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Experimental study designs to improve the evaluation of road mitigation measures for wildlife

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A B S T R A C T

An experimental approach to road mitigation that maximizes inferential power is essential to ensure that mitigation is both ecologically-effective and cost-effective. Here, we set out the need for and standards of using an experimental approach to road mitigation, in order to improve knowledge of the influence of mitigation measures on wildlife populations. We point out two key areas that need to be considered when conducting mitigation experiments. First, researchers need to get involved at the earliest stage of the road or mitigation project to ensure the necessary planning and funds are available for conducting a high quality experiment. Second, experimentation will generate new knowledge about the parameters that influence mitigation effectiveness, which ultimately allows better prediction for future road mitigation projects. We identify seven key questions about mitigation structures (i.e., wildlife crossing structures and fencing) that remain largely or entirely unanswered at the population-level: (1) Does a given crossing structure work? What type and size of crossing structures should we use? (2) How many crossing structures should we build? (3) Is it more effective to install a small number of large-sized crossing structures or a large number of small-sized crossing structures? (4) How much barrier fencing is needed for a given length of road? (5) Do we need funnel fencing to lead animals to crossing structures, and how long does such fencing have to be? (6) How should we manage/manipulate the environment in the area around the crossing structures and fencing? (7) Where should we place crossing structures and barrier fencing? We provide experimental approaches to answering each of them using example Before-After-Control-Impact (BACI) study designs for two stages in the road/mitigation project where researchers may become involved: (1) at the beginning of a road/mitigation project, and (2) after the mitigation has been constructed; highlighting real case studies when available.

1. Introduction

Roads and traffic have negative impacts on a wide range of animals (reviewed in Trombulak and Frissell, 2000; Spellerberg, 2002; Fahrig and Rytwinski, 2009; Benítez-López et al., 2010; Rytwinski and Fahrig, 2012; van der Ree et al., 2015a). The main focus of road ecology research is to quantify these negative impacts, with the aim of avoiding, minimizing, mitigating, or offsetting negative impacts on individuals, populations, communities, and ecosystems (van der Ree et al., 2011). Options to avoid or mitigate these negative impacts are numerous and have been widely and increasingly implemented around the world (van der Ree et al., 2015b). Examples of mitigation measures include: animal

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detection systems, wildlife warning signs, changes in road-verge management, measures to reduce traffic volume, speed and/or noise, temporary road closures, wildlife crossing structures, wildlife fences [e.g., barrier fencing (or exclusion fencing) that prevents wildlife from accessing the road, or funnel fencing that primarily funnels animals to wildlife crossing structures but can also prevent wildlife from accessing the road], wildlife reflectors, wildlife repellents, and modified road designs/viaducts/bridges/lighting (Clevenger and Ford, 2010; Huijser and McGowen, 2010). Wildlife crossing structures (e.g., under- or over-passes: amphibian tunnels, badger pipes, ledges in culverts, land bridges, rope bridges, glider poles), combined with fencing to prevent mortality and funnel wildlife towards crossing structures, have gained considerable recent attention by transportation agencies because they enhance landscape connectivity without affecting traffic flow (van der Grift et al., 2013).

There is compelling evidence that many wildlife species regularly and frequently use crossing structures (reviewed in van der Ree et al., 2007), and that well-designed and maintained fencing greatly reduce rates of wildlife mortality and funnels animals towards the crossing structures (reviewed in Glista et al., 2009). Unfortunately, documenting use of a crossing structure (i.e., 'success' at the individual level) is so far removed from higher level quantities of interest (i.e., population size and persistence), that such studies provide little information as to whether the structure actually mitigates the effect of the road enough to ensure a viable population (van der Grift et al., 2013). Consequently, the influence of these mitigation structures on population viability is unclear for most road-affected species.

Ultimately, we want to be confident that the predicted impact of a road on a wildlife population will be at least partially mitigated by the proposed road design and that the investment in crossing structures and/or fencing is justified. For example, if the mitigation for an endangered species is ineffective such that the population of the target species declines, the road agency must respond and retrofit the road or modify the mitigation structures. In such cases, it is essential that road agencies have reliable evidence to make informed decisions about which feature of the road or mitigation should be implemented or modified and by how much.

Here we identify seven key questions road planners commonly have about crossing structures and/or fencing that for many species and structure types remain largely unanswered at the level of ultimate concern (e.g., population or community) and at the required level of certainty by existing research (Box 1). These questions must be answered not only so that resources for road mitigation are allocated in the most effective manner, but that they indeed have the predicted (desired) effect.

There are two main reasons why these questions have remained unanswered. First, the existing approach to road mitigation is to simply adopt current best-practice in terms of the type, number, and location of mitigation. While this approach identifies the best known mitigation for installation, it does not explicitly facilitate learning about the effectiveness of mitigation because the mitigation was installed to solve a problem, not generate new information. Second, studies evaluating the effectiveness of mitigation structures have low inferential strength, and, as such, comparatively low predictive power. For example, studies often lack: (1) comparisons between treatment sites (also referred to as 'impact' sites in Before-After-Control-Impact (BACI) study designs (Roedenbeck et al., 2007; van der Ree et al., 2015b)) and control sites (i.e., sites that have not been affected by the treatment – these will vary depending on the question and goals of the road mitigation, but may include e.g., road-free areas, areas with narrow or low-traffic volume roads, unmitigated roads, and/or unmanipulated mitigation measures; see section 5 on experimental designs for more detail); (2) data on population sizes or trends prior to mitigation; (3) replication in both space and time; and (4) randomization of treatment and control sites across the pool of potential study sites. Moreover, many study designs confound mitigation variables (e.g., overpass width, density of shrubs at culvert entrance) such that their independent effects cannot be evaluated (reviewed in van der Ree et al., 2007; Glista et al., 2009). For road agencies to make informed and reliable decisions, we need to improve the rigor of studies that evaluate the effectiveness of mitigation measures.

Ways to improve the quality and impact of road ecology research and monitoring have been previously discussed. Roedenbeck et al. (2007) provided a research agenda for road ecology, identifying relevant questions (e.g., Under what circumstances do roads affect population persistence?, and Under what circumstances can road effects be mitigated?), and specifying a hierarchy of study designs for answering these questions. van der Grift et al. (2013) used the principles outlined in Roedenbeck et al. (2007) to propose a methodological framework for increasing the inferential strength of mitigation monitoring schemes. Lesbarrères and Fahrig (2012) proposed the use of such monitoring schemes as a type of experiment, but they did not suggest associated experimental protocols. van der Ree et al. (2015b) summarises these papers into an accessible format for practitioners. Here, we set out the need and standards for using experimental approaches to road mitigation to improve knowledge on the influence of mitigation structures on wildlife populations. We first demonstrate the need for an experimental (manipulative) approach to road mitigation projects. We then outline the road/mitigation project stages and describe how flexibility in experimental design depends on the stage in the road project at which researchers become involved. We provide experimental approaches to answering each of the questions in Box 1, highlighting real case studies when possible, and we conclude with a discussion of potential issues in using experimentation to evaluate the effectiveness of crossing structures and fencing.

Box 1
Seven key questions road planners commonly have about crossing structures and fencing.

Questions road planners have about mitigation structures:

Question 1
Does a given crossing structure work? What type and size (width, height and length) of crossing structures should we use?

Question 2
How many crossing structures should we build?

Question 3
Is it more effective to install a small number of large-sized crossing structures or a large number of small-sized crossing structures?

Question 4
How much barrier fencing is needed for a given length of road?

Question 5
Do we need funnel fencing to lead animals to crossing structures, and how long does such fencing have to be?

Question 6
How should we manage/manipulate the environment in the area around the crossing structures and fencing?

Question 7
Where should we place crossing structures and barrier fencing?

2. Why we need an experimental approach to road mitigation

Most road agencies currently evaluate the effectiveness of