Anthropogenic outdoor sound and wildlife: it's not just bioacoustics!

Guillaume Dutilleux

Anthropogenic outdoor sound and wildlife: it's not just bioacoustics!

G. Dutilleux

Laboratoire Régional de Strasbourg, 11, rue Jean Mentelin, 67035 Strasbourg Cedex 2, France
guillaume.dutilleux@developpement-durable.gouv.fr

The two last decades have seen the growth of a large body of scientific and technical literature regarding the effects of anthropogenic noise on terrestrial wildlife and their mitigation. These effects range from behavioral modifications like signalling louder, increasing the signalling rate or redundancy, signalling at a higher pitch, signalling outside noisy periods, but also alterations of intraspecific or interspecific interactions. Moreover it is now proven that man-made noise may lead to reduced reproductive success, reduced species richness or reduced density. The careful design of experiments helps avoid methodological biases some more ancient studies in this field may suffer of. This paper reviews the published literature from an engineering perspective. The focus is put on recommendations for impact assessment and mitigation. The analysis carried out emphasizes that more attention paid to anthropogenic noise emission, especially road surfaces, and propagation issues, in particular micro-meteorology and the range of validity of the prediction methods used, would significantly improve the guidance available.

1 Introduction

The sensitivity of animals to noise has been known at least since Xenophon [28]. It must be obvious to everyone that very few places in the industrialized countries enjoy a soundscape free from any kind of anthropogenic noise. The main cause of this situation is transportation, be it terrestrial - where roads are the main source - , or aerial. Extractive and productive activities contribute also to some extent, not to forget leisure activities which may be quite noisy even though their contribution is more localized in time. The ubiquitous availability of the stable source of power brought by electricity plays also a significant role in this situation. Spatial aspects should not be overlooked though, since the proportion of the ground devoted to human activities has also significantly grown, which leads to the multiplication and the uniformization of the distribution of noise sources over the territory. Arguably, the last decades have seen the generalization of what Schafer coined the low-fi soundscape [24].

In reaction to this, most of the industrialized countries have developed environmental noise regulations, in order to limit the level of complaints from the citizens and the burden of disease due to noise. In France, the first one on road traffic noise dates back to 1978 [13]. Sticking to the French context, the regulatory literature on noise has developed significantly since then, in the wake of the so-called ”noise law” adopted in 1992 [23]. The regulations cover now the most significant sources on the emission or the immission side. The large modelling effort implied by the so-called Environmental Noise Directive [11] from the European Community helps to grasp the extent of the problem. From the population exposure data provided is has been assessed that more than 1 million healthy life years are lost yearly in the cities of Western Europe [10] due to noise.

An outstanding feature of these noise regulations is that they are focused on human beings only, except a few notable exceptions in the Netherlands and Germany. The rest of biodiversity is simply ignored. This is rather puzzling because biodiversity loss raises a lot of concerns and because, as mentioned earlier, common sense suggests that noise matters also for wildlife. Common sense is confirmed by scientific evidence. A first reason is that acoustic communication is essential to many species. Due to the limited space available here the reader this topic shall not be developed in this paper. The reader shall refer to [2].

The Natura 2000 network was set up by the European Community, in order to protect endangered ecosystems and endangered species. Since these islands devoted to biodiversity must be connected to each other, a few countries in Europe like the Netherlands and France are considering the identification and protection of a so-called ”green infrastructure” connecting natural reserves. If acoustic issues are not considered it can be expected that the identified areas or corridors will not accomplish their mission of conservation. So how to take into account the state of the knowledge on the effects of anthropogenic noise on wildlife ?

This paper tries to shed some light on this topic for terrestrial ecosystems. It is organized as follows. Section 2 reviews the effects of anthropogenic noise on wildlife from scientific literature. Section 3 deals with noise mitigation approaches for wildlife. Section 4 suggests improvements from a noise control perspective, since it will appear that this topic reaches beyond bioacoustics.

2 Effects of anthropogenic noise on wildlife

There is already a broad spectrum of scientific evidence that noise interferes with acoustic communication because of masking. Due to the limited space available, not all references are provided for this section. However, most of them are collected in [2, 25]

Species with low-pitched signals like the great bittern (*Botaurus stellaris*) and several others are the most exposed to masking because the power spectral density of traffic noise is in first approximation a decreasing function of frequency. In some species the plasticity of signalling is inexistent so the only possible reaction when masking is chronically too strong is to move away and to search for a better territory. In a noisy environment, there is evidence that the density of a bird species is correlated with its main singing frequency [22].

Arguably, the most obvious reaction when faced to a higher background noise is to signal at a higher sound pressure level. Indeed, the Lombard's effect is not limited to human beings. It has been observed on several species including nightingales (*Luscinia megarynchos*) with control of the confounding factors of size and body mass. In this species the increase of sound power level is significant although is does not compensate totally for the increase in background noise. In general, this increase should not be considered neutral to the species, because laboratory experiments indicate that signalling acoustically means a significant increase in the metabolic level although this measurement is difficult to carry out. Therefore, territories with high levels of background noise can be considered of poor quality. A finer examination show that nighthingales increase the sound power level of their softest notes. So the increase in sound power level is partly obtained by the mechanism of amplitude compression.

Increasing the signalling frequency in noisier places is a behavior observed in several common birds like the Chaffinch (*Fringilla coelebs*), the Great tit (*Parus major*), the European Blackbird (*Turdus merula*) and amphibians. The rate of the increase is around 4 to 6 Hz/dB. In general, this is not sufficient to compensate for the reduction of active space caused by masking. At higher frequencies this approach is likely to be thwarted by the steep increase of atmospheric attenuation with frequency. Even if it were an efficient mitigation strategy, it may conflict with the use of pitch by females to assess the quality of a male in some species. A general rule in this respect is: the lower pitched the better, because the older and the more experienced.

Another reaction to traffic noise observed in birds is to start singing earlier. In spring, dawn is a time of the day which is highly valued by birds for singing because attenuation of sound over distance is usually lower due to favorable sound speed gradients. However dawn sometimes overlaps with the morning rush hours, which means a high level of background noise. Singing earlier has been observed in several common passerine birds like the Blue tit (*Parus caeruleus*) or the Robin (*Erithacus rubecula*). On the latter species a study has shown that artificial light has no influence on this behavior. Singing earlier probably has negative side effects although they do not seem clearly identified.

Increasing redundancy to compensate for background noise is also used in many a species. Repeating the message several times increases the chances to "get it through", possibly to benefit from a window of silence or to activate a correlation mechanism with a reference signal in the brain of the receiver. This phenomenon was first observed in the King Penguin in the Antarctic[1]. There the problem is not anthropogenic noise but conspecifics, since the species gathers in huge colonies. This was observed too in more temperate latitudes in amphibians or bird species like the Great tit where a song with less syllables is selected in noisy conditions and is repeated more often than in quieter habitats. The metabolic issue has been mentioned. This mechanism means a longer time dedicated to singing at the expense of other important activities like foraging. For perched singers, this may lead to a higher predation risk.

Beside modifications of signalling behavior, anthropogenic sound may trigger stress reactions like characteristic postures or plainly cause the animal to flee from the noise source. Stress increases the metabolic level. If the disruptions happen too often they may become a real threat on the survival of an individual, especially during the cold season in the context of food scarcity. This kind of effect was mostly documented on large mammals. It seems that foreseeable events like regular train pass-bys are better tolerated than random ones like single road vehicle pass-bys.

Anthropogenic sound may also disturb the location of conspecifics when using acoustic cues. This is particularly important for amphibians where sight is not far reaching. Phonotactism is essential in the location of reproduction sites during the spring migration. On the reproduction site, the females rely on it to locate calling males. A laboratory study on the Grey treefrog (*Hyla chrysoscelis*) shows that in traffic noise there is an increase in time of response of the female and an increase in the detection threshold level. However the artificial stimulus used seems too stationary to bee realistic. Also disorientation is observed on the female. The same pattern was observed in *Hyla cinerea* and *Bufo woodhousei* however the experiment was not replicated [3]. In the same context of spring migration, another paper reports that mute species like newts are likely to listen to frog calls. Traffic noise is likely to hamper their orientation to the pond. There is however a potential methodological bias since this study on newts is pseudo-replicated.

An interesting work which suffers however also from a lack of replication shows on two species of amphibians that noise alters the social structure of the population of a pond [3]. In the control situation without traffic noise, there are dominant males who are calling and other males grouped around the dominant ones. In the test situation with noise males are evenly distributed around the pond they are all calling.

Several authors report also that noise caused by vehicle pass-bys or fly-bys affects the acoustic activity of amphibians. The call rate can either be increased or decreased by events of anthropogenic noise. In one experiment where 4 species are monitored around a pond, 3 are inhibited whereas the 4$^{\text{th}}$ one is stimulated. The modulation takes place either during (aircraft fly-by) or after (motorcycle pass-by). It must be emphasized here that the duration of the noise event is not controlled and that a fly-by is likely to be significantly longer. In the European *Hyla arborea* it is observed that the same noise event will inhibit a single calling individual and not a chorus, probably because emergence is affected only in the first case. If the noise event is strong enough, the single caller will be stopped during the noise event and its activity will be reduced for a while after the noise event has ceased.

While most papers in this field considered transportation noise and birds, some study mammal species like the California ground squirrel (*Spermophilus beechyi*) and its behaviour with wind turbine noise in the background. This species lives in burrows. In comparison to control sites the vigilance state is more frequent with wind turbine noise. In addition, the alarm response is different. On control sites the individuals go away from the burrow, on the test site they return to it. The behavior suggests a reaction to noise masking. Since the predators are less audible due to masking, visual detection may be more reliable. The authors consider hearing loss due to exposure to wind turbine noise, which is unlikely.

The impact of these behavioral responses of wildlife to anthropogenic sound in terms of conservation is not always obvious. When it is, its quantification is difficult. At a more macroscopic scale, another body of research is focused on the very response to anthropogenic noise in terms of density, or species richness. The work of Van der Zande was one of the first in this direction [29]. But the large scale project conducted by Reijnen and Foppen in the Netherlands in the 1980s and published in a series a peer-reviewed papers in the mid 1990s ([19] for instance) must be considered as a milestone in establishing the evidence of the impacts on species richness and density. The authors conclude to the causal relationship between noise and reduced density albeit the relationship is established somewhat by default. Noise may cause reduced density up to 1000 m away from the infrastructure, depending on traffic intensity. This work shows also that territories with noise are mostly occupied by young birds, with a poorer reproductive success. It provided the basis of the first guidelines on the reduction of the effects of roads on breeding bird populations [21]. These guidelines are analyzed further in section 3. In retrospect several authors have critized this Dutch research in sofar as it suffers from several methodological flaws including confounding factors, pseudo-replication, loose statistical tests or flawed census techniques. See [8] for a thorough examination. In [20] the equivalent noise level is presented as a good indicator of traffic load even though noise *per se* is not the single cause of the impact.

In the last decade, the relation between anthropogenic noise and density or species richness has been investigated in forest land [27, 22], meadows [26], agroforest [18] or several kinds of habitat [8]. The conclusion is essentially that a significant proportion of species are noise sensitive with the notable exception of generalist species. The protocols are still questionable because with road or rail infrastructure as a noise souce it is not possible ot seperate visual disturbance form noise disturbance or to correct for edge effects. In a more recent publication the same Reijnen and Foppen note that species of national or international significance are more impacted than the others and call for experimental designs with a better control of confounding factors [20].

More recent publications benefit from the development of oil and gas extraction in remote areas which helps the design of almost flawless experiments using paired (control, test) plots where everything is kept constant except noise [17, 5, 14]. In [17], the target species is the Ovenbird (*Seiurus aurocapilla*), a species of the boreal forest and peatland with a large repertoire of songs. It is shown that reproductive success is significantly lower with noise and that more experienced birds prefer control plots. This is consistent with the findings of the Dutch study. The same authors have also studied 27 species of the boreal forest [5] in 4 forest configurations around clear cuts : (close to the edge,far from the edge)x(control,test). The density of passerine birds is 50% higher in control sites and one third of species support the hypothesis of the influence of noise on abundance. The density close to the noise sources is also lower for 7 species.

Finally a study in New Mexico, concludes that species richness is lower in noise for 21 species out of the 32 investigated [14]. These authors show also that noise disturbs the balance of species. A species of nest predator avoids noisy areas. Therefore the reproductive success is higher for prey species.

3 Evaluation and mitigation procedures

Barrett reports in 1995 that 9 million USD has been spent or is planned to be spent on noise mitigation projects for endangered bird species in a single district of California [4]. This figure does not reflect the average concern for the topic in the Western countries. This author reports about an experience with temporary noise mitigation for the endangered least Bell's vireo (*Vireo bellii pusillus*) during a highway reconstruction project. A 60 dB(A) Leq for the loudest hour of the day is taken as a threshold for mitigation. From the discussion, it appears that this criterion is quite empirical and of general purpose. It does not take into account the sensitivity and the ecology of the considered species. This is clearly problematic if costly measures are likely to miss their objective of conservation. It reflects the lack of knowledge and of established methodology at the time.

As mentioned above, the first guidelines about the prediction and the reduction of the impact of anthropogenic noise have been published in the Netherlands [21]. The document addresses road traffic and breeding bird populations only and covers both forest and agricultural grassland. Its purpose is to compute the distance of impact of the road. At shorter distances, negative impacts are expected for breeding birds. Density is assumed to be a function of the noise level with a threshold noise level. Below this noise level density is not noise-dependent. Over this level density decreases rapidly. Even though noise sensitivity is supposed to vary greatly from one species to another, the Dutch guidelines set the threshold to 42 (reps. 47) dB(A) for forest (resp. meadow) birds. This work seems to have strongly influenced regulations and field practice in german-speaking countries [15, 8]) although the extra-territorial transposition led to serious mistakes [8]. To the author's knowledge it has remained almost unknown in France.

The approach is close to the one of the French Guide du Bruit [9] with charts and tabulated values. The road is divided into 500 m long sections. On the emission side, the inputs are the traffic intensity and speed with a default percentage of HGV. On the propagation side, a flat ground is supposed. Basic corrections are proposed for more complex profiles like depressed road or barrier. For grassland, the impact distance is provided directly by the tables. The maximum impact distance reaches 1350 m away from the road. For forest land, there are several candidate impact distances depending on the proportion of forest in a 113° angle of sight from a receiver point. Each distance is considered starting from the lowest one. If the percentage of forest land associated to the candidate distance is lower than the real one in the 113° angle, the candidate impact distance is the one to keep. Otherwise, the next distance must be considered, and so on. As an example, the maximum impact distance is 515 m when the percentage of woodland is between 50 and 90% in 113°.

One of the most disturbing features of [21] is that bird species are treated in two very large groups: forest and agricultural grassland birds. This does not reflect the sensitivity of the species to noise. Some do not rely strongly on acoustic communication. The first attempt to address this issue can be found in [15] with an extension in [16]. Here the authors develop a predictive model for the sensitivity of a species to road traffic noise. Species by species, their analysis covers several biological or ecological functions in relation to noise: foraging, contact, detection of dangers, defense of territory and partner finding. They also assess the sensitivity of the call or song to masking. The evaluation is carried out for more than 200 bird species. For instance owls depend heavily on acoustic cues when foraging and for contact with conspecifics, since they are mostly active at night, a duck like *Aythya fuligula* exhibits no sensitivity to masking and is concerned by acoustics only to detect danger.

In [21], noise alone is considered in the assessment of impacts. The work of Garniel and her colleagues restores a balance between noise and other perturbations like visual stimuli [16]. This work defines recommandations on the basis of noise levels for species that are sensitive to noise, and impact distances for species sensitive to other disruptions. Occasionally both criteria are used. Breeding birds are classified in 5 categories. An additional category covers wintering and resting birds. Category 1 concerns species highly sensitive to noise. For category 2 noise is not the main disrupting factor, but the impact distance is sensitive to traffic intensity. Category 3 groups species for which predation noise increases with background noise. Species whose distribution is not influenced by noise are in category 4. The two last categories are not sensitive to noise.

On the basis of this classification, two methods are outlined in [16] for the evaluation of impacts a standard prediction and an extended spatial one for new infrastructure projects like for transformation of existing infrastructures. The prediction provides results expressed as percentages of degradation of land quality for a given species. The standard prediction is on the safe side and designed to be straightforward. It requires bird census results, traffic data and the geometry of the infrastructure. It does not take into account topography and occasional barriers. The extended spatial prediction relies on more detailed data including a geo-referenced census for each species of interest. Its main advantage is a more accurate evaluation of the impact with lower costs for avoidance, mitigation or compensation.

4 The noise control perspective

The concern for the impact of anthropogenic noise arised probably more from people with knowledge of biodiversity issues, so more among conservationists and biologists than among acousticians. But this issue would certainly benefit from an extended cooperation between biologists and noise control engineers. The author has most of his background in physical acoustics and a just a beginner's knowledge of ecology or behavior. For him, collecting and reading the literature on this topic was quite enriching. However, some sentences found on technical aspects of acoustics are obsolete, questionable, if not completely wrong.

In the literature surveyed the use of noise prediction models is not always sufficiently documented. These models should not receive to much confidence because they come from a so-called exact science. A noise prediction models has a range of application although its limits may lack of a clear definition. For instance engineering models are mostly designed for open land. Application in forests is only experimental even though it is explicitly covered in the method. Furthermore, biologists do know that the name forest covers a very wide variety of habitats. This variety proves difficult to be reflected in a noise prediction model. In addition a noise prediction model is never completely specified on paper. What is specified does not avoid ambiguities. This leaves some room for interpretation by software developers. And the method is used by a noise consultant who relies on input data like topography, traffic, from various sources. The amount of input data is difficult to check. Therefore, a recommended practice in noise control engineering is to check the modelling of a real site with a few measurements.

In addition, there are a few misconceptions on noise emission form road infrastructures. Well designed actions on vehicle speed do reduce noise levels. In general speed does not only affect engine noise but also rolling noise. With a speed dependence roughly in $30 \log V$ in the 50-130 km/h range, a moderate reduction makes a difference, provided that it applies to all vehicles and that it is enforced. It is also more realistic than actions on traffic intensity, since it requires a large reduction of traffic volume before the noise reduction is visible. Moreover it proves generally difficult to influence traffic volume. Low noise pavements are certainly of interest when it comes to impact mitigation, even if they are used alone. They are efficient in the frequency range where most of the energy of traffic noise is concentrated. Sweeping through the various pavement formulations available, the current amplitude of performances is 12 dB(A) for the French techniques [7]. In addition, a positive aspect it that a new pavement does not increase the barrier effect created by the road itself, when compared to a man-made noise barrier.

About sound propagation, the prediction methods used in [21, 15, 8] are obsolete. One major advance in this respect is the integration of micro-meteorological aspects [6]. For open land, downward-refraction conditions make a big difference on propagation compared to homogeneous conditions[12]. When a road is perpendicular to dominating winds, one side is likely to experience downward-refraction conditions whereas the opposite side will experience upward-refraction conditions. The influence of micro-meteorology increases as distance increases. For instance 300 m away from a point source, attenuation is likely to vary over more than 20 dB(A), depending on the propagationl condition. In forests, the state of knowledge indicates that sound speed gradients are more stable around homogeneous conditions than in open land and that in the case of propagation from one side to the other side of a forest, the magnitude of sound speed gradients is reduced. Of course, the long-term sound level approach taken in impact assessment for human beings is not relevant *a priori*, since acoustic communication is not essentiel to wildlife all over the year, at any time of the day. The acoustic impact assessment would benefit from integration of the ecology of a species.

5 Conclusion

A review of the effects of noise on wildlife has been presented for terrestrial ecosystems. Beside numerous effects on behavior, the most striking result from a conservation perspective is that recent research with carefully designed protocols demonstrates in an unquestionable way that anthropogenic noise has adverse effects on species richness, population density or reproductive success. Therefore, if biodiversity loss is be struggled against, anthropogenic noise must be taken into account in impact assessments over natural areas and in the light of scientific evidence it seems that the time has come for noise to enter in regulatory texts on biodiversity.

This paper has also reviewed the available recommendations for impact assessment of anthropogenic noise and related mitigation. Significant progress has been made in the recent years. First noise is placed in a more global picture of disturbances including visual stimuli. Second a predictive model has been proposed in order to go down to the species level in the assessment of sensitivity to noise. However there is still room for improvement, at least from a noise control engineering perspective. More attention should be paid to anthropogenic noise emission, especially road surfaces, and propagation issues, in particular micro-meteorology and the range of validity of the prediction methods used, would significantly improve the guidance available.

References

[1] Thierry Aubin and Pierre Jouventin. Localisation of an acoustic signal in a noisy environment: the display call of the king penguin *Aptenodytes patagonicus*.

The Journal of Experimental Biology, 205:3793–3798, september 2002.

[2] Jesse R. Barber, Kevin R. Crooks, and Kurt M. Fristrup. The cost of chronic noise exposure for terrestrial organisms. *Trends in ecology and evolution*, 25(3):180–189, 2009.

[3] Andrew N. Barrass. *The effect of highway traffic noise on the phonotactic and associated reproductive behavior of selected anurans*. PhD thesis, Vanderbilt University, 1985.

[4] Douglas E. Barrett. Traffic-noise impact study for least Bell's vireo habitat along California state route 83. *Transportation research record*, 1559:3–7, 1995.

[5] Erin M. Bayne, Lucas Habib, and Stan Boutin. Impact of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology*, 22(5):1186–1193, 2008.

[6] Francis Besnard, Jérôme Defrance, Michel Bérengier, Guillaume Dutilleux, Fabrice Junker, David Ecotière, Emmanuel Le Duc, Marine Baulac, Bernard Bonhomme, Jean-Pierre Deparis, Benoit Gauvreau, Vincent Guizard, Hubert Lefèvre, Vincent Steimer, Dirk Van Maercke, and Vadim Zouboff. *Road noise prediction - 2-Noise propagation computation method including meteorological effects (NMPB 2008)*. SETRA, 2009.

[7] Francis Besnard, Jean-François Hamet, Joël Lelong, Vincent Guizard, Nathalie Fürst, Sonia Doisy, and Guillaume Dutilleux. *Road noise prediction : 1 - Calculation of sound emissions from traffic*. SETRA, 2009.

[8] Georg Bieringer, Hans-Peter Strohmayer, and Gerhard Strohmayer. Strassenlärm und Vögel. In *Strassenforschung*, volume 587, page 85p. Bundesministerium für Verkehr, Innovation und Technologie, Wien, Österreich, 2010.

[9] Collective. *Guide du bruit des transports terrestres - Prévision des niveaux sonores*. CERTU, 1980.

[10] Collective. *Burden of disease from environmental noise - Quantification of healthy life years lost in Europe*. World Health Organization, Copenhagen, 2011.

[11] European Community. 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 Community, june 2002.

[12] Tony F. W. Embleton. Tutorial on sound propagation outdoors. *Journal of the Acoustical Society of America*, 100(1):31–48, 1996.

[13] République Française. Arrêté du 6 octobre 1978 relatif à l'isolement acoustique des bâtiments contre les bruits de l'espace extérieur. Journal officiel de la République Française, october 6th 1978.

[14] Clinton D. Francis, Catherine P. Ortega, and Alexander Cruz. Noise pollution changes avian communities and species interactions. *Current Biology*, 19:1–5, august 2009.

[15] Annick Garniel, Winfried D. Daunicht, Ulrich Mierwald, and Ute Ojowski. Vögel und Verkehrslärm. Technical report, Kieler Institut für Landschaftökologie, 2007.

[16] Annick Garniel and Ulrich Mierwald. Arbeitshilfe Vögel and Strassenverkehr. Technical Report 140p, Bundesministerium für Verkehr, Bau and Stadtentwicklung, Bonn, Allemagne, 2010.

[17] Lucas Habib, Erin M.Bayne, and Stan Boutin. Chronic industrial noise affects pairing success and age structure of Ovenbirds *seiurus aurocapilla*. *Journal of Applied Ecology*, 44:176–184, 2007.

[18] S. J. Peris and M. Pescador. Effect of traffic noise on passerine populations in mediterranean wooded pastures. *Applied acoustics*, 65:357–366, 2004.

[19] Rien Reijnen and Ruud Foppen. The effect of car 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, 1994.

[20] Rien Reijnen and Ruud Foppen. *The ecology of transportation. Managing mobility for the environment*, chapter Impact of road traffic on breeding bird populations, pages 255–274. Number 12. Springer, 2006.

[21] Rien Reijnen, Geesje Veenbaas, and Ruud Foppen. Predicting the effects of motorway traffic on breeding bird populations. Technical Report 91p, Ministerie van Verkeer en Waterstaat, Delft, 1995.

[22] Frank E. Rheindt. The impact of roads on birds: does frequency song play a role in determining susceptibility to noise pollution. *Journal für Ornithologie*, 144:295–306, 2003.

[23] Royal. Loi n°92-1444 relative à la lutte contre le bruit. Journal officiel de la République Française, 31 december 1992.

[24] R. Murray Schafer. *The soundscape - Our sonic environment and the tuning of the world*. Destiny books, Rochester, USA, 2nd edition, 1977.

[25] Hans Slabbekoorn. *Nature's music: the science of birdsong*, chapter Singing in the wild: the ecology of birdsong, pages 178–205. Number 6. Elsevier Academic Press, 2004.

[26] E. Waterman, I. Tulp, R. Reijnen, K. Krijgsveld, and C. ter Braak. Noise disturbance of meadow birds by railway noise. In *Proceeding inter-noise 2004*, page 4. I-INCE, 2004.

[27] Anne Weiserbs and Jean-Paul Jacob. Le bruit engendré par le trafic autoroutier influence-t-il la répartition des oiseaux nicheurs ? *Alauda*, 69(4):483–489, 2001.

[28] Xénophon. *De l'art équestre (The art of horsemanship)*. Les Belles Lettres (*Dover*), 2002(2006).

[29] A. N. Van Der Zande, W. J. Ter Keurs, and W. J. Van Der Weijden. The impact roads on the densities of four bird species in an open field habitat - evidence of a long distance effect. *Biological Conservation*, 18:299–321, 1980.