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Systematic review

A review of searcher efficiency and carcass persistence in infrastructure-driven mortality assessment studies

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ABSTRACT

Infrastructures in natural areas are expanding rapidly worldwide. Consequently, roads, power-lines, and wind-farms cause millions of fatalities across several animal groups. Assessing the population impact of these infrastructures requires sound estimates of the total number of fatalities. These estimates can be heavily biased due to differences in searcher efficiency and carcass persistence rates, which may ultimately lead to the incorrect quantification of actual mortality, or to the inadequate prioritization of locations for mitigation. We reviewed 294 studies using carcass surveys conducted worldwide and performed analyses on the effects of variables potentially influencing searcher efficiency and carcass persistence rates. Our analytical review, including the largest number of studies to date, the use of multivariate approaches, and the study weighting by sample size, contradicts some previous findings. Whereas body mass is confirmed as the most important variable accounting for both biases, equally important was the use of dogs in searches, as they increased searcher efficiency for small carcasses, and the taxon of carcasses for persistence, as mammals persisted at higher rates than birds and the latter at higher rates than amphibians. Our results provide little support for previous ideas on the influence of the use of domestic or thawed carcasses on persistence rates. Our findings contribute to synthesizing knowledge on the main factors affecting the two main mortality biases across carcass field experiments, and suggest recommendations for improving survey designs in future studies to minimize the biases identified.

1. Introduction

The human footprint is rapidly growing worldwide, with few places on Earth not affected by the vast network of linear infrastructure and its associated impacts (Loss et al., 2015; Ibisch et al., 2016). Several authors have highlighted the mortality of wildlife species, from elephants to invertebrates, caused by roads and railways (van der Ree et al., 2015; Borda-de-Água et al., 2017), or by collision and electrocution with power-lines (Lehman et al., 2007; Loss et al., 2015; Bernardino et al., 2018; D'Amico et al., 2018). The recent development of wind-farms also poses an important source of mortality for birds and bats (Kunz et al., 2007; Marques et al., 2014). Additionally, collisions with other human structures like communication towers, windows or fences also cause wildlife fatalities (Stevens and Dennis, 2013; Loss et al., 2015). However, great uncertainty exists about the impact of this mortality on the population viability of the affected species, a key question from an ecological perspective (Loss et al., 2015; Barrientos and Borda-de-Água, 2017).

Surveys of dead animals have been widely used to estimate fatality rates caused by infrastructures (e.g. Barrientos et al., 2012; Stevens and Dennis, 2013; D'Amico et al., 2015; Ascensão et al., 2017). The number of carcasses found during surveys is an underestimated measure of the true mortality rate, as it is affected by two major biases: the overlooking of carcasses, the probability of a researcher not finding a carcass present

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in the field; and carcass disappearance, the probability of a carcass disappearing before being counted due to removal by scavengers or other means. These are the two most important biases because they can affect mortality estimates for all infrastructure types, and therefore have been the subject of numerous studies. To a lesser extent, habitat is another bias accounted for but this lacks comparability among studies. Finally, crippling bias might be considerable for certain infrastructure like power-lines, but this has rarely been quantified (but see Savereno et al., 1996; Bevanger and Brøseth, 2004; Murphy et al., 2016). Adequate quantification of biases is needed to better evaluate the impact of roads (Beckmann and Shine, 2015; Skórka, 2016), railways (Barrientos et al., 2017), power-lines (Ponce et al., 2010), and wind-farms (Kunz et al., 2007; Smallwood, 2007, 2013; Arnett et al., 2008) on wildlife. This is not a trivial matter, as the better these estimations are, the better we will be able to identify impacted species, locate mortality hotspots, implement adequate mitigation measures (Barrientos et al., 2011; van der Ree et al., 2015), and parameterize the fraction of mortality associated with human-related causes to forecast its impact on population viability (Hels and Buchwald, 2001; van der Ree et al., 2009; Borda-de-Água et al., 2014). Some authors have argued for more scientifically sound, peer-reviewed research on these biases to develop carcass-monitoring protocols that include fewer, smaller biases (Kunz et al., 2007; Smallwood, 2007, 2013). This reflects the growing interest of both scientists and practitioners in this topic, with an increasing amount of literature available. Nevertheless, despite the existence of some specific protocols, such as those from the American National Wind Coordinating Collaborative (NWCC) (Anderson et al., 1999; Strickland et al., 2011), there is a lack of broadly applicable guidelines to minimize biases in mortality estimates in field trials.

In this study, we performed an analytic review of the main variables affecting the two most important biases in studies which aimed to correct mortality estimators associated with human infrastructures. First, we reviewed studies that quantified overlooked carcass bias by assessing the *searcher efficiency rate* (the percentage of carcasses found by the searchers), by placing trial carcasses and calculating the proportion of them found by uninformed surveyors. Second, we reviewed studies that estimated carcass disappearance bias by estimating *carcass persistence rate* (percentage of carcasses that persisted) by placing trial carcasses and monitoring their persistence in the field for a specified period of time. We focused on these approaches because they are the most commonly employed in the literature, although other methods like mark-recapture have been used as well. Corrections taking these biases into account aim to adjust the number of carcasses found during surveys in order to estimate the actual number of fatalities, which is key to understanding the population-level impacts on wildlife associated with human infrastructure. Despite the fact that these trials are a common component of monitoring programs for some types of infrastructure, like wind-farms or power-lines, they are scarce or absent in others, like road or railway studies (van der Ree et al., 2015; Barrientos et al., 2017). Furthermore, methodological details are highly variable among studies. This is the case, for instance, with the sampling interval between searches, the number of replicates per study area, and the origin (e.g. domestic vs. wild) or condition (e.g. fresh vs. defrosted) of carcasses (Arnett et al., 2008; Smallwood, 2007, 2013). Additionally, the reliability of the correction estimates is often compromised by limitations of time and financial resources, leading to trials with insufficient sample sizes that limit applicability (Arnett et al., 2008; Smallwood, 2013). This can lead to simplistic assumptions in study designs (e.g. a lack of testing of potential taxon-related differences), to discordant results, or even to misleading findings (Arnett et al., 2008; Smallwood, 2007, 2013). To explore the drivers of searcher efficiency and carcass persistence rates we carried out a systematic review, with the additional novelty that we used the trial sample size to weight the importance of every single trial. This approach lends more importance to the patterns found in those experiments with larger sample sizes, thus avoiding spurious conclusions.

Specifically, we aimed to address the following hypotheses, based on previous research: for searcher efficiency trials, we expected that: i) dogs perform better than humans (e.g. Paula et al., 2011; Reyes et al., 2016); ii) searcher efficiency varies among habitats and seasons (Arnett et al., 2008); iii) detectability increases with searcher experience (Ponce et al., 2010); and iv) larger carcasses are detected at higher rates (reviewed for birds at wind-farms in Smallwood, 2007). For carcass persistence trials, we expected that: v) larger carcasses persist at higher rates (Smallwood, 2007); vi) fresh carcasses are removed at higher rates than thawed ones (see Kerns et al., 2005 for bats); vii) mammals are removed more rapidly than birds (Kerns et al., 2005); and viii) carcasses from wild specimens are removed at a different rate than those of domestic specimens (Prosser et al., 2008; Urquhart et al., 2015). These are the most common factors addressed in the literature to date, and are testable with the dataset available. However, it is worth mentioning that other, and perhaps a minority of, hypotheses were not studied here: density of carcasses and scavenger swamping is mainly related to wind-farm studies (reviewed in Smallwood, 2007); carcass colour is not specified in several studies, and we could not test it; very few studies tested whether searchers were aware of the trial; and road traffic flow is only applied to road-related studies (see below). Based on evaluations of our selected hypotheses, we aimed to set recommendations for future trials.

2. Materials and methods

2.1. Data collection

We searched ISI Web of Science in October 2016 for experiments that corrected mortality estimates to obtain a set of papers potentially useful for our review, using a combination of the terms 'carcass', 'trial', and 'searching'. We carried out a similar search in Google Scholar™, which also includes reports and other sources. Whereas the inclusion of reports does not bias analytical reviews (Barrientos et al., 2011), they notably increased the number of studies potentially useful for review. However, in order to retain only the most significant studies, and following the recommendations by Haddaway et al. (2015), we focused the Google Scholar search on the first 300 results. We also identified additional studies in the reference lists of the papers and reports found with the above mentioned search engines. In order to facilitate future research, all the studies we reviewed (294) are listed in Table S1. Carcass searches and the assessment of the potential associated biases are usually carried out in studies on the impacts of human infrastructure like wind-farms, power-lines, fences, solar plants or communication towers. Furthermore, as the same methodology has been employed in studies on pesticides, oil spills and epidemic outbreaks, all of these study sources are found in Table S1. In order to focus solely on studies with more reliable research designs, we restricted the studies included in our analyses to those complying with the following conditions: i) a known number of carcasses were experimentally placed in the field; ii) whole carcasses were used (either virtually undamaged or euthanized) or, in the case of incomplete carcasses, their exact weights were provided; and iii) sample sizes were larger than five carcasses. In searcher efficiency experiments, we discarded those studies using decoys, as their realism was highly variable ranging from dissected specimens to simple plastic tubes. In persistence experiments, we only selected studies that reported the persistence rate for the first 24 h.

Although we agree that the inclusion of feather spots could increase the realism of the correction biases (Stevens et al., 2011; Smallwood, 2013; Reyes et al., 2016), we did not take into account these trials because feather spots cannot be related to a known carcass weight. Furthermore, a small number of feathers is not necessarily evidence of mortality (Balcomb, 1986; Ponce et al., 2010). For carcass persistence, we only used studies for which persistence rates were reported after 24 h to reduce heterogeneity, as the use of the average number of days that a carcass persists would have biased the estimates, since there is an