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What proportion of badgers (*Meles meles)* are killed on roads in rural areas in the Republic of Ireland?

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Introduction

Road casualties are often believed to be a significant cause of mortality for badgers. However, it is unusual for data on badger road casualties to come from a population that is well studied, with the rare exceptions being those of Woodchester Park and Wytham Wood in England (Rogers *et al.*, 1997; Macdonald and Newman, 2002). Previously published road mortality data have led to a consensus amongst researchers that a high proportion of adult badgers are expected to be killed by road traffic each year (Harris *et al.*,1995). This stems mainly from studies in Holland and Britain (e.g. Vink *et al.*, 2008, Roper, 2010), countries with dense human populations and busy road networks. Clarke *et al.* (1998) reported that about 50,000 badger road casualties occurred per year in the UK for an adult population of 250,000 (i.e. 20 % mortality per annum), and that as much as 66 % of annual mortality of adults and post-emergence cubs could be due to road casualties in some areas. They also showed that mortalities were higher on motorways and dual carriageway roads due to the higher traffic levels experienced on such roads. In contrast, a questionnaire-based, country-wide study in Sweden (Seiler *et al.*, 2004) found an annual mortality rate for badgers due to road traffic accidents of 12-13 %.

The road network of Ireland is unusual, principally because the human population was once much larger, approximately 8 million mainly rural people in the mid 19th Century, compared with about 4 million predominantly urban dwellers now (Hall, 2011, Aalen *et al.*, 2011). The country has some 2,800 km of national roads (primary routes, including motorways) and around 2,700 km of secondary roads. It also has a significant meshwork of narrow regional and local roads totalling about 90,000 km (National Roads Authority, 2008). It has the equivalent of 26 km of road per thousand people, which is high by European standards (Stapleton, 1996). As a result, most badger setts are no more than one or two fields away from a road. On the other hand, traffic densities and vehicle speeds on most of these rural roads are relatively low. Here, we examine badger road casualties in relation to eight previously investigated populations in rural areas in the Republic of Ireland. This was possible in the context of the Irish Four Area Project (FAP) (1997-2002) which was conducted to assess the impact of badger removal on bovine tuberculosis, which was also used to provide more accurate estimates of the Irish badger population (Sleeman *et al*., 2009). The FAP consisted of four areas where badgers were removed (Removal Areas) and four contiguous areas where few badgers were removed (Reference Areas). Pairs of such areas were located in Counties Cork, Donegal, Kilkenny and Monaghan.

A recent review of the ecology of Irish badgers (Byrne *et al.*, 2012) has identified lack of knowledge of road casualty rates as a significant obstacle to such modelling. Our study aimed to remedy this deficiency.

Methods

Standardized search and capture methods were used throughout the FAP. Efforts to find road casualty badgers were clearly defined. Field team techniques are described in Griffin *et al*., (2005). During the FAP, team members were instructed to search roads and road verges for badger casualties. It was stressed, in training, that such casualties were believed to be a major mortality factor. Badger road casualty data were obtained in the following three ways. Firstly, survey teams recorded any casualties detected during the course of their surveys, or when travelling by road. Secondly, cattle herd owners from the study areas were asked to report dead badgers. Thirdly, one member of each survey team conducted a careful monthly search of a 16km transect of main roads, one running through each of the four Removal Areas and one through each of the four Reference Areas (O'Shea *et al*., 2010).

We examined road casualties for Removal Areas for the first two years, assuming that most of the population had been caught in this period (Sleeman *et al.*, 2009). We took the 'observed number' as that for the year with the highest count of road casualties. This was 1998 in all cases (Table 1A & B).

We also estimated the population of badgers in the Reference Areas by extrapolating the population density (badger numbers km^{-2}) from the adjacent Removal Area data for the first two years of the FAP. We present road casualty data solely for the year 1998, both for the Removal and Reference Areas (Table 1).

A t test using log transformed data was used to ascertain if the numbers of road casualty badgers differed between Removal and Reference Areas. The location and seasons of such casualties are examined elsewhere (Sleeman *et al.*, submitted).

Results

Table 1A shows road casualties and estimated badger populations of Removal Areas for 1998 (the latter taken from Sleeman *et al*., 2009). It can be seen that road casualties in that year made up a small proportion (mean 1.11%, range 0.44-1.78%) of the total population of badgers.

Table 1 Recorded numbers of badger road casualties in relation to the estimated population of adult badgers in 1998.

A: For Removal Areas of the Four Area Project

County	**Estimated adult population** **Area : 960 km^{-2}**	**Number of recorded casualties**	**Casualties as % population**
Cork	338	6	1.78
Donegal	229	1	0.44
Kilkenny	272	4	1.47
Monaghan	260	2	0.77
TOTAL	**1,099**	**13**	**1.11**

B: For Reference Areas of the Four Area Project

County	**Estimated adult population** **Area: 1,010 km^{-2}**	**Number of recorded casualties**	**Casualties as % population**
Cork	358	1	0.28
Donegal	292	1	0.34
Kilkenny	273	3	1.10
Monaghan	227	0	0.0
TOTAL	**1,150**	**5**	**0.43**

Table 1B shows casualties and estimated populations of Reference Areas for the same year. It

can be seen that the road casualties in that year also made up a small proportion (mean 0.43%, range 0.0-1.10 %) of the total estimated population.

The t tests showed that significantly more badgers were found killed on the roads of the Removal Areas than on those of Reference areas ($t = 3.89$, $P < 0.01$), especially so in Cork.

Discussion

Roads, especially wide ones and where traffic is frequent and fast moving, are often barriers to carnivores (Riley *et al.*, 2006). In areas of high road densities, for example in parts of Essex in England, badgers are often scarce or absent (e.g. Skinner *et al.*, 1991). However, the data presented here demonstrate that badger road casualties occur at low levels over large parts of rural Ireland. The average annual mortality rates in badgers due to road accidents (1.11% in Removal Areas, 0.43% in Reference Areas of the FAP) are below that of Wytham Wood, (5%, Macdonald and Newman, 2002), and well below the level reported from Sweden (12-13 %, Seiler *et al.*, 2004). Since Ireland is a largely rural country this implies that road casualties are a relatively unimportant source of badger mortality.

Traffic data are available for the FAP areas, but only for main roads. Measures of traffic flows are expressed as Annual Average Daily Traffic (AADT) (National Roads Authority, 2002). These are 24 hour, two-way flows and the locations where they were measured were on main roads within parts of the Four Areas. They averaged about 5,000 vehicles per day. We note that daily vehicle flows (2009) on A class rural roads in the SE region of the UK ranged from 8,356-23,431 per day, while those of Oxfordshire A class roads ranged between 3,362 and 49,757 per day (Department of Transport, 2009). Clearly, Irish rural main roads have low traffic flows by comparison, while the meshwork of narrow lanes that make up the bulk of the length of the rural road network must have extremely low average flows. It therefore seems probable that the low rate of badger road casualties stems from low traffic densities.

Although still low, the relatively higher rate of road casualties in the Cork Removal Area in 1998 probably reflects the high density of badgers there (Sleeman *et al*., 2009), which in turn reflects the low rate of badger removals there prior to the onset of the Four Area Project (More, 2004). However, we cannot exclude differences in traffic density as a source of the differences. In general, the higher numbers of road casualties in the Removal Areas may be the result of the slightly higher estimated population densities in those areas (Table 1) or due to disturbance caused by the removal process.

Conclusion

This study demonstrates that rates of badger mortality due to collisions with road vehicles in rural Ireland are low by comparison with those reported for populations in other parts of Europe. The low rate of road casualties is significant for the management of bovine tuberculosis because analyses of road casualties have contributed to estimates of rates of tuberculosis incidence in badgers in Ireland, both north and south (O'Boyle, 2002, Corner *et al*., 2008, Department of Agriculture for Northern Ireland, 2008). Such estimates are used for planning the management of Irish badgers. Since they clearly rely on a small proportion of the badger population, further study is needed to determine how representative badger road casualties are of the general Irish population of *Meles meles* in their tuberculosis incidence.

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