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Systematic review

The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis

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ABSTRACT

Biodiversity is being lost at an increased rate as a result of human activities. One of the major threats to biodiversity is infrastructural development. We used meta-analyses to study the effects of infrastructure proximity on mammal and bird populations. Data were gathered from 49 studies on 234 mammal and bird species. The main response by mammals and birds in the vicinity of infrastructure was either avoidance or a reduced population density. The mean species abundance, relative to non-disturbed distances (MSA), was used as the effect size measure. The impact of infrastructure distance on MSA was studied using meta-analyses. Possible sources of heterogeneity in the results of the meta-analysis were explored with meta-regression.

Mammal and bird population densities declined with their proximity to infrastructure. The effect of infrastructure on bird populations extended over distances up to about 1 km, and for mammal populations up to about 5 km. Mammals and birds seemed to avoid infrastructure in open areas over larger distances compared to forested areas, which could be related to the reduced visibility of the infrastructure in forested areas. We did not find a significant effect of traffic intensity on the MSA of birds. Species varied in their response to infrastructure. Raptors were found to be more abundant in the proximity of infrastructure whereas other bird taxa tended to avoid it. Abundances were affected at variable distances from infrastructure: within a few meters for small-sized mammals and up to several hundred meters for large-sized mammals.

Our findings show the importance of minimizing infrastructure development for wildlife conservation in relatively undisturbed areas. By combining actual species distributions with the effect distance functions we developed, regions sensitive to infrastructure development may be identified. Additionally, the effect distance functions can be used in models in support of decision making on infrastructure planning.

1. Introduction

Global biodiversity is changing at an unprecedented rate as a result of several human-induced changes in the global environment (Vitousek, 1994; Pimm et al., 1995; Sala et al., 2000; MEA, 2005). Biodiversity loss at the species level tends to result in the so-called homogenisation process (Lockwood and McKinney, 2001). This process is generally characterised by a decrease in the abundance of many species, culminating into an increase in the number of threatened species and the extinction of others, in combination with a simultaneous increase in the abundance of a few species. The main drivers of biodiversity change are land-use and land-cover change, climate change, pollution, fragmentation and infrastructure development (UNEP, 2001; Sala et al., 2000; Sanderson et al., 2002; Alkemade et al., 2009).

The ubiquity of road networks and the growing body of evidence of the negative impacts that roads and other linear infrastructure have on wildlife and ecosystems suggest that infrastructure represents a major driving factor of biodiversity loss. The most commonly reported impacts from roads and utility corridors include habitat loss, intrusion of edge effects in natural areas, isolation of populations, barrier effects, road mortality and increased human access (Andrews, 1990; Forman and Alexander, 1998; Spellerberg, 1998; Trombulak and Frissell, 2000; Forman et al., 2003). Road construction leads to habitat destruction and creates open spaces in otherwise closed forests (Gullison and Hardner, 1993; Reed et al., 1996; Santos and Tabarelli, 2002). The open spaces may fragment populations (barrier effect), attract light-demanding species and may be avoided by others (edge effect)

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(Kroodsma, 1984; Vos and Chardon, 1998; Bolger et al., 1997; Ortega and Capen, 1999). Additionally, the use of infrastructure by cars or trains increases the risk of collisions with wildlife and the stress on (breeding) individuals (due to noise and visual stimuli), both of these risks affecting animal populations (Van der Zande et al., 1980; Reijnen et al., 1996; Romin and Bissonette, 1996; Boarman and Sazaki, 2005; Parris and Schneider, 2009).

Besides roads, other types of infrastructure, such as railways, powerlines, pipelines, hydroelectric developments, oil wells, seismic lines and wind parks, have an impact on wildlife populations (Dunthorn and Errington, 1964; McLellan and Shackleton, 1989; Cameron et al., 1992; Van Dyke and Klein, 1996; Mahoney and Schaefer, 2002; Nellemann et al., 2003a; Barrios and Rodriguez, 2004). All these impacts may influence the long-term viability of populations and, eventually, biodiversity.

Qualitative reviews provide a broad understanding of the ecological effects of infrastructure that affect a range of taxa and ecosystems, but lack quantitative evidence (Trombulak and Frissell, 2000; Forman et al., 2003). However, the few attempts to quantify the effects of infrastructure (UNEP, 2001; Nellemann et al., 2003b; Fahrig and Rytwinski, 2009), or to model the vulnerability of animal populations to road effects (Jaeger et al., 2005), are not based on meta-analysis, which is the statistical procedure for combining the results of independent studies in a quantitative way (Arnqvist and Wooster, 1995). In this study, we aim at estimating the decline of animal populations in relation to proximity to infrastructure by using a meta-analytical approach.

Among all animal taxa, mammal and bird populations were chosen for our analysis since both have been widely reported to be declining in relation to their distance from infrastructure. However, large differences in disturbance sensitivity seem to exist between and within these groups. Bird populations seem to be affected within a few hundred metres from infrastructure, whereas a reduction in mammal populations has been found at distances of a few hundred metres up to several kilometres from infrastructure (McLellan and Shackleton, 1989; Cameron et al., 1992; Ortega and Capen, 1999; Nellemann et al., 2003a). Additionally, traffic intensity seems to play a role in the decline of both bird and mammal populations close to roads (Van der Zande et al., 1980; Reijnen et al., 1995, 1996; Dyer et al., 2001; Rheindt, 2003; Gagnon et al., 2007).

To quantify the patterns of reduced population densities in relation to infrastructural development, we searched the scientific and non-scientific literature for quantitative data on mammal and bird populations at varying distances from infrastructure. As the metric of effect size, we calculated the ratio between the species abundance at varying distances to infrastructure (Disturbance or Effect distance) relative to the species abundance at the largest (control) distance reported in the study. This ratio is a form of the biodiversity indicator mean species abundance (MSA) which represents the mean abundance of (remaining) original species in an area related to an undisturbed situation (Alkemade et al., 2009). Meta-analysis was used to combine the effect sizes (MSA values) across all studies for several distance intervals and test their level of significance. Furthermore, meta-regression was applied to model the relationship between distance to infrastructure and MSA for birds (MSA_B) and mammals (MSA_M) (infrastructure–distance effect), and to examine sources of heterogeneity in this relationship.

2. Methods

2.1. Search and selection of published studies on infrastructural effects

Relevant studies were searched by using the following electronic databases: Ebsco, ISI Web of Knowledge, JSTOR, Omega (Utrecht University Digital Publications Search Machine), Science Direct, Scopus, Springer Link and Wiley InterScience. The search terms were: road* AND impact* AND biodiversity OR mammal, bird; infrastructure AND impact* AND biodiversity OR mammal, bird; road* AND distance AND biodiversity OR mammal, bird; road-effect zone AND mammal abundance, bird abundance; road* AND disturbance* and biodiversity OR mammal, bird; powerline AND impact AND biodiversity OR mammal, bird; wind park AND biodiversity OR mammal, bird; road traffic* AND impact* AND biodiversity* OR mammal, bird; infrastructure AND disturbance AND biodiversity OR mammal, bird. An Internet search was also performed using the meta-search engine Google scholar. Bibliographies of articles viewed at full text were searched for relevant secondary articles. Authors and recognized experts in the field of infrastructure development, road establishment and effects on biodiversity (Christian Nellemann, UNEP-Grid Arendal, and Rien Reijnen, Alterra) were also contacted for further recommendations, and for provision of any unpublished material or missing data that may be relevant (grey literature). Foreign language searches were undertaken by using cross-reference.

2.2. Study inclusion criteria

From this bulk of literature we selected those studies of which title and keywords were associated to the objective of this review. Subsequently, information contained in the abstracts was examined to further narrow down the selection to those studies that met the following criteria:

- Relevant study objects: Populations of any mammal or bird species. Studies were included irrespective of habitat or spatial scale.
- Types of intervention: Disturbance distances or distances close to infrastructure at which mammal and bird populations might be reduced compared to larger distances or control distances (see Types of comparator).
- Types of outcome: Species abundance (density and/or counts) at varying distances to infrastructure.
- Types of comparator: Control distances or distances at which mammal and bird populations are unaffected by infrastructure and roads.

2.3. Data extraction

Finally, 49 studies met the selection criteria for data extraction, from which 90 datasets were extracted and stored in a database, resulting in 2107 data points. The data included the mean abundance at disturbance distances close to infrastructure and at a larger control distance; furthermore we recorded the sample size, the variance, and standard deviation or standard error, depending on the study. These data were used to estimate an effect size and its variance as required in meta-analysis (Osenberg et al., 1999). Additionally, we stored data on location, habitat, infrastructure type, taxon (order) and traffic intensity to explore sources of heterogeneity (see Table 2 in Supplementary material, available at http://www.environmentalevidence.org/SR68.html). These variables are considered biologically meaningful and could affect the way different taxa respond to infrastructure. Thus, we expected that different taxa would respond differently to different infrastructure types (linear and clustered) and in different habitat types according to varying visibility of infrastructure, while traffic intensity could affect the response due to the influence of noise and visual stimuli.

2.4. Effect size calculation: Mean Species Abundance (MSA)

For each study, individual effect sizes were calculated as the ratio between the abundance of each species close to the infrastructure