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Does the reaction of nocturnally migrating songbirds to the local light source depend on backlighting of the sky?

Victor N. Bulyuk, Casimir V. Bolshakov,
Alexandra Y. Sinelschikova & Michael V. Vorotkov

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Address: V.N.B., C.V.B., A.Y.S.: Biological Station Rybachy, Zoological Institute, Russ. Acad. Sci., Rybachy 238535, Kaliningrad Region, Russia. E-mail: bulyuk@bioryb.koenig.ru; M.V.V.: Pulkovo Observatory, Russ. Acad. Sci., Pulkovskoye sh. 65/1, St. Petersburg 196140, Russia. E-mail: biser_gao@mail.ru

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1. Introduction

Many avian species prefer to migrate at night (Alerstam 2009, 2011). For tens of thousands of years the only light sources during the dark period of the night were the polarized sunlight, the Moon and stars. However, in the recent decades, due to extensive industrial and urban development, many migrating birds encounter during their nocturnal flights vast areas of bright artificial lights, often including tall structures. Numerous evidences is available showing that anthropogenic lights may attract and disorient birds, sometimes causing their mass mortality (Avery et al. 1980; Verheijen 1985; Evans Ogden 1996; Gauthreaux & Belser 2006; Loss et al. 2012; Longcore et al. 2013). Increasing number and size of the cities, numbers of streetlights, heights of office buildings and the number of offices with lights often lit on after dark make the study of response of nocturnally migrating birds to artificial light sources rather relevant.

We have considered a question whether response of night-migrating passerines to the local source of white light differs under (a) natural nocturnal illumination and (b) in urban light environment. The data of observation were collected by the Optical Electronic Device (Vorotkov et al. 2009; Bolshakov et al. 2010, 2013) during autumn nocturnal passage of passerines at the Courish Spit of the Baltic Sea und within the city limits of St. Petersburg.

2. Material and methods

Our study site on the Courish Spit was located on Cape Rossitten (55°09´N, 20°51´E). Cape Rossitten has almost no anthropogenic lights, with an exception of several street lights 100–200 m from the study site. These light sources do not create any noticeable sky glow over the adjacent area even in dense fog. The nearest areas with anthropogenic lights located on the Courish Spit are 10 km to the NE and 20 km to the SW and the next site is on the eastern shore of Courish Lagoon (30 km to the E; see Fig. 1 in Bolshakov et al. 2013). Observation site in St. Petersburg was located on the northern coast of Gulf of Finland at Cape Lahta (59°59´N, 30°10´E). Unlike Cape Rossitten, the sky above Cape Lahta was at night strongly illuminated by street lights, apartment blocks and other objects of the adjacent urban area.

At both sites we used the same Optical Electronic Device (OED), which consists of the electronic optical system and the illumination system (Vorotkov et al. 2009; Bolshakov et al. 2010, 2013). The illumination system formed an illuminated inverted cone of white light with an open angle of 5° at both sites. OED makes it possible 1) to detect birds aloft, 2) to estimate bird flight tracks in the illuminated zone, 3) to identify the group of songbirds (small passerines or thrushes) from silhouette, flight pattern and body size (body length and wing span; Vorotkov et al. 2009; Bolshakov et al. 2010, 2013).

At Cape Rossitten the range of bird detection in the light cone was limited by altitudes of 100–1000 m a.g.l., where a relatively uniform field of light is formed. At Lahta, the ceiling of detection was lower, ca. 600 m a.g.l. The reason for this was the illumination of the environment by anthropogenic light. Lower relative brightness of the standard vertical beam of white light in the illuminated environment caused a lower quality of detected silhouettes of flying birds in St. Petersburg. Comparing the quality of images along the six-grade scale (from 1 – lowest quality image to 6 – the highest quality; Bolshakov et al. 2010) showed that the mean quality of images obtained by OED was notably poorer under condition of urban light pollution. Under natural nocturnal illumination the proportion of high-quality images of small songbirds (grades 4–6) was 44.3%, and in the urban environment it did not exceed 6.2% ($\chi^2_1 = 220.3$, $p < 0.0001$). For thrushes the corresponding proportions were 77.9% and 18.2%, respectively ($\chi^2_1 = 266.8$, $p < 0.0001$; Fig. 1).

For analysis of the reaction of night-migrating songbirds to the cone of white light on the Courish Spit we used the data on 3841 small passerines and 2696 thrushes obtained by OED during three autumn migratory seasons: 12/13.09–26/27.10 in 2008–2010 (93 nights with observations). For St. Petersburg we used the data on

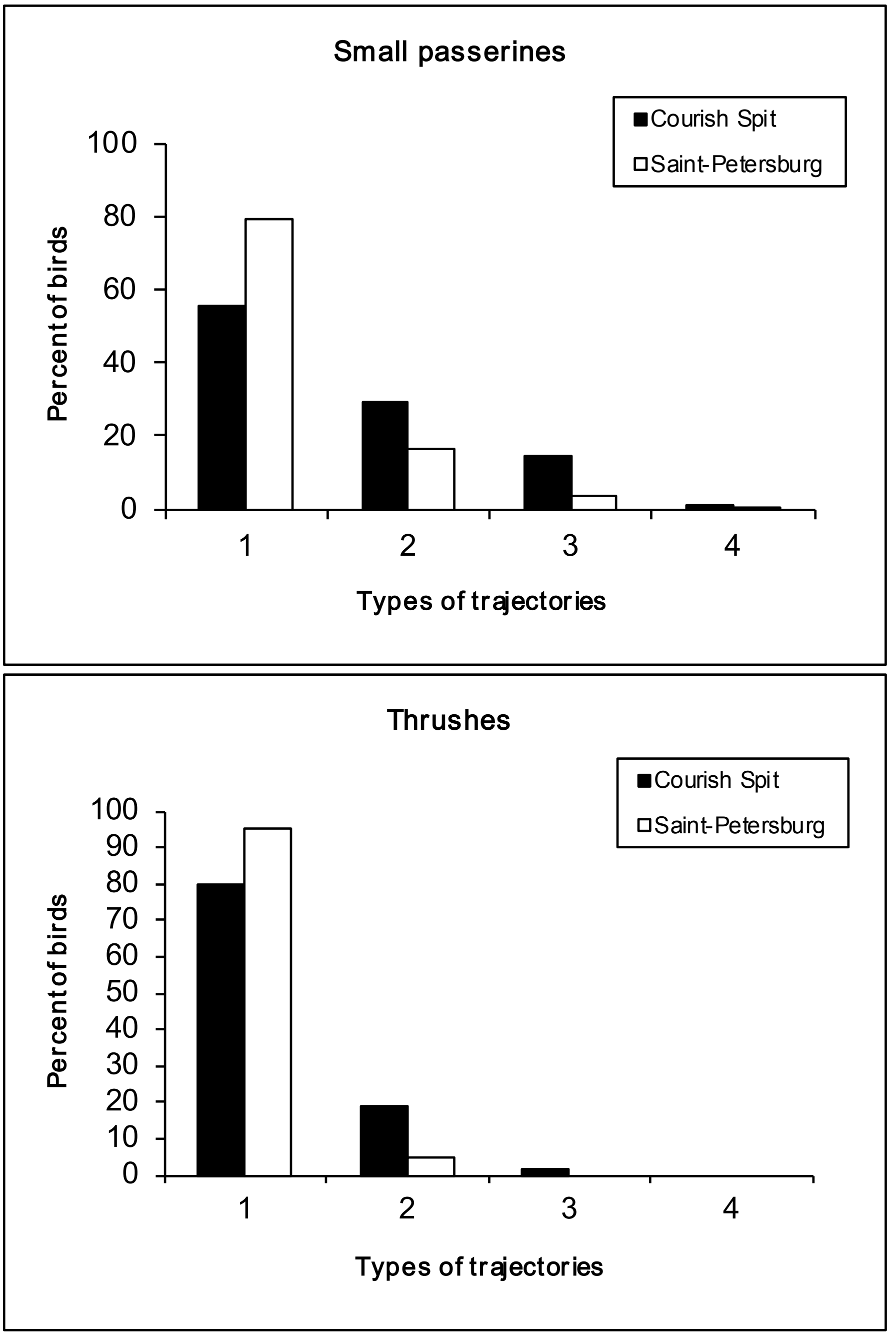

Figure 1. Frequency distribution of the quality of images (scores from 1 to 6) of small passerines and thrushes under natural nocturnal illumination (the Courish Spit) and in an urban area (St. Petersburg). For criteria of quality scores see Bolshakov et al. (2010).

403 small passerines and 149 thrushes obtained by OED during 1/2.09–15/16.11 in 2011 (56 nights with observations). We used the shape of flight track (its curvature) as a criterion of response to light. We distinguished four types of tracks across the light beam: (1) linear tracks; (2) weakly curved tracks; (3) strongly curved tracks; (4) broken tracks, including apparent circling (these types of trajectories are illustrated in Fig. 9 in Bolshakov et al. 2010).

3. Results

Considering the limitations mentioned above, we could compare the proportions of linear and curved flight tracks from images scored 2 and 3 for small passerines and 3 in thrushes. The proportion of small songbirds with linear tracks (no apparent response to the light beam) was significantly smaller under natural illumination on the Courish Spit (55.2%) than in the heavily light-polluted urban area near St. Petersburg (79.2%; $\chi^2_1 = 64.6$, $p < 0.0001$; Table 1). This tendency was even more pronounced in thrushes. The proportions of those birds that did not respond to the vertical light beam and had straight tracks was 79.6% on the Courish Spit and 95.3% near Cape Lahta ($\chi^2_1 = 12.0$, $p < 0.001$; Table 1).

Reaction of the nocturnally migrating songbirds to the light beam differed between small passerines and thrushes. Small passerines significantly more often changed their flight direction when crossing the vertical beam of white light than did the thrushes. On the Courish Spit, the proportion of linear tracks was 63.2% in small passerines and 83.3% in thrushes ($\chi^2_1 = 314.4$, $p < 0.0001$; Table 2). Unlike small passerines, very few thrushes had strongly curved tracks and no broken tracks or apparent circling were recorded in thrushes (Table 1).

Why was the proportion of songbirds that changed their flight direction when crossing the vertical light beam over a city much smaller than under natural nocturnal illumination? The most obvious reason could be that the white light beam was much less apparent against the background of the already light-polluted urban sky. We cannot rule out than birds, when they fly over a heavily illuminated urban area, adapt their vision to the anthropogenic light and respond weaker to local strong lights. For instance, relatively strong backlighting of the sky during full moon is known to strongly decrease bird kills at tall lit structures (Verheijen 1981a, b). It is worth noting that response of nigh-migrating birds to the light may depend not just on the type of light source, its spectral composition, brightness and direction, but also on the weather conditions (Bolshakov et al. 2013).

Another factor that significantly influences the response of flying birds to anthropogenic light exhibited in the form of changing flight trajectory is their taxonomic affinity. Small passerines, when they enter a light beam, more often change their flight direction than the thrushes. The larger proportion of curvilinear tracks across the light beam in small songbirds (like European Robins *Erithacus rubecula* and Goldcrests *Regulus regulus*), unlike larger thrushes, may be due to their undulating flight pattern. A second cause may be their lower air speed as compared to thrushes (Bolshakov et al. 2010, 2013).

Table 1. Percentage of small passerines (image quality scores 2 and 3) and thrushes (image quality score 3) showing different types of tracks under natural nocturnal illumination (Courish Spit) and in an urban area (St. Petersburg).

Types of tracks	Small passerines		Thrushes	
	Courish Spit (n = 1433)	Cape Lahta (n = 342)	Courish Spit (n = 343)	Cape Lahta (n = 86)
(1) linear tracks	55.5	79.2	79.6	95.3
(2) weakly curved tracks	29.2	16.7	18.7	4.7
(3) strongly curved tracks	14.6	3.8	1.7	0
(4) broken tracks, including apparent circling	0.7	0.3	0	0

Table 2. Percentage of small passerines and thrushes showing different types of tracks when crossing the vertical beam of white light (angular size 5°) under natural nocturnal illumination on the Courish Spit.

Types of trajectories	Small passerines (n = 3818)	Thrushes (n = 2696)
(1) linear tracks	63.2	83.3
(2) weakly curved tracks	24.5	15
(3) strongly curved tracks	11.3	1.7
(4) broken tracks, including apparent circling	1.0	0

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