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ORIGINAL PAPER

The effects of railway modernization and noise pollution on forest birds

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ABSTRACT

Railway lines act in different, often opposing, ways on the fauna and flora occupying the habitats adjacent to them. The expansion of rail infrastructure destroys the natural habitats in the land designated for that purpose. Forest habitats are particularly at risk. Birds and other animals are killed in collisions with trains; they are also indirectly affected by their noise and lights, and by the presence of people. On the other hand, railway lines can have positive consequences, creating edge effects as well as anthropogenic niches which birds can take advantage of. Whereas various elements of the infrastructure can provide good nesting sites, look-out posts or roosts, the habitats it brings about can also turn out to be ecological traps, increasing the mortality of animals. In this paper we discuss the results of a study that we carried out during the rebuilding of a busy railway line in the absence of train movements. The results relate to the effect of noise emitted by construction machinery and the presence of people on an assemblage of woodland birds. As the study was performed on a plot previously used when trains were running normally, we were able to compare the results of two studies carried out by the same researchers on the same plot using the same methodology. Birds were counted at 45 listening/observation points situated at three distances from the tracks (30, 280 and 530 m). At each point we measured the noise level and assessed the habitat parameters. We recorded a total of 806 birds from 39 species during all the counts. The highest levels of noise were recorded alongside the railway line that was being modernised. The noise produced by the heavy construction machinery did not affect the numbers or species diversity of birds in the neighbourhood of the line and none of the 11 habitat factors influenced the distribution of birds on the study plot. Birds with low-frequency vocalisations, easily masked by the noise from the construction site, avoided the vicinity of the tracks. Moreover, a consequence of the noise and the transformation of the habitats within the transport corridor where building work was in progress was that particular bird species did not display any apparent preference for spending time either near the tracks or deep in the forest. The removal of bushes and herbaceous vegetation from both sides of the tracks in connection with the construction work caused a deterioration in foraging conditions and a distinct attenuation of the edge effect. The upshot was that the birds were more seriously affected by noise, the edge effect was weaker and the distribution of birds more even in comparison to the situation when trains were running normally.

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KEY WORDS

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Introduction

Railway lines are important components of the transport network in every country. Despite the proliferation of tarred roads, which provide an alternative to railway transport, rail infrastructure is continually being expanded and is an important economic stimulus on all continents (Dulac, 2013; Clewlow *et al.*, 2014). Although much is already known about the impacts of railway lines on ecosystems, numerous aspects of these interactions still require study (Borda de Agua *et al.*, 2017; Barrientos *et al.*, 2019). Collisions between trains and animals are one of the main problems arising from railway-nature interactions, as they obviously lead to a high level of mortality among the latter (Carvalho *et al.*, 2017; Santos *et al.*, 2017). In addition, railway tracks set up barriers to the migration of wild animals and fragment habitats (Barrientos and Borda de Agua, 2017; Fahrig, 2017). Habitats are destroyed where new railway lines are constructed, and a variety of factors impede the proper functioning of whole assemblages of animals in the vicinity of railway tracks, for example, noise and/or light pollution, and the presence of humans (Borda de Agua *et al.*, 2017; Lucas *et al.*, 2017; Barrientos *et al.*, 2019).

A number of studies have shown that railway operations can have positive effects on birdlife: railway infrastructure provides song posts and roosting sites for a variety of species as well as look-out posts for raptors (Morelli *et al.*, 2014). In contrast, this infrastructure, when used for nesting, can also lead to mortality among birds (Malo *et al.*, 2016). The boundary between railway tracks and the patches of vegetation along them may be rich in food, and thus an attractive foraging area for many animal species. This well insolated mosaic of synanthropic and natural habitats supports many species of plants, which are colonised by numerous invertebrates and small mammals, as well as their predators (Delgado *et al.*, 2007; Barbaro *et al.*, 2014; Batary *et al.*, 2014). Some studies have shown that woodland edge ecotones, being rich in food and nesting sites, may be very attractive to birds, which will colonise such habitats in preference to areas deeper in the forest (Wiącek *et al.*, 2015a). Other research, however, has revealed quite different reactions of birds occupying territories close to railway lines: Waterman *et al.* (2002), for example, detected a drop in bird densities in open meadow habitats in the Netherlands, wherever these lay adjacent to railway tracks. In contrast, greater bird densities were recorded on transects running close to railway tracks both in open terrain in Tibet and in the forests of eastern Poland (Li *et al.*, 2010; Wiącek *et al.*, 2015a). In the light of this wide spectrum of results, it seems worth investigating this issue further: no such results have been based on long-term surveys, so drawing more general inferences is not yet possible (Barrientos *et al.*, 2019).

The main aim of the present research was to assess the effect of a railway line during its modernisation and consequent temporary disuse on the assemblage of birds inhabiting a forest complex contiguous with the tracks. It was a repetition of the work carried out in the 2014 breeding season on a sampling plot in eastern Poland by the line when this was in normal operation (ca 100 trains daily). Then, we recorded a positive edge effect on that bird assemblage, as numbers and species diversity were significantly higher along the edge of the forest adjoining the tracks (Wiącek *et al.*, 2015a). In 2017 the reconstruction and modernisation of this section of the line began and all passenger and freight traffic ceased. In this situation, we were able to repeat our earlier study at the same site using the same methodology in order to assess the influence on the birds of the construction work undertaken for the line's modernisation. The zero hypothesis assumed that the cessation of railway traffic and commencement of building operations near our study plot would not affect either the numbers or the species diversity of birds on that plot. The alternative hypothesis assumed that this work would lead to a fall in numbers and species diversity of birds close by the railway tracks. This subject appears to be interesting as no research has been carried out into the anthropogenic factors affecting birds in the vicinity of a railway line in the process of modernisation.

Materials and methods

STUDY SITE. The study plot (Fig. 1) was situated in an extensive forest complex near the town of Puławy, along the railway line Warsaw-Lublin (51°50'02" N, 21°91'94" E) in eastern part of Poland. The forest where the study plot lay consisted mainly of Scots pine *Pinus sylvestris* L. with a small admixture of Silver birch *Betula pendula* Roth. During this research, the double-track line to be modernised was closed to all traffic, *i.e.*, the regular movement of passenger and freight trains was halted. During the day just 2 or 3 trains bringing ballast or other materials passed through at irregular intervals. Heavy-duty equipment was employed during the extensive construction work: this took place mainly on the railway embankment, but also along the entire transport corridor which here is around 50 m wide. The old tracks were lifted, and together with the spoil from the original embankment and other infrastructure, were removed from the site. Fresh aggregate was brought to the site, from which the embankment was reconstructed. Upon this the new tracks were laid and the new overhead lines erected. Along this same section of line there were two aggregate dumps and a storage site for concrete elements used in the construction of station platforms, culverts and level crossings. Every day from 30 to 40 persons were working on this 3 km section of the line. The construction workers did not enter the forest farther

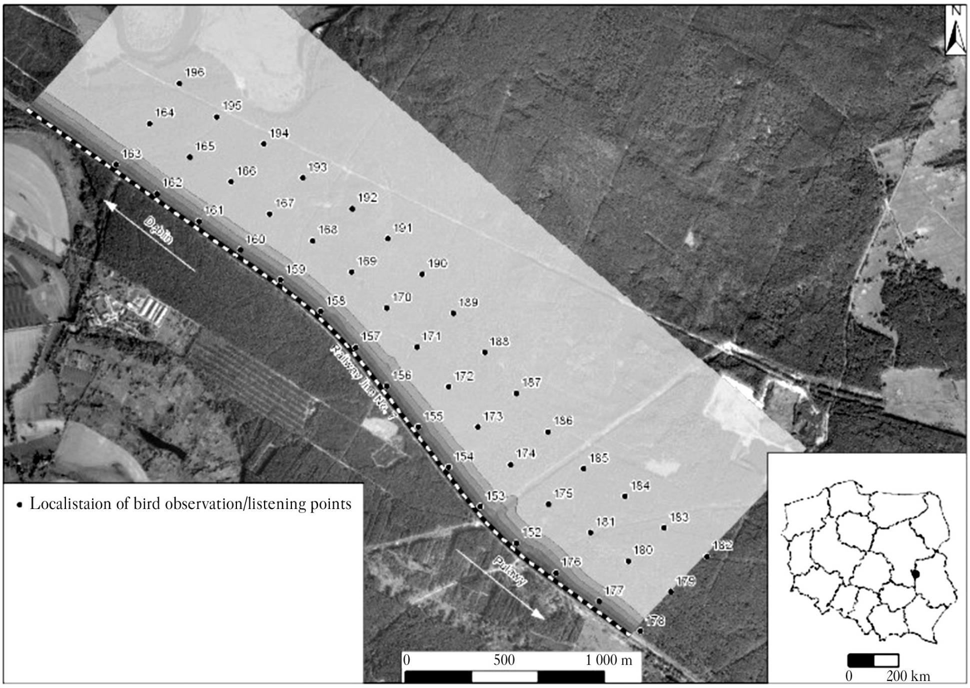

Fig. 1.
The study area with the 45 points-count stations near a railway Lublin-Warsaw

than 10 m from its edge. The movement of dumper trucks carrying aggregate and other building materials was continuous from 06:00 to 16:00 hrs. The herbaceous vegetation and bushes growing within the transport corridors on either side of the railway tracks were removed before construction work commenced. But the forest edge, the boundary of our study plot in 2014, remained untouched since then (Wiącek *et al.*, 2015a).

Rail surveys. The study was carried out during the breeding period by means of counts performed at observation/listening points (Bibby *et al.*, 1992). As in our previous study, the counts were done on the same plot by the same team of recorders (Wiącek *et al.*, 2015a). Birds were counted at 45 points located along 3 rows (ABC) lying 30, 280 and 530 m from the tracks. There were 15 points along each row at intervals of 250 m (Fig. 1). Bird calls were noted for 5 minutes at each point and birds were counted within a radius of 100 m. Birds in flight not associated with the study plot were ignored. The counts (by the same three experienced ornithologists – JW, MP, MF) took place from 06:00 to 08:30 hrs on 19 April, 22 May and 26 June 2018. All three recorders simultaneously walked the three parallel rows (ABC), on each occasion along a different row.

Habitat parameters. The study plot, which we have been using since 2014, was carefully selected such that its parameters ensured a uniform habitat patch (Table 1). The habitat parameters at each listening point were assessed during the fieldwork (Table 2). The criteria for dividing the birds into ecological guilds (feeding, nesting and bioacoustic) were the same as those we used in our earlier research on this plot (Wiącek *et al.*, 2015a). Background noise was measured at the listening points during the counts using CHY 650 digital sound level meters purchased from

Table 1.
The habitat parameters measuring at the listening/observation points

Variable	Meaning
Tree age [years]	Age of tree stand at the point-count location (years)
Canopy cover [%]	% canopy cover in eleven categories: 0 – 0%; 10 – 1-10%; 20 – 11-20%; 30 – 21-30%; 40 – 31-40%; 50 – 51-60%, 60 – 61-70%, 70 – 71-80%, 80 – 81-90%, 90 – 91-99%, 100 – 100% within circle (radius 30 m)
Tree height [m]	Mean height of 5 trees growing within circle (radius 30 m) and measured by the altimeter
Number of tree species	Number of species of the nearest 30 trees that were >20 cm diameter at breast height
Number of deciduous trees	Number of deciduous trees of the nearest 30 trees that were >20 cm diameter at breast height
Number of dead trees	Number of dead trees that were >20 cm diameter at breast height within circle (radius 50 m)
DBH [cm]	Diameter at breast height
Number of shrub species	Number of shrub species and/or young trees (<20 cm diameter at breast height) growing within circle (radius 30 m)
Shrub cover [%]	% shrub cover in eleven categories: 0 – 0%; 10 – 1-10%; 20 – 11-20%; 30 – 21-30%; 40 – 31-40%; 50 – 51-60%, 60 – 61-70%, 70 – 71-80%, 80 – 81-90%, 90 – 91-99%, 100 – 100% within circle (radius 30 m)
Herb cover [%]	% herb cover in eleven categories: 0 – 0%; 10 – 1-10%; 20 – 11-20%; 30 – 21-30%; 40 – 31-40%; 50 – 51-60%, 60 – 61-70%, 70 – 71-80%, 80 – 81-90%, 90 – 91-99%, 100 – 100% within circle (radius 30 m)
Herb height [cm]	Mean height of herb vegetation at 5 places chosen randomly within circle (radius 30 m)

Table 2.
Habitat parameters at the listening/observations points in relation to distance from the railway (A-points – 30 m, B-points – 280 m, C-points – 530 m). All data showed as median. Data were tested by Kruskal-Wallis test

Variable	A-points	B-points	C-points	$H_{2, 45}$	*p*
Tree age	59	59	59	0.245	ns
Canopy cover	5	7	7	23.52	<0.001
Tree height [m]	14.5	15.9	15.2	1.275	ns
Number of tree species	2	1	1	9.26	<0.001
Number of deciduous trees	2	0	0	11.08	<0.005
Number of dead trees	4	1	2	2.35	ns
DBH [cm]	19.8	17.7	19.6	0.673	ns
Shrub cover	2	1	2	3.867	ns
Density of shrubs	115	40	120	3.28	ns
Herb cover	2	1	1	3.188	ns
Herb height [cm]	33	22.8	20	5.58	ns

ECOTONE. Noise was measured for five minutes at each point and the highest level during this time recorded.

DATA ANALYSIS. RDA, ANOVA and MANOVA were used for the statistical calculations for differentiating numbers of birds and species richness with respect to distance from the railway line, and the Kruskal-Wallis test served to differentiate the habitat parameters within the study plot. The computations were done in STATISTICA 12.0 (Statsoft Inc., 2014) and Canoco 4.0 (ter Braak and Smilauer, 1998). All these statistical analyses were described in detail in our earlier paper on the effect of railway noise on birds (Wiącek *et al.*, 2015a).

Results

NOISE LEVEL. The mean noise level during all the counts was 52.4 dB (range 36.6-85.0 dB; SD=10.14, n=135). The mean noise level was 58.1 dB (range 39.9-85.0 dB; SD=11.45, n=45) along the first row of listening points (A), closest to the railway tracks; it was 51.27 dB (range 36.6-69.8 dB; SD=9.04, n=45) along the second row (B), and 47.74 dB (range 37.7-66.1; SD=6.61, n=45) along row C, the farthest from the tracks deep in the forest. The differences in noise level between the consecutive rows ABC were statistically significant (ANOVA; $F_{(2.132)}$=14.567; p<0.001). Statistically significant differences in noise levels were found between points in row A and row B (Tukey test p<0.005), as well as between row A and row C (Tukey test p<0.0001). We also found statistically significant differences in noise intensity during counts along each row of points (ABC) for April (ANOVA; $F_{(2.42)}$=6.30; p<0.005) and May (ANOVA; $F_{(2.42)}$=11.1; p<0.001), but not for June (ANOVA; $F_{(2.42)}$=2.41; p=0.1; Fig. 2). Statistically significant differences in noise levels were found in April between row A and row C (Tukey test p<0.005). A similar relationship was also found in May between lines A and B (Tukey test p<0.05) and A and C (Tukey test p<0.005).

NUMBERS OF INDIVIDUALS. A total of 806 birds from 39 species were counted (Table 3). The most frequent species in all rows (A,B,C) was Chaffinch *Fringilla coelebs* L. 1758 (316 ind., 39.8% of the bird assemblage); the dominant species also included Great Tit *Parus major* L. 1758 (69 ind., 8.7%). Numbers of the other species did not exceed 5% of the total assemblage. The numbers of the most numerous birds (more than 10 in the assemblage) did not differ significantly with respect to distance from the railway tracks (Monte Carlo test of the significance of the first

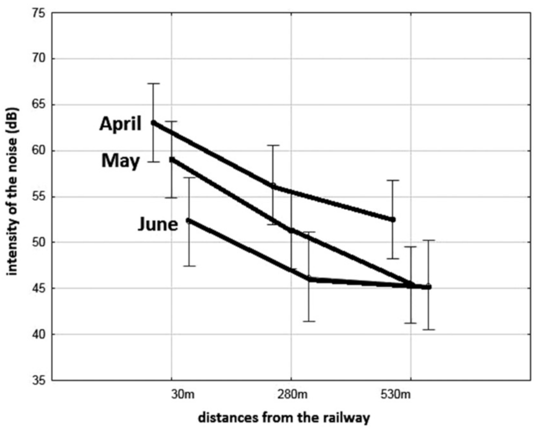

Fig. 2.
Intensity of the railway traffic noise (dB) at the listening/observations points in different distances from the railway in April, May and June

axis; F ratio = 2.1, *p*=0.09; Monte Carlo test of the significance of all axes; F ratio = 1.47, *p*=0.08). The mean number of birds per listening point in April was 6.2 (range 3-13, SD=2.0, n=45), in May it was 5.8 (range 2-11, SD=2.1, n=45) and in June it was 5.7 (range 2-17, SD=2.8, n=45). No significant differences were found in the numbers of birds between the months (ANOVA; $F_{(2.132)}=0.49$; $p=0.6$). An average of 19.1 (range 12-32; SD=4.9, n=45) birds were recorded on row A, 18.1 (range 11-37; SD=6.8, n=45) on row B, and 15.7 (range 10-26; SD=4.1, n=45) on row C. The number of birds per listening point was independent of distance from the railway line (ANOVA; $F_{(2.42)}=1.53$; $p=0.22$). None of the 11 habitat parameters were demonstrated to have affected the numbers of individuals of birds at the listening points (Multiple regression analyses, $p>0.49$).

Number of species. There was an average of 9.4 species on the first row of points (A) (range 6-12; SD=1.6, n=45), 8.1 on row B (range 4-17; SD=3.7, n=45) and 8.3 on row C (range 5-14; SD=2.5, n=45). There were no significant differences between the numbers of species at the listening points on each row (ABC) (ANOVA; $F_{(2.42)}=0.97$; $p=0.38$). The mean number of species per point in April was 4.5 (range 2-8; SD=1.4, n=45), the figure for May was 3.9 (range 1-7; SD=1.8, n=45) and that for June was 3.7 (range 1-9; SD=1.8, n=45). The mean numbers of species counted in the successive months did not differ significantly from one another (ANOVA; $F_{(2.132)}=2.48$; $p=0.087$), and neither were any of the 11 habitat parameters shown to influence the bird species richness at the listening points (Multiple regression analyses, $p>0.31$).

Guilds. We found no significant differences in the proportion of insectivorous (30 species) and granivorous species (6 species) with respect to distance from the tracks (MANOVA; $F_{(4.82)}=1.75$; $p=0.14$; Fig. 3). The most abundant species among the granivorous was the Chaffinch (316 individuals). On the other hand, the most numerous insectivorous species was the Great Tit (69 individuals). Likewise, there were no significant differences between the proportions of the three nesting guilds (14 species nesting near the ground, 13 nesting high in the trees and 12 species nesting in tree-holes) in their distribution with respect to the tracks (MANOVA; $F_{(6.80)}=1.12$; $p=0.35$; Fig. 4). The most numerous low nesting species was Eurasian Blackcup *Sylvia atricapilla* (L.) (34 ind.), most abundant hole nester was Great Tit (69 ind.) and Chaffinch (316 ind.) as high nesting species. Two species like Common Cuckoo *Cuculus canorus* L. (13 ind.) and Wood Pigeon *Columba palumbus* L. (5 ind.) with low-frequency vocalisations avoided the neighbourhood of the railway line, whereas those with high- and medium-band frequency vocalisations (19 and 18 species,

Table 3.

Woodland bird community composition in different distances from the railway (A-points – 30 m, B-points – 280 m, C-points – 530 m) in eastern Poland. The birds classification due to nesting, foraging and bioacoustics guilds: H – Hole-nesters, Hn – High nesters, Ln – Low nesters; R – Raptorial, G – Granivorous-insectivorous; I – Insectivorous; Hf – High frequency singers, Mf – Medium frequency singers, Lf – Low frequency singers. The percentages shown in parentheses

Species	Guilds	Total number	Number of individuals		
			A-points (n=15)	B-points (n=15)	C-points (n=15)
Fringilla coelebs L.	Hn, G, Hf	316 (39,8)	102	117	97
Parus major L.	H, I, Hf	69 (8,7)	31	26	12
Periparus ater L.	H, I, Hf	38 (4,8)	9	15	14
Sylvia atricapilla L.	Ln, I, Mf	34 (4,1)	16	7	11
Erithacus rubecula L.	Ln, I, Hf	33 (4,1)	11	12	10
Lophophanes cristatus L.	H, I, Hf	28 (3,5)	12	10	6
Anthus trivialis L.	Ln, I, Hf	24 (3,0)	3	17	4
P. phoenicurus L.	H, I, Mf	23 (2,9)	13	4	6
Garrulus glandarius L.	Hn, G, Mf	20 (2,5)	6	4	10
Dendrocopos major L.	H, G, Mf	20 (2,5)	6	7	7
Lulla arborea L.	Ln, I, Mf	20 (2,5)	7	5	8
C. coccothraustes L.	Hn, G, Mf	19 (2,5)	7	8	4
Turdus merula L.	Hn, I, Hf	18 (2,3)	9	2	7
Phylloscopus trochilus L.	Ln, I, Hf	14 (1,8)	9	1	4
Cuculus canorus L.	Ln, I, Lf	13 (1,6)	2	5	6
Poecile montanus Conrad	H, I, Hf	12 (1,5)	5	3	4
Phylloscopus collybita Vieillot	Ln, I, Mf	11 (1,4)	7	3	1
Oriolus oriolus L.	Hn, I, Mf	11 (1,4)	2	4	5
Muscicapa striata Pallas	H, I, Hf	8 (1,0)	3	5	0
Corvus corax L.	Hn, R, Mf	8 (1,0)	2	3	3
Turdus viscivorus L.	Hn, G, Mf	8 (1,0)	2	3	3
Emberiza citrinella L.	Ln, I, Hf	7 (0,9)	7	0	0
Rhadina sibilatrix Bechstein	Ln, I, Hf	6 (0,7)	1	1	4
Columba palumbus L.	Hn, G, Lf	5 (0,5)	2	3	0
Dryocopus martius L.	H, I, Mf	5 (0,6)	3	1	1
Turdus philomelos C.L. Brehm	Hn, I, Mf	4 (0,5)	0	2	2
Cyanistes caeruleus L.	H, I, Hf	4 (0,5)	2	2	0
Ficedula hypoleuca Pallas	H, I, Hf	3 (0,4)	0	0	3
Buteo buteo L.	Hn, R, Hf	3 (0,4)	2	1	0
Troglodytes troglodytes L.	Ln, I, Hf	2 (0,3)	0	1	1
Prunella modularis L.	Ln, I, Mf	2 (0,3)	1	0	1
Sylvia communis Latham.	Ln, I, Hf	1 (0,1)	1	0	0
Regulus regulus L.	Hn, I, Hf	1 (0,1)	0	0	1
Hippolais icterina Vieillot	Hn, I, Mf	1 (0,1)	0	1	0
Phoenicurus ochruros S.G. Gmelin	H, I, Hf	1 (0,1)	1	0	0
Accipiter nisus L.	Hn, R, Mf	1 (0,1)	1	0	0
Sturnus vulgaris L.	H, I, Mf	1 (0,1)	1	0	0
Lanius collurio L.	Ln, I, Mf	1 (0,1)	0	0	1
Caprimulgus europaeus L.	Ln, I, Mf	1 (0,1)	0	1	0
Total		806	286	274	246

respectively) were dominant near the tracks, a statistically significant dependence (MANOVA; $F_{(6.80)}=2.26$; $p<0.05$; Fig. 5). The most abundant species with high frequency vocalisation was Chaffinch (316 ind.), while the Eurasian Blackcup (34 ind.) was the most abundant species with medium band frequency vocalisation. Detailed data for all species are presented in Table 3.

Discussion

Most authors studying the effect of tarred roads on birds recorded a drop in their numbers and species richness near them (Reijnen and Foppen, 2006; Polak *et al.*, 2013; Wiącek *et al.*, 2015b;

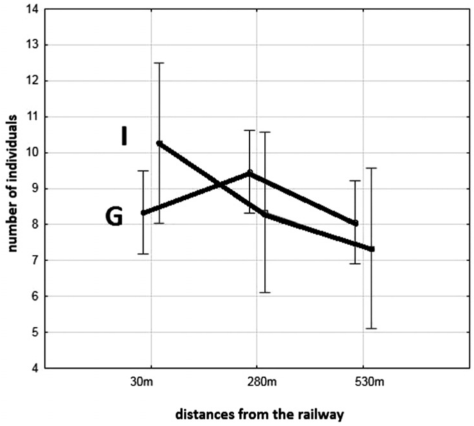

Fig. 3.

Foraging guilds (G – granivorous and I – insectivorous) as an average number of individuals from different guilds in relation to the distance from the tracks

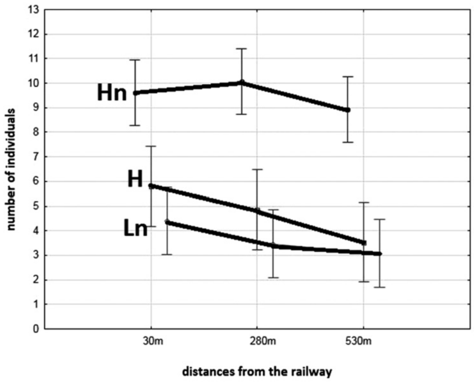

Fig. 4.

Nesting guilds (Hn – high nesters, H – hole nesters , Ln – low nesters) as an average number of individuals from different guilds in relation to the distance from the tracks

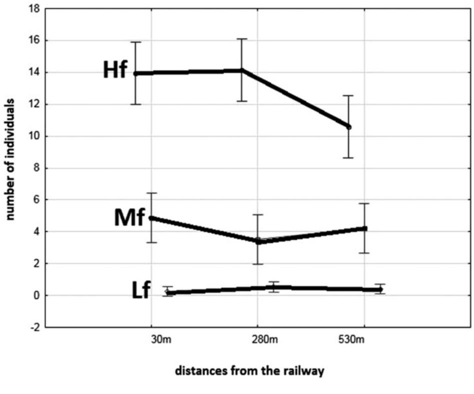

Fig. 5.

Bioacoustics guilds (Hf – high frequency singers, Mf – medium frequency and Lf – low frequency singers) as an average number of individuals from different guilds in relation to the distance from the tracks

Sacramento *et al.*,2022). In contrast, both negative (Waterman *et al.*, 2002; Zawadzka, 2015; Malo *et al.*, 2016) and positive (Li *et al.*, 2010; Morelli *et al.*, 2014; Wiącek *et al.*, 2015a,b) interactions between railway infrastructure and bird assemblages were found. However, the broad diversity of these interactions precludes drawing unequivocal inferences from the results of such research or from assessments of the scale of such disturbances to bird populations. In the context of anthropogenic disturbances, principally light and noise pollution, some recent papers on railway ecology (Borda de Agua *et al.*, 2017; Barrientos *et al.*, 2019) have underlined the impossibility of making such inferences regarding the effect of railway lines on animals. The present research provided a unique opportunity to compare the scale of birds' reactions to anthropogenic factors on the same study plot in similar phenological periods during the normal operation of a railway line (Wiącek *et al.*, 2015a,b) and again during its extensive reconstruction. The intensity of noise generated by this modernisation work was far lower than during the line's normal operation, when some 80 trains a day passed by (Wiącek *et al.*, 2015a,b). Even so, in both situations the highest noise levels were recorded at the trackside. The differences in noise levels between the rows of listening points (ABC) in both study seasons were statistically significant (Wiącek *et al.*, 2015a,b, this study). The more complex structure of the vegetation along the forest edge, with its large number of potential nesting sites and richer food resources, may be responsible for the greater species richness and numbers of animals inhabiting this zone of the forest (Delgado *et al.*, 2007). Indeed, the species richness of birds may be up to 40% greater at the edge of a forest than deep inside it (Helle, 1983). Similar numbers of birds were recorded at the listening points during the modernisation work and during normal railway operations (Wiącek *et al.*, 2015a,b); the species composition of the most numerous birds was likewise similar. Under the conditions created by the modernisation work, the dominant species exhibited no significant preferences with regard to the tracks, in stark contrast to the situation in 2014, when trains were running normally (Wiącek *et al.*, 2015a,b). The noise generated by the modernisation work had no adverse effect on the numbers of birds or on their distribution with respect to the tracks in the successive months of the study. We had found the same situation when railway traffic was normal: the numbers of birds on the rows of listening points were very similar (Wiącek *et al.*, 2015a,b). There were no evident differences between the effects elicited by train noise and that from the heavy equipment used in the modernisation work.

Quite different results were obtained for species richness along the three rows of listening points in 2014 and 2018. In 2014, when trains were running normally, the species richness of birds was distinctly higher close to the tracks than far inside the forest (Wiącek *et al.*, 2015a,b). During the reconstruction work in 2018 we failed to find any significant differences in species richness between the listening points along the three rows. The greater species richness recorded in 2014 was due to the edge effect: the mosaic of habitats at the edge of the forest, rich in food and with abundant nesting sites, attracted the birds there (Helle and Muona, 1985; Huhta *et al.*, 1999). This phenomenon, continually being studied (Barbaro *et al.*, 2012, 2014; Batary *et al.*, 2014), elicits a strong reaction on the part of birds, manifested by their occupation of niches at the edge of a patch of woodland that extends along existing transport corridors (Wiącek *et al.*, 2015a,b). The modernisation work in this corridor required the removal from it of shrubs and herbaceous vegetation, thus reducing their coverage. The partial destruction of the vegetation in this once rich habitat thus weakened the edge effect. It also increased the homogeneity of our study plot: in 2018 none of the habitat factors affected the numbers and species richness of birds, in contrast to the 2014 season, when herb coverage influenced both parameters (Wiącek *et al.*, 2015a,b).

The modernisation work also elicited changes in the reactions of birds from different ecological guilds. The present study showed that the proportions of the feeding and nesting guilds did not vary with respect to distance from the railway line. Only birds using low-frequency vocalisations as Wood Pigeon and Common Cuckoo avoided the neighbourhood of the line where heavy machinery was in use and lorries frequently passed by. The reaction of such birds is the same as in the case of tarred roads carrying heavy traffic (Francis *et al.*, 2011; Goodwin and Shriver, 2011; Polak *et al.*, 2013). The intensive lorry traffic moving back and forth along the line being modernised was similar to the unceasing movement of vehicles on busy roads. Consequently, it produced a linear, continuous source of noise, which adversely affects some sensitive bird species (Brumm, 2004; Halfwerk *et al.*, 2011). Such incessant noise disrupts vocal communication among birds, and leads to detrimental behavioural effects; some bird species thus avoid the neighbourhood of the road (Brumm and Slabbekoorn, 2005; Blickley *et al.*, 2012). Species that persist by transport arteries, in spite of the noise coming from them, communicate at higher frequencies or sing in the quieter gaps between passing vehicles (Brumm, 2004; Polak *et al.*, 2013). This stands in contrast with a railway line, where the periods between passing trains are quite long and the birds become accustomed to the rapidly moving, point source of noise that is a train (Wiącek *et al.*, 2015a,b).

Conclusions

This research has shown that the species diversity of birds in the zone immediately adjacent to a railway line was significantly smaller when the line was in the process of modernisation than during its normal operation. The destruction of a ca 50 m wide swath of trackside habitat evidently attenuated the edge effect along this section of the line. A consequence of this was the smaller number of species along the first row of listening points (A). The effects of other anthropogenic factors associated with construction works, such as the continuous, linear noise of machinery and vehicles or the presence of humans, are much the same as the influence of noise produced by heavy traffic moving along asphalt roads. As a result, both the numbers and the species richness of birds were distributed fairly evenly right across the study plot. We did not, however, record any distinct drop in numbers or species richness by the tracks where modernisation work was in progress, unlike what happens by motorways or expressways (Reijnen and Foppen, 2006).

Authors' contributions

J.W. – conceptualization, material collection, statistical analysis, writing – original draft preparation; M.P. – material collection, statistical analysis; M.F. – material collection.

Conflicts of interest

The author declare the absence of potential conflicts of interest.

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STRESZCZENIE

Wpływ rozwoju kolei i hałasu na ptaki leśne

Linie kolejowe oddziałują w różny, często przeciwstawny sposób na faunę i florę zajmującą siedliska bezpośrednio przylegające do torów. Budowa i rozbudowa infrastruktury kolejowej niszczy siedliska przyrodnicze lub znacząco je degraduje, co szczególnie wyraźnie widać w siedliskach leśnych. Linie kolejowe mogą wywoływać również pozytywne konsekwencje, gdyż przyczyniają się do powstawania na krawędzi lasu tzw. efektu brzegowego, który zwiększa bioróżnorodność fauny i flory. Tworzą się w ten sposób nowe nisze ekologiczne, które ptaki mogą zasiedlić i w różnoraki sposób wykorzystywać. W niniejszej pracy omówiono wyniki badań, które przeprowadzono podczas przebudowy ruchliwej linii kolejowej Lublin – Warszawa, przy całkowitym braku ruchu pociągów. Wyniki te dotyczą wpływu hałasu emitowanego przez maszyny budowlane oraz obecności ludzi na zespół ptaków leśnych zamieszkujących tereny przyległe do linii kolejowej. Ponieważ badania przeprowadzono na powierzchni badawczej, gdzie poprzednio wykonano obserwacje przy normalnym ruchu pociągów, można było porównać wyniki dwóch cykli badań przeprowadzonych przez ten sam zespół badawczy na tej samej powierzchni przy użyciu tej samej metodyki. W trakcie normalnej eksploatacji linii kolejowej (ok. 100 przejeżdżających pociągów na dobę), w warunkach dobrze wykształconej i urozmaiconej siedliskowo krawędzi lasu, stwierdzono wyraźne preferencje ptaków do zajmowania siedlisk w strefie brzegowej lasu (Wiącek i in. 2015). W obydwu cyklach badawczych ptaki liczono w 45 punktach nasłuchowo-obserwacyjnych (ryc. 1) zlokalizowanych w 3 odległościach od torów: 30, 280 i 530 m. W każdym punkcie mierzono poziom hałasu (ryc. 2) i oceniano parametry siedliska (tab. 1, 2). Podczas liczeń wykonanych w trakcie modernizacji linii kolejowej odnotowano łącznie 806 ptaków z 39 gatunków (tab. 3). Dominującymi gatunkami były zięba *Fringilla coelebs* L. (39,8% zgrupowania) i sikora bogatka *Parus major* L. (8,7% zgrupowania), pozostałe gatunki nie przekraczały 5% udziału w zgrupowaniu ptaków na terenie powierzchni badawczej. Najwyższe poziomy hałasu zarejestrowano wzdłuż przebudowywanej linii kolejowej, średnio 58,1 dB, w zakresie od 39,9 do 85,0 dB (SD=11,45, n=45; ryc. 2). Hałas emitowany przez ciężkie maszyny budowlane nie wpływał jednak na liczebność (ANOVA; $F_{(2.42)}$=1,53; p=0,22) ani różnorodność gatunkową (ANOVA; $F_{(2.132)}$=2.48; p=0,087) ptaków egzystujących w sąsiedztwie linii kolejowej. Dodatkowo żaden z 11 mierzonych czynników siedliskowych (tab. 2) nie wpływał na rozmieszczenie ptaków na badanej powierzchni

(p>0,31). W wyniku oddziaływania hałasu i przekształcenia siedliska leśnego na krawędzi korytarza transportowego, w którym prowadzone były prace budowlane, ptaki z gildii pokarmowych i gniazdowych nie wykazywały preferencji do zasiedlania sąsiedztwa torów czy obszarów położonych w głębi lasu (ryc. 3, 4). Nie stwierdzono różnic pomiędzy rozmieszczeniem ziarnojadów i ptaków owadożernych względem torów (MANOVA; $F_{(4.82)}$=1,75; p=0,14), tak samo jak w przypadku ptaków gnieżdżących się na różnych wysokościach (MANOVA; $F_{(6.80)}$=1,12; p=0,35). Natomiast w przypadku ptaków wykorzystujących w komunikacji głosowej między sobą różne częstotliwości stwierdzono, że te, które wykorzystują niskie częstotliwości (grzywacz *Columba palumbus* L. i kukułka *Cuculus canorus* L.), unikały sąsiedztwa torów, natomiast ptaki wykorzystujące średnie i wysokie częstotliwości chętnie zasiedlały siedliska przy torach (MANOVA; $F_{(6.80)}$=2,26; p<0,05). Usunięcie krzewów i roślinności zielnej z obu stron torów spowodowało pogorszenie warunków gniazdowania i żerowania oraz wyraźne osłabienie efektu brzegowego. Niemal ciągły ruch ciężkich pojazdów przemieszczających się wzdłuż placu budowy wytwarzał ciągłe liniowe źródło hałasu, podobne do hałasu wytwarzanego przez pojazdy na ruchliwej drodze asfaltowej. W rezultacie ptaki były bardziej dotknięte hałasem, efekt krawędziowy był słabszy, a rozmieszczenie ptaków bardziej równomierne w porównaniu z sytuacją, gdy pociągi kursowały normalnie. Liniowe źródło hałasu, jakim był hałas emitowany przez maszyny budowlane, samochody ciężarowe i penetrację człowieka, okazał się czynnikiem znacznie bardziej szkodliwym dla ptaków w porównaniu z punktowym i szybko przemieszczającym się źródłem hałasu, jakim jest przejeżdżający pociąg. Dodatkowym bardzo ważnym czynnikiem było usunięcie części roślinności z krawędzi lasu, co zniszczyło lub zubożyło siedliska przyrodnicze i doprowadziło do spadku liczebności i różnorodności gatunkowej ptaków na skraju lasu.