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The Thrush Nightingale (*Luscinia luscinia*) in Moscow and Moscow Suburbs: City Noise Influences the Frequency Parameters of Its Song

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Abstract—The localization of the minimum frequency for 12 vocal components from 4 types of songs of the thrush nightingale was studied. These types of songs are widespread both in Moscow and in the rural localities of Moscow oblast. Their low-frequency components are overridden by city noises to a great extent. Statistically significant distinctions for all components were revealed in pair comparisons. On average, the minimum frequency in the city is higher by 260 Hz than in the rural habitats, and this pattern is implemented not only for low-frequency components of songs, but also for the components localized higher in the frequency range. Upon a simultaneous consideration of all 12 control components using discriminant analysis, a sufficiently complete division of the populations of Moscow and Moscow oblast is reached. The data obtained confirm the hypothesis of a shift of the frequency range of bird singing as a response to city noise.

Keywords: thrush nightingale, avian song, urban noise, adaptations, bioacoustics
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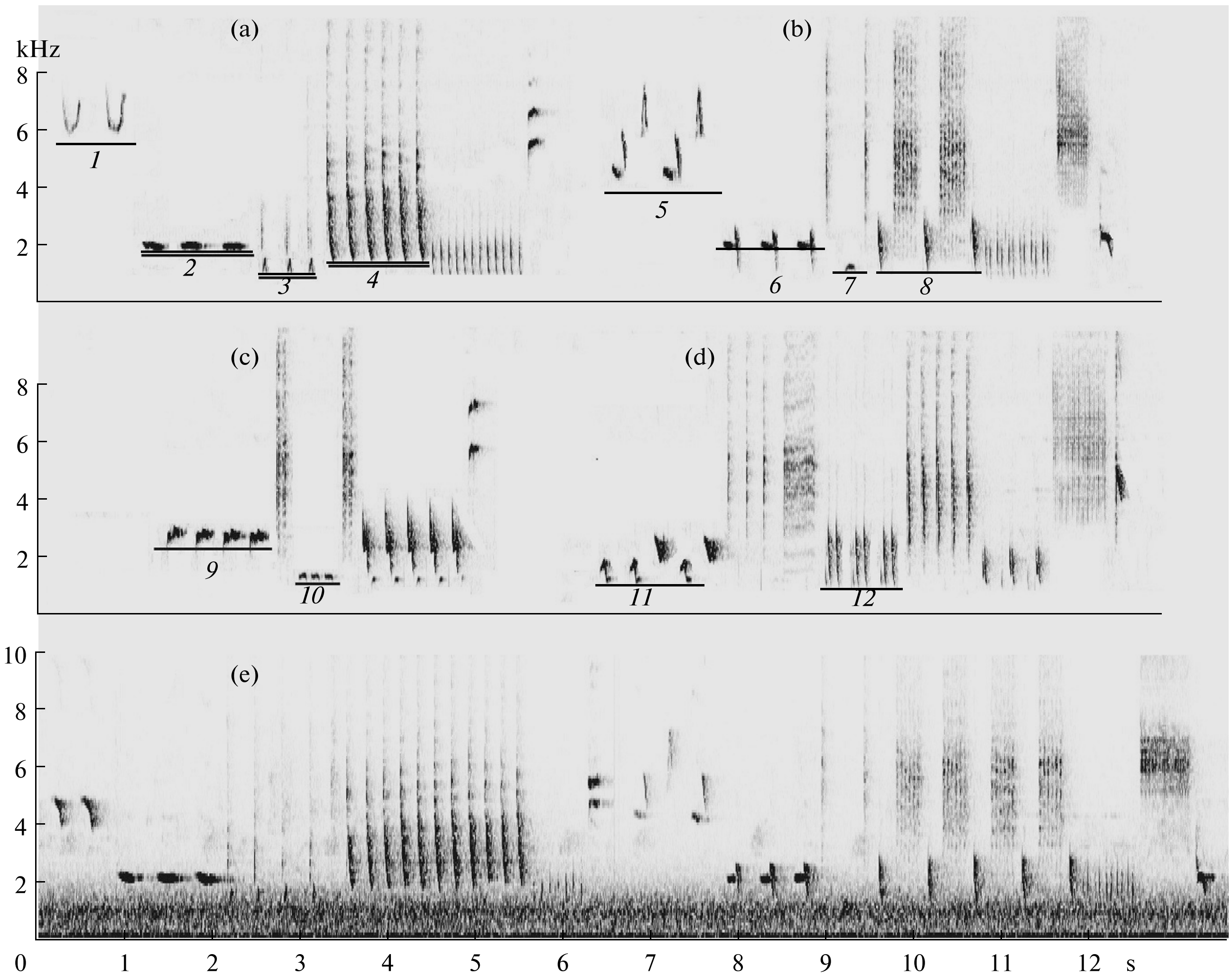
INTRODUCTION

The acoustic communication of animals is often carried out against a variety of background noises. Nowadays, when many species of animals must successfully master anthropogenic landscapes, they are forced to adapt to very noisy environments. In the last decade, indications have begun to appear in the literature that low-frequency urban noise affects the acoustic parameters of advertising vocalization of songbirds. One of the first reports concerned the great tit (*Parus major*). It was found that the minimum frequencies in the songs of individuals living under conditions of high noise are localized in a higher spectral region than in the songs of individuals living in less noisy stations (Slabbekoorn and Peet, 2003). The characteristics of the amplitude of songs also change in noisy environments. For example, the volume of singing of the common nightingale (*L. megarhynchos*) increases with the level of anthropogenic noise (Brumm, 2004). The impact of noise is felt not only by birds but also by other animals that actively use acoustical communication. It was shown, for example, that the maximum activity of vocalization of the singing cicada (*Cryptotympana takasagona*), which inhabits the streets of one of the major cities in Taiwan, coincides with the periods of minimum transport noise (Bao-Sen et al., 2011).

It is of interest at what time intervals the frequency parameters of songs change under the influence of noise pollution. Long-term monitoring of three vocal dialects of the white-crowned sparrow (*Zonotrichia leucophrys*) on the Pacific coast of the United States showed that over 30 years in two of them the minimum frequency of the song increased on average by 170 and 300 Hz, while the third dialect was completely replaced by a neighboring, more high-frequency dialect. The authors associate these changes with progressive increase in the transport noise in the surveyed areas (Luther and Baptista, 2010). At the same time, there is evidence that the response of the singing birds to noise can be purely behavioral, i.e., rapid and reversible. Thus, the house finch (*Carpodacus mexicanus*) immediately increases the minimum frequency in response to a sudden loud noise arising, for example, due to a car or motorcycle (Bermúdez-Cuamatzin et al., 2009).

In this report we compare the frequency characteristics of the songs of thrush nightingales dwelling within the boundaries of the Moscow megalopolis and in Moscow oblast. Currently, Moscow nightingales are ordinary urban birds. At the same time, they are surprisingly tolerant to the presence of people and high noisiness of the territory. We repeatedly observed males recklessly singing just tens of meters away from the busiest thoroughfares such as Leninskii Prospekt.

Earlier, we conducted a detailed analysis of the song organization of the thrush nightingale from the Moscow urban population (Ivanitskii et al., 2013,



Song types of the thrush nightingale (a–d). The vocal components for which the minimum frequency was measured are underlined (*1–12*). (e) Song types *A* and *B* against the background of the city noise. The vertical axis shows the frequency (kHz), and the horizontal axis shows the time reckoning (s).

2013a). It is worth noting some important characteristics of the singing of this species that make it an interesting model for studying the effects of noise on the vocalization of birds. First of all is the saturation of the song with sounds lower than 2.0–2.5 kHz. Such low-frequency components are rarely present in the songs of small songbirds (Bergmann and Helb, 1982). Meanwhile, it is these sounds that have a relatively small rate of decay and hence spread over long distances (hundreds of meters) providing distant sound communication and giving the nightingale's singing its extraordinarily long-range and specific sound. But at the same time, it is the low-frequency components that are affected the most by urban noise (Fig. 1e).

Another interesting feature of the thrush nightingale's song is its pronounced population and geographic conservatism. It is well known that advertising vocalization (singing) of this species consists of discrete, strictly stereotyped vocal structures divided by clear pauses (Simkin 1981; Sorjonen, 1987; Naguib and Kolb, 1992). Each of these constructions can be attributed to a certain type, so it is convenient to call them the types of songs. According to our data, the individual repertoires of nightingales from Moscow and Moscow suburbs include from 7–8 to 20–23 types of songs. Many of them are performed unchanged and in the same sequence by males inhabiting the entire area surveyed (Ivanitskii et al., 2013, 2013a). This provides a unique opportunity to compare the frequency characteristics of the same types of songs, as both in the city and in the oblast they contain the same vocal components and, in essence, hardly differ in terms of the overall structure (the main source of variability is variations in the number of identical components performed in a row).

The figure shows sonograms of four types of songs that we have chosen as a model. Note that these four types of songs form a stereotyped sequence and, as a

Table 1. Frequency parameters (kHz) of the songs of the thrush nightingale and of city street noise

Type of signal	Dominant frequency	Average frequency		
		value	first quantile	second quantile
Song type *A*	2.23	2.67	2.15	3.83
Song type *B*	2.23	2.54	2.02	4.82
Song type *C*	1.55	3.83	1.89	5.46
Song type *D*	2.23	2.84	2.19	5.03
City noise	–	0.85	0.46	155

rule, are performed by most males in the order in which they are placed in the figure (a → b → c → d). The vocal components for which we measured the minimum frequency are underlined.

In May–June of 2010–2012, in Moscow and Moscow suburbs, we recorded a total of over 200 males singing, however, the analysis includes only those whose repertoire contained all four model types of songs (59 males in the city and 49 in the oblast). To record the songs, we used Marantz PMD 660 professional digital recorders and a Seinheiser–ME 66 condenser microphone with a K-6 module preamplifier (“short shotgun”) and AKG. The spatial distribution of recording points in the city and the region was relatively uniform: in Moscow, it included almost every major park (Vorobevye Gory, Bitsevskii Park, Izmailovskii Park, Setuni valley, the Main Botanical Garden, etc.). In Moscow oblast, recordings were made in the area from Dmitrov and Sergiev-Posad to the Oka valley and from Mozhaisk to Shatura. Thus, the samplings used in our work were obtained from a sufficiently large area.

The procedure was conducted as follows. One song from four model types was randomly selected from the phonogram of each male. The signals were visualized, and the lower boundary of the frequency range was measured for the control components of songs indicated in the figure using the Syrinx program (Blackman window, the length of the Fourier transform is 512 points with a resolution of 20 Hz along the frequency axis and 1.4 ms along the time axis). All measurements were performed by one author with the aim to standardize inevitable errors. The lowest frequency components of the songs were selected for measurements, which, as we can consider, are affected the most by noise. In addition, for comparison, we measured the position of the lower boundary of the range for relatively higher frequency components of the songs as well: the “openings” (figure, components *1* and *5*), which are much higher than the main band of noise. The characteristics of energy ranges were obtained using the Avisoft SASLab Pro software package.

The frequency parameters of model types of songs and urban street noise are presented in Tables 1 and 2. No special recordings and measurements of the noise were made. On sonograms, the noise recorded directly at the points of nightingale singing appears like a contrasting dark band (Fig. 1e). According to visual estimates, its upper boundary extends in the region of 2.5–3.0 kHz. According to the spectral analysis of 20 samples recorded directly against the background of nightingale singing, about 90% of the noise power is lower than 3.0 kHz. Its average frequency separating half of the power is 0.85 ± 0.21 kHz, quartiles: 0.46 ± 0.09 and 0.155 ± 0.34 kHz. The average values of the minimum frequency of control components of four model song types (with the exception of components *1* and *5*) vary from 1.0 to 2.8 kHz. The dominant (peak) frequencies for all model types of songs (except for components *1* and *5*) are localized well below 3 kHz—the border separating approximately 90% of the noise power. This observation means that the lowest frequency components of nightingale songs are substantially covered by urban noise, which is also quite obvious when observing the sonograms visually (Fig. 1e).

Comparing the values of the minimum frequency in the songs of the Moscow and Moscow oblast populations, we obtained statistically significant variations in paired comparisons for all 12 control components (Mann–Whitney test, $P < 0.01$ for all comparisons). On average, the minimum frequency in the city is higher by 260 Hz than in the oblast. It is interesting that this pattern is implemented not only for low-frequency components of songs, but for both song “openings” included in the analysis (components *1* and *5*), which are localized significantly higher in the frequency range (Table 2). Simultaneous consideration of all 12 control components by discriminant analysis allows us to achieve a sufficiently complete separation of the Moscow and Moscow oblast populations: 96.9% correct identifications (Wilks lambda = 0.23, $P < 0.001$).

Thus, our findings confirm the hypothesis of a shift in the frequency range of bird signing in response to urban noise. The minimum frequencies of all 12 studied vocal components from the four types of songs of the thrush nightingale in the city are higher in the range than in the oblast. Most likely, these differences are caused by different levels of background noise pollution of habitats. The question of whether the change in frequency parameters of songs is purely a behavioral response or whether it has formed in a number of generations as a specific adaptation to particular features of the environment requires further research. Note, however, that while examining the sonograms, we failed to reveal any significant changes in the minimum frequency of the vocal components of songs in response to short-term interventions of loud noise (for example, during the passing of a train).

Table 2. Minimum frequency (kHz) of vocal components of songs of the thrush nightingale from Moscow and Moscow region

Song components (according to the figure)	City population			Regional population		
	x ± *SD*	min	max	*x* ± *SD*	min	max
1	6.36 ± 0.27	5.74	7.01	6.00 ± 0.41	5.26	7.00
2	1.98 ± 0.11	1.70	2.31	1.72 ± 0.09	1.50	1.93
3	1.20 ± 0.11	0.95	1.47	1.05 ± 0.07	0.90	1.20
4	1.82 ± 0.14	1.51	2.31	1.45 ± 0.15	1.13	1.86
5	4.26 ± 0.14	3.96	4.53	4.00 ± 0.22	3.4	4.39
6	2.04 ± 0.16	1.81	2.68	1.70 ± 0.09	1.49	1.96
7	1.14 ± 0.08	0.97	1.56	1.00 ± 0.10	0.71	1.25
8	1.26 ± 0.15	1.03	1.74	1.09 ± 0.11	0.88	1.43
9	2.83 ± 0.38	1.40	3.85	2.21 ± 0.16	1.93	2.79
10	1.24 ± 0.11	1.06	1.79	1.10 ± 0.07	0.93	1.28
11	1.32 ± 0.15	1.05	1.64	1.05 ± 0.10	0.85	1.32
12	1.22 ± 0.08	1.08	1.44	1.08 ± 0.09	0.91	1.28

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