WILDLIFE CROSSING STRUCTURES: CAN WE PREDICT EFFECTS ON POPULATION PERSISTENCE?

Edgar A. van der Grift (+31 (0)317 486011, edgar.vandergrift@wur.nl), MSc, Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, Netherlands

Peter Schippers (+31 (0)317 485018, peter.schippers@wur.nl), PhD, Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, Netherlands

ABSTRACT

Wildlife crossing structures are important means to mitigate road impacts. While empirical studies that examine population-level effects of crossing structures are rare, monitoring the use of crossing structures has become a routine in many countries. Our objective is to explore whether empirical data on crossing structure use can be used to assess to what extent the impacts of roads on population persistence have been mitigated. We investigate whether general guidelines can be developed on how many crossings should take place per year to maintain viable populations and what this implies for the number and type of crossing structures. We analyzed population survival probabilities for three species of different size classes with the model METAPOP in a simple landscape: two suitable habitat patches that are separated by a road over which a wildlife overpass has been constructed. We varied (1) the maximum size (carrying capacity) of the subpopulations on either side of the road, and (2) the percentage of mixing, i.e. the percentage of the total number of animals in the population that take part in the exchange across the road. We ran analyzes for three model species that represent a small, medium-sized and large mammal species. As indicator for population performance, we used the percentage of time that one of the habitat patches – hereafter referred to as the target area – was occupied by a population. The simulations showed for all model species that mixing, i.e. the exchange of animals across the overpass, has a positive effect on population persistence if small to medium-sized target areas are linked with medium-sized to large source areas. Only small effects of mixing occur when the target area is large, as the population in the target area will be large enough to survive on its own. Furthermore, small effects of mixing occur when the source area is small, as the population in such areas will be too small to significantly affect population persistence. Although models can never be a full substitute of empirical studies into road mitigation effectiveness, they provide us with a quick scan of possible bottlenecks and indicative predictions whether preset population-level objectives are being met. The model simulations, together with data on crossing frequencies acquired in field surveys, help to assess what types of wildlife crossing structure, and how many, are needed in any particular situation to facilitate the necessary wildlife movements. Although model simulations do not exactly reflect reality due to model assumptions and the rather simple model landscape chosen, they do provide a first indication whether our road mitigation measures are, in terms of improving population persistence, on the right track or not. Consequently, guidelines derived from these simulations will allow for better decision making and planning of future crossing structures.

INTRODUCTION

Wildlife crossing structures are an important means to mitigate road impacts. Until now only a few studies have been carried out that fully evaluate the effectiveness of such road mitigation measures, including impacts on population persistence (*Fahrig and Rytwinski 2009*). The difficulty with such studies in practice, is that they are often time-consuming, costly and complicated to carry out (*Van der Grift et al. 2013a*). After all, for proper evaluations of population-level effects a BACI study design is preferred. In such study design population parameters are measured both before and after the construction of the crossing structures, at both sites where crossing structures are build and sites where they are not (see also *Roedenbeck et al. 2007*). While empirical studies that examine population-level effects of crossing structures are rare, monitoring the use of wildlife crossing structures has become a routine in many countries. Our objective is to explore, through population modeling, whether empirical data on crossing structure use can be used to answer the question of to what extent the impacts of the road and traffic on population persistence have been mitigated. We investigate whether general guidelines can be developed on how many crossings should take place per year to maintain viable populations and what this implies for the number and type of crossing structures.

METHODS

We analyzed population survival probabilities for three species of different size classes with the model METAPOP (*Schippers et al. 2009*) in a simple landscape: two suitable habitat patches that are separated by a road over which a wildlife overpass has been constructed (Fig. 1). We assumed that animals which used the crossing structure mix with the subpopulation on the other side of the road. All animals in both subpopulations have the same probability to cross the road, no matter if they cross for the first time or have crossed before. The model simulates population dynamics in space and time with the help of Leslie-matrices. Each year the following lifecycle events occur: recruitment, adult mortality, and mixing of animals of all age groups over both habitat patches. Population growth was limited by density dependent recruitment that yields zero growth at carrying capacity. We ran analyzes for three model species that represent a small, medium-sized and large mammal species. Appendix A provides an overview of the parameters used in the simulation for each model species.

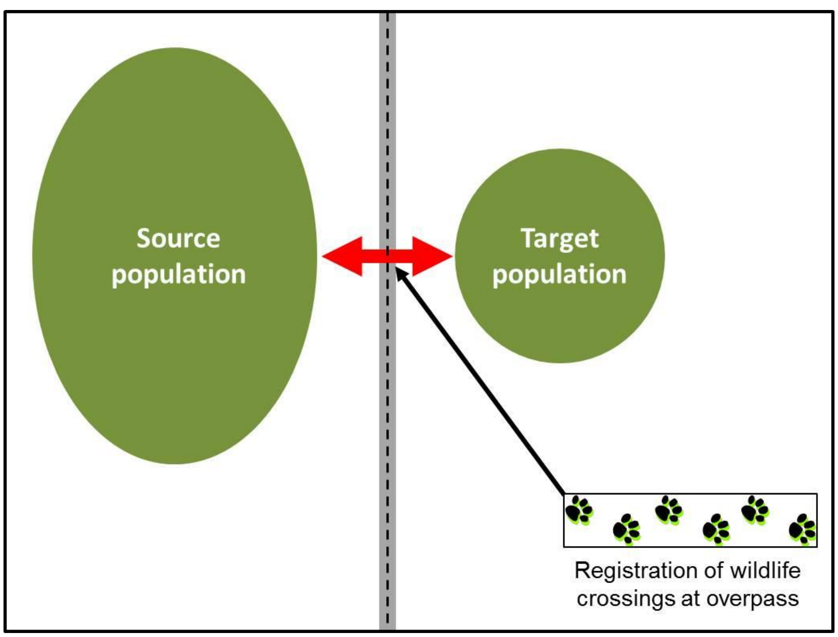

FIGURE 1 Model landscape in which population survival probabilities were analyzed.

We varied (1) the maximum size (carrying capacity) of the subpopulations on either side of the road (2, 4, 8, 12, 16, 20, 30, 40, 50, 60, 70, 80, 100, 120, 140, 160, 180, 200, 220, 240 individuals), and (2) the percentage of mixing (0, 1, 2, 5, 10, 20, 50, 100%), i.e. the percentage of the total number of animals in the population that take part in the exchange across the road. A mixing percentage of 100% means that all individuals in the population are randomly allocated to one of the two subpopulations every year, in proportion with the maximum size of each subpopulation. For example, if carrying capacity of the largest subpopulation is 60% of that of the total population, all animals will have a probability of 0.6 to be allocated to that subpopulation and 0.4 to be allocated to the other subpopulation. In this case the number of animals that cross the overpass is such that both subpopulations function as one well mixed population. Hence, this scenario can be used as a baseline as it represents – in case of relatively small habitat patches – the situation before the road was built. In case of mixing percentages less than 100 but not 0, first the individuals that will take part in the mixing will be stochastically determined. For example, in case of a mixing percentage of 50%, each animal in both subpopulations has a probability of 0.5 to take part in the mixing. The selected animals will then again be randomly allocated to one of the two subpopulations in proportion with the maximum size of each subpopulation. Note that the percentage of mixing is directly related to the number of crossings at the overpass as it can be calculated through:

$$M\% = \left[1 - \exp\left(\frac{-N_s}{2 \cdot N_t \cdot A_s \cdot (1 - A_s)}\right)\right] \cdot 100$$

where:

N_s = number of crossings of a species per year at the overpass, regardless the direction
N_t = total number of animals in both subpopulations
A_s = area fraction of the smallest subpopulation

Population persistence was measured in only one of the two subpopulations, which we will further refer to as the *target population*. The subpopulation on the other side of the road is addressed as the *source population*. The habitat patches in which these populations occur are respectively referred to as *target area* and *source area*. As indicator for population performance, we used the percentage of time that the target area was occupied by a population. A population is here defined as at least one adult male and one adult female. The simulations were initiated at 75% of carrying capacity and cover 200 years. Occupation of the target area was monitored between year 100 and 200. For each scenario, differing in population size of the target area and source area and differing in mixing percentage, 100 simulations were run.

RESULTS

The simulations showed for all model species that mixing, i.e. the exchange of animals across the overpass, has a positive effect on population persistence if small to medium-sized target areas are linked with medium-sized to large source areas. No or only small effects of mixing occur when the target population is large, as it will be large enough to survive on its own. Furthermore, no or only small effects of mixing occur when the source population is small, as it will be too small to significantly affect population persistence of the target population.

Appendix B provides one example of the 60 model simulation output tables (3 species x 20 population sizes at carrying capacity in the source area; *Van der Grift et al. 2013b*). This table can be used, together with the above presented formulae for calculating mixing percentage, to estimate whether the number of crossings registered at an existing overpass will be enough for the survival of the population. For example, if at an overpass 146 red deer crossings are registered in a year (N_s), estimated population size is 100 animals (N_t), and the population is divided by the road in a ratio of 70-30% (A_s), mixing percentage is 97% (see equation). Hence, measured use of the overpass results in almost full mixing of the population. This calculated mixing percentage can be used to explore population persistence. To do so we use the for this example relevant table (Appendix B), i.e. the table for large mammal species and a source area that provides habitat for 70% of the total population. The table tells us that at 50% and 100% mixing – between which 97% occurs – occupation probability of the target area is 100%. Hence, the measured crossing frequencies of red deer at the overpass are expected to be high enough for the red deer population to survive.

Likewise, the model simulations allow us to calculate the minimum number of crossings needed to ensure population persistence at locations where a crossing structure still needs to be build. This may help decision-making on what type of crossing structure is needed and/or how many of them should be installed, with the use of empirically determined species performance ratios for each type of crossing structure.

CONCLUSIONS

Although models can never be a full substitute of empirical studies into road mitigation effectiveness, they provide us with a quick scan of possible bottlenecks and indicative predictions whether preset population-level objectives are being met. Here we developed general guidelines - based on model simulations - for the number of movements across an overpass needed for population persistence. Hence we linked information on the use of crossing structures, i.e. the variable that most monitoring studies focus on, to population persistence. The model simulations, together with data on crossing frequencies acquired in field surveys, help to assess what type of wildlife crossing structure, and how many, are needed in any particular situation to facilitate the necessary wildlife movements. Although the model simulations do not exactly reflect reality due to model assumptions and the rather simple model landscape chosen, they do provide an indication whether our road mitigation measures are, in terms of improving population persistence, on the right track or not. Consequently, guidelines derived from these simulations will allow for better decision making and planning of future crossing structures.

ACKNOWLEDGEMENTS

This research has been financed by the Dutch Ministry of Economy, Agriculture and Innovation - Policy Support Research Nature, Landscape and Countryside, Theme Biodiversity, Subtheme Networks, Habitats and Species, BO-11-011.03-003.

BIOGRAPHICAL SKETCHES

Edgar A. van der Grift
Edgar van der Grift works as a senior research scientist at Alterra, part of Wageningen University and Research Center, The Netherlands. In his research he focuses on the impacts of habitat fragmentation on wildlife populations and the effectiveness of measures that aim to restore habitat connectivity, e.g., the establishment of landscape linkages, ecological corridors and wildlife crossing structures at roads and railroads. Besides his scientific research he acts as a consultant for policy makers, road planners and conservation groups during the preparation and implementation phase of projects that aim for the establishment of effective ecological networks and road mitigation measures.

Peter Schippers
Peter Schippers works as a research scientist at the Biodiversity and Policy group of Alterra and the Forest Ecology and Management group of Wageningen University, The Netherlands. In his research he focuses on ecological modelling. His work includes spatial explicit population models and plant growth and competition models as well as models related to habitat connectivity and the impacts of roads and traffic on nature conservation.

REFERENCES

Fahrig, L. and T. Rytwinski (2009) Effects of roads on animal abundance: An empirical review and synthesis. Ecology and Society 14: http://www.ecologyandsociety.org/vol14/iss1/art21.

Roedenbeck, I.A., L. Fahrig, C.S. Findlay, J.E. Houlahan, J.A.G. Jaeger, N. Klar, S. Kramer-Schadt and E.A. van der Grift (2007) The Rauischholzhausen agenda for road ecology. Ecology and Society 12: http://www.ecologyandsociety.org/vol12/iss1/art11.

Schippers, P., R.P.H. Snep, A.G.M. Schotman, R. Jochem, E.W.M. Stienen and P.A. Slim (2009) Seabird metapopulations: searching for alternative breeding habitats. Population Ecology 51:459-470.

Van der Grift, E.A., R. van der Ree, L. Fahrig, S. Findlay, J. Houlahan, J.A.G. Jaeger, N. Klar, L.F. Madriñan and L. Olson (2013a) Evaluating the effectiveness of road mitigation measures. Biodiversity and Conservation 22: 425-448. DOI 10.1007/s10531-012-0421-0.

Van der Grift, E.A., R. Pouwels, P. Schippers, H.A.H. Jansman, R. Jochem, M.M.P. Cobben, J. Bovenschen, T. Hofmeester, J. van der Hout, H.P. Koelewijn, D.R. Lammertsma, F.G.W.A. Ottburg and R.M.A. Wegman (2013b) Ecological networks: form and function. Evaluation of promising strategies and indicators for biodiversity conservation within the Dutch National Ecological Network and the European NATURA 2000 network. Alterra-report 2390. Alterra, Wageningen, Netherlands. [in Dutch]

APPENDIX A: MODEL PARAMETERS

TABLE 1 Parameters and Values used in the Simulations with METAPOP for each Model Species

Parameter	Unit	Model species		
		Small mammal	*Medium-sized mammal*	*Large mammal*
Lifetime	Year	3.3	5	10
Survival probability adults	$Year^{-1}$	0.7	0.8	0.9
Recruitment 1 year old animals (male+female)	$Male_{juv}$ + $Female_{juv}$ $female^{-1}$ $year^{-1}$	0	0	0
Recruitment 2 year old animals (male+female) (D=0) #	$Male_{juv}$ +$Female_{juv}$ $female^{-1}$ $year^{-1}$	2	1	0
Recruitment ≥3 year old animals (male+female) (D=0)	$Male_{juv}$ + $Female_{juv}$ $female^{-1}$ $year^{-1}$	2	1	0.5
Recruitment at carrying capacity (D=1) *	$Male_{juv}$ + $Female_{juv}$ $female^{-1}$ $year^{-1}$	0.86	0.5	0.25
Recruitment factor at carrying capacity, i.e. ratio of recruitment at carrying capacity and recruitment ≥3 year old animals (male+female)	-	0.42	0.5	0.5
Standard deviation Survival	$Year^{-1}$	0.18	0.12	0.03
Standard deviation Recruitment	$Year^{-1}$	1	0.35	0.1
Sexes	-	2	2	2
Growth D=0, i.e. growth at low densities	$Year^{-1}$	1.256	1.148	1.075
Growth D=1, i.e. growth at carrying capacity	$Year^{-1}$	0	0	0

D = relative density, i.e. the number of animals / carrying capacity.
* The recruitment decreases linearly between D=0 and D=1.

APPENDIX B: EXAMPLE MODEL OUTPUT

TABLE 2 Occupation Probabilities in the Target Area, i.e. the Percentage of Time the Target Area is Populated

Model species: Large mammal **Carrying capacity source area:** 70							
Carrying capacity target area	% mixing						
	0	1	5	10	20	50	100
2	0%	18%	51%	70%	78%	85%	88%
4	0%	33%	82%	92%	96%	98%	98%
8	12%	65%	98%	100%	100%	100%	100%
12	43%	88%	100%	100%	100%	100%	100%
16	70%	97%	100%	100%	100%	100%	100%
20	79%	98%	100%	100%	100%	100%	100%
30	94%	100%	100%	100%	100%	100%	100%
40	99%	100%	100%	100%	100%	100%	100%
50	100%	100%	100%	100%	100%	100%	100%
60	100%	100%	100%	100%	100%	100%	100%
70	100%	100%	100%	100%	100%	100%	100%
80	100%	100%	100%	100%	100%	100%	100%
100	100%	100%	100%	100%	100%	100%	100%
120	100%	100%	100%	100%	100%	100%	100%
140	100%	100%	100%	100%	100%	100%	100%
160	100%	100%	100%	100%	100%	100%	100%
180	100%	100%	100%	100%	100%	100%	100%
200	100%	100%	100%	100%	100%	100%	100%
220	100%	100%	100%	100%	100%	100%	100%
240	100%	100%	100%	100%	100%	100%	100%