignoring variables that influence habitat preferences of species may lead to less robust inference by managers (Roger and Ramp, 2009). Where occurrence is influential for multiple species, managers may decide to control animal presence on or near the roads and this may involve a mixture of mitigation strategies (see Beckmann et al., 2010). Likewise, if traffic speed or volume is a significant driver of collisions for many species, managers may consider control mechanisms such as speed enforcement or alternative transportation planning.

2. Materials and methods

2.1. Study area

We used the 227,819 square kilometre state of Victoria in south-east Australia as a study area (Fig. 1). The Victorian road authority (VicRoads) manages 25,256 km of major roadway within the state. The remaining sealed roads (approx. 125,000 km) are controlled by seventy-nine municipal districts. Our study analysed collision risk across 147,970 km of sealed roads. To organise our spatial data and modelling, we overlaid a spatial grid of 1 km^2 resolution (extents: −58000,5661000 × 764000,6224000, projection: GDA94 MGA zone 55, number of cells: 462,786) on the study area. Each grid cell was the modelling unit for species occurrence. All roads in the study area were bisected by the grid resulting in road segments that were approximately 1 km or less in length. We used these 612,791 segments as our modelling units for the collision model.

2.2. Study species

We obtained records of WVC from the Wildlife Victoria database (see 'Collision Model' Section 2.5), and selected the species of mammal most frequently recorded as roadkill (Table 1). Only mammals with at least 80 reported collision events were selected for use in the study resulting in six study species. Eastern grey kangaroos (*Macropus giganteus*, Shaw) are the second largest mammal (up to 85 kg for males) in Australia and share many management issues regarding abundance with ungulates found in North America and Europe (Croft, 2004; Coulson and Eldridge, 2010). They occur in groups and have home range sizes between 25 and 125 ha (Dawson, 2012). Black wallabies (*Wallabia bicolor*, Desmarest) are medium-sized (13–17 kg), solitary mammals more often found at higher elevations and in areas of denser foliage (Van Dyck and Strahan, 2008). Common wombats (*Vombatus ursinus*, Shaw) are medium-sized (22–39 kg), burrowing mammals and one of three wombat species in Australia (Van Dyck and Strahan, 2008). Although wombats occasionally share burrows, they are typically solitary animals and occupy home range sizes of about 20 ha. Common possums, brushtail (*Trichosurus vulpecula*, Kerr) and ringtail (*Pseudocheirus peregrinus*, Boddaert), are small arboreal mammals (one to 4 kg) that are often more abundant throughout Victorian urban and suburban environments than other arboreal mammals. Koalas (*Phascolarctos cinereus*, Goldfuss) are medium-sized (eight to 15 kg) arboreal mammals. They are mainly sedentary due to the exclusive diet of *Eucalyptus* leaves which have low caloric content and nutritional value and are toxic to many other species (Van Dyck and Strahan, 2008).

2.3. Conceptual model framework

We employed a quantitative risk model framework (Visintin et al., 2016) to examine how collision risk of each species related to occurrence of the species, traffic volume, and traffic speed on all road segments. Using the open-source software package 'R' version 3.3.0 (R Core Team, 2016) to perform all statistical analyses, we developed species distribution models (SDM) to predict occurrence across the study area for each of the six species, and linear regression models to predict traffic volume and speed. Predicted traffic volume and speed values for all road segments were modelled by regressing annual average daily traffic (AADT) counts and posted speed limit data on anthropogenic variables using *Random Forests*; detailed methods are provided in Visintin et al. (2016).

2.4. Species occurrence models

We obtained observation records of the six study species from the Victorian Biodiversity Atlas (VBA) that satisfied the following criteria: survey date between 1 January 2000 and 31 December 2013 and spatial coordinate certainty of ≤500 m (DELWP, 2015). As our occurrence models are correlative, we grouped the records based on identical spatial coordinates regardless of observation dates; thus multiple observations were aggregated to single presence observations in space. For each of the six study species, we selected all 1 km^2 grid cells that contained at least one occurrence record to represent presences across the study area. This ensured that we maintained at least 1000 m between all observations. As we did not have access to recorded absence data, we randomly selected 10,000 1 km^2 grid cells (without replacement) within the study area as background data and combined them with presence