Amphibia-Reptilia 28 (2007): 25-31

Spatial distribution and seasonal pattern in road mortality of the common toad *Bufo bufo* in an agricultural landscape of south-western Poland

Grzegorz Orłowski

Abstract. Amphibians are the group of animals suffering particularly from the presence of roads and vehicle traffic. The seasonal migration to breeding places undertaken by amphibians in the temperate climate zone is the main reason for their appearance on roads. Between June 2001 and August 2003, 957 common toads *Bufo bufo* were recorded killed on 48.8 km road network with various traffic volumes (350-10500 cars per 24 h), situated in the agricultural landscape of south-western Poland. The highest mortality was recorded in April (57% of all road-kills). The places with highest recorded mortality varied markedly throughout the year. In spring, many more animals died within the built-up areas, while in summer and autumn their number increased in the open countryside. During the whole study period, 73% of all road-kills were recorded on roads (55% of all controlled) with the lowest traffic volume (350-470 cars per 24 h). The average number of road-kills on roads with the high traffic volume (5700-10500 cars per 24 h) was over 15 times lower than on the roads with low traffic (0-0.17 road-kills per 100 m on roads with high traffic vs 2.59 road-kills per 100 m on roads with low traffic). The number of road-kills on 15 road sections was most closely related to the abundance of local populations of *Bufo bufo* and to the size of water bodies situated in the road vicinity. The yearly level of local mortality in breeding populations of *Bufo bufo* due to the vehicle traffic ranged from 2 to 18%.

Introduction

Amphibians are the group of animals suffering particularly from the presence of roads and vehicle traffic, both directly, due to collisions with vehicles (Hels and Buchwald, 2001; Mazerolle, 2004), and indirectly, through the increasing isolation of populations and difficulties in reaching the particular breeding sites (Vos and Chardon, 1998; Pellet et al., 2004), resulting in reduced genetic diversity of the affected populations (Hitchings and Beebee, 1998; Scribner et al., 2001). The seasonal migration to breeding places undertaken by most amphibians in the temperate climate zone is the main reason for their appearance on roads. In some parts of the world road mortality currently poses the biggest threat to many species of amphibians (e.g. Cooke and Sparks, 2004). In a highly transformed landscape smooth road surfaces and roadsides can also be used as migration routes (Seabrook and Dettmann, 1996), making the migration easier and faster but also increasing the risk of collision with vehicles.

Department of Agricultural Bases for Environmental Management, Agricultural University of Wrocław, pl. Grunwaldzki 24, 50-363 Wrocław, Poland
e-mail: orlog@poczta.onet.pl

Alarming reports of dramatic decline of many amphibian species due to human activities such as drainage and destruction of breeding sites, growing agricultural and industrial pollution, excessive UV radiation, climatic changes (e.g. Kiesecker and Blaustein, 1995; Blaustein et al., 2001; Collins and Storfer, 2003; Cooke and Sparks, 2004), introduction of exotic, invasive vertebrate species (e.g. Cruz and Rebelo, 2005; and the reference herein) and the expansion of road networks coupled with increasing traffic (Beebee and Griffiths, 2005) are an urgent call for a thorough investigation of threats to this group of animals. Rapid increase of road traffic, currently observed in many parts of Europe, may be the main cause of local drops of amphibian abundance (discussed in Cooke and Sparks, 2004), although the actual reasons for decline of many common species are hardly known (e.g. Carrier and Beebee, 2003).

Studies devoted to amphibian road mortality have been conducted by many authors. However there are virtually no publications presenting the relationship between large-scale landscape variables, such as road characteristics (e.g. traffic volume), abundance of local populations and mortality level of herpetofauna, or studies devoted to mortality on road networks with various traffic volumes and describing the yearly dynamic of road-kills abundance (discussed in Mazerolle, 2004). Traffic volume and its daily variability, distance from the nearest water bodies and field topography are usually mentioned as decisive for the road mortality level of amphibians (Fahrig et al., 1995; Hels and Buchwald, 2001; Clevenger et al., 2003; Mazerolle, 2004; Rybacki and Domańska, 2004).

The aim of the present study was to determine the yearly dynamic of the mortality level in the common toad *Bufo bufo* on a road network with various traffic volumes, situated in an intensively farmed area of Lower Silesia (SW Poland) and to specify the main relationships between habitat quality and number of road-kills.

Material and methods

Study area

The research was conducted on a network of 15 roads (total length 48.8 km) with various traffic volumes (table 1) situated in Lower Silesia, south of Wrocław city (SW Poland). The study area (51°02′N, 17°03′E; ca. 55 km^2; fig. 1) is characterized by one of the lowest woodland shares in Poland, ca. 1.6%. The dominant form of land use is arable, covering ca. 92% of the total area. In the year 2000 the main crops were wheat (50%), oilseed rape (25%), root crops (10%) and maize (8%). The rest (5.5%) consists of built-up areas and communication routes. The area is inhabited by ca. 8000 people. 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.

Counts of road-kills and local populations of Bufo bufo

The survey of road-killed animals was conducted from 24th of June 2001 to 18th of August 2003. All roads were checked from a car, driving at 20 to 50 km/h. During the migration period of amphibians, road sections with more abundant appearance of road-kills (mainly in the vicinity of water bodies) were checked on foot. From the second half of March until the end of September all roads were surveyed three times a week. Outside this period a maximum of two counts a week were made. The length of each survey depended on the number of road-kills and weather conditions. It lasted from 1.5 to over 3 hours. The counts were conducted usually in the afternoon, in dry weather. Findings of dead amphibians were recorded, including road number and the habitat (village or open countryside). To avoid repeated counting of the same animals, all road-kills were removed from the road.

To describe the relationships between road features and number of road-killed toads, seven habitat variables were determined (range and units are given in brackets): 1) traffic volume (350-10500 cars per 24 h); 2) number of ponds within 200 m of the road (0-8); 3) area of ponds within 200 m of the road (0-1.25 ha); 4) share of adjacent built-up areas (0-73.2%); 5) share of adjacent arable land (0-96.5%); 6) mean number of breeding individuals of *Bufo bufo* recorded in ponds within 200 m of the road (0-1700); 7) number of road-killed *Bufo bufo* per 100 m of road (0.00-17.16).

These data were determined on the basis of ordnance survey maps (1:25000 and 1:10000) and direct field study. Out of 46 analysed water bodies, 26 (57%) were situated within villages, and the remainder (43%) in open countryside. In order to determine local population abundance of *Bufo bufo*, the results of a special inventory were used. All breeding sites of *Bufo bufo* were recorded in the whole area (ca. 55 km^2) from the middle of March until May in 2000-2001 (G. Orłowski – unpublished data). The counts of *Bufo bufo* were conducted 2-3 times in each season. The collected data provide information about the occurrence of breeding *Bufo bufo* in ca. 70 small water bodies scattered throughout the area. In the relationships between the number of *Bufo bufo* road-kills and the road features, the mean number of all adults recorded in a water body during two years was used. The presented relationships include abundance of local populations from water bodies ($n = 46$) localized up to 200 m from roads, where anywhere between 10 (small, concrete anti-fire reservoirs) and ca. 1500 individuals bred (fig. 1). The total breeding population of *Bufo bufo* within the belt of 200 m either side of the roads was estimated at ca. 5500 individuals. It accounted for ca. 80-90% of all *Bufo bufo* breeding within the study area (ca. 55 km^2).

Statistical analysis

Differences in the number of road-kills on particular roads with various traffic volumes were determined with the use of the Wilcoxon test. Differences in the number of road-kills within built-up areas and open farmland were tested using Chi-square (χ^2) goodness-of-fit analysis. Road length was used to calculate the expected values. Pearson's correlation coefficient was applied in order to identify the relation between the number of *Bufo bufo* road-kills per 100 m of road and the road features. Three variables with the spread $P < 0.05$ in the Kolmogorow-Smirnov test (traffic volume, number of breeding individuals and number of road-kills), were subjected to logarithmic transformation based on the equation: $x = \log(x' + 1)$. The results with probability $P \leqslant 0.05$ were treated as statistically significant. Statistical analysis of the collected material was conducted with the help of Statistica 5 and Excel software.

Table 1. Characteristics of the studied roads in the farmland of Lower Silesia (SW Poland) in 2001-2003.

Average 24 h traffic volume (number of cars per 24 h)	Length of roads (m)	Share (%)	Number of sections	Built-up areas (m)	Total number of ponds within 200 m of road	Total area of ponds within 200 m of road (ha)	Number of *Bufo bufo* road-kills
10500	3750	7.7	1	1600	2	0.15	0
5700	8350	17.1	1	1750	4	0.45	14
2900	2050	4.2	1	2300	5	0.56	21
2100	5150	10.6	1	400	3	1.22	94
1900	2400	4.9	1	1900	8	1.12	126
470	2500	5.1	1	450	4	0.59	16
350	24600	50.4	9	4500	21	2.59	686
Total	48800	100	15	12900	47	6.68	957

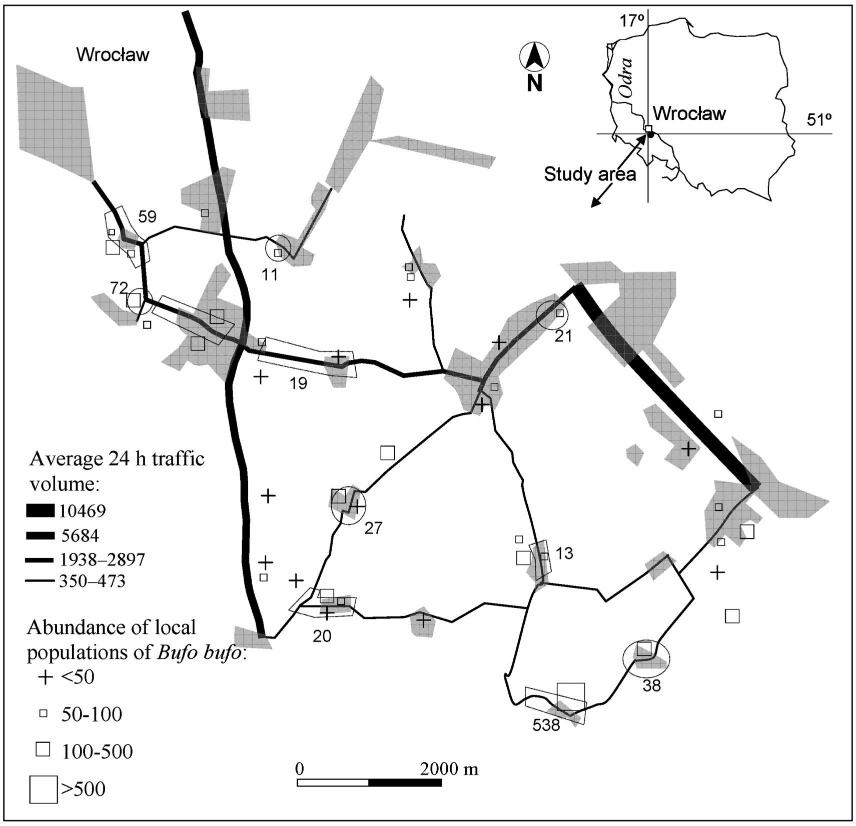

Figure 1. The main locations of *Bufo bufo* mortality on the road network in the agricultural landscape of Lower Silesia (SW Poland) in 2001-2003. Grey colour denotes built-up areas, dashed line – places where the number of road-kills was especially high (digits indicate the total number of casualties on a given road section). Traffic volume = number of vehicles per 24 hours. Abundance of local populations of *Bufo bufo* is given for the water bodies (breeding sites) situated within 200 m of the road.

Results

Seasonal pattern of road-kills

During the whole study period a total of 957 road-killed individuals of *Bufo bufo* were found. All recorded road-kills were adults (in at least 2nd calendar year). The earliest and latest dates of findings were 12th of March and 6th of November. A clearly visible peak of mortality occurred in April (fig. 2). In this month in both compared years (2002 and 2003), respectively 307 (2002) and 237 (2003) road-kills were found. During the active period of the year, the lowest mortality was noted in July (fig. 2).

The mortality level of *Bufo bufo* in 10 day periods of particular months of compared years was close (fig. 2). There were no statistically significant differences in the number of road-kills between 30th of June and 8th November of 2001 and 2002 (Wilcoxon test, $Z = 1.92$, $P = 0.054$, $n = 13$). Also, the comparison of mortality level between 12th of March and 20th August of 2002 and 2003 showed no statistically significant differences (Wilcoxon test, $Z = 1.70$, $P = 0.09$, $n = 16$, fig. 2).

Spatial distribution of road-kills

As many as 720 (75.2%) out of 957 road-kills were recorded on road sections situated within the built-up areas, that constituted barely 26% of the total length of the road network. The rest ($n = 237$, 24.8%) were found in the open countryside ($\chi^2 = 1204.2$, $df = 1$, $P < 0.0001$). The proportion of toads killed within the built-up areas was highest in spring and decreased later in the season ($\chi^2 = 69.0$, $df = 7$, $P < 0.0001$). In the spring period (March-May), the clear majority of road-kills died within the villages (657 road-kills in built-up areas vs 128 road-kills in open countryside; $\chi^2 = 1359.1$, $df = 1$, $P < 0.0001$). In summer and autumn (June-October) the share of animals killed in the open countryside was increasingly prominent (63 road-kills in built-up areas vs 108 road-kills in open countryside; $\chi^2 = 10.4$, $df = 1$, $P = 0.01$).

During the whole study period, from 0 to 592 (median = 14, interquartile range = 22) road-kills were recorded on 15 specified road sections (table 1). The highest mortality was noted on a local village road in the southern part of the study area, where 538 road-kills were found (fig. 1). The very high mortality on this section resulted from frequent concentrations of adults on the asphalt road surface, where the pair formation took place, hampering seriously their further common journey to the water. Killed adults *in amplexus* were often found on this road.

Throughout the whole study period 73% of all road-kills were found on roads with the lowest traffic volume (table 2). The share of all road-kills ($n = 957$) on four road types with different traffic volumes, was not proportional to their lengths ($\chi^2 = 282.2$, $df = 3$, $P < 0.0001$; table 2).

Factors affecting road mortality in local populations of Bufo bufo

The level of losses of *Bufo bufo* on 15 road sections was most closely related to the abundance of local populations and to the area of water bodies situated in the road vicinity (table 3). No statistically significant correlation between the abundance of local populations or mortality level and the traffic volume was found (table 3).

On the basis of local population abundance of *Bufo bufo* breeding in the roadside water bodies ($n = 5500$ individuals) and its yearly mortality ($n = 568$ road-kills in 2002), the overall losses can be estimated at ca. 10% of the population. Similar calculations also indicate that the local population losses on 15 road sections (no breeding sites were detected in the vicinity of three of them) ranged from 2 to 18% (median = 6%, interquartile range = 8%). The highest percentage (18%) of killed *Bufo bufo* was recorded on the previously described section of local road with the highest amphibian mortality (fig. 1).

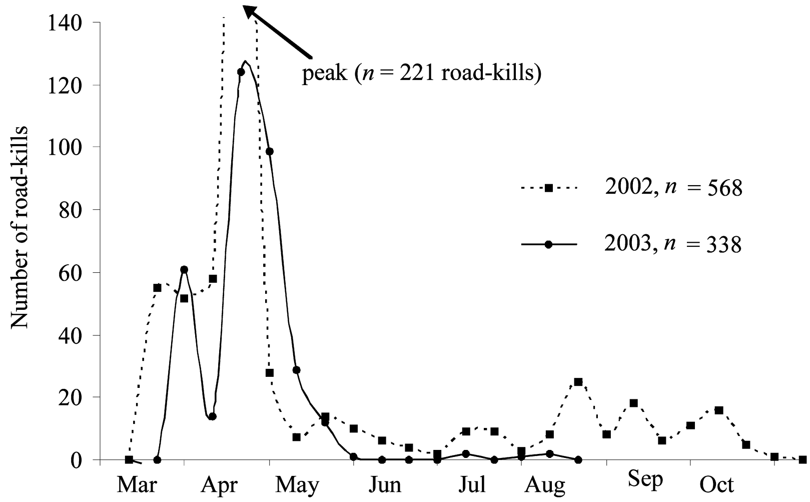

Figure 2. The mortality dynamic of *Bufo bufo* ($n = 957$) in 10 day periods of particular months of the year for 2002 and 2003 on roads (48.8 km) in the farmland of Lower Silesia (SW Poland). Data from 2001 ($n = 55$) are omitted.

Table 2. Comparison of number of *Bufo bufo* road-kills on roads with different traffic volumes in the farmland of Lower Silesia in 2001-2003.

	Average 24 h traffic volume				
	350-480	1900-2900	5700	10 500	All roads
Total number of road-kills in the whole study	702	241	14	0	957
Mean number of road-kills per 100 m of road in the whole study	2.59	2.51	0.17	0.00	1.96
Number of road-kills in 2002	390	169	9	0	568
Mean number of road-kills per 100 m of road in 2002	1.44	1.76	0.11	0.00	1.16

Table 3. Pearson's linear correlation coefficients between the average number of road-kills per 100 m of road and the number of breeding individuals of *Bufo bufo* and the specified habitat variables on 15 road sections in the farmland of Lower Silesia (SW Poland) in 2001-2003; ns, $P > 0.05$; ***, $P < 0.001$.

Variable	Number of breeding toads	Area of ponds within 200 m of the road	Traffic volume	Number of ponds within 200 m of the road	% of adjacent built-up areas	% of adjacent arable land
Number of road-kills	0.952***	0.794***	−0.219 ns	0.472 ns	−0.180 ns	0.269 ns
Number of breeding toads	–	0.801***	−0.346 ns	0.472 ns	−0.242 ns	0.348 ns

Discussion

The results of this study have shown that on roads of Lower Silesia the main factor affecting road mortality of *Bufo bufo* is the abundance of local breeding populations of this species. There was no significant correlation between the number of road-killed toads and traffic volume. This is a novel, unexpected result that differs from other studies which showed or predicted higher mortality with higher traffic density (e.g. Fahrig et al., 1995; Mazerolle, 2004; Carr and Fahrig, 2001; and references herein). The survey in Lower Silesia was conducted on a large landcape scale, thus these results are difficult to compare with other studies conducted on short road streches. However, it should be emphasized that on a single, short road section, the relationship between mortality and temporal (daily) traffic volume will be positively correlated (Hels and Buchwald, 2001; Mazerolle, 2004), but the results of these studies cannot be used to predict the spatial pattern of road mortality of amphibians. It can be supposed that the absence of the significant impact of traffic volume was caused by the long-lasting *cumulative effect* (e.g. Cook and Sparks, 2004; Mazerolle, 2004) lethally affecting local populations occurring along the busiest roads, which led to their decimation or even total extinction (see also Fahrig et al., 1995; Vos and Chardon, 1998; Carr and Fahrig, 2001). It cannot be ruled out that only the populations around the roads with lowest traffic have managed to survive and the lack of significant impact of traffic volume can be seen rather as a historical artifact. According to Cook and Sparks (2004), it seems that fewer road-kills mean that the problem is getting worse because the population is shrinking. Bearing in mind, however, the close correlation between traffic volume and amphibian mortality presented in models by Hels and Buchwald (2001), it must be stressed that even a slight increase of traffic can increase the number of road-kills sharply, especially around roadside water bodies with abundant amphibian populations.

In Lower Silesia the highest mortality of *Bufo bufo* was recorded on roads with the lowest (350-470 cars per 24 h) and moderate (1900-2900 cars per 24 h) traffic volume (table 2). The low mortality on the busiest roads within the study area can be explained by their small length, low abundance of amphibian populations and the lack of water bodies in their vicinity. The number of road-killed *Bufo bufo* in the farmland of Wrocław Plain was positively correlated with the abundance of the local population and the overall area of water bodies (ponds). In the case of traffic volume and the number of ponds, the correlations were not significant. The lack of significance of the variable 'number of ponds' could result from the often very small populations of *Bufo bufo* in some of them (sometimes even below 20 individuals), which meant that it was not the number but the area of the ponds that was decisive.

The very high mortality of adults in the initial period of the breeding season (see Fig. 2), suggests that these individuals died before breeding. The lack of records of young road-killed *Bufo bufo* (in late summer/autumn the road sections near ponds were also checked on foot) proves that adult toads are much more likely to be eliminated from the population. The elimination of adults before they managed to breed affects undoubtedly the abundance and may induce some changes in the demographic structure of the population, leading potentially to its gradual disappearance (e.g. Heusser, 1968; Hels and Nachman, 2002). According to Schmidt et al. (2002) most *Bufo bufo* females breed only once in a lifetime and the mean annual survival rate in this species amounts to ca. 35%. It seems therefore that the only practical implication from the above analysis, aiming at the conservation of toad populations, is securing of the safe migration of adults to the water bodies in spring or construction of the mitigation ponds at new safe sites away from the road. The negative correlation between traffic density and number of road-kills suggests that conservation action should not be necessarily on roads with high traffic volume. The results of this study also indicate the need for further studies devoted to determining the relationships between large-scale habitat features (e.g. roads configuration, traffic volume), abundance of populations and road mortality of amphibians.

Roads might also be considered as an ecological trap (e.g. Schlaepfer et al., 2002). In the study area the pair formation of *Bufo bufo* took place near roads or even on their surfaces, before reaching the breeding sites. Pairs of adults *in amplexus* were seen moving very slowly across the roads and often freezing. The probability of a single Common Toad getting killed while crossing the road at the above speed amounted to ca. 100% at the traffic volume of around 4000 vehicles per 24 h (Hels and Buchwald 2001). According to Kuhn (1987) even at the very low traffic volume – 4 vehicles per hour – around 10% of the population die, while at 60 vehicles per hour this value goes up to 75%. The level of mortality depends also on the position of the migration route against the road and the time of day (Hels and Buchwald, 2001). Some toads were also seen using roads and roadsides as migration routes, especially within villages, where these were often the only undeveloped spaces.

Bearing in mind the increasing rate of vehicle traffic and the continuing expansion of the road network in Europe, a dramatic decline of many herpetofauna species can be anticipated (Carrier and Beebee, 2003; Cook and Sparks, 2004). The identification of threats and monitoring of abundance and road mortality of common amphibian species should become essential research activities aimed at the conservation of these animals in Europe.

Acknowledgements. I would like to thank B. Schmidt, M. Rybacki, and K. Hałupka for the valuable remarks on this paper. I also thank G. Walters and M. Sęk for the preparation of the English version of the text.

References

Beebee, T.J., Griffiths, R.A. (2005): The amphibian decline crisis: A watershed for conservation biology? Biol. Cons. **125**: 271-285.

Blaustein, A.R., Belden, L.K., Olson, D.H., Green, D.M., Root, T.L., Kiesecker, J.M. (2001): Amphibian breeding and climate change. Cons. Biol. **15**: 1804-1809.

Carr, L.W., Fahrig, L. (2001): Effect of road traffic on two amphibian species of differing vagility. Cons. Biol. **15**: 1071-1078.

Carrier, J., Beebee, T.J. (2003): Recent, substantial, and unexplained declines of the common toad *Bufo bufo* in lowland England. Biol. Cons. **111**: 395-399.

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

Collins, J.P., Storfer, A. (2003): Global amphibian declines: sorting the hypotheses. Divers. Distrib. **9**: 89-98.

Cooke, A.S., Sparks, T.H. (2004): Population declines of Common Toads *(Bufo bufo)*: the contribution of road traffic and monitoring value of casualty counts. Herpetol. Bull. **88**: 13-26.

Cruz, M.J., Rebelo, R. (2005): Vulnerability of southwest Iberian amphibians to an introduced crayfish, *Procemberus clarkii*. Amphibia-Reptilia **26**: 293-303.

Fahrig, L., Pedlar, J., Pope, S.E., Taylor, P.D., Wegner, J.F. (1995): Effect of road traffic on amphibian density. Biol. Cons. **73**: 177-182.

Hels, T., Buchwald, E. (2001): The effect of road kills on amphibian populations. Biol. Cons. **99**: 331-340.

Hels, T., Nachman, G. (2002): Simulating viability of a spadefoot toad *Pelobates fuscus* metapopulation in a landscape fragmented by a road. Ecography **25**: 730-744.

Heusser, H. (1968): The biology of the Common Toad *Bufo bufo* (L.), biometrical data and population dynamic. Mitt. Naturforsch. Ges. Schaffhausen **29**: 1-29.

Hitchings, S.P., Beebee, T.J. (1998): Loss of genetic diversity and fitness in common toad *(Bufo bufo)* populations isolated by inimical habitat. J. Evol. Biol. **11**: 269-283.

Kiesecker, J.M., Blaustein, A.R. (1995): Synergism between UV-B radiation and a pathogen magnifies amphibian embryo mortality in nature. Proc. Nat. Acad. Sci. Unit. Stat. Am. **92**: 11049-11052.

Kuhn, J. (1987): Road mortality of the Common Toad *Bufo bufo* L., level of losses and the traffic impact, behaviour on the road. Beih. Veröff. Natur. Landschaft. Baden-Würten. **41**: 175-186.

Mazerolle, M.J. (2004): Amphibian road mortality in response to nightly variation in traffic intensity. Herpetologica **60**: 45-53.

Pellet, J., Guisan, A., Perrin N. (2004): A concentric analysis of the impact of urbanization on the threatened european tree frog in an agricultural landscape. Conserv. Biol. **18**: 1599-1606.

Rybacki, M., Domańska, E. (2004): Migration intensity and mortality of amphibians on roads of Oleśnica fish farm (Chodzież county, wielkopolskie province). Proceedings of the 7-th Herpetological Conference, Kraków. Kraków Pedagogical Univeristy Press, pp. 90-95 (in Polish with English abstract).

Schlaepfer, M.A., Runge M.C., Sherman P. (2002): Ecological and evolutionary traps. Trends Ecol. Evol. **17**: 474-480.

Schmidt, B.R., Schaub, M., Anholt B.R. (2002): Why you should use capture-recapture methods when estimating survival and breeding probabilities: on bias, temporary emigration, overdispersion, and common toads. Amphibia-Reptilia **23**: 375-388.

Scribner, K.T., Arntzen, J.W., Cruddace, N., Oldham, R.S., Burke, T. (2001): Environmental correlates of toad abundance and population genetic diversity. Biol. Cons. **98**: 201-210.

Seabrook, W.A., Dettmann, E.B. (1996): Roads as activity corridors for cane toads in Australia. J. Wild. Manag. **60**: 433-440.

Sinsch, U. (1988): Seasonal changes in the migratory behavior of the toad *Bufo bufo*: direction and magnitude of movements. Oecologia **76**: 390-398.

Vos, C.C., Chardon, J.P. (1998): Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. J. Appl. Ecol. **35**: 44-56.

Received: August 20, 2005. Accepted: April 11, 2006.