Published by Associazione Teriologica Italiana
Volume 23 (2): 58–66, 2012
Hystrix, the Italian Journal of Mammalogy
Available online at:
http://www.italian-journal-of-mammalogy.it/article/view/4747/pdf doi:10.4404/hystrix-23.2-4747

Research Article

Annual patterns of mammalian mortality on Irish roads

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Keywords:
roads
mammals
seasonal variation
dispersal
Ireland

Article history:
Received: 3 October 2011
Accepted: 2 July 2012

Acknowledgements
The author would gratefully like to acknowledge the assistance of all the people who assisted with the road kill survey, the Department of Environment, Heritage and local Government for granting licenses and Crawford Hayes fund for PhD scholarship.

Abstract

Roads are fast becoming one of the leading causes of mortality in a number of mammalian species. Between April 2008 and November 2010, 227 km of road between Cork and Caherlistrane, Co. Galway in Southern Ireland were monitored for mammalian road kill. A further 32.5 km, between Cork city and Bandon Co. Cork, was screened from January 2009 to November 2010. In total 45815 km were surveyed over the three year period. In this time 548 mammal fatalities were observed, representing 1.20 per 100 km. Rabbits, hedgehogs, badgers and foxes were the four most common fatalities on both stretches of road, constituting 78% of the mammals killed. May, August and September were the months in which the greatest numbers of casualties were observed. Peaks in fatalities varied on a species basis and coincided with breeding and dispersal patterns.

Introduction

Ireland is currently undergoing the largest extension to the national road network in recent years (Dolan, 2006). Roads are a major cause of mortality in a number of species, and sometime in the last three decades, they probably overtook hunting as the leading direct human cause of vertebrate mortality on land (Forman and Alexander, 1998). The number of wildlife casualties on roads and railways have constantly grown worldwide as traffic and vehicle speeds have increased and infrastructure networks expanded (Seiler et al., 2004). Road traffic represents the most important cause of death of otters (*Lutra lutra*) in most European Countries (Hauer et al., 2002). Philcox et al. (1999) noted that with regard to otters, an increase in the number of road traffic accidents (RTAs) recorded nationally began in 1983 and has been more rapid than the increases in any other known cause of otter mortality in Great Britain. In a survey of 32 km of roads in Slovakia between September 2000 and December 2002, a total of 3009 carcasses were found of which 45.5% were mammals (Hell et al., 2005). Similarly, the results of a study on a motorway section in France emphasized that traffic considerably affected vertebrate populations (14.5 animals per day/100 km), of which 43.2% were mammals (Lodé, 2000). In the Netherlands it is estimated that between 113000 and 340000 hedgehogs (*Erinaceus europaeus*) are killed each year on roads, which may reduce hedgehog density by around 30% (Huijser and Bergers, 2000).

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doi:10.4404/hystrix-23.2-4747

Figure 1 – The road from Cork city to Caherlistrane Co Galway (227 km) and Cork city to Bandon Co. Cork (32.5 km).

Roads affect animal populations in three adverse ways. They act as barriers to movement, enhance mortality due to collisions with vehicles, and reduce the amount and quality of habitat (Jaeger and Fahrig, 2004). With the increase in new roads further mortality may occur when new roads cross traditional tracks, unless under-passes and fencing are provided (Smiddy, 2002). Furthermore, very high traffic levels may even inhibit road crossings (Morris and Morris, 1988). Forman and Alexander (1998) suggested that road kills are a premier mortality source, yet except for local spots, rates rarely limit population size. However, road avoidance has a greater ecological influence. Populations living in habitat surrounded by roads are less likely to receive immigrants from other habitats, and thus may suffer from lack of genetic input and inbreeding (Jaeger et al., 2005).

The aim of the current study was to identify the most frequently killed mammals on a subset of Ireland's roads and examine monthly fluctuations in RTAS for a number of mammalian species.

Materials and Methods

Cork and Caherlistrane network

Between April 2008 and November 2010, the road from Cork city to Caherlistrane Co. Galway (227 km) (Fig.1) was monitored for mammalian road kill on both directions. This network consisted predominantly of national roads (137.3 km) where there were two lanes of traffic, with stretches of motorway (64.2 km) and single lane regional roads (26.5 km). Towns and villages were situated along the route, and the speed limit was 50 km/h in these areas. Speed limits on regional roads were 80 km/h, national roads 100 km/h and the motorway 120 km/h. The traffic flow along these routes ranged from an annual average daily traffic flow of 10152 ± 4.7 (SE) to 33517 ± 3.21 vehicles (National Roads Authority, 2012). Traffic flow was at its highest in August and lowest in January. Underpasses consisting of concrete pipes, primarily designed for the movement of otter (*Lutra lutra*) and badger (*Meles meles*), had been incorporated into 14 km of this route (National Roads Authority, 2012). On another 10 km of dual carriageway, along the route four underpasses and eight culverts were constructed (National Roads Authority, 2012).

Cork and Bandon network

In January 2009, a further stretch of road from Cork city to Bandon, Co. Cork (32.5 km) was also monitored on both directions and this continued until November 2010 (Fig.1). This network consisted of national road in which there were two lanes of traffic (28.5 km) and single lane, regional roads (4 km). The traffic flow along this route consisted of an annual average daily traffic flow of 9696 to 31848 vehicles (National Roads Authority, 2012). No underpasses had been constructed along this route.

Habitat

The proportion of each habitat along both routes was quantified through examining aerial photographs of the route on Google Earth and the Ordnance Survey Ireland website (Ordnance Survey Ireland, 2012). The most prominent habitat along both stretches was pasture (grazed or silage) (58%), residential (including single houses and housing estates, 16%) and scrub (areas consisting predominantly of bramble and gorse) (13%) (Fig.2).

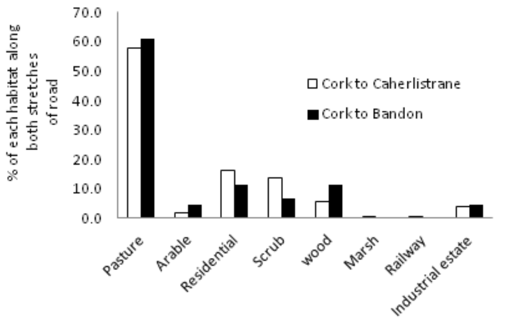

Figure 2 – The percentage of each habitat type along the road from Cork to Caherlistrane, Co. Galway and Cork to Bandon, Co. Cork.

Sampling effort

These two routes, representing a total distance of 259.5 km, were surveyed at regular intervals for 11 months of the year, excluding December, when winter break interrupted the regular travel along these networks. The road between Cork and Caherlistrane was surveyed 150 times (∼34050 km) over three years and that between Cork and Bandon was surveyed 362 times (∼11765 km) over two years. The car, with at least two passengers, travelled at an average speed of 60 km/h. In almost all cases the carcasses were identified from the vehicle, however, if this was not possible they would be identified by approaching the carcass on foot. Bird casualties and domestic animals were not included in the survey and rodents were not separated into species. Sightings were converted to numbers per km, to allow for differences in the number of times the roads had been surveyed per month.

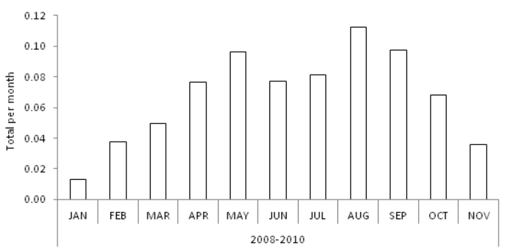

Figure 3 – The months in which there was the greatest number of fatalities on both stretches of road.

Results

Months when there was the greatest number of road kill

In total 45815 km were monitored and 548 mammal casualties were observed representing 1.20 per 100 km (0.012 per km) (Tab. 1) Using an ANOVA, there was no significant difference in the months in which animals were killed ($F_{9,38} = 1.827$, $p = 0.095$). However, May, August and September represented the months in which the greatest number of road casualties were observed (Fig. 3).

Months in which each species was most vulnerable

The most commonly killed mammals were rabbits (*Oryctolagus cuniculus*), hedgehogs (*Erinaceus europaeus*), badgers and foxes (*Vulpes vulpes*) (Tab. 1). The months in which an animal was most vulnerable to being killed on the road varied amongst species. However, the majority displayed a bimodal pattern with one peak at the start (March-July) and another corresponding peak towards the end of the year (August-November) (Tab. 1).

Cork to Caherlistrane over three year

The four most commonly killed mammals showed a similar pattern of fatalities over the three years that the road from Cork to Caherlistrane was monitored (Tab. 2). If the peak was not observed in the same month in the following years, it was found to occur either the month before or after (Tab. 2). Hedgehogs for instance, peaked in May in all three years and while they peaked again in August 2008 and 2010, in 2009 they peaked one month earlier in July (Tab. 2).

Table 1 – Total number of mammalian road kill on the road between Cork and Galway from April 2008-November 2010 and the road from Cork to Bandon between February 2009 and November 2010, and the months in which there was a peak in each species when comparing the means.

Species		Total	%	Highest occurrence
Rabbit	*Oryctolagus cuniculus*	140	26	August and September
Hedgehog	*Erinaceus europaeus*	130	24	May and August
Badger	*Meles meles*	75	14	March and May
Fox	*Vulpes vulpes*	83	15	July and September
Rodents		72	13	September-November
Mink	*Mustela vison*	15	3	August and November
Hare	*Lepus timidus hibernicus*	10	2	April and November
Otter	*Lutra lutra*	10	2	August and September
Pine Marten	*Martes martes*	7	1	February and July
Stoat	*Mustela erminea hibernicus*	6	1	March and November
Total		548	100	

Discussion

Seiler et al. (2004) reported that in several of the commonly occurring mammal species in Sweden, road traffic causes an average loss of 1-12% of the estimated population sizes, approximately 10-100% of the annual game bags. Including both national and local road networks, the republic of Ireland has an extensive road network of 78972 km over an area of 70273 km^2 (National Roads Authority, 2012). This equals 1.28 km of road per km^2, which is lower than the 3.8 km roads per km^2 in Belgium (Holsbeek et al., 1999).

It is therefore not surprising that fatalities are also lower on Irelands roads (548 over 29 months) than in Belgium where a total of 7706 animals were found over a period of 24 months (Holsbeek et al., 1999). In Slovakia, Hell et al. (2005) found 6.3 mammals per 100 km, which was higher than the 1.20 fatalities per 100 km found in the current study. When comparing the results of this study with previous work in Ireland Smiddy (2002) recorded 1.54 casualties per 100 km (domestic cats were removed from calculations in order to compare with the present study). With increased road construction, the National Roads Authority in Ireland has also increased the number of crossing structures for wildlife. In Ireland these are mainly targeted at protected species whose habitat is directly disturbed by road such as otter and badger (Dolan, 2006). On the road from Cork city to Caherlistrane, Co. Galway, underpasses were constructed from concrete pipes with fencing to guide the animal to the tunnel (National Roads Authority, 2012). In another area (Watergrasshill by-pass, Co. Cork), that was not part of the current study, Dolan (2006) found that the oversized arched culverts with mammal ledges constructed along the route were utilised by otter, fox, rabbit, pygmy shrew (*Sorex minutus*) and wood mice (*Apodemus sylvaticus*). She also felt that overpasses constructed for the movement of cattle, along this route, offered potential for the movement of a variety of species (Dolan, 2006). Various wildlife passages (tunnels, pipes, underpasses, overpasses) operating for animal movement have been installed in order to minimise detrimental ecological impacts in other countries (Forman and Alexander, 1998). A number of studies (Ascensão and Mira, 2007; Clevenger et al., 2001; Dolan, 2006; Mata, 2004), have reported the successful use of these mitigation schemes by mammals including rodents, badgers and deer. Included in the roads monitored in the present study was the Ennis bypass. This opened in 2007 and consists of 14 km of standard dual carriageway and 6 km of single carriageway (National Roads Authority, 2012). Included in the construction were wildlife underpasses and fencing for badgers, otters and pine martens (*Martes martes*) and the provision of alternative bat roost sites (Clare County Council). However, while these underpasses have been found to be successfully utilised by bats (Abbott, 2011, *pers. comm.*), their use by other species is currently unclear. Interestingly, hedgehog carcasses which were collected as part of a larger study during the same time period, were found to be absent along this stretch of road (Haigh 2011). Whether this indicated that hedgehogs

Table 2 – The months in which there was a peak in fatalities each year on the road from Cork to Galway for the four most commonly killed species. For each species, peaks are taken as the months in which the greatest numbers were observed. This was >5 per month.

Species	Year	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Rabbit	2008	N/A	N/A	■					■		
	2009					■			■		
	2010				■			■			
Hedgehog	2008	N/A	N/A		■			■			
	2009			■		■					
	2010				■			■			
Badger	2008	N/A	N/A	■			■				
	2009		■		■						
	2010		■		■						
Fox	2008	N/A	N/A		■		■				
	2009							■	■		
	2009						■		■		

were using underpasses or in fact avoiding roads is unclear. Forman and Alexander (1998) reported that road avoidance, has a greater ecological impact on population size than the mortality caused by roads and that road width and traffic density were major determinants of the barrier effect. It is therefore of paramount importance that further research is conducted on the use of underpasses by mammals in Ireland.

Counts of road kill may prove useful in monitoring changes in abundance of mammalian species (Baker et al., 2004). If a particular road is monitored for several years, the dynamics of populations of certain species can be accessed from the findings, and seasonal patterns of mortality identified (Hell et al., 2005). Generally the frequencies of mammalian road kills are highest in summer and lowest in winter (Hell et al., 2005). However, this varies depending on the species' breeding season and dispersal patterns.

In the present study August and September were months in which mammals were seen to be particularly vulnerable to road mortality. August was the month in which there was a greatest volume of traffic on the survey roads (National Roads Authority, 2012), which may impact on the mortality rate. This is also a period of dispersal for a number of species (Erlinge and Sandell, 1986; Gerell, 1970; Macdonald et al., 2008; White and Harris, 1994). Natal dispersal is defined as the definitive movement of an individual from its birth site to the place of its first breeding attempt (Howard, 1960). It is possible that dispersing individuals benefit from both increased access to unrelated mates and increased intrasexual competition (Dobson and Jones, 1985).

Rabbits were the most commonly killed mammal on the roads surveyed. This may be accounted for by their high numbers and widespread distribution, with population densities ranging from 15 per ha in winter to up to 40 per hectare in summer (Hayden and Harrington, 2001). In Germany, Kunkele and von Holst (1996) recorded that rabbits breed between March/April and September/October every year and that at 5 months of age 72% of the litter had dispersed, by the following spring this number had increased to 88%. This peak in rabbit road deaths in the August/September period may therefore be represented by juvenile dispersers born earlier in the year.

Doncaster (1993) suggested that hedgehogs do not have a fixed natal territory from which to disperse, nor a clearly defined dispersal stage. However, during the breeding season males increase their home range (Jackson, 2006; Kristiansson, 1984; Morris, 1969) and Holsbeek et al. (1999) observed that the pattern of hedgehog road kill shows a gradual increase towards July (>300) gradually decreasing to less than 10 towards December and January. Hedgehogs were the second most commonly killed mammal in the present study, with peaks observed in May and August. Road kill studies have reported a peak in road deaths in May and July in Belgium, The Netherlands and Ireland (Holsbeek et al., 1999; Huijser and Bergers, 2000; Smiddy, 2002). The breeding season in the European hedgehog has been reported to occur between

April and August, with peaks in activity varying between studies (Jackson, 2006; Kristiansson, 1984; Morris, 1961, 1969; Riber, 2006). This may therefore explain a peak in road kill in the present study. While Goransson et al. (1976) found that 80% of traffic victims were male hedgehogs in Sweden, in autumn he found that high numbers of females were killed which was attributed to a greater need to forage wider, in order to build up fat prior to hibernation after raising young. This second peak in August may therefore be a result of this.

In Britain, road traffic is the largest cause of recorded deaths of badgers, with an estimated 50,000 badgers being killed on the roads each year (Davies et al., 1987) which equates to 48.8% of all adult and post-emergence cub fatalities (Clarke et al., 1998). Permanent dispersal is not common in badgers, however, in the U.K. movements between social groups were most common in autumn (17.1%, n = 626 trapping events) and least common in winter (10.9%, n = 339) (Macdonald et al., 2008). Badger road fatalities have been found to be bi-modal with peaks in late spring and summer (Clarke et al., 1998) no difference has been observed between the seasonal distribution of deaths between the two sexes and it has been suggested that peaks in mortality reflect increased activity in conjunction with mating (Davies et al., 1987). February and March is a period of increased boundary marking behaviour just prior to breeding (Delahay et al., 2000) and the results of this study corresponds to the peaks in badger road deaths observed elsewhere (Clarke et al., 1998; Davies et al., 1987; Smiddy, 2002).

Foxes showed a bimodal pattern in road deaths with peaks in July and September in the present study. Fox cubs begin to forage with their parents in July and are usually self sufficient by this time (Fairley, 1975) and this period of exploration may lead to an increase in road deaths. During September and October, competitive behaviour in both the dog fox and male offspring stresses their relationship until the young male's disperse (Henry, 1986). Dispersal occurs once a year in foxes from autumn to winter and all sub adults that did not find space in their natal social groups dispersed (Rushton et al., 2006). Harris and Trewhella (1988) found that by the end of march 67% of males and 31.8% of females had dispersed and dispersal distances for foxes marked as cubs and retrieved as adults was 1.6 ± 0.2 km for females and 2.8 ± 0.3 km for males. These dispersing individuals would be at a greater risk of being killed on the road and would explain the peak observed in September in the present study.

Of those least frequently observed casualties, hares (Lepus timidus hibernicus) were observed mostly in April and November. Under ideal weather conditions hares may breed all year and males may increase their home range in order to search for females (Hayden and Harrington, 2001). Peaks in mink (*Mustela vison*) casualties occurred in August and November in the present study. Mink have reached sub adult size in November (Enders, 1952) but the largest-scale movements in a mink population are the dispersal of the juveniles which starts in the beginning of July but families have been found to keep together until the middle of August (Gerell, 1970). This may account for the peak in the present study. Winter is a difficult time for many mammals and corresponds to a period of dormancy or decreased activity for species such as the hedgehog and badger. It is a time of reduced prey and food supply for many animals and as a result individuals may have to travel further in search of food leading to a greater susceptibility to road deaths which may account for the peak observed in hare and mink in November.

Roads are particularly damaging to vulnerable and endangered species. In Northern Ireland one of the greatest threats to pine marten currently appears to be the rise in the number of road kill incidents and since the 1960s the number of pine marten killed on the roads has increased from 5 per cent of total records to 22 per cent of total records in the late 20^{th} century (Tosh et al., 2007). In Otters, Kubasch (1992) has suggested that 10% of the total population of Saxony has been lost to road accidents. The number of these species observed as road kill in the present study was small with only seven pine marten and ten otter observed over the three years. However for species like the pine marten, who in O'Sullivan (1983) study were found confined to localised areas of woodland and scrub in mid western Ireland and who may have a population density ranging between one per km^2 to 1 per 10 km^2 (Hayden and Harrington, 2001), the loss of even small numbers may signification effect the survival of local populations. Although the small numbers make it difficult to incur a pattern in road deaths, peaks were observed in February and July. The breeding season begins in July, and transient pine marten were caught from January to March in Sweden (Helldin and Lindström, 1995). Similarly, in Ireland, Tosh et al. (2007) observed that records of pine martens are greater during the summer, which is attributed to greater activity associated with breeding.

Hauer et al. (2002) found that 69.9% of mortality in otters was due to road fatalities but there was no significant difference in relation to different time periods. Philcox et al. (1999) found a seasonal correlation between otter road traffic accidents and rainfall and that floodings are likely to create the critical conditions leading to otter road traffic accidents. In the present study a preponderance of fatalities occurred in August 2010 and September 2008. In both of these months there was a dry period following widespread flooding and exceptionally wet weather the month before. In Munster and Leinster rainfall was 50% lower in August 2010 while in July 2010 rainfall totals were above normal everywhere and were more than twice the average at some stations (The Irish Meteorological Service Online, 2012). Similarly, August 2008 was a month of exceptionally heavy rain over most of the country, bringing flooding in many areas, while rainfall levels were normal in September 2008 rainfall (The Irish Meteorological Service Online, 2012).

Of the four most commonly killed species on both stretches of road, a similar pattern was observed over the three years. Peaks were observed in the same months over at least two years, with May proving a vulnerable time for the hedgehog throughout the study. However, in months were a peak was observed differently in a proceeding year, in all cases the peak occurred either the month before or after. It is suggested that this is related to variations in the onset of the breeding season and correspondingly that of dispersal which may be related to annual changes in food supply or weather conditions. Hares for instance are known to breed for a shorter duration of time when food is scarce or almost continuously when conditions are favourable (Hayden and Harrington, 2001). By identifying these peaks, certain measures could be put in place to minimise these mortalities. Signs could be used to inform drivers of the movement of a given species during certain months. While **?** felt that signs have become so prevalent that they are now ignored by motorists, there usage in Ireland is moderate and confined to warnings in relation to deer crossings. In a survey by Stout et al. (1993) in the United States, 76% of respondents stated that caution signs increased their alertness. Similarly, Sullivan et al. (2004) observed that the erection of signs decreased the percentage of speeding vehicles from 19% to 8% and decreased collisions by an estimated 50%.

Mammals were most vulnerable to road mortality in May, August and September, with the majority of species showing a peak earlier in the year and a corresponding one towards the end. The four most commonly killed mammals showed definite annual patterns in relation to their occurrence as road kill which appeared to be in relation to movement during times of breeding and dispersal. It is suggested that motorists should be informed of the times of year when certain species are expected to be crossing in order to increase their alertness.

While this study has successfully identified peaks in mammal fatalities for a number of species and identified those most vulnerable to road mortality, it has also highlighted the need for further investigation into the effect of roads on mammals. In particular, while the number of roads continues to grow, more long term monitoring is warranted to identify accident black spots and the effectiveness of underpasses, so that effectual measures can be implemented to minimise road fatalities.

References

Ascensão F., Mira A., 2007. Factors affecting culvert use by vertebrates along two stretches of road in southern Portugal. Ecol. Res. 22(1): 57–66.

Baker P., Harris S., Robertson C., Saunders G., White P., 2004. Is it possible to monitor mammal population changes from counts of road traffic casualties? An analysis using Bristol's red foxes *Vulpes vulpes* as an example. Mammal Rev. 34(1-2): 115–130.

Clarke G.P., White P.C.L., Harris S., 1998. Effects of roads on badger *Meles meles* populations in south-west England. Biol. Conserv. 86(2): 117–124.

Clevenger A., Chruszcz B., Gunson K., 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. J. Appl. Ecol. 38(6): 1340–1349.

Davies J., Roper T., Shepherdson D., 1987. Seasonal distribution of road kills in the European badger (*Meles meles*). J. Zool. 211 (3): 525–529.

Delahay R., Brown J., Mallinson P., Spyvee P., Handoll D., Rogers L., Cheeseman C., 2000. The use of marked bait in studies of the territorial organization of the European badger (*Meles meles*). Mammal Rev. 30(2): 73–87.

Dobson F.S., Jones W.T., 1985. Multiple Causes of Dispersal. Amer. Nat. 126(6): 855–858.

Dolan L., 2006. Monitoring of wildlife crossing structures on irish national road schemes. In: Irwin C.L., Garret P., Mc Dermott K.P. (Eds.). International Conference on Ecology and Transportation North Carolina State University, 2006.

Doncaster C., 1993. The influence of predation threat on foraging pattern: the hedgehog's gambit. Rev. ecol. (La Terre et la Vie) 48: 207–213.

Enders R.K., 1952. Reproduction in the Mink (*Mustela vison*). Proc. Am. Philos. Soc. 96(6): 691–755.

Erlinge S., Sandell M., 1986. Seasonal changes in the social organization of male stoats, *Mustela erminea*: an effect of shifts between two decisive resources. Oikos 47(1): 57–62.

Fairley J., 1975. An Irish Beast Book. Belfast Blackstaff.

Forman R.T.T., Alexander L.E., 1998. Roads and their major ecological effects. Annu. rev. Ecol. Syst. 29: 207–231.

Gerell R., 1970. Home Ranges and Movements of the Mink *Mustela vison* Shreber in Southern Sweden. Oikos 21(2): 160–173.

Goransson G., Karlsson J., Lindgren A., 1976. Road mortality of the hedgehog *Erinaceus europaeus* in southern Sweden. Fauna Flora, Stockholm 71: 1–6.

Haigh A., 2011. The ecology of the european hedgehog (*Erinaceus europaeus*) in rural Ireland. PhD thesis, University College, Cork.

Harris S., Trewhella W.J., 1988. An Analysis of Some of the Factors Affecting Dispersal in an Urban Fox (*Vulpes vulpes*) Population. J. Appl. Ecol. 25(2): 409–422.

Hauer S., Ansorge H., Zinke O., 2002. Mortality patterns of otters (*Lutra lutra*) from eastern Germany. J. Zool. 256(3): 361–368.

Hayden T., Harrington R. (Eds.), 2001. Exploring Irish Mammals. Town House, Dublin.

Hell P., Plavý R., Slame ka J., Gašparík J., 2005. Losses of mammals (Mammalia) and birds (Aves) on roads in the Slovak part of the Danube Basin. Eur. J. Wildlife Res. 51(1): 35–40.

Helldin J., Lindström E.R., 1995. Late winter social activity in pine marten (*Martes martes*) false heat or dispersal? Suomen Biologian Seura Vanamo, 1964-, vol 1, Helsinki. 145–149.

Henry J.D., 1986. The red fox, the cat like canine. Washington D.C.

Holsbeek L., Rodts J., Muyldermans S., 1999. Hedgehog and other animal traffic victims in Belgium: results of a countryside survey. Lutra 42: 111–119.

Howard W.E., 1960. Innate and environmental dispersal of individual vertebrates. Am. Midl. Nat. 63(1): 152–161.

Huijser M., Bergers P., 2000. The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. Biol. Conserv. 95(1): 111–116.

Jackson D., 2006. Factors affecting the abundance of introduced hedgehogs (*Erinaceus europaeus*) to the Hebridean island of South Uist in the absence of natural predators and implications for nesting birds. J. Zool. 271(2): 210–217.

Jaeger J., Bowman J., Brennan J., Fahrig L., Bert D., Bouchard J., Charbonneau N., Frank K., Gruber B,. von Toschanowitz K., 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecol. Model. 185(2-4): 329–348.

Jaeger J., Fahrig L., 2004. Effects of road fencing on population persistence. Conserv. Biol. 18(6): 1651–1657.

Kristiansson H., 1984. Ecology of a hedgehog *Erinaceus europaeus* population in southern Sweden. PhD thesis, University of Lund.

Kubasch H., 1992. Otterschtz in Sachsen, Otterschutz in Deutschland. Habitat 7: 109–112.

Kunkele J., Von Holst D., 1996. Natal dispersal in the European wild rabbit. Animal Behaviour 51(5): 1047-1059.

Lodé T., 2000. Effect of a Motorway on Mortality and Isolation of Wildlife Populations. Ambio 29(3): 163–166.

Macdonald D.W., Newman C., Buesching C.D., Johnson P.J., 2008. Male-biased Movement in a High-density Population of the Eurasian Badger (*Meles meles*). J. Mammal. 89(5): 1077–1086. doi:doi:10.1644/07-MAMM-A-185.1

Mata C., 2004. Effectiveness of wildlife crossing structures and adapted culverts in a highway in Northwest Spain. In: Irwin C.L., Garret P., Mc Dermott K.P. (Eds.). International conference on Ecology and Transportation, North Carolina State University. 265–276.

Morris B., 1961. Some observations on the breeding season of the hedgehog and the rearing and handling of the young. Proc. Zool. Soc. Lond. 136(2): 201–206.

Morris P., 1969. Some Aspects on the ecology of the hedgehog (*Erinaceus europaeus*). PhD thesis, University of London.

Morris P., Morris M., 1988. Distribution and abundance of hedgehogs (*Erinaceus europaeus*) on New Zealand roads. New Zeal. J. Zool. 15(4): 491–498.

National Roads Authority, 2012. Available at www.nra.ie [last accessed March 2012]

Ordnance Survey Ireland, 2012. Available at www.osi.ie [last accessed March 2012]

O'Sullivan P., 1983. The distribution of the Pine marten (*Martes martes*) in the Republic of Ireland. Mammal Rev. 13(1): 39–44.

Philcox C., Grogan A., Macdonald D., 1999. Patterns of otter *Lutra lutra* road mortality in Britain. J. Appl. Ecol. 36(5): 748–762.

Putmam R.J., 1997. Deer and road traffic accidents: options for management. J. Environ. Manage. 51: 43–57.

Riber A.B., 2006. Habitat use and behaviour of European hedgehog *Erinaceus europaeus* in a Danish rural area. Acta Theriol. 51(4): 363–371.

Rushton S.P., Shirley M.D.F., MacDonald D.W., Reynolds J.C., 2006. Effects of Culling Fox Populations at the Landscape Scale: A Spatially Explicit Population Modeling Approach. J. Wildl. Manage. 70(4): 1102–1110.

Seiler A., Helldin J., Seiler C., 2004. Road mortality in Swedish mammals: results of a drivers' questionnaire. Wildl. Biol. 10(3): 225–233.

Smiddy P., 2002. Bird and mammal mortality on roads in counties Cork and Waterford, Ireland. Bull. Irish Biogeogr. Soc. 26: 29–38.

Stout R.J., Stedman R.C., Decker D.J., Knuth B.A., 1993. Perceptions of risk from deer-related vehicle accidents: implications for public preferences for deer herd size. Wildl. Soc. Bull. 21: 237–249.

Sullivan T.A., Williams A.F., Messmer T.A., Hellinga L.A., Kyrychenko S.Y., 2004. Effectiveness of temporary warning signs in reducing deer–vehicle collisions during mule deer migrations. Wildl. Soc. Bull. 32: 907–915.

The Irish Meteorological Service Online, 2012. Available at www.met.ie [last accessed February 2012]

Tosh D., Preston S.J., McDonald R.A., 2007. The Status of Pine Martens *Martes martes* (L.) in Northern Ireland, 1850-2004. Irish Nat. J. 28(11): 433–439.

White P.C.L., Harris S., 1994. Encounters between Red Foxes (*Vulpes vulpes*): Implications for Territory Maintenance, Social Cohesion and Dispersal. J. Anim. Ecol. 63(2): 315–327.

Associate Editor: D.G. Preatoni