Indicators and focal species for evaluating ecological effects of transport infrastructure

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Abstract. Knowledge on dose-response relationships in the ecological effects of transport infrastructure is a crucial prerequisite for the development of evaluation tools to be used in sustainable landscape planning. The impact of transport infrastructure on wildlife depends on many factors including characteristic of transport infrastructure itself, the transportation intensity, landscape pattern and the ecological traits of species. In this paper, we review scientific literature in the quest for species that due to their life-histories, abundance, occurrence pattern, and sensitivity to anthropogenic disturbance are most suitable for assessing the impact of transport infrastructure on biodiversity and sustainability criteria. We focus on disturbance, barrier and mortality effects with ultimate goal to provide set of indicators that relate to the specific requirements that focal species or species groups (theoretical model species, ecotypes) impose on habitat quality and connectivity.

Key words: bioindicators, focal species, transport infrastructure, wildlife, INCLUDE

1. Introduction

Achieving an ecologically sustainable transport system is part of the overall attempt towards attaining a sustainable development of landscapes and regions. One of the basic requirements for ecological sustainability is safeguarding the diversity of species, land cover types and structures that provide functional habitats to these species, and of the processes and functions that link species to habitats (Noss 1990). The impact of traffic and transport infrastructure on these qualities is very complex and includes many dimensions at different spatial scales and organisational levels (Spellerberg 1998; Forman *et al*. 2003; Seiler 2003b). The physical presence of roads and railways in the landscape has both direct and indirect effects. These transport infrastructures disrupt directly natural processes and dissects habitat and migration corridors. Road maintenance and operational activities degrade the surrounding environment with a variety of pollutants and noise. In addition, infrastructure and traffic impose movement barriers to most non-flying terrestrial animals and cause the death of millions of vertebrates each year. Reduction of habitat quality and connectivity through disturbance and barrier effects characterise the environmental impact of the transport infrastructure. Additionally, by making natural resources accessible, an important indirect effect of the development of transport infrastructures is that the overall degree of naturalness and cultural authenticity is affected (Tsamboulas & Mikroudis 2000; Angelstam *et al*. 2004). Thus, compared with other land use forms, transport infrastructure occupies a small fraction of the land, yet it affects the ecological functionality at multiple spatial scales from road-sides and road corridors to entire landscapes and regions.

Typically, infrastructure management focuses on individual road or railroad corridors rather than addressing the entire network of infrastructure facilities in a landscape or a region. This is the practise in the management of public roads, and certainly true for private roads for agriculture or forestry. As a consequence, the combined impact on habitat suitability, and landscape connectivity in particular, caused by the entire infrastructure network is often underestimated, if not completely overlooked (Seiler & Eriksson 1997). The cumulative impact will ultimately lead to a loss of different elements of biodiversity at the regional scale (Angelstam *et al.* 2004). To overcome this deficiency, cumulative impacts should be assessed and evaluated not only in strategic regional and spatial landscape planning, but also be part of environmental impact assessment (EIA) at project level (Eriksson & Skoog 1996; Piepers *et al.* 2003). However, tools and concepts for integrating landscape ecology, sustainability, and biodiversity issues in EIA are rarely implemented and usually not appropriate to support this broad-scaled evaluation (e.g., Treweek *et al.* 1993; Seiler & Eriksson 1997; DeJong *et al.* 2004). Spatially explicit models of selected species, habitat requirements and responses to landscape pattern can provide such tools (Scott *et al.* 2002; Store & Jokimäki 2003, Gontier *et al.* 2006), especially if the direct effects of infrastructure and traffic on these species can be integrated in the model. Knowledge on dose-response relationships in the ecological effects of transport infrastructure is a crucial prerequisite for the development of evaluation tools to be used in sustainable landscape planning.

We review scientific literature in the quest for species that due to their life-history traits, abundance and occurrence pattern, sensitivity to anthropogenic disturbance, economic value or public interest are most suitable for assessing and communicating the impact of transport infrastructure on biodiversity. We focus on barrier, disturbance and mortality effects with ultimate goal to provide a set of indicators that relate to the specific requirements of focal species or species groups on habitat quality and connectivity. In this paper, we present a first analysis of which focal species are commonly used in research related to infrastructure effects. We discuss the need for ecologists to understand the planning processes involved with transport infrastructure, and select adequate indicators. This paper is an introductory step into further analyses aiming at finding appropriate tools for planning and for ecological assessment of transport infrastructure within the new Swedish research programme INCLUDE (www.includemistra.org) as part of the Swedish 'Sustainable Mobility Initiative'.

2. Using species as tools in spatial planning

Habitat Suitability Index (HSI) modelling (Scott *et al.* 2002) for focal species (*sensu* Lambeck 1997, 1999) is a useful tool that may help to incorporate the issue of biodiversity maintenance into spatial planning (e.g., Angelstam *et al.* 2004; Gontier *et al.* 2006; Mörtberg *et al.* in press). By combining empirical or hypothetical data on habitat requirements of species or species groups and their responses to infrastructure with data on land cover and transport infrastructure, spatially explicit computer models can be used to produce HSI maps that may guide planning decisions. At a broad scale, infrastructure density or other summary indices (Forman *et al.* 1997, Jaeger 2002) may be used as predictor variables in HSI models with habitat suitability (in a broader sense – species presence/fitness/population viability/persistence) as the response variable. HSI models can be combined with rule-based movement models describing least-cost paths of individuals through a landscape. Habitat quality, connectivity and mortality risk can be translated into spatially explicit movement (or presence) cost for an individual (e.g., Adriaensen *et al.* 2003). Together, these spatial models provide a means to (*i*) evaluate the cumulative and long-term impact, (*ii*) illustrate the outcome of alternative scenarios, and (*iii*) communicate consequences of actions to decision-makers.

3. Which species are commonly addressed?

The number of studies that looked upon the effects of transport infrastructure on wildlife is quite impressive and encompasses a variety of taxonomic groups, spatial scales, infrastructure types and traffic intensities. From this bulk of available literature, we selected 234 articles that focused primarily on barrier effects of roads and railroads and on noise disturbance. This selection was made by aid of literature search engines such as Wildlife & Ecology Studies Worldwide, Biosis, CAB, and Web of Science. In our search, we used following pairs of key-words: "road* AND barrier*", "railway* AND barrier*", "road* AND noise*", "railway* AND noise*".

Among the different taxa dealt with in the selected studies, mammals clearly dominated (55%) (Fig. 1). Among mammals, large carnivores and ungulates were most commonly addressed, followed by rodents and other smaller species (Fig. 2). Studies specifically concerning bear (*Ursus* spp.), wolf (*Canis lupus*), caribou (*Rangifer tarandus*), hedgehog (*Erinaceus europaeus*), and badger (*Meles meles*) were the most common ones.

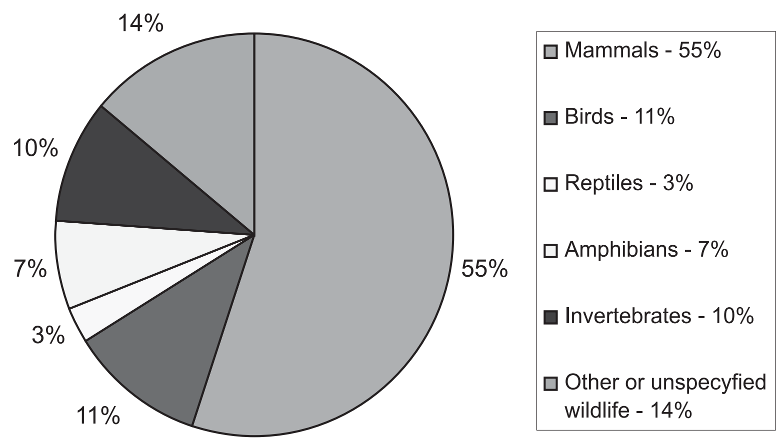

Fig. 1. Different groups of organisms being subject to papers and reports dealing with effects of transport infrastructure (n=232)

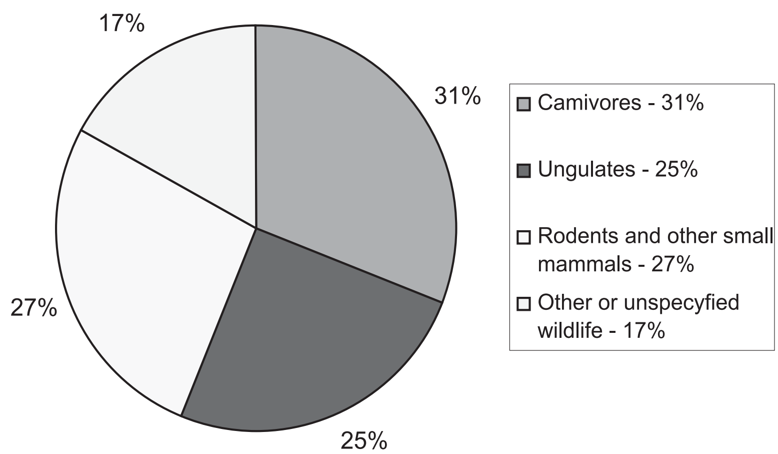

Fig. 2. Mammals as subjects of papers and reports dealing with effects of transport infrastructure (n=124)

Our preliminary analysis indicated differences concerning the spatial scale of the investigation and groups of organisms studied. The articles concerning amphibians were most often linked to the local scale while articles on carnivores and ungulates related to regional scale.

The reviewed articles also considered different landscape types (Table 1). Interestingly, most studies on amphibians were linked to forested landscapes. The problem of mortality linked to transport infrastructure was mentioned in 71 articles and was almost exclusively occurring in articles on vertebrates. More than half these articles concerned mammals, but articles on amphibians, birds and reptiles were also present. Almost one-third (75) of the articles considered population processes (i.e. effects of transport infrastructure on population persistence/viability). Some of them examined barrier effects on genetic structure of populations and found such impact in small mammals, large carnivores, one ungulate species and ground beetles. Effects of transport infrastructure on the dispersal of individuals were considered in 48 articles. Here, the share of amphibians and invertebrates was higher than expected from their share in all reviewed articles. Among invertebrates, dispersal studies on insects (flies, beetles and butterflies) were most common. Issues of habitat fragmentation and habitat alteration were explicitly discussed in 23 respectively 37 reviewed articles. Finally, 16 out of 23 articles that dealt with effect of traffic noise concerned birds.

Table 1. Proportion of articles that linked group of species with particular landscape types

	Forest [n=44]	Farmland [n=24]	Urban areas [n=46]
Carnivores	0.14	0.08	0.11
Ungulates	0.09	0.08	0.22
Small mammals	0.23	0.17	0.15
Birds	0.23	0.21	0.20
Amphibians	0.14	0.04	0.02
Other species	0.17	0.42	0.30

The great majority of the reviewed studies revealed negative effects of transport infrastructure on wildlife. These effects included barrier, disturbance, and mortality effects demonstrated for different groups of organisms, different spatial scales and varying degree of anthropogenic impact. However, only a few studies were able to estimate the cumulative impact of transport infrastructure on species persistence/viability. Moreover, several articles found that closely related species showed contradictory, species-specific responses to transport infrastructure. We acknowledge that results presented above are based on the limited set of publications and as such shall be treated as provisional.

4. Looking for indicators and focal species

Because ecosystems are complex and the effects of transport infrastructures on them need to be communicated effectively there is need to develop indicators as short-cuts (Busch &Trexler 2003). As the impacts of roads and railroads occur at multiple spatial scales, and charismatic species are interesting to a wide range of actors, so called focal species can be used (Lambeck 1997; Roberge & Angelstam 2004). Species as indicators need to be selected according to their response to the direct and indirect effects, to the spatial scale at which they utilise the landscape, to their land cover preferences (forest, agricultural land, stream habitat), and to the value of these species as proxies to illustrate and communicate the overall impact, and last but not least to aid decision making in the complex planning process for transport infrastructure. With ‘knowledge’ about the behaviour and ecology of the focal species or species groups, their requirements on habitat quality and habitat structure (size, dispersion, connectivity of habitat patches) and their response to traffic and infrastructure, rule-based, spatially explicit models can be developed using land cover and infrastructure data in a Geographic Information Systems.

Our analysis as well as several earlier reviews (e.g. Spellerberg 1998; Forman *et al.* 2003; Seiler 2003b) demonstrated that many species with different ecologies are clearly affected by transport infrastructure. Which of those species would make a good indicator species to be used in planning and assessment of transport infrastructure?

Large carnivores appear to be very good candidates for use in planning at regional scale because their distributional patterns often strongly reflect regional-scale population processes and individual behaviour. However the choice of species is crucial. Carroll *et al.* (2001) demonstrated for instance that among 4 large carnivores in the Rocky Mountains two species (grizzly bear and wolverine) were clearly affected by roads while two other (lynx and fisher) were not. Ungulates also have characteristics that fit into requirements for good focal species at regional and landscape scale (e.g. Bruinderink *et al.* 2003). Ungulates are usually in public focus because of the large number of deer-vehicle collisions occurring annually, and because of the economic and recreational (hunting) value of these species (Seiler & Helldin 2006). On the other hand, among species that appear to be suitable in landscape to local scale planning, amphibians are interesting candidates (Fahrig *et al.* 1995). An attempt to organize focal species as indicators of various disturbance and barrier effects at the different spatial scale at which they utilise the landscape, and to their land cover preferences is presented in Table 2.

Table 2. Examples of possible focal species as indicators for the study of disturbance and barrier effects at regional, landscape and local scales

	Disturbance effects (noise, pollution, human activity, mortality, edge effects) = affecting suitability of adjacent habitat	Barrier effects (avoidance, physical barriers, traffic mortality) = affecting habitat connectivity and movement pattern
Regional- or continental scale	large mammals	large mammals
Landscape scale	breeding birds	large and semi-aquatic mammals, fish (salmon)
Local scale	breeding birds, amphibians	Small mammals, amphibians, arthropods

In all of the reviewed papers, animal species were selected a priori to study a certain effect of transport infrastructure without intend to serve as indicator in a planning case. Before focal species can be used in models applied to decision processes, dose-response relationships in their responses to disturbance and barrier effects must be understood and parameterized (Muradian 2001; Angelstam *et al.* 2004; Seiler 2005). A key task is therefore to define variables and parameter values for these effects on the selected species. This can be done either through empirical field studies or through simulation studies that help identifying potential limit values in the response (e.g., Jaeger & Fahrig 2004).

In addition, the models and hence the selected species, must match in scale and result, the requirements of the particular stages in the hierarchical planning process of infrastructure (e.g. Eriksson). A study of butterfly movements may be irrelevant at the first scoping level in the planning process, but highly adequate during the design planning level. Modelling occurrence pattern in large carnivores may help to predict regions sensitive to infrastructure development, but may not help during road alignment and design.

5. Understanding planning processes

Landscape ecology, which focuses on the spatial aspects of ecological patterns and processes, provides important guidelines for mitigation of the adverse effects of transport infrastructure on the living landscape (Dramstad *et al.* 1996; Forman *et al.* 2003; Seiler 2003a). However, the science of landscape ecology is a new research discipline. Hence, the broader public, spatial planners, and stakeholders may not readily understand its principles and applications that combine land cover information, variables and parameters in a models expressing landscape functionality using Geographical Information Systems (Sandström *et al.* 2006; Manton *et al.* 2005). Therefore, it is of paramount importance that we (*i*) understand the extent to which planners and professionals involved in Environmental Impact Assessments (EIA) and Strategic Environmental Assessment (SEA) dealing with transport infrastructure already apply landscape ecological knowledge in their work, and (*ii*) help to develop planning tools and concepts that integrate landscape ecological principles (e.g. Seiler & Sjölund 2005). It is obvious that recent scientific and technical achievements for applying this discipline need to be better incorporated into planning process (e.g. Seiler & Eriksson 1997; Sandström *et al.* 2006), both by policy-makers, road planners who commission EIA and SEA, as well as the consultancy bureaus and their employees. Such research must be international as the value systems of planners vary among both sectors and regions (Angelstam *et al.* 2005).

6. Programme INCLUDE

In the research programme INCLUDE (Integrating ecological and socio-cultural dimensions in transport infrastructure management), we will, among others, develop and apply spatial modelling approaches that match the respective planning levels and ecological scales at different stages of infrastructure management process (e.g., strategic level planning, project level planning, road maintenance). For this, adequate indicators and focal species shall be selected that help infrastructure planning decisions in terrestrial as well as in aquatic environments. We will further evaluate, by interviewing actors and stakeholders in a suite of case studies, the extent to which GIS application techniques, and landscape ecology principles are implemented in the transport infrastructure planning process. INCLUDE will thus contribute to the understanding and active mitigation of negative effects of transport infrastructure on the functionality of habitat networks needed to maintain viable populations of species with landscape ecological requirements.

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