Anthropogenic sound and terrestrial ecosystems: a review of recent evidence

Guillaume Dutilleux[1]

[1] Acoustics Research Centre, Department of Electronic Systems, University of Science and Technology, O.S. Bragstads plass 2 B, 7491 Trondheim, Norway (corresponding author)

Corresponding author's e-mail address: guillaume.dutilleux@ntnu.no

ABSTRACT

Since the beginning of the 1980s a large body of scientific and technical literature regarding the effects of anthropogenic noise on terrestrial wildlife has developed. These effects are mostly documented for birds and anurans. They range from behavioral modifications like signalling louder, increasing the signalling rate or redundancy, signalling at a higher pitch, signalling outside noisy periods, but also to 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. This paper reviews the published literature on the topic since the beginning of the 2010s. The careful design of experiments helps avoid methodological biases some more ancient studies in this field may suffer from. The paper highlights the progress of knowledge among the different taxa including invertebrates and also on the effects of anthropogenic noise relating to the operation of an ecosystem.

INTRODUCTION

Environmental noise has been recognized as a public health problem for many decades and most the industrialized countries have developed *ad hoc* regulations. Although environmental noise is not limited to populated areas, a remarkable feature of these regulations is that they focus on human beings only with a few notable exceptions in some European countries [1]. But public health does depend on the good operation of all ecosystems around us. Acoustic communication is essential to a great many of species and anthropogenic noise is now well identified as a source of perturbations for wildlife too at different levels from species to ecosystems [2].

The study of the effects of anthropogenic noise on wildlife appears to be a quite vast and active research field. The purpose of this paper is to provide a short review of the effects of anthropogenic noise on ecosystems. This paper focusses on terrestrial ecosystems. To avoid any ambiguity freshwater ecosystems are beyond its scope.

The present paper relies exclusively on peer-reviewed articles in English language identified through a literature search with the following keywords: "anthropogenic noise" and ["animal" or "insect" or "bird" or "amphibian" or "mammal" or "behaviour"]. The original aim was to cover publications from 2010 to the time of writing. Since early in the process an extensive review on the same topic as the current paper was identified which goes until 2013 [3], only publications from 2014 on are referred to in the following except for other review papers not mentioned in [3]. As of April 2017, the literature search generated 46 references.

On the basis of the outcome of the literature search the paper is organized as follows. First review and methodology papers in the field are addressed, second the impacts of anthropogenic noise on acoustic communication, third the effects on behaviour, fourth the effects on physiology, fifth multi-sensory effects and last the cases where the absence of effect was observed or claimed.

REVIEW AND METHODOLOGY PAPERS

Beside [3] already mentioned on the very same topic as the one of the present paper, other review papers were identified by the literature search. In [4] a review is provided of the indirect effects of noise on animal communication and its implications for social structure and natural selection. The avian sensitivity to anthropogenic noise is reviewed in [5] for 183 bird species. This author found little correspondence between sensitivity and the position on the phylogenetic tree. The most important predictors of noise sensitivity were first low-frequency vocalizations – because of higher masking probability by anthropogenic noise - and an omnivorous or carnivorous diet – because audition is involved in prey detection. Many publications have provided evidence that some species develop strategies to reduce masking by anthropogenic noise. A discussion of the potential fitness costs of these strategies can be found in [6], including increase predation risks, altered energy budget, loss of information. A recent review of the overall impacts renewable energy on avian species refers in several places to noise impacts and reminds that construction noise is another possible disturbance cause [7].

Research on the impacts of anthropogenic noise requires acoustic measurements or simulations. These aspects require skills beyond biology and are not the most unquestionable part of the literature on the subject discussed here [1]. In [8] guidance is given about the way to carry out and report sound level measurements. This is a step forward although there is certainly more to say on the topic. From a more global perspective, [9] introduces a framework to assess responses to anthropogenic light and sound.

EFFECTS ON ACOUSTIC COMMUNICATION

Anthropogenic noise causes masking in the source-propagation-receiver chain and reduces the active space of vocalizations. Not all species develop strategies to avoid or reduce masking. Such strategies involve either time-domain modifications, or an upward frequency shift or an increase in amplitude.

Time-domain effects

In the case of fluctuating traffic noise a European and several American tree crickets (*Oecanthus sp.*) were reported to reduce their activity to reduce the risk of masking when traffic noise level is high [10][11]. The European species modulated its signalling over a very short time scale in relation to noise [10]. In North-American amphibians exposed to road traffic

noise it has been shown that some species avoided vocalizing when traffic noise intensity is high and select favor quieter moments whereas other species are not influenced by traffic [12]. The difference is explained by the fact that the former have a lower call peak frequency. Therefore, they are more exposed to masking. Another field study shows that a common European bird (*Troglodytes troglodytes*) exposed to a synthetic intermittent white noise (experimental exposure) or to real traffic noise does not adapt the timing of its vocalizations [13] although it was obviously disturbed by the experimental exposure.

At a larger scale within the circadian rhythm, a well-known strategy is to select a quieter period for vocalizations, for instance singing before rush hour for birds. Such a behaviour was observed for aircraft noise in several birds nesting close to airports at two different latitude groups in Europe which help control for the potential confounding factor of dawn time [14]. The same result was found in the Tropical rufus-collared sparrow (*Zonotrichia capensis*). Due to the equatorial latitude dawn time is not a confounding factor [15].

For most the species investigated in [14] no increase in singing time was observed in the vicinity of airports. But a field study on the Pacific Wren (*Troglodytes pacificus*) shows that the species develops longer songs due to road traffic noise exposure [16]. This may have consequences on metabolic needs.

Frequency-domain effects

Frequency-domain adjustments are the most investigated effect in the literature surveyed for this paper. A meta-analysis based on 36 studies covering 60 species of birds and anurans shows that the latter are less capable to increase the frequency of their vocalizations to reduce masking from a typical anthropogenic noise rich in low frequency components [17]. In birds, a broader shift is found for smaller birds which is somewhat counterintuitive but explained by the existence of alternative strategies for larger birds to overcome masking. A field study in the spotted dove (*Streptopelia chinensis*), a bird with a low-pitched song concurs with the classical result that individuals living in urbanized noisier areas sing at higher frequency than their rural conspecifics [18]. Other authors found for the Califonian white-crowned sparrows (*Zonotrichia leucophrys nuttalli*) that regional noise was better than territorial noise at predicting the minimum frequency of vocalizations but suggested also the existence of an upper limit for this frequency even though noise levels keep on increasing [19]. The relevance of the regional scale indicates that variation in pitch is not only a short term adjustment but partly reflects a cultural evolution. An upward frequency shift was also observed in the *Horseshoe Bat* (*Myotis myotis*) when exposed to band-limited white noise which appeared to be the only adjustment when the noise did not overlap the main sonar frequency [20]. However a real-world anthropogenic source which produces such a high frequency spectrum at significant sound levels seems hard to find.

The related signal processing question of pitch estimation in noise is addressed in another biology paper [21]. Two methods – the so-called bye-eye-practice (BEP) and threshold method (TM) – are evaluated with the conclusion that TM is more robust than BEP that may lead to spurious results.

Effects both on pitch and amplitude

With the same reservations as above about the stimulus, [20] found that *Myotis myotis* increased also the amplitude of its sonar emissions when the noise signal was in the same frequency range as its sonar. Investigations across a gradient of anthropogenic disturbance featuring both increasing urbanization and increasing noise levels showed that breeding eastern bluebirds (*Sialia sialis*) increase both pitch and amplitude [22] as noise increases.

The importance of noise levels

Two studies highlight that the influence of extraneous noise on vocalization is not due the nature of noise (anthropogenic or not) but to its intensity. In [16] it was observed that the ocean surf noise had more influence on song than traffic noise because the former led not only to longer songs but to longer syllables whereas in [19] it was found that the highest minimum song frequency across the territories investigated was reached for birds living close to the ocean and exposed to its noise.

EFFECTS ON BEHAVIOUR

Space use

In the European robin (*Erithacus rubecula*) it was suggested that males living in noisy territories select higher perches above the ground for their vocalizations which is deemed likely to improve the auditory perception of conspecific rivals but also to increase the risk of predation [23]. However, the protocol chosen does not clearly eliminate confounding factors and the regression analysis may be influenced by outliers depending on the estimator used.

Regarding space use, most papers address horizontal distribution. In an attempt to transfer results in the lab showing that foraging efficiency of some bat species can be reduced in noisy environments, a field study along transects perpendicular to a highway observed that fast flying bats were not repelled by the proximity of the road whereas slow flying species stayed away [24]. There was clearly a correlation between space use and noise for the latter but there are again potential confounding factors. Another field study in the context of gas extraction showed that bat species with low frequency sonar (<35 kHz) tended to avoid noisy areas whereas bats with higher frequency sonar did not seem to be influenced by noise [25]. For both assemblages of species the results were obtained in comparison to control sites without anthropogenic noise. In the same context, other authors concluded from a field playback experiment that white-tailed deer (*Odocoileus virginianus*) avoided areas where noise levels are above Leq=70 dB(C) which occurred in a radius of 200 m around the source. The animals where reported to have relocated in less noisy areas [26].

A study [27] on a Spanish breeding colony of cinereous vultures (*Aegypius monachus*) concluded that the species avoided areas where road traffic noise is above Leq=40 dB which means a reduction by more than 11 % of the potential breeding habitat area. The time constant for Leq is not clearly stated, however, and little detail is provided about the treatment of confounding factors. Reference [28] deals with the little addressed wintering phase in birds. This 3-month study in a woodland crossed by a highway shows a correlation between traffic noise and lower bird density and species richness except for the first month. The variation over time is explained by the variation in the type of birds over time.

Foraging

Space use is directly related to foraging. In a laboratory experiment, traffic noise was reported to reduce foraging efficiency in Daubenton's bats (*Myotis daubentonii*) [29] but not in the expected way. Trafic noise impairs foraging even though its spectrum does not overlap with the one of the sonar and the echoes backscattered from preys. Noise worked as repellent that caused avoidance response. A laboratory study in pallid bats (*Antrozous pallidus*) reported that the search time for a prey was two to three times longer when bats were exposed to realistic anthropogenic noises than in the control situation [30], but the authors consider the explanation for this result remains to be found. Species that use passive acoustics for hunting are likely to be more disturbed by anthropogenic noise [5]. Northern saw-whet owls (*Aegolius*

acadius) exposed to compressor noise playback showed odds of hunting success reduced by 8 % per decibel increase [31]. No mice were captured at noise levels above 61 dB(A). There are well known deleterious cascade effects in ecosystems when predation is impaired or eliminated.

Contact

In mixed flocks of Black-capped Chickadee (*Poecile atricapillus*) and Tufted Titmouse (*Baeolophus bicolor*), [32] showed that the intra-flock communication was significantly disturbed by anthropogenic noise since mobbing calls from the former species trigger much less reaction than in the control situation.

In wood frogs (*Lithobates sylvaticus*) a field experiment with playback demonstrates that females are impaired by anthropogenic noise when it comes to locating a chorus of male conspecifics [33]. This consequence of noise was already documented for other anuran species.

Anti-predator behaviour

Hearing is an essential sense for perception of danger and then an increased background noise is likely to impair this capability. A field experiment in house-sparrows (*Passer domesticus*) exposed either to traffic noise or rural background noise led to the conclusion that females flush more rapidly in treatment than in control situations which is interpreted by the fact that they compensate the impairment by an increased vigilance [34]. In some social species like the dwarf mongoose (*Helogale parvula*) vigilance in the context of foraging is delegated to sentinels. In a playback experiment it was shown that foragers increased personal vigilance when exposed to traffic noise probably because the audibility of sentinel calls was impaired by noise [35]. Although the authors do not report about this, such compensations could be linked with increased stress and other physiological responses.

Another study evaluated anti-predator behaviours of 10 urban bird species in response to the playbacks of calls from Coopers hawks (*Accipiter cooperii*) with or without overlapping road traffic noise [36]. The results of this is that urban birds tended to detect reasonably well predation-related signals. Under exposure to aircraft fly-bys the Great tits (*Parus major*) is reported to increase vigilance during noise events at the expense of foraging [37]. The vigilance level is strongly correlated to noise levels.

Territorial behaviour

In the North American spotted towhee (*Pipilo maculatus*) and the chipping sparrow (*Spizella passerina*) exposed to conspecific intruder songs in an anthropogenic noise gradient generated by gas compressors the reaction to intrusion decreased as noise levels increased [38].

Two papers considered whether trying to escape masking through song modifications is beneficial or not [39][40]. In the American northern cardinal (*Cardinalis cardinalis*), males gave stronger response to the standard male song than to the frequency-shifted one although the difference tended to level off as the signal to noise ratio decreased. So the benefit of frequency-shifted songs is not obvious especially if one considers that frequency is a cue for fitness, status or motivation. In *E. rubecula* it was observed that when presented a frequency-shifted song, conspecific males responded with increased minimum frequency, reduced song duration and complexity. Thus the modification in the sender's message was taken into account by the receiver in its reply although the meaning of the modification remains to clarify.

In quiet rural settings the case of a territorial intrusion *E. rubecula* is known to increase the low-frequency components of its song which are linked either to aggression or body size. This behavior was suppressed in the presence of wind turbine noise [41]. The territorial male was then deprived of it verbal weapon with potential negative consequences for the individual, the stability of neighbour territories and reproductive success.

Offspring production

A field experiment with two bird species, Great tits (*Parus major*) and Blue tits (*Cyanistes caeruleus*) known to compete over nest sites, using nest-boxes with or without anthropogenic noise playback, it was shown that the former tended to occupy control nest-boxes whereas the latter tended to nest more often in noisy nest-boxes [42]. But no reduced reproductive success was observed in *P. major* between control and treatment nest-boxes.

In tree swallows (*Tachycineta bicolor*) breeding in nest-boxes with or without playback of anthropogenic noise at 65 dB the treatment led to the absence of response from the parents when begging calls were played back, in contrast to the increase in feeding rate observed in control nests [43].

EFFECTS ON PHYSIOLOGY

Bats are known to dwell in man-made noisy places. Skin temperature was monitored in torpid bats under exposure to different noise types during a laboratory experiment [44]. It was observed that skin temperature was less influenced by road traffic noise than by bird songs. The authors also found that bats rapidly habituated to repeated and prolonged exposure to traffic noise. The absence of reaction could not be linked to the low frequency content of traffic noise because its spectrum spans over larger a frequency range than the bird song stimuli used. But nothing is said in the paper about the time structure of the signals used in the experiment.

Several recent studies in anurans following a treatment/control protocol illustrate the connection between noise exposure and stress hormones. In [33], a high level of glucocorticoid hormone (corticosterone) was found in *L. sylvaticus* when exposed to road traffic noise. High levels of corticosterone were also observed in White's treefrog (*Litoria caerulea*) [45] and in the European tree frog (*Hyla arborea*) [46] exposed to similar stimuli. Moreover, these papers highlight other physiological responses. The first one is on reproductive function. Decreased sperm count and sperm viability was found in *L. caerulea* [45]. The second effect is that immune response intensity was reduced in *H. arborea* [46]. The third one is a lower chromaticity of the vocal sac in the male of the same species due to a lower level of carotenoids which is likely to influence sexual selection [46].

MULTI-SENSORY ASPECTS

Multi-sensory aspects are also present in recent papers on the effects of noise on ecosystems. In *H. arborea*, the lower chromaticity induced by traffic noise can also be seen as an impact on visual communication [46]. During a field experiment, *H. parvula* mongooses were exposed simultaneously to traffic noise and faeces from predators. Compared to the control situation the individuals exposed to noise did not show increased vigilance due to the presentation of predator cues [47].

ABSENCE OF EFFECT

It was already mentioned that the vocalizations of some amphibian species were not influenced by traffic noise [12] and that torpid bats were found to habituate rapidly to traffic noise [44].

In the context of oil and gas extraction in North America, on the basis of nest monitoring, other authors rejected noise as the cause of the reduced nesting success of grassland bird species Savannah sparrow (*Passerculus sandwichensis*) and vesper sparrow (*Pooecetes gramineus*) for which no correlation between nest success was found, putting the blame on the physical footprint of infrastructure [48]. These authors warn against potential mismanagement if mitigation targets only noise.

CONCLUSION AND PERSPECTIVES

A short review of recent peer-reviewed papers on the impacts of anthropogenic noise on wildlife has been presented. It covers years 2014 to 2016 and the first months of 2017. The field of evaluation of impacts of anthropogenic noise on wildlife and terrestrial ecosystems remains remarkably active. Among the papers reviewed more than the half deal with bird species. Bats are relatively well represented also.

In this recent literature, research at the species level dominates. The broader scale of the impacts on habitats or ecosystems in terms of conservation, density of populations or specific diversity is not represented. This could be related to the difficulty to control confounding factors at this scale and also to a focus on more short-term research targets.

Judging from the affiliations of the different contributors, this research is carried out mostly if not exclusively in biology/ecology-oriented departments and organizations. The study of the impacts of anthropogenic noises is an interdisciplinary field by definition. Future research would certainly gain from the association of biologists and plain acousticians.

Although in parts of this corpus confounding factors may cast some doubt about the causal relationship between noise and the various impacts observed several well design field or laboratory experiments provide additional evidence of the impacts of noise and of highlight its pervasive character. Indeed, negative effects are now documented at several scales and for numerous aspects of physiology, intraspecific and interspecific interactions. One cannot but conclude that the soundscape is an essential dimension of the quality of natural habitats. As such it should find its place in environmental impact assessments.

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