The reasons why animal populations decline in response to anthropogenic noise are still poorly understood. To understand how populations are affected by noise, we must understand how individuals are affected by noise. By modifying the acoustic environment experimentally, we studied the potential relationship between noise levels and both spatial and singing behaviour in the European robin (*Erithacus rubecula*). We found that with increasing noise levels, males were more likely to move away from the noise source and changed their singing behaviour. Our results provide the first experimental evidence in a free-ranging species, that not merely the presence of noise causes changes in behaviour and distribution, but that the level of noise pollution plays a crucial role as well. Our results have important implications for estimating the impact of infrastructure which differs in the level of noise produced. Thus, governmental planning bodies should not only consider the physical effect on the landscape when assessing the impact of new infrastructure, but also the noise levels emitted, which may reduce the loss of suitable habitats available for animals.

1. Introduction

Many species are currently experiencing environmental changes. One such change is the modification of the acoustic environment caused by an increase in anthropogenic noise. This increase in noise has profound implications on animals, since noise may be a major factor causing the decline of animal populations [1–3]. To set the right conservation actions, we must understand the consequences of noise pollution at the population level [4]. Noise-polluted habitats can be seen as areas with a novel selection pressure, and a shift into a novel habitat is ‘almost without exception initiated by a change in behaviour’ [5]. Thus, to attain a more comprehensive understanding of how populations are affected by noise, we must identify how behaviour is affected by noise.

Increasing noise levels may be a specific problem for species relying on acoustic communication [6], as acoustic signals are used in a variety of contexts, such as mate choice, parent–offspring communication and predator–prey interactions [7]. A detrimental impact of noise on these different stages of an individual’s life history may decrease individual’s reproductive success, translating to lower population densities. Increasing noise levels may also alter an animal’s spatial behaviour by eliciting movements to avoid noise-polluted areas [8]. Therefore, assessing any changes in spatial behaviour provoked by noise exposure is important, as spatial movement may lead to animals leaving vital breeding/feeding grounds. Species relying on acoustic signals can therefore either adjust their signals to changing noise levels or avoid noise-polluted areas by moving away.

Bird song plays a crucial role in determining an individual’s reproductive success, and anthropogenic noise levels have been correlated with changes in singing behaviour [9]. In the European robin (*Erithacus rubecula*), males produce complex songs that are used in mate choice and territory defence [10]. Thus, it is important for robins to mitigate the effects of noise on
communication either by avoiding noise-polluted habitats completely or by adjusting their songs to noise. Here we (i) test whether a causal relationship between changes in song and increasing noise levels exists, using observations and noise exposure experiments; and (ii) investigate whether different levels of noise change spatial movements of birds. We predicted that (i) with increasing noise levels robins adjust their singing behaviour accordingly. If increasing noise levels are perceived as more disturbing, we predicted that (ii) the number of birds moving away from the sound source will increase with increasing noise levels.

2. Material and methods

The study was conducted on the European robin from April to June 2010 in Northern Ireland. To investigate whether song differed with varying noise levels, we recorded the song of 27 males, using a Marantz, PMD660 recorder connected to a Sennheiser ME 66/K6 microphone. Background noise levels (dB(A)) were measured with a digital sound-level metre SL-100 (Voltcraft, Hirschau). Background noise levels in territories where experiments were conducted were below 55 dB(A). The experiment comprised three 3 min periods: (i) a control to get a baseline level, (ii) a noise exposure at 70 dB(A), and (iii) a noise exposure at 90 dB(A). The volume of broadcast noise was adjusted before playback to either 70 dB(A) or 90 dB(A) at 1 m, as measured with the sound-level metre. The order of the noise exposures was randomized; however, the 3 min control recording was always completed first. We are aware that this was not a completely randomized design, but starting with a noise exposure treatment would prevent us from getting a natural baseline, affecting a subsequent control recording (cf. [11]). We decided that since the baseline recording was merely a control, randomization was less important than obtaining a recording of undisturbed bird behaviour. Ten males were exposed experimentally to noise. One male flew away during the 90 dB noise exposure and could not be included in the song analysis (n = 9), but was included in the spatial behaviour analysis (n = 10).

Noise stimuli were created by filtering random noise with a low-pass set to 100 Hz and a decrease in spectral energy of 6.5 dB kHz\(^{-1}\) towards the higher frequencies (for details, see [12]). Stimuli were played through an SME-AFS loudspeaker (Saul Mineroff Electronics, USA) via a Marantz PM660 recorder. The loudspeaker was positioned in the direction of the bird, about the height of the bird’s position and without obstructions between the bird and the speaker. To standardize the distance between the bird and the loudspeaker, a 30 s recording of a robin song was played back first during which all focal birds approached; when the focal bird was within 4 m of the loudspeaker, the noise exposure experiment began. Thus, the 90 dB(A) treatment will always be perceived as higher than the 70 dB(A) treatment within the 4 m area. To measure any alteration to spatial behaviour, any movement of the bird away from the loudspeaker within the 4 m area was noted.

Spectrograms were generated with AUSCOPY SASLab (R. Specht, Berlin). For each individual, we randomly selected 10 songs. For each song, we measured (i) the minimum frequency (kHz), i.e. the lowest frequency of any element in the song [13,14]; (ii) song complexity, i.e. number of different elements [15]; and (iii) song duration (seconds), i.e. the start of the first element to the end of the last element of a song. To test whether song changes in response to increasing noise levels, we modelled the change in a song parameter as a function of noise level with linear regression. To fulfil the assumptions of a linear regression song complexity was log transformed. To test whether experimentally manipulated noise level changed singing behaviour, we used repeated measures ANOVA. To test whether varying noise levels affected spatial behaviour, we used a \(\chi^2\)-test comparing the number of birds that moved in each treatment. Data are provided in the electronic supplementary material.

3. Results

With increasing noise levels, males increased the minimum frequency of their songs (observations: \(R^2 = 0.54, F_{1,26} = 30.08, p < 0.001\); experiments: \(F_{2,16} = 33.58, p < 0.001\); figure 1a). Song complexity decreased with increasing noise levels (observations: \(R^2 = 0.16, F_{1,26} = 4.87, p = 0.037\); figure 1b; experiments: \(F_{2,16} = 21.87, p \leq 0.001\); figure 1c). With increasing noise level, song duration did not change (\(R^2 = 0.002, F_{1,26} = 0.06, p = 0.8\); figure 1c). However, when birds were exposed to noise experimentally they sang shorter songs with increasing noise level (\(F_{2,16} = 7.32, p = 0.006\); figure 1f). With increasing noise levels, birds were more likely to move away from the noise source (\(x^2 = 12.38, p = 0.002\); figure 2).

4. Discussion

Our study provides the first experimental evidence in the wild that not only the presence of anthropogenic noise induces behavioural changes, but also most importantly it shows that the level of noise, i.e. the amplitude of noise, is a crucial factor affecting spatial and singing behaviour. Our study experimentally shows a gradual behavioural change in response to increasing background noise levels, which has been suggested by many observational studies [9]; thus the greater the noise level, the greater the behavioural change. Increasing background noise levels may disrupt acoustic communication, which is important in many species for successful reproduction [7]. Such adjustments to increasing noise levels may have deleterious consequences on an individual’s life history [16]. For example, increasing the minimum frequency of a song decreases its range [17]; and females appear to prefer males producing low frequency acoustic signals, longer signals and/or more complex signals in many taxa [7]. Thus, an increase in minimum frequency, a decrease in signal complexity or a decrease in signal duration in response to anthropogenic noise, limits the expression of a sexually selected trait on which females base their mate choice. This negative effect on the individual level, which may decrease reproductive success of an individual, could then translate to lower population densities along roads as reported in earlier studies [4,18–21].

Most research on the effects of anthropogenic noise has indirectly examined the effects of noise on animal populations near roads. However, most road ecology studies cannot isolate noise from other possible factors associated with roads, such as visual disturbance and road mortality [22]. Our study circumvents this problem, by manipulating the acoustic environment experimentally. When noise levels increased, birds moved away from the noise source, suggesting that animals avoid areas with high levels of noise. Our results are in line with studies comparing population changes in response to noise levels, which found that noise negatively correlated with population density and occupancy [23–25]. The changes observed during the experiment can either be due to the disturbance of the experiment or due to the noise itself. However, a previous study reported that birds differ in their response to an experimental exposure.
of noise and a biotic control sound, suggesting that birds specifically respond to the noise being played and not simply any disturbance [13]. Furthermore, the observed gradual response to increasing noise levels further suggests birds are responding to the noise and not disturbance.

Taking all these results together, we conclude that anthropogenic noise could indeed be an important factor affecting animal populations. Therefore, not only the massive changes in the landscape that come with greater infrastructure but also noise levels alone can affect an animal’s behaviour and potentially animal population dynamics.

The gradual behavioural changes in response to increasing noise levels found in our study show that distance from a noise source influences the magnitude of a behavioural change. Noise levels decrease with increasing distance from a sound source, thus the closer an animal is to a noise source, the greater the behavioural change. Therefore, governmental planning bodies should consider both the distance the

**Figure 1.** Relationship between song characteristics and noise levels (a–c; n = 27) and mean response ± s.e. during control, 70 and 90 dB, noise exposure experiment (d–f; n = 9).

**Figure 2.** Number of males that moved away from speaker during noise exposure experiment (control, 70 and 90 dB; n = 10).


14. Slabbekoorn H, Peet M. 2003 Ecology: birds sing at a higher pitch in urban noise—great tits hit the high notes to ensure that their mating calls are heard above the city’s din. Nature 424, 267. (doi:10.1038/424267a)


