Title
AMPHIBIAN MITIGATION MEASURES IN CENTRAL-EUROPE

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AMPHIBIAN MITIGATION MEASURES IN CENTRAL-EUROPE

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Abstract: Studies from different continents have proved amphibians to be the most frequently killed vertebrates on roads. In Central-Europe their ratio is between 70 and 88 percent. Local populations are known to become extinct or genetically isolated, and avoidance is also recognised, especially where the road network is dense and the traffic is intensive. Besides ecological and conservation considerations, amphibian road kills also present a hazard for motorists when amphibians migrate in large numbers.

Mitigation measures for amphibians have been applied since the 1960s. In Central-Europe the first amphibian-related culvert modification occurred at Parassapuszta, Hungary, in 1986. A number of amphibian-oriented mitigation measures have been made in the region under roads and motorways since then, especially after 1995. The aim of this paper is to describe the main features of these constructions, overview the different designs, and make suggestions for their improvement as well as for future amphibian-oriented mitigation measures in general. A total of 31 road sections was monitored. Besides amphibian tunnels, game passages and game bridges were also investigated. Both the detailed characterisation of the technical solutions and the survey of amphibian populations and habitats were included in the methodology.

The investigation of the tunnel systems showed a great diversity, e.g., in tunnel and fence material, their position in relation to the road, and connections between them. For economical reasons concrete tunnels were the most common. Both circular and square cross-section tunnels were in place. The accessibility of the entrance was a possible problem, especially in areas where erosion is considerable. Plastic mesh and concrete fences were both applied with a height fluctuating between 45 and 70cm. Plastic fences are usually fixed to wooden poles, which need to be checked before the migration period starts. However, the advantage of such fencing is flexibility, which makes possible, e.g., the turning back of its ends to prevent amphibians from getting on the road.

Some systems did not work because certain elements (usually fences) were in bad condition. Elsewhere lack of maintenance reduced the efficiency of mitigation measures. Missing elements should be replaced immediately, even if the amphibian migration period is over, because other animals, e.g., small mammals, also use these systems. The lowest distance between tunnels in amphibian mitigation systems is 40m in the region (Kudowa Zdrój, Poland). Usually, amphibian tunnels were placed 50-100m from each other, which is an acceptable distance. In case of adequate fencing, game passages and game bridges would also be appropriate for the crossing of amphibians as well as reptiles and small mammals, similar to slightly modified existing culverts under high road mortality sections, and there would be a need for such conservation improvements at several sites.

As a result of this work, several recommendations on the maintenance of amphibian tunnels and fences were also developed. Further cooperation among different agencies and organisations was urged, nationally as well as internationally. The improvement of public relation activities on fauna passages also seems to be needed for the effective protection of wildlife on roads.

Introduction
Effect of Road Kills on Amphibians

Transportation infrastructure has a many-fold impact on the environment. Road kills are an obvious example recognised early on because they also threaten the safety of motorists. Amphibian road kill is a worldwide phenomenon due to the bi-phasic amphibian life cycle and the consequent migration among the different habitat types that amphibians use. Because of construction considerations, roads are often situated along the edge of geographical features that provide different habitats for amphibians, e.g., as winter hibernation sites, breeding sites, or summer habitats. As a consequence, a seasonal migration pattern is likely to occur in such road sections that run, e.g., between foothills of mountains and floodplains, along large lakes or reservoirs, etc. (Rybacki 1995). In other cases, roads cut the same habitat, e.g., wetlands, into smaller fragments causing road kill problems to be present as long as the animals are active. Though road traffic can have a considerable effect on different animals (see Bambaradeniya et al. 2001, Becker and Canters 1997, Dodd et al. 1989), studies from different continents have proved amphibians to be the most frequently killed vertebrates on roads (see Ashley and Robinson 1996). Local populations are known to become extinct (Cooke 1995) or genetically isolated (Reh 1989, Vos et al. 2001), and avoidance is also recognised (Fahrig et al. 1995, Vos & Chardon 1998), especially where the road network is dense and the traffic is intensive. Besides ecological and conservation considerations (general decline of amphibians, protection of International Red Data Book amphibian species, etc.), it also means a hazard for motorists when amphibians migrate in large numbers. Mitigation measures for amphibians have been applied since the 1960s, first in Western-Europe. However, individual countries can greatly differ as the first amphibian tunnels were created in the 1960s in Switzerland and Germany, and in the mid-1980s in the U.K. In the United States the first salamander tunnels were built in 1987 (Jackson and Tyning 1989).

Geographical Extent of the Study

The present study deals with mitigation measures in Central-Europe, which is an ambiguously applied term in politics, economics, etc. Here it is used according to the geography of the continent. The geographical centre of Europe is in the Tisza valley in the present Ukraine or, according to another method, in Poland, near Bialystok. Investigations presented in this paper were mostly carried out in the western part of the region, also called Central-Eastern Europe, because in countries with a less developed economy, e.g., Ukraine, there are no amphibian mitigation measures on roads due to financial reasons (Rheshetylo, pers. comm. 2003). Most examples in this article are taken from Hungary, Poland, and Slovenia. Mitigation measures in Austria are not discussed here.

Knowledge of the Herpetofauna of Central-Europe

Individual Central-European countries greatly differ with regard to what extent the distribution of local herpetofauna is known. The Czech Republic has the best-known herpetofauna in the region, having both its amphibian and reptile atlas published (Moravec 1994, Mikátová et al. 2001) with detailed descriptions on the conservation status and threats of the species, including road-related issues. In other countries, however, such information is less detailed, more scattered, but there are important new developments in several of them, e.g., the publication of a very detailed and well-illustrated determination key in Slovenia (Veenvliet and Kus Veenvliet 2003).

Importance of Amphibians in Vertebrate Road Kills in Central-Europe

Unrelated to the actual status of herpetological research in the different countries, road kills have been studied by Bartoszewicz (1997) and Wolk (1978) in Poland, Denac (2003) in Slovenia, Fenyves (1989) in Hungary, and Holisová and Obrtel (1986) in the Czech Republic (Czechoslovakia at the time of publication), proving the importance of the topic. The main characteristics of the investigations are presented in table 1. There are considerable differences between the individual works. Duration, for example, varied between one day (Fenyves 1989) and 10 years (Holisová and Obrtel 1986). However, interestingly enough, more individuals were reported from the single day study than from the longest observation due to driving speed differences, part of the day studied, and most probably the characteristics of the area, and optimal weather in the single day study also expressed by far the highest number of average road-killed individual number per km per survey. The length of the monitored road stretch was between 11.3 and 110km (Bartoszewicz 1997 and Fenyves 1989, respectively), and the total number of road-killed animals was between 137 and 2,045 (Wolk 1978 and Denac 2003, respectively), while the number of recorded species or groups was between 21 and 71 (Fenyves 1989 and Denac 2003, respectively).

Table 1
Main characteristics of Central-European road kill surveys

	Bartoszewicz 1997	Denac 2003	Fenyves 1989	Holisová & Obrtel 1986	Wolk 1978
Region	Western-Poland	Central-Slovenia	Western-Hungary	Eastern-Czech Republic	Northeastern-Poland
Site	Slonsk Nature Reserve	Ljubljana moor	Transdanubia	Moravia	Bialowieza Nature Reserve
Road type	highway	main road, lower road	lower roads	motorway, highway, lower roads	lower road
Length of monitored road section (km)	11.3	26.1	110	96.5	17
Means of transport	bycicle or car	bycicle or car	bycicle	car	motorcycle
Speed (km/hr)	< 40	< 40	< 25	50-70	30
Study period	8. 1995. - 8. 1996	30. 8. 2000 - 29. 8. 2001	21. 8. 1987	6. 1976 - 6. 1978 2. 1980 - 8. 1985	13. 5. 1975 - 24. 9. 1975
Number of surveys	91	85	1	> 580	19
Total number of road-killed animals recorded	1,367	2,045	1,117	226	137
No. road-killed species or groups*	52	71	21	23	23
Avarage number of road killed animals (individual number/km/survey)	1.329	0.921	10.154	0.004	0.424

*In case determination to the species level was impossible higher taxonomical categories (usually genera) are given, which may overlap with listed species.

Three investigations extended for at least one complete year (Bartoszewicz 1997, Denac 2003, Holisová and Obrtel 1986), providing opportunities to analyse seasonal changes and make more general estimates. Most probably due to different sampling strategies biased towards larger animals in the Czech survey due to faster driving speeds, that work reported mammals to be the most frequently killed animals on roads. All other investigations found amphibians to die in the largest number on roads with a relative frequency between 70.4 and 88.1 percent in comparison with other vertebrates, as demonstrated in detail in figure 1. Because dead amphibians have the greatest chance to be missed during vertebrate road-kill surveys (Kline and Swan 1998) and they presumably also have a shorter duration on roads than mammals, for example, whose furry skin and usually larger size make them visible longer, the actual ratio is probably more shifted towards amphibians (Hels and Buchwald 2001). Newts and salamanders especially can be overlooked easily due to their size and shape in spite of their frequent mass migration and road kill (Denac 2003, Evans 1989, pers. obs.).

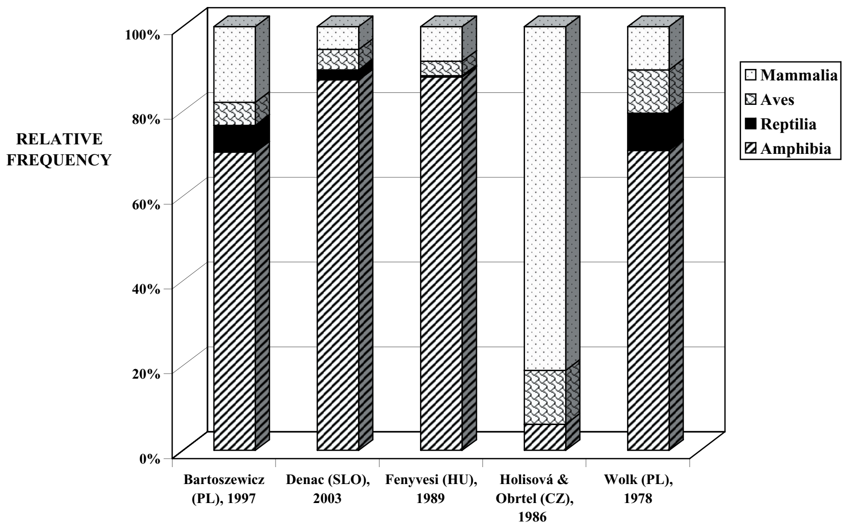

Fig. 1. Ratio of vertebrate groups in road kills in different Central-European countries.

Approaches to Lessen Amphibian Road Kill in Central-Europe

Amphibian mortality due to traffic widely occurs in Central- and Eastern-Europe, not only on public roads but also on low traffic routes. At the Gemenc section of the Danube near Szekszárd an estimated 100,000 juvenile Bufo viridis were killed in summer 1998 while migrating out from the floodplain through a 10-km dike section with a traffic density of less than five cars per hour (Puky 2000). Even in countries where the economical situation has made the building of amphibian tunnels impossible so far, several reports and articles deal with this issue. In Romania, for example, Török (1996, 1998) monitored several road sections in Dobrogea and worked out possible mitigation measures from the temporary closing of a road to a drift fence-tunnel system.

Besides the work of researchers, volunteers also make important contributions towards our knowledge in this field. This activity is best utilised in Slovenia in the region where the Center for Mapping Fauna and Flora set up a database on amphibian road mortality. As of the year 2000, 988 sites have been listed, which can be reached through the Internet (www.ckff.si/DvoCeste/dvoceste.htm). Temporary protective measures are introduced by several Polish national parks, using strong plastic material and metal poles produced by "King Frog" to set up a fence system (Wisniewski 2001). Buckets are dug into the soil at the fences to trap amphibians, which are carried over the roads manually by volunteers in the morning and during the night. In Hungary and other countries in the region, the same type of activity is organised instead by NGOs, who have patrolled dangerous road sections with or without fencing since 1987 (Puky et al. 1990).

Road-related scientific research in the region also resulted in the building of permanent mitigation measures. In 1997 a new national programme was launched in Hungary to make a systematic survey of amphibian road mortality in the most important natural areas and lessen amphibian road-kill problems there (Simonyi et al. 1999). Five surveys have been finished in the Danube - Ipoly, Körös - Maros, Balaton Uplands and Bükk National Parks (the latter also included the Mátra and the Eastern-Cserhát Landscape Protection Areas) and in the Zemplén Landscape Protection Area. In total 1,410km (4.7 percent) of state-managed roads were investigated, each section for at least 1.5 years. Each amphibian crossing point was listed and categorised. The colour code developed to describe the intensity of the migration and traffic is seen in table 2.

Table 2.
Colour code developed to describe amphibian road kill characteristics

Colour code	Number of migrating amphibians	Traffic density	Amphibian road kill	Numeric code
red	high	high	great	1.
yellow	high	medium	great	2.
violet	low	small	small	3.
grey	low	high	small	4.
green	high	small	very small	5.
blue	medium	medium	medium	6.

As a result of the surveys, new amphibian tunnels were built at a site near Ipolydamázsd where not only amphibians but also grass snake (Natrix natrix), aesculapian snake (Elaphe longissima), and smooth snake (Coronella austriaca) frequently cross the road (Puky and Vogel 2001), and a national database was developed for amphibian road kills. Professional expertise is also utilised in Poland, where detailed habitat surveys were carried out by international conservationists to determine the most important crossing sites for amphibians to provide firm scientific basis for building mitigation measures on Via Baltica, scheduled for autumn 2003 (Adrados et al. 2002).

Aims of Study

As amphibian road kill is exceptionally intensive along several road stretches in Central-Europe, such as the 8518 road at the southern shore of Lake Fertõ/Neusiedlersee, where more than 100,000 amphibians cross roads every year (Kárpáti 1988, Frank et al. 1991), mitigation measures were also applied along several road sections in the region. The first amphibian-related culvert modification occurred at Parassapuszta, Hungary, in 1986 (Csincsa 1986). It was unsuccessful due to compromises made during the construction, e.g., the low (<65 degree) angle of the concrete fence elements directing amphibians towards the culvert; individuals of all amphibian species present in the area can climb over them (Puky 1997). As Langton (1989a) established at the end of the 1980s, this part of Europe was behind in the number of amphibian-oriented mitigation measures. Since then, amphibian tunnel systems have been built in several Central-European countries especially after 1995, even if at present it is restricted to those countries that will join the European Union in 2004. The aim of this paper is to describe the main features of these constructions in Hungary, Poland, and Slovenia; overview the different designs; and make suggestions for their improvement as well as for future amphibian-oriented mitigation measures in general.

Sites and Methods

Sampling Sites and Dates

Different mitigation measure types were surveyed. The distribution of the investigated permanent amphibian mitigation measures can be seen in figure 2. It includes all Hungarian amphibian tunnels built until 2000 both by road or conservation authorities, the first Polish amphibian tunnel system opened in spring 2003 and two Slovenian sites. Amphibian-specific, but temporary amphibian mitigation measures, which are known both in Europe and North-America (see, e.g., Ballasina 1989, Linck 2000), together with game passages, game bridges, and a viaduct, were also studied. Hungarian mitigation measures were visited at least three times between March 26 and August 18, 2000. Several more field trips have been carried out since then at some sites. Polish and Slovenian mitigation measures are described on the basis of site visits and expert interviews in 2002 and 2003, an article of Baldy (2002), a manuscript of Mleczko-Król (2003), and a report of Adrados et al. (2002).

Fig. 2. Distribution of amphibian mitigation measures on roads in Hungary, Poland, and Slovenia.

Technical Parameters Recorded
Technical descriptions included short, general remarks: material, length, width and height (or diameter) of the tunnels; type of the tunnel head; material, height, length, mesh size (if applicable) of the fences; general status; suggested improvements; and other remarks.

Herpetological Methods
Six internationally accepted methods were used to study amphibians (Fellers and Freel 1995, Griffiths and Langton 1998, Heyer et al. 1994, Olson et al. 1997). Road transects (e.g., determining and counting live and dead amphibians on hard surface roads) made during both day and night (Puky 2001) along the mitigation measures was the most important method. To get information on population sizes, visual encounter surveys focused on nearby aquatic habitats were carried out at each site. Audial surveys, based on the cassette of the MONITOR2000 training kit (Anthony and Puky 2001), also proved to be a useful additional method. Certain species (e.g., Hyla arborea) are the easiest to detect with this method and distinguishing between the taxa in Rana esculenta "complex" is also possible on the basis of differerences in sounds (Wycherley et al. 2002). Torching and netting were done to collect newts in their aquatic phase by night and by day, respectively.
To estimate the number of individuals, the transect method was used. Data were recorded in data sheets; habitats and mitigation measures were photographed. If adequate data could be collected, two indices were calculated to describe the effectiveness of the mitigation measures. Besides the relative importance of mortality caused by traffic (Mv), which was made from the estimated number of killed animals and the estimated population size, P efficiency (Ep) was also used. It expresses to what extent the mitigation measure decreases road kills and is made as follows:

Ep=100 x [1-(No. of killed animals after construction /No. killed animals before construction)]

Earlier data are needed to make such comparisons, but it is useful on existing roads and after modifications, as well. It is also applicable at a smaller scale (e.g., fences), and it is easier to make than the mortality estimate.

Results
Altogether, 31 mitigation measures were monitored. Results on amphibian tunnels are presented in table 3. Game passages, game bridges, and temporary mitigation measures were also investigated (see photos 1-6, mitigation measures in Central-Europe). All investigated systems are evaluated together according to the main structural and functional elements of the mitigation measures (tunnels, fences, tunnel-fence connections).

Table 3.
Location and type of permanent amphibian mitigation measures on roads in Hungary, Poland, and Slovenia.

Location	Road Type	Tunnel				Fence			Remarks	Suggested Improvement
		Number	Material	Length (m)	Diameter (m)	Material	Length (m)	Height (cm)		
Mosonszent-miklós Hungary	motorway	3	concrete metal	34, 34, 36	1	concrete	120	60	tunnel and fences in good condition but two entrances are above ground level	entrance modification
Lébény Hungary	motorway	1	concrete	39	1	concrete	50	60	tunnel and fence in good condition	
Kál Hungary	motorway	11	metal	35.7 - 40	0.95	plastic mesh	1,700	50	tunnels, tunnel heads and most fences are in good condition	replacement of damaged fence elements (plastic mesh and poles)
Hont Hungary	main road	1	concrete	12	1.5 x 1.9	concrete	150	60	tunnel in good condition, fence inappropriate and only on one side	modification and addition of fences
Sződ Hungary	highway	1	concrete	13.05	12.05 x 2.24	plastic mesh	100 + 400	60	fences do not reach the tunnel	creating tunnel - fence connection, replacement of damaged fences
Nagyiván Hungary	main road	1	concrete	15	0.6	plastic mesh	40	65	tunnel and fence in good condition	
Nagyiván Hungary	main road	1	concrete	15	0.6	plastic mesh	42	65	missing fence elements	substitution of missing elements
Hortobágy Hungary	main road	1	concrete	15	0.6	plastic mesh	300	65	erosion damaged tunnel entrance and fences on one side	replacement of damaged elements, improvement of tunnel entrance
Ipolydamázsd Hungary	lower road	3 + 1	concrete	6.5	0.72 x 0.62	plastic mesh	386	60	vegetation push down fences	replacement of fence elements
Ipolydamázsd Hungary	lower road	2	concrete	6.5	0.72 x 0.62	plastic mesh	86	60	missing fence elements	substitution of missing elements
Fertőboz Hungary	lower road	5	concrete	8-9 + 5	0.8 x 0.95 or 0.4	polythene, concrete	450	60-65	new tunnels and new, concrete fences	
Lébény Hungary	lower road	2	concrete	8.8	1.3 x 0.6	polythene, concrete	-		tunnels are in good condition, fences missing	building fences
Lébény Hungary	lower road	1	concrete	8.8	1.3 x 0.6		-		tunnels are in good condition, fences missing	building fences
Lébény Hungary	lower road	2	concrete	8.8	1.3 x 0.6		-		tunnels are in good condition, fences missing	building fences
Kudowa Zdrój Poland	lower road	4	concrete	7	1 x 0,56	concrete	220	47	most modern tunnel system in the region, design also support research	
Sentjur pri Celju Slovenia	lower road	2+3	concrete	8.57	0.48				one tunnel blocked by rubble, fences missing	remove rubble, building permanent fences
Ljubljana Slovenia	motorway	?	concrete	28	0.63 -0.58				tunnel entrance highly overgrown, fences missing	building permanent fences

Photo 1. Amphibian measure with 45 degree angle fence arrangement along the M3 motorway, Hungary.

Photo 2. Game bridge over the M1 motorway, Hungary.

Photo 3. Game passage under the M3 motorway, Hungary.

Photo 4. Game passage with amphibian fence under the M15 road, Hungary.

Photo 5. Modern amphibian mitigation measure at Kudowa Zdroj, Poland.

Photo 6. Modified viaduct for game and amphibians at Domzale, Slovenia.

Discussion

All amphibian species living in the region have been reported to suffer from road kill (Ballasina 1989, Kárpáti 1988, Ryser and Grossenbacher 1989, Schád et al. 1999, Scoccianti 2001). Similar to other regions, the most common species die the most frequently on Central-European roads. According to the local conditions, it is usually the common toad (Bufo bufo) and the agile frog (Rana dalmatina) or green frogs (Rana esculenta c.) and the green toad (Bufo viridis), as can be seen in figure 3 (Puky 2001). Road kill, combined with other factors, usually causes decline (Schád et al. 1999), but it can also be a very important factor in the process. In the Karst of Trieste a considerable difference was found between the presence of Rana esculenta complex on the Slovenian and the Italian side (Bressi 1999). A factor responsible for this difference was the higher density of the road network in Italy. Though it is rather unusual, in some cases road kill can also be the single reason for decline, such as in the Austrian Alps (Landmann et al. 1999). Due to these facts the efficiency of mitigation measures is crucial to prevent or at least slow down the rate of amphibian decline in the region. Mitigation measures are discussed below according to their structural elements (tunnels, fences) and function, followed by recommendations for their building and maintenance.

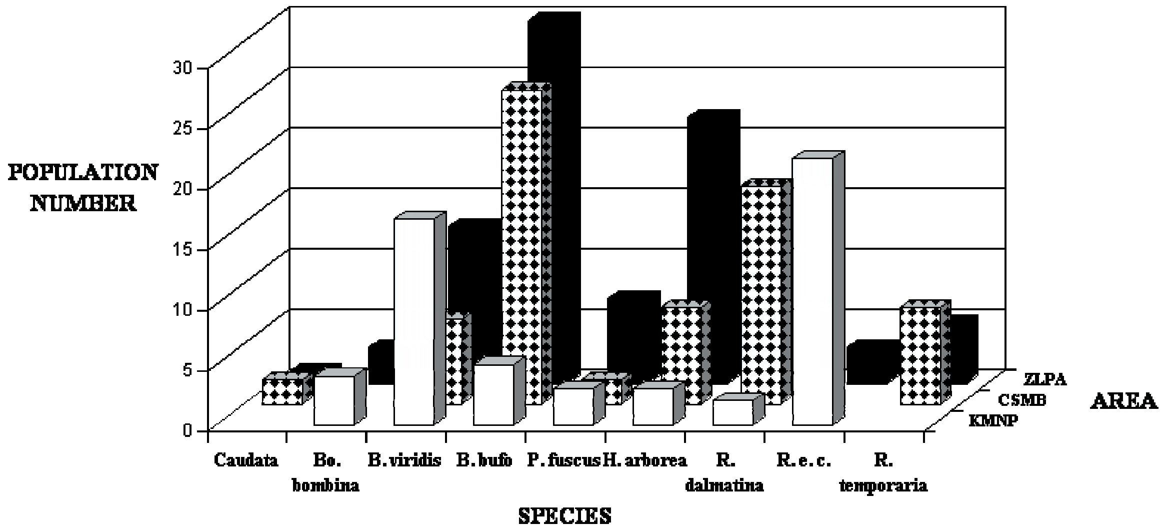

Fig. 3. Number of amphibian populations crossing roads in three protected regions in Hungary.

(Bo=Bombina, B=Bufo, P=Pelobates, H=Hyla, R=Rana, R. e. c.=Rana esculenta complex, KMNP=Körös – Maros National Park, CSMB=Bükk National Park including the Eastern-Cserhát and the Mátra Landscape Protection Areas, ZLPA=Zemplén Landscape Protection Area)

Tunnels

The investigated tunnels showed a great diversity in many characteristics, such as length, diameter, and their connections to the fences (see photos 7-10, amphibian tunnel types in Hungary). In spite of this diversity, there was no one-way tunnel, which was often created, e.g., in Switzerland until the 1980s (Ryser and Grossenbacher 1989), among the investigated mitigation measures. According to Dexel (1989), this can be considered a positive development because two-way tunnels with large cross-sections would seem to represent a better solution since those systems enjoy a higher degree of acceptance by migrating amphibians (Dexel 1989). Most amphibian tunnels have been made from concrete in the investigated countries (potential future amphibian crossing sites utilising existing structures; however, they also include some metal tunnels made, e.g., at stream crossings.). It is the most economical solution, and another advantage is that making similar structures, e.g., to lead rainwater from a steep hillside under the road to a lowland area, is part of the day-to-day engineering practice. At the same time, however, this fact can lead to the lack of consultation on making the plans or even more often on building the systems, which may result in inadequate solutions.

Both circular and square cross-section tunnels were made in the region with the diameter ranging from 0.48m to 1m (The two larger-size amphibian mitigation measures are a culvert modification and an amphibian-oriented stream crossing design.). They are larger than the tunnels built in Lower Saxony between 1979 and 1982 (Stolz and Podloucky 1983), as figure 4 demonstrates. It is again a positive development, showing that experience gained elsewhere has successfully been transfered into the region as a larger proportion of toads use larger tunnels than smaller ones (Dexel 1989).

Photo 7. Circular tunnel opening and concrete fence.

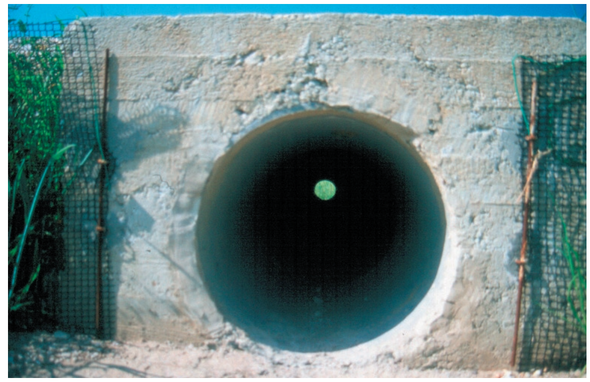

Photo 8. Circular tunnel opening and plastic mesh fence fixed by metal pole.

Photo 9. Circular tunnel opening, plastic mesh fence fixed by wooden pole.

Photo 10. Square culvert opening with concrete fence set up for directing amphibians into the culvert.

The accessibility of the entrance is a key issue in keeping the tunnels functional, especially in areas where erosion is considerable. Where it is unavoidable and a lot of material is expected to get into the tunnels, more regular maintenance is necessary. The positioning of the tunnel entrance is an important characteristic, too. If it is above the ground, i.e., animals should climb or jump to reach it, amphibians can move farther along the fences without entering. This problem can be solved by minor additional concreting and the proper setting up of the fences.

Length is a most crucial element of an amphibian tunnel, too, especially at multi-lane roads and motorways, where the shortest possible ways are favoured. If the tunnel is longer than 20m, then the diameter should be increased. According to the literature, openings that provide better light conditions are important because several species show tunnel hesitation in connection with such changes (Jackson and Tyning 1989, Langton 1989b). In spite of observing this phenomenon, however, Jackson (1996) measured a 76-percent crossing success for Ambystoma maculatum through 0.2m-diameter polymer concrete tunnels. In Europe the same design was used by 12-45 percent of individuals from different species (Brehm 1989).

Light shafts are applied in the region, especially at motorways, where they can be put between the sides without getting into conflict with the traffic. In lower roads, where cars can get into direct contact with the lids, accidents can happen. On the 8518 road of Hungary two lids broke, and one seriously damaged a car. A good compromise to solve this problem is to put this structure into the road shoulder instead of the middle of the road as on road 1201 in Hungary.

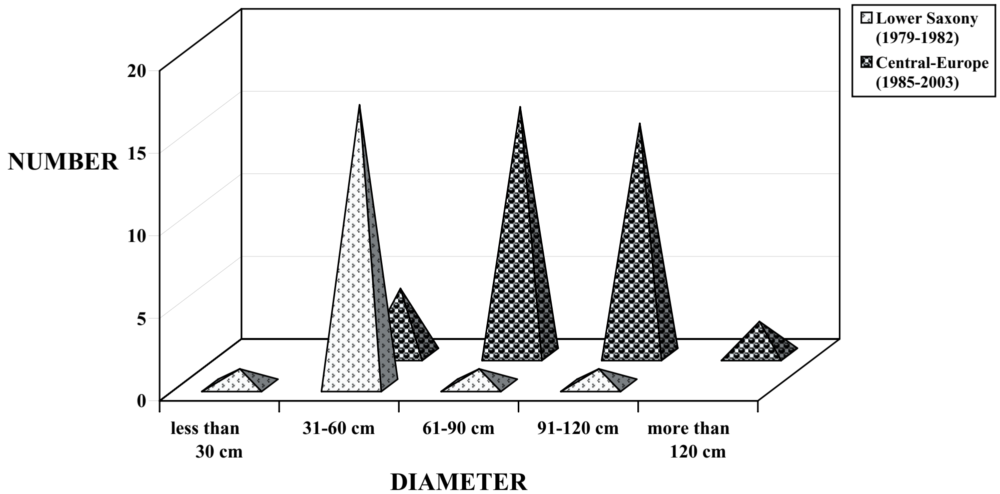

Fig. 4. Diameter of amphibian tunnels in Central-Europe (1985-2003) and in Lower Saxony in 1979-1982 (Stolz and Podloucky 1983).

Fences

Similar to what was found in other studies (e.g., Ryser and Grossenbacher 1989), fences were key elements of the investigated amphibian mitigation measures because their realisation, size, positioning, and condition basically determine the success of the system. They can be quite effective. For example, Arntzen et al. (1995) found that 69 percent of Triturus cristatus could be directed by fences according to their age, migration direction, etc. With the exception of concrete fences, good maintenance fundamentally determines fence durability as weather or human influence can affect durability the most.

Four materials were recorded to use for building fences: concrete, plastic mesh, small mesh wire and polythene (see photos 11-15, amphibian fences in Central-Europe). Concrete elements are the most durable and also need the least maintenance; however, they are by far the most expensive and were installed only at 22.5 percent of the investigated sites (figure 5). Plastic mesh fences are of medium durability and cost, while polythene fences should be built in every migration season. In nearly 20 percent of the cases no fences were set up, which makes the complete mitigation measure without any conservation use. The optimal height of the fences is 45-60cm. The fences should be erected vertically, with the bottom 10cm buried into the ground to avoid amphibians getting onto the road under the fence. The top of the fence should be bended towards the direction the animals are expected to arrive in order to prevent amphibians from climbing over, as was also suggested by Haslinger (1989). Fixing the fence is usually done with the help of wooden poles. A potential problem with this design is that it loosens, which should be checked and repaired regularly. Plastic fences are known to need regular maintenance and repair. In Denmark, Briggs and Friesenvaenge (1999) found that after a year many plastic fences were broken by erosion, people, and unknown factors, and rodents made many holes under the fence. On the other hand, an advantage of plastic fences is that they are flexible, and at practically any site, their ends can be turned back to avoid fenced animals from getting on the road where the fences end.

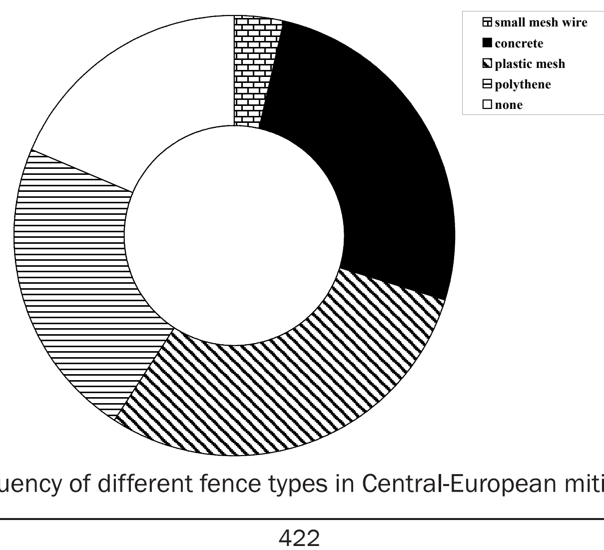

Fig. 5. Relative frequency of different fence types in Central-European mitigation measures.

Photo 11. Concrete fence on motorway, Hungary.

Photo 12. Plastic mesh fence on main road, Hungary.

Photo 13. Polythene fence set up by Boy Scouts.

Photo 14. Small mesh wire fence in Slovenia.

Photo 15. The end of the fence is turned back to prevent amphibians from getting onto road.

Tunnel - Fence Connections, The Analysis of the Systems

The investigated tunnel systems considerably differed, e.g., in their size, their position in relation to the road, and connections between the elements. Some systems did not work because fences were missing, their orientation was inappropriate, or they were in bad condition. The distance between tunnels is a key characteristic of the given mitigation measure. In this study the lowest value recorded was 40m at Kudowa Zdrój, Poland (not taking into consideration site 12, 14 and 17, where fences have never been erected, and as such, they have not functioned as amphibian mitigation measures). From a biological viewpoint, the migration radius of amphibians to their breeding site should be decisive in this matter. As amphibian species living in Central-Europe migrate 0.3 and 2.2km on average (Blab 1986, Nöllert and Nöllert 1995, Verkehrsministerium Baden-Württenberg), 80-100m can be considered as the optimal distance between tunnels, which is also influenced by the angle at which fences and tunnels meet (45 degrees can be considered optimal, if it is possible to use the area next to the road). Some species showed a very low rate of using tunnels, e.g., only 12 percent of Triturus vulgaris (22-45 percent of other European species) crossed through a 0.2m-diameter polymer concrete tunnel (Brehm 1989). As T. vulgaris was reported to cross tunnels in other cases, too (Meinig 1989), so fragmentation can be compensated even with that species having a small migration radius if tunnels are nearer to each other, especially if additional habitats are made (Bekker et al. 2001). With one exception, the distance between tunnels were within the optimal distance in the studied Central-European amphibian mitigation measures. The durability and type of tunnel-fence connections are also important. Problems in the functioning of the mitigation measures often originated from improper guidance of amphibians into the tunnels. Similar to what Briggs and Friesenvaenge (1999) reported from Denmark, gaps between fences and tunnels occured at some Central-European sites with the extreme of 50m. Naturally, the efficiency of those systems were extremely low. As shown in previous works, the present study also proves that amphibians crossed mitigation measures with considerably different characteristics. In case of adequate fencing and development of other appropriate conditions (Jackson 1996), game passages, game bridges, and viaducts would also be adequate for the crossing of amphibians as well as reptiles and small mammals similar to slightly modified existing culverts (Yanes et al. 1995). An excellent example for such additional conservation improvement is Viaduct Blata on the A1 motorway at Domzale, Slovenia, where small mesh wire fencing directs amphibians under the road (refer to photo six, mitigation measures and photo 14, fences). Small water bodies are also present on the way to the other side, which most probably also improves the stepping stone function of the viaduct for crossing amphibians. Along high road mortality sections there is a chance and need for such conservation improvements (e.g., setting up amphibian fences) at several sites (e.g., on the M1 motorway in Hungary) after intensive consultation with other experts. This work is on the way on the A4 motorway in Poland (Elmeros et al. 2003), where game bridges and tunnels were created for the first time in the country in 2002 (Mleczko-Król 2003).

Recommendations for Buiding and Maintenance of Effective Amphibian Mitigation Measures

On the basis of the investigated Central-European mitigation measures the following recommendations are to be considered and applied to local (e.g., geographical, hydrological, financial, etc.) conditions to secure maximal efficiency. They have been made for all fence and tunnel types; consequently, not every statement is valid for all systems (e.g., mesh size for concrete fences).

1. The mitigation measure should be in the centre of the usual migration routes. However, as there might be alterations between years according to the actual meteorological conditions, a thorough analysis of landscape elements (ponds, streams, amphibian-directing earth roads, etc.) with a special emphasis on hydrological characteristics should be made in the decision-making process together with the results of field surveys on amphibian migration characteristics.
2. Recommended tunnel size is 100cm x 60cm or 100cm in diameter; both rectangular or circular tunnels are appropriate. If the tunnel is longer than 20 m, its size should be larger up to 200cm x 150cm or 200cm in diameter.
3. Tunnels are above the water table and they are not flooded.
4. Tunnels are easily accessible because the tunnel floor is not above the ground.
5. Concrete or polymer concrete is used to build tunnels.
6. Light shafts or holes help optimal conditions inside the tunnels (see photos 16-18, light shafts in Hungarian roads).
7. Distance between tunnels is determined on the basis of the migration radius of the target species; under normal conditions this is 80-100m.
8. Fences lead amphibians to the tunnels.
9. Fences are erected at both sides of the road.
10. Fences are 50-60cm high; there are no gaps in them or between the fences and the tunnels.

11. The bottom 10cm of the fence is buried into the ground; animals cannot crawl under it.
12. The top end of the fences are turned towards the side from which the amphibians are expected to migrate in order to prevent them from climbing over the fence.
13. The end of the fences are turned back to avoid amphibians from getting on the road.
14. The mesh size of plastic mesh fences is not more than 4mm.
15. Amphibians getting on lower roads are also protected by temporary signs during migration.
16. Tunnels should be cleaned every year.
17. According to local latitude and altitude, In the temperate zone of the Northern Hemisphere, the most suitable time for cleaning the tunnels ranges from early March (occasionally late February) to April.
18. Fences should be checked regularly.
19. Vegetation should be removed from the fences.
20. Missing fence elements should be replaced even if the amphibian migration is over.

Photo 16. Circular light shaft in the median of a motorway.

Photo 17. Circular light shaft on a lower road.

Photo 18. Diagonal light shaft in the median of a motorway.

Besides the above described recommendations, two additional conclusions are important to stress here.

21. A close cooperation between engineers and biologists specializing on amphibians is vital from the planning phase to the actual construction of the mitigation measure in order to overcome unforeseeable problems and to find mutually acceptable solutions. Further, negotiations among different agencies and organisations and the exchange of expertise are urged on this matter, nationally as well as internationally.
22. Especially if the mitigation measure is built in at a lower road, it is important to inform local people as well as the general public on the aim, benefits, and functioning of the mitigation measure to get social support. At the beginning of the 21st century the improvement of public relation activities on fauna passages is vitally needed for the effective protection of wildlife on roads.

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