USING THE DEAD TO MONITOR THE LIVING: CAN ROAD KILL COUNTS DETECT TRENDS IN MAMMAL ABUNDANCE?

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Abstract. Counts of animal corpses resulting from road traffic collisions can give useful information on changes in animal abundance if there is a correlation between the population density of the species in neighbouring habitats and the number of road kills observed. Collection of data on mammal road casualties can be carried out by untrained volunteers; it can be collected across large areas; and it is cost effective in terms of time and expense. We carried out a study to determine if road casualty data can be used to monitor mammal abundance and distribution using one of the most commonly recorded road casualty species in the UK, the rabbit (*Oryctolagus cuniculus*), as an example. We found a direct relationship between the numbers of rabbit road casualties and the numbers living in the wider landscape. Nearly 60% of the deviance in the live rabbit density index could be explained using only rabbit road casualty, landclass group and traffic flow data. Therefore the use of road casualty data is a cost effective method of monitoring rabbits and, by implication, other species over a large area in the UK, and is a highly effective means of monitoring terrestrial mammals.
Keywords: *road-kill, abundance, monitoring, rabbit, oryctolagus cuniculus*

Introduction

There are a number of conservation and management issues associated with terrestrial mammals worldwide. Some are classified as rare or in serious decline (UK examples include the common dormouse (Bright and Morris, 1996); Eurasian otter (Mason and Macdonald, 2004) and red squirrel, *Sciurus vulgaris* (Gurnell et al., 2004), and the identification of trends in the abundance of these species is critical to their conservation. Others are considered problem species and require population management as a result. Red foxes (*Vulpes vulpes*), for example, are considered pests to livestock (Greentree et al., 2000); European badgers are thought to be linked to outbreaks of tuberculosis in cattle (Krebs, 1997); and brown rats (*Rattus norvegicus*) can transmit disease to humans (Kobayashi, 2001). Furthermore there is the increasing problem of non-indigenous species (e.g., grey squirrels, *Sciurus carolinensis*, and American mink, *Neovison vison*) that have important impacts on local biodiversity (Clout and Russell, 2008; Roy et al., 2009). Only by monitoring population changes regularly and over a long period can important trends be identified and robust priorities set for conservation and management action.

Obtaining accurate estimates of mammal numbers in diverse habitats and landscapes is the key to successful monitoring (e.g. National Bat Monitoring Programme, UK (Battersby and Greenwood, 2004); Biobasis Programme in north East Greenland (Schmidt et al., 2008; Meltofte, 2006). The fact that mammals are generally elusive and crepuscular or nocturnal means that it can be extremely difficult to count actual numbers living in the wider landscape, so measures of population size are almost always based on indices, based on counts of field signs such as faeces (Bailey and Putman, 1981), tracks (Beier and Cunningham, 1996), damage caused (Bryce et al., 1997) or game bag records (Tapper, 1987).

Before an index of abundance can be used to make quantitative assessments of population trends, it must first be calibrated, ideally, against an absolute measure of abundance. However, since this is generally not practical for mammals, an alternative option is to calibrate two indices of abundance against one another. A strong association between the two indices indicates that they can be considered reliable reflections of actual abundance, particularly if the association is maintained in a variety of habitats (Krebs, 1998). For example Drennan et al. (1998) calibrated track station counts of Aberts squirrels (*Sciurus aberti*) against estimates from capture-mark-recapture methods, and in Tasmania, eastern barred bandicoot (*Perameles gunnii*) road casualty numbers have been calibrated using population data that was obtained from live trapping grids in fields adjacent to the roads surveyed (Mallick et al., 1998).

To aid in the calibration of sign surveys, the validity of pellet and dung counts in different habitat and weather conditions has been studied extensively (Taylor, 1956; Angerbjorn, 1983; Iborra and Lumaret, 1997; Palomares, 2001) and all findings suggest that differences in habitat and weather should be taken into account. Limitations on when and where data can be collected mean that such surveys may be invalid, impractical or very expensive over large areas (i.e. countrywide). New methods are therefore needed that can provide indices of abundance for very large areas, without too many constraints on data collection. In particular, they should be practical on a large scale and be suitable for use by volunteers, as this is highly cost effective (Macdonald et al., 1998).

Approximately one million wild animals are killed on roads each year in the UK alone (Underhill and Angold, 2000). Counts of road traffic casualties are a potential means of monitoring changes in the abundance of several mammal species. Collection of data on mammal road casualties can be carried out by untrained volunteers; it can be collected across large areas; and it is cost effective in terms of time and expense. However it is vital to first determine the relationship between animal density and numbers of road traffic casualties (Baker et al., 2004; Brockie et al., 2009).

The aim of the present study was to calibrate a road-kill-based index of rabbit abundance against actual numbers in the wider landscape. Rabbits were selected as the study species because they are frequently sighted and easily identifiable road casualties (Gibb and Flux, 1983; Holsbeek et al., 1999; Caro et al., 2000), and because their status as a pest species (Thompson and King, 1994) means that much work has been conducted on methods by which to assess their abundance (Trout et al., 1986; Moller et al., 1996; Poole et al., 2003).

During the 1950s an outbreak of myxomatosis in Britain reduced the rabbit population to less than 1% of its previous size (Thompson and Worden, 1956). Since that time, attenuation of the myxoma virus (Ross et al., 1989) and increased genetic resistance within the rabbit population (Ross and Sanders 1984) have together resulted in steadily increasing numbers. The UK rabbit population is now estimated at more than 37 million individuals (Harris et al., 1995) and they are an important prey species for many predators and scavengers, including foxes, stoats (*Mustela erminea*) and mink (Corbet and Harris, 1991). Monitoring of rabbit abundance across the UK is thus of considerable importance in relation to conservation and management programmes. If road casualty data can be reliably linked to actual rabbit population density then surveys

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of rabbit road-kill numbers could potentially be used to monitor fluctuations in the rabbit population across different regions and habitats throughout the UK, with minimal effort and cost.

Methods

Road casualty counts

During July, August and September 2002, 29 transects were surveyed by car. Each transect was approximately 97km (60 miles) in length, and was situated in one of two landclass groups as classified by the CEH (Bunce et al., 1996). Fourteen transects were surveyed in areas classified as 'pastoral V' and 15 in 'arable II'. All transects included only non-urban roads (i.e., only those that did not pass through ≥3.2km of built up land), and each covered 'A', 'B' and 'Minor' roads in the ratio 4:3:1, respectively. A record was taken of the nearest town, county, odometer reading and road number at the start and end of each transect, and at approximate 16km intervals along each. Traffic flow was measured for each road type on each transect by recording the total number of oncoming vehicles.

Upon sighting a mammal road casualty, the surveyor identified it to species level (or recorded it as unidentifiable if this was not possible) and recorded the nearest town, county, road number, and odometer reading at the casualty site. The time of each sighting was also recorded.

The 29 transects driven had also been surveyed for road casualties in a separate study conducted during the same months of the previous year (2001). The survey protocols used were identical, and hence rabbit road casualty data were directly comparable between the two years.

Measuring live abundance

Surveys to determine live rabbit abundance were conducted along each road transect, in each case within eight randomly selected 1km sample squares that were spaced approximately 12km apart along the route. All sampled areas were immediately adjacent to the road. If a selected 1km square contained an urban area, a new square was selected as close to the original as possible.

The owner of the land within each survey square was asked multiple-choice questions about rabbit and predator control (*Table 1*). When the landowner could not be located, an observer answered as many of these questions as possible whilst surveying the square, and noted that the landowner had not been questioned.

Table 1. *Data collected during landowner surveys*

Questions asked	**Responses recorded**
Predators present?	Fox / Stoat or Weasel / Other
Predators controlled?	Yes / No / Unknown
Area of square where predators removed	None / Part / All / Unknown
Predator removal effort	None / Little / Seasonal / Full Time / Unknown
Pheasant release pens present?	Yes / No
Estimate of pheasant numbers released	[figure quoted]
Predator traps present?	Yes / No [plus details]
Rabbit-ting carried out?	Yes / No / Unknown
How frequent is rabbit control?	None / Some years / Annual / Unknown
Seasonality of rabbit control	None / All year / Summer / Winter / Unknown
Rabbit control effort	None / Little / Hotspots / Widespread / Unknown
Rabbit control method	[method quoted]

Surveyors walked across each 1km square twice, in either a north-south or east-west direction, following linear habitat features (*Figure 1*). Each half of the grid transect was approximately 200m from the parallel edge of the square and located sufficiently far from the second grid transect to avoid double counting of live mammals. Linear features were followed because they provide boundaries between different habitats and/or fields and because they are potential denning and breeding areas for rabbits. In addition, foxes tend to travel along linear habitat features, and so following them facilitated the counting of predator signs. The presence/absence of rabbits droppings, live sightings, burrows and scrapes within 5m of either side of the transect line was recorded for every 100m section of it. Since the total transect distance walked within each square was 2km, this resulted in a count out of 20 for the presence of each sign.

Additionally, within each 100m segment surveyors recorded the major type of land-use, the presence/absence of roads and water features, and the presence/absence of predator signs within 5m of the transect line.

The timing of the survey (July, August and September) was selected so that it coincided with the Mammals on Roads survey (Battersby, 2005), and so that results from the two were comparable. However, this is not an ideal seasonal period for rabbit sign surveying because it tends to be associated with high variance in rabbit numbers and with increased vegetation height and density (which make field signs harder to detect).

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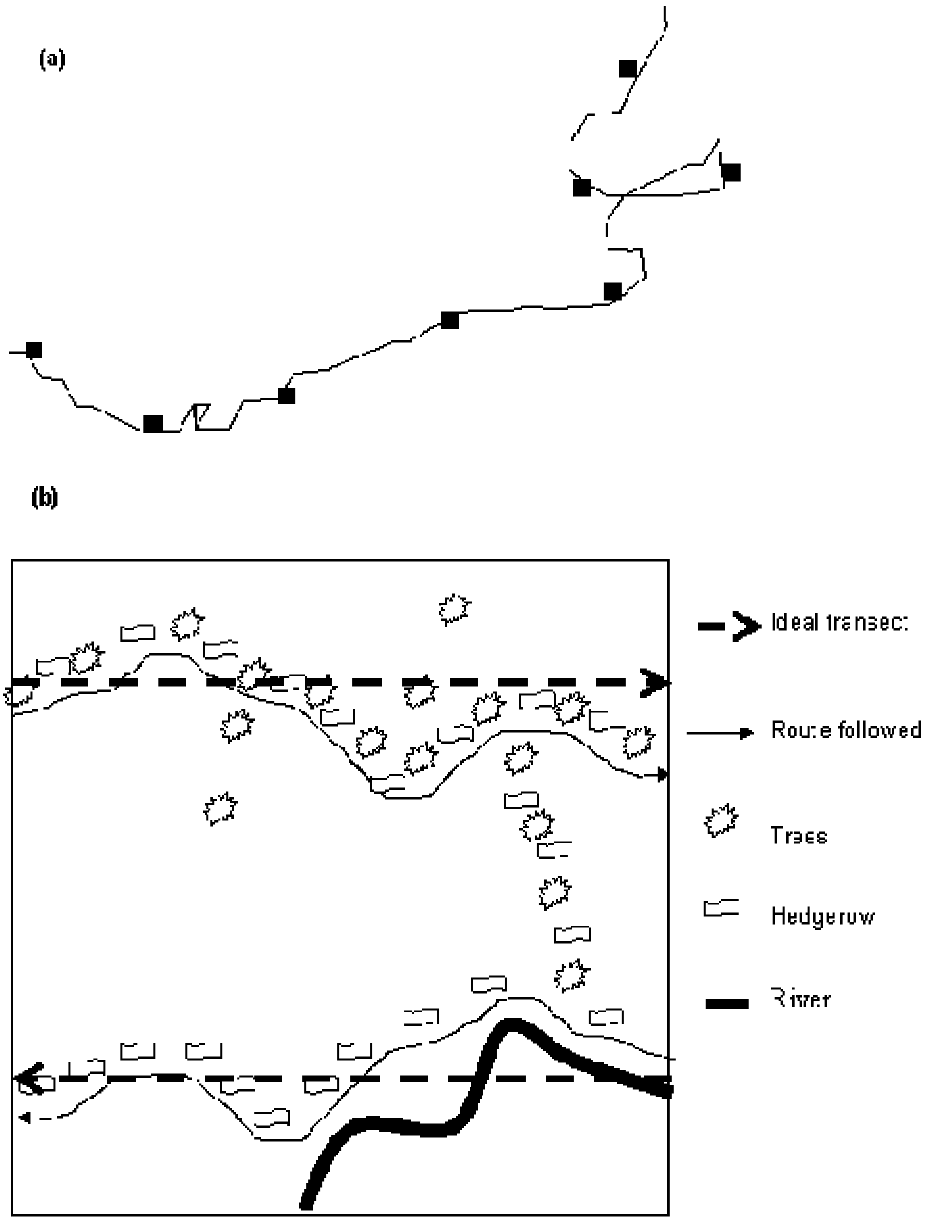

Figure 1. *Examples of (a) a road transect (black line) with 1km squares (black squares) surveyed along the road transect route, and (b) ideal and actual 1km grid square transects*

Data analysis

As it was not possible to ensure that all road transects were identical in length, counts of rabbit road casualties were standardised as the number per 100km of road surveyed.

For each 1km square surveyed, counts of rabbits and their signs were used to calculate a rabbit density index (y) using a previously calibrated regression equation (MAFF, 1982); *Equation 1*). This equation was previously produced following calibrations of rabbit sightings to live rabbit abundance (Poole et al., 2003), and hence has been validated as a method for accurately determining rabbit density.

For each 100m segment of every 2km grid transect, counts of the following were recorded: rabbits (V1) and hares (V2 $\approx$ 0.25), both living and dead; holes/forms (V3); scrapes/digs (V4); tracks/runs (V5 $\approx$ 8.70); dropping patches (V6); hair/fleck

(V7≈ 0.76); grazing/grazing damage (V8 ≈ 2.3); barking (V9 ≈ 0.39). The values recorded for each parameter in each 1km square were substituted into *Equation 1* to calculate a density index for live rabbit abundance within each survey area.

$$y = K + 0.531\ V1 + 0.120\ V12 + 0.455\ V2 + 0.078\ V3 + 0.351\ V4 - 0.323\ V5 + 0.387\ V6 + 0.508\ V7 - 0.129\ V8 - 0.404\ V9 \quad \text{(Eq 1.)}$$

Where equation parameters were unknown, mean data for England and Wales from a survey in 1982 (MAFF, 1982) were substituted (shown in brackets above). Inclusion of a constant (*K*) in the equation ensures that all indices are positive.

A generalised linear model (GLM) with a Poisson error structure and $\log_e$ link function was used to model the relationship between live rabbit density, rabbit road casualties and a number of habitat-related variables. The response variable was the mean live rabbit density index for each road transect, calculated from the corresponding eight survey squares. were used as explanatory variables. A total of 24 potential explanatory variables were considered, including habitat, rabbit/predator-control variables, oncoming traffic count and the number of rabbit road casualties per 100km of transect driven. Values for edge habitat and land-use were recorded as percentages and hence were subject to the unit sum constraint. To ensure independence, the data were log-ratio-transformed before analysis (Aebischer et al., 1993). The most parsimonious model was obtained via stepwise removal of non-significant explanatory variables by χ^2 deletion (Crawley, 1993).

In order to determine whether the GLM could accurately predict inter-annual changes in rabbit road casualty numbers, road-kill counts were compared for the years 2001 and 2002. Data used in this analysis were collected on the same transect routes, in the same seasonal period and using identical recording methods.

Results

On average, more rabbit road casualties were sighted per 100km in the arable II landclass group than in the pastoral V landclass group (Mann Whitney test: U = 58.0, P = 0.041, n_1 = 15, n_2 = 14; *Figure 2*).

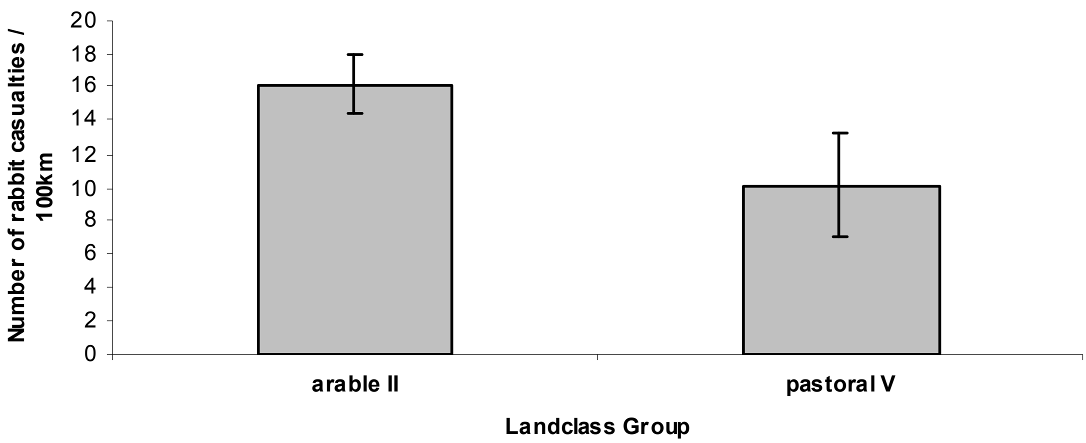

Figure 2. *The number of rabbit road casualties per 100km in arable II and pastoral V landclass groups (mean ± SE)*

Overall, the live rabbit density index tended to be higher in arable II areas than in pastoral V. The mean live rabbit density in arable II areas was 10.45 (SE = 1.040, n = 120), compared to 6.45 in pastoral V areas (SE = 1.165, n = 111), and this difference was significant (Mann Whitney: U = 3740.5, n_1 = 120, n_2 = 111, P = <0.001; *Figure 3*).

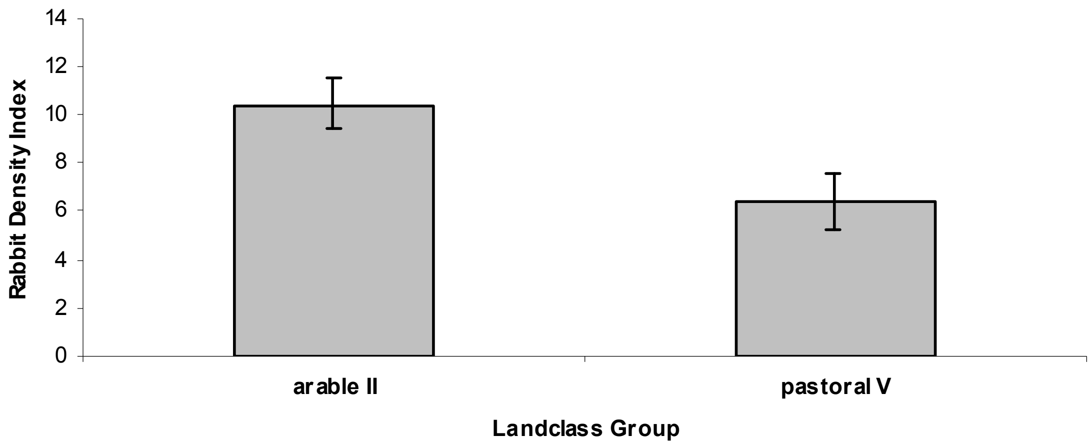

Figure 3. *Live rabbit density indices calculated for survey areas classified as arable II and pastoral V (mean ± SE)*

During simplification of the generalised linear model, variables removed included all those relating to rabbit and predator control, pheasant management and habitat. Three explanatory variables and two interactions remained in the minimum adequate model, which explained 57.76 % of the deviance in the live rabbit density index (P < 0.001, df = 5, *n* = 28; *Table 2*).

Table 2. *Generalised linear model of live rabbit density against traffic flow, rabbit road casualties per 100km and landclass group*

Variable	Parameter Estimate	SE	p	Deviance	% deviance explained
Constant	2.566	0.456	-	-	-
Traf_km	-0.0613	0.0757	<0.001	29.458	23.14
Rab_km	0.32	1.68	0.001	2.044	1.61
LCG arable II	0	-	-	-	-
LCG pastoral V	-0.460	0.519	0.387	1.570	1.23
Traf_km & LCG	-0.2610	0.0967	0.012	14.845	11.66
Rab_km & LCG	8.53	2.41	0.002	25.614	20.12
Total Deviance Explained					57.76

The majority of the variation in live rabbit density between the 1km survey squares was explained by traffic flow (Traf_km = 23.14 %), and the interaction between the number of rabbit road casualties per 100km and the landclass group (Rab_km.LCG = 20.12 %). This indicates that the relationship between live rabbit density and rabbit road casualty numbers can be explained using the traffic flow and landclass group variables (*Figure 4a*).

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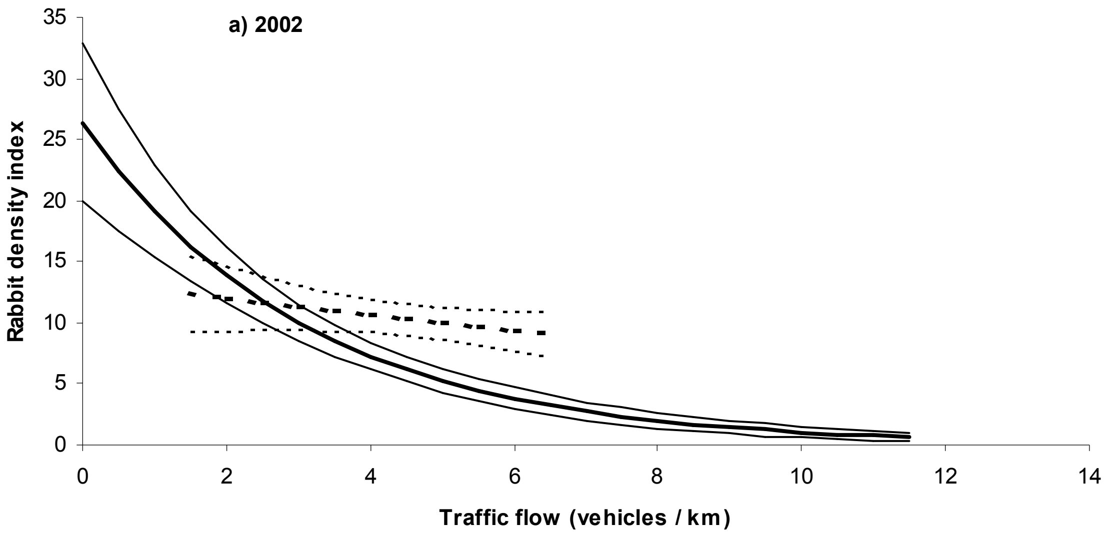

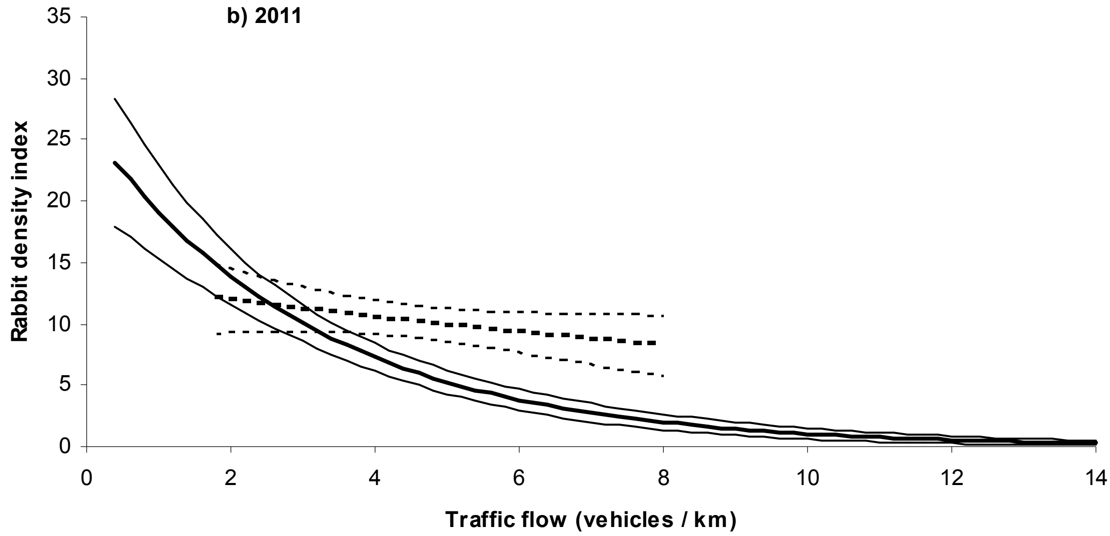

Figure 4. *Relationships between traffic flow and live rabbit density indices in arable II (dotted lines) and pastoral V (solid lines) landclass groups (one outlier excluded from calculations): (a) shows mean traffic flows recorded in 2002 (b) shows predicted traffic flow in 2011 (bold lines = mean values, light lines = ±SE)*

With regards to both landclass groups, the model indicates a negative correlation between live density and traffic flow (Traf_km parameter estimate = - 0.0613; *Figure 4a*), and a positive correlation between live density and road casualty numbers (Rab_km estimate = 0.32). Road casualty counts and traffic flow showed greater variance within pastoral V land, and therefore the predictions of the model (*Figures 5 and 6*) are given only between the parameters that would be found in the relevant landclass group.

Based on the results of this study, a regression equation (*Equation 2*) was devised to quantitatively explain the relationship between rabbit density and the three key variables, that is, traffic flow on neighbouring roads, road casualty counts, and landclass group. **A** is the live rabbit density index in a 1km square; **B** is the number of vehicles

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counted per 100km on the respective road transect; **C** is the number of rabbit road casualties per 100km of road surveyed on the respective transect; and **D** is the landclass group (0 = 'arable II' land; 1 = 'pastoral V' land).

$$A = 2.566 + (-0.0613B) + (0.32C) + (-0.460D) + (-0.2610(BD)) + (8.53(CD)) \quad \text{(Eq. 2)}$$

Across the UK as a whole, traffic flow was approximately three percent higher in the third quarter of 2002 than in the same period in 2001 (DTLR, 2003). Since traffic flow and rabbit density were found to be negatively related (*Figure 6*), our model would thus predict a decrease in rabbit road casualties from 2001 to 2002 (see *Figures 5 and 6*). There was, however, no significant change in the number of rabbit road casualties per 100km in either of the two landclass groups between the two years (Mann Whitney test: arable II: U = 109.0, n_1 = 15, n_2 = 15, P = 0.902; pastoral V: U = 89.0, n_1 = 14, n_2 = 14, P = 0.701).

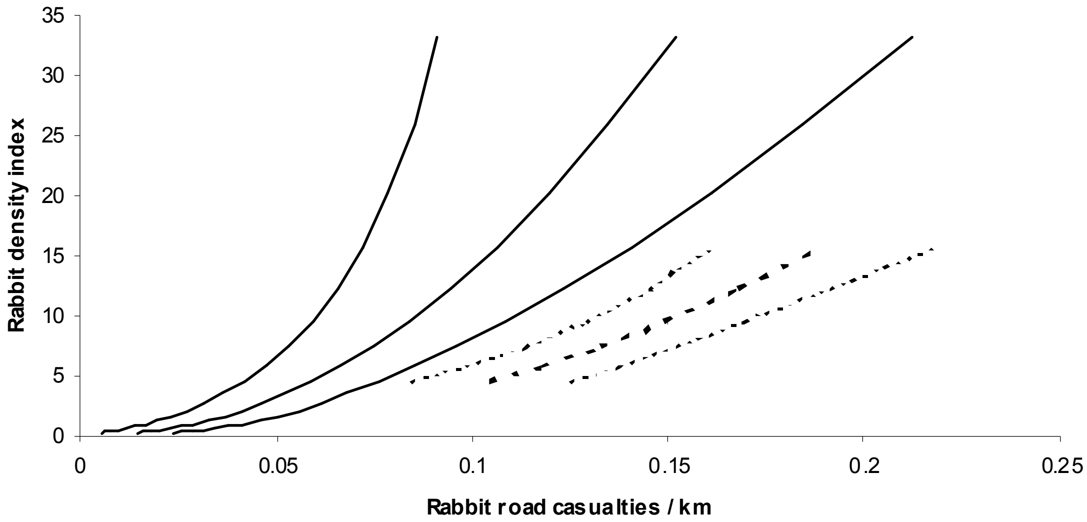

Figure 5. *Predicted relationships between rabbit density and road casualty counts in arable II (dotted line) and pastoral V (solid line) landclass groups (mean = heavy lines; ±SE = light lines)*

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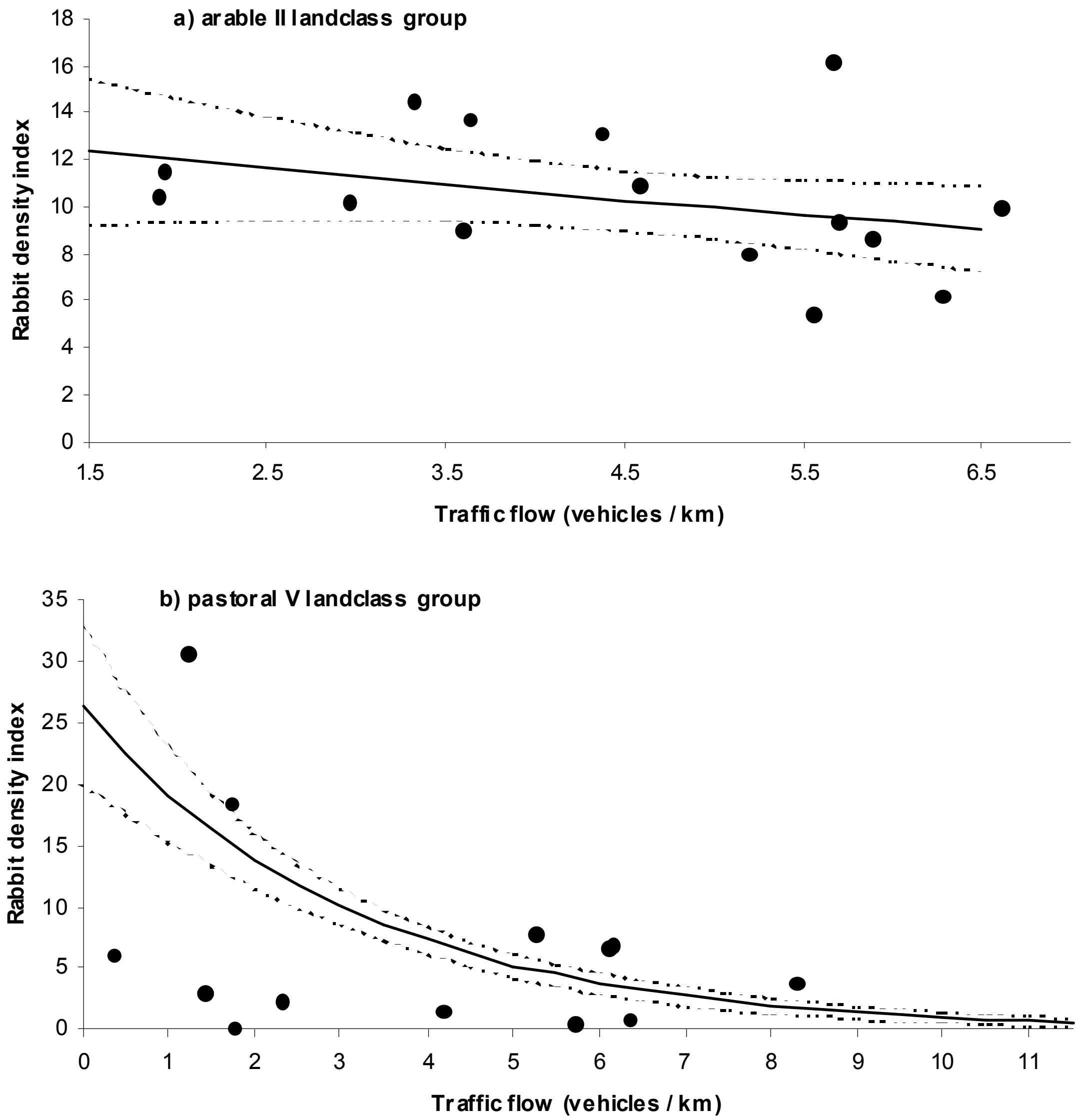

Figure 6. *Recorded (dots) and predicted (solid lines) live rabbit density indices in relation to changing traffic flow in (a) arable II and (b) pastoral V landclass groups (broken lines = ±SE)*

Discussion

This study demonstrates a strong relationship between rabbit road casualty numbers and the actual abundance of rabbits living in adjacent areas. Furthermore it shows that, so long as a small number of other variables are taken into consideration (namely traffic flow and landclass group), an index of abundance based on road-kill-counts (e.g., number of casualties per 100km) could be employed to monitor rabbit populations. Such an index of abundance based on counts of road casualties would be easy, cheap and practical to obtain across wide geographic areas.

Counting the numbers of rabbit road casualties as one travels in a vehicle is considerably cheaper than other methods of calculating indices of abundance that require trained personnel, and a larger area can be covered in the time available. The timing of the survey is also not restricted to times of day when rabbits are active, as are surveys utilising live counts which are usually limited to dawn or dusk surveys (Moller et al., 1996; Poole et al., 2003).

The number of rabbit road casualties found in both arable II and pastoral V landclass groups was high compared to indices recorded for rabbits in other studies (Sleeman et al., 1985). There was great variability in the numbers of rabbit road casualties per 100km recorded on each transect, however there were still significantly more rabbit road casualties recorded in the arable II than the pastoral V landclass group. The larger range in both the number of rabbits per 100km and the rabbit density index in the pastoral landclass group in comparison to the arable landclass group suggests that the arable landclass group as a whole is a more favourable environment for rabbits, and that there are only patches of suitable environment in the pastoral landclass group. This may account for the greater effect an increase in traffic flow is predicted to have on rabbit densities in the pastoral V landclass group than in the arable II landclass group (*Fig 3 and 4*). In the pastoral V landclass group rabbits may be more highly dispersed with fragmented populations, therefore any changes in the environment such as increased traffic flow may have a greater affect upon the localised rabbit populations (Forys and Humphrey, 1996).

The model presented here predicts a decrease in the live rabbit density index with increasing traffic flow. Similar conclusions were drawn from a study on frogs and toads in Ottawa Canada (Fahrig et al., 1995) where a negative relationship was found between the number of live amphibians and traffic flow.

Between 2001 and 2002 the traffic flow on UK roads increased by approximately 3% (DTLGR, 2003), however no change in the numbers of rabbit road casualties were recorded per 100km travelled in the two landclass groups in this chapter. This lack of correlation between the predictions of the model and the numbers of rabbit road casualties recorded is likely to be because only two years of data was available and it is unlikely that such a small timescale would show trends. Annual rabbit abundance fluctuates quite widely, consequently many years of data are required to show trends over time and also, rabbits may be continuing to increase their numbers since the population crash in the 1950s due to myxomatosis (Ross and Sanders, 1984).

The live rabbit density index was originally calibrated using counts of rabbits by the min of ag and fisheries using data from England and Wales. This explained 83-91% of the variance in live rabbit numbers (MAFF, 1982). This was validated by Poole et al. (2003) who showed that the relationship between counts of rabbits and live rabbit abundance still stands. It is therefore not necessary to recalibrate this equation for the landclass groups not studied here. However, the model presented here is based on data collected from two landclass groups (arable II and pastoral V) and extrapolation to include other land-types may not be justified, particularly since landclass was an important explanatory variable in the model. Factors such as predator densities and climate are likely to vary between landclass groups and may affect the relationship between rabbit road casualty rates and live abundance. Therefore, further calibration studies within the remaining five landclass groups will be required. Extension of this work should include calibration of road-kill indices for other UK mammal species using similar methods. Additional factors that may influence road casualty rates, including local road density and traffic speed should be considered when using such work to generate models to predict abundance from road-kill numbers.

The months of July and August 2001 were much wetter than the same period in 2002 (MetOffice, 2003). Therefore, since higher rainfall levels would be expected to increase the rate of disintegration of road casualties (de Carvalho and Linhares, 2001), it is possible that the higher casualty numbers recorded in the drier year of 2002 reflected climatic factors rather than rabbit population density.

The amount of rainfall may have affected the collection of the signs data as faecal pellets may be washed away during periods of heavy rain (Iborra and Lumaret, 1997; Palomares, 2001). To overcome this, surveys were not carried out on days when there was heavy rain; however there is a possibility that more pellets were counted in areas that had been drier for longer periods than others. The habitat in the surveyed 1km squares may have also influenced the number of faecal pellets recorded, as some squares had tall grasses or arable crops which were difficult to see through to ground level. Both these factors could have reduced the final live rabbit density estimates for the areas concerned.

Using traffic flow, numbers of rabbit road casualties and landclass group 57.75% of the deviance in the live rabbit density index could be explained using the model described here. The model could therefore be used over both time and large areas to monitor changes in the index of abundance of rabbits. If the limitations of the data are considered, the model could also be used as a method of calculating absolute abundance of rabbits living in the arable II and pastoral V landclass groups on an annual basis.

The model presented here fits well to both high and medium rabbit density areas. Road casualty data has been shown to correlate with the densities of other mammal species such as eastern barred bandicoot, racoons (*Procyon lotor)* and foxes (Mallick et al., 1998; Gehrt et al., 2002). This method should therefore be investigated further by calibrating other live populations of mammal species to the numbers of road casualties.

Road casualties of most mammal species are highly visible and easily recognisable and therefore are a ready source of data to be used for monitoring mammals. One of the main benefits of using road casualty data rather than other measures of rabbit abundance is the speed with which the data can be collected. Moller et al. (1996) found that using daytime transect counts of rabbits to get an index of abundance within 20% accuracy would require 20 counts, and for 10% precision would need 80-90 transect counts. It is not practical to carry out transect counts of this nature over large areas, especially if 20 or more counts are required at each site. We found that the numbers of rabbit road casualties can be directly linked to the numbers living in the wider landscape using only rabbit road casualty, landclass group and traffic flow data. There is therefore a huge potential for monitoring rabbits and by implication other species over a large area by using data collected in this manner.

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