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Patterns of otter *Lutra lutra* road mortality in Britain

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Summary

1. This paper examines patterns of otter road traffic accidents and the possibilities for reducing this mortality.
2. Records of otter road casualties in Britain (673 between 1971 and 1996) were compiled and accident sites were plotted on 1:50000 scale Ordnance Survey maps. Casualty records were categorized by geographical region, road type, distance to watercourses and presence and type of river crossings. The data were analysed for demographic, seasonal, temporal and spatial trends.
3. A rapid increase in numbers of road traffic accident records has occurred since 1983. Fifty-six per cent of fatalities were males, representing a statistically significant bias.
4. The number, but not the sex ratio, of otter road casualties differed between seasons and in all areas was positively correlated with either seasonal rainfall or river flow.
5. Significant effects of geographical region, road density and year were found on the annual number of casualties recorded in mainland regions, and the regional rates of increase in numbers of road traffic accidents were significantly different. There is also evidence that road traffic accidents are influenced by otter site occupancy of a region.
6. Trunk and A-roads accounted for 57% of road traffic accident records, even though they comprise only 13% of the road network.
7. A 100-m wide zone surrounding fresh water and the coast accounted for 67% of all casualty records. Measures to reduce road mortality should target this zone.
8. The seasonal correlations of otter road traffic accidents with rainfall and river flow, and the fact that 91% of accidents occurred where a road crossed a watercourse, suggest that substantial reductions in road mortality could be achieved by improving the design of road crossings of watercourses.
9. We suggest that the optimal approach to road crossing design is to maintain a continuous, and where possible, natural bank above the level of high flows, using either wide-span bridges, over-sized culverts or artificial ledges.
10. The use of otter-proof fencing may be required to reduce mortality where roads pass close to watercourses, but care must be taken that this does not create a barrier to all movements of otters and other wildlife.

Key-words: Mustelidae, population-recovery, road-kills.

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Introduction

Over the past four decades the Eurasian otter *Lutra lutra* L. has generally suffered a widespread and rapid decline in numbers and range, and the species is now rare or absent from most of Central Europe (Macdonald 1995). In Britain, this decline has been attributed principally to the introduction of organochlorine pesticides in the 1960s, which led to contamination of aquatic food chains. This occurred when the otter population was already stressed by persecution through organized hunts and gamekeeping control (Strachan & Jefferies 1996). Other

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factors – such as polychlorinated biphenyl (PCB) and heavy metal contamination of watercourses – have been examined, but the influence of these on the population decline and potential future recovery is uncertain (see Smit *et al.* 1994 and Strachan & Jefferies 1996 for reviews). There is now evidence that in recent years populations have been increasing at different rates in countries bordering the Atlantic coast and parts of northern and eastern Europe, eastern Austria and parts of Norway (Green & Green 1997).

Several studies have investigated causes of mortality in otters (Mason & Madsen 1990; Heggberget 1991; Kruuk & Conroy 1991; Striese & Schreyer 1993; Madsen 1996). Some authors have found road deaths to be the predominant cause of non-natural mortality (Green 1991; Stubbe 1993; Körbel 1994; O'Sullivan & FitzGerald 1995; Rosoux & Tournebize 1995; Ansorge, Schipke & Zinke 1997) excepting pollution incidents such as oil spills (Green 1991). The number of deaths attributable to road traffic accidents is thought to be increasing (Green 1991; Stubbe 1993; Körbel 1994; Green & Green 1997).

There is scant knowledge of otter populations in Britain. Clearly, road traffic accident records underestimate the true toll and are over-represented amongst causes of otter death (Green 1991; Heggberget 1991; Kruuk & Conroy 1991; Rosoux & Tournebize 1995; Green & Green 1997). Environmental pollution and persecution no longer limit otter survival in Britain, as demonstrated by the successful restocking programmes carried out by the Otter Trust and the Vincent Wildlife Trust (VWT), whereas road traffic levels are projected to increase (Department of Transport 1996). The expansion of the otter population in Britain and other parts of Europe, combined with the development of the economies of eastern European countries, concomitant with continued road building and increasing traffic flows throughout Europe, has raised concerns about increased mortality of otters on the roads (Green & Green 1997). Since the early 1980s there has been an increase in research into the causes of otter mortality. This has led to increased collection of dead otters which, in turn, will have contributed to higher numbers of recorded road deaths over time. Mortality attributed to natural causes in a sample of 113 dead otters recovered on Shetland was found to be 49% (Kruuk & Conroy 1991) and was considered to be the principal cause of death. In Norway, Heggberget (1991) concluded that drowning in fish nets or traps was responsible for more otter deaths than road traffic accidents, though fewer drowned corpses were recovered.

Intensive studies in Europe (Striese & Schreyer 1993; Fehlberg 1994; Rosoux & Tournebize 1995; Madsen 1996) suggest that the toll of traffic on wild animals can be serious and may have been critical in the decline of some populations: the last two known otters in the Netherlands were both killed by traffic (Green 1991). Lafontaine (1991) suggests that 5% of the total otter population of France may be killed by traffic each year. Kubasch (1992) has suggested that 10% of the total population of Saxony has been lost to road accidents. Road accidents claim many healthy animals (Kruuk & Conroy 1991), compounding an already high natural mortality rate. Where otters live at low density, as in England, the Netherlands and Italy, a single otter road death can affect a large area (recent DNA analysis suggests that a 75 km stretch of the River Itchen in Hampshire, England, where field signs of otters are particularly abundant, is populated by just three otters; T. Sykes, personal communication).

Since the 1970s, otter road casualties have been collected and studied by several organizations and individuals in Britain. In this paper all available records of otter road traffic accidents in Britain were collated. The purpose of this study was to investigate demographic, seasonal, temporal and spatial patterns that might reveal ways in which otter road mortality could be reduced, either through the design or alignment of roads. Key areas where mortality is concentrated are highlighted and possible ways of reducing road mortality are discussed (see also Macdonald *et al.* 1997).

HYPOTHESES

We investigated trends in otter road traffic accidents over time, together with factors implicated by previous studies (see above) to test whether the rate of otter road mortality is increasing and to identify causal factors in any increase. The overall sex ratio in the data set, and seasonal sex and age ratios were examined to reveal any evidence for behavioural differences between individuals, e.g. in ranging behaviour, which might affect the number of road traffic accidents. Seasonal patterns of casualties were analysed in relation to rainfall and river flows to determine whether the design of road crossings over rivers may restrict the passage of otters underneath roads in high river flow conditions (implying that otters then attempt to negotiate the river crossing by travelling across the road). Trends in the number of otter road casualties were compared with road density, road traffic and a measure of otter population density nationally and regionally to test the hypotheses that road density, the volume of traffic and otter population density may influence the incidence of otter road mortality. The proportion of casualties occurring at different types of river crossings was examined to investigate the hypothesis that culverts are an inferior design to bridges in terms of allowing otters to pass beneath roads safely. The proportion

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of casualties occurring on different road types was examined to test the hypothesis that major roads (carrying greater volumes of traffic at higher speed) are responsible for the greatest number of otter casualties per kilometre.

Methods

Road traffic accident (RTA) records were collected from the UK Wildlife Trusts, the Environment Agency, the Institute of Terrestrial Ecology (ITE) and individuals from other relevant organizations within the UK. The majority of otter casualty records consisted of date, grid reference and sex of the recovered corpse. The site of each casualty was examined using 1:50 000 scale Ordnance Survey maps, and road type, river crossing type and distance from the nearest fresh water or the coast were noted. Annual and seasonal rainfall, river volume flows, and road traffic data were also collected (Department of Transport 1996; Institute of Hydrology 1981–95). The results of the national otter surveys of England 1978/79, 1984/86 and 1991/94 were used (Strachan & Jefferies 1996), as well as survey results from Wales (Andrews, Howell & Johnson 1993) and Scotland (Green & Green 1997). Definitions of each variable used in the analysis, its source and the number of records are given in Table 1. The data were analysed using the programs Microsoft Excel, SAS (SAS Institute Inc. 1989) and SPSS (Norusis 1998) for Windows. All analyses assume data are independent and drawn at random although, in reality, efficiency of casualty recording between sexes, season and region may vary. The chi-square analyses assume that equal sampling effort is applied to each category. The sample size in each analysis is different because some casualty records do not contain information on all variables. It is assumed that the number of RTA records collected and used for analysis provides a representative sample of the total casualties in the region.

SEASONALITY, AGE AND SEX RATIOS

To test the hypothesis that a peak in casualties occurred during the winter months, when high rainfall and high river flow rates normally occur, all dated casualty records were allocated to each of the seasons of the year (seasons are defined in Table 1, see variable 'Month'). A chi-square test was used to determine whether significantly more casualties occurred in any particular season.

To test whether there was an overall or a seasonal sex-bias in casualties, the sex ratio of casualties in the dataset was determined. Chi-square analysis was used to test the null hypothesis that sex was independent of season. A similar analysis was used to test for any differences between the ratio of adults to subadults among seasons.

Long-term average monthly rainfall and river flow figures (Institute of Hydrology 1981–95) were averaged over six well-spaced gauging stations in each region, to give means for monthly rainfall and river flow (see Table 1 for definition of regions). To test whether RTAs were correlated with rainfall or river flows, RTA records were sorted by region and month. Spearman's Rank correlations were determined in each region between the total RTAs in each month and the average monthly rainfall for the region (in the Islands region figures were available only from Shetland, Orkney and Skye). Spearman's Rank correlations were also determined between total RTAs in each month and average monthly river flow in all four mainland regions. To test whether seasonal patterns of rainfall were correlated with river flows, Spearman's Rank correlations were calculated between average monthly rainfall and average monthly river flow in mainland regions (no river flow data for Islands).

TRENDS OVER TIME

To test whether otter road casualties, the density of roads and/or the level of traffic were correlated, trends in RTAs, road length and traffic (see Table 1 for definitions) over the period 1970–96 were examined using Spearman's Rank correlations. Data for road lengths and traffic were obtained from the Department of Transport (1996). Spearman's Rank correlations between road density (see Table 1) and year for each mainland region were also determined, to establish the consistency of these trends (no data for road density on the Islands were available for this period).

To test the hypothesis that the number of RTAs differed between regions and showed trends over time, general linear models (GLM; SAS Institute Inc. 1989, PROC GLM) were fitted using the density of road kills as the dependent variable (expressing the number of casualties in each region as a figure per unit area), with region and year as predictors. Year was treated as a continuous and region as a categorical variable with five levels (Islands, Scotland, England, Wales and South-west, see Fig. 1). Tukey's mean separation procedure was used to distinguish differences among the regions where appropriate. A second model incorporated road density data (which was unavailable for the Islands), to test the effect of road density on otter casualties and to evaluate trends over time adjusting for changes in road density. We interpolated for those years for which road density data were unavailable; a reasonable assumption since road density is unlikely to fall in any of these time periods (see also above).

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DISTANCE FROM WATER

To determine how far casualties occurred from fresh water, records were sorted by region and by distance from fresh water (streams or lakes; no records were located in wetlands). Only records with six-figure grid references were used (specifying locations to $\pm$ 50 m, $n = 387$, 57·5% of total dataset). The proportion of records less than 100 m and greater than 100 m from fresh water was compared for each region.

MORTALITY ON DIFFERENT CROSSING TYPES

To test the hypothesis that the number of casualties differed between crossing types (i.e. bridge, culvert, etc., see Table 1), records were sorted by nearest crossing type and by distance from water. A chi-square test for association was performed on all records (i) within 100 m, and (ii) zero distance from water for the road crossing types: bridge, culvert or no crossing.

MORTALITY ON DIFFERENT ROAD CLASSES

To determine the relative risk posed by each type of road, road casualties were first standardized in the following way: records were sorted by region and by road type (see Table 1 for definitions). The number of records in each region was divided by the percentage site occupation of otters (the proportion of sites examined where signs of otters were found, see Table 1) in the region using figures from the 1991/94 survey of England, the 1991 survey of Wales and the 1991/94 survey of Scotland (Andrews, Howell & Johnson 1993; Strachan & Jefferies 1996; Green & Green 1997). Percentage site occupation for the Island region were only available for Shetland, Orkney and the Outer Hebrides, but the rest of the Islands region is considered to have similar occupation levels (R. Green, personal communication). The number of casualties on each road type in each region was divided by the length of each road type within the region (1995 figures, Department of Transport 1996; see Table 2). Road lengths for the Islands region were only available for Shetland and Orkney. To test whether each road type was associated with different numbers of standardized RTAs, a Friedman's test was used to compare number of standardized RTAs across road types with mainland region as a block effect. To determine which road types could account for the significant results in the Friedman's test, the different road types were compared pair-wise for standardized RTAs. Wilcoxon's Signed Rank tests were performed on each pair of road types using data from the four mainland regions (no motorways or trunk roads on Islands).

Results

NUMBERS AND DISTRIBUTION OF CASUALTIES

This study used data from the whole of Britain from 1971 to the end of 1996 amounting to 673 records of otter road casualties. The locations of road casualties were not distributed uniformly throughout Britain (Fig. 1). Table 2 presents the regional total, annual mean and annual density of RTAs with regional percentage site occupation (see above) recorded during the otter surveys of England, Wales and Scotland, and road density.

SEASONALITY, AGE AND SEX RATIOS

Numbers of male and female, adult and subadult road casualties are shown in Table 3, with sex ratios of each age class (see Table 1 for definitions of age classes). The overall ratio of males to females was 1·28:1, which was significantly different from 1:1 ($\chi^2_1 = 8{\cdot}338$, $n = 571$, $P < 0{\cdot}05$). The ratio of adults to subadults was 4·14:1 (265 : 64). No significant dif-

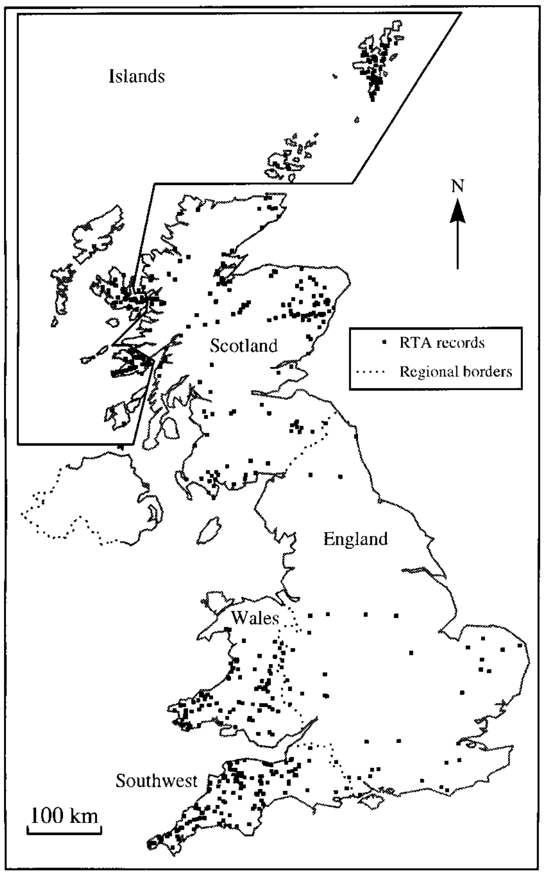


Fig. 1. The location of casualty records and regions described in the text.

Table 1. Definition and description of variables used in the analysis

Variable name	Definition	Source	Number of records
Region	Geographical location of records: Islands (Shetland, Orkney, Outer Hebrides, Skye, Mull, Islay), Scotland, Wales, The South-west (Counties Cornwall, Devon, Dorset and Somerset), and the remainder of England	Grid reference or place names given by records	663
Year	Year of record	Original RTA records	672
Month	Month of record Seasons defined as: Spring = Mar, Apr, May; Summer = Jun, Jul, Aug; Autumn = Sept, Oct, Nov; Winter = Dec, Jan, Feb	Original RTA records	659
Sex	Male, Female, Unknown	Original RTA records	673
Age	Adult, stated as such, or of age 2 years or above; Sub-adult, aged less than 2 years. Ages are usually estimated by counting dentine rings on a tooth section during *post mortems*	Original RTA records	329
Road type	Classification into: Motorway (special route on which certain vehicle classes are dis-allowed); Trunk road; A-road (both are of national or regional importance for long-distance traffic, the distinction is largely administrative); B-road; unclassified road (roads of district or local importance)	Original RTA records and matching grid references to maps	515
Crossing type	Where road crosses a river or the sea by bridge, culvert, ford, causeway or pier	Matching grid references to maps. Where a road crossing occurs, a bridge symbol was taken to indicate the presence of a bridge, no symbol was taken to indicate a culvert, other crossings were marked as such on the maps	452
Fresh water distance	Distance from casualty to fresh water (streams, rivers and lake shores)	Matching grid references to maps. Accuracy ± 50 m. A range of possibility was determined for 4-figure grid references	387 specific; 16 to 100 m distance classes
Sea distance	Distance from casualty to the sea	Matching grid references to maps. Accuracy ± 50 m. A range of possibility was determined for 4-figure grid references	97 specific; 10 to 100 m distance classes
Annual rainfall	Average annual rainfall for a region (e.g. Wales). Number of records (right column of this table) refers to the number of years for which this value is known	Institute of Hydrology 5 yearly reports (Institute of Hydrology 1981–95)	Islands (14) Scotland (12) Wales (11) South-west (10) England (11)
Average monthly rainfall	Long-term average rainfall for a particular region in a particular month. Six gauging stations' readings across each region were averaged to give the mean for the region	Institute of Hydrology 5 yearly reports (Institute of Hydrology 1981–95)	Islands (12) Scotland (12) Wales (12) South-west (12) England (12)
Average monthly river flow	Long-term average river flows for a particular region in a particular month. Six gauging stations' readings across each region were averaged to give the mean for the region	Institute of Hydrology 5 yearly reports (Institute of Hydrology 1981–95)	Scotland (12) Wales (12) South-west (12) England (12)

Table 1. (*Continued*)

Variable name	Definition	Source	Number of records
Road length	The total length of all roads in a particular region in a particular year. Alternatively the total length of a particular class of roads within a region in a given year	Department of Transport Traffic Statistics (Department of Transport 1996), County Councils	Nationally (9) Scotland (15) Wales (15) South-west (15) England (15) By road class in each region (5)
Road density	Total length of all roads in a region divided by regional area	Department of Transport Traffic Statistics (Department of Transport 1996), County Councils	As above
Traffic	The number of km driven by all vehicles in the UK in a single year. Estimated by counting vehicles on selected routes across the UK	Department of Transport Traffic Statistics (Department of Transport 1996)	Nationally (9)
Vehicle licences	Number of vehicles registered in a given year	Department of Transport Traffic Statistics (Department of Transport 1996), County Councils	Shetland (26)
Percentage site occupation	The percentage of sites surveyed for otters showing otter signs in the national surveys of 1979, 1984 and 1994	Strachan & Jefferies 1996; Andrews, Howell & Johnson 1993; Green & Green 1997	Islands (2) Scotland (3) Wales (3) South-west (3) England (3)

ference in sex ratios was observed across age classes ($\chi^2_1 = 0{\cdot}461$, $n = 302$, $P > 0{\cdot}05$).

The monthly distribution of all casualties and the proportion of males, females and individuals of unknown sex are shown in Fig. 2. The difference in the number of all casualties occurring between seasons was highly significant ($\chi^2_3 = 37{\cdot}695$, $n = 665$, $P < 0{\cdot}001$; see Table 1 for definition of seasons). The trend of reduced casualties in spring and summer and increased casualties in autumn and winter was consistent within each region (Scotland $\chi^2_3 = 10{\cdot}47$, $n = 303$, $P < 0{\cdot}05$; Wales $\chi^2_3 = 9{\cdot}20$, $n = 100$, $P < 0{\cdot}05$; South-west $\chi^2_3 = 21{\cdot}69$, $n = 151$, $P < 0{\cdot}01$; England $\chi^2_3 = 3{\cdot}74$, $n = 35$, $P > 0{\cdot}05$;

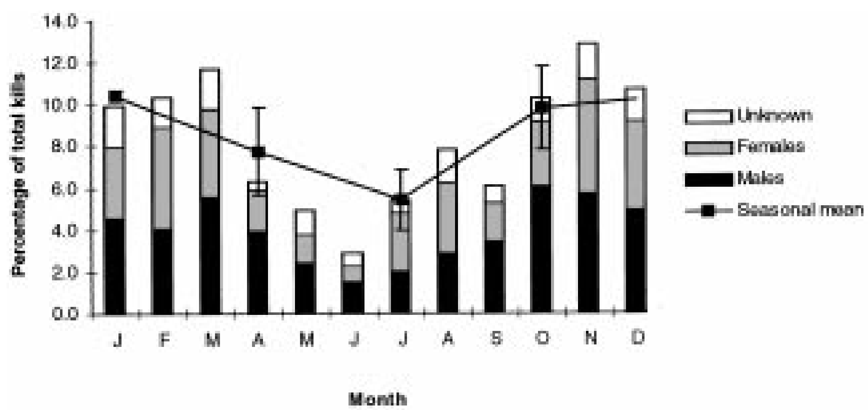


Fig. 2. The seasonal distribution of otter road casualties (data from 1971 to 1996). Seasonal means are shown as connected points with bars indicating one standard error ($n = 665$). Seasons were defined as follows: Spring = Mar, Apr, May; Summer = Jun, Jul, Aug; Autumn = Sept, Oct, Nov; Winter = Dec, Jan, Feb.

Table 2. Summary of regional differences in ranking of RTAs, RTA frequency, standardized RTA frequency, percentage site occupation of otters and road density

Region	Total RTAs (1971-96)	Rank	RTAs per year (mean 1971-96)	Rank	RTAs year^{-1} per regional area (× 1000)	Rank	Latest % site occupation figs*	Rank	RTAs year^{-1} area^{-1} per % site occupation (× 100)	Rank	Road density 1995 (regional road length per regional area)	Rank
Scotland	303	1	11·65	1	8·10	4	73·9	2	10·961	4	0·734	4
South-west	151	2	5·80	2	13·92	2	67·1	3	20·745	2	2·324	2
Wales	100	3	3·85	3	9·05	3	53·0	4	17·075	3	1·591	3
England	42	5	1·62	5	0·90	5	23·4	5	3·846	5	2·623	1
Islands	77	4	2·96	4	27·7	1	97·0	1	28·556	1	0·594	5

*From Strachan & Jefferies (1996) and Green & Green (1997).

Islands $\chi^2_3 = 2{\cdot}00$, $n = 76$, $P > 0{\cdot}05$). The subadult sex ratio was significantly different between seasons but not in a consistent manner ($\chi^2_3 = 14{\cdot}788$, $n = 55$, $P < 0{\cdot}001$). The adult sex ratio did not differ significantly between seasons ($\chi^2_3 = 0{\cdot}241$, $n = 237$, $P > 0{\cdot}05$). No significant difference was observed in the ratio of adults to subadults between seasons ($\chi^2_3 = 1{\cdot}402$, $n = 318$, $P > 0{\cdot}05$).

The correlation coefficients between the total number of RTAs per month in each region and both average monthly rainfall and river flow are shown in Table 4. No data on river flows exist for the Islands region. In all mainland regions seasonal rainfall was significantly and positively correlated to river flow, with Scotland and Wales showing a stronger association than the South-west and England. With the exception of Wales, all regions showed a significant positive correlation between the number of RTAs per month and the average monthly rainfall for the region. However, Wales and the South-west showed a stronger positive correlation between monthly RTAs and average monthly river flow (no data for Islands).

TRENDS OVER TIME

Figure 3 shows the number of casualty records for each year together with the national mean percentage of otter site occupation, the length of all roads and amount of traffic (the total number of kilometres driven by all vehicles in Britain) over the period. The line of best fit predicting the annual total RTAs since 1983 was: RTAs = 6·09 × Year + 0·3956, $R^2 = 0{\cdot}92$.

Nationally, the number of RTAs, the length of all roads and amount of traffic all increased with year [Spearman's Rank correlations for annual RTAs and year (1971–96) $R^2 = 0{\cdot}952$, $n = 26$, $P < 0{\cdot}001$; road length and year (1970–95) $R^2 = 1{\cdot}000$, $n = 6$, $P < 0{\cdot}001$; traffic and year (1970–95) $R^2 = 1{\cdot}000$, $n = 6$, $P < 0{\cdot}001$].

Figure 4 shows the density of casualty records over time in each of the regions. The annual average number of RTAs in each region, when standardized for area, coarsely reflected percentage site occupancy: the Islands and England were at the high and low extremes, respectively, with Scotland, Wales and the South-west intermediate (see Table 2).

Table 5 gives the Spearman's Rank coefficients between year, RTAs and road density within regions. The Islands did not show a significant correlation between the number of RTAs and year, consistent with their stable population level (the drop in the last few years was probably due to the end of research activities on the Islands; see Discussion). All of the other mainland regions showed a significant positive correlation between the annual number of RTAs and year. All mainland

Table 3. The number of casualties of different sex and age classes. * denotes a sex ratio significantly different from 1 : 1 at the 95% probability level

Age	Males	Females	Unknown	Total	Sex ratio (M: F)	χ^2_1
Sub-adults	30	26	8	64	1·15 : 1	0·080
Adults	144	102	19	265	1·41 : 1	3·417
Unknown	146	123	75	344	1·19 : 1	0·900
Total	320	251	102	673	1·28 : 1	8·338*

regions also showed a significant positive correlation between road density and year (no data for road density with year for Islands; see Table 5).

In the GLM model predicting RTA density there was a significant interaction between year and region ($F_{4,57} = 2{\cdot}71$, $P = 0{\cdot}039$; $R^2 = 0{\cdot}538$). This indicates that the relationship between RTA density and year differed among the regions. This would be expected from inspection of Fig. 4, where a linear trend is plainly not a good model for the trend in the Islands data. However, bearing in mind the significance of the interaction, the density of casualties was significantly higher in the Islands region [$F_{4,57} = 2{\cdot}79$, $P = 0{\cdot}035$, for the main effect of region, and with a Tukey's procedure separating the Islands from the other regions ($P < 0{\cdot}05$)]. As the pattern in the data for the Islands region is clearly different from elsewhere, we repeated the analysis omitting this region. In this second analysis, strong evidence for differences in the annual increase in casualty density among regions was also apparent ($F_{3,46} = 8{\cdot}65$, $P < 0{\cdot}0001$, $R^2 = 0{\cdot}673$). The upward trends were significant in all four remaining regions, but clearly lowest in England. The main effect of region was also strongly significant ($F_{3,46} = 7{\cdot}44$, $P < 0{\cdot}001$) and Tukey's procedure indicated a lower overall casualty rate in England ($P < 0{\cdot}05$). While interpreting main effects in the presence of interactions may be problematical, this result is consistent with the observed pattern (see Fig. 4). The residuals for all these models were scrutinized for normality, and none showed any evidence for significant departure (Shapiro–Wilk test, all $P > 0{\cdot}20$).

When road density data were incorporated into the model in all regions for which data were available, the close correlation between year and road density meant that these effects were confounded in their relationship with road casualties. Interpretation of models including road density as a continuous covariate is therefore problematical. However, if casualty density is expressed adjusted for road density, in terms of casualties per unit area, divided by km of road per unit area, then the conclusions about trends in otter road casualties are unaffected. Also, in this model there was evidence for differences in trends among regions ($F_{3,46} = 8{\cdot}36$, $P = 0{\cdot}0002$). The upward trends for individual regions were again significantly positive, with the lowest rate of increase in England. The evidence is, therefore, that the observed trend in otter RTAs is not simply an artefact of there tending to be more roads in recent years.

Table 4. Correlation coefficients for seasonal analysis of rainfall and river flow, RTAs and rainfall, and RTAs and river flow

Spearman's Rank correlations	Coeff.	*n*	*P*
Rainfall vs. River Flow			
Islands	–	–	–
Scotland	0·923	12	< 0·001
Wales	0·832	12	0·001
South-west	0·615	12	0·033
England	0·629	12	0·028
RTAs vs. Rainfall			
Islands	0·638	12	0·026
Scotland	0·873	12	< 0·001
Wales	0·568	12	0·054
South-west	0·621	12	0·031
England	0·591	12	0·043
RTAs vs. River Flow			
Islands	–	–	–
Scotland	0·880	12	< 0·001
Wales	0·723	12	0·008
South-west	0·649	12	0·022
England	0·527	12	0·078

DISTANCE FROM WATER

The distance RTAs occurred from fresh water is shown in Fig. 5a (note: number of records of known distance from fresh water = 401; number of known distance from fresh water by region = 387). In total, 62·5% (251/401) of all casualties occurred within 100 m of fresh water. The number of casualties occurring within 100 m of fresh water in each region is shown in Table 6.

Figure 5b shows the distribution of casualties within 5 km of the coast in Scotland and the Islands regions: 40·5% (49/121) of these records occurred

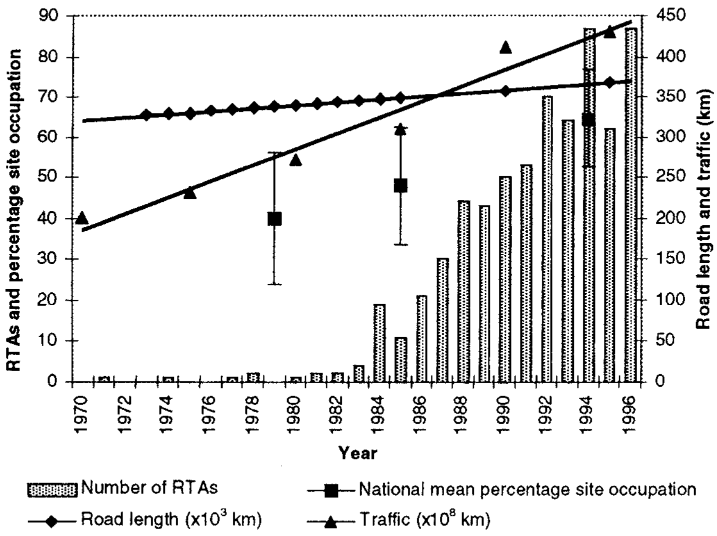


Fig. 3. The number of casualty records received annually, with total road length in Britain, traffic (kilometres driven by vehicles) and percentage site occupation of otter (mean for Britain). For definitions see Table 1.

within 100 m of the sea. Combining these results gives a total of 67·1% (278/414) of RTAs that occurred within 100 m of fresh or sea water (sea distance was recorded only for Scotland and Islands regions).

MORTALITY ON DIFFERENT CROSSING TYPES

The proportion of casualties at each river crossing type is shown in Table 7. No significant difference was found in the number of casualties located within 100 m of a watercourse between culverts, bridges or where no road crossing occurred ($\chi^2_2 = 5{\cdot}267$, $n = 251$, $P > 0{\cdot}05$). Significantly fewer RTA records originated on a watercourse where a road ran alongside, than where it was crossed by a culvert or bridge $\chi^2_2 = 51{\cdot}4737$, $n = 171$, $P < 0{\cdot}001$). Of those otters killed on a watercourse, 1·36 (90/66) times as many were killed at culverts than at bridges.

MORTALITY ON DIFFERENT ROAD CLASSES

The proportion of otters killed on each class of road over the period is shown in Fig. 6a. RTAs on each road class were standardized for road length and for

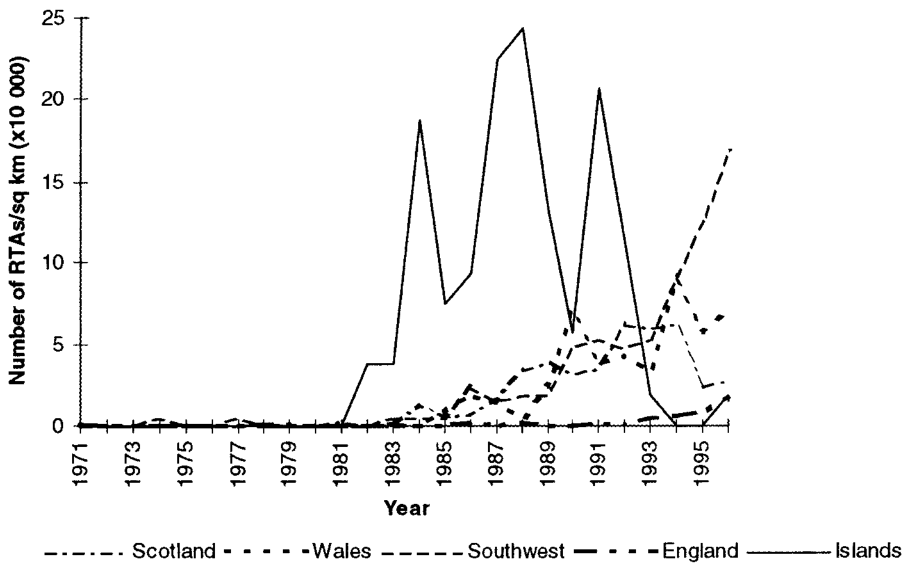


Fig. 4. Annual number of road casualty records in each of the regions in Britain (specified above), standardized for area.

Table 5. Correlation between RTAs and year, road density and year, vehicle licences on Shetland and year, vehicle licences and road length, vehicle licences and traffic (see Table 1 for definitions)

Spearman's Rank correlations	Coeff.	*n*	*P*
RTAs vs. Year:			
Islands	−0·121	13	0·693
Scotland	0·740	15	0·002
Wales	0·813	12	0·001
South-west	0·959	16	< 0·001
England	0·815	12	0·001
Road density vs. Year			
Scotland	0·982	14	< 0·001
Wales	1·000	14	< 0·001
South-west	1·000	14	< 0·001
England	1·000	14	< 0·001
Vehicles Licenced vs. Year			
Shetland	1·000	26	< 0·001
Vehicle Licences vs. Road Length (1970–95)			
UK	1·000	6	< 0·001
Vehicle Licences vs. Traffic (1970–95)			
UK	1·000	6	< 0·001

percentage site occupation in each region in Fig. 6b. A significant difference was found in the proportions of standardized RTAs recorded on different road classes between the four mainland regions (Friedman's test: $\chi^2_3 = 9{\cdot}900$, $n = 515$, $P = 0{\cdot}019$; B-roads included with unclassified roads).

To establish which road types had significantly different standardized RTAs, different road types were compared pair-wise using Wilcoxon's Signed Ranks tests. The results of these comparisons are shown in Table 8, suggesting that more RTA records originate from trunk roads than from any other road class per km in mainland regions.

Discussion

The 673 road traffic accidents recorded between 1971 and 1996 were not distributed evenly in space or time. An increase in the number of RTAs recorded nationally began in about 1983 and has been more rapid than the increases in any other known cause of otter mortality. This may be due in part to increased interest in documenting otter road mortality and in carcass recording effort. The different regional patterns suggest that generalizations over large geographical areas may be inappropriate (O'Sullivan & FitzGerald 1995).

Table 6. Proportion of casualties occurring within 100 m of fresh water in each region. Total $n = 387$

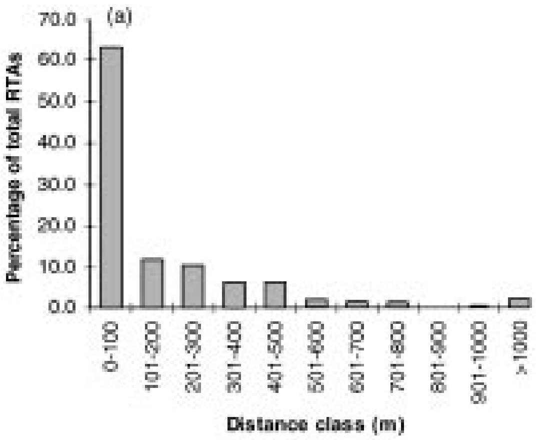
Region	*n*	0–100 m (%)	> 100 m (%)
Scotland	110	52·7	47·3
Wales	82	57·3	42·7
South-west	145	66·2	33·8
England	41	82·9	17·1
Islands	9	33·3	66·7
Mean		61·5	38·5
SE		10·34	10·34

PATTERNS IN AGE AND SEX

The male bias in RTA records (1·28:1) accords with results from Heggberget (1991) in Norway (1·28:1), Rogoschik *et al.* (1994) in Germany (1·38:1), Körbel (1994) (1·3:1) and Madsen (1996) in Denmark (1·6:1). The actual ratio of animals in the wild is not known in Britain but Ansorge, Schipke & Zinke (1997) modelled the population structure of otters in Germany and predicted a female-bias among live otters. It is possible that the male bias in RTAs is a result of their different patterns of movement (Green, Green & Jefferies 1984). Heggberget (1991) found more independent young males represented in her sample of 410 otters killed by human activity than other categories. Reasons suggested for this were: home range expansion, greater dispersal distances, higher energetic requirements and less cautious behaviour than females. Buskirk & Lindstedt (1989) attribute a trapping sampling bias towards males to sexually dimorphic home-range sizes, rates of travel or sex-specific behaviours. Otters are thought to breed at all times of year but summer peaks of breeding are normal in Shetland (Kruuk 1995). However, no seasonal increase in mortality of subadults compared to adults was observed nationally in the data presented here, which might have been expected during a dispersal peak.

SEASONAL PATTERNS

Both rainfall and river flow were positively correlated to RTAs, but a stronger association to one or other of these variables was found in different regions. This might be expected according to regional differences in hydrological regime and topography, but the pattern revealed by the correlation analysis was not readily explicable in these terms. Obviously, as otters are largely aquatic they fre-



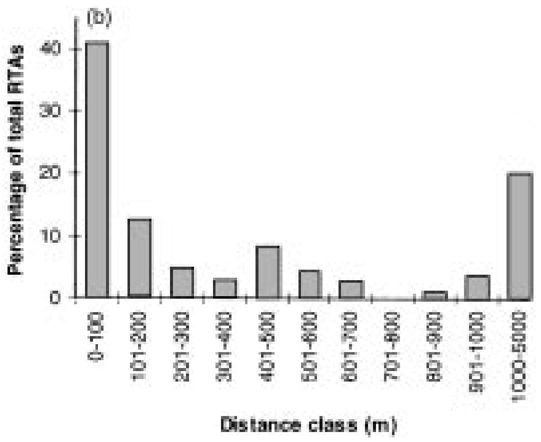
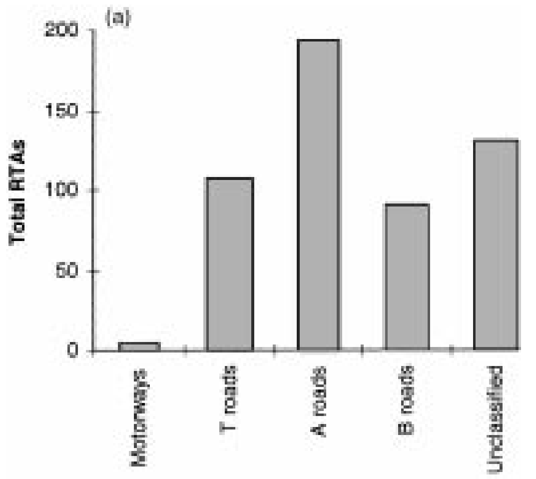


Fig. 5. (a) The distance RTAs occurred from fresh water (n = 401). (b) The distance RTAs occurred within 5 km of the coast (includes Scotland and Islands regions only, n = 121).



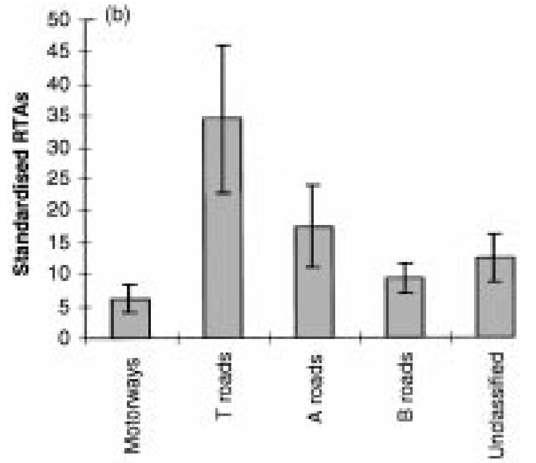


Fig. 6. (a) The total number of RTA records from each road class. For definitions of road classes see Table 1. (b) The relative proportion of casualty records occurring on each mainland road class (standardized for total length of each road class and for percentage site occupation in each region). Bars give standard errors of means of each of the four regions, n = 515.

quently contact the road network at bridges and culverts. However, the fact that the majority of deaths coincide with high river flow conditions implicates the way water is channelled through these crossings as a factor involved in RTAs. Spate flows and flooding are likely to create the critical conditions leading to otter RTAs, exacerbated by bridge design.

TEMPORAL PATTERNS

Effect of the road network

Regional road density is steadily increasing (Department of Transport 1996). This was reflected in a significant positive correlation of road density with year in all mainland regions (where data exist), and a correlated measure of registered vehicle ownership (Table 5) showed a similar trend on Shetland (no information was available for the other islands). The trend of increasing RTAs with road expansion was consistent in all mainland regions. The number of vehicles licensed on Shetland has been rising, but there has been no increase in RTA records on Shetland (nationally, the number of vehicles licensed was positively correlated with road length, see Table 5).

The GLM analysis (on mainland regions only) provides evidence for an effect of road density on the number of RTA records. Simple comparison of the mean values of standardized RTAs and road density between regions (Table 2) suggests an inverse relationship. This is misleading because of the link between industrialization, intensive agriculture and development of the road network. The collapse of the otter population in the wake of organochlorine agro-chemicals during the 1960s and 1970s follows this pattern of intensive agriculture and has left low densities of otters in road-dense regions, particularly

Table 7. Number of RTAs recorded at each main crossing type (includes records from known crossing types only)

Crossing type	None	Bridge	Culvert	Causeway	Ford	Pier	Dam	*n*
Number of RTAs (all data) (%)	262 (58·0%)	74 (16·4%)	111 (24·6%)	2 (0·4%)	1 (0·2%)	1 (0·2%)	1 (0·2%)	452
Number of RTAs within 100 m of a watercourse (%)	80 (31·5%)	71 (28·0%)	100 (39·4%)	2 (0·8%)	1 (0·4%)			254
Number of RTAs right on watercourse (%)	15 (8·6%)	66 (37·9%)	90 (51·7%)	2 (1·1%)	1 (0·6%)			174

the eastern counties where organochlorine-treated wheat was grown (Table 2; see Strachan & Jefferies 1996). The lower number of RTAs in these regions implies that population density may be closely linked to road mortality.

Effect of otter population density

All mainland regions show a trend of increasing site occupation and increasing casualty records with time. The GLM analysis also indicates that throughout the mainland there was an effect of year on casualty records after increasing road density has been accounted for. This suggests the influence of a further time-dependent variable, such as otter population density, increasing traffic flows/speeds or likelihood of reporting RTAs. The lack of a trend of increasing casualties with time in the Islands region, in conjunction with a constant site occupation level, also suggests that frequency of RTAs may be related to otter population density. In fact, the GLM analysis revealed a significantly higher rate of casualties per unit area in the Islands region than in other regions, all of which have lower population densities (as measured by percentage site occupation, see Table 2). Green (1991) analysed RTAs between administrative regions in Scotland, comparing the number of otter deaths with human population density, number of vehicles registered and otter site occupancy. She found RTAs to be correlated only with otter site occupancy.

SPATIAL PATTERNS

Since at least 62·5% (251/401) of casualty records were within 100 m of fresh water, the opportunity exists to target safety measures economically [Madsen (1996) observed 70·4% of recorded casualties within 100 m of watercourses in Denmark]. Of the British records within 100 m of fresh water, 68·5% (174/254) occurred at a road crossing of a watercourse or the sea. Coastal otters are known to require fresh water to wash their fur and to drink. The average distance from the nearest fresh water of those otters killed within 1 km of the coast was 194 m ($\pm$ 28·5, n = 76). Coastal roads are therefore particularly hazardous to otters in the vicinity of fresh water streams. Another dangerous situation occurs where roads are located very close to rivers over long distances, as in steep valleys: 31·5% (80/254) of RTAs within 100 m of a watercourse occurred on roads that did not actually cross the watercourse. A high risk zone can therefore be defined as one where roads are present within 100 m of a watercourse or the coast. This definition encompasses 67·1% of all casualties where distance to fresh water or the sea was known.

Table 8. Results of paired Wilcoxon's Signed Ranks tests between standardized numbers of RTAs on different road types in mainland regions

	Motorways	Trunk roads	A-roads	B-roads
Trunk roads	$z = -1{\cdot}826$, $P = 0{\cdot}068$			
A-roads	$z = -1{\cdot}461$, $P = 0{\cdot}144$	$z = -1{\cdot}826$, $P = 0{\cdot}068$		
B-roads	$z = -0{\cdot}730$, $P = 0{\cdot}465$	$z = -1{\cdot}826$, $P = 0{\cdot}068$	$z = -0{\cdot}730$, $P = 0{\cdot}465$	
Unclassified roads	$z = -0{\cdot}730$, $P = 0{\cdot}465$	$z = -1{\cdot}826$, $P = 0{\cdot}068$	$z = -0{\cdot}730$, $P = 0{\cdot}465$	$z = -1{\cdot}461$, $P = 0{\cdot}144$

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Major roads made a disproportionately high contribution to RTAs. A-roads and trunk roads together account for 57·3% (295/515) of casualty records nationally (range 47·7% in England, 64·4% in Scotland), though they comprise only 13·1% of the road network (they comprise 13·3% in England and 20·4% in Scotland, Department of Transport 1996). Motorways were a notable exception in this respect; almost certainly carcasses have less chance of being recorded on motorways as it is an offence to stop. In addition, the size of motorway river crossings results in bridges and viaducts being installed more frequently, leaving watercourses less affected. The large embankments and greater use of fencing associated with motorways may also provide a more effective barrier to otters, and the continuous traffic noise may be a greater deterrent to crossing the carriageway.

There are limitations to the dataset used in this study and some sources of potential bias. The intensity of recording will not be even over the whole country, as recording efficiency may be influenced by variation in local interest, and not all records were available to us in all regions.

The Islands data reveal the extent of temporal trend bias that may exist in relation to reporting RTAs and publicity. The large fluctuations in RTA reports were not explained by rainfall, and were not consistent with increasing numbers of vehicles registered on Shetland or with a stable otter population density. It is likely that peaks in rates of RTA reports followed research interests and the occasional publicity events that encouraged the reporting of RTAs on the islands during the ITE study on Shetland from 1981 to 1994 (H. Kruuk, personal communication), Yoxon's study on Skye from 1984 to 1996 (Yoxon & Yoxon 1997) and Burch's study on Mull from 1988 to 1996 (N. Burch, unpublished data). The paucity of records from the Outer Hebrides reflects the lack of any study there. In fact, the Outer Hebrides have a large otter population comparable with the rest of the region (R. Green, personal communication). The increase in RTA records in other regions may similarly reflect a co-ordinated effort to obtain these data by other conservation bodies (R. Green, personal communication). This illustrates the variation in RTA record collection intensity within and potentially between regions. Information regarding sex and age may also be lost since some corpses may have been too damaged to recover or to determine their sex at *post mortem*.

Smaller streams (< 0·5 m wide) are not likely to be well represented on maps at a scale of 1:50 000 but are known to be well-used by otters (Andrews & Crawford 1986; Kruuk *et al.* 1993); therefore, the percentage of RTAs occurring at road crossings of streams found here was likely to be an under-estimate.

Assessing the potential bias in the distribution of casualties across road-types is complicated. The likelihood of individual road users reporting an accident or a carcass on the more major roads, carrying traffic of higher speeds (particularly motorways where stopping is prohibited), may be lower than on more minor roads and a carcass may remain recognizable on the carriageway for a shorter time. However, many more drivers will pass an accident site on a major road and visibility might be better. Further bias might occur where each road type passing through areas of very high or low population density may be unequally represented. The characteristics of particular road classifications also varies regionally as, for instance, trunk roads are not found on the Islands, and A-roads in that region may be only a single carriageway wide with passing points.

Conclusions

The data support the view that otter road mortality is likely to increase as otter populations and the road network continue to expand. The greater number of male casualties suggests that the more wide-ranging individuals in the population may face the greatest risks. This could apply also to dispersing individuals. We have identified high-risk areas for otters in the transport network. A 100-m wide zone surrounding fresh water and the coast accounts for two-thirds of otter road traffic accident records and should be the principal focus for efforts to mitigate the effects of direct road mortality on otters. The seasonal correlations with rainfall/river flow and the fact that, where otters were killed on watercourses, 91·4% (159/174) were killed on a river crossing, imply that substantial reductions in RTAs could be achieved by improving the design of river crossings.

We suggest that the optimal approach for river crossings is the use of wide-span bridges which permit the retention of the river bank under the bridge, enabling otters and a wide variety of other wildlife to cross beneath roads along the bank in times of high flows. Where bridges are impractical, oversized culverts incorporating ledges above the water-level may achieve similar results, providing that ledges and air-space above the water do not become covered during winter flows. This solution is obviously less desirable because of the discontinuity of the river habitat corridor. Ledges with ramps leading to the bank may also be attached to existing bridges or large culverts where no dry passage is available for otters during high flows. Dry underpasses have been used with success in various places in Britain, particularly in alleviating road casualties at particular 'accident black spots' for otters (Green 1991).

It is notable that almost one-third of RTAs occurred where roads run within 100 m of rivers but did not cross them, indicating that otters travel out of the water. Reducing RTAs in these situations may require otter-proof fencing to be placed along the roadside, to prevent access to the carriageway. This would require fencing on both sides of the road. There are, however, considerable practical difficulties in providing human access where necessary, particularly to field and property entrances and for river maintenance machinery, since such access points are difficult to keep otter-proof. Coastal roads and those running alongside rivers in steep valleys also present a problem. The advantage of reducing RTAs may be more than offset by the increase in the barrier effect of such a fenced road, not only to otters but to all wildlife. In such cases it is essential that any streams and ditches running under the road should allow the safe passage of otters, and provision should be made at appropriate intervals for all wildlife to cross this barrier safely.

The issue of otter road death seems likely to increase in significance and to affect the recovery of otter populations in central England, where road density and development are greatest. Currently, we are testing different road crossing designs and existing mitigations using a combination of traditional surveying techniques (Striese & Schreyer 1993) and infra-red filming of crossing points (Madsen 1996) and behaviour (Stewart, Ellwood & Macdonald 1997). Mitigating features for otters should routinely be built into the design of new roads and fitted to existing roads whenever possible, not only where otters currently occur, but where they are expected to spread in the future.

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