Oecologia Australis
17(1): 48-62, Março 2013
http://dx.doi.org/10.4257/oeco.2013.1701.05

ASSESSMENT OF TRAFFIC NOISE IMPACT IN IMPORTANT BIRD SITES IN SWEDEN – A PRACTICAL METHOD FOR THE REGIONAL SCALE

Jan Olof Helldin[1,2*]; *Per Collinder*[3]; *Daniel Bengtsson*[3,4]; *Åsa Karlberg*[4,6] & *John Askling*[7]
[1]Swedish University of Agricultural Sciences (SLU), Swedish Biodiversity Centre. P.O.Box 7007, Uppsala, Sweden, Postal code: SE-75005
[2]Present affiliation: Calluna AB. Torsgatan 30, Stockholm, Sweden, Postal code: SE-11321
[3]Ecology group. Åsögatan 121, Stockholm, Sweden, Postal code: SE-11624
[4]Linnaeus University. Barlastgatan 11, Kalmar, Sweden, Postal code: SE-39182
[5]The Swedish Transport Administration. P.O.Box 186, Härnösand, Sweden, Postal code: SE-87124
[6]Present affiliation: Tyréns AB. Strandgatan 4, Härnösand, Sweden, Postal code: SE-87145
[7]Calluna AB. Linköpings slott, Linköping, Sweden, Postal code: SE-58228
E-mails: j-o.helldin@calluna.se, per.collinder@ekologigruppen.se, daniel.bengtsson@lnu.se, asa.karlberg@tyrens.se, john.askling@calluna.se

ABSTRACT

Previous research has pointed out the negative impact of traffic noise on wildlife adjacent to major roads, but despite the scientific evidence, the impact of traffic noise in natural environments is rarely assessed, and even more rarely mitigated, in road planning, in Sweden as well as in most other countries. It has been argued that the reason to this shortcoming is the lack of a practical method to assess this impact on natural environments. We developed a desktop method for assessing the traffic noise impact on areas of importance for nature conservation, with special emphasis on important bird sites. The method output is a calculation of the effective habitat loss due to traffic noise for each site, based on dose-effect relationships presented in literature, available GIS data on selected habitat types, official road data, and a simplified model for noise distribution. The method has a dual purpose; to estimate the impact of traffic noise on birds at larger geographic scales, and to identify priority sites for mitigation efforts. We applied the method in two Swedish regions with relatively low or moderate road and traffic densities. The results from these case studies pointed out that i) at regional level, the impact zone covers a small part of the land area (0.6 and 3.3% of lower and higher density regions, respectively), ii) for certain important bird habitat types, >10% of sites are within the impact zone, iii) the impact from traffic noise represents an effective loss of 0.02-1.7% of the total area of the selected habitat types. The latter figures can be taken as estimates of the present conservation debt of traffic noise. The results indicate that traffic noise may have a disproportionate impact on some important bird habitats. Because bird sites are often rich also in other taxa, and in addition tend to be important areas for outdoor recreation, we argue that traffic noise may have a broad impact on nature conservation, and that mitigation efforts should be made to minimize this impact. We discuss the general applicability of the method.
Keywords: Traffic noise; birds; assessment; method; Sweden.

RESUMO

AVALIAÇÃO DO IMPACTO GERADO PELO RUÍDO DO TRÁFEGO EM IMPORTANTES HABITATS DE AVES NA SUÉCIA – UM MÉTODO PRÁTICO PARA A ESCALA REGIONAL. Estudos anteriores indicam os impactos negatives do ruído gerado pelo tráfego para a biota que vive em ambientes adjacentes a grandes rodovias, mas apesar das evidências científicas, o impacto do ruído gerado pelo tráfego em ambientes naturais é raramente estudado, e ainda mais raramente mitigado, no planejamento de rodovias, na Suécia e também na maioria dos outros países. Tem-se discutido que a razão para a ausência de estudos é a falta de métodos práticos que avaliem este impacto nos ambientes naturais. Nós desenvolvemos um método computacional para avaliar o impacto do ruído do tráfego em áreas importantes para a conservação da natureza, com ênfase especial em importantes habitats de aves. O funcionamento do método se dá pelo cálculo da perda efetiva de habitat pelo ruído do tráfego para cada área, com base nas relações de dose-efeito

obtidas na literatura, dados GIS disponíveis para os habitats selecionados, dados oficiais das rodovias, e um modelo simplificado para a propagação do ruído. O método tem dois objetivos; estimar o impacto do ruído do tráfego nas aves em grandes escalas geográficas; e identificar as áreas prioritárias para ações mitigadoras. Nós aplicamos este método em duas regiões na Suécia com relativamente baixa ou moderada densidades de rodovias e táfego. Os resultados destes estudos de caso indicaram que i) em nível regional, a zona de impacto abrange uma pequena parte da área terrestre (0,6 e 3,3% das áreas de menor e maior dendidade, respectivamente), ii) para alguns tipos importantes de habitats das aves, >10% das áreas estão dentro dos limites da zona de impacto, iii) o impacto do ruído do tráfego representa uma perda efetiva de 0,02-1,7% da área total dos habitats selecionados. Estas informações podem ser vistas como estimativas da atual ausência de ações de conservação relacionadas ao ruído do tráfego. Os resultados indicam que o ruído do tráfego pode ter um impacto desproporcional em alguns habitats importantes para aves. Já que estes habitats são frequentemente ricos também em outras espécies, e ainda tendem a ser importante áreas de recreação ao ar livre, nós argumentamos que o ruído do tráfego pode ter um grande impacto na conservação da natureza, e que as ações mitigadoras devem ser realizadas para diminuir este impacto. Nós discutimos a aplicabilidade geral do método.
Palavras-chave: Ruído do tráfego; aves; avaliação; método; Suécia.

RESUMEN

EVALUACIÓN DEL IMPACTO GENERADO POR EL RUIDO DEL TRÁNSITO EN LUGARES IMPORTANTES PARA LAS AVES EN SUECIA – UM MÉTODO PRÁCTICO A ESCALA REGIONAL. Estudios preliminares han indicado el impacto negativo del ruido del tráfico en la biota adyacente a grandes carreteras, pero a pesar de las evidencias científicas, el impacto del ruido del tránsito en ambientes naturales es raramente evaluado, y más raramente mitigado en el planeamiento de carreteras, tanto en Suecia como en la mayor parte de los países. Se ha afirmado que la razón para la ausencia de estudios es la falta de metodologías prácticas para evaluar el impacto en ambientes naturales. Desarrollamos un método computacional para medir el impacto del ruido del tránsito en áreas con importancia para la conservación, con énfasis especial en regiones importantes para las aves. El resultado del análisis es un cálculo de la pérdida de hábitat efectiva debida al ruido para cada región, basada en relaciones dosis-efecto presentadas en la literatura, datos de SIG de los tipos de hábitat seleccionados, datos oficiales de carreteras y un modelo simplificado para la distribución del ruido. El método tiene un propósito doble; estimar el impacto del ruido del tránsito en las aves a gran escala geográfica e identificar lugares prioritarios para concentrar los esfuerzos de mitigación. Aplicamos el método en dos regiones suecas con densidades de tránsito relativamente bajas o moderadas. Los resultados de este estudio de caso sugirieron que: i) a nivel regional, la zona de impacto cubre una pequeña parte del área terrestre (0.6 y 3.3% de regiones de baja y alta densidad, respectivamente), ii) para algunos tipos importantes de hábitat para las aves, >10% de las áreas están dentro de la zona de impacto, iii) el impacto del ruido del tránsito representa una pérdida efectiva de 0.02-1,7% del área total de los tipos de hábitats seleccionados. Las últimas cifras pueden ser tomadas como estimativas del área de conservación faltante actual relacionada con el ruido del tránsito. Los resultados indican que el ruido del tránsito puede tener un impacto desproporcionado en algunos hábitats importantes para las aves. Debido a que las áreas con aves son a menudo ricas en otros taxones y adicionalmente tienden a ser áreas para la recreación al aire libre, sugerimos que el ruido del tránsito puede tener un amplio impacto en la conservación de la naturaleza y que esfuerzos de mitigación deben ser realizados para minimizar este impacto. Discutimos la aplicabilidad general del método.
Palabras clave: Ruido del tránsito; aves; valoración; método; Suecia.

INTRODUCTION

One of the many adverse effects of traffic and roads on wildlife is noise disturbance. Previous studies have shown that several bird species occur in lower numbers in the vicinity of high traffic roads (reviewed by Reijnen & Foppen 2006, Benítez-López *et al.* 2009), and that a major cause of this effect is likely to be traffic noise (Reijnen *et al.* 1995, Forman & Alexander 1998, Reijnen & Foppen 2006, Garniel *et al.* 2007, Parris & Schneider 2009, Barber *et al.* 2010, Kociolek *et al.* 2011, but see Summers *et al.* 2011).

Many animal species including birds, mammals, frogs and insects use acoustic signals to attract mates, to defend territories, to maintain group cohesion, to hunt, and to warn for predators (Brumm & Slabbekoorn 2005). Anthropogenic noise has negative effects on the function of such signals. For example, high levels of traffic noise may lead to difficulties for birds and frogs to attract mates (Reijnen & Foppen 1994, Bee & Swanson 2007), and may result in reduced foraging efficiency in bats (Siemers & Schaub 2011).

Behavioral responses to traffic noise in birds and frogs include singing/calling at higher pitch (to reduce the masking from low-frequency noise; Slabbekoorn & den Boer-Visser 2006, Parris & Schneider 2009, Parris *et al.* 2009) or at higher volume (Brumm 2004, Katti & Warren 2004), altering the time spent singing/calling (Sun & Narins 2005, Díaz *et al.* 2011), and shifting to nocturnal singing (Fuller *et al.* 2007). Such adaptations may reduce the problem with masking but still involve costs in the form of physiological and energetic stress. However, not all species have the possibility to behavioral adaptation, and for these species traffic noise may lead to reduced reproductive success, increased mortality risk, and emigration, resulting in decreased population densities (Fletcher & Busnel 1978, Reijnen & Foppen 1994, Patricelli & Blickley 2006, Lengagne 2008, Barber *et al.* 2010, Halfwerk *et al.* 2011).

Along busy-traffic roads, more than half of the bird species may be negatively affected, and the effects have been shown to be particularly strong in species of conservation concern (Forman & Deblinger 2000, Foppen *et al.* 2002, Reijnen & Foppen 2006, Garniel *et al.* 2007). In comparisons among habitat types, wetlands, grassland and natural woodland appeared to have a larger proportion of affected species than arable land or urban habitats (Reijnen *et al.* 1996, Reijnen & Foppen 2006).

Traffic noise also decreases the value of human recreation in natural environments, urban green areas as well as more remote wilderness. Tranquility is increasingly perceived as an important landscape value (Shaw 1996, Health Council of the Netherlands 2006, National Board of Housing Building and Planning 2007). Technical noise causes an array of physiological and psychological effects in humans, such as raised stress levels, disturbed conversation and sleep, and increased ill-health (WHO 2000, Mace *et al.* 2004). Outdoor environments provide important opportunities for human physical exercise and psychological restoration (Grahn & Stigsdotter 2003, Ottosson 2007, National Board of Housing Building and Planning 2007), but technical noise has a negative impact on the value of outdoor recreation (Mace *et al.* 2004, Nilsson & Berglund 2006).

Interestingly, some of the most comprehensive studies that we have come across concerning the effects of noise on outdoor recreation (Nilsson 2007) and wild bird fauna (Reijnen & Foppen 1995, Reijnen *et al.* 1996) show strikingly similar dose-effect relationships (Figure 1), which reveals

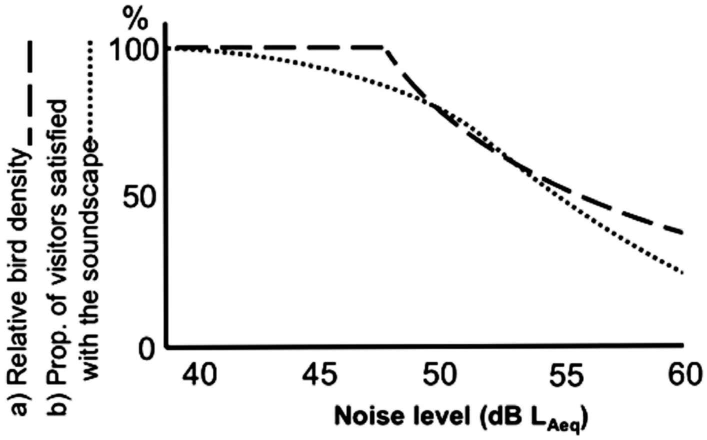

Figure 1. Effects of noise on wild bird fauna and outdoor recreation; a) relative frequency of breeding birds in Dutch grasslands, adopted from Reijnen *et al.* (1996), and b) proportion of visitors in Swedish urban-suburban green areas perceiving the soundscape as good or very good, adopted from Nilsson (2007).

a promising prospect for a coordinated treatment of noise disturbance in environmental assessment and mitigation. The first discernible effects occur at noise levels of 42-47dBL_{Aeq}, at 48-49dBL_{Aeq} the environmental quality (measured as perceived soundscape quality for people and breeding population density for birds, respectively) has dropped to 80% of that in the undisturbed surroundings, and at 55dBL_{Aeq} the environmental quality is halved. At higher noise levels, environmental quality further decreases asymptotically towards 10-20% of the undisturbed surroundings.

Due to its impact on wildlife and outdoor recreation, noise emissions from transport infrastructure can be seen as a considerable problem for nature conservation (Nilsson & Berglund 2006, Swedish Environmental Protection Agency 2007, Barber *et al.* 2010, Kociolek *et al.* 2011). With the ongoing urbanization and the rise in motorization, and the resulting increase in anthropogenic noise in the landscape, the need for efficient noise mitigation measures will further increase. However, until now, the impact of traffic noise in natural environments has only incidentally been addressed in Swedish transport infrastructure planning. Present noise regulations in Sweden (Swedish Government 2004a) and the European Union (European Parliament and Council 2002) require traffic noise to be mitigated only in residential areas. Existing general (non-binding) advices on noise prevention in recreational areas, issued by Swedish transport authorities (Swedish Road Administration 2001), are rarely followed, even by the authorities themselves. Sweden is not unique in this sense; in most countries the impact of traffic noise on wildlife is receiving scant attention (Reijnen & Foppen 2006).

The lack of a practical method to assess the impact of traffic noise in natural environments may be one reason why this question not has been addressed in planning and conservation. It has been argued that without a baseline assessment, the obstacle to implementation is twofold: i) there are no results to illustrate the overall severity of the problem, and ii) there are no means to identify priority sites for mitigation (A. Sjölund, Swedish Transport Administration; personal communication).

In this paper, we describe a desktop method for assessing regional scale impact of traffic noise on areas of importance for nature conservation, with special emphasis on important bird sites. The purpose of the method is dual; to estimate the impact of traffic noise on birds at larger geographic scales, and to identify priority sites for mitigation efforts. We present results derived from the method applied in two Swedish regions with relatively low or moderate traffic densities. The significance of the results in a broader nature conservation perspective is discussed.

THE METHOD

In one sentence, the method maps the overlaps between noise impact zones and important bird sites within a specified region, and ranks the sites according to priority for noise mitigation. The method offers a standardized procedure, and relies on a number of simplifications and assumptions described below. It is a desktop method, in the sense that it uses only data derived from existing data bases. The method is here described as it was applied in the two case studies presented below.

PREDICTION OF NOISE IMPACT ZONES

Traffic noise levels along roads were calculated using the so-called Nordic prediction method (Jonasson *et al.* 1996, Bendtsen 1999, Swedish Environmental Protection Agency 2008), which is the present standard prediction model for noise propagation in Sweden. In order to make the model operational at regional scale, we simplified it by assuming no noise screening, flat terrain, road surface in level with adjacent terrain, receiver at 2m above ground level and soft (unpaved) ground surface between road and receiver. Hence, only data on traffic density (separated between light and heavy vehicles) and signed speed were needed for model input. Data were derived from the Swedish Data Base for Road Traffic (http://www22.vv.se/nvdb2_templates/default____36975.aspx), administered by the Swedish Transport Administration. Roads with speed limits below 70km/h and with less than 3000 vehicles/day were excluded, because no significant noise impact on birds has been proven for these minor roads (Reijnen & Foppen 2006). Three noise impact zones were calculated; the selection of zone intervals being based on the dose-effect relationships described in previous research (see introduction and Figure 1), and approximated to the nearest 5dB:

- inner impact zone: 55+dBL_{Aeq} – assumed to correspond to an average 70% decrease in habitat quality;
- mid impact zone: 50-55dBL_{Aeq} – assumed to correspond to an average 30% decrease in habitat quality; and
- outer impact zone: 45-50dBL_{Aeq} – assumed to correspond to an average 10% decrease in habitat quality.

SELECTION OF HABITAT TYPES AND CRITERIA FOR INCLUSION

In order to identify bird sites of conservation concern, we selected four habitat types (bird lakes, high nature value grasslands, large open bogs and high nature value deciduous woodlands), based on general knowledge about bird richness and importance for particular species of conservation concern (Berg & Tjernberg 1996, Pärt & Söderström 1999). Furthermore, a high proportion of the bird species occurring in these habitats have been shown to be negatively affected by noise (following Reijnen *et al.* 1996, Reijnen & Foppen 2006).

Bird lakes

These are shallow lakes (Figure 2a) with a high biodiversity and bird density, hosting a large number of wetland bird species, many of which are red-listed. Because no national survey of bird lakes has been conducted, we defined these as areas where at least 4 of 8 indicator species were observed during the breeding period in the last 5 years. As indicator species for bird lakes the following were selected: pochard (*Aythya ferina*), shoveler (*Anas clypeata*), horned grebe (*Podiceps auritus*), coot (*Fulica atra*; only breeding birds), black-headed gull (*Larus ridibundus*; only breeding birds), grasshopper warbler (*Locustella naevia*), reed warbler (*Acrocephalus scirpaceus*), and sedge warbler (*Acrocephalus schoenobaenus*). Bird observations were derived from the Species Gateway (http://www.artportalen.se/birds), the national web-based system for voluntary reports of observations of birds administered by the Swedish Species Information Centre.

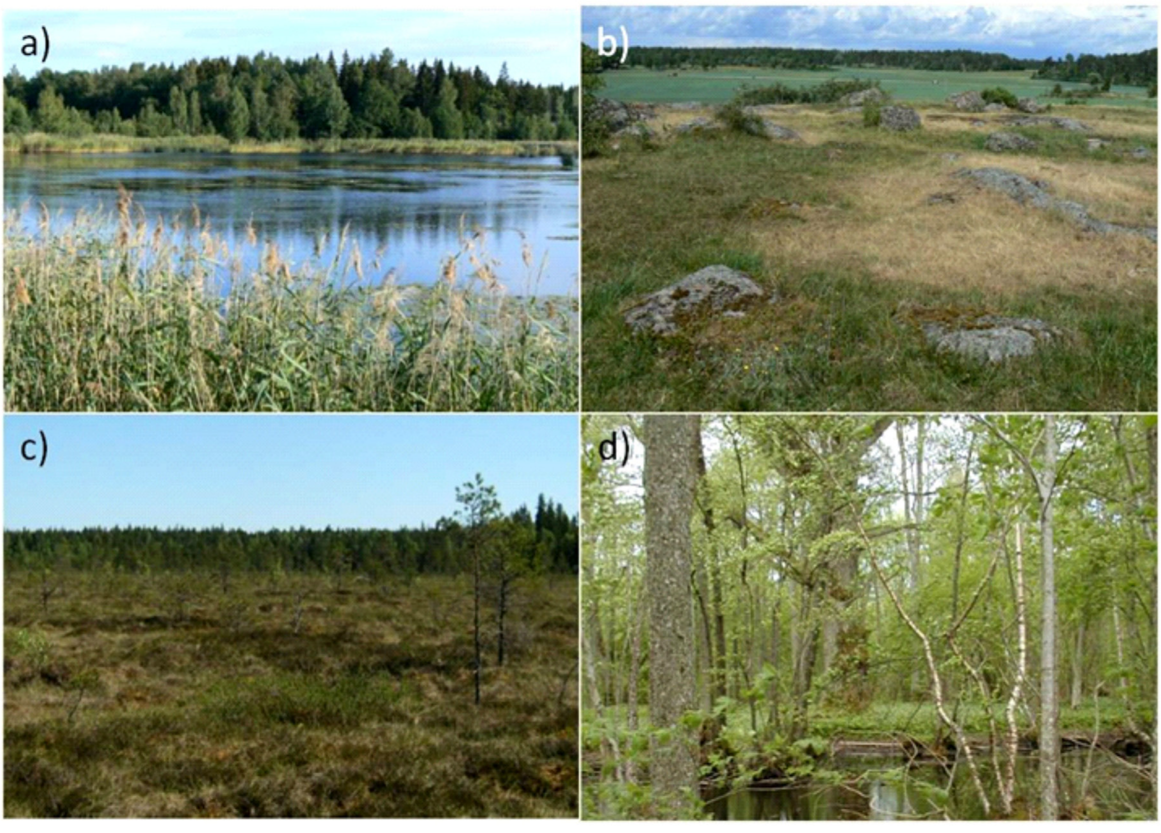

Figure 2. Habitat types with assumed large importance to birds, and therefore selected for the method: a) bird lake, b) high nature value grassland, c) large open bog, and d) high nature value deciduous woodland. Photos: Jan Olof Helldin.

High nature value (HNV) grasslands

These are semi-natural grasslands (Figure 2b) – pastures and meadows – that host a large proportion of the declining agricultural bird community (Pärt & Söderström 1999). In Sweden these grasslands are often small in size. Therefore, grasslands within <500m from each other were lumped into one HNV grassland cluster, including a 250m buffer zone around each grassland. Because larger grassland areas are expected to have larger value for birds, clusters <50ha were excluded. Data on area and position of grasslands were derived from the Swedish Grassland Survey (https://etjanst.sjv.se/tuva2/site/index.htm), administered by the Swedish Board of Agriculture.

Large open bogs

These (Figure 2c) often have low numbers of bird species and individuals, but host species that are characteristic for the boreal region (Boström & Nilsson 1983). Because larger bogs are expected to have larger value for birds, bogs <30ha were excluded. Data on area and position of bogs were derived from the Wetland Survey, accessed through the Environmental Data Gateway (http://gpt.vic-metria.nu/GeoPortal/#/startMenu), administered by the Swedish Environmental Protection Agency.

High nature value (HNV) deciduous woodlands

Woodlands dominated by deciduous tree species of particular conservation value: *Quercus*, *Ulmus*, *Fagus*, *Tilia*, *Acer*, *Fraxinus* and *Carpinus* (Figure 2d). Such woodlands generally have a high biodiversity and bird density, and host several bird species on the red-list (Berg & Tjernberg 1996, Berg *et al.* 2002). Because such woodlands in Sweden are often small in size, woodlands within <500m from each other were lumped into one HNV deciduous woodland cluster, including a 250m buffer zone around each woodland. Because larger deciduous woodland areas are expected to have larger value for birds, clusters <50ha were excluded. Data on area and position of deciduous woodlands were derived from the Swedish Forest Data Base (http://www.skogsstyrelsen.se/Aga-och-bruka/Skogsbruk/Karttjanster/Skogens-Kalla), administered by the Swedish Forest Agency.

In most cases, data were available through internet databases without cost. All data was downloaded as shape files and further handled in ArcGIS 9 and Excel. Road data was recalculated to width of the three noise impact zones as described above. Overlaps between important bird sites (as defined by the criteria described above) and the noise impact zones were calculated. Each of the habitat types was treated separately in the following procedure.

CALCULATIONS OF EFFECTIVE LOSS OF HABITAT AND LOSS-PER-ROAD-LENGTH RATIO

For each bird site overlapping with the noise impact zones, the total overlapping area (all three zones combined), the effective habitat loss, the length of the road section causing the loss, and the loss-per-road-length ratio were calculated (Figure 3). The effective loss of habitat due to traffic noise was calculated as the sum of habitat losses in the three impact zones, and the habitat loss in each impact zone was in turn calculated as the area in that zone multiplied by the assumed decrease in habitat quality (70, 30 and 10% for inner, mid and outer zones, respectively).

The road section causing the impact at each site was defined as the road within 250m from the site (this distance was arbitrarily selected to cover most impact zones). The loss-per-road-length ratio was calculated by dividing the effective habitat loss with the length of the road section (ha/km). This calculation was done because noise mitigation measures such as screens or adapted paving have a constant cost per road meter, so the ratio can be interpreted as an expected mitigation efficiency, the amount of habitat that would be recovered per distance of noise preventive measure along the road. Because this was an aspect that was developed late in the project, road length and loss-per-road-length could only be calculated in one of the case study regions (Mid-Sweden). In order to explore the data, correlations were tested between i) effective habitat loss and size of each site, and ii) effective habitat loss and the length of the road section causing the impact at each site.

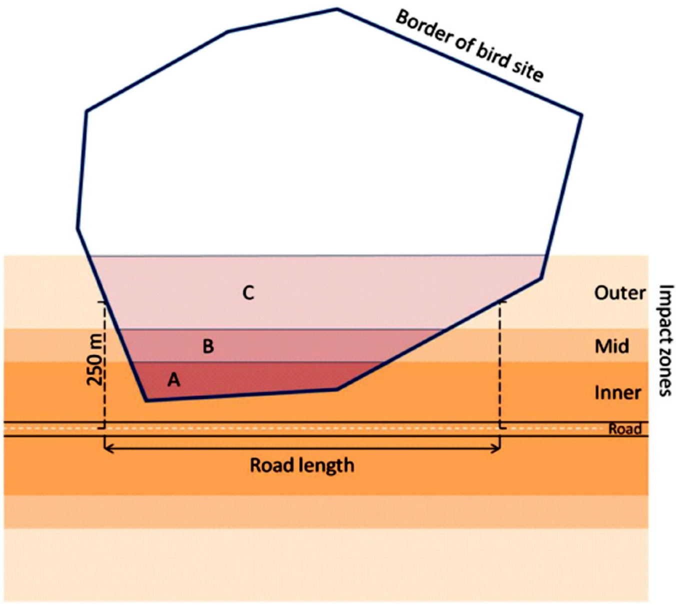

Figure 3. Principal illustration of expected impact zones along larger roads, the area overlapping with a bird site (A+B+C), the effective habitat loss for the site (A x 0.7+B x 0.3+C x 0.1), and the length of the road section causing the loss. Further explanations are given in the text.

THE CASE STUDY REGIONS

We applied the method in two Swedish regions, Mid-Sweden and West Götaland (Figure 4), during 2009-2011.

Figure 4. Map of Sweden, with location of the two case study regions (grey areas), with their networks of larger roads (black lines).

REGION MID-SWEDEN

This 117,000km^2 region is sparsely populated (7.8 inhabitants/km^2), with a density of the state road net of 18km road/100km^2 and the traffic density on this road net is on average about 360 vehicles/road km. The natural environment in the region is typically boreal; hilly terrain covered by coniferous forest, and with a high frequency of bogs. The few agricultural areas, villages and towns are generally concentrated in narrow river valleys. HNV deciduous woodlands are largely lacking.

REGION WEST GÖTALAND

This 25,000km^2 region is more densely populated with Swedish standards (66.1 inhabitants/km^2), and include one of Sweden´s larger cities, Gothenburg. The density of the state road net in this region is 62km road/100km^2 and the traffic density on these roads is on average about 740 vehicles/road km. Also in this region, hilly terrain with coniferous forest of boreal type is a dominant trait, but with nemoral/continental elements; agricultural land makes up a larger proportion, at some places concentrated in agricultural plains, and HNV deciduous woodlands occur.

It should be noted that despite the different traffic intensity in the two regions, neither of them can be considered densely populated, nor densely roaded, in comparison with, for example, western and central Europe, were road densities in most parts are considerably higher (Jaeger *et al.* 2011).

RESULTS FROM THE CASE STUDIES

REGIONAL LEVEL IMPACT

In Mid-Sweden, the total length of the roads included was 1,570km, and the total width of the predicted noise impact zones along these roads varied between 110 and 350m on each side of the road. The noise impact zones covered a total of 735km^2, or 0.63% of the total area of the region. The impact zones affected 8.4% of the bird lakes, 6.9% of HNV grassland clusters, and 1.5% of the large open bogs in the region (Table 1; see also Figure 5 for an example). In most cases the impact zones covered only a minor part of each bird site, and the proportion of the total area of each habitat type within the impact zones was therefore considerably lower; 1.4% of the total bird lake area, 2.0% of HNV grassland cluster, and 0.1% of large open bog (Table 1). The effective habitat losses due to traffic noise were 0.48km^2 bird lake (=0.3% of a total of 154km^2 bird lake; Table 1), 3.63km^2 HNV grassland cluster (=0.6% of totally 635km^2), and 2.22km^2 large open bog (=0.02% of totally 11,680km^2). Due to the low occurrence of HNV deciduous woodland in the region, this habitat type was excluded from the analysis.

Table 1. Results for each of the selected habitat types in the two case studies.

	Bird lakes	HNV grassland clusters	Large open bogs	HNV decid. woodland clusters
I. Mid-Sweden				
a) Total nº of sites in the region	153	726	5 600	-
b) Nº of sites within impact zones	13	50	85	-
c) Total area in the region (ha)	15 400	63 500	1 168 000	-
d) Total area within impact zones (ha)	210	1 290	1 050	-
e) Total effective habitat loss in the region (ha)	50	360	220	-
f) Effective habitat loss per affected site (ha, mean±SD)	3.7±3.1	7.3±6.1	2.6±3.3	-
g) Road length per affected site (km, mean±SD)	1.4±1.2	1.3±0.7	1.3±1.2	-
h) Loss-per-road-length ratio (ha/km, mean±SD)	2.8±1.7	1.3±1.6	1.8±1.6	-
II. West Götaland				
a) Total nº of sites in the region	120	1 736	998	476
b) Nº of sites within impact zones	19	261	87	83
c) Total area in the region (ha)	19 900	235 500	97 100	42 000
d) Total area within impact zones (ha)	340	9 100	1 270	2 790
e) Total effective habitat loss in the region (ha)	80	2 690	330	730
f) Effective habitat loss per affected site (ha, mean±SD)	4.5±10.2	10.3±11.7	3.8±6.4	8.8±9.0

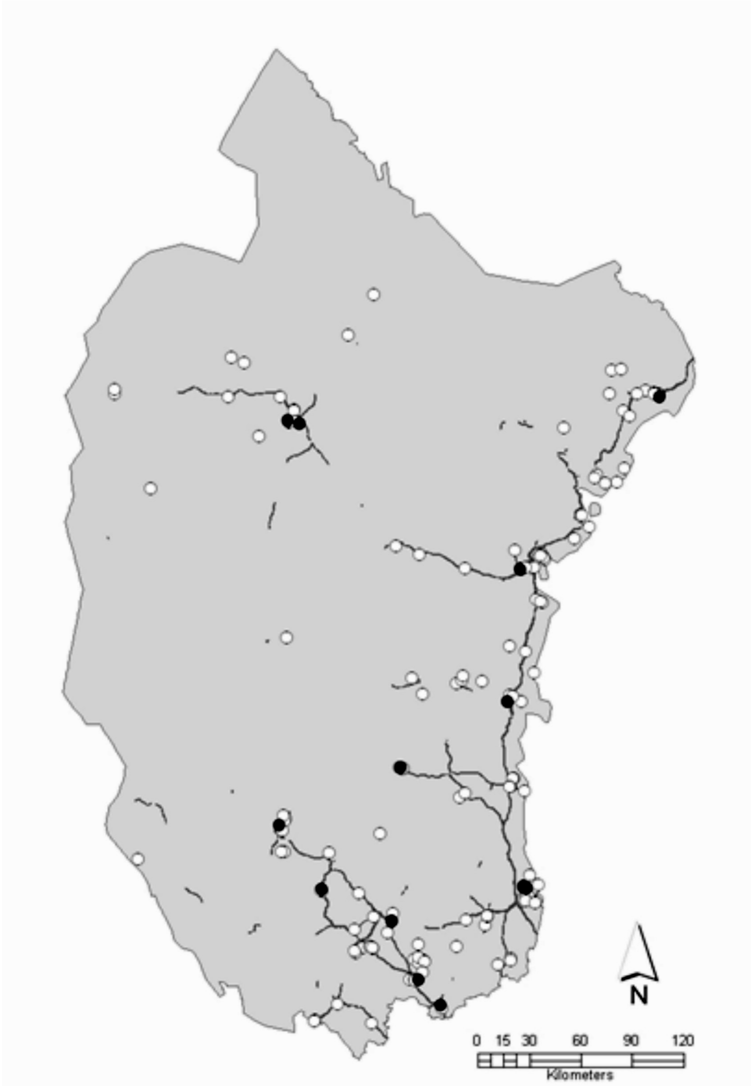

Figure 5. Bird lakes covered by the noise impact zone (black circles) and outside the noise impact zone (white circles) in Mid-Sweden.

In the region West Götaland, the total length of the included roads was 2,624km, and the total width of the predicted noise impact zones varied between 95 and 1,410m on each side. The impact zones together covered 1,133km^2 in total, or 3.28% of the region's total area, and affected 15.8% of the bird lakes, 15.0% of HNV grassland clusters, 8.7% of the large open bogs, and 17.4% of the region's HNV deciduous woodland clusters (Table 1). The proportion of the total area of each habitat type covered by the noise impact zones was 1.7% of the total bird lake area, 3.9% of HNV grassland clusters, 1.3% of large open bog, and 6.6% of HNV deciduous woodland clusters (Table 1). The effective habitat losses due to traffic noise were 0.8km^2 bird lake (=0.4% of a total of 199km^2 bird lake; Table 1), 26.9km^2 HNV grassland cluster (=1.1% of totally 2,355km^2), 3.3km^2 large open bog (=0.3% of totally 971km^2), and 7.3km^2 HNV deciduous woodland cluster (=1.7% of totally 420km^2).

SITE LEVEL IMPACT

Both the size of the sites and the effective habitat loss varied greatly among sites in each region and habitat type (Tables 1 and 2). The variation in effective habitat loss indicated that a smaller number of sites constituted particular conflict points, where much of the total habitat loss was concentrated. For example in bird lakes in region Mid-Sweden, >50% of the total habitat loss derived from the four most affected sites (Table 2). The variation among sites in size and effective habitat loss were not strongly correlated, neither in Mid-Sweden ($r^2 \leq 0.20$ for the three habitat types) nor in West Götaland ($r^2 \leq 0.10$ for the four habitat types), showing that the effective habitat loss was not well associated with the size of the site.

Table 2. Bird lakes in region Mid-Sweden, as an example of calculations of effective loss of habitat due to traffic noise and mitigation efficiency. Lakes are sorted by size.

Name of site and location	Site area (ha)	Effective habitat loss (ha)	Percent of site lost	Road length (km)	Loss-per-road-length (ha/km)
Lake Håvran, Hedemora	1132	1.08	0.1	1.04	1.04
Lake Idbyfjärden, Örnsköldsvik	607	0.57	0.1	0.14	3.92
Lake Sässman, Edsbyn	473	9.50	2.0	4.48	2.12
Lake Sonnboviken, Avesta	439	7.12	1.0	1.06	6.71
Lake Ändsjön, Frösön	347	6.76	1.9	1.51	4.48
Lake Mårdängsjön, Gävle	237	5.18	2.2	1.35	3.84
Lake Hillesjön, Gävle	236	2.99	1.2	1.48	2.07
Lake Selångersfjärden, Sundsvall	145	6.14	4.2	2.86	2.15
Lindänget/Lake Orsasjön, Orsa	136	1.59	0.0	1.49	1.07
Lake Limsjön, Leksand	133	5.08	3.8	1.65	3.09
Lake Karlslundstjärn, Falun	32	1.50	4.7	0.95	1.58
Lake Lillsjön, Östersund	26	0.02	0.1	0.00	-
Leachate pond, Hudiksvall´s dump	5	0.79	15.8	0.69	1.14

The length of the road section causing the impact (only measured in region Mid-Sweden) were for most sites between a few hundred meters and a few km, with a mean around 1.3km (Tables 1 and 2). The variation in the road length explained 42-63% of the variation in effective habitat loss ($r^2=0.42$ to 0.63 for the three habitat types). The ratio of loss-per-road-length averaged around a few ha/km road (Table 1), with maximum values for individual bird lakes 6.7ha/km (Table 2), HNV grasslands 8.4ha/km, and large open bogs 5.3ha/km.

DISCUSSION

The case studies showed that the predicted noise impact zones cover only a few percent of the total area of these two swedish regions. Still a considerably larger proportion of the important bird sites are to some degree impacted by noise, for exemple 13.5% of all bird sites (450/3330) identified in West Götaland. Even if the noise impacts only part of a site it is possible that this will create secondary, long-term effects on the area as a whole, for exemple by an increased pressure on the non-disturbed parts, or by reducing the total population size of some species below critical population thresholds.

Even if only considering the area within the noise impact zones, important bird sites may to some degree be more affected by noise than the average landscape. In the present case studies, bird lakes and HNV grassland in region Mid-Sweden and HNV deciduous woodland in West Götaland overlapped with the noise impact zones 2-3 times more than the average landscape for the respective region. The reason to this pattern is probably to be found in landscape structure; both some bird rich habitats and human settlements, with associated roads, tend to be concentrated in agricultural areas and river valleys. Traffic noise may therefore have a disproportionate impact on some important bird habitats.

Previous attempts to estimate the proportion of habitats ecologically affected by roads have presented higher estimates than the present cases. Reijnen & Foppen (2006) concluded that between 8 and 19% of bird habitat area in the Netherlands was located within road effect zones, where noise is expected to be the dominating road-induced factor affecting bird density. Forman (2000) estimated that at least 20% of the land area in the United States is affected by roads, but in that assessment a variety of taxa and effects were included (in addition to noise, also mortality and barrier effects, hydrology, spread of exotic plants, etc.), so the study from the Netherlands is more comparable to our study. Obviously, the Netherlands has on average a much denser road net and higher traffic densities than Sweden, which explains the larger effect of traffic noise. However, our results highlight that also in regions with low or moderate traffic densities, critical noise levels may be reached at many sites of importance for nature conservation. In addition, the disproportionate impact on certain habitats due to landscape structure can make noise disturbance a more serious issue than first expected.

Because areas impacted by noise are not totally lost as bird habitat, only their value as habitat impaired, we calculated an effective loss of habitat due to noise, taking into consideration the expected relative decrease in bird abundance at different noise levels. The effective loss of habitat ranged from 0.02 to 0.6% of the total area of the selected habitat types in the region with the lower traffic density, and from 0.3 to 1.7% in the region with the higher traffic density. These figures can be taken as estimates of the relative conservation debt of traffic noise in the two regions.

Clearly one can argue that if not more than a few percent of the important bird habitat is lost, traffic noise is a small threat to the conservation of birds, and other factors (in Sweden mainly habitat changes due to agriculture and forestry) probably have a larger general impact on bird populations. However, noise effects may well be additive to other impacts, and therefore critical to bird conservation under the present circumstances. Furthermore, according to principles stated in article 6b of the Convention on Biological Diversity (United Nations 1992), each sector is responsible for its own impact on biodiversity. Particularly at the restricted number of major conflict points, it is of potentially high conservation importance that noise emissions are mitigated.

This in turn points at the importance of identifying such major conflict points. The effective loss of habitat at individual sites provides one possible basis for the ranking of sites. As indicated by our results, much of the total habitat loss is concentrated to a relatively small number of sites of each habitat type, and should therefore be possible to mitigate with limited efforts. The described method will, however, not point out any cut off value, that is what sites that need to be mitigated and what sites that need no measures, since this is a matter of policy and available funding. As described in the introduction, present swedish environmental legislation does not state acceptable noise levels in natural environments, but environmental targets refer to the long-term viability of populations (Swedish Government 2004b). We therefore recommend that any mitigation efforts are accompanied by field monitoring of their effect on bird populations, to provide data for assessing the compliance of the road system to environmental targets.

An alternative for identifying priority sites for mitigation, that may appear more practically relevant, is to rank according to the loss-per-road-length ratio. This ratio indicates the amount of habitat that would be recovered per distance of road if noise mitigation would be conducted at the site. With the assumption that any noise mitigation has a constant cost per road meter (which is true for the most common noise mitigation measures, such as walls, earth berms or noise-absorbing paving), it points out the most cost-efficient road stretches to mitigate.

By calculating the effective habitat loss and pointing out the major conflict points, the present method is qualitatively different from previously published attempts to estimate road effects on larger geographic scales (Forman 2000, Reijnen & Foppen 2006). The method was developed to provide a reasonable trade-off between ecological rigour and the simplification often required by management. One assumption in the method that could be discussed is that the character of the impact on habitat quality is equal over the gradient in noise level, so that the loss in a certain area within the inner impact zone equals the loss in a three times larger area in the mid zone or in a seven times larger area in the outer zone. Another simplification is that the method does not take site-specific conservation value within habitat types into consideration. The biodiversity and conservation status may vary considerably among sites (Collinder *et al.* 2012), but because current swedish nature conservation management does not provide any generally accepted means to assess the conservation value of a site or an area, we chose not to include this aspect. Obviously also the simplified noise propagation model may open for misclassifications of sites, but detailed noise predictions (including for example effects of topography and ground structure) applied at a regional scale would be very expensive, and were judged not cost-efficient. All in all we believe that we found a reasonable balance between rigour and applicability, but the details in the application of the method as well as in the presentation of results can of course be fine-tuned.

Moreover, the method as it is described here is developed for a swedish context and relies on data not available in all countries. Adaptation of the method would be necessary in other biogeographical regions and with available data being of less or different detail. The minimum requirements are that a selection of important bird habitats can be made, that baseline data of the geographic distribution of these habitats are available, and that an established model for noise propagation can be applied to the entire road network at reasonable cost.

We want to underline that the described method is designed to work as a first and coarse identification of priority sites for mitigation. Before any practical mitigation is conducted, a field based assessment should be made to establish the appropriateness of the action at that particular site. Such an assessment may reveal local circumstances not covered by the method, such as topography or additional (non-traffic) noise sources, that would alter the expected effectiveness of mitigation efforts. A site-specific assessment should also involve a detailed noise propagation prediction.

Although only recently presented in the context of swedish infrastructure planning and environmental management (Bengtsson *et al.* 2009, Collinder *et al.* 2012), the described method has been adopted (in slightly adapted versions) in the environmental assessment of a large swedish infrastructure project under construction (Collinder & Bengtsson 2010) and as input to landscape analyses in infrastructure planning (Swedish Transport Administration 2012). Albeit this implementation of the method in current transport infrastructure planning can be considered a success, it has yet to be proven whether the process will eventually lead to practical action to mitigate the propagation of noise in particularly vulnerable natural environments such as bird sites.

The habitat types included in the described method were selected primarily on the basis of value for birds. However, they tend to be important habitats also for other taxa, such as amphibians and bats (possibly with the exception of bogs; Ahlén *et al.* 1995, Ahlén 2006), and also for other taxa that may be negatively affected by traffic noise (see introduction). Similarly, these habitat types are also expected to be of value for human recreation, because of their accessibility, high biodiversity and wilderness qualities (National Board of Housing Building and Planning 2007, Slabbekoorn & Ripmeester 2008). Hence, we argue that birds are useful indicators of nature conservation value in a broader perspective, and particularly in relation to noise disturbance. The species-rich and important bird taxon may well be reason enough for substantial conservation efforts, but noise mitigation in important bird areas will probably have multiple conservation benefits (Mace *et al.* 2004, Slabbekoorn & Ripmeester 2008, Arévalo & Newhard 2011, Kociolek *et al.* 2011).

ACKNOWLEDGEMENTS: We thank Åke Berg, Mattias Olsson, Andreas Seiler and two anonymous referees for their reading and helpful commenting on earlier drafts of this paper. The study was performed within the research programme TRIEKOL, financed by the Swedish Transport Administration.

REFERENCES

AHLÉN, I. 2006. *Report nº 5546 – Handlingsprogram för skydd av fladdermusfaunan.* Swedish Environmental Protection Agency, Stockholm, Sweden. 26p.

AHLÉN, I.; ANDRÉN, C. & NILSSON, G. 1995. *Sveriges grodor, ödlor och ormar.* Svenska Naturskyddsföreningen, Stockholm, Sweden. 56p.

ARÉVALO, J.E. & NEWHARD, K. 2011. Traffic noise affects forest bird species in a protected tropical forest. *Revista de Biología Tropical*, 59: 969-980.

BARBER, J.R.; CROOKS, K.R. & FRISTRUP, K.M. 2010. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution*, 25: 180–189.

BEE, M.A. & SWANSON, E.M. 2007. Auditory masking of anuran advertisement calls by road traffic noise. *Animal Behaviour*, 74: 1765-1776.

BENDTSEN, H. 1999. The Nordic prediction method for road traffic noise. *The Science of the Total Environment*, 235: 331-338.

BENGTSSON, D.; COLLINDER, P. & HELLDIN, J.O. 2009. Konfliktpunkter mellan värdefulla fågelmiljöer och vägbuller. *Interrim technical report*. Ekologigruppen AB, Stockholm and Swedish Biodiversity Centre, Uppsala, Sweden. 38p.

BENÍTEZ-LÓPEZ, A.; ALKEMADE, R. & VERWEIJ, P.A. 2009. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation*, 143: 1307-1316.

BERG, Å. & TJERNBERG, M. 1996. Commonness and rarity in Swedish vertebrates – distribution and habitat preferences. *Biodiversity and Conservation*, 5: 101-128.

BERG, Å.; GÄRDENFORS, U.; HALLINGBÄCK, T. & NORÉN, M. 2002. Habitat preferences of red-listed cryptogams in woodland key habitats in southern Sweden – analyses of a national survey. *Biodiversity and Conservation*, 11: 1479-1503.

BOSTRÖM, U. & NILSSON, S.G. 1983. Latitudinal gradients and local variation in species-richness and structure of bird communities on raised peat-bogs in Sweden. *Ornis Svecica*, 14: 213-226.

BRUMM, H. 2004. The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology*, 73: 434-440.

BRUMM, H. & SLABBEKOORN, H. 2005. Acoustic communication in noise. *Advances in the Study of Behavior*, 35: 151-209.

COLLINDER, P. & BENGTSSON, D. 2010. Konfliktpunkter mellan värdefulla fågelmiljöer och buller från Botniabanan. *Technical report*. Ekologigruppen AB, Stockholm, Sweden. 44p.

COLLINDER, P.; HELLDIN, J.O.; BENGTSSON, D.; KARLBERG, Å.; JANGIUS, A. & ASKLING, J. 2012. *Trafikbuller i värdefulla naturmiljöer – en metod för att identifiera konfliktpunkter.* Swedish Biodiversity Centre publication nº 62, Swedish University of Agricultural Sciences, Uppsala, Sweden. 36p.

DÍAZ, M.; PARRA, A. & GALLARDO, C. 2011. Serins respond to anthropogenic noise by increasing vocal activity. *Behavioral Ecology*, 22: 332-336.

EUROPEAN PARLIAMENT AND COUNCIL. 2002. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. *Official Journal of the European Communities*, 198: 12-25. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:189:0012:0025:EN:PDF> (Accessed on 09/07/2012)

FLETCHER, J.L. & BUSNEL, R.G. 1978. *Effects of noise on wildlife.* Academic Press, New York, USA. 305p.

FOPPEN, R.; VAN KLEUNEN, A.; LOOS, W.B.; NIENHUIS, J. & SIERDSEMA, H. 2002. Broedvogels en de invloed van hoofdwegen, een nationaal perspectief. *Technical report nº 2002/08*. SOVON Vogelonderzoek Nederland, Beek-Ubbergen, The Netherlands. 112p.

FORMAN, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*, 14: 31-35.

FORMAN, R.T.T. & ALEXANDER, L.E. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29: 207-231.

FORMAN, R.T.T. & DEBLINGER, R.D. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conservation Biology*, 14: 36-46.

FULLER, R.A.; WARREN, P.H. & GASTON, K.J. 2007. Daytime noise predicts nocturnal singing in urban robins. *Biology Letters*, 3: 368-370.

GARNIEL, A.; DAUNICHT, W.D.; MIERWALD, U. & OJOWSKI, U. 2007. *Vögel und Verkehrslärm. Schlussbericht, langfassung.* FuEVorhaben 02.237/2003/LR des Bundesministeriums für Verkehr, Bau- und Stadtentwicklung, Bonn/Kiel, Germany. 264p.

GRAHN, P. & STIGSDOTTER U. 2003. Landscape planning and stress. *Urban Forestry & Urban Greening*, 2: 1-18.

HALFWERK; W.; HOLLEMAN, L.J.M.; LESSELLS, C.M. & SLABBEKOORN, H. 2011. Negative impact of traffic noise on avian reproductive success. *Journal of Applied Ecology*, 48: 210-219.

HEALTH COUNCIL OF THE NETHERLANDS. 2006. *Quiet areas and health – executive summary.* The Hague, The Netherlands. 6p.

JAEGER, J.A.G.; SOUKUP, T.; MADRIÑÁN, L.F.; SCHWICK, C. & KIENAST, F. 2011. *Report nº 2/2011 – Landscape fragmentation in Europe.* European Environment Agency & Swiss Federal Office for the Environment. Luxembourg. 92p.

JONASSON, H.; KRAGH, J.; PARMANEN, J.; SANDBERG, U. & STOREHEIER, S. 1996. *Report 525/1996 – Road traffic noise: Nordic prediction method (TemaNord).* Nordic Council of Ministers, Kopenhagen, Denmark. 122p.

KATTI, M. & WARREN, P.S. 2004. Tits, noise and urban bioacoustics. *Trends in Ecology and Evolution*, 19: 109-110.

KOCIOLEK, A.V.; CLEVENGER, A.P.; ST. CLAIR, C.C. & PROPPE, D.S. 2011. Effects of road networks on bird populations. *Conservation Biology*, 25: 241–249.

LENGAGNE, T. 2008. Traffic noise affects communication behaviour in a breeding anuran, *Hyla arborea*. *Biological Conservation*, 141: 2023-2031.

MACE, B.L.; BELL, P.A. & LOOMIS, R.J. 2004. Visibility and natural quiet in national parks and wilderness areas – Psychological considerations. *Environment and Behavior*, 36: 5-31.

NATIONAL BOARD OF HOUSING BUILDING AND PLANNING. 2007. *Landskapets upplevelsevärden: Vilka är de och var finns de?* Report, Board of Housing Building and Planning, Karlskrona, Sweden. 70p.

NILSSON, M.E. 2007. Soundscape quality in urban open spaces. Paper nº 115. *In:* Proceedings of the 36th International Congress and Exhibition of Noise Control Engineering (Inter-Noise 2007). Istanbul, Turkey.

NILSSON, M.E. & BERGLUND, B. 2006. Soundscape quality in suburban green areas and city parks. *Acta Acustica united with Acustica*, 92: 903-911.

OTTOSSON, J. 2007. The importance of nature in coping: Creating increased understanding of the importance of pure experiences of nature to human health. *PhD Thesis*. Swedish University of Agricultural Sciences (SLU), Alnarp, Sweden. 79p.

PARRIS, K.M. & SCHNEIDER, A. 2009. Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and Society*, 14: 29. <http://www.ecologyandsociety.org/vol14/iss1/art29/>. (Accessed on 09/07/2012).

PARRIS, K.M.; VELIK-LORD, M. & NORTH, J.M.A. 2009. Frogs call at a higher pitch in traffic noise. *Ecology and Society*, 14: 25. <http://www.ecologyandsociety.org/vol14/iss1/art25/>. (Accessed on 09/07/2012).

PÄRT, T. & SÖDERSTRÖM, B. 1999. The effects of management regimes and location in landscape on the conservation of farmland birds breeding in semi-natural pastures. *Biological Conservation*, 90: 113-123.

PATRICELLI, G.L. & BLICKLEY, J.L. 2006. Avian communication in urban noise: causes and consequences of vocal adjustment. *The Auk*, 123: 639-649.

REIJNEN, R. & FOPPEN, R. 1994. The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. *Journal of Applied Ecology*, 31: 85-94.

REIJNEN, R. & FOPPEN, R. 1995. The effects of car traffic on breeding bird populations in woodland. IV. Influence of population size on the reduction of density close to a highway. *Journal of Applied Ecology*, 32: 481-491.

REIJNEN, R. & FOPPEN, R. 2006. Impact of road traffic on breeding bird populations. Pp. 255-274. *In:* J. Davenport & J.L. Davenport (eds). The Ecology of Transportation: Managing Mobility for the Environment. Springer, Dordrecht, The Netherlands. 393p.

REIJNEN, R.; FOPPEN, R.; TER BRAAK, C. & THISSEN, J. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology*, 32: 187-202.

REIJNEN, R.; FOPPEN, R. & MEEUWSEN, H. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biological Conservation*, 75: 255-260.

SHAW, E.G. 1996. Noise environments outdoors and the effects of community noise exposure. *Noise Control Engineering Journal*, 44: 109-119.

SIEMERS, B.M. & SCHAUB, A. 2011. Hunting at the highway:

traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of The Royal Society B*, 278: 1646-1652.

SLABBEKOORN, H. & DEN BOER-VISSER, A. 2006. Cities change the songs of birds. *Current Biology*, 16: 2326-2331.

SLABBEKOORN, H. & RIPMEESTER, E.A. 2008. Birdsong and anthropogenic noise: implications and applications for conservation. *Molecular Ecology*, 17: 72-83.

SUMMERS, P.D.; CUNNINGTON, G.M. & FAHRIG, L. 2011. Are the negative effects of roads on breeding birds caused by traffic noise? *Journal of Applied Ecology*, 48: 1527-1534.

SUN, J.W.C. & NARINS, P.M. 2005. Anthropogenic sounds differentially affect amphibian call rate. *Biological Conservation*, 121: 419-427.

SWEDISH ENVIRONMENTAL PROTECTION AGENCY. 2007. *Ljudkvalitet i natur- och kulturmiljöer: God ljudmiljö...mer än bara frihet från buller*. Report nº 5709, Swedish Environmental Protection Agency, Stockholm, Sweden. 23p.

SWEDISH ENVIRONMENTAL PROTECTION AGENCY. 2008. *Vägtrafikbuller, Nordisk beräkningsmodell, reviderad 1996*. Report nº 4653, Swedish Environmental Protection Agency, Stockholm, Sweden. 74p.

SWEDISH GOVERNMENT. 2004a. *Förordning (2004:675) om omgivningsbuller*. Swedish Government Office, Stockholm, Sweden. <http://www.notisum.se/rnp/sls/lag/20040675.htm>. (Accessed on 09/07/2012).

SWEDISH GOVERNMENT. 2004b. *Environmental Quality Objectives– A Shared Responsibility*. Summary of Government Bill 2004/05:150. 98p. <http://www.sweden.gov.se/content/1/c6/06/69/79/80a58d03.pdf>. (Accessed on 09/07/2012).

SWEDISH ROAD ADMINISTRATION. 2001. *Bullerskyddsåtgärder – Allmänna råd för Vägverket*. Publication 2001:88, Swedish Road Administration, Borlänge, Sweden. 42p.

SWEDISH TRANSPORT ADMINISTRATION. 2012. Landskap i långsiktig planering – Pilotstudie i Västra Götaland, del 2. Pp. 99-126. *In:* Publication 2011:122, Swedish Transport Administration, Borlänge, Sweden.

UNITED NATIONS. 1992. *Convention of Biological Diversity*. <http://www.cbd.int/convention/text/>. (Accessed on 09/07/2012).

WHO (World Health Organisation). 2000. *Guidelines for Community Noise*. World Health Organization, Geneve, Switzerland. 159p.

Submetido em 12/07/2012
Aceito em 19/01/2013