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Research Paper

A spatial ecological assessment of fragmentation and disturbance effects of the Swedish road network

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HIGHLIGHTS

- Loss and degradation of habitat are primary effects of the Swedish road network.
- Natural grasslands + southern broadleaved forest were most exposed to road effects.
- Forest species with high area demands were most prone to be adversely impacted.
- The quantitative approach has high potential for use in environmental assessment.

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ABSTRACT

Transportation infrastructure has a wide range of effects on ecological processes, which result in both positive and negative impacts for biodiversity. However, the treatment of biodiversity in planning and environmental assessment have been criticized, especially regarding habitat loss and fragmentation effects, the low use of quantitative methods and that of assessments being descriptive rather than analytical and predictive. The aim of this study was to assess the impacts of the Swedish road network by spatial modelling of road effects, to explore potential impacts of fragmentation and disturbance effects of roads on habitat networks for selected ecological profiles, and to discuss the utility of applying quantitative methods for environmental assessment purposes. Habitat and landcover data was used for creating habitat networks for six ecological profiles. Fragmentation and disturbance effects were modelled in GIS and FRAGSTATS was used to quantify ecologically important landscape metrics on habitat amount and connectivity. The results showed that natural grasslands and southern broadleaved forest were substantially more exposed to road effects in Sweden, compared to old coniferous and trivial broadleaved forest. Furthermore, habitat loss was a main consequence of road effects, and forest species with high area demands were most prone to be adversely impacted. Suggestions on method development in order to increase the quality of the analysis methods for environmental assessment are discussed. The potential is seen as high for use of quantitative ecological methods to generate baseline environmental information as well as coarse predictions on likely consequences of development options, useful for environmental assessment.

1. Introduction

Roads and other transport infrastructure interact with ecological processes by fragmenting and converting natural habitats, introducing barriers and disturbance regimes, and perturbing trophic structures through road mortality and the introduction of exotic species (Fahrig & Rytwinski, 2009). Roads also alter hydrological processes, with subsequent changes in erosion and sedimentation rates. The utilization and management of transport infrastructure also causes emissions into air and water (Forman et al., 2003). Furthermore, transport infrastructure can be considered one of several biophysical factors driving land use change, by altering human mobility patterns and introducing various socio-economic incentives for alternative land uses (Freitas, Hawbaker, & Metzger, 2010; Jaeger, Schwarz-von Rammer, Esswein, Muller, & Schmidt-Luttman, 2007).

From an ecological perspective, these impacts cause both positive and negative changes on local scales. However, they often have overall detrimental effects on biodiversity on larger scales, and road networks have been considered a major contributor to the global

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biodiversity crisis by several authors (Coffin, 2007; Eigenbrod, Hecnar, & Fahrig, 2009; Forman, 1998; Trombulak & Frissell, 2000). Comprehensive overviews of these and other impacts are available in Coffin (2007), Davenport and Davenport (2006), Fahrig and Rytwinski (2009), Forman et al. (2003), Holderegger and Di Giulio (2010), Rytwinski and Fahrig (2012) and Spellerberg (1998).

These impacts manifest themselves throughout the infrastructure lifecycle. Habitat conversion and fragmentation occur during the construction phase, whereas pollution, traffic noise, road mortality and the introduction of exotic species result from the utilization of the infrastructure. Further, the infrastructures' physical structure and novelty as a landscape element may cause barrier effects and indirect effects on aquatic environments when hydrological patterns change, and may provide new habitat and migration corridors for some species.

The effects of transport infrastructure, e.g. the road network, on the landscape can be observed within a certain distance, creating "effect zones" along the road where environmental characteristics can be significantly distinguished from a control location (Forman & Deblinger, 2000). Several studies support the existence of such zones (Benítez-López, Alkemade, & Verweij, 2010b; Biglin & Dupigny-Giroux, 2006; Bissonette & Rosa, 2009; Boarman & Sazaki, 2006; Eigenbrod et al., 2009; Helldin & Seiler, 2003; Huijser & Bergers, 2000; Pocock & Lawrence, 2005; Reijnen, Foppen, & Meeuwsen, 1996). Studies estimating the extent of road effect zones suggest that 15–20% of the total land area of the US (Forman & Alexander, 1998) and around 16% of the Netherlands (Reijnen, Foppen, & Veenbaas, 1995) are covered by road effect zones, increasing the actual transportation infrastructure land-take considerably.

The actual causes of some of the observed effects are, however, still being discussed. For example, it has been shown that the abundance, diversity and breeding activities of forest and grassland bird species are significantly diminished within 300–1000 m from roads (Forman, Reineking, & Hersperger, 2002; Francis, Ortega, & Cruz, 2011; Helldin & Seiler, 2003; Reijnen et al., 1996; Rheindt, 2003). These authors argue that this may be caused by disturbance regimes like traffic noise and light pollution. Other authors stress road mortality as a most likely overall cause for depressed densities of mammal and bird populations within similar distances (Eigenbrod et al., 2009; Fahrig & Rytwinski, 2009; Fahrig, Pedlar, Pope, Taylor, & Wegner, 1995; McCall et al., 2010; Summers, Cunnington, & Fahrig, 2011).

Another perspective that builds on meta-population theory is that species richness and abundance are determined by the rate of extinction and colonization in a habitat mosaic landscape, which in turn depend upon habitat abundance and connectivity (Hanski & Gilpin, 1991; Hanski, 1994; Holderegger & Di Giulio, 2010). According to this theory, habitat amount and connectivity are positively correlated with population viability, which means that habitat loss and fragmentation can be interpreted as major transport infrastructure impacts. The fragmentation of habitats implies a bisection of a habitat patch into two or more smaller patches. Apart from reducing habitat size, species now need to transcend the surrounding non-habitat, often called the matrix, to reach the bisected part(s) of the previously uniform habitat. Hence, fragmentation reduces the connectivity of habitat, which is further reduced by the barrier effect posed by transport infrastructure on many species (e.g. Stewart & van der Ree, 2006; van der Ree, van der Grift, Mata, & Suarez, 2007). Fragmentation effects can thus be distinguished from disturbance effects, which are considered to reduce the quality of habitats to varying degrees.

The effects of transport infrastructure vary among different species. For ecological assessment purposes, species with similar habitat requirements can be grouped based on their traits and an ecological profile can be developed to represent each group's response to environmental change (Angelstam, Edman, Dönz-Breuss, & Wallis deVries, 2004; Mörtberg, Zetterberg, & Balfors, 2012; Vos, Verboom, Opdam, & Ter Braak, 2001). Recent studies evaluating landscape connectivity using ecological profiles indicate that species with an intermediate movement capacity tend to be the most sensitive to changes in landscape connectivity (Bodin & Saura, 2010; Saura & Rubio, 2010). By contrast, species with a very large or small movement capacity seem to be more sensitive to changes in habitat amount. Hence, species dependent on prioritized habitat types with intermediate movement capacity would be suitable model species for analysing fragmentation and disturbance effects.

The ecological assessment of both fragmentation and disturbance effects can be supported by GIS-based quantitative methods (Jaeger et al., 2005, 2007; McGarigal, Cushman, & Ene, 2012; Saura & Torné, 2009; Zetterberg, Mörtberg, & Balfors, 2010). However, such methods are seldom used in environmental assessment of transport infrastructure plans and projects (Geneletti, 2006; Gontier, Balfors, & Mörtberg, 2006; Karlson, Mörtberg, & Balfors, 2014). The assessment of impacts on ecological processes has also been criticized for being descriptive rather than analytical and predictive by these and other authors. Recent studies show that current practice relies mainly on expert knowledge, and that not even fundamental landscape characteristics like habitat amount and the number of habitat patches were used to inform decision making (Karlson et al., 2014). Still, information on landscape characteristics, such as habitat amount and connectivity as well as anticipated habitat loss and fragmentation, are necessary in order to address impacts on ecological processes and thus biodiversity. Therefore, quantitative methods would favourably complement current methods for environmental assessment.

Although Sweden is a sparsely populated country, it claims an extensive transportation network, with 558,700 km of road covering 3,493 km^2 of land including forest and farmland roads. That represents around 0.8% of the total area, excluding railways and other forms of transport infrastructure (Statistics Sweden, 2008). Even so, new corridors for both roads and railways are planned throughout the country. In order to better inform planning and policy making, this calls for a coherent assessment and exploration of the above theories on transport infrastructure effects on sensitive and prioritised biodiversity components.

The main aim of this study was to explore the utility of applying GIS-based quantitative methods for modelling ecological processes, supporting ecological impact assessment of roads. The first target was to assess the overall impacts of the Swedish road network by modelling effects of transport infrastructure on mammals and birds identified in the literature. The second target was to explore potential effects of fragmentation and disturbance on mammals and birds, by analysing changes in the habitat amount and connectivity of habitat networks for a selection of ecological profiles. These steps were seen as parts of a method development process that aims to mobilize existing scientific knowledge and methods, foster a discussion on the utility of the applied methodology for environmental assessment and demonstrate how such information can complement current methods.

2. Methods

2.1. Study area

The first part of the study analyzed the overall effect of the Swedish road network on Mean Species Abundance (MSA) in habitat types of high biodiversity value on a national scale. Thus the entire country of Sweden represented Study Area A (Fig. 1). Sweden is an elongated country measuring 1,572 km from north to south, with distinct seasonal variations spanning three different climatic