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Roadside hedgerows and trees as factors increasing road mortality of birds: Implications for management of roadside vegetation in rural landscapes

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ABSTRACT

The 26-month study was carried out in 2001–2003 on a network of 15 roads (48.8 km) with different traffic volumes (350–10,500 cars day^{-1}) and varying structure of the surrounding landscape in farmland of south-western Poland. A total of 862 road-killed birds were recorded. The most abundant group was made up by urban species (50.2%), followed by hedgerow specialists (30.3%), woodland birds (7.7%) and those associated with open areas (3.8%). The total shares of the three most numerous victim species (*Passer domesticus*, *Passer montanus* and *Hirundo rustica*) amounted to 79.3%. The mean (±1 S.E.) yearly number of casualties per 100 m of road calculated for 15 roads reached 0.91 ± 0.20 for all groups, 0.44 ± 0.14 for urban birds, 0.28 ± 0.07 for hedgerow specialists, 0.06 ± 0.02 for woodland species and 0.03 ± 0.01 for birds of open areas. For the three commonest species the values were as follows: *P. domesticus* 0.40 ± 1.37, *H. rustica* 0.07 ± 0.03 and *P. montanus* 0.13 ± 0.05. A disproportionately high mortality was recorded near tree belts, hedgerows and built-up areas, while it was much lower in open farmland. Traffic volume had a clear negative impact on the mortality of *P. domesticus* and woodland species. In order to limit the losses among birds due to vehicle traffic the spontaneous bushy vegetation should be removed from the immediate road vicinity. New hedgerows should be made "safe" for wildlife by planting them further away from the roads, i.e., along dirt roads, watercourses and ditches.

1. Introduction

The decline of farmland birdlife has become nowadays a major concern in many European countries (Tucker and Heath, 1994; Hagemeijer and Blair, 1997; Donald et al., 2006). The most quoted threats include land-use changes, massive introduction of winter cereals (Chamberlain and Fuller, 2000), shrinking food supply due to widespread use of pesticides (Robinson and Sutherland, 2002), abandonment of traditional livestock rearing and destruction of non-crop landscape elements (Gillings and Fuller, 1998; review in Schifferli, 2001). The vehicle traffic with its negative consequences has not made it into this list, although it was estimated as early as in 1960s that 13% of the English population of house sparrow *Passer domesticus* died on roads every year (Hodson and Snow, 1965). Some more recent studies point to the road accidents as a main cause of mortality among the declining European populations of owls in rural areas, e.g. barn owl *Tyto alba* (Fajardo, 2001; Meek et al., 2003; Ramsden, 2003) and little owl *Athene noctua* (Hernandez, 1988). It seems however that at the time of a dramatic increase of the vehicle traffic in Europe much more attention should be paid to the assessment of potential threats for birds due to this phenomenon (Fajardo, 2001; Erritzoe et al., 2003). The traffic volume and the vehicle speed are seen as the main factors affecting the overall wildlife mortality level (Underhill and Angold, 2000; Erritzoe et al., 2003). Over the last 40 years the number of cars in Poland has grown over 15-fold (from 600,000 to 9 million; Central Statistical Office, 2005), while in the UK over 20-fold (from 1.6 million to nearly 33 million; data of the UK Department of Transport).

The analysis of papers devoted to the bird mortality on European roads in the last few decades has revealed the shortage of studies dealing with relations between habitat characteristics, large scale (landscape scale) road parameters (e.g. traffic volume, presence of hedgerows and trees) and the level of avian losses (Erritzoe et al., 2003). Most research of bird road mortality was carried out several decades ago when the traffic intensity was incomparably lower. In addition, a large number of studies covered very short road stretches with identical traffic volume, and the results were confined mainly to the lists of victim species and numbers (review in Erritzoe et al., 2003).

Recently published study on the barn swallow *Hirundo rustica* road mortality (a sharply declining species in western Europe;

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Turner, 1994; Møller and Vansteenwegen, 1997) conducted on 20 rural roads in south western Poland showed that the level of losses in this species was positively correlated with the number of reared livestock and the length of roadside tree belts and hedgerows (Orłowski, 2005). A very rough estimate of the yearly swallow mortality on Polish roads points to around 180,000 individuals (Orłowski, 2005), which is much more than its entire breeding populations in some western European countries (compare data in Turner, 1994). It must be also emphasized that midfield hedgerows and trees constitute an inextricable element of European countryside, shaped within the framework of farming activities (Le Cour et al., 2002; Marshall and Moonen, 2002), and large part of these biotopes is situated on roadsides, providing essential refuges for farmland birds and other wildlife (Laursen, 1981; Paruk, 1990; Munguira and Thomas, 1992; Meunier et al., 1999). Currently more and more new hedgerows are planted as a part of the agri-environmental schemes, creating optimal habitats for many declining bird species (Gillings and Fuller, 1998; Vickery et al., 2004).

Many papers suggest different ideas of preventing roadkills among birds (review in Erritzoe et al., 2003). Some of them include planting of thorny hedges and rows of closely spaced tall trees (>3 m) as well as construction of embankments to force birds to fly higher (Institut für Naturschutz and Tierökologie, 1977; Pons, 2000). Other authors recommend creation of special perches for birds near roads (Hernandez, 1988) and even the removal of all trees and hedges growing along verges, although the latter solution is a controversial proposal (Erritzoe et al., 2003). On the other hand, Baudvin (2004) and Ramsden (2003) claim that, for the sake of birds of prey and owls' conservation, the open verges and regularly mown grasslands located near roads should be allowed to overgrow with permanent shrubby vegetation. Such a change of habitat would decrease the availability of rodents and subsequently discourage predators from hunting near roads (Baudvin, 2004). However, most of the quoted papers dealt only with casualties of only one species, or a group of species with specific ecological requirements (mainly owls and some raptors). Undoubtedly the roadside vegetation is used by birds as an attractive breeding, foraging or resting zone (Paruk, 1990; Meunier et al., 1999; Erritzoe et al., 2003) but its presence may act as an ecological trap with lethal consequences.

The aim of the present study is to assess the scale of bird mortality on a road network with different traffic volume and landscape structure situated in an intensively used agricultural region of south-western Poland. The paper contains an analysis of relationships between road habitat features (presence of hedgerows, tree belts, built-up areas and open countryside; traffic volume) and the number of bird roadkills. The obtained results have helped to formulate the recommendations for shaping woody vegetation on road verges with the objective of bringing down the mortality level of birds in rural areas.

2. Material and methods

The survey was carried out on a 48.8 km road network (15 roads) with different traffic volumes (Fig. 1), situated in south-western Poland (the Lower Silesia region), south of Wrocław city. The study area (51°02′N, 17°03′E; *ca.* 55 km^2) has one of the lowest forest cover indices in Poland, barely 1.6%. The dominant land use form is arable, covering *ca.* 92% of the area. In 2000 the most widespread crops were wheat (50%), oil-seed rape (25%), root crops (10%) and maize (8%). The rest (5.5%) was made up of villages and communication routes. The level of traffic volume was obtained from the data of General Management of Public Roads in Wrocław and Wroclaw District Council for the year 2000. The highest traffic volume was on a section of the national road Wrocław-Opole (10,500 cars day^{-1}, Fig. 1). On more than half of the studied roads the average daily traffic volume was many times lower (350–470 cars day^{-1}). All studied roads are asphalt-covered, 6–9 m wide, with the verge width ranging from 1 to 3 m.

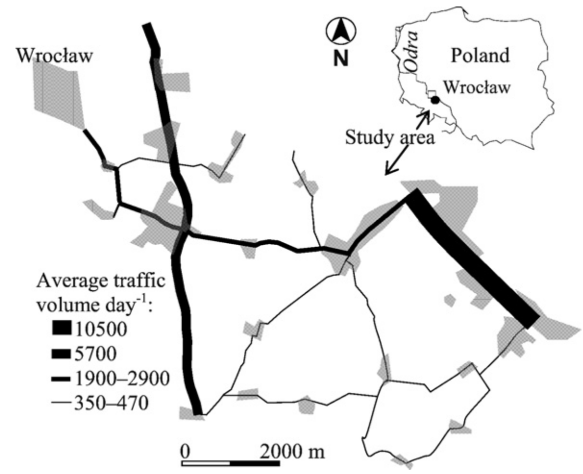

Fig. 1. Road network (48.8 km) with different traffic volumes in the agricultural landscape of south-western Poland surveyed in 2001–2003. Grey colour denotes built-up areas. Traffic volume = number of vehicles day^{-1}.

Detailed calculations of lengths of particular biotopes adjacent to the studied roads were made with the help of ordnance survey maps and direct field measurements. Four habitat types were specified: (1) built-up areas, (2) tree belts, (3) hedgerows and (4) open countryside (Table 1). Tree belts and hedgerows were situated on one or both sides of the road up to *ca.* 20 m from its edge (see Appendix A). Tree belts were planted (up to *ca.* 30 m from roads) in rows (*Quercus robur*, *Tilia cordata*, *Robinia pseudoaccacia*, *Acer* spp. and *Populus* sp.), without undergrowth. Hedgerows were made up mainly by spontaneous bushy vegetation (*Prunus spinosa*, *Crataegus monogyna* and *Salix cinerea*) up to *ca.* 2.5 m high (located *ca.* 10–15 m from roads), growing along drainage ditches and cleared every few years (see Appendix A).

Killed birds were counted between 24 June 2001 and 18 August 2003. All roads were checked from the car, moving at 20 to 50 km h^{-1}. The surveys were made three times a week from the second half of March until the end of September and twice a week outside this period. The duration of a single visit depended on the roadkill number and weather conditions. It lasted normally from 1.5 to over 3 h. The counts were made usually in the afternoon, during dry weather. In order to avoid repeated counts of the same victims all killed animals and their remnants were removed from the road.

In order to characterize the bird fauna killed by road traffic a provisional division into four ecological groups was made, based mainly on habitat preferences in the breeding season: (1) birds of anthropogenic (urban) habitats, (2) woodland species (breeding in forests and woodlots), (3) hedgerow specialists (nesting and foraging along bushy vegetation), (4) birds of open biotopes (inhabiting crop fields, abandoned farmland, reedbeds, etc.). The barn swallow was treated as a hedgerow specialist, due to its clear preference of the woody vegetation edges as foraging sites (e.g. Evans et al., 2003). The collision places were put down on a special form, complete with the road number and adjacent habitat type (built-up area, hedgerow, tree belt or open farmland). Detailed habitat associations of particular bird species are presented in Table 2.

2.1. Statistical analysis

To assess the differences between the actual (recorded) and expected mortality levels on road sections with four adjacent habi-

Table 1
Characteristics of 15 road sections in agricultural landscape of south-western Poland surveyed in 2001–2003

Number of section	Traffic volume (cars day^{-1})	ength of section (m)	Share (%) of road in adjacent habitat				Number of roadkills	Number of roadkill bird species
			Built-up areas	Open countryside	Hedgerows	Tree belts		
1	10,500	3,750	66.7	3.3	0.0	30.0	102	20
2	5,700	8,350	24.0	50.9	1.2	23.9	225	26
3	1,900	2,400	8.3	77.1	6.3	8.3	88	11
4	2,900	2,050	73.2	17.1	4.9	4.8	49	6
5	2,100	5,150	40.8	35.9	3.9	19.4	172	21
6	470	2,500	60.0	20.0	8.0	12.0	13	6
7	350	3,450	24.6	49.3	11.6	14.5	18	7
8	350	1,400	0.0	71.4	7.1	21.5	4	3
9	350	5,550	19.8	64.0	5.4	10.8	64	15
10	350	3,450	24.6	53.6	7.2	14.6	14	9
11	350	2,850	3.5	86.0	3.5	7.0	22	9
12	350	2,300	21.7	58.7	13.1	6.5	42	12
13	350	2,150	27.9	37.2	11.6	23.3	31	8
13	350	1,050	85.7	14.3	0.0	0.0	13	6
15	350	2,400	10.4	72.9	8.3	8.4	5	3
	–	48,800	–	–	–	–	862	

tat types and different traffic volumes in compared seasons, the chi-square (χ^2) goodness-of-fit analysis was used. The expected values were calculated on the base of the length of particular road sections and the even roadkill distribution in the compared periods. In some statistical analyses a roadkill index was used, standing for the victim number per 100 m of road. The differences in average roadkill indexes and shares of the four ecological bird groups were calculated with one-way ANOVA and Mann–Whitney tests. The relationships between the habitat features of roads and the roadkill number were tested with the Pearson's linear correlation coefficient. The variable called 'traffic volume' was subjected to logarithmic transformation based on the equation: $x = \log(x' + 1)$. The other variables had a normal distribution (Kolmogorov–Smirnov test, $p > 0.2$). Results with probability $p \leq 0.05$ were treated as statistically significant. The statistical analysis of the collected material was carried out with the use of Statistica 5 and Excel software.

3. Results

3.1. Species composition and seasonal distribution of roadkills

A total of 862 killed birds, belonging to 49 species, were recorded in over 2 years of study (Table 2). The most abundant group, among 765 victims whose species was identified, were urban birds (50.2%, $n = 384$), followed by hedgerow specialists (38.3%, $n = 293$), woodland species (7.7%, $n = 59$) and those associated with open habitats (3.8%, $n = 29$). Three most numerous species (*P. domesticus*, *Passer montanus* and *H. rustica*) accounted for 79.3% ($n = 607$) of the total number of roadkills.

The number of victims increased clearly in spring months, peaking in July/August (Fig. 2) which coincided with the appearance of young birds. July and August saw as many as 57.7% of all roadkills recorded throughout the year (chi-square test, $\chi^2 = 543.3$, d.f. = 1, $p < 0.0001$). Among 508 roadkills with known age 59.5% ($n = 302$) were juveniles, while immatures accounted for 3.9% ($n = 20$), and adults for 36.6% ($n = 186$). Young birds (1st calendar year) usually made up a large majority of all victims in particular species: *P. domesticus* (66%, 161; among 245 with known age), *H. rustica* (66%, 44; among 67 with known age), *P. montanus* (73%, 50; among 68 with known age), *Lanius collurio* (80%, 8; among 10 with known age) and *Sylvia communis* (75%, 6; among 8 with known age). The exceptions were *Carduelis carduelis* (67%, 14 adults among 21 roadkills) and *Fringilla coelebs* (67%, 6 adults among 9 roadkills). The share of juveniles among roadkills increased markedly as the breeding season progressed (chi-square test, $\chi^2 = 39.9$, d.f. = 5, $p < 0.0001$) starting from 0% in April (in this month all 15 roadkills with known age were adults), then rising steadily to 17% in May (among 53 roadkills with known age), 50% in June (among 48 roadkills with known age), 63% in July (among 160 roadkills with known age), to reach 82% in August (among 144 roadkills with known age), and 81% in September (among 58 roadkills with known age).

3.2. Factors affecting road mortality of birds

Among the independent variables describing habitat differentiation of roads (see Table 1), statistically significant relationships were found only between two pairs of variables, i.e., traffic volume × share (%) of hedgerows (Pearson's correlation coefficient, $r = -0.593$, $p = 0.020$, $n = 15$) and share of open countryside × share of built-up areas ($r = -0.942$, $p < 0.0001$, $n = 15$). On the roads with low traffic volume (350–470 cars day^{-1}) the average share of sections with hedgerows was statistically significantly higher than on those with moderate/high traffic volume (1900–10,500 cars day^{-1}) (7.6% vs. 3.2%; Mann–Whitney test, $U = 8.50$, $p = 0.043$). The share of roads with tree belts did not differ on both road types (Mann–Whitney test, $U = 1.50$, $p = 0.36$).

During the entire study period the mean (±1 S.E.) victim number of the four ecological groups of birds on 15 studied road sections was highest for urban birds (0.69 ± 0.17 roadkills 100 m^{-1} of road), and lowest for open habitat species (0.06 ± 0.01 roadkills 100 m^{-1} of road). The differences in the mean roadkill indexes of the four ecological groups varied significantly both in the whole period (one-way ANOVA, $F_{3,56} = 9.37$, $p < 0.0001$), as well as in 2002, when found 61.7% ($n = 532$) of all roadkills (one-way ANOVA,

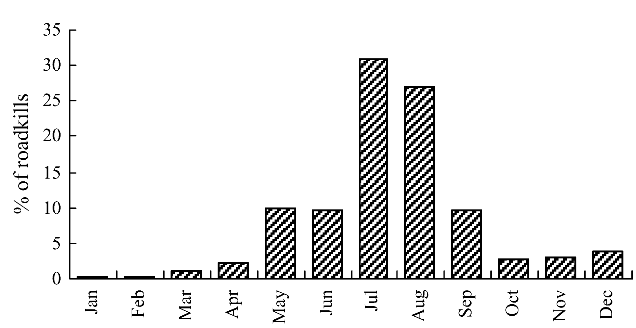

Fig. 2. Comparison of monthly distribution (in %) of bird roadkills ($n = 532$) on the road network (48.8 km) in south-western Poland during one survey year (2002).

Table 2
Seasonal distribution of bird roadkills on 48.8 km road network in agricultural landscape of Lower Silesia between June 2001 and August 2003

Species (ecological group)[a]	Number of roadkills				All casualties of given species	Habitat associations[b]			
	Spring (22 March–21 June)	Summer (22 June–22 September)	Autumn (23 September–21 December)	Winter (22 December–21 March)		Hedge	Trees	Open	Urban
Passer domesticus (S)	59	245	30	8	342			+	+
Hirundo rustica (H)	6	87	7		100	+	+		+
Passer montanus (H)	9	80	9	1	99		+	+	
P. domesticus/montanus	11	52	3		66				
Small unident. passerines	4	24	2		30				
Carduelis carduelis (H)	10	11			21	+	+	+	
Streptopelia decaocto (S)	1	5	12		18			+	+
Columba livia (S)	5	8	2		15				+
Carduelis chloris (H)		6	5	2	13		+		
Sylvia communis (H)	6	7			13	+		+	
Turdus merula (H)	6	5		2	13	+	+		+
Lanius collurio (H)	1	10			11	+			
Acrocephalus palustris (H)	6	4			10	+		+	
Parus major (W)		2	7	1	10		+		+
Carduelis cannabina (H)	1	8			9		+	+	
Fringilla coelebs (H)	6	3			9		+		+
Motacilla flava (A)	1	7			8			+	
Sylvia atricapilla (W)	5	2			7		+		+
Phasianus colchicus (A)		4	1		5	+		+	
Phoenicurus ochruros (S)	1	4			5				+
Sturnus vulgaris (W)	1	4			5		+	+	+
Alauda arvensis (A)	3			1	4			+	
Erithacus rubecula (W)	2		2		4		+		
Emberiza citrinella (H)	2	1			3	+		+	
Miliaria calandra (A)		2		1	3			+	
Parus caeruleus (W)			3		3		+		+
Serinus serinus (W)	1	2			3		+		
Hippolais icterina (W)	1	1			2		+		+
Luscinia megarhynchos (W)		2			2	+	+		
Muscicapa striata (W)		2			2		+		
Regulus regulus (W)			2		2		+		
Saxicola rubetra (A)	1	1			2			+	
Saxicola torquata (A)	1	1			2			+	
Turdus philomelos (W)	1	1			2		+		
Accipiter gentilis (W)		1			1		+		
Acroc. aurundinaceus (A)	1				1			+	
Acroc. schoenobaenus (A)		1			1			+	
Columba palumbus (W)		1			1		+		+
Corvus frugilegus (S)			1		1		+		+
Coturnix coturnix (A)			1		1			+	
Delichon urbica (S)		1			1				+
Emberiza hortulana (H)		1			1			+	
Lanius excubitor (H)		1			1	+			
Locustella naevia (A)		1			1			+	
Motacilla alba (S)		1			1				+
Oenanthe oenanthe (A)		1			1			+	
Phylloscopus collybita (W)		1			1		+		
Phylloscopus trochilus (W)		1			1		+		
Pica pica (S)		1			1	+			+
Sylvia curruca (W)		1			1	+			+
Sylvia sp.	1				1				
Troglodytes troglodytes (W)			1		1		+		
Turdus pilaris (W)		1			1		+		
Total number of roadkills	153	605	88	16	862				
Total number of species	25	42	14	7	50				

[a] Ecological groups: hedgerow specialists (H); woodland species (W); species characteristic for settlements (S); species using arable (A) and other open habitats (crop fields, abandoned farmland, reedbeds).

[b] Habitat associations: species nesting in or using hedgerows (Hedge) as feeding sites; species nesting in trees (Trees) or in woodland areas; species nesting or feeding in open (Open) habitats; species nesting in urban areas (Urban).

$F_{3,56} = 6.05$, $p = 0.0001$; Fig. 3). In 2002 the mean roadkill index on 15 roads amounted to 0.91 roadkills 100 m^{-1} of road (±0.20; min–max = 0.71–2.50; Fig. 3). In the case of the three most often killed species the mean roadkill indexes in 2002 were 0.40 roadkills 100 m^{-1} of road (min–max = 0–1.96) for *P. domesticus*, 0.07 roadkills 100 m^{-1} of road (min–max = 0–0.37) for *H. rustica* and 0.13 roadkills 100 m^{-1} of road (min–max = 0–0.83) for *P. montanus*.

Fig. 4 presents the actual losses in farmland birds on 15 studied road sections and the expected values calculated on the base of their length. Five sections with medium–highest traffic (1900–10,500 cars day^{-1}), that made up 44.5% of all checked roads were the scene of as many as 74% ($n = 636$) of all roadkill incidents. Number of victims on these roads exceeded by 166% the expected values (chi-square test, $\chi^2 = 124.5$, d.f. = 1, $p < 0.0001$).

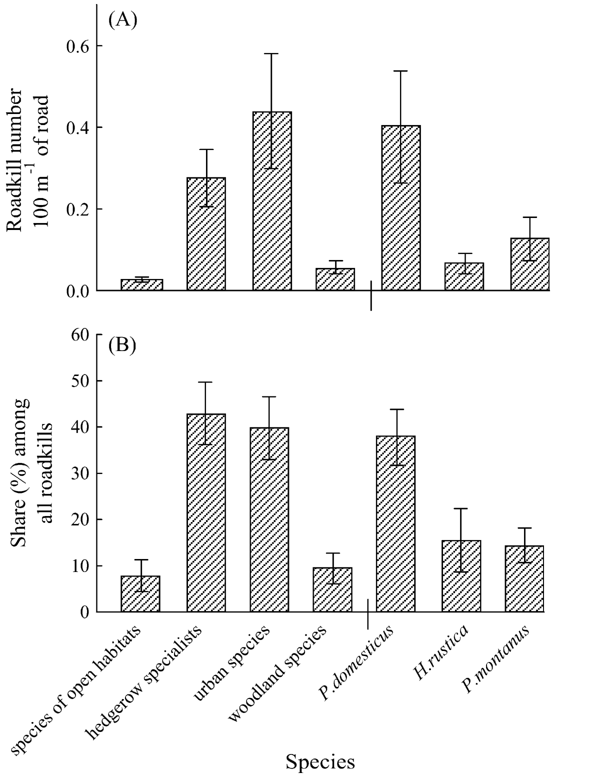

Fig. 3. The average (±1 S.E.) number (A) of bird roadkills 100 m^{-1} of road and share (B) of roadkills among all casualties on 15 road sections of Lower Silesia during the entire year of study (2002). Data for the four specified ecological groups and three most commonly killed species are presented.

The opposite relationship was recorded on roads with low traffic (350–470 cars day^{-1}), where total number of roadkills was 212% lower than the expected value (chi-square test, $\chi^2 = 180.4$, d.f. = 1, $p < 0.0001$). Similar results were obtained in the analysis of the recorded and expected level of avian mortality for 424 roadkills where species was identified (without *P. domesticus*, *Passer* sp. and unidentified passerines). On the five road sections with medium–highest traffic the recorded and expected victim number amounted respectively to 269 and 189 (chi-square test, $\chi^2 = 27.9$, d.f. = 1, $p < 0.0001$), while on roads with low traffic these values were 155 and 235 (chi-square test, $\chi^2 = 32.8$, d.f. = 1, $p < 0.0001$). In this group of birds the mean victim number 100 m^{-1} of road was also over two times higher on roads with medium–high traffic than on roads with low traffic (1.18 vs. 0.55 roadkills respectively per 100 m^{-1} of road), and the difference was statistically significant (Mann–Whitney test, $U = 6.00$, $Z = 2.33$, $p = 0.02$).

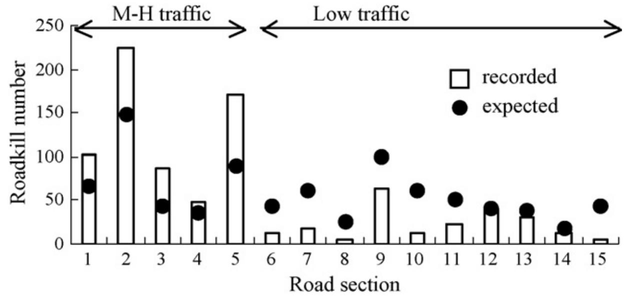

Fig. 4. Recorded and expected number of bird roadkills ($n = 862$) on 15 road sections with different traffic volumes in agricultural landscape of Lower Silesia; medium–highest (M–H) traffic (1900–10,500 cars day^{-1}), low traffic (350–470 cars day^{-1}). The expected mortality was calculated on the base of the length of particular roads. Road section numbers as in Table 1.

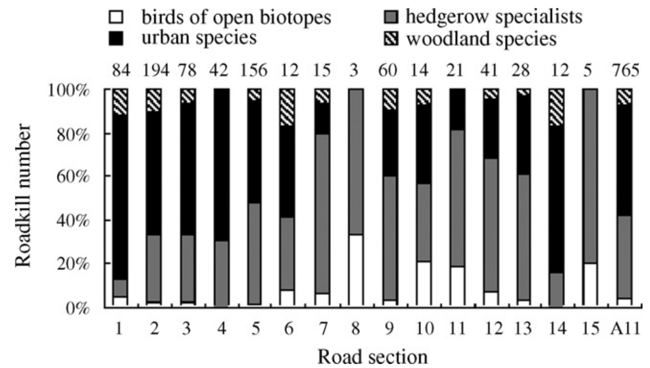

Fig. 5. The share (%) of four ecological groups of birds among roadkills on 15 surveyed roads in agricultural landscape of Lower Silesia. Numbers above bars refer to the roadkills on each road section.

The relative proportions of roadkills from the four specified ecological groups of birds on 15 studied road sections are presented in Fig. 5. Due to a very small number of victims on some sections (sections 8 and 15; compare data in Fig. 4) the testing of general differences in relative proportions of bird groups was given up. Under consideration of only five road sections with medium–highest traffic (sections 1–5) urban birds clearly dominated (57.9%, Fig. 4), while on the remaining 10 sections with low traffic (sections 6–15) their share among all roadkills was markedly lower (29.8%, chi-square test, $\chi^2 = 52.7$, d.f. = 1, $p < 0.0001$). On the contrary, the proportion of hedgerow specialists was visibly higher on low traffic roads (55.0%) than on those with medium–highest traffic (31.9%) (chi-square test, $\chi^2 = 14.31$, d.f. = 1, $p = 0.0002$). The shares of birds associated with open habitats also differed between the road sections (2.2%—medium–highest traffic vs. 8.1%—low traffic; $\chi^2 = 13.15$, d.f. = 1, $p = 0.0003$), while for woodland species they remained similar (7.9%—medium–highest traffic vs. 7.1%—low traffic; $\chi^2 = 0.13$, d.f. = 1, $p = 0.72$). A much more realistic picture of differences in proportions of the ecological groups emerges when the mean values obtained on 15 studied roads are taken into consideration (Fig. 3). In this case, just as with average roadkill indexes, some significant differences in the mean shares were noted, both for the whole study period (one-way ANOVA, $F_{3,56} = 21.00$, $p < 0.0001$), as well as for 2002 alone (one-way ANOVA, $F_{3,56} = 12.55$, $p < 0.0001$). However, other than in average roadkill indexes, the highest mean (±1 S.E.) share among roadkills was recorded for hedgerow specialists (46.0 ± 5.5%; Fig. 3).

The actual number of all birds killed on road sections with four adjacent habitat types (Fig. 6) diverged substantially from the expected values calculated on the base of their length (chi-square test, $\chi^2 = 224.3$, d.f. = 3, $p < 0.0001$). The roadkill number was noticeably higher near tree belts (by 46%, $\chi^2 = 14.7$, d.f. = 1, $p = 0.0001$), hedgerows (by 106%, $\chi^2 = 18.9$, d.f. = 1, $p < 0.0001$), built-up areas (by 37%, $\chi^2 = 23.6$, d.f. = 1, $p < 0.0001$), while in the open countryside the mortality was by 202% lower than expected ($\chi^2 = 99.9$, d.f. = 1, $p < 0.0001$). In addition, the large majority of species (except for *P. montanus*, *Columba livia* and *Motacilla flava*) showed a disproportionate distribution of collision spots in relation to the four adjacent habitat types (Fig. 6). The close associations with hedgerows were noted in *S. communis* (77% of all roadkills), *Turdus merula* (61%), *L. collurio* (91%) and *Acrocephalus palustris* (90%). The majority of *H. rustica* (61%), *Carduelis chloris* (69%) and *F. coelebs* (89%) victims were recorded near tree belts (see Appendix A) while most *P. domesticus* (66%) and *Streptopelia decaocto* (72%) died within built-up areas. Open countryside sections accounted for all roadkilled *M. flava*, and 45% of *P. montanus* (Fig. 6).

Table 3
Pearson's correlation coefficients between the number of bird roadkills and the features of the 15 road sections in agricultural landscape of south-western Poland

Roadkills data	Traffic volume	Length of					
		Road section	Built-up areas	Tree belts	Hedgerows	Tree belts and hedgerows	Crop fields
Number of *P. domesticus* roadkills	**0.86*****	**0.74****	**0.67****	**0.82*****	−0.33	**0.75****	0.40
Number of *P. domesticus* 100 m^{-1} of road	**0.83****	0.23	0.47	0.33	−0.44	0.24	−0.04
Number of *H. rustica* roadkills	0.23	**0.59***	0.42	0.44	0.21	0.28	0.30
Number of *H. rustica* 100 m^{-1} of road	0.15	−0.07	0.28	0.22	0.27	0.28	0.30
Number of *P. montanus* roadkills	0.50	**0.56***	0.18	**0.52***	−0.05	**0.51***	**0.54***
Number of *P. montanus* 100 m^{-1} of road	0.25	−0.01	−0.18	−0.08	0.02	−0.07	0.07
Number of roadkills of species of open habitats	0.37	**0.57***	0.23	**0.58***	−0.11	**0.55***	**0.50***
Species of open habitats 100 m^{-1} of road	−0.01	0.15	−0.26	0.01	−0.02	0.01	0.13
Number of roadkills of hedgerow specialists	0.43	**0.77****	0.46	**0.66****	0.12	**0.69****	**0.61***
Hedgerow specialists 100 m^{-1} of road	0.27	0.31	0.14	0.20	0.22	0.25	0.29
Number of roadkills of urban species	**0.87*****	**0.75****	**0.70****	**0.84*****	−0.34	**0.77****	0.39
Urban species 100 m^{-1} of road	**0.87*****	0.27	**0.55***	0.38	−0.47	0.27	−0.05
Number of roadkills of woodland species	**0.72****	**0.86*****	**0.68****	**0.92*****	−0.25	**0.87*****	**0.54***
Woodland species 100 m^{-1} of road	**0.68****	0.46	**0.61***	**0.58***	−0.42	0.49	0.11
Number of all roadkills	**0.77****	**0.82*****	**0.66****	**0.85*****	−0.20	**0.81*****	**0.51***
All roadkills 100 m^{-1} of road	**0.79*****	0.35	**0.50***	0.41	−0.30	0.35	0.08
Number of bird species	**0.70****	**0.85*****	**0.71****	**0.87*****	−0.13	**0.84*****	**0.51***

Asterisks denote the significance level; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. The statistically significant relationships are marked in bold.

The relationships between features of surveyed roads and roadkill indexes are presented in Table 3. In most cases the actual mortality level relationships differ markedly from the average roadkill indexes calculated per 100 m road. The recorded number of roadkills, both in three most often killed species, as well as in the four ecological groups, was much more closely correlated with the road characteristics. The highest obtained correlation coefficient, between the roadkill number of woodland species and length of tree belts ($r = 0.92$, $p < 0.0001$) certainly reflects habitat preferences of this group of birds. The lack of any significance of hedgerow length may come as a surprise, explained most likely by the small overall share (5.4%) of this habitat among all studied roads and also by the fact that the statistical analysis involved only 15 data points (roads with different proportions of adjacent habitats). The roadkill number of hedgerow specialists was however positively correlated with the total length of tree belts and hedgerows (more with the first of the mentioned habitats) and crop field borders, which hints at the general association of these birds with biotopes situated in the open countryside. Statistically significant positive correlation coefficients between the number of killed *P. montanus* and the length of roadside hedgerows, tree belts and crop field borders as well as the proportional distribution of collision places (Fig. 6) point to the use of all four specified midfield habitats by this species.

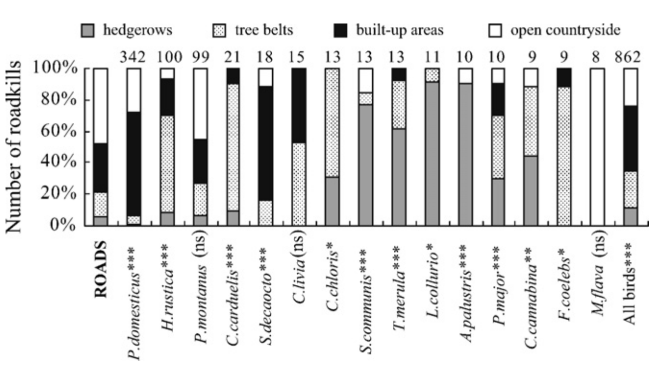

Fig. 6. Comparison of the number of killed bird species recorded on roads with four adjacent habitat types in agricultural landscape of Lower Silesia. The "ROADS" bar shows the overall proportions of biotopes bordering the studied roads (48.8 km). Values above the bars refer to the total number of roadkills of each species. Asterisks indicate differences (chi-square test) between recorded and expected values calculated on the base of the length of four adjacent habitat types: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; ns: not significant; for all cases the number of degrees of freedom is 3.

4. Discussion

The high mortality of *P. domesticus*, *P. montanus* and *H. rustica* in Lower Silesia is consistent with their widespread incidence among roadkills throughout Europe (Erritzoe et al., 2003). The markedly higher victim density near tree belts, hedgerows and within built-up areas, compared to the open countryside, is no surprise and for most species it confirms their close association with the occurrence of suitable biotopes. The presence of mature alleys encourages birds nesting in the canopy (e.g. *C. carduelis* or *F. coelebs*) or, as in the case of *H. rustica*, those finding abundant foraging places along hedgerows (Evans et al., 2003). In rural landscape *H. rustica*, *P. montanus* and other species from the group of hedgerow specialists (*S. communis*, *L. collurio*, *T. merula* and *A. palustris*) use woody vegetation growing on crop field borders as the main feeding and nesting grounds (Evans et al., 2003; Field and Anderson, 2004), and because in many areas such habitats have survived mainly along the communication routes, these birds are particularly vulnerable to the collisions with vehicles.

Results of this study may seem to contradict conclusions from other papers saying that the presence of high hedgerows, trees and embankments encourages birds to fly higher and avoid getting hit (review in Erritzoe et al., 2003). Hodson (1962) found the highest number of roadkilled birds near gaps in hedgerows, but not in hedgerows themselves. Mortality of owls was lower on road sections with available high (>2 m) perches (Hernandez, 1988; Ramsden, 2003). Pons (2000) found that relative probability of bird collision was highest on the road sections without or with lower (<1.5 m) rocky embankment. On sections with high embankment (>3 m) the relative mortality of birds was up to three times lower (Pons, 2000). Probably these discrepancies are the consequence of different vegetation structure in the study area in Poland. In Lower Silesia hedgerows growing along roads were very short and in some cases actually made up of sparse single shrubs or trees. Undoubtedly the roadside presence of these isolated remnant habitats attracts birds, especially when such biotopes are the only ones of their kind available within a larger area of structurally impoverished farmland (see Appendix A). On the other hand, in places where roadside hedgerows form long compact belts, birds might indeed fly over them. However, when the shrubs are more spaced (i.e. there are gaps in hedgerows), birds may fly closer to the ground and therefore be more vulnerable to the collision. These findings seem to be in line with the thesis about "danger zones" defined as high mortality spots on road sections near habitat edges

(=ecotonal zones), where birds fly from one side of the road to the other (Institut für Naturschutz and Tierökologie, 1977; Erritzoe et al., 2003; see also below for further implications for road planning).

Probably one of the factors affecting the mortality level of particular species and groups of species is their inter-specific sensitivity to the traffic noise load, which affects the bird abundance in roadside habitats (e.g. Forman et al., 2002). Three commonest roadkills (*P. domesticus*, *P. montanus* and *H. rustica*) are ubiquitous, urbanized species adapted to heavy anthropogenic disturbances (discussed in Brotons and Herando, 2001). Another pattern can be traced in the differences between the mortality levels of species inhabiting woody habitats (hedgerow specialists and woodland species) and open biotopes. Woodland birds (which comprise also some species adapted to life within built-up areas, e.g. *Parus major*, *P. caeruleus*, *T. merula*, *F. coelebs*) show a visibly lower sensibility to the noise level than those typical for open habitats (Reijnen et al., 1995, 1996). Tiny percentage of the latter group (3.8%), coupled with the very high share of open habitats in overall length of studied roads (48.2%) and abundant occurrence of these birds on surrounding fields, indicates a clear avoidance of roads (except for *M. flava*, the most numerous victim in this group). It seems to confirm the earlier reports of substantial decreases in open habitat species around roads, proved, e.g. for *Alauda arvensis* but not for *M. flava* (Reijnen et al., 1996). It is also possible that the small number of roadkilled birds found in the open countryside may be related to the lower detectability of victims, which, at the time of collision, may be thrown further away from road, outside its verges (Slater, 2002).

Traffic volume, pointed as the main bird mortality factor, was correlated positively with the group of ubiquitous bird species breeding in built-up areas, especially with *P. domesticus*, declining in rural areas of Western Europe (Robinson et al., 2005). The clear differences in mortality are visible also in the comparison of victim number on roads with high–medium versus low traffic volume (see Fig. 4). Traffic volume should be therefore looked at much more carefully in further studies on bird population trends, as despite some already almost historical reports on its definitely negative impact (especially *P. domesticus*; see data compiled by Erritzoe et al., 2003), it is not currently mentioned among the main threats for the populations of declining bird species (e.g. for British population of *P. domesticus*; Robinson et al., 2005). The absence of statistically significant correlation coefficients between the traffic volume and mortality level in hedgerow specialists is most probably the result of the lack of statistical power of this algorithm, calculated for only 15 data points. The lower mortality of hedgerow specialists and birds of open biotopes on roads with medium–high traffic volume is also most probably associated with the small amount of hedges and, in the latter group, seems to reflect the markedly higher sensitivity to traffic noise on busy roads (discussed above). Undoubtedly the traffic volume on a single road section, measured in daily or seasonal time scale will affect substantially the wildlife mortality level (Lodé, 2000; Cooke and Sparks, 2004). The foreseeing of bird mortality level on a large spatial scale (apart from *P. domesticus*) on the base of traffic flow figures is more complex (apparently confirmed by the contradictory study results in literature; Erritzoe et al., 2003; see also Clevenger et al., 2003) and is more likely to be the cumulative effect of habitat preferences, inter-specific sensitivity to traffic noise, species abundance and character of adjacent habitat. Not all presented relationships can be however properly explained in the biological context—e.g. those between roadkill number of open habitat species and length of tree belts or between total roadkill number and length of crop field border. More likely, they seem to reflect the increasing diversity of adjacent habitats as the roads get longer. Similarly, the positive relationship between the number of killed bird species and traffic volume does not appear to be a result of increased use by birds of the biotopes bordering busy roads; it rather reflects the mathematical pattern of greater species diversity in a large roadkill sample from these road sections. Still, the obtained statistically significant positive relationships between the road length and victim number (for three most numerous species, all ecological groups and particular bird species) point undoubtedly to the lack of randomness in overall mortality level of birds, which can be predicted on the large scale, based on the very road length. Statistically significant relationships between traffic volume and mortality level in *P. domesticus*, woodland and urban species may be the reflection of their high abundance in villages, which in the study area are situated at the roads with medium–high traffic volume.

The high proportion of juveniles among roadkills (59.5%) was repeatedly mentioned before (review in Erritzoe et al., 2003) but it must be emphasized that in the case of birds restricted to human settlements (specific habitat islands within rural landscapes, e.g. for *P. domesticus* and *H. rustica*) the losses among juveniles and ensuing demographic consequences are likely to be much more profound than in the species dispersed in open countryside (e.g. Dunthorn and Errington, 1964). In the house sparrow these losses may be, however, compensated by the immigration of birds from urban areas (Robinson et al., 2005). Similarly, in the North American *Aphelocoma coerulescens*, significantly higher road mortality (both of adults and juveniles) was recorded among the individuals from territories adjacent to the roads (Mumme et al., 2000).

4.1. The limitation of avian road mortality by the proper management of roadside vegetation

At the time of rapid vehicle traffic increase with road infrastructure often lagging behind (evident particularly on rural roads in Europe; Jaarsma, 1997), the adequate management of roadsides in order to minimize wildlife losses seems to be the priority issue. Up till now the recommendations for roadside vegetation planning have concerned mainly the conservation of owls and some raptors (see references herein) and there is a lack of analogous general proposals for all species, especially small passerines. The current recommendations for shaping woodlots in rural areas have included planting alleys along communication routes as barriers against noise, pollution and dust (Institut für Naturschutz and Tierökologie, 1977; Zajączkowski et al., 1993; Jones et al., 2000; Bałazy, 2002). However, due to the high mortality of birds as well as butterflies (Munguira and Thomas, 1992) and many declining species of wild bees and bumblebees (Hirsch, 2000) on road sections with hedgerows, this direction of road planning requires further studies in relation to the actual levels of wildlife mortality. Following the above conclusions, any spontaneous bushy vegetation (being an attractive habitat for wildlife) should be removed from the immediate road vicinity. The hedge clearance during the breeding season is of course unacceptable and must be carried out at other time of the year. It must be also stressed that many of the existing roadside tree belts (e.g. monumental alleys) have a great ecological and historical value (Orłowski and Nowak, 2007) and in such cases they should be obviously spared. In return, to preserve the habitat diversity in rural areas, the “safe” woodlots (i.e. those located further away from communication routes, along dirt roads, watercourses and ditches) should be encouraged and protected. The research carried out so far proves also the very high bird mortality in places of perpendicular crossings of hedgerows with communication routes (Dunthorn and Errington, 1964; Institut für Naturschutz and Tierökologie, 1977; Lorek and Stankowski, 1991), which is one more argument for leaving treeless spaces along roads. The most adequate means of accident preven-

Fig. A.1. Two types of roadside woodlots with different vegetation structure. *Top photo*: tree belt (alley), one or two tree rows without hedge layer; in their proximity a high mortality of *Carduelis carduelis* (81% of all roadkills), *Fringilla coelebs* (89%) and *Hirundo rustica* (84%) was recorded. *Bottom photo*: hedgerow, spontaneous bushy vegetation growing along road verges and ditch slopes; places of increased mortality of *Lanius collurio* (90%), *Turdus merula* (61%), *Acrocephalus palustris* (90%), *Sylvia atricapilla* (57%) and *S. communis* (77%).

tion in built-up areas seems to be the installation of tall screens, which, apart from their main protective role, will force birds to fly higher, thus reducing the risk of collision with vehicles (Pons, 2000).

To round up it must be stressed that the wildlife mortality on rural roads certainly needs to be further investigated, including more detailed research into the scale of the phenomenon and habitat relationships as well as finding ways of reduction of the negative traffic impact on the environment. These should be subsequently implemented both in planning applications for new road schemes and in the management rules of existing roadside hedgerows and tree belts with the aim to reduce losses of wildlife in rural landscapes.

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Appendix A

See Fig. A.1.

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