Evaluating factors affecting amphibian mortality on roads: the case of the Common Toad *Bufo bufo,* near a breeding place

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Santos, X., Llorente, G. A., Montori, A., Carretero, M. A., Franch, M., Garriga, N. & Richter–Boix, A., 2007. Evaluating factors affecting amphibian mortality on roads: the case of the Common Toad *Bufo bufo,* near a breeding place. *Animal Biodiversity and Conservation*, 30.1: 97–104.

Abstract

Evaluating factors affecting amphibian mortality on roads: the case of the Common Toad, Bufo bufo, *near a breeding place*.— The Common Toad *Bufo bufo* is the amphibian with the highest rates of road mortality in many European countries. This elevated incidence of road kills has frequently been associated with migration to breeding sites. In this study, we analysed the mortality of the Common Toad in the road network in Catalonia (NE Spain), and investigated the related causative factors on four roads near a breeding site in the Pyrenees. Results suggest that the high mortality rate is due to a combination of factors: toad abundance, traffic density and quality of water bodies for breeding. On the road with the highest incidence of road kills we investigated whether deaths occurred at specific spots or in a random manner. The road was divided into 500 m sections and each section was classified according to biotic (type of vegetation) and abiotic (presence of streams, roadside topography) variables. Multiple correspondence analysis showed that sections with streams crossing under the road had the highest mortality rate, suggesting that such water bodies flowing into the breeding pond are the toads' main migratory pathways for hibernation and breeding. As toads use the same migratory routes each year, it is critical to identify areas with a high potential mortality so that efficient measures can be designed to increase wildlife permeability, and thereby reduce habitat fragmentation. This methodology could be applied in other areas with high amphibian mortality.

Key words: Amphibian, Common Toad, *Bufo bufo*, Landscape fragmentation, Migration, Mortality, Road permeability, Pyrenees.

Resumen

Evaluando los factores que afectan a la tasa de mortalidad en la carretera: el caso de Sapo Común Bufo bufo*, cerca de un área de reproducción*.— El Sapo Común *Bufo bufo,* es el anfibio con mayor tasa de mortalidad en la carretera en numerosos países de Europa. Esta elevada mortalidad se debe principalmente a las migraciones que realiza hacia las zonas de reproducción. En este estudio se analiza la mortalidad del Sapo Común en la red de carreteras de Cataluña (NE España) y más específicamente qué factores influyen sobre dicha mortalidad en cuatro carreteras cercanas a un punto de reproducción en los Pirineos. Los resultados sugieren que la alta tasa de mortalidad se debe a la combinación de tres factores: abundancia de sapos, densidad de tráfico y calidad de los puntos de agua para la reproducción. En la carretera con mayor índice de atropellos, se analizó si existía agregación en los animales atropellados o estos se distribuían al azar. Para ello, la carretera se dividió en tramos de 500 m, cada uno de los cuales se caracterizó por el tipo de vegetación circundante, así como otros factores que pudieran influir sobre la migración de los sapos (p. e. inclinación del margen de la carretera, presencia de riachuelos, etc.). El análisis de correspondencias múltiple demostró que los tramos con torrentes cruzando bajo la carretera presentaban mayor mortalidad. Esto sugiere que dichos torrentes son las vías principales usadas por los sapos para acudir a los puntos de reproducción. Dado que los sapos utilizan cada año las mismas vías migratorias, es fundamental identificar dichos puntos para predecir cuáles presentan mayor mortalidad potencial y así diseñar más eficazmente los mecanismos de permeabilidad para la fauna en las vías de comunicación. Esta metodología puede ser aplicada a otras zonas con elevada mortalidad de anfibios en la red de carreteras.

ISSN: 1578–665X

Palabras clave: Anfibio, Sapo Común, *Bufo bufo*, Fragmentación del paisaje, Migración, Mortalidad, Permeabilidad de la carretera, Pirineos.

(Received: 13 XII 06; Conditional acceptance: 14 II 07; Final acceptance: 18 III 07)

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Introduction

Wildlife road mortality has been extensively studied and there is general consensus that it dramatically affects amphibians (Ehmann & Cogger, 1985; Fahrig et al., 1995; Hels & Buchwald, 2001; Montori et al., 2001; PMVC–CODA, 2003; Seiler, 2001; Trombulak & Frisell, 2000). Studies devoted to amphibian road kills have detected the most vulnerable species, identified "black spots" in the road network (for Spain, see Lizana, 1993; Lizana & Barbadillo, 1997; PMVC–CODA, 2003) and proposed strategies to reduce mortality on roads (see Langton, 1989a). Mortality of amphibians, reptiles and other vertebrates has recently been assessed in short segments of roads by standardized field surveys (Carretero & Rosell, 2000; Clevenger et al., 2003; Montori et al., 2004). This methodological approach identifies the species most vulnerable to road traffic, predicts the possible demographic effects of road mortality on species (i.e. population reduction, extinction, fragmentation) (Fahrig et al., 1995; Seiler, 2001; Trombulack & Frissell, 2000; Wilson, 1988) and provides useful information for developing correction measures to reduce mortality (Langton, 1989b; Vogel & Puky, 1995).

The Common Toad *Bufo bufo*, present in most parts of Europe, is the amphibian with the widest Palaearctic distribution (Lizana, 2002). It is abundant and unfortunately the amphibian most frequently found dead on roads in many European countries (Langton, 1989a). *Bufo bufo* mortality has frequently been associated with migration to breeding sites (Feldmann & Geiger, 1989; Orlowski, 2007; Van Gelder, 1973), when hundreds of specimens are killed by traffic during the reproductive period (Cooke, 1995; Frétey et al., 2004). However, reports on biotic (i.e. vegetation) and abiotic (i.e. roadside topography) data related to toad mortality are scarce (Clevenger et al., 2003). This aspect is relevant, since every year toads use the same migratory pathways from hibernation to breeding sites. Areas with migratory routes that present potentially high mortality should be determined and efficient measures should be adopted to reduce road kills.

The aims of this study were: 1) to detect road mortality of the common toad in the study area, 2) to determine the influence of traffic density on toad mortality and, 3) to examine whether road kills occurred randomly or at specific spots related to toad migratory pathways.

Material and methods

The study was conducted in La Pobla de Segur (542 m a.s.l., Lleida province, Spain), a mountainous region located in the Pyrenees (41º 15' N and 0º 58' E, fig. 1). Field work was carried out in the valley of the Noguera Pallaresa River, in an area where the river forms the Sant Antoni reservoir (267 hm^3). The topography is moderately abrupt with several streams that flow into the reservoir. Potential vegetation is composed of oak (*Quercus faginea*) although often replaced by pine plantations (e.g. *Pinus nigra*) and, in areas with low slope, by agricultural fields. All the roads studied in this work were surveyed by car at 20 km/h speed and recently killed common toads and other amphibians were recorded. At this speed it is possible to observe all kind of road–kills, hence avoiding biases due to the size of the amphibian species sampled (see Montori et al., 2001 for methodological details).

To determine whether the common toad mortality was important with respect to other amphibian causalities in the study area a 20–km stretch of a road near La Pobla de Segur was surveyed every two weeks from May 2000 to April 2001, to detect the species with highest mortality rates. *Bufo bufo* road kills in the study area were compared with respect to results on another 45 roads in the Catalan road network , using the same methodology (Montori et al., 2004).

To find whether traffic density and size of breeding sites were relevant factors to explain toad mortality dead toads were searched in four stretches of road around La Pobla de Segur. These roads differed in traffic density and type of breeding pond (fig. 1): a. C–13, between La Pobla de Segur and Tremp (11 km), the main road, running alongside the dam, with high traffic density as it links big cities further south (Barcelona, Lleida) with the tourist area of the Pyrenees; b. N–260, from La Pobla de Segur in the direction of Sort (5 km), with the same traffic density but running close to the Noguera Pallaresa River; c. N–260, from La Pobla de Segur going towards Senterada (5 km), with half the former traffic density and running close to the Flamisell River, a medium–size river which flows into the Noguera Pallaresa River in La Pobla de Segur, and d. A local road from La Pobla de Segur to Aramunt (7 km), with low traffic density, running alongside the dam on the opposite side to that of the C–13. No correction measures to reduce wildlife mortality (e.g. drift fences and tunnels) have been adopted on these roads to date. The common toad is an explosive breeder (Wells, 1977) that selects spring periods with high temperature and rainfall to move from hibernation to breeding sites (Sinsch, 1988; Zuiderwijk, 1989). For this reason, these four roads were surveyed during the peak of migratory activity, which occurred on 5–7 April 2001, during a rainy episode, when hundreds of specimens migrated from hillsides to the dam for breeding. Mortality on these four roads was compared by the number of killed toads per km, IKA (see Carretero & Rosell, 2000).

To assess whether toad road kills were randomly distributed on roads running close to breeding points we studied only the C–13 stretch between La Pobla de Segur and Tremp as it runs alongside the dam (fig. 1) and showed the highest IKA score. The 11 km section between these two localities was divided into 500–meter segments and toads were

counted in each of them. Segments were separately characterized according to the type of vegetation, type of roadside, roadside slope, presence of local roads and presence of streams that cross under the road. Association between these variables and the abundance of toads was assessed by a multiple correspondence analysis.

Results

Common toad mortality in the Pyrenees

On the road surveyed from May 2000 to April 2001, we found three species of amphibians in road kills: the midwife toad *Alytes obstetricans*, the common toad *Bufo bufo* and the common frog *Rana temporaria*. Most of the species present in this area (Llorente et al., 1995) were thus affected, although the common toad was that most frequently killed (92% of occurrence). Consistent with these results, preliminary data of standardized transects on 45 roads in Catalonia (NE Spain) showed that the common toad *Bufo bufo* is the amphibian most frequently killed on roads (29% of observations, n = 1,240, unpublished data from the authors) in this area. Half–mountainous and rainy regions as our study area showed the highest mortality rates of common toads in Catalonia.

Toad mortality related to traffic density and breeding sites

The numbers of *Bufo bufo* found killed on the four roads surveyed is shown in table 1. The IKA scores revealed differences between roads according to traffic density and potential reproductive sites. Roads with high density traffic reached high IKA scores when they ran close to the dam (C–13 road), whereas they showed lower values running alongside rivers (N–260 from La Pobla de Segur to Sort). Furthermore, the local road from La Pobla de Segur to Aramunt ran close to the reservoir and, despite its low traffic density, the IKA score was higher than in the N–260 road.

Factors affecting toad mortality

In the C–13 road (La Pobla de Segur–Tremp), 99 common toads recently killed in the 11 km section were recorded. Toads did not appear randomly along the road. The number of toads did not increase from the closest to the farthest segment to the head of the dam (Spearman r = 0.04, p = 0.8, n = 21). Although there were toads in all the segments, the distribution differed significantly between them (range from 1 to 23 toads), suggesting that certain spots concentrated many specimens. The multiple correspondence analysis (fig. 2) revealed that segments with high mortality were characterized by: 1) the presence of streams crossing under the road, 2) low slope of the roadside, and 3) vegetation characterized by a mosaic of natural vegetation and agricultural lands. The variable best associated with mortality was the presence of streams crossing under the road. Segments with a stream had more kills than those without (median = 5, mean = 8.9 ± 2.8 toads in 7 segments with stream; median = 2, mean = 2.5 ± 0.4 toads in 14 segments without stream; Z = 10, p = 0.004).

Discussion

Differences in the numbers of amphibians killed on different roads may be due to several factors as toad abundance and quality of breeding ponds in the road vicinity. Stretches of N–260 exhibited fewer road kills than C–13 and the local road (table 1). These differences suggest that toad populations are smaller in the vicinity of mountainous rivers like the Noguera Pallaresa and the Flamisell than in the hills around the dam. In Poland, road–kills were closely related to toad abundance and to the size of water bodies for breeding (Orlowski, 2007). Our results agree with these conclusions as the Sant Antoni reservoir is the biggest water body for breeding in the study area as mountainous rivers have only small ponds for breeding due to the water–speed. This finding supports the fact that the presence of quiet or slow–moving water seems to be *Bufo bufo's* only requirement for breeding (Augert & Guyetant, 1995; Lizana, 1997). Reservoirs in the Pyrenees like the Sant Antoni dam seem to be suitable water bodies to maintain important breeding populations of the common toad. Differences in toad road kills between the two roads that run alongside the dam (C–13 and the local road, fig. 1 and table 1) support the role of traffic density in toad mortality as has been extensively reported (Fahring et al., 1995).

Intensive surveys of roads near the breeding ponds proved an effective method to detect migratory paths from hibernation sites to reproductive ponds. In the study area, we detected that common toads followed small streams to move from hibernation to breeding sites. Generally, toads exhibit a high fidelity to their natal pond (Sinsch, 1989) and, like other amphibians, non–random migratory routes through specific corridors are followed every year (Langton, 1989b; Dodd & Cade, 1998; De la Torre & Sobrino, 2001). The streams that flow into the Sant Antoni reservoir in La Pobla de Segur seem suitable routes for toad migration because amphibian displacements are sensitive to all barriers, both natural and anthropic (Sinsch, 1988, 1992; Ray et al., 2002), whereas natural routes originated by rivers present few obstacles. Measures to minimise toad mortality should focus on spots where streams cross under roads near the breeding sites. The section with the highest number of killed toads in the C–13 road includes a hillside of 40º slope with herbaceous and shrub vegetation. In this section, a stream crosses under the road through a 30 m long, 10 m wide, and 8 m high tunnel. High mortality in this spot was detected in previous visits, most

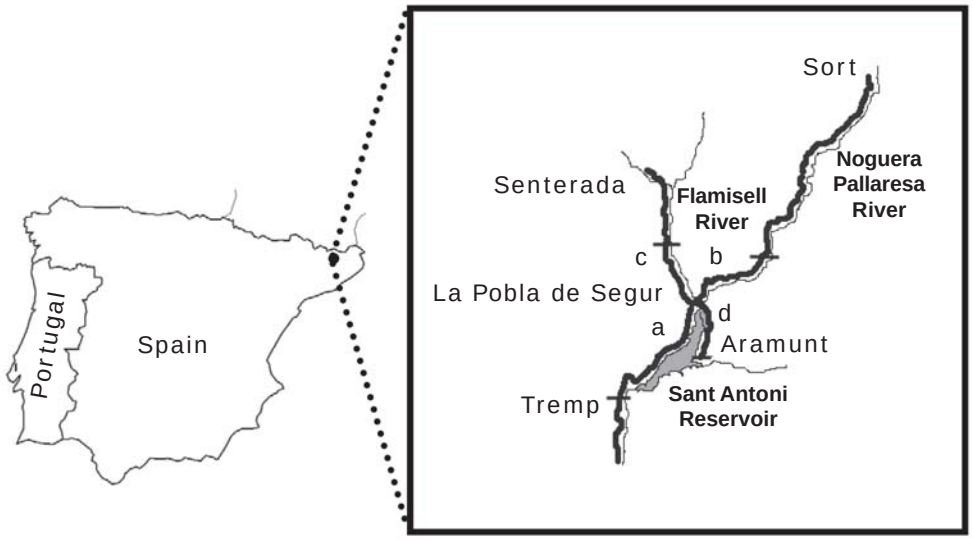

Fig. 1. Map of the breeding pond and the four roads around La Pobla de Segur surveyed for toads: a. C–13 from La Pobla de Segur to Tremp (11 km); b. N–260 from La Pobla de Segur in the direction of Sort (7 km); c. N–260 from La Pobla de Segur going towards Senterada (5 km); d. A local road from La Pobla de Segur to Aramunt (5 km). (For more information see Material and methods.)

Fig. 1. Mapa del punto de reproducción y las cuatro carreteras alrededor de La Pobla de Segur donde se han buscado sapos atropellados: a. C–13 desde La Pobla de Segur a Tremp (11 km); b. N–260 desde La Pobla de Segur en dirección a Sort (7 km); c. N–260 desde La Pobla de Segur hacia Senterada (5 km); d. Carretera local desde La Pobla de Segur a Aramunt (5 km). (Para más información ver Material y métodos.)

toads were dry carcasses which persisted for weeks after death although corvids and other scavengers had removed part of the specimens (Slater, 1989, 1994, pers. obs.). In April 1998, 2000 and 2001, this point had been visited and 64, 46 and 82 kills were detected, respectively implying that multiple road kills occurred every year at this point and suggesting that the stream crossing the road in this section could be a key migratory pathway for common toads. Unfortunately, we lack information concerning the proportion of the breeding populations which were killed by traffic. However, the fact that the road is not new suggests that a sufficient number of specimens manage to cross the road annually and road kills are not of particular relevance for the breeding population.

Other results are, however, interesting in other ways. Despite the existence of tunnels for streams, many toads climbed the embankment onto the road and were killed by traffic. This observation suggests that road permeability by big tunnels is not always an effective measure to prevent toad mortality during migration. The use of some sort of low fencing or barrier to prevent road access for migrating amphibians and ideally guide them to a tunnel entrance may contribute to decreasing toad mortality (Galet, 1995; Marshall et al., 1997; Rosell et al.,

Table 1. Number of common toads *Bufo bufo* killed and IKA scores (no. / km) of four roads in La Pobla de Segur (Lleida, Spain): R. Road; L. Length, in km; Td. Traffic density; N. Number of killed toads; IKA. Number of killed toads per km. (For other abbreviations see fig. 1.)

Table 1. Número de sapos comunes Bufo bufo *muertos y valor IKA (nº individuos / km) en cuatro carreteras alrededor de La Pobla de Segur (Lleida, España): R. Carretera; L. Longitud, en km; Td. Densidad de tráfico; N. Número de sapos muertos; IKA. Número de sapos muertos por km (Para otras abreviaturas ver fig. 1.)*

R	L	Td	N	IKA
a	11	High	99	9.0
b	5	High	3	0.6
c	5	Medium	4	0.8
d	7	Low	9	1.3

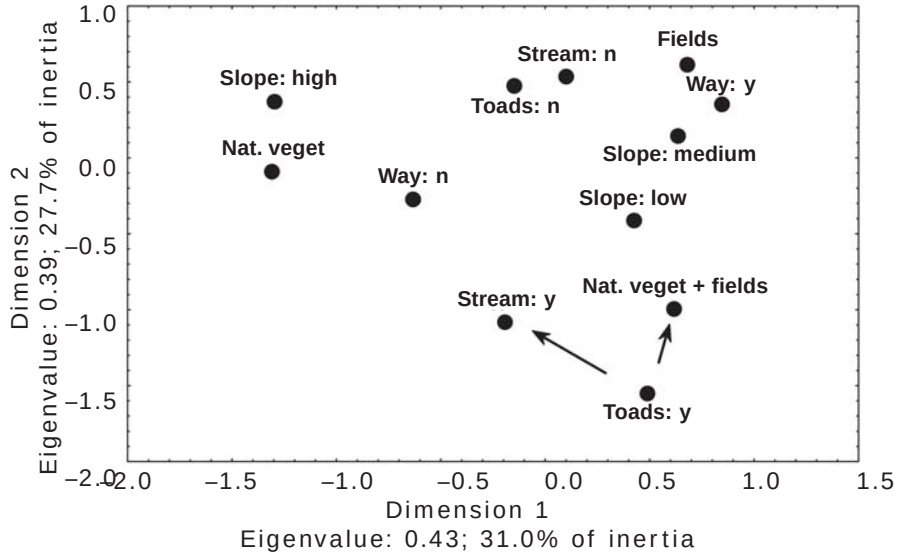

Fig. 2. Plot of the multiple correspondence analyses to detect the variables linked to the presence of killed common toads *Bufo bufo* in the C–13 road. Variables (categories): Toad presence (yes, no); Presence of streams (yes, no); Presence of local ways (yes, no); Slope of the road side (high, medium, low); Type of vegetation (natural vegetation, fields, nat. veget. + fields).

Fig. 2. Análisis de correspondencias multiples que muestra las variables relacionadas con la presencia de sapos comunes Bufo bufo *atropellados en la carretera C–13. Variables (categorías): Presencia de sapos (sí, no); Presencia de arroyos (sí, no); Presencia de caminos (sí, no); Pendiente del margen de la carretera (alto, medio, bajo); Tipo de vegetación (vegetación natural, cultivos, vegetación natural + cultivos).*

1997; SCV, 1997; Rosell & Velasco, 1999). Moreover, new infrastructures like highways and high speed railways use viaducts when they cross threatened ecosystems. This seems to be a suitable solution to increase wildlife permeability and reduce landscape fragmentation. In short, the present study shows that streams that flow into breeding points may be effective migratory routes for common toads to follow between breeding and terrestrial hibernation sites. Once detected, these natural pathways, partially blocked by roads, should be given high attention and taken into account when applying measures to reduce mortality (Schlupp & Podloucky, 1994). Although the common toad is a widespread species in Spain, its high mortality rate and the increasing road network suggest it is necessary to pay attention to breeding areas, particularly in very disturbed regions.

Acknowledgements

We thank German Pascual and Ester Berniola for their hospitality during the field work and Marta Pascual for her assistance during the field work. The present study is part of a project to study amphibian and reptile mortality on Catalan roads and is funded by the Departament de Medi Ambient of the Generalitat de Catalunya (FBG301492). X.S. was supported by a Beatriu de Pinós grant (Generalitat de Catalunya). M.A.C. also thanks Fundação para a Ciência e a Tecnologia (Portugal) for funding (PhD position SFRH/BPD/27025/2006).

References

Augert, D. & Guyetant, R., 1995. Space occupation for egg deposition in amphibians living in plain woodland and pasture land (east of France). In: *Scientia Herpetologica*: 165–169 (G. A. Llorente, A. Montori, X. Santos & M. A. Carretero, Eds.). Asociación Herpetológica Española, Barcelona.

Carretero, M. A. & Rosell, C., 2000. Incidencia del atropello de anfibios, reptiles y otros vertebrados en un tramo de carretera de construcción reciente. *Boletín de la Asociación Herpetológica Española*, 11: 40–44.

Clevenger, A. P., Chruszcz, B. & Gunson, K. E., 2003. Spatial patterns and factors affecting small

vertebrate fauna road–kill aggregations. *Biological Conservation*, 109: 15–26.

Cooke, A. S., 1995. Road mortality of common toads (*Bufo bufo*) near a breeding site 1974–1994. *Amphibia–Reptilia*, 16: 87–90.

De la Torre, J. G. & Sobrino, E., 2001. Dispositivos para evitar el atropello de anfibios. *Quercus*, 183: 20–22.

Dodd, C. K. & Cade, B. S., 1998. Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. *Conservation Biology*, 12: 331–339.

Ehmann, H. & Cogger, H., 1985. Australia's endangered herpetofauna: a review of criteria and policies. In: *The biology of Australasian frogs and reptiles*: 435–447 (G. Grigg, R. Shine & H. Ehmann, Eds.). Royal Zoological Society of New South Wales, Sydney.

Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D. & Wegner, J. F., 1995. Effect of road traffic on amphibian density. *Biological Conservation*, 73: 177–182.

Feldmann, R. & Geiger, A., 1989. Protection for amphibians on roads in Nordrhein–Westphalia. In: *Amphibian and roads*: 51–57 (T. E. S. Langton, Ed.). Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.

Frétey, T., Cam, E., Le Garff, E. & Monnat, J. – Y., 2004. Adult survival and temporary emigration in the common toad. *Canadian Journal of Zoology*, 82: 859–872.

Galet, M., 1995. Autoroute A71, crossing of the Sologne. Devices to protect amphibians. *Habitat fragmentation and infrastructure*. Maastrich, The Netherlands.

Hels, T. & Buchwald, E., 2001. The effect of road kills on amphibian populations. *Biological Conservation*, 99: 331–340.

Langton, T. E. S. (Ed.), 1989a. *Amphibian and roads*. Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.

– 1989b. Reasons for preventing amphibian mortality on roads. In: *Amphibian and roads*: 75–80 (T. E. S. Langton, Ed.). Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.

Lizana, M., 1993. Mortalidad de anfibios y reptiles en carreteras: Informe sobre el estudio AHE–CODA. *Boletín de la Asociación Herpetológica Española*, 4: 37–41.

– 1997. *Bufo bufo* (Linnaeus, 1758). In: *Distribución y biogeografía de los Anfibios y Reptiles en España y Portugal*: 152–154 (J. M. Pleguezuelos, Ed.). Monografías de Herpetología 3, Universidad de Granada y Asociación Herpetológica Española, Granada.

– 2002. *Bufo bufo* (Linnaeus, 1758). In: *Atlas y libro rojo de los Anfibios y Reptiles de España*: 109–112 (J. M. Pleguezuelos, R. Márquez & M. Lizana, Eds.). Dirección General de Conservación de la Naturaleza, Asociación Herpetológica Española, Madrid.

Lizana, M. & Barbadillo, L. J., 1997. Legislación, protección y estado de conservación de los anfibios y reptiles españoles. In: *Distribución y biogeografía de los Anfibios y Reptiles en España y Portugal*: 477–516 (J. M. Pleguezuelos, Ed.). Monografías de Herpetología 3, Universidad de Granada y Asociación Herpetológica Española, Granada.

Llorente, G. A., Montori, A., Santos, X. & Carretero, M. A., 1995. *Atlas dels amfibis i rèptils de Catalunya i Andorra*. Editorial El Brau, Figueres, Spain.

Marshall, I. C., Corner, A. & Tattersfield, P., 1997. An amphibian mitigation scheme for the A34 Wilmslow and Handforth Bypass, Chesire, United Kingdom. In: *Habitat fragmentation and infrastructure:* 227–237 (K. Canters, A. Piepers & D. Hendriks–Heersma, Eds.). Proceedings of the international conference on habitat fragmentation, infrastructure and the role of ecological engineering. Maastricht and The Hague, The Netherlands, Delft.

Montori, A., Llorente, G. A., Carretero, M. A. & Santos, X., 2001. La gestión forestal en relación con la herpetofauna. In: *Conservación de la biodiversidad y gestión forestal. Su aplicación en la fauna vertebrada*: 251–289 (J. Camprodon & E. Plana, Eds.). Edicions de la Universitat de Barcelona, Barcelona.

Montori, A., Santos, X., Llorente, G. A., Richter–Boix, A. & Garriga, N., 2004. Incidència dels atropellaments sobre l'herpetofauna al Parc Natural del Garraf: eix viari Olivella. Rat–penat. *IV Trobada d'Estudiosos del Garraf, Monografies*, 37: 107–112.

Orlowski, G., 2007. Spatial distribution and seasonal pattern in road mortality of the common toad *Bufo bufo* in an agricultural landscape of south–western Poland. *Amphibia–Reptilia*, 28: 25–31.

PMVC–CODA, 2003. Mortalidad de vertebrados en carreteras. Proyecto provisional de seguimiento de la mortalidad de vertebrados en carreteras (PMVC). *Documentos Técnicos de Conservación,* 4: 1–346. SCV, Madrid.

Ray, N., Lehmann, A. & Joly, P., 2002. Modelling spatial distribution of amphibian populations: a GIS approach based on habitat matrix permeability. *Biodiversity and Conservation*, 11: 2143–2165.

Rosell, C., Parpal, J., Campeny, R., Jové, S., Pasquina, A. & Velasco, J. M., 1997. Mitigation of barrier effect of linear infrastructures on wildlife. In: *Habitat fragmentation and infrastructure:* 367–371 (K. Canters, A. Piepers A & D. Hemdriks–Heersma, Eds.). Proceedings of the international conference on habitat fragmentation, infrastructure and the role of ecological engineering. Maastricht and The Hague, The Netherlands, Delft.

Rosell, C. & Velasco, J. M., 1999. Manual de prevenció i correcció dels impactes de les infraestructures viàries sobre la fauna. *Documents dels Quaderns de Medi Ambient,* 4: 1–95. Generalitat de Catalunya, Departament de Medi

Ambient, Barcelona, Spain.
Schlupp, I. & Podloucky, R., 1994. Changes in breeding site fidelity – a combined study of conservation and behavior in the common toad *Bufo bufo*. *Biological Conservation*, 69: 285–291.
SCV, 1997. Primeras soluciones a los atropellos de anfibios en España. *Boletín de la Asociación Herpetológica Española*, 8: 51–52.
Seiler, A., 2001. Ecological effects of roads. A review. *Introductory research essay*, 9: 1–40. Uppsala.
Sinsch, U., 1988. Seasonal changes in the migratory behaviour of the toad *Bufo bufo*: direction and magnitude of movements. *Oecologia*, 76: 390–398.
– 1989. Migratory behaviour of the common toad *Bufo bufo* and the natterjack toad *Bufo calamita.* In: *Amphibian and roads*: 113–115 (T. E. S. Langton, Ed.). Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.
– 1992. Structure and dynamics of a natterjack toad metapopulation (*Bufo calamita*). *Oecologia*, 90: 489–499.
Slater, F. M., 1989. Amphibian barrier in mid–Wales. In: *Amphibian and roads*: 175–180 (T. E. S. Langton, Ed.). Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.
– 1994. Wildlife road casualties. *British Wildlife*, 5: 214–221.
Trombulak, S. C. & Frissell, C. A., 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, 14: 18–30.
Van Gelder, J. J., 1973. A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo*. *Oecologia*, 13: 93–95.
Vogel, Z. & Puky, M., 1995. A fast environmental assessment method for the evaluation of road constuction effects on amphibian communities, In: *Scientia Herpetologica*: 349–351 (G. A. Llorente, A. Montori, X. Santos & M. A. Carretero, Eds.). Asociación Herpetológica Española, Barcelona.
Wells, K. D., 1977. The social behaviour of anuran amphibians. *Animal Behaviour*, 25: 666–693.
Wilson, E. O., 1988. *Biodiversity*. National Academy Press, Washington D.C.
Zuiderwijk, A., 1989. Amphibian and reptile tunnels in the Netherlands. In: *Amphibian and roads*: 67–74 (T. E. S. Langton, Ed.). Proceedings of the Toad Tunnel Conference, Rendsburg, Germany.