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An estimate of the annual number of hedgehog (*Erinaceus europaeus*) road casualties in Great Britain

David E. Wembridge¹, Martin R. Newman², Paul W. Bright³ and Pat A. Morris⁴

ABSTRACT

Counts of hedgehog (*Erinaceus europaeus*) road casualties identified in car surveys have been used previously only once to estimate road traffic mortality nationally (Morris, 2006). Here, we use data from four surveys (conducted between 1952 and 2004) to estimate annual road-casualty numbers in Great Britain. Our estimate of 167,000–335,000 is substantially greater than Morris' (2006) value, with possible implications for hedgehog conservation.

INTRODUCTION

Estimates of wildlife road-casualty numbers nationally are difficult to ascertain but may impact negatively on wild populations. Hedgehog populations in Britain are declining (Roos *et al.*, 2012) but counts of hedgehog road casualties identified in car surveys have been used previously only once to estimate national mortality (Morris, 2006). The relationship between casualty numbers and local abundance of hedgehogs needs to be validated before such surveys can be used to monitor abundance changes, but consistency in the ranking of regional counts in successive years (e.g. Morris, 1993)

suggests the two are linked. Moreover, traffic flow, which has been argued to affect variation in casualty counts more than local abundance, shows no correlation with counts of hedgehog casualties (Bright *et al.*, 2015). Here, we use data from four surveys of hedgehog casualties (conducted between 1952 and 2004) to estimate annual road casualties, and compare this with the estimate from Morris (2006) of 15,000 road casualties per year.

¹ People's Trust for Endangered Species, 3 Cloisters House, 8 Battersea Park Road, London, SW8 4BG, UK

² 15 Winton Road, Reading, Berkshire, RG2 8HH, UK

³ c/o People's Trust for Endangered Species

⁴ West Mains, London Road, Ascot, Berkshire, SL5 7DG, UK

Corresponding author: David Wembridge: david.wembridge@ptes.org

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METHODS

Using count data to estimate casualty rate

Counts of road casualties can be used to estimate casualty rate, i.e. the number of casualties in a given time and distance (Teixeira *et al.* 2013). Repeated surveys of road casualties along the same section of road, removing casualties between surveys (e.g. Hodson, 1966; Santos *et al.*, 2011), can directly estimate casualty rate if the interval between repeat surveys is short (e.g. a day). However, typically these surveys are limited by the distance that can be regularly driven. Greater distances can be obtained if surveys do not need to be repeated (e.g. Davies, 1957; Morris, 1993; Bright *et al.*, 2005); in this case, a section of road is surveyed only once or the interval between repeat counts is unknown but likely to be weeks rather than days. The incidence of casualties (undisturbed by surveyors) represents a steady-state value, at which casualties are scavenged or deteriorate to an unrecognisable condition at a rate equal to that at which new casualties occur. To estimate casualty rate from a single survey, it is necessary to divide counts (per unit distance) by the average persistence time of a corpse. A further consideration is that only a proportion of extant casualties will be observed by recorders. Casualty rate, λ ($\text{km}^{-1}\text{day}^{-1}$), therefore can be estimated by dividing counts (per unit distance) by the product of persistence time and detected fraction of corpses. The derivation of λ is described algebraically in the appendix. Scaling up the estimated rate that casualties occur in a given time and distance to a period of a year and to the total length of the road network, gives an estimate of the annual, national number of casualties, assuming counts per unit distance are from a representative sample of roads.

How long do hedgehog corpses persist and what proportion is detected in car surveys?

Few data exist to support estimates of the proportion of identifiable casualties detected (detection rate, d) and the period that a corpse remains identifiable (persistence time, t_i). For mammals, Teixeira *et al.* (2013) estimated a detection rate of 0.43 ± 0.13 (mean \pm SD). Slater (2002) found up to 41% of casualties identified on foot were detected in car-surveys (including very degraded amphibian corpses, visible only on close inspection). Hedgehog carcasses are likely to be detected with a greater probability than those of taxa considered in the estimates above, because of their distinctive appearance. In this paper, we use two values, 0.4 and 0.8; as the value increases, the estimate of total casualty numbers based on counts will decrease.

Daily surveys of four road sections, totalling 37 km, in southern Portugal by Santos *et al.* (2011) identified 106 hedgehog carcasses in a period of 15 months. The median persistence time was 4.5 days and 38% of carcasses were estimated to persist for seven days. Bright *et al.* (2005) found three (of five) hedgehog carcasses remained identifiable on day 12 of a study in southern England; the others were unidentifiable after one and seven days respectively (mean = 8.8 days). In England, persistence times greater than 20 days have been recorded (P. Morris, per. obs.). Thus, persistence time appears highly variable and is likely to be dependent on physical conditions, including traffic flow, and scavenger activity (Santos *et al.*, 2011); we consider values of 4.5, 9 and 18 days here.

Comparison of datasets

We examine four surveys that report counts of hedgehog casualties along known road lengths in Great Britain: Davies (1957); Hodson (1966); Morris (1993); and Bright *et al.* (2005). With the exception of Hodson (1966), survey methodologies are broadly similar to each other and obtain counts of hedgehog casualties along roads. In estimating casualty rate from these data, we assume a particular corpse is recorded only once, i.e. data are independent of each other. A pair-wise comparison of journey data in Bright *et al.* (2005) shows about 70% of survey pairs within any year had start points separated by two or more times the mean survey length (71.7 km); and 68% of pairs had start dates >15 days apart. Taken together, these suggest survey transects were repeated only rarely in a period comparable to the persistence time.

A second consideration is that Davies (1957) and Hodson (1966) recorded casualties throughout the year, including winter months when hedgehogs are largely inactive; data in Morris (1993) and Bright *et al.* (2005) are restricted to a three-month period when hedgehogs are active.

Casualty rate is strongly predicted by road width (Bright *et al.*, 2015), which varies with road class. Information about road type is available for two of the surveys: Hodson (1966), who surveyed a 3.2 km section of single-carriage A-road; and Bright *et al.* (2005), who surveyed single-carriage roads outside urban areas, recording road type at approximately ten-mile intervals and found that 71% of waypoints were identified as A-roads; 15% as B roads; and 13% as 'minor' (C- and unclassified roads). In comparison, rural, single-carriage A-roads comprise 7.8% of the road network length (excluding motorways); and C- and unclassified roads comprise 48% (DoT, 2015).

RESULTS

Total counts of hedgehog casualties (n) and distances surveyed (l) for each of the surveys, with the number of corpses per unit distance, s ($= n/l$), are shown in Table 1.

Estimates of annual hedgehog casualty numbers, N , are shown in Tables 2 and 3 for several values of detection rate, d and persistence time, t_r . Representative values of N are shown in Table 2, using $d = 0.8$ and $t_r = 9$ days. Estimates derived from counts in Morris (1993) and Bright *et al.* (2005) assume hedgehogs to be active for seven months of the year (214 days) (Morris, 2006).

Using a value of $s = 0.0145 \text{ km}^{-1}$, derived from the largest dataset, Bright *et al.* (2005), an estimate of 167,000–335,000 hedgehog road casualties in Great Britain annually is obtained (Table 3). Values of t_r used are those obtained by Santos *et al.* (2011) and Bright *et al.* (2005) of 4.5 and 9 days respectively and an upper estimate of 18 days; values of d of 0.4 and 0.8 were used. We consider a detection rate of 0.8 to be most realistic for hedgehog carcasses.

Table 1. Comparison of surveys and average counts per unit distance.

Survey	Data period	Area covered	Number of recorded hedgehog casualties (n)	Total distance surveyed (l km)	Number of casualties per unit distance ($s \text{ km}^{-1}$)
Davies, 1957	1952-1954	Hampshire	112	23 384	0.0048
Hodson, 1966	1959-1960	Northamptonshire	15	2339	0.0064
Morris, 1993	1990-1993	GB	4625	214 435	0.0216
Bright <i>et al.</i> , 2005	2001-2004	GB	7009	484 153	0.0145

Table 2. Estimates of casualty rate (λ) and annual hedgehog road casualty numbers in Great Britain (N) derived using values of s in Table 1, $d = 0.8$, and $t_r = 9$ days.

Survey	Casualty rate ($\lambda \text{ km}^{-1}\text{day}^{-1}$)	Length of GB road network (excl. motorways)* (L km)	Estimated annual number of casualties in GB (N)
Davies, 1957	0.00042†	299 758	72 800
Hodson, 1966	0.00641‡	312 349	731 000
Morris, 1993	0.00193†	359 177	230 000
Bright <i>et al.</i> , 2005	0.00129†	388 864	167 000

* Value at the midpoint of the data-collection period (DoT, 2015). Count data were not recorded on motorways and we assume these to be sufficiently different from other road types that values of λ , d and t_r also differ. Currently, motorways make up less than 1% of the total road network length (DoT, 2015) and carry 21% of vehicle miles (DoT, 2016). However, the number of motorway casualties is unlikely to increase significantly the estimate of total road casualty number given here.

† Using equation 1 in Appendix

‡ Using equation 2 in Appendix

Table 3. Estimates of annual hedgehog road casualty numbers in Great Britain, N for a range of values of persistence time, t_r and detection rate, d , using $s = 0.0145 \text{ km}^{-1}$.

Persistence time (t_r days)	Detection rate (d)	Annual number of road casualties in GB (N)
4.5	0.4	669 000
4.5	0.8	335 000
9	0.4	335 000
9	0.8	167 000
18	0.4	167 000
18	0.8	83 700

DISCUSSION

We have derived a hedgehog casualty rate, λ ($\text{km}^{-1} \text{ day}^{-1}$) from counts of corpses and have used this to estimate annual casualty numbers over the whole road network. The values for annual casualty numbers are an order of magnitude greater than the previous estimate of 15,000 (Morris, 2006). In part, Morris (2006) underestimates λ (and hence, totals) because he takes the calendar period of the survey, rather than persistence time, as the period in which casualties occurred: ‘an average of about one hedgehog per 42 miles of road [is recorded]. Since there are 245,000 miles of similar roads in Britain, one might estimate an annual mortality of 5,900 animals, but the surveys only covered three months [...] each year. So, scaling this up to take account of hedgehogs being active for at least six months of the year, the annual mortality seems likely to be at least 12,000 animals and perhaps 15,000’ (Morris, 2006, p167). In effect, this assumes no other casualties occurred in the survey period other than those recorded.

An implicit assumption in the current estimate is that casualty rate is independent of location. This is unlikely to be true but few data exist to improve the estimate. The validity of extrapolating from particular count data to a national estimate is dependent on the data being representative of road type in the network as a whole. The data of Bright *et al.* (2005) over-represent A-roads but suggest that sightings are evenly distributed over the sample of road types surveyed (68% occurred on A-roads; 18%, on B-roads; and 13% on ‘minor’ roads). Casualty rate may also differ between built-up and wider landscapes. Data in Morris (1993) and Bright *et al.* (2005) were collected only on roads outside of the former and there is evidence that casualty rates in peri- or suburban areas are higher (Göransson *et al.*, 1976; Reichholf & Esser, 1981; Morris, 1993; Orłowski & Nowak, 2004). Urban roads constitute 36% of the network length (DoT, 2015) and estimates of N that are derived from counts in rural and peri-urban areas only will tend to underestimate N .

Regional differences in s (e.g. MTUK, 2001) may give an inaccurate estimate of λ nationally if biases exist in the geographic coverage of the dataset. However, Bright *et al.* (2005) noted that coverage ‘was excellent in all four years [...] with only western areas of Scotland having consistently lower coverage’ (p72).

Individual surveys within each of the datasets used here are assumed to be independent of each other (i.e. if a section of road is surveyed more than once, the interval between surveys (t) is such that a particular corpse is not counted more than once). For values of $t \geq 4t_r$, Teixeira *et al.* (2013) estimate an error of less than 5% in counts, using the same model as that used here (*ibid.*, equation 5). It is difficult to estimate the extent of non-independence (pseudoreplication) in the datasets used here; however, for data in Bright *et al.* (2005), the indication is that it was small.

Estimates of N from Davies (1957) and Hodson (1966) are smaller and larger respectively than those from the other two studies (Table 2). Notably, the geographic coverage of Hodson (1966) is highly localised and counts in the region (Northamptonshire) are high in other surveys (Morris, 1993; Bright *et al.*, 2005). Hedgehog densities in this region (near roads at least) are also greater than those elsewhere (Hof & Bright, 2009).

Our estimates of λ are sensitive to values of both d and t_r , which vary with local physical conditions, weather and scavenger populations, as well as characteristics of the corpse. No attempt is made here to refine values of these parameters further than an average nationally. A need exists for better empirical data in this regard to improve estimates.

The estimates of road casualty number presented here can only be indicative, but point to how a figure can be obtained given better parameter estimates. Considerable uncertainty in the total population size, estimated to be about 1.55 million in 1995 (Harris *et al.*, 1995), makes interpretation of the effect of road mortality at a population level difficult. Counts of casualties per unit distance are notably consistent however. Values of s in the South East region in Morris (1993) and Bright *et al.* (2005) are similar to each other and to those in Hampshire recorded by Davies (1957) in the same calendar period: 0.0162–0.0222 mi^{-1} , 0.014–0.024 mi^{-1} and 0.0125–0.0201 mi^{-1} respectively. Marked differences in other regions, however, are apparent between the two most recent surveys (i.e. 1991 compared to 2001), most notably in the East (MTUK, 2001).

CONCLUSIONS

The estimate of 167,000–335,000 road casualties annually here represents an annual mortality of 10–20%, given the current population estimate, comparable to that from capture-recapture studies that have included counts of road casualties in other countries (Göransson *et al.*, 1976; Kristiansson, 1990; Orłowski & Nowak, 2004). Road mortality may affect hedgehog abundance: Huijser & Bergers (2000) estimate that roads and traffic are likely

to reduce hedgehog density by about 30%, sufficient to affect the survival probability of local populations. If road mortality in Britain is appreciable, as suggested here, populations isolated as a result of habitat fragmentation may face a greater extinction risk than considered previously.

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APPENDIX

Derivation of casualty rate from counts

Along a section of road, casualties occur at a rate, λ ($\text{km}^{-1}\text{day}^{-1}$). Corpses remain in an identifiable condition on the road for a mean persistence time of t_r (days) before they are either scavenged or deteriorate to an unrecognisable condition. The average number of (identifiable) corpses per unit distance, σ , therefore, is given by:

$$\sigma = \lambda \cdot t_r \cdot \text{km}^{-1}$$

If only a fraction of corpses, d , is detected by surveyors (such that d is between 0 and 1), the number of corpses recorded per unit distance, s , is:

$$s = \lambda \cdot t_r \cdot d \cdot \text{km}^{-1}$$

Rearranging:

$$\lambda = \frac{s}{t_r \cdot d} \text{ km}^{-1}\text{day}^{-1} \quad [1]$$

The number of corpses recorded per unit distance, s , is given by:

$$s = \frac{n}{l} \text{ km}^{-1}$$

where n = the number of recorded corpses; and l = the total distance surveyed (i.e., the sum of transect lengths). Substituting for s :

$$\lambda = \frac{n}{l \cdot t_r \cdot d} \text{ km}^{-1}\text{day}^{-1}$$

If the same section of road is surveyed multiple times, such that the interval between repeat surveys, t , is short compared to t_r ($t \ll t_r$), and each corpse is counted only once, then:

$$\lambda = \frac{n}{l \cdot t \cdot d} \text{ km}^{-1}\text{day}^{-1}$$

If the number of repeats is large, as in Hodson (1966), such that any particular corpse has a high probability of detection (i.e. d tends to 1):

$$\lambda \approx \frac{n}{l \cdot t} \text{ km}^{-1}\text{day}^{-1} \quad [2]$$

