POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	54	2	283–294	2006

Regular research paper

Grzegorz ORŁOWSKI*, Lech NOWAK

Department of Agricultural Bases for Environmental Management,
Agricultural University of Wrocław, Grunwaldzki sq. 24, 50-363 Wrocław, Poland;
*e-mail: orlog@poczta.onet.pl (*Corresponding author*)

FACTORS INFLUENCING MAMMAL ROADKILLS IN THE AGRICULTURAL LANDSCAPE OF SOUTH-WESTERN POLAND

ABSTRACT: The aim of the present study was to determine the yearly mortality level and identify the collision places of mammals on a road network with varying traffic volume, as well as to establish the main relations between habitat structure and the number of roadkills. During 26 months of survey on a 48.8 km road network (15 roads) with different traffic volumes (350–10500 cars per 24 h) situated in an agricultural landscape of SW Poland 383 killed mammals of 23 species were found. The most abundant group were small rodents (40%), with dominant common vole *Microtus arvalis* (26%) followed by insectivores (32%), topped by two species of hedgehogs *Erinaceus* spp. (20%). The average (± SD) road-kills index during the whole study period on 11 road sections with the lowest traffic volume (350–460 cars per 24 h) amounted to 0.29 ± 0.14 (range = 0.08–0.56) casualties per 100 m. This value was over seven times lower than on the section with the highest (10500 cars per 24 h) traffic volume (2.13 casualties per 100 m). Over 80% of victims were found between May and October. During the whole study period 38% of victims were recorded within built-up areas, where 26% of the studied roads were localized. The other 62% were found on the roads situated in the open farmland (74% of all roads). The clear majority of hedgehogs *Erinaceus* spp., weasels *Mustela nivalis*, brown rats *Rattus norvegicus*, beech martens *Martes foina* and red foxes *Vulpes vulpes* died within villages, while the animals killed on roads in the open farmland included all recorded common voles, moles *Talpa europaea* and common shrews *Sorex araneus*. The decisive factor affecting the mortality level in mammals in the multiple regression model was the daily vehicle traffic volume. This variable had significant, positive influence on the number of victims both within the most abundant species, their groups (insectivores, rodents, mustelids), as well as all mammals. The road location in the open countryside was an additional factor affecting the level of losses in rodents, while its presence in the built-up area increased the mortality of hedgehogs.

KEY WORDS: roadkills, road ecology, environmental factors, mammal habitats, rural areas

1. INTRODUCTION

The negative impact of roads on wild animals is associated mainly with the mortality caused by vehicle traffic and indirectly also with the increasing fragmentation of biotopes (Forman and Alexander 1998) resulting in the genetic isolation of populations (Gerlach and Musolf 2000). It is usually assumed that the road mortality does not affect critically the survival of populations of small mammals (Adams and Geis 1983, Bennet 1991), in many parts of the world, however, it is currently one of the main factors limiting the abundance of some medium-sized and large animals, especially in the areas with strong human impact (e.g. Clark *et al.* 1998, Huijser and Bergers 1998, Philcox *et al.* 1999, Saeki and Macdonald 2004). Although the road mortality has been the subject of research all over the world, there are few studies dealing with this issue in small and medium-sized mammals, embracing the yearly dynamic of roadkills and assessment of environmental factors affecting the mortality level (e.g. Clevenger *et al.* 2003). The large number of publications devoted to this last aspect dealt with large mammals, mainly ungulates (e.g. review in Groot and Hazebroek 1996, Finder *et al.* 1999, Malo *et al.* 2004, Seiler 2005).

The factors affecting road mortality of particular mammal species are very varied. The results of many studies suggest however that the overall level of mortality is connected mainly with traffic volume, speed of vehicles, landscape structure and field topography (Clevenger *et al.* 2003, Malo *et al.* 2004, Orłowski and Nowak 2004, Saeki and Macdonald 2004). The probability of collisions can also be associated with age or sex of individuals, time of the year and the tendency to migration (e.g. Clark *et al.* 1998, Finder *et al.* 1999, Philcox *et al.* 1999). In a highly transformed landscape roads and roadsides can be used as migration routes (Doncaster *et al.* 2001), speeding up the migration but simultaneously increasing the risk of accidents. In the agricultural landscapes overgrown roadside drainage ditches, accompanied by hedgerows, act as mid-field refuges providing shelter for small animals (Adams and Geis 1983, Bellamy *et al.* 2000, Maisonneuve and Rioux 2001).

Although many recent studies proved that small mammals avoid crossing the roads, even those with virtually no vehicle traffic (Mader 1984, Bąkowski and Kozakiewicz 1988, Merriam *et al.* 1989, Gerlach and Musolf 2000), this group of animals makes up a large proportion of all roadkills (e.g. Oxley *et al.* 1974, Fuellhaas *et al.* 1989, Bartoszewicz 1997, Clevenger *et al.* 2003). It may be supposed that the factor pushing up the mortality of some rodents in agricultural areas can be the seasonal increase in farming activities (Rolley and Lehman 1992), flushing the animals out onto the roads and causing the long-distance movements (Jacob and Hempel 2003).

In Poland and in other central European countries, in spite of a relatively dense road network, rising number of vehicles and ongoing expansion and modernisation of motorways (Jędrzejewski *et al.* 2004), the impact of roads and vehicle traffic on wildlife is still poorly recognized.

The aim of the present study was to determine the yearly mortality level and identify the collision places of mammals on a road network with varying traffic volume, located in an intensively farmed area of SW Poland, as well as to establish the main relations between habitat structure and the number of roadkills.

2. MATERIAL AND METHODS

2.1. Study area

The survey was carried out on a 48.8 km road network (15 roads) with different traffic volumes (Table 1), situated in the Lower Silesia region, south of Wrocław city (SW Poland). The study area (51°02'N, 17°03'E, ca. 55 km^2) has one of the lowest forest cover indices in Poland, reaching 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 study area is inhabited by ca. 8000 people. The traffic volume level was based on the data from Wroclaw department of the General Management of Public Roads and Wroclaw District Authority. The obtained data refer to the year 2000. The highest traffic volume was on the section of the national road Wrocław-Opole (10500 cars per 24h, Fig. 1). On more than half of the studied roads the average daily traffic volume was many times lower (350–470 vehicles per 24h). All studied roads are asphalt-covered, ca. 6 m wide. The proportion of sections crossing the built-up areas ranged on particular roads from 0 to 73.2% (mean ± SD = 31.2 ± 24.8; Table 1). On the roads with moderate/high traffic volume (1900–10500

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

No. of road section	Traffic volume (cars per 24 h)	Length of section (m)	% of total length of surveyed roads	% of road in		Number of roadkills	Number of roadkills per 100 m of road	Number of species of roadkilled mammals
				built-up area	open countryside			
1	10469	3750	7.7	66. 7	33.3	80	2.13	14
2	5684	8350	17.2	23.9	76.1	125	1.50	14
3	1938	2400	4.9	8.3	91.7	28	1.17	7
4	2897	2050	4.2	73.2	26.8	16	0.78	4
5	2106	5150	10.5	40.8	59.2	59	1.14	7
6	473	2500	5.1	60.0	40.0	5	0.20	2
7	350	3450	7.1	24.6	75.4	9	0.26	4
8	350	1400	2.9	0.0	100	7	0.50	4
9	350	5550	11.4	19.8	80.2	13	0.23	6
10	350	3450	7.1	24.6	75.4	11	0.32	8
11	350	2850	5.8	3.5	96.5	7	0.24	3
12	350	2300	4.7	21.7	78.3	13	0.56	7
13	350	2150	4.4	27.9	72.1	5	0.23	3
13	350	1050	2.1	71.4	28.6	3	0.29	2
15	350	2400	4.9	10.4	89.6	2	0.08	2
Total	–	48800	100	26.4	73.6	383	0.78	23

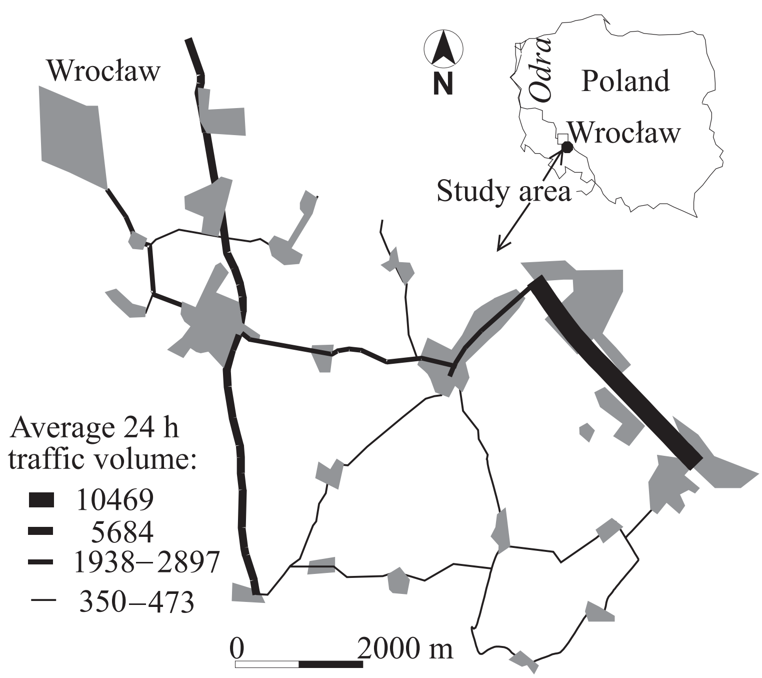

Fig. 1. Road network with different traffic volumes in the agricultural landscape of South-Western Poland surveyed in 2001–2003. Grey colour denotes built-up areas. Traffic volume = number of vehicles per 24 h.

cars per 24 h) the average share of sections in built-up areas was slightly higher and of those in open countryside lower than for roads with the lowest traffic volume. This difference was not, however, statistically significant for either habitat (share of built-up areas with moderate/high traffic: 42.6 ± 27.6% vs roads with the lowest traffic: 26.4 ± 22.9%, Kolmogorov-Smirnov test, P> 0.10; and, respectively share of open field sections: 57.4 ± 27.6% vs 73.6 ± 22.9%, Kolmogorov-Smirnov test, P> 0.10). The additional description of the studied roads was presented by Orłowski and Nowak (2004) and Orłowski (2005).

2.2. Counts of roadkills

Killed animals 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}. From the second half of March until the end of September all roads were surveyed three times a week. During the rest of the year two visits per weak were made. The duration of a single visit depended on the roadkill number and weather conditions. It lasted normally for 1.5 to over 3 hours. The counts were made usually in the afternoon, during dry weather. The collision places were put down on a special form, complete with the road number and habitat (village or open farmland). In order to avoid repeated counts of the same victims all killed animals and their remnants were removed from the road. Some of them were taken to the Vertebrate Zoology Department of Wrocław Uniwersity and the Agricultural University in order to identify the species.

2.3. Statistical analysis

In order to establish differences between the actual and expected mortality on particular road sections with different traffic volume and in the compared seasons of the year the chi-square (χ^2) goodness-of-fit analysis was used. The expected values were calculated based on the length of the particular road sections or the even distribution of roadkills in the compared seasons. Results with $P \leq 0.05$ were treated as statistically significant. Mortality models for the particular species and genera were calculated with the help of the standard multiple regression. Data about the victim number per 100 m of road were used in the models. Due to the linear relationship (r = 1) between the two independent variables applied in the regression model (% of the road length in the built-up area and in the open field), one "β" value for both variables was given in the final solution of the regression, with the respective "–" or "+" sign. The variable "traffic volume" (with the spread P <0.05 in Kołmogorow-Smirnov test), was subjected to logarithmic transformation based on the equation: $x = log(x'+1)$. The Pearson's linear correlation coefficient was applied in this study (where appropriate on log transformed data). The statistical analysis of the collected material was conducted with the use of Statistica 5 and Excel software.

3. RESULTS

3.1. Species composition and seasonal pattern of roadkills

A total of 383 killed mammals belonging to 23 species were recorded during 26 months of the study. The most abundant group were small rodents (40% of all victims), with dominant common vole *Microtus arvalis* (26% of the victims) (Table 2). The second most numerous group were insectivores (32% of roadkills), where two hedgehog species (*Erinaceus europaeus* and *E. concolor*) prevailed (20% of the victims). The share of other groups was insignificant, ranging from 9% (mustelids) to less than 1% (Table 2).

During the entire study period 84% of roadkills were recorded during 6 months of the year (May-October, Table 2, Fig. 2). Likewise in 2002 (when data for the full year were collected; n = 250 victims) 87% of killed mammals were found between May and October (Fig. 2). The highest mortality was noted in August (Fig. 2). The difference in victim number in both halves of 2002: May-October (n = 217) and November-April (n = 33) is highly statistically significant (χ^2 = 135.4, df = 1, P <0.0001). The roadkill number in particular months of 2002 differed clearly from the expected values (χ^2 = 267.8, df = 11, P <0.0001).

Table 2. Monthly distribution of mammal roadkills in agricultural landscape of Lower Silesia (SW Poland) in 2001–2003.

Species*	Month												All casualties of given species
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sorex araneus				1			5	2		1	1		10
Neomys fodiens				1	2					1			4
Crocidura suaveolens								1					1
Unidentified small insectivores								1					1
Erinaceus concolor				8	7	3	12	5	12	10	6	1	64
Talpa europaea			1		9	9	10	2		2			33
Erinaceus europaeus				1	1		3		1	1			7
Erinaceus sp.					1					1	1	1	4
Microtus arvalis			1	2	1	5	16	43	25	7			100
Apodemus agrarius	1	1			2		1	8	8		1	3	25
Apodemus flavicollis						1	2		1				4
Apodemus sp.								1	2	1			4
Mus musculus										1			1
Clethrionomys glareolus									1				1
Unidentified small rodents			1				4	3	3	4	2		17
Rattus norvegicus			2	1		1	12	15	9	6	2		48
Ondatra zibethica							1				1		2
Lepus europaeus											1		1
Mustela nivalis	1	1				2	1	7	2	2	1		17
Mustela erminea				1			1						2
Mustela vison			1										1
Mustela sp.								1	2				3
Martes foina			3		1	2	1	1					8
Martes martes									1				1
Martes sp.							1						1
Unidentified medium-sized mammals	1		1						2	1		1	6
Meles meles						1	1						2
Vulpes vulpes	3	3	1				1	2		2		1	13
Nyctereutes procyonoides										1			1
Capreolus capreolus		1											1
Total number of roadkills	6	6	11	15	24	24	72	92	69	40	16	7	383
Total number of species	3	4	6	7	7	8	14	10	9	11	7	3	23

*Domestic animals were excluded.

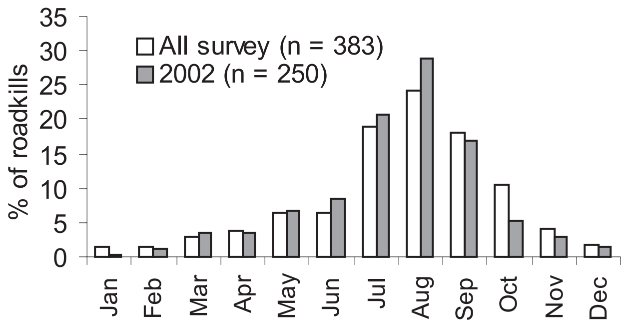

Fig. 2. Comparison of monthly distribution of mammal roadkills during the whole survey (24 June 2001 to 18 August 2003) and in 2002.

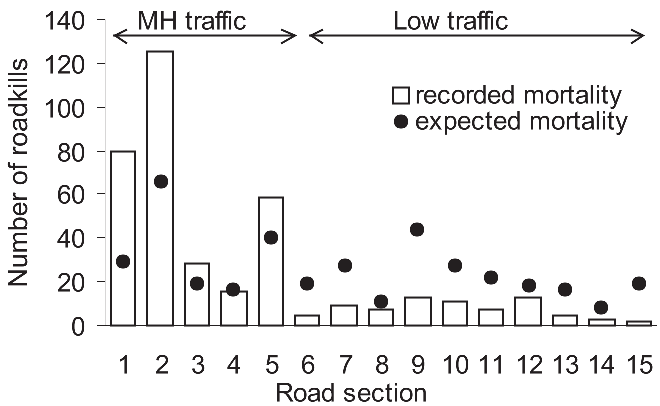

Fig. 3. Number of mammal roadkills on 15 surveyed road sections with different traffic volumes; (MH) medium-highest traffic (1900–10500 cars per 24 h), low traffic (350–470 cars per 24 h). The expected mortality was calculated on the base of the length of particular roads. Numbers of the consecutive sections as in Table 1.

3.2. Spatial distribution of roadkills

During the whole study period 38% of animals died within villages, where 26.4% of the studied roads were localized. The other 62% were found on the roads in the open countryside (73.6% of all roads). The difference in proportion of the number of all victims in relation to the road length was statistically significant (Table 3). The marked variation in roadkill pattern within built-up and open areas was visible also for several most often killed species. The large majority of hedgehogs *Erinaceus* spp., weasels *Mustela nivalis*, brown rats *Rattus norvegicus*, beech martens *Martes foina* and red foxes *Vulpes vulpes* died within villages (Table 3), while collisions on roads in the open farmland accounted for most losses in the common vole, mole *Talpa europaea* and common shrew *Sorex araneus* (Table 3).

On 11 road sections with the lowest traffic volume (350–460 cars per 24 h) the average (± SD) roadkills index during the entire study period amounted to 0.29 ± 0.14 (range = 0.08–0.56) casualties per 100 m. It was over seven times lower than on the section with the highest (10500 cars per 24 h) traffic volume (2.13 casualties per 100 m) (Table 4).

The number of roadkills recorded on 15 studied road sections differed clearly from the expected values calculated on the base of their length (χ^2 = 247.9, df = 14, P <0.0001; Fig. 3). The overall length of roads with medium (1900–2900), high (5700) and the highest traffic volume (10500 cars per 24 h) constituted 44.5% of all roads, but as many as 80.4% of all animals died on them (Table 4

Table 3. Comparison of mammal roadkills (n = 383) in built-up areas (BuA) and open countryside (Op) in agricultural landscape of Lower Silesia, 2001–2003.

Taxa	Number of roadkills		Ratio	χ^2 test on the differences in ratio of road-kill number to length of road type*
	Built-up areas	Open countryside		
Erinaceus spp.	70	5	BuA<Op	χ^2 = 176.80, P <0.0001
Mustela nivalis	11	6	BuA<Op	χ^2 = 13.34, P <0.001
Rattus norvegicus	30	18	BuA<Op	χ^2 = 33.13, P <0.001
Martes foina	6	2	BuA<Op	χ^2 = 10.60, P <0.001
Vulpes vulpes	8	5	BuA<Op	χ^2 = 8.40, P <0.01
Apodemus agrarius	2	23	BuA>Op	χ^2 = 4.20, P <0.05
Microtus arvalis	3	97	BuA>Op	χ^2 = 27.40, P <0.001
Talpa europaea	3	30	BuA>Op	χ^2 = 4.90, P <0.05
Sorex araneus	0	10	BuA>Op	χ^2 = 3.58, P <0.07
All roadkills	147	236	BuA<Op	χ^2 = 30.70, P <0.001

*For all cases: df = 1.

Table 4. Mammal roadkill indices and frequency by road with different traffic volumes in agricultural landscape of Lower Silesia in 2001–2003.

Index	Average 24 h traffic volume				
	350–480	1900–2900	5700	10500	All roads
Total number (%) of roadkills in 2001–2003	78 (20.3)	104 (27.2)	124 (32.4)	77 (20.1)	383 (100)
Mean number of roadkills per 100 m of road in 2001–2003	0.29	1.08	1.48	2.05	0.78
Total number (%) of roadkills in 2002	47 (18.8)	65 (26.0)	91 (36.4)	47 (18.8)	250 (100)
Mean number of roadkills per 100 m of road in 2002	0.17	0.68	1.09	1.25	0.51

and 5). In general, on five road sections with medium to highest traffic volume the actual victim number was by 180% higher compared to the expected values (χ^2 = 79.7, df = 1, P <0.0001). On roads with the lowest traffic volume the actual mortality was, in turn, by 283% lower than the expected values (χ^2 = 130.8, df = 1, P <0.0001; Fig. 3). Unproportionately high mortality on roads with medium/high traffic volume was also recorded for particular species, except for *Talpa europaea* and *Sorex araneus* (Table 5).

Only 18% out of 78 victims recorded on roads with the lowest traffic volume died within built-up areas (38.2% of all roads), while among 305 victims on roads with medium to highest (23.9% of roads) traffic volume (1900–10500 cars per 24 h) this value was 44% (χ^2 = 17.3, df = 1, P <0.0001). The share of roadkills recorded in built-up areas on the roads with the lowest and medium to highest traffic volume was not proportional to the length of these roads (χ^2 = 57.8, df = 1, P <0.0001).

3.3. Factors affecting road mortality

A high statistically significant correlation was found for 15 studied road sections between road length and the victim number (r = 0.72, P = 0.003, n = 15; Fig. 4A), the number of killed mammal species (r = 0.69, P = 0.004, n = 15), and the daily traffic volume (for log transformed data, r = 0.85, P <0.0001, n = 15). Likewise, a high positive correlation was shown between the daily traffic volume and roadkill number per 100 m of road (for log transformed data, r = 0.94, P <0.0001, n = 15;

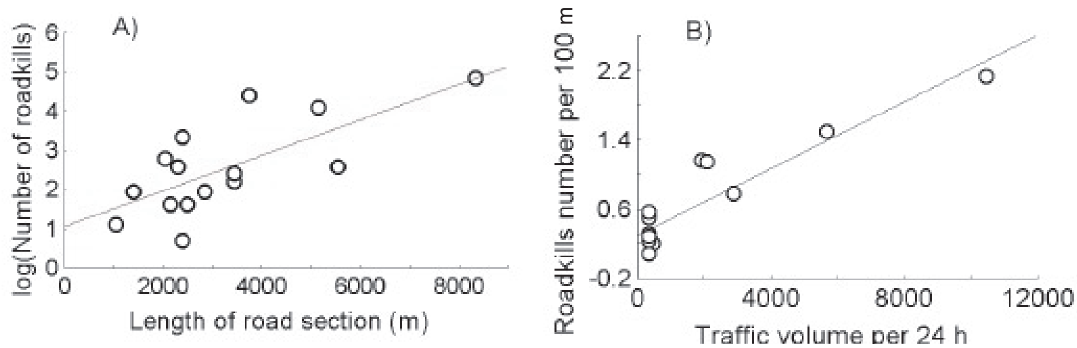

Fig. 4. Roadkills as a function of A) length of road section and B) traffic volume (number of cars per 24 h) on 15 road sections in agricultural landscape of south-western Poland in 2001–2003. Equation obtained for Fig. 4A: log(Number of road-kills) = 1.0610 + 0.00045 × Length of road section; for Fig. 4B: Number of road-kills per 100 m of road = 0.300 + 0.0002 × Traffic volume.

Table 5. Comparison of mammal roadkill number on roads with medium-highest (1900–10500) (MH) and low (350–460 cars per 24 h) (L) traffic volume in agricultural landscape of Lower Silesia, 2001–2003. *For all cases: df = 1.

Taxa	Traffic volume		Ratio	χ^2 test on the differences in ratio of road-kill number to length of road type
	MH	L		
Erinaceus spp.	71	4	MH<L	$\chi^2 = 78.1$, $P < 0.0001$
Mustela nivalis	15	2	MH<L	$\chi^2 = 13.4$, $P < 0.001$
Rattus norvegicus	46	2	MH<L	$\chi^2 = 51.1$, $P < 0.0001$
Martes foina	8	0	MH<L	$\chi^2 = 10.0$, $P < 0.01$
Vulpes vulpes	13	0	MH<L	$\chi^2 = 15.2$, $P < 0.01$
Apodemus agrarius	17	8	MH<L	$\chi^2 = 5.84$, $P < 0.02$
Microtus arvalis	86	14	MH<L	$\chi^2 = 70.0$, $P < 0.0001$
Talpa europaea	11	22	MH≈L	$\chi^2 = 1.7$, $P > 0.2$
Sorex araneus	3	7	MH≈L	$\chi^2 = 0.84$, $P > 0.5$
All roadkills	308	75	MH<L	$\chi^2 = 201.4$, $P < 0.0001$

on Fig. 4B untransformed data were used) and the number of killed species (r = 0.81, $P < 0.0001$, n = 15).

In the multiple regression models presented in Table 6 the main factor decisive for the level of losses was the daily traffic volume. This variable had a significant ($P \leq 0.017$) positive influence, both on the victim number of the particular species (except for *Talpa europaea* and *Apodemus agrarius*), families, and all mammals (Table 6). The proportion of roads situated in built-up/open area had a much smaller effect on mortality. Statistically significant effect of this variable (negative of built-up areas, positive of farmland) was noted for *Apodemus agrarius* ($P = 0.05$), *Microtus arvalis* ($P = 0.006$) and all rodents ($P = 0.0015$). The opposite statistically significant relationship (positive effect of built-up areas, negative of farmland) was found only for two hedgehog species ($P = 0.003$). Statistically significant regression models ($P \leq 0.032$) were obtained in 10 out of 12 cases presented in Table 6. The variability of mortality level on 15 studied roads ranged, depending on species, from 43% (*Vulpes vulpes*) to 78% (*Microtus arvalis*), and it was even higher for all mammals (90%, Table 6).

4. DISCUSSION

The obtained results regarding collision places of mammals with vehicles on Lower Silesian roads are to a large degree the reflection of their habitat preferences. It is visible in the high proportion both of species typical for central European farmland – common vole, striped field mouse, mole (jointly 41% of all victims), as well as of synanthropic species, inhabiting built-up areas – hedgehogs, brown rat, weasel, beech marten (jointly 34% of all victims). While the collision places of farmland species on roads outside villages and of some synanthropic species within built-up areas can be attributed to their habitat preferences, the localization of the large majority of roadkilled foxes within villages and a large percentage of dead rats among arable land may come as a surprise (Table 3). The results of the latest research show that the staple food of foxes in Polish farmland is poultry (Panek and Bresiński 2002, Gołdyn *et al.* 2003), which may explain their frequent occurrence in villages. The rats killed beyond villages were, in turn, found mainly near maize cultivations (up to 600 m from the nearest buildings), the fact suggesting that these animals apparently move out of built-up areas in search of food (maize seeds were spotted in the stomachs of run-over animals on several occasions). Unproportionately high mortality of mammals on road sections within villages (Table 3), seems also to point at the high densities of some species and the importance of these biotopes as "habitat islands" for the farmland populations of these animals.

The high mortality of mammals recorded in summer months (with peak in August) is in line with the results of survey carried out in Germany by Fuellhaas *et al.* (1989). Most probably this period sees the surge in the animal activity, associated with reproduction, as well as with appearance and dispersion of offspring (Clevenger *et al.* 2003). The high mortality recorded in Lower Silesia in July-September is connected mainly with the large number of killed common voles, that during the intensified farming operations (harvesting, mulching, ploughing) are flushed away from their territories and made to move on to the surrounding undisturbed fields (Jacob 2003, Jacob and Hempel 2003). That is why some animals may turn up on the roads. A large mortality of voles *Microtus* sp., due to disruption in their habitats, was also described by Bartoszewicz (1997). During three days of winter flooding, on the 11.3 km national road section bordering the meadowland of the Warta River Mouth National Park (Park Narodowy "Ujście Warty", north-west Poland) the author found as many as 128 killed voles (96% of all recorded animals) (Bartoszewicz 1997). The high

Table 6. Results of multiple regression analysis of the mammal roadkills per 100 m of road and environmental factors of 15 road sections in agricultural landscape of south-western Poland, 2001–2003.

Taxa	Traffic volume		% of road in built-up areas (1) / % of road in open countryside (2)			Regression model $F_{2,12}$*
	β	*P*-value	β	*P*-value	Sign at 1/2	
Erinaceus spp.	0.75	0.0002	0.57	0.003	+/-	24.35, $P<0.00006$, $R^2 = 0.80$
Mustela nivalis	0.81	0.0016	0.23	0.40	+/-	8.97, $P<0.004$, $R^2 = 0.60$
Rattus norvegicus	0.79	0.0009	0.28	0.31	+/-	11.49, $P<0.0016$, $R^2 = 0.66$
Martes foina	0.74	0.003	0.37	0.18	+/-	8.69, $P<0.0046$, $R^2 = 0.59$
Vulpes vulpes	0.64	0.017	0.38	0.16	+/-	4.61, $P<0.032$, $R^2 = 0.43$
Apodemus agrarius	0.44	0.11	0.57	0.05	-/+	2.78, $P<0.10$, $R^2 = 0.31$
Microtus arvalis	0.96	0.00003	0.49	0.006	-/+	21.81, $P<0.0001$, $R^2 = 0.78$
Talpa europaea	-0.20	0.49	0.33	0.26	-/+	1.52, $P<0.26$, $R^2 = 0.20$
Rodents	1.02	0.000001	0.45	0.0015	-/+	42.46, $P<0.0001$, $R^2 = 0.88$
Insectivores	0.66	0.002	0.31	0.09	+/-	13.95, $P<0.0007$, $R^2 = 0.70$
Mustelids	0.80	0.001	0.32	0.23	+/-	11.04, $P<0.002$, $R^2 = 0.65$
All mammals	0.99	0.00001	0.27	0.32	+/-	55.25, $P<0.00001$, $R^2 = 0.90$

* For all regression models the number of degrees of freedom was identical, df = 2,12.

share of rodents among the roadkills in Lower Silesia (this study), as well as in other areas (Oxley *et al.* 1974, Fuellhaas *et al.* 1989, Bartoszewicz 1997, Clevenger *et al.* 2003) proves that these animals do cross the roads, that cannot be seen, therefore, as permanent barriers restricting their dispersion.

The roadkill indices for small and medium-size mammals provided by different authors vary greatly. In the farmland of west Germany 13.06 mammal roadkills per 1 km were recorded during one year (Fuellhaas *et al.* 1989). Bartoszewicz (1997) found on the above mentioned road section 21.6 casualties per 1 km. In the farmland of California during 27 months of study only 0.012 victims per 1 km were detected (Caro *et al.* 2000). On motorways and express roads (total length 248.1 km) crossing the coniferous forests of Banff National Park (Alberta, south-west Canada) during three years of study (April-October only) 1.26 casualties per 1 km were shown (Clevenger *et al.* 2003). Oxley *et al.* (1974) recorded 4.01 mammal roadkills per 1 km on two roads and a motorway (total length 94.9 km) in SE Ontario during 4 months (June-September). Against these results the mortality index obtained in the farmland of Lower Silesia (7.8 casualties per 1 km of road during the whole survey and 5.1 casualties in 2002) seems to be quite high.

The results of this study prove that the daily traffic volume had the decisive effect on on the mortality level of the most often killed species and genera as well as all mammals on the 15 road sections in Lower Silesia. In an earlier study made in this area it was also shown that 90% of hedgehog loss variability on 22 road sections in villages was explained by the traffic volume and the length of the road crossing built-up areas (Orłowski and Nowak 2004). These results confirm the research that has been done so far, which points at the positive correlation between mammal mortality level and traffic volume (e.g. Rolley and Lehman 1992, Clark *et al.* 1998, Trombulak and Frissell 2000, Saeki and Macdonald 2004, Seiler 2005). Most of these studies dealt, however, with individual species, and the collected data was not usually the result of regular, systematic fieldwork. Clark *et al.* (1998) proved that the mean mortality index for badger *Meles meles* in south-west England was 6 times higher on motorways and express roads (traffic volume = ca. 15000 cars per 24 h), than on local roads (<1000 cars per 24 h). On the Japanese motorways Saeki and Macdonald (2004) showed a close positive correlation between the number of dead raccoon dogs *Nyctereutes procyonoides* and the yearly traffic volume that varied both between the roads and years (increasing trend). The work done by Oxley *et al.* (1974) is one of the few studies where mortality of more than 10 medium-sized mammals was compared on roads with different traffic volumes in south-west Canada. These authors also showed that the mortality indices on particular roads were rising clearly with traffic volume (Oxley *et al.* 1974).

Apart from the traffic volume, the environmental factors, such as type of biotope adjacent to the road, e.g. herb vegetation, woodland, built-up area, arable fields, ponds, watercourses, affect the mammal mortality level (e.g. Clevenger *et al.* 2003, Saeki and Macdonald 2004, Seiler 2005). Although in the present study a very simplistic description of roadside habitats was given (only built-up areas and open farmland were specified), the regression models explaining the mortality seem to reflect quite realistically the habitat preferences of the victims (Table 6). The overall mortality on 15 road sections depended on the presence of the built-up areas (Table 6), which, as it was described above, points at higher densities of mammals in villages than in the open countryside. In the earlier study from the area a high, statistically significant, positive correlation was found between the number of killed hedgehogs and the number of inhabitants in the 19 controlled villages and settlements (Spearman's rank correlation coefficient, $r_s = 0.71$, $P = 0.001$; Orłowski and Nowak 2004). A similar relationship is likely to exist for other most often roadkilled mammals recorded in villages of Lower Silesia.

In the study area, a particularly high mortality of some species (weasel, beech marten, hedgehogs, mole, common shrew) was recorded on the outskirts of villages as well as near junctions with other roads, drainage ditches and hedgerows. Due to the applied research methods it is impossible to characterize these relationships in more detail. They may confirm, however, the results of telemetric studies, which showed that the linear landscape elements in the areas dominated by arable fields are used by medium-sized mammals as the main migration routes (e.g. by hedgehogs – Doncaster *et al.* 2001; beech marten – Rondini and Boitani 2002; weasel – Macdonald *et al.* 2004). It cannot be ruled out that some of the dead moles, common shrews and water shrews *Neomys fodiens* found on the Lower Silesian roads were carried there by predators, which would imply lower actual losses of these species. An additional factor increasing mole mortality could be the rainfall, which very often preceded the appearance of roadkilled specimens of this species.

Bearing in mind the expected expansion of the road network and increasing traffic volume in central Europe it is essential to undertake further studies aiming at the better recognition of mortality in mammals and the role of habitat conditions influencing its level (Jędrzejewski *et al.* 2004). In the light of the research carried out so far (e.g. Clevenger *et al.* 2003, Saeki and Macdonald 2004, Seiler 2005) one of the important protection measures aimed at reducing road mortality should be the speed restriction in places of most abundant occurrence and migration of animals. It seems possible to achieve a substantial reduction of the very high number of roadkills in the built-up areas (see Results) just by imposing speed limits to 40–50 km h^{-1}.

ACKNOWLEDGEMENTS: We would like to thank Dr. Barbara Pikulska and Dr. Dorota Jakubiec-Benroth for the help with identification of the collected mammals. I also thank Marcin Sęk for the translation of this paper into English.

5. REFERENCES

Adams L.W., Geis A.D. 1983 – Effects of roads on small mammals – J. Appl. Ecol. 20: 403–415.

Bąkowski C., Kozakiewicz M. 1988 – The effect of forest roads on bank vole and yellow-necked mouse – Acta Theriol. 33: 345–353.

Bartoszewicz M. 1997 – Mortality of vertebrates on the highway bordering on the Słońsk Reserve, western Poland – Parki Narodowe i Rezerwaty Przyrody 16: 59–69 (in Polish).

Bellamy P.E., Shore R.F., Ardeshir D., Treweek J.R., Sparks T. H. 2000 – Road verges as habitat for small mammals in Britain – Mammal Rev. 30: 131–139.

Bennet A.F. 1991 – Roads, roadsides and wildlife conservation: a review (In: Nature conservation 2: The role of corridors, Eds.: D.A. Saunders, R.J. Hobbs) – Surrey Beatty & Sons, Chipping Norton, pp. 99–118.

Caro T.M., Shargel J.A., Stoner C.J. 2000 – Frequency of medium-sized mammal road kills in an agricultural landscape in California – American Midland Natur. 144: 362–369.

Clark G.P., White P.C., Harris S. 1998 – Effects of roads on badger *Meles meles* populations in south-west England – Biol. Conserv. 86: 117–124.

Clevenger A.P., Chruszcz B., Gunson K.E. 2003 – Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations – Biol. Conserv. 109: 15–26.

Doncaster C.P., Rondini C., Johnson P.C. 2001 – Field test for environmental correlates of dispersal in hedgehogs *Erinaceus europaeus* – J. Anim. Ecol. 70: 33–46.

Finder R.A., Roseberry J. L., Woolf A. 1999 – Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois – Landsc. Urban Plann. 44: 77–85.

Forman R.T.T., Alexander L.E. 1998 – Roads and their major ecological effects – Annual Rev. Ecol. System. 29: 207–231.

Fuellhaas U., Klemp C., Kordes A., Ottersberg H., Pirmann M., Thiessen A., Tschoetschel C., Zucchi H. 1989 – Studies of road mortality in birds, mammals, amphibians and reptiles – Beiträge zur Naturkunde Niedersachsen, 42: 129–147. (in German)

Gerlach G., Musolf K. 2000 – Fragmentation of landscape as a cause for genetic subdivision in bank voles – Conserv. Biol. 14: 1066–1074.

Gołdyn B., Hromada M., Surmacki A., Tryjanowski, P. 2003 – Habitat use and diet of the red fox *Vulpes vulpes* in an agricultural landscape in Poland – Zeitsch. Jagdwissen. 49, 191–200.

Groot G.W.T., Hazebroek E. 1996 – Ungulate traffic collisions in Europe – Conserv. Biol. 10: 1059–1067.

Huijser M.P., Bergers P. 1998 – Platte egels tellen: resultaten van een VZZ actie – Zoogdier, 9(2), 20–25. (in Dutch)

Jacob J. 2003 – Short-term effects of farming practices on populations of common voles – Agric. Ecos. Environ. 95: 321–325.

Jacob J., Hempel N. 2003 – Effects of farming practices on spatial behaviour of common voles – J. Ethol. 21: 45–50.

Jędrzejewski W., Nowak S., Kurek R., Mysłajek R., Stachura K. 2004 – Animals and roads. Methods of reducing the negative impact of roads on wild animal populations – Zakład Badania Ssaków PAN. Białowieża. 84 pp (in Polish).

Macdonald D.W., Tew T.E., Todd I.A. 2004 – The ecology of weasels *(Mustela nivalis)* on mixed farmland in southern England – Biologia (Bratislava), 59: 235–241.

Mader H.J. 1984 – Animal habitat isolation by roads and agricultural fields – Biol. Conserv. 29: 81–96.

Maisonneuve C., Rioux S. 2001 – Importance of riparian habitats for small mammal and herpetofaunal communities in agricultural landscape of southern Quebec – Agric. Ecosys. Environ. 83: 165–175.

Malo J.E., Suarez F., Diez A. 2004 – Can we mitigate animal-vehicle accidents using predictive models? – J. Appl. Ecol. 41: 701–710.

Merriam G., Kozakiewicz M., Tsuchiya E., Hawley K. 1989 – Barriers as boundaries for metapopulations of *Peromyscus leucopus* in farm landscapes – Landsc. Ecol. 2, 227–235.

Orłowski G. 2005 – Factors affecting road mortality of the Barn Swallow *Hirundo rustica* in farmland – Acta Ornithol. 40, 117–125.

Orłowski G., Nowak L. 2004 – Road mortality of hedgehogs *Erinaceus* ssp. in farmland in Lower Silesia (south-western Poland) – Pol. J. Ecol. 52: 369–374.

Oxley D.J., Fenton M.B., Carmody G.R. 1974 – The effects of roads on populations of small mammals – J. Appl. Ecol. 11: 51–59.

Panek M., Bresiński W. 2002 – Red fox *Vulpes vulpes* density and habitat use in a rural area of western Poland in the end of 1990s, compared with the turn of 1970s – Acta Theriol. 47: 433–442.

Philcox C.K., Grogan A.L., Macdonald D.W. 1999 – Patterns of otter *Lutra lutra* road mortality in Britain – J. Appl. Ecol. 36: 748–762.

Rolley R.E., Lehman I.E. 1992 – Relationship among raccoon road-kill surveys, harvests, and traffic – Wildl. Soc. Bull. 20: 313–318.

Rondini C., Boitani L. 2002 – Habitat use by beech martens in a fragmented landscape – Ecography, 25: 257–264.

Saeki M., Macdonald D.W. 2004 – The effects of traffic on the raccoon dog *(Nyctereutes procyonoides viverrinus)* and other mammals in Japan – Biol. Conserv. 118: 559–571.

Seiler A. 2005 – Predicting locations of moose-vehicle collisions in Sweden – J. Appl. Ecol. 42: 371–382.

Trombulak S.C., Frissel C. 2000 – Review of ecological effects of roads on terrestrial and aquatic communities – Conserv. Biol. 14: 18–30.

(Received after revising February 2006)