Potential impacts of transport infrastructure and traffic on bird conservation in Swedish Special Protection Areas

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Abstract

The ecological impacts of roads and railways extend into the surrounding landscape, leading to habitat degradation and reduced animal densities within an area that is considerably larger than the actual road or railway corridor. For birds an extensive meta-analysis has pointed at an average of 20% density reduction within 1 km from the infrastructure. I investigated to what extent this density reduction could potentially compromise the habitat quality and conservation value of Swedish Natura 2000 areas designated for the protection of birds (Special Protection Areas; SPAs). A majority (63%) of Swedish SPAs are at least to some extent found within this 1 km potential effect zone. The total overlap between SPA and effect zone is 126,000 ha, or 4.2% of the country´s SPA area. There are however large differences among biogeographical regions. In the southern (continental) and coastal regions combined, 25.8% of the total SPA area fall within the effect zone, representing an estimated 4-7% reduction in bird abundance within SPAs. The probablility of overlap with effect zone is higher for larger SPAs. However, the proportion of overlap is higher for smaller SPAs, and accordingly smaller sites can be assumed to experience a greater impact from transport infrastructure and traffic. The impacts on Natura 2000 sites are particularly concerning as this network of protected areas is a cornerstone to maintain and restore biodiversity within EU. I recommend to put a stronger emphasis in the management of Natura 2000 sites on the potential threats to wildlife conservation caused by transport infrastructure and traffic. Special attention should be paid in sites with a large overlap with the effect zone, and in sites hosting particularly vulnerable taxa or habitats. Infrastructure owners and managers should do their best to minimize and compensate for the negative impacts of roads and railways and related traffic in SPAs and other protected areas.

Keywords

Bird conservation, Effect zone, Natura 2000, Railways, Roads, Special Protection Areas, Sweden, Transport infrastructure

Introduction

Infrastructure development is recognised as one of the significant drivers of the global biodiversity loss, and with increasing traffic and expanding infrastructure networks worldwide the pressure on biodiversity is expected to increase in the nearest decades (EEA 2011, 2012, OECD 2012). The impacts of transport infrastructures on wildlife are well described (reviewed by, e.g., Forman et al. 2003, van der Ree et al. 2015), and include loss of habitat, traffic casualties, creation of physical barriers, disturbance by noise, light and other visual cues, spread of chemicals, dust and alien species, changes in hydrology and microclimate, and accidental spill. Most of these impacts extend into the surrounding landscape, leading to a degradation and fragmentation of habitats, and for some animal species to restricted movements, increased mortality, and avoidance of a zone around the infrastructure (Forman et al. 2003, EEA 2011, van der Ree et al. 2015).

Due to these impacts, the population densities of many animal species are reduced within a distance from larger infrastructures (Rytwinski & Fahrig 2015). For example, the population densities may be reduced on up to about 1 km distance for birds (Forman & Deblinger 2000, Forman et al. 2002, Benítez-López et al. 2010) and anurans (Eigenbrod et al. 2009), and up to 5 km for mammals (Benítez-López et al. 2010). Not only large infrastructures but also minor and unpaved roads may have a considerable impact on some wildlife species (e.g., van Langevelde & Jaarsma 2009, Benítez-López et al. 2010, Shanley & Pyare 2011). Based on an extensive meta-analysis, Benítez-López et al. (2010) showed that the mean bird and mammal abundance in an effect zone around infrastructure is reduced by 20-30 %, and with an increasing reduction with proximity to the infrastructure (see Fig. 1).

Accordingly, in regions with dense infrastructure networks, large natural areas may be situated within this effect zone, and therefore impoverished in species sensitive to traffic and transport infrastructures. For example, in the United States, the road effect zone covers 15-22 % of the total land area, and more than 60 % of some particularly exposed biomes, such as coastal regions and river basins (Forman 2000, Riiters & Wickham 2003). In Spain, a country with intermediate road density with European standards, reduced bird densities due to transportation infrastructure are expected in 49 % of the country, and reduced mammal

densities in as much as 96 % of the country (Torres et al. 2016). Some habitats of particular importance to biodiversity in Europe, such as wetlands, semi-natural grasslands and temperate broad-leaved forest, may be disproportionately affected by roads because of the landscape structure (Helldin et al. 2013, Karlson & Mörtberg 2015, Torres et al. 2016). Disturbance (noise and visual cues) tend to be stronger and extend further from the road in open habitats as compared to forest (Forman & Deblinger 2000, Reijnen & Foppen 2006). There is a growing concern globally about impact of roads and traffic on wildlife populations in protected areas and other biodiversity hotspots (Forman & Deblinger 2000, Ament et al. 2008, Selva et al. 2011, Laurence & Balmford 2013, Bager et al. 2015, Gadd 2015, Seshadri & Ganesh 2015).

The Natura 2000 network of protected areas is a key tool in the maintenance and restoration of biodiversity within the European Union (EU). The network consists of Special Protection Areas (SPAs) designated according to the Birds Directive, and Special Areas of Conservation (SACs) designated according to the Habitats Directive (EEC 1992, 2010). Under these directives, the network is supposed to provide protection for vulnerable wildlife and habitats. One important motivation for designating Natura 2000 sites, particularly in coastal and other lower-elevation areas, is the protection against negative impacts of urbanization and infrastructure development (EEA 2012). There are presently more than 26,400 sites in the Natura 2000 network, accounting for *ca* 18 % of EUs land territory.

The network is however biased toward highland areas, and lowland areas are underrepresented (Oldfield et al. 2004, Mariorano et al. 2007). In addition, the average size of the Natura 2000 sites is quite low, and particularly so in lowlands (Maiorano et al. 2007, Gaston et al. 2008, EEA 2012). As smaller sites are more susceptible to pressure from land use and human activities surrounding them, major concerns are expressed about the capacity of existing protected areas to maintain their biodiversity values (Chape et al. 2005, Gaston et al. 2008, Maiorano et al. 2008, Kati et al. 2015).

Though many assessments of the Natura 2000 network´s effectiveness in protecting species have been reported in the last years, a vast majority of these relied on rather static population data, such as species´ geographic distribution, species presence/absence, or habitat suitability (e.g., Araujo et al. 2007, Maiorano et al. 2007, 2015, Sánchez-Fernández et al. 2008, Iojă et al 2010, López-López et al. 2011, Gruber et al. 2012, Albuquerque et al. 2013, D'Amen et al. 2013, Lison et al. 2013, Rubio-Salcedo et al. 2013, Trochet & Schmeller 2013), and accordingly were designed to assess ecological representativeness of the network rather than

tracking changes in population densities due to environmental impacts. Studies of national bird population trends have indicated a positive impact of conservation action under the Birds Directive, including the establishment of SPAs (Devictor et al. 2007, Donald et al. 2007, Pelissier et al. 2012, Brodier et al. 2014). A majority of bird species in EU currently have stable or increasing populations, though species associated with certain habitat types and biomes are doing worse (EEA 2015). For species under the Habitats Directive (non-avian species), the situation is generally unsatisfactory, with only 23% of the species having favourable conservation status.

In view of the many negative population trajectories among both avian and non-avian species in the EU, it appears necessary to analyze the ecological functionality of the Natura 2000 network, with regard to pressures both within and outside the designated areas, but few studies have taken this course. Frequency of transport infrastructure within Natura 2000 sites was investigated by Tsiafouli et al. (2013), showing that as a European average, roads are present in 29% of the sites, with a higher frequency in the countries in the south. A preceeding study of Greek Natura 2000 sites, by Votsi et al. (2012), showed that 85% of sites are bisected by roads. Insufficient functional connectivity of the Natura 2000 network was reported by Gurrutxaga et al. (2011) and Opermanis et al. (2012), suggesting that dispersal barriers exist between sites, for example in the form of large roads (Gurrutxaga et al. 2011). With regard to disturbance, the European Environmental Agency (EEA 2016) estimates that almost 20% of Natura 2000 areas are presently adversely affected by high levels of environmental noise, to a large extent owing to major transport infrastructures. In an assessment of the impact on Natura 2000 sites of major traffic arteries planned or under construction as part of EU´s TEN-T framework, Byron & Arnold (2008) estimated that 379 SPAs (8 % of sites) and 953 SCIs (4 % of sites) would be adversely affected by these new traffic arteries, with potential effects also on Natura 2000 network coherence.

Sweden are one of the European countries that are least fragmented by transport infrastructures and built-up areas (EEA 2011), and the physical impact of infrastructure is generally not well acknowledged in nature conservation. It is not until recently that national status reports for biodiversity have described the threats from infrastructure and traffic on species conservation (Bernes 2011, Naturvårdsverket 2015a), and the current national conservation action plan contains few requirements to infrastructure managers (Naturvårdsverket 2015b). Biodiversity is generally insufficiently described in impact assessments of transportation infrastructure plans and projects (Wärnbeck 2013, Karlson et al.

2014). Few, if any, management plans for protected areas address the full array of potential ecological impacts of transport infrastructures on the areas´ conservation status or management (Helldin & Tytor 2017). This ignorance is not unique for Sweden, but appear to be largely similar in most EU member states (Tsiafouli et al. 2013, EEA 2015; but see, e.g., Selva et al. 2011, Votsi et al. 2012).

In order to illustrate and highlight the impacts of infrastructure on protected areas in particular, I estimated the frequency and proportion of Swedish SPAs situated within the potential effect zone for birds around existing larger transport infrastructures (roads and railways), and hence can be expected not to reach their full conservation potential due to infrastructure impacts. I included only SPAs in the estimation, i.e., areas designated specifically for the protection of birds, because the effects of roads and railways on birds are well described in literature, and apparently can impact a majority of bird species (Reijnen & Foppen 2006, Benítez-López et al. 2010, Rytwinski & Fahrig 2015). I assessed the conservation value of SPAs that is lost due to infrastructure in terms of reduced predicted bird abundance. Because of the large geographic variation over the country in density of the infrastructure network and proportion of area within SPA, I separated the analyses between biogeographical regions. I tentatively explored the association between the infrastructure impact on an individual SPA and its size and dominating habitats. In this paper, I present the results of these analyses and propose improvements for the management of Swedish SPAs.

Methods

A map of the effect zone for birds around the existing larger Swedish transport infrastructure was produced. I assumed a standardized effect distance of 1 km from the infrastructure, following the result from a meta-analysis presented by Benítez-López et al. (2010). To my knowledge, this is the most comprehensive analysis of infrastructure impacts on bird densities, including 49 bird datasets and a total of 201 bird species. Most studies in the meta-analysis were conducted in biomes that occur in Sweden, i.e., taiga, temperate broadleaf forest or alpine/tundra (39 of the 49 datasets), and on species that occur in Sweden (105 of the 201 species), and I therefore judged the results relevant in a Swedish perspective. The results have also previously been applied to assess the impacts of the road network on birds in Sweden (Karlson & Mörtberg 2015) and Europe (Torres et al. 2016). I consider the assumption of a 1 km effect distance to be conservative because i) individual studies in the meta-analysis indicated reduced bird populations on larger distances, and ii) impacts on longer distances may not necessarily result in direct population declines, but yet be of ecological significance.

Infrastructure data were obtained from Open Street Map (http://openstreetmapdata.com), using only the following road classes: primary road, secondary road, tertiary road, motorway, trunk road, railway (thus excluding minor roads for which ecological effects are less well known).

The effect zone map was overlaid with all Swedish SPAs to calculate the area and proportion of each site situated within the effect zone. Shape of areas and habitat distribution were obtained from European Environment Agency´s Natura 2000 database (http://www.eea.europa.eu/data-and-maps/data/natura-2000-eunis-database). SPAs were separated depending on biome (based on a combination of the Natura 2000 database and Global Biomes data from the CIESIN; http://sedac.ciesin.columbia.edu/data/set/nagdc-population-landscape-climate-estimates-v3/maps?facets=theme:climate) and proximity to coast (data on coastline obtained from Lantmäteriets open geodata; https://www.lantmateriet.se/en/maps-and-geographic-information/oppna-data/) on the following terms:

- *continental region:* sites with >50% of the area within EU continental region,
- *mixed-forest region:* sites with >50% of the area within EU boreal region and in CIESIN broadleaf and mixed-forest region,
- *boreal region:* rest of sites within EU boreal region but with no part within EU alpine region, or
- *alpine region:* sites with at least some part of the area within EU alpine region.

in combination with

- *coastal:* mainland sites with at least some part within 20 km from coast of mainland Sweden (including mainland islands Öland and Gotland), or
- *inland:* the rest of mainland sites.

The alpine region in Sweden is only inland, i.e., no alpine coastal sites exist. Because only two continental sites are inland, all continental sites were pooled in one region. In addition, an off-coastal region was formed including all sites with no contact with mainland Sweden, irrespective of terrestrial biome. Hereby a total of 7 biogeographical regions were obtained (see Table 1 and Fig. 2).

To assess the bird conservation value of SPAs that is lost due to infrastructure, I assumed an average of 20% (C.I. 12-33%) reduction of bird abundance within the 1 km effect distance from infrastructure, as indicated by the results presented by Benítez-López et al. (2010; see Fig. 1).

To explore how the degree of impact on an SPA is associated with its size and dominating habitat, two different analyses where performed for each region. For the probability of overlap with effect zone (response variable either 0 or 1), a generalized linear model with a logit link function (logistic regression) was used, and for the proportion of overlap with the effect zone (i.e., a response variable between 0 and 1), a beta-regression model (Ferrari & Cribari-Neto 2004) was used. In both types of models explanatory variables were 1) SPA size, 2) proportion forest habitat, 3) proportion wetlands, and 4) proportion agricultural land and grasslands. SPA size was log-transformed to improve normality and all variables were standardized to make parameter estimates comparable. Model selection was based on AIC and the final models were the ones with a combination of explanatory variables resulting in the lowest AIC.

Results

The overlay of SPAs and effect zone of larger transport infrastructures showed that 339 of Swedens 538 SPAs (63%) have at least some part, and 123 (23%) have most their area, within the effect zone (Table 1). In terms of area, a total of ca 126,000 ha, or 4.2% of the total SPA area in the country, lies within the effect zone.

National level figures on impacted area however gives a crude picture, as the results pointed at large differences among the biogeographical regions (Table 1). Alpine and marine areas have a number of large SPAs and hold most of Swedens total SPA area, but have sparse networks of large (terrestrial) transport infrastructures, and accordingly they reduce the national average. Continental, mixed-forest coastal and boreal coastal regions, however, are comparably more impacted; in these three regions combined a total of 46,046 ha, or 25.8% of the total SPA area, fall within the effect zone. In terms of bird conservation value, present infrastructure impacts are estimated to cause a 4-7% reduction in bird abundance in SPAs in the three most impacted regions (continental, mixed-forest coastal and boreal coastal), and an average of 1% reduction when all SPAs in the country are taken in consideration (Table 1).

The overlap models with the lowest AIC included SPA size or habitat composition in all regions except the continental (Table 2). As the most emergent pattern, larger SPAs appear to have a higher probability of overlap with effect zone (in three regions) but a lower proportion of overlap with effect zone (in all regions except continental). Another pattern, however less emergent, is that the overlap with effect zone is larger in SPAs with more agricultural land

and grasslands (in four regions), and smaller in SPAs with more forest habitat (in two regions).

Discussion

The results indicate that a significant proportion of Swedish SPAs, both in terms of area and number of sites, lies within a potential effect zone for birds around present larger transport infrastructures and therefore can be assumed not to reach their full potenial as bird habitat. The reduction due to transport infrastructure impacts may not be dramatic when seen on the country as a whole, with only around 4% of the total SPA area affected, corresponding to a ca 1% reduction in predicted bird abundance within SPAs. But for more urbanized parts of the country, with a denser infrastructure network, the predicted impact and reduction is nearly an order of magnitude larger, and may well be one of the main factors determining bird abundance in protected areas. This is the case in the southern (continental) and coastal regions of the country, where the urbanization and landscape fragmentation is in level with that of most western and central European countries (EEA 2011).

At the level of individual SPAs, smaller sites tend to have a higher proportion of overlap with the effect zone and accordingly can be assumed to experience a greater impact than larger sites. This pattern emerge in all biogeographical regions, except the continental where most SPAs are small and indeed impacted to a large degree. This is in line with general concerns previously expressed about the small size of many protected areas in Europe and about the impacts from transport infrastructure, traffic and other urban development in the landscape surrounding them (Shafer 1995, Gaston et al. 2008, Maiorano et al. 2008, Kati et al. 2015).

The function of predicted bird abundance and distance to infrastructure described by Benítez-López et al. (2010) have previously been applied twice to assess the ecological impact of an infrastructure network on a larger geographical level. Karlson & Mörtberg (2015) presented an assessment of the impacts of roads on habitats of high diversity value in Sweden (irrespective of their protection status), concluding that natural grasslands and southern broadleaved forest are likely to be particularly impacted; on national level, 13-19% and 16-24% of the total areas of these habitats are found within predicted effect zone for birds. Torres et al. (2016) estimated a 19.0% (CI = 9.6–25.6%) reduction in national bird numbers due to transport infrastructure for Spain, with all land in view and not only protected areas. They too concluded that some habitats (most notably farmland and maritime wetlands) are disproportionally affected by transport infrastructure. In relation to these previous

assessments, the present study is unique in that it points out the impacts specifically on protected areas, i.e., areas where nature conservation should be a top priority.

The assessment was aimed to give a general picture, and was therefore simplified in several respects. A fixed-width effect zone is less realistic, as the actual effect depend on the local context, such as the habitat distribution, topography, species and ecological processes involved (Forman & Deblinger 2000, Riitters & Wickham 2003, Biglin & Dupigny-Giroux 2006) or the road characteristics (e.g., Reijnen & Foppen 2006, Rytwinski & Fahrig 2015). Also the stronger reduction in bird densities near the infrastructure within the effect zone (Fig. 1) provides an opportunity to assess the decline in bird abundance within the effect zone in individual sites in greater detail than here conducted (e.g., Torres et al. 2016).

Furthermore, the analysis of impacts of different habitats within SPAs was rather coarse, since the Natura 2000 database does not provide habitat maps. Therefore I could not explore to what degree EU priority habitats (habitat types of community interest; EEC 1992) were found disproportionally within the effect zone.

Implications for management of protected areas

The present study underlines the concern about the impact of transport infrastructures on wildlife in protected areas in general (Forman & Deblinger 2000, Ament et al. 2008, Selva et al. 2011, Tsiafouli et al. 2013), and in the smaller areas in particular (Shafer 1995, Maiorano et al . 2008). Following article 4 of the Birds Directive, EU Member States must take appropriate steps to avoid habitat deterioration and significant species disturbance within SPAs (EEC 2010). Accordingly, a stronger emphasis on keeping natural areas free from the impacts of heavy traffic and new roads and railways has been proposed for conservation and transport planning (Selva et al. 2011, 2015, Laurance & Balmford 2013, IENE 2015).

Management plans for Natura 2000 sites should better acknowledge the threats to wildlife conservation caused by both present transport infrastructure and new development projects in and near sites (Cortina & Boggia 2014, Helldin & Tytor 2017). Assessments of the effectiveness of individual Natura 2000 sites in maintaining biodiversity should include monitoring of population density and demography of species of special conservation concern (Gaston et al. 2006). A detailed assessment of the predicted impacts from transport infrastructure should be conducted based on habitat maps, species occurrences, and local road characteristics, to serve as a basis for priorities in conservation planning and action. Special attention to road effects should thus be paid in protected areas with a large overlap with the

effect zone, in areas hosting particularly vulnerable taxa, and in areas with pronounced impacts on EU priority habitats.

Conservation authorities should secure that infrastructure owners and managers do their best to minimize the negative impact of nearby roads and railways and related traffic. Technical mitigation of impacts of transport infrastructure on birds could include preventing bird—vehicle collision (e.g., with flight diverters), planning the timing of infrastructure maintenance and construction work to avoid particularly sensitive periods, providing crossing structures (safe over-/underpasses), and reducing noise and visual impacts through walls, berms or adapted paving. Traffic calming, speed reduction or road closing (permanent or temporary) would also provide reductions in road mortality, disturbance and barrier effects. Finally, compensatory measures such as habitat improvement or additional area protection could reinforce remnant populations and restore vital ecological processes.

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References

Albuquerque FS, Assunção-Albuquerque MJT, Cayuela L, Zamora R, Benito BM (2013) European Bird distribution is ‘‘well’’ represented by Special Protected Areas: Mission accomplished? Biological Conservation 159: 45–50.

Ament R, Clevenger AP, Yu O, Hardy A (2008) An Assessment of Road Impacts on Wildlife Populations in U.S. National Parks. Environmental Management 42: 480–496.

Araújo MB, Lobo JM, Moreno JC (2007) The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. Conservation Biology 21: 1423–1432.

Bager A, Borghi CE, Secco H (2015) The influence of economics, politics and environment on road ecology in South America. Pp 407-413 in: van der Ree R, Smith DJ, Grilo C (Eds.). Handbook of Road Ecology. John Wiley & Sons Ltd, UK.

Benítez-López A, Alkemade R, Verweij PA (2010) The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biological Conservation 143: 1307–1316.

Bernes C (2011) Biodiversity in Sweden. Monitor 22, Swedish Environmental Protection Agency, Stockholm.

Biglin K, Dupigny-Giroux L-A (2006) Mapping the road-effect zone to assess impacts of proposed road segments. Journal of Conservation Planning 2: 1-16.

Brodier S, Augiron S, Cornulier T, Bretagnolle V (2014) Local improvement of skylark and corn bunting population trends on intensive arable landscape: a case study of the conservation tool Natura 2000. Animal Conservation 17: 204–216.

Byron H, Arnold L (2008) TEN-T and Natura 2000: the way forward. An assessment of the potential impact of the TEN-T Priority Projects on Natura 2000. Report from BirdLife International. http://www.birdlife.org/eu/pdfs/TEN_T_report2008_final.pdf

Chape S, Harrison J, Spalding M, Lysenko I (2005) Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Phil. Trans. R. Soc. B 360: 443-455.

Cortina C, Boggia A (2014) Development of policies for Natura 2000 sites: A multi-criteria approach to support decision makers. Journal of Environmental Management 141: 138-145.

D'Amen M, Bombi P, Campanaro A, Zapponi L, Bologna MA, Mason F (2013) Protected areas and insect conservation: questioning the effectiveness of Natura 2000 network for saproxylic beetles in Italy. Animal Conservation 16(4): 370-378.

Devictor V, Godet L, Julliard R, Couvet D, Jiguet F (2007) Can common species benefit from protected areas? Biological Conservation 139: 29–36.

Donald PF, Sanderson FJ, Burfield IJ, Bierman SM, Gregory RD, Waliczky Z (2007) International Conservation Policy Delivers Benefits for Birds in Europe. Science 317(5839): 810-813.

EEA (2011) Landscape fragmentation in Europe; Joint EEA-FOEN report. EEA report No 2/2011. European Environment Agency, Copenhagen.

EEA (2012) Protected areas in Europe – an overview. EEA report No 5/2012. European Environment Agency, Copenhagen.

EEA (2015) State of nature in the EU; Results from reporting under the nature directives 2007–2012. EEA report No 2/2015. European Environment Agency, Copenhagen.

EEA (2016) Quiet areas in Europe; The environment unaffected by noise pollution. EEA report No 14/2016. European Environment Agency, Copenhagen.

EEC (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities No L 206/7-50.

EEC (2010) Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. Official Journal of the European Union No L 20/7-25.

Eigenbrod F, Hecnar SJ, Fahrig L (2009) Quantifying the Road-Effect Zone: Threshold Effects of a Motorway on Anuran Populations in Ontario, Canada. Ecology and Society 14(1): 24.

Ferrari S, Cribari-Neto F (2004) Beta Regression for Modelling Rates and Proportions. Journal of Applied Statistics 31(7): 799-815.

Forman RTT (2000) Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14(1): 31-35.

Forman RTT, Deblinger RD (2000) The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology 14: 36-46.

Forman RTT, Reineking B, Hersperger AM (2002) Road traffic and nearby grassland bird patterns in a suburbanizing landscape. Environmental Management 29(6): 782-800.

Forman RTT, Sperling D, Bissonette JA, Clevenger AP, Cutshall CD, Dale VH, Fahrig L, France R, Goldman CR, Haenue K, Jones JA, Swanson FJ, Turrentine T, Winter TC (2003) Road ecology – Science and solutions. Island Press (Washington, USA).

Gadd ME (2015) Expected effects of a road across the Serengeti. Pg 455-464 in: van der Ree R, Smith DJ, Grilo C (Eds). Handbook of Road Ecology. John Wiley & Sons Ltd, UK.

Gaston KJ, Jackson SF, Nagy A, Cantú-Salazar L, Johnson M (2008) Protected Areas in Europe; Principle and Practice. Ann. N.Y. Acad. Sci. 1134: 97–119.

Gruber B, Evans D, Henle K, Bauch B, Schmeller D, Dziock F, Henry PY, Lengyel S, Margules C, Dormann C (2012) "Mind the gap!" – How well does Natura 2000 cover species of European interest? Nature Conservation 3: 45–62.

Gurrutxaga M, Rubio L, Saurac S (2011) Key connectors in protected forest area networks and the impact of highways: A transnational case study from the Cantabrian Range to the Western Alps (SW Europe). Landscape and Urban Planning 101: 310–320.

Helldin J-O, Tytor S (2017) Hur uppmärksammas ekologiska effekter av vägar och järnvägar inom naturvården? – innehållsanalys av bevarandeplaner för Natura 2000-områden. Report from Calluna AB. http://www.calluna.se/userfiles/files/5_Innehållsanalys_SPA_bevarandeplaner_2017(1).pdf (In Swedish)

Helldin J-O, Collinder P, Bengtsson D, Karlberg Å, Askling J (2013) Assessment of traffic noise impact in important bird sites in Sweden – a practical method for the regional scale. Oecologia Australis 17(1): 70-84.

Iojâ CI, Pâtroescu M, Rozylowicz L, Popescu VD, Verghelet M¸, Zotta MI, Felciuc M (2010) The efficacy of Romania's protected areas network in conserving biodiversity. Biological Conservation 143: 2468–2476.

Karlson M, Mörtberg U (2015) A spatial ecological assessment of fragmentation and disturbance effects of the Swedish road network. Landscape and Urban Planning 134: 53–65.

Karlson M, Mörtberg U, Balfors B (2014) Road ecology in environmental impact assessment. Environmental Impact Assessment Review 48: 10–19.

Kati V, Hovardas T, Dieterich M, Ibisch PL, Mihok B, Selva N (2015) The challenge of implementing the European network of protected areas Natura 2000. Conservation Biology 29(1): 260–270.

Laurance WF, Balmford A (2013) A global map for road building. Nature 495: 308-309.

Lison F, Palazon JA, Calvo JF (2013) Effectiveness of the Natura 2000 Network for the conservation of cave-dwelling bats in a Mediterranean region. Animal Conservation 16(5): 528-537.

López-López P, Maiorano L, Falcucci A, Barba E, Boitani L (2011) Hotspots of species richness, threat and endemism for terrestrial vertebrates in SW Europe. Acta Oecologica 37(5): 399-412.

Maiorano L, Falcucci A, Garton EO, Boitani L (2007) Contribution of the Natura 2000 Network to Biodiversity Conservation in Italy. Conservation Biology 21(6): 1433–1444.

Maiorano L, Falcucci A, Boitani L (2008) Size-dependent resistance of protected areas to land-use change. Proc. R. Soc. B 275: 1297–1304.

Naturvårdsverket (2015a) Målövergripande analys av miljömålen; Underlag till fördjupad utvärdering av miljömålen 2015. Swedish Environmental Protection Agency, Report No 6692. (In Swedish)

Naturvårdsverket (2015b) Styr med sikte på miljömålen – Naturvårdsverkets fördjupade utvärdering av miljömålen 2015. Swedish Environmental Protection Agency, Report No 6666. (In Swedish)

OECD (2012) OECD Environmental Outlook to 2050; The Consequences of Inaction. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264122246-en

Oldfield TEE, Smith RJ, Harrop SR, Leader-Williams N (2004) A gap analysis of terrestrial protected areas in England and its implications for conservation policy. Biological Conservation 120: 307–313.

Opermanis O, MacSharry B, Aunins A, Sipkova Z (2012) Connectedness and connectivity of the Natura 2000 network of protected areas across country borders in the European Union. Biological Conservation 153: 227-238.

Pellissier V, Touroult J, Julliard R, Siblet JP, Jiguet F (2012) Assessing the Natura 2000 network with a common breeding birds survey. Animal Conservation 16: 566–574.

Reijnen R, Foppen R (2006) Impact of road traffic on breeding bird populations. Pp. 255-274 in: Davenport, Davenport J (Eds) The Ecology of Transportation: Managing Mobility for the Environment. Springer, Dordrecht, the Netherlands.

Riitters KH, Wickham JD (2003) How far to the nearest road? Front. Ecol. Environ. 1(3): 125–129.

Rubio-Salcedo M, Martínez I, Carreño F, Escudero A (2013) Poor Effectiveness of the Natura 2000 Network Protecting Mediterranean Lichen Species. Journal for Nature Conservation 21(1): 1–9.

Rytwinski T, Fahrig L (2015) The Impacts of Roads and Traffic on Terrestrial Animal Populations. Pp 237-246 in: van der Ree R, Smith DJ, Grilo C (Eds.). Handbook of Road Ecology. John Wiley & Sons Ltd, UK.

Sánchez-Fernández D, Bilton DT, Abellán P, Ribera I, Velasco J, Millán A (2008) Are the endemic water beetles of the Iberian Peninsula and the Balearic Islands effectively protected? Biological Conservation 141(6): 1612-1627.

Selva N, Kreft S, Kati V, Schluck M, Jonsson B-G, Mihok B, Okarma H, Ibisch PL (2011) Roadless and Low-Traffic Areas as Conservation Targets in Europe. Environmental Management 48: 865–877.

Seshradi KS, Ganesh T (2015) Road ecology in south India: issues and mitigation opportunities. Pg 425-429 in: van der Ree R, Smith DJ, Grilo C (Eds). Handbook of Road Ecology. John Wiley & Sons Ltd, UK.

Shanley CS, Pyare S (2011) Evaluating the road-effect zone on wildlife distribution in a rural landscape. Ecosphere 2(2): 16.

Shafer CL (1995) Values and Shortcomings of Small Reserves: Dealing with the smallest habitat fragments when some of them are all that is left. BioScience 45(2): 80–88.

Torres A, Jaeger JAG, Alonsoa JC (2016) Assessing large-scale wildlife responses to human infrastructure development. PNAS 113(30): 8472-8477. https://doi.org/10.1073/pnas.1522488113

Trochet A, Schmeller DS (2013) Effectiveness of the Natura 2000 network to cover threatened species. Nature Conservation 4: 35–53.

Tsiafouli MA, Apostolopoulou E, Mazaris AD, Kallimanis AS, Drakou EG, Pantis JD (2013) Human Activities in Natura 2000 Sites: A Highly Diversified Conservation Network. Environmental Management 51: 1025–1033.

van der Ree R, Smith DJ, Grilo C (2015). Handbook of Road Ecology. John Wiley & Sons Ltd, UK.

van Langevelde F, Jaarsma CF (2009) Modeling the effect of traffic calming on local animal population persistence. Ecology and Society 14(2): 39.

Votsi N-E, Mazaris AD, Kallimanis AS, Zomeni MS, Vogiatzakis IN, Sgardelis SP, Pantis JD (2012) Road effects on habitat richness of the Greek Natura 2000 network. Nature Conservation 1: 53–71.

Wärnbäck A (2013). Beaktande av biologisk mångfald och ekosystemtjänster i miljökonsekvensbeskrivningar och miljöbedömningar. Annex 5 to SOU 2013:68, Synliggöra värdet av ekosystemtjänster – Åtgärder för välfärd genom biologisk mångfald och ekosystemtjänster. http://www.regeringen.se/49bba7/contentassets/ba53cd9f18b74f348eb0ff31e8280d60/synliggora-vardet-av-ekosystemtjanster-sou-201368 (In Swedish)

Tables

Table 1. Number, area and proportion of Swedish SPAs within an assumed effect zone of 1 km from larger transport infrastructure, and predicted total reduction in bird abundance (with 95% confidence interval) due to the effects. Results are given for the entire country and separated by biogeographical region.

Region	Total no. of SPAs	Total area of SPA (ha)	No. of SPAs affected to		Total area of SPA in effect zone (ha)	Proportion of total SPA in effect zone (%)	Reduction in bird abundance (% with C.I.)
			>0%	>50%			
Continental	41	53,331	41	18	19,202	36.0	7.2 (4.3-11.9)
Mixed-forest coastal	94	103,064	71	24	20,865	20.2	4.0 (2.4-6.7)
Mixed-forest inland	161	258,804	119	43	34,622	13.4	2.7 (1.6-4.4)
Boreal coastal	22	21,712	15	8	5,968	27.5	5.5 (3.3-9.1)
Boreal inland	130	162,924	63	30	13,122	8.1	1.6 (1.0-2.7)
Alpine (only inland)	26	1,984,005	16	0	28,242	1.4	0.3 (0.2-0.5)
Off-coastal	64	415,308	14	0	3,913	1.0	0.2 (0.1-0.3)
All Sweden	*538*	*2,999,149*	*339*	*123*	*125,946*	*4.2*	*0.8 (0.5-1.4)*

Table 2. Variables associated with effect zone overlap with Swedish SPAs devided by biogeographical region. Values given are mean estimates of coefficients of logistic regressions and beta-regressions with standard errors (SE) and probabilities (P). Values are only given for variables that were included in the final model.

	Log(size)		**Forested area**		**Wetland**		**Agri & grassland**	
Region	Estimate (SE)	*P*	Estimate (SE)	*P*	Estimate (SE)	*P*	Estimate (SE)	*P*
Logistic regression (probability of overlap)								
Continental †	-	-	-	-	-	-	-	-
Mixed-forest coastal	0.45(0.27)	0.094						
Mixed-forest inland					0.49(0.21)	0.019	0.91(0.38)	0.016
Boreal coastal			-1.06(0.57)	0.065				
Boreal inland			-2.61(0.75)	<0.001	-2.06(0.70)	<0.001		
Alpine (only inland)	1.31(0.64)	0.039						
Off-coastal	1.07(0.40)	0.008						
Beta-regression (proportion of overlap)								
Continental ‡								
Mixed-forest coastal	-0.56(0.15)	<0.001					0.44(0.15)	0.002
Mixed-forest inland	-0.64(0.12)	<0.001					0.47(0.11)	<0.001
Boreal coastal	-0.85(0.34)	0.013						
Boreal inland	-0.56(0.16)	<0.001	-0.48(0.16)	0.004			0.43(0.16)	0.009
Alpine (only inland)	-0.78(0.11)	<0.001			-0.38(0.17)	0.022		
Off-coastal	-1.09(0.24)	<0.001					0.40(0.19)	0.036

† Could not be analysed as all sites had value 1, i.e., overlap to some degree with the effect zone.

‡ No variable contributed to the final model; i.e., the model including only the intercept had the lowest AIC.

Figures

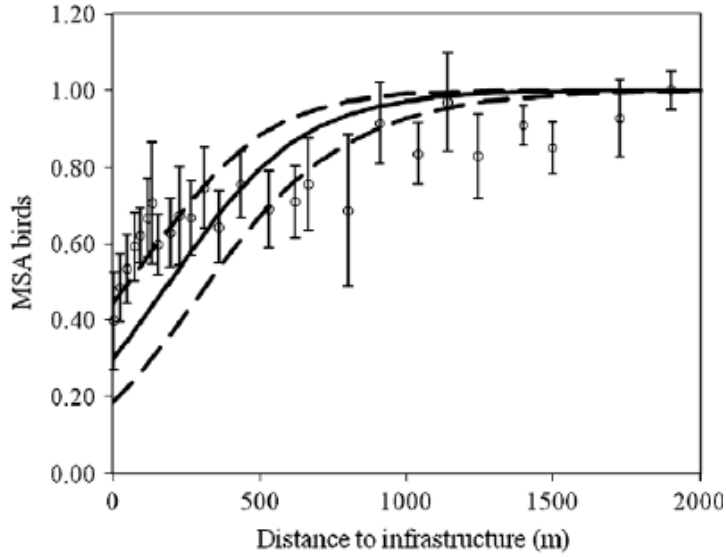

Figure 1. Mean species abundance (MSA) of birds as a function of distance to infrastructure (logistic regression). Open dots represent the pooled results of a meta-analysis per distance interval ±SE. Solid black line denotes the estimated curve for the decline of MSA in proximity to infrastructure; dashed lines are the 95% upper and lower limits of the confidence bands of the curve. Figure from Benítez-López et al. (2010).

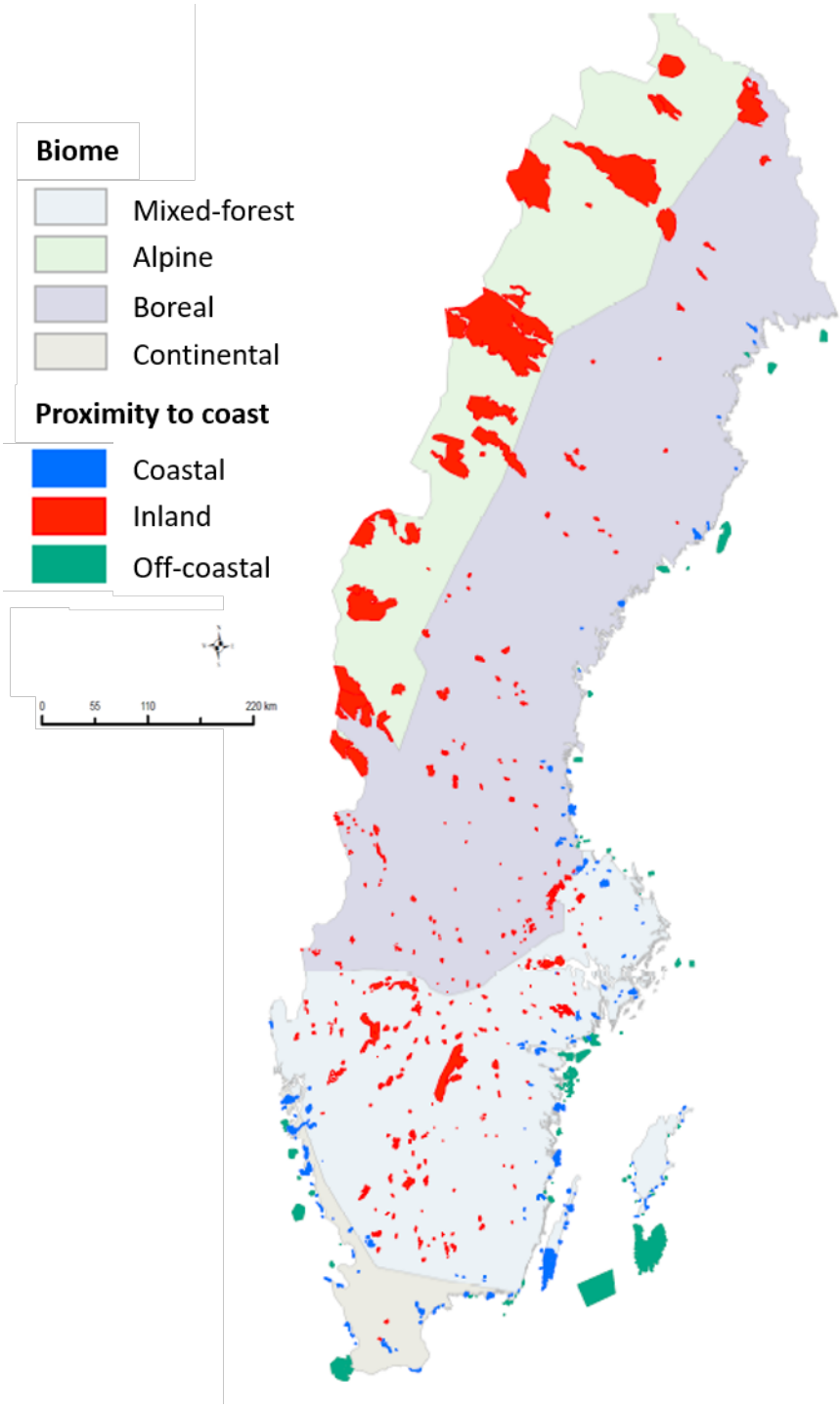

Figure 2. Special Protection Areas (SPAs) in Sweden, divided by biogeographical region; see text for further explanation.