

# Measuring Behavioural Changes to Assess Anthropogenic Noise Impact on Singing Birds

H. Slabbekoorn

*Institute of Biology, Leiden University, Leiden, The Netherlands. H.W.Slabbekoorn@Biology.LeidenUniv.nl*

## Sound aspects of avian singing

Many animals use sounds for communication. Calls and songs often serve functions that have direct fitness consequences, for example in warning for predators, defending critical resources, and attracting mates. The tight link with fitness makes such sounds suitable for studying the impact of natural selection on vocal variation and the consequences for evolutionary change in acoustic signals. Birds are well-known and well-studied with respect to acoustic behaviour. Most species have a repertoire of calls but the majority of studies have addressed the typically most prominent vocal behaviour of singing. The two most important functions of singing in birds concern defending a territory for food, nesting and hiding places and attracting a social partner for mating. Visual cues often also play an important role in avian communication, such as during display of colours and plumage patterns or during courtship rituals and song flights. However, sounds, in concert with visual cues or by themselves, are a prime communication channel for the majority of all birds.

The importance of acoustics in animal communication in general and for birds in particular is closely related to features that are more or less specific to sound. For example, sound can travel over relatively large distances, does not rely on the presence of light, and is relatively little affected by obstacles such as leaves and branches. Furthermore, sound is multidirectional both from the perspective of the sender as from the receiver of a signal. Acoustic signals radiate away in all directions with only relative amplitude being affected by the facing direction of the singing bird. Similarly, receivers hear acoustic signals coming in from all directions and do not need to face the source direction to detect its presence. Although sounds have many benefits for communicating animals, there are also several environmental factors causing problems. Attenuation and degradation of signals during transmission through the environment and interference of other sounds can lead to selection on the acoustic design of signals. Especially the latter impact of ambient noise on production and perception of acoustic signals has received a lot of recent attention due to the global rise of anthropogenic noise.

## Noise impact factors

Natural habitats are full of natural sounds from abiotic sources, such as wind and water flow, and biotic sources, such as calling frogs and singing birds. However, human activities elevate these ambient noise levels artificially. The so-called anthropogenic noise from traffic, industry, and recreational activities concerns a global pollution factor which is still expanding in time and space. The artificially high noise levels are typically of relatively low frequency and can cause many different problems such as physical damage in cases of extreme overexposure, physiological stress, and auditory masking, which are all factors that an animal is more or less passively undergoing (see Figure 1). Furthermore, anthropogenic noise may lead to spatial deterrence, behavioural interruption, and signal modifications, which are all factors that involve some sort of active response from the animal. The three passive factors are typically positively related: if one is getting worse the others are likely to follow the same pattern. An increase in any of the three passive factors also increases the probability that any of the three active factors occurs. Vice versa the opposite may be the case: the active factors have the potential for providing relief on the passive factors by reducing the level and duration of exposure.

Many negative effects of increased noise levels along highways, in cities, or at industrial sites, have been confirmed for birds [1]. It has for example been shown that anthropogenic noise causes passive effects such as increased heart beat in birds (physiological stress), reduced mating success (auditory masking), and reduced reproductive success (through physiological stress and/or auditory masking). There are also reports on birds that start singing at more quiet times of day and/or stop singing after bursts of noise or with rising noise levels

## Noise Impact on birds

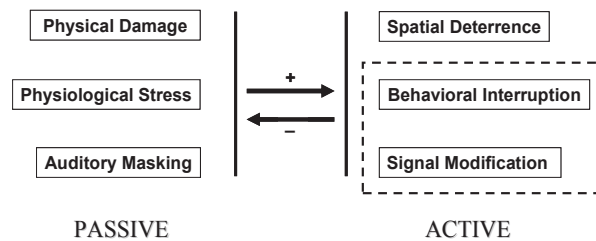


Figure 1. Schematic overview of six dominant factors that may play a role in assessing the impact of anthropogenic noise on bird welfare and fitness. The arrows indicate the relationship between factors. The 'passive' factors on the left reflect consequences of undergoing a particular exposure, which typically also increase the probability of occurrence of the 'active' factors on the right. The 'active' factors, in contrast, involve behavioural decisions by the individual that are likely to reduce the severity of the 'passive' factors. The purpose of this subdivision into categories is just to emphasize the complexity of noise impact assessments as, although the overall representation is generally true, the relative importance of factors and the magnitude and even direction of the relationships will vary per exposure level and duration, per species, and with physiological and environmental conditions. The dashed line block demarcates the focus of the reported experimental noise exposure studies.

(behavioural interruption). Especially common are reports on birds singing louder or higher in frequency, or with more concentrated sound energy bands in more noisy conditions (signal modification). Patterns of noise level dependent song frequency use have been found both between and within populations. Great tits (*Parus major*) in cities across Europe, for example, were found to sing with consistently higher minimum frequency on average compared to birds in nearby forest sites [2]. Individual great tits in and around Leiden were also found to have a repertoire of song types with higher minimum frequencies if they had a relatively noisy territory compared to nearby birds that were singing further away from traffic.

### Mechanistic explanations

These patterns of noise-dependent frequency use in birdsong raised the question whether the association had emerged at an evolutionary, ontogenetic, or more immediate temporal scale [3]. Habitat-dependent selection could drive micro-evolutionary changes and explain song differences between populations in relatively noisy and more quiet habitat, but the urban habitat and the rise in traffic noise is relatively recent and is also less likely to be an explanation for variation between individuals in territories that differ in noise level but are only a few hundred meters apart. Reduced audibility at noisy sites of low-frequency relative to high-frequency songs could result in a noise-dependent bias when young birds are building up a song repertoire from memorizing what they have heard in their surroundings. This possible mechanism could account for patterns between and within populations, but would not allow for more rapid frequency modifications in response to current fluctuations in noise level. Such ability of relatively immediate flexibility was revealed in great tits for the first time using experimental exposure tests in the field.

Singing great tits were exposed to traffic-type 'city noise' to test for changes in frequency use before, during, and after the period of artificially increased ambient noise level [4]. It turned out that this species was not shifting upward in frequency by singing a specific song type at higher frequencies, but that it used a noise-dependent way of switching between song types. Individual birds that were exposed to noise continued to repeat song types for longer when these song types had a minimum frequency that was relatively high. If they happened to sing a song type with a minimum frequency that was relatively low, there was more masking and they switched more quickly. These tendencies provide an explanation for the correlations between song frequency and noise levels through a noise-dependent assortment: low song frequencies with quiet conditions and high song frequencies with noisy conditions. Interestingly, this means that the spectral adjustment to noise is actually achieved in great tits by temporal adjustment (singing particular song types for shorter or longer periods).

However, although immediate flexibility can explain all patterns of noise dependent frequency use between and within populations, a contribution of micro-evolutionary or ontogenetic changes can not be excluded yet.

## **Methodological issues of experimental exposure**

### **Collecting song recordings**

Noise-dependent frequency use may contribute to survival ability of birds in environments heavily exposed to anthropogenic noise [5]. It is therefore important to collect more song recordings and study more species that have a different singing style than the great tit to investigate whether they can also achieve spectral adjustment and in what way. Comparative data will eventually provide insight into the species requirements for behavioural flexibility under noisy conditions and has the potential to help in predicting and mitigating noise impact in the context of conservation. Planning and conducting new studies starts with checking previous investigations to sort out, for example, how the singing styles of potential target species compare to e.g. the song type repertoire style of singing of the great tit [4] or the syllable repertoire style of singing of the chiffchaff (*Phylloscopus collybita*) [6].

It is important to get enough song recordings with and without anthropogenic noise, or with low and high levels of ambient noise, that are not affected by any other acoustic disturbance. Songs or calls of other animal species overlapping the song recordings of the target individual have the potential to impede accurate measurements. Prominent activity of other individuals of the same species is also better avoided as in that case social stimulation may cause dramatic fluctuations in song characteristics that may overrule noise-dependent vocal changes. Ten clear song recordings or more in each noise level category should do for most types of analyses. It is good to realize in this context that bird species singing with so-called *eventual variety* will repeat one song or syllable type for a number of times before switching to another. Bird species singing with so-called *immediate variety* will sing another variant every other song they sing. And then there are also species that are single song type singers which have only variety in the spectral and temporal details of the one song variant they continuously sing. This type of variety among species has the potential to affect the sample distribution and can play a critical role in understanding the mechanism underlying noise-dependent song characteristics, as revealed for the great tit.

### **Experimental exposure conditions**

The target of experimental exposure experiments in the field is to induce a rise in traffic-like ‘city noise’ at the position of a singing bird while all other factors remain the same as much as possible. Keeping recording periods for songs under different noise conditions, before, during, and possibly also after experimental exposure, as close as possible together in time will guarantee the optimal extent of condition similarity. Acoustic data collection on free-ranging animals always requires sensible action by the investigators. Approaching a singing bird off-trail, setting up equipment that is atypical to be there, pointing at the target individual with a long and pointy dark microphone, and staring at it repeatedly by one or more investigators for the duration of the trial, will all make the probability higher that the bird will stop singing (see Figure 2). It may also fly away to another perch to resume singing at a distance from the speaker planned to use for the experimental noise exposure. However, careful operation and selection of optimal distances for the recording and playback equipment, which will depend on season, specific target species, and local habituation to people, will usually allow getting sufficient recordings.

It is important to consider the implications of stimulus choice for the noise exposure file to be played back to the target bird. Different approaches are possible to avoid the problem of pseudo-replication when using just a single recording of traffic noise as the overlapping noise stimulus file. One can apply a replicated set of traffic noise recordings [7] or generate a completely artificial sound file with an average traffic-type noise spectrum [4]. Note that alternative masking approaches have the potential to get answers to more fundamental research questions. One can apply for example a noise stimulus file which is below and non-overlapping in frequency with the song frequency range of the target species [8] or which is similar to ‘city noise’ but spectrally reversed; putting most energy at higher frequencies and masking the upper instead of the lower part of birdsong more [4].

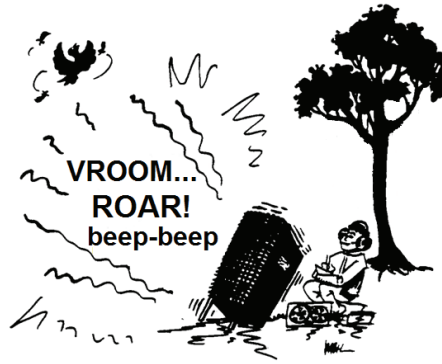


Figure 2. Cartoon by Mart Ottenheim showing an example of how experimental noise exposure can interrupt natural singing behaviour of a free-ranging bird.

It is also important to assess the background noise levels and the achieved rise in noise levels after the trial is over at the song perch used by the focal bird during exposure. Note that the noise level broadcasted through the speaker will decline with 6 dB per doubling of distance. This means, when you playback a noise file at 90 dB(A) as measured at one meter in front of the speaker, that the noise exposure level will range between 72 and 66 dB(A) at a distance between 8 and 16 meters in the direction at which you have pointed the speaker. Also note that the noise spectrum at the bird will be determined by the natural spectrum of the background noise together with the artificial spectrum, which is dependent on the noise stimulus file, the broadcasting properties of the speaker, and site-specific attenuation and reverberation. As the noise coming from the speaker will also affect the recording quality of the singing bird, it is best to use a highly directional microphone pointed at the bird and away from the speaker. An optimal recorder position is at a side of the speaker and pointed parallel to the broadcasting direction. Furthermore, getting as close as possible to the bird and as far as possible away from the speaker, positioning some natural objects in between microphone and speaker if possible, will guarantee the best recording quality for measurements.

### Sonographic measurements

A variety of measures can be taken from sonographic representations of the recorded songs, which will depend partly on the target bird species and on the acoustic software used. Interesting temporal parameters include the duration of song bouts, individual songs, syllables, elements, or intervals between particular song units. Note that the start of a sound is typically a very accurate and reliable measure, while the assessment of the end of a sound is typically affected to some extent by reverberations or echoes. The associated measurement error increases in relative importance with decreasing duration of the song units and is only a problem when reverberative qualities of the environment co-vary with noise conditions. Interesting spectral parameters include: the minimum and maximum frequency, which are typically assessed by marking the lowest and highest visible trace on the sonogram attributed to the bird's song; the so-called peak frequency, which is the frequency at any particular moment in the song with the highest amplitude, and the dominant frequency, which is the frequency with the highest level of accumulated energy over the duration of the target song unit. Note that this terminology is not always consistent across publications and across software packages. So, always check the details of acoustic definitions. Some software packages, such as Avisoft Bioacoustics (<http://www.avisoft.com/>), have the option to extract additional and potentially interesting measures on the energy distribution within the song frequency range by providing spectral demarcation values for energy quartiles below which 25%, 50%, and 75% of all energy is concentrated [8].

Measuring spectral changes in song recordings from quiet and noisy periods has the potential for noise-related artefacts. These artefacts can yield measurement biases away or in the direction of the expected changes in noise-dependent vocal production. This is especially true for minimum and maximum frequency and less true for peak and dominant frequency. The extent and direction of this potentially problematic measurement error depends on the software program and the extent to which measurements rely on cursor placements on the sonographic display. Note that more digital assessments are typically more objective but also less accurate than

manual assessments. Our visual interpretation of sonographic traces of signals and noise are usually best to rely on. A double-blind procedure with the measurements being taken by somebody unaware of the presence or absence of treatment is difficult as the noise level is always audible and at least visible to some extent. The best way to go is to assess the potential measurement error by conducting a playback-rerecording session with known signal properties and controlled variation in ambient noise level at the position of the microphone [6]. Note that also the energy distribution values, as measured in for example Avisoft Bioacoustics, are potentially affected by noise conditions, as they accumulate energy from birdsong as well as ambient noise, and they are therefore only feasible with high signal-to-noise ratios. An advantage is, however, that in this case the potential measurement artefact due to experimental noise exposure is typically in the opposite direction of the expected change in song frequency use.

## Conclusions

Vocal communication often plays a critical role in the life of birds while noisy human activities are deteriorating acoustic conditions for signalling in and around cities, along highways, and in the vicinity of airports. Spectral song adjustments seem a general ability among bird species that persist in such noisy areas, although the relief of the negative impact from masking noise is not straightforward due to compromises on signal value related to the adjustment [9]. Nevertheless, the use of higher frequencies reduces the extent of masking by anthropogenic noise, which usually has a bias to relatively low frequencies. Experimental exposure provides a tool to investigate the underlying mechanism and an opportunity to compare different species with different singing styles and different coping abilities. Methodological concerns involve aspects of both the data collection in the field as the data processing in the laboratory. However, recognition of potential problems and applying adequate solutions provide perfect opportunities for future studies by which we can gain fundamental understanding about the ecology and evolution of signal plasticity. At the same time, this information may become of applied value in a world that is becoming ever more noisy due to human activities.

## References

1. Kight, C.R., Swaddle, J.P. (2011). How and why environmental noise impacts animals: an integrative, mechanistic review. *Ecology Letters* **14**, 1052-1061.
2. Slabbekoorn, H., den Boer-Visser, A. (2006). Cities change the songs of birds. *Current Biology* **16**, 2326-2331.
3. Patricelli, G.L., Blickley, J.L. (2006). Avian communication in urban noise: causes and consequences of vocal adjustment. *Auk* **123**, 639-649.
4. Halfwerk, W., Slabbekoorn, H. (2009). A behavioural mechanism explaining noise-dependent pitch shift in urban birdsong. *Animal behaviour* **78**, 1301-1307.
5. Slabbekoorn, H., Peet, M. (2003). Birds sing at a higher pitch in urban noise. *Nature* **424**, 267.
6. Verzijden, M.N., Ripmeester, E.A.P., Ohms, V.R., Snelderwaard, P., Slabbekoorn H. (2010). Immediate spectral flexibility in singing chiffchaffs during experimental exposure to highway noise. *Journal of Experimental Biology* **15**, 2575-2581.
7. Gross, K., Pasinelli, G., Kunc, H.P. (2010). Behavioral plasticity allows short-term adjustment to a novel environment. *American Naturalist* **176**, 456-464.
8. Hanna, D., Blouin-Demers, G., Wilson, D.R., Mennill, D.J. (2011). Anthropogenic noise affects song structure in red-winged blackbirds (*Agelaius phoeniceus*). *Journal of Experimental Biology* **214**, 3549-3556.
9. Halfwerk, W., Bot, S., Buikx, J., van der Velde, M., Komdeur, J., ten Cate, C., Slabbekoorn, H. (2011). Low-frequency songs lose their potency in noisy urban conditions. *Proceedings of the National Academy of Sciences USA* **108**, 14549-14554.