Deer and Road Traffic Accidents: Options for Management

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Statistics from the U.S. or from Continental Europe suggest that damage to persons and property arising from road or railway accidents involving deer amounts to a very significant annual total and is increasing everywhere. Despite this, the relative efficacy or cost-effectiveness of different control options is poorly understood.

This review presents an analysis of deer movement patterns in relation to roads in order to try and develop some general conclusions about the probable or expected pattern and behaviour of road crossings. Based on such framework the various possible options available for reducing accident rates are more formally evaluated. The review focuses primarily on deer and roadside management within Europe.

Approaches to the management of deer on roads consist either of methods to increase driver awareness of deer (deer warning signs) and/or methods to reduce deer crossing activity or change the pattern of crossings (fences, reflectors or chemical repellents). Effective reduction of deer road-crossings can only be assured in erection of a genuinely impermeable barrier fence. Cost considerations usually result in erection of barriers which are only partially effective. Such fencing must be viewed merely as a deterrent to crossing and not an absolute barrier; effectiveness can be enhanced by providing alternative means of passage, thus reducing the probability of deer intent on crossing, forcing the fence. Some means of exit (one-way gates, deer-leaps) should be provided for animals that do get on to the carriageway and are then unable to escape.

Provision of fencing, with the additional structures of one-way gates and underpasses, is likely to be extremely costly; such high costs may only be justified in regard to major roads. For minor roads where traffic flow is lighter and intermittent, deer-mirrors or game-reflectors are a more economical and a more appropriate solution, since the intention is to delay crossing, rather than prevent it. The effectiveness of both fencing and mirrors may be reinforced in especially sensitive areas by erection of appropriate road signs to increase driver awareness.

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1. Introduction

In 1982 20 people died and 1500 were injured on roads in West Germany in accidents involving wildlife. In the same year some 10 000 road accidents in Sweden were due to
collisions with moose, *Alces alces*, red deer, *Cervus elaphus*, and roe deer, *Capreolus capreolus* (with accidents involving deer amounting to over 40% of all road accidents recorded). By 1993 the number of road kills of deer in Sweden had risen to 55 000, with mortality of roe deer alone in excess of 50 000 (Groot Bruinderink and Hazebroek, 1996). Road kills of deer in Germany similarly increased to c. 12 000 and statistics presented by Groot Bruinderink and Hazebroek (1996) show this to be a general trend throughout Europe. Such a high rate of accident may impose significant mortality on the deer populations themselves; road traffic deaths may cause losses as high as 5–6% of the estimated spring population of some species (roe deer: Netherlands, Germany; Groot Bruinderink and Hazebroek, 1996). Furthermore, as noted, many accidents result in significant damage to persons or property.

Numbers of humans killed or injured in Germany in the late 1980s/early 1990s were estimated at approximately 25 killed and 2500 injured *per annum* (Hartwig, 1991), with damage to property estimated in 1993 at U.S. $280 million (Fehlberg, 1994). In Norway, where an estimated 1400 accidents per year involve collisions with moose and a further 3200 accidents involve roe deer, costs (calculated on the basis of direct damage to property, medical costs of personal injury etc.) currently exceed 280 million Norwegian crowns per year—equivalent to £28 million (County Governor’s Office, Oslo, pers. comm.). In the U.S. the average cost of a deer–vehicle accident was estimated at about $650 in 1983 (Hansen, 1983) with a national monetary loss in excess of $95 million. By 1992 this figure had risen to an estimated $1200 per vehicle (Romin and Bissonette, 1996) with an estimated total of 538 000 deer killed along highways nationally during 1991/2.

Equivalent national statistics are not readily available for the U.K., where, perhaps rather surprisingly, we know very little about the scale of the problem at a national level, either in terms of the numbers of animal deaths or injuries, or in terms of economic cost, although some preliminary work is now in progress (Langbein, 1997). Without any comprehensive data however, it is clear that traffic accidents involving deer are, at least locally, of considerable significance. We might note that there are areas of the country where in excess of 60 such accidents per year have been reported every year since 1980, such as the New Forest in the south of England, Cannock Chase and Thetford Forest. Furthermore, approaching the question from a different direction, we may note that in a study carried out through several different areas of England of the cause of death or injury of fallow deer, *Dama dama*, the most frequent cause of death was found to be road accidents, accounting for between 50–80% of all carcasses found (Chapman and Chapman, 1975).

Such a high accident rate must represent a serious problem simply in regard to human loss of life or property. Furthermore, it is clear that while traffic kill rates experienced by most deer populations are not sufficient to threaten the population status (see Putman and Sharma, 1987; Groot Bruinderink and Hazebroek, 1996), the number of fatalities, and perhaps more insidiously, the unknown number of seriously injured animals which are not killed outright but escape alive to die after some further period of suffering, must pose a serious welfare issue.

Even where more precise statistics are maintained on the frequency and cost of wildlife accidents, as in the U.S. or many continental European countries, there is commonly little knowledge of the efficacy, or cost-effectiveness of different measures that may be implemented in an attempt to reduce accident rates. Often measures adopted to reduce accident rates are arbitrarily selected, with no subsequent analysis of their effectiveness. As also noted by Romin and Bissonette (1996): “few rigorous
evaluations [are undertaken] regarding the effectiveness of these techniques; yet they still continue to be used”.

Furthermore, selection of the appropriate deterrent measures in any given situation is itself dependent on a proper understanding of the actual pattern of such accidents (whether they occur primarily on major highways or minor roads of low and irregular traffic volume, whether they tend to occur by day or by night, whether they occur throughout the year or are concentrated into particular seasons, associated with dispersal movements of juveniles away from their natal range, or reproductive movements of mature animals seeking mating opportunities during the rut). Without such biological understanding, we cannot really determine where preventative measures should be concentrated, or suggest a priori which of a variety of deterrent options is likely to be most effective in given circumstances.

In this review I present a biological framework for deer movement patterns in relation to roads (and railways) in order to try and develop some general conclusions about the probable or expected pattern and behaviour of road crossings. Based on such a framework, I will introduce the various possible options that might be considered at least potentially effective in different contexts, and then evaluate the true effectiveness of such measures and the circumstances under which they may be expected to work effectively. The paper focuses attention primarily on deer and their roadside management within Europe. The situation in the U.S. has recently been comprehensively reviewed by Romin and Bissonette (1996).

2. Road crossing patterns

Deer of all species regularly cross minor roads (narrow roads of relatively low traffic volume) during routine daily movements around an established home range. Although surprisingly few published data are available for red deer or fallow deer, it is common experience to encounter red, roe or fallow crossing such roads in the course of regular movements to or from foraging areas within their range. Although deer are neither strictly crepuscular or nocturnal, all species are shy of human disturbance and thus shun open areas during the hours of daylight (van de Veen, 1979; Putman and Mann, 1990). In consequence most such road crossings will occur at night (with peaks at dawn and dusk as animals move to and away from feeding areas away from cover; Langbein, 1985; Desiré and Recorbet, 1990; Groot Bruinderink and Hazebroek, 1996), except in well-wooded areas where crossings may occur at any time of day or night.

Few radio-tracking data are available to define range maps for red, fallow or muntjac deer, *Muntiacus reevesi*, in relation to geographical features such as roads, railways or canals. A number of detailed range maps are however, available for roe deer (e.g. Sempere, 1979; Bideau et al., 1983; Gent, 1983; Vincent et al., 1983; Johnson, 1984; Chapman et al., 1993). Examination of these maps in relation to underlying geographical features again shows that areas on both sides of relatively minor roads will regularly be included within the home range; such areas are commonly visited during the course of one single 24-h period (Gent, 1983, for example has shown that some 40% of any animal’s entire seasonal range will be visited within any one 24-h period).

By contrast, examination of these same published range maps shows that for roe deer at least, the actual boundaries of home ranges do tend to coincide with, or at least not cross primary roadways, railways or other major “barriers”. Railways certainly seem to act as boundaries also to fallow and sika deer, *Cervus nippon*, in the New
Deer and road traffic accidents

Forest (pers. obs.) and others have noted for other species, too, that the boundaries to established home-ranges seem to “recognize” primary roadways, with limits to “routine” daily movements clearly coinciding with road-lines. By contrast Feldhamer et al. (1986) noted that both summer and winter home ranges of individual white-tailed deer, *Odocoileus virginianus*, frequently overlapped Interstate Highway-84 in Pike County, Pennsylvania: of 44 seasonal home range estimates, 16 (36.4%) overlapped either I-84 or a secondary route during one season or more.

In the absence of more detailed data, general consensus at present would thus suggest that seasonal home range boundaries of most European species of deer: red, roe, fallow and sika deer, “acknowledge” boundaries imposed by major primary routes or motorways (which in many cases of course may already be fenced) and that animals would not commonly cross these during the course of routine daily foraging movements. By contrast, more minor roads of low traffic volume are not recognized as barriers and will regularly be crossed during the course of normal daily movements around an established home range. Major roadways are however, not totally impermeable and will be crossed during dispersal movements (e.g. juveniles leaving their natal range, or mature males seeking mating opportunities during the rut).

In response to this we might expect crossings of minor roads of low traffic volume to be frequent, regular and distributed throughout the year (albeit primarily at night in other than wooded areas), while crossings of primary routes would be highly seasonal with peaks in late winter (dispersal of juvenile male roe), early summer (dispersal of juvenile male fallow) and autumn (September–November: a peak associated with mating movements of mature males).

This provisional conclusion is supported by a survey of deer crossings of the trunk route A120 near Hatfield Forest, during consultations over the development of the Stansted–Braintree section of the road, where local police confirmed a high accident rate (averaging about two per week for the year as a whole) but with most occurring during autumn (Blamey and Blamey, 1990). In a study of movement patterns of fallow deer and the frequency and distribution of traffic accidents involving deer in an area of north Staffordshire (straddling the main north–south motorway, the M6, and bounded by major trunk routes A34, A51 and A53) between 1983 and 1985, Langbein (1985) also notes that minor roads showed a high level of deer crossings throughout the year, but crossings of major roads were notably seasonal and concentrated in autumn (October) and in the period between February and April (conclusions based on a sample of 986 recorded crossings). Deer accidents were heavily biased towards males (despite the fact that the population sex ratio was strongly female-biased) and were found to be most common during late autumn, coinciding once again with the peak of the fallow rut in that area (Langbein, 1985). Similar results are reported by Groot Bruinderink and Hazebroek (1996) from the Netherlands, where mortality rates of red and roe deer also showed distinct seasonal variation, with the majority of accidents occurring on major roads concentrated in periods of the rut and of juvenile dispersal.

Such records as are available also confirm that on both major and minor roads, the majority of accidents occur at night, coinciding with the period of increased deer activity (Langbein, 1985; Desire and Recorbet, 1990; Groot Bruinderink and Hazebroek, 1996). On roads of pronounced variations in traffic flows associated with morning and evening commuter traffic, accidents rates are at their highest at these times and accentuated when “rush hour” periods coincide with poor light conditions of dawn and dusk in autumn (Hampshire County Council, 1983; Sanders, 1985; Langbein, 1985).
If the patterns described above are further confirmed, then we must recognize two distinct types of road crossings with very different contexts and characteristics. Measures taken to reduce the risk of traffic accidents must then be different in the very different contexts.

3. Control measures on roads

Approaches to the management of deer on roads consist either of methods to increase driver awareness of deer (deer warning signs) and/or methods to reduce deer crossing activity or change the pattern of crossings (fences, reflectors or chemical repellents).

3.1. Deer warning signs

Deer warning signs are the most frequently used approach to reducing accidents. Such signs are only likely to be of benefit if erected on approaches to known regular crossing points. Furthermore, it is doubtful whether they are very effective in the long term, since drivers readily habituate to them unless the message is reinforced by actual experience of deer crossings. Some limited trials have been carried out in the U.S. using “animated” signs (Pajar et al., 1975), but these also had limited effectiveness. In effect, roadside warning signs are likely to be of much value only on minor roads subject to regular crossing activity and primarily on the approach to wooded areas. However, because the majority of accidents occur during the hours of darkness, they may prove of limited value. Blamey and Blamey (1990) note, however, that the relatively low cost of provision makes them an essential part of any management strategy.

3.2. Roadside reflectors

These devices seek to warn deer of approaching vehicles and/or to act as an effective visual barrier to prevent deer crossing roads in advance of oncoming traffic. The mirrors are attached to posts at a height of approximately 0.6 m and are installed at 20-50 m intervals along the road. They are two basic types. Simple metal mirrors with dimpled indentations are designed to deflect a warning flash of white light from the headlights of an approaching vehicle into the vegetation at the side of the road. Reflectors (Swareflex or WEGU Wildwarnreflektoren, D. Swarovski and Company, Tirol, Austria and WEGU, Gummi-und Kunststoffwerke, Kassel, Germany, respectively) are again designed to capture light from approaching vehicles but transmit it to create a continuous barrier of white, red or blue-green light as a strip parallel to the road edge (from the overlap and merging of light beams transmitted from adjacent reflectors).

Both types of device are of course only operational at night, being dependent on transmission of incident light from approaching headlights. Flash mirrors have limited efficacy in that animals easily habituate to them and effectiveness is in any case quickly diminished because of corrosion (Gilbert, 1982). Visual barrier reflectors may have greater potential and a number of studies have been made in Europe and the U.S. of their effectiveness. The choice of red for commercial reflectors manufactured both by Swarovski and WEGU is based on the claim that deer can distinguish red as a colour, although the evidence for this is slim (based indeed upon the study of one female red deer) and the difference in the behavioural response of deer as a result of red as opposed to white light is apparently unknown (Gilbert, 1982, see also Waring et al., 1991). More recently trials have been undertaken in the state of Illinois, in testing the possible
effectiveness of reflectors transmitting blue-green light (Markwell, pers. comm.) based on a suggestion that deer might in practice be more sensitive to light towards the ultraviolet end of the (human) visible spectrum.

Various published and unpublished data are available in assessment of the effectiveness of the conventional red reflectors but offer somewhat inconsistent conclusions. Accident rates on minor roads have been reduced by up to 85% after installation of Wildwannreflektoren WEGU in Denmark (Thomsen, 1996). Similar success rates for Swareflex reflectors have been reported by some authors. In tests in Washington State, reflectors were installed along four test sections of SR 395 where high accident rates with white-tailed deer had previously been experienced. Reflectors were alternately covered and uncovered at regular intervals during known winter movement periods (between autumn and early spring) from 1981 to 1984. During this period 52 deer were killed at night in test sections where reflectors were covered, and only six deer killed when reflectors were uncovered and thus operative (Schafer and Penland, 1985). Reductions of between 60 and 90% are reported from Wisconsin, (Ludwig, unpublished data), where reflectors have been installed along sections of a number of State-maintained roadways. By contrast, Swareflex reflectors were found to be ineffective in reducing road accidents in studies by Woodard et al. (1973), Gilbert (1982), Ford and Villa (1993), Reeve and Anderson (1993).

In assessing such reports we should note that in all cases reflectors were installed on sections of road already noted to have a high rate of deer-related incidents. Furthermore, in a number of these reports, it is clear that road accidents involving deer are highly seasonal, with mortality recorded in autumn and late winter, coinciding with regular seasonal migrations of white-tailed deer, *Odocoileus virginianus* or mule deer, *O. hemionus*, between disparate winter and summer ranges. Indeed Schafer and Penland (1985) tested the effectiveness of Swarefslex reflectors only during that winter period. Although this seasonality might appear not dissimilar to seasonal peaks in road traffic accidents in European studies, associated with dispersal of juveniles or rutting movements of adult males in spring and autumn, there is in fact an important distinction.

Movements of dispersing juveniles or rutting males are seasonally synchronized but remain movements of individuals with no necessarily predetermined route. By contrast, in those parts of their geographical range where white-tailed deer and mule deer do undertake pronounced seasonal movements of this kind, migration events involve directional movements of large numbers of animals which habitually use traditional and thus predictable routes. (Thus over 1000 approaches to a single underpass under a motorway were recorded by Reed et al. (1975) in each of 2 years, within a 6-week period between October and early December; 76 individual deer passed through the underpass in a single night in November 1973.) Given that the barrier is encountered by an individual animal only once during a seasonal and unidirectional migration, there is little opportunity for animals to habituate in their response to the novel stimulus. Any test of the effectiveness of reflectors is restricted to naive animals encountering them for the first time and once only, as they pass through the barrier on a long-distance migration.

Conclusions from such studies might perhaps be extrapolated with caution to mating movements of adult males or dispersal movements of juveniles, but we should note that the high level of effectiveness reported for reflectors in these published studies may result in some part from the ability to deploy them along sections of highway known to be especially prone to deer crossings. Furthermore, results of these rather specific studies certainly may not be representative of what might be the effect of such reflectors
on animals regularly crossing and re-crossing minor roads during the course of daily movements about an established range.

3.3. LIMITATIONS IN USE OF ROADSIDE REFLECTORS

Whether or not red or blue-green reflectors produce an effective visual barrier to road crossings, they are of course dependent on incident light and thus they are operational only at night and when a vehicle or vehicles are approaching. This has profound implications. If deployed on relatively minor roads of low traffic volume, periods of deterrence will be interspersed with longer periods of “permeability”. Therefore, if effective at all they provide only a temporary barrier and do not prevent movement but simply delay it until the road is free of traffic. This is in their favour, since unlike wire fencing, which may provide a totally impermeable barrier to movement (below), reflectors provide a barrier only during that period when crossing would be dangerous, leaving no barrier to subsequent movement when the roadway is clear and thus causing minimum disruption to natural movement patterns within an animal’s home range, or to dispersal movements.

On the other hand, such action militates against their use on roads of comparatively higher traffic volume, when the reflectors might be continuously activated. In the first place, the deer are likely to habituate more quickly to the “visual barrier” provided. More seriously, if under conditions of heavy traffic use the barrier is continuously maintained, allowing no intervening periods of darkness for deer to cross in safety, pressure to cross will commonly result in them forcing a crossing anyway; the fact that the “barrier” is psychological rather than physical means it may in practice be readily breached. In such circumstances of continuous activation with heavy traffic it seems certain that mirrors/reflectors will not provide an effective barrier where deer are determined to cross.

This suggests that reflectors may potentially be of some value in reducing night-time accidents on roads of irregular, light, traffic flow, but should not be considered an appropriate option for roads of high traffic volume, where a more absolute, physical barrier will be required. Even on more minor roads however, actual rather than potential effectiveness is unknown; to date no objective tests have been published of the use of reflectors in such conditions and we have no knowledge of the speed with which animals might habituate to them.

3.4. CHEMICAL REPELLENTS AND SOUND-SCARRERS

Two further measures have been suggested for providing a temporary barrier to deer movement across roads at least for that period when traffic is actually approaching. Neither has yet been adequately proven. A number of commercial companies are now offering for sale a device for attachment directly to the front of a motor vehicle which emits a high frequency whistle claimed to be a deterrent to deer or other roadside wildlife. In a study in Utah (Romin and Dalton, 1992) mule deer showed no behavioural response to suggest acknowledgement or avoidance of vehicles equipped with such devices, nor could any reduction in the number of deer–vehicle collisions be demonstrated.

In Germany, one of the country’s motoring organisations (ADAC) has promoted the use of a “scent-fence” as an olfactory deterrent. Repellent compounds are micro-encapsulated within an organic foam which is sprayed from an aerosol onto vegetation
at the road edges. Under the effect of daylight the hardened foam gradually disintegrates releasing the volatiles. Not effective as a barrier in itself it is claimed to cause deer to pause, alert and thus become more responsive to additional dangers such as approaching traffic.

From trials on six test sections in Bavaria and northern Westphalia, the manufacturers report that 60% of the animals encountering the treated areas withdrew and crossed the road beyond the scent-fence at an untreated section. 20% of the animals crossed despite the treatment but crossed very rapidly without delay. The remaining 20% were unaffected. On one section of treated road, reported accidents with roe deer fell within a year from 22 per year to two (Kerzel and Kirchberger, 1993). More recent independent studies have, however, suggested that such scent-fences are not, in practice, as effective as claimed (Lutz, 1994).

3.5. ROADSIDE FENCING

Effective reduction of deer road crossings can only be absolutely assured in erection of a genuinely impermeable barrier fence. If truly effective this has of course serious implications (see below) in disruption of natural movement patterns and in isolation of fragments of previously continuous populations. In practice however, no fence is absolutely 100% effective, particularly if no alternative route is offered (overpass or underpass).

A 2.7-m fence erected along sections of I-84 in Pike County, Pennsylvania reduced the number of white-tailed deer observed actually on the right of way as compared with an alternative 2.2-m fence erected on other sections but was not effective in stopping all deer, or reducing the number of road-kills (Feldhamer et al., 1986). A 2.4-m fence with underpasses providing alternative routes for crossing was however, effective in reducing deer–vehicle accidents on a 7.8 mile section of I-80 in southern Wyoming from between 40 and 60 each year to nearly zero (Ward, 1982).

Cost considerations usually result in erection of barriers that are only partially effective because; (a) only short sections of roadway are fenced, and (b) the height of fencing installed is usually between 2 m and 2.4 m. The use of angled extensions on the fence is not recommended as deer have been known to become trapped on such fencing (Blamey and Blamey, 1990).

However, as noted, such fencing must be viewed as a deterrent to crossing and not an absolute barrier; effectiveness can be enhanced by providing alternative means of passage thus reducing the probability of deer intent on crossing, forcing the fence. In addition, given that the intention of the fence is that it should be as impermeable as practicable, some means of exit should be provided for deer which do get on to the carriageway and are then unable to escape. Such escape routes may be provided as one-way gates (e.g. Reed et al., 1974), or as deer leaps (e.g. Madsen, 1993).

Perhaps the most elegant demonstration of these principles is the detailed study by Ward (1982) of the effects of different preventative measures in reducing road traffic accidents on a section of I-80 in southern Wyoming, where the highway crosses the known migration route of mule deer. In 7 years from the time this particular section of highway opened in 1970 until 1977 about 1000 mule deer were killed by vehicles on a 55 mile stretch of the highway. In response to this an experimental section of 6.7 miles of I-80 was fenced in 1977 on both sides to a height of 2.4 m. This section of roadway was already provided with two machinery tunnels and four box-type underpasses, providing deer with alternative routes for crossing and fences were engineered.
in such a way as to funnel deer towards the entrances of these underpasses. One-way (down-fall) gates were also provided at intervals along the road fence to facilitate escape of any deer trapped on the carriageway (after Reed et al., 1974).

Before fence construction, roadkills were between 37 and 60 on the 6.7-mile section over the previous 3 years; in spring and autumn migrations of the year preceding erection of the fence, 52 deer were killed on that section of road. In the first year after the deer fence was constructed along this experimental section, 59 deer were killed, suggesting no reduction in deer-related accidents. However, most of the accidents now occurred at the ends of the fences, where deer were moving along the fenceline and attempting to cross where the fencing ended. The fenceline was thus extended a further 1.1-mile eastwards in 1978. From this time the number of deer-related accidents declined significantly; in the subsequent three years of spring and winter migrations (1978–1981) only one deer was killed within the fenced section and three deer killed beyond the end of the now extended fenceline to the east. “End-runs” still continued to the west of the fenced section but remained at 4–5 per year in total which showed no increase over the level recorded before initial construction of the fence in 1977 (Ward, 1982).

Spring and autumn migrations of mule deer were not disrupted by the erection of the fence, because alternative means of passage were available. In the first migration period after fence construction deer were initially reluctant to cross under the highway and accumulated in large numbers on the south side of the road for a period in the spring. About 200 deer never did cross the highway, but the majority eventually passed through; data from individually radiocollared animals suggested delays in migration of between 2 weeks and 3 months. In subsequent years collared animals spent only a few days in the area around the highway and in many cases moved through within one single day.

Ward’s detailed studies make it clear that appropriate fencing may be used most effectively to reduce the number of road traffic accidents providing:

(a) a long enough section of road is fenced to discourage end-runs;

(b) one-way gates, or other escape mechanisms are provided allowing deer that do get on to the carriageway to escape readily;

(c) alternative provision is made for crossing the road by under/overpass, in areas where roads must be crossed in the course of migration movements.

3.6. OVERPASSES AND UNDERPASSES: “CERVIDUCTS”

Where extensive lengths of roadside are to be fenced, some provision must be made to allow passage of animals, or any animals determined to cross will simply break through the fences or make end-runs (as Ward, 1982). Migrating mule deer in Ward’s (1982) study made more extensive use of machinery tunnels (9 m × 4 m in section with earth floors) than they did square concrete “box-tunnels” (3 m × 3 m; concrete floors). They were initially reluctant to use any form of underpass (migration movements in the first year were delayed for some weeks until the deer had learnt to use these passages above). Artificial baits (alfalfa hay, apple pulp, vegetable trimmings etc.) were provided during the first spring to increase familiarity and use and in subsequent seasons, no apparent disruption to migration movements was observed.

Reed et al. (1975) also found some reluctance of migrating mule deer to use similar box underpasses (3 m × 3 m × 30.5 m long) under I-70 in west central Colorado. However, 230–295 deer passed through the underpass on movements to summer feeding grounds
in the spring, and 400–500 animals returned during autumn migration in the 2 years 1972 and 1973. Reed et al. calculated that the underpass was successful in permitting about 61% of the local deer population to migrate safely under the highway. Artificial lighting did not significantly affect the number of deer using the underpass, nor reduce wariness. Reed et al. conclude, as we may from results of Ward (1982), that larger and more open underpasses result in greater use by deer; they recommend (Reed et al., 1975) underpasses with a minimum of 4·3 m height and width and shortest practicable length.

Perhaps the most extensive study made of the use of such passages is that of Olbrich (1984), who assessed the use made by red deer, roe deer and fallow of no fewer than 824 over- and under-passes of different construction on 823 km of federal highway in West Germany.

Roe deer used 44·7% of all underpasses available; fallow used 26·3% of underpasses within their distribution and red deer used only 8·1% of available structures. In analysis of the characteristics of those passages that were used, against those that were not, Olbrich concludes that likelihood of use is affected most by the overall dimensions of the structure: like Reed et al. (1975) he specifies minimum height and breadth as 4 m and stresses that length of underpass should be as short as possible (although in statistical analyses this was found significantly to affect use of underpasses only by red deer).

More specifically Olbrich found for all species, that the ratio of aperture size to overall length is critical to use (as (height × breadth)/length). He suggests red deer and fallow deer did not use underpasses where this ratio was less than 1·5; for roe deer the ratio should be at least 0·75. Angle of passage (perpendicular to road, or at a diagonal) did not affect use for any species; nor did slope. Like previous authors, Olbrich notes that tunnels with concrete floors were less readily used than those with earth floors. Finally, the degree of cover (“woodedness”) of entrance and exit did, however, affect use, with both red and roe deer more readily using underpasses with secluded entrances. Olbrich also notes (pursuing the theme of familiarization noted earlier) that the length of time take by deer to overcome initial wariness of the structures is approximately 6 months for roe deer and between 2 and 3 years for other species.

Olbrich’s conclusions were based on such a comprehensive survey that they are widely accepted and have been quoted frequently, without further verification, by later authors (e.g. Madsen, 1993); his conclusions about the importance of “relative narrowness” (as (height × breadth)/length) in particular are commonly taken as definitive. To be fair, no other studies have been undertaken of such a comprehensive nature, and I have no reason to dispute the conclusions reached; we should however be aware that every reference to this critical aperture ratio may be traced back to this single study.

Reed et al., (1975) found no effect of increased use of underpasses by mule deer when these were artificially illuminated or provided with skylights (e.g. open to the sky in central reservations). In a more recent study of the effects of tunnel design on use by fallow deer, Kruger and Wolfel (1991) found that an illuminated tunnel was significantly avoided; light-grey painted underpasses, however, were used significantly more readily than structures with black or dark-grey walls.

In general, provision of underpasses during construction of a new road will prove less costly than the alternative measure of providing overpasses, particularly because the game corridors can often be derived by simply enlarging the specifications of tunnels which must be provided for other purposes (permitting passage of canals/rivers;
accommodating machinery or allowing passage of agricultural vehicles). On existing roads however, extension of such tunnels, or provision of underpasses *de novo* may prove prohibitively expensive. In such cases (or on new road schemes where the road must in any case pass through a deep cutting) consideration may be given to construction of the alternative overpass.

Deer, like other larger wildlife, do not readily cross narrow bridges, particularly over railways or busy roads where disturbance levels are also high. Specifications for effective overpasses are therefore extremely demanding; the two (highly successful) “cerviducts” of which I have personal experience in the Netherlands have widths in excess of 30 m with widely splayed “mouths”. In Olbrich’s (1984) survey of game-passages in West Germany, he assessed the effectiveness of overpasses as well as underpasses. For all species considered (red, roe and fallow) use of overpasses was lower than that of underpasses (respectively 4.8, 22.4 and 16.3% of structures provided); small data sets hampered detailed analysis of the factors affecting use, but overall breadth again seemed the critical consideration. As with underpasses, overpasses with bare concrete floors are not utilized by wildlife; successful overpasses in the Netherlands are grassed, and even planted with trees to provide a suitable corridor.

Whichever form of passage is favoured it is clear that it takes a period of time for deer to become used to such corridor structures and to use them freely. Ward (1982) increased use of underpasses by mule deer by artificial baiting through one migration season; this is unlikely to prove practical as a general measure. Use of tunnels and overpasses can however be increased by siting them within wooded areas (which is indeed where most deer movements occur and is thus where they would in any case be most likely to be needed) and landscaping the entrances to ensure entrance and exit are within cover. It is also critical that highway fences themselves do not simply provide a flat barrier to deer movement, but are “sculpted” to funnel deer towards the entrances of such passages.

### 3.7. MANAGEMENT OF ROADSIDE VEGETATION

Use of both underpasses and overpasses is increased where both the entrance and exit are within cover. Thus we may recommend that habitat management is undertaken in order to increase the use of such passages where they are provided. By the same token, cover planted near to road fences will encourage deer usage and increase the risk of road crossings; ironically, the current practice of planting trees on motorways cuttings and verges, while effective in landscaping terms, actually encourages deer to the road edges and increases the risks of deer-related accidents.

Even in the absence of fencing, management of roadside vegetation may help to reduce risks of traffic accidents. Almost all European species of deer primarily favour woodland areas or woodland edge. In studies of the distribution of mule deer and wapiti, *Cervus canadensis*, in relation to roads in Colorado, Rost and Bailey (1979) found that these species tended to avoid areas within 200 m of a road. Road avoidance was greater along more heavily travelled roads and in more open habitats, when compared with wooded (pine and juniper) habitats.

In experimental manipulations to test the effectiveness of vegetation removal along a railway in reducing the frequency of collisions between trains and moose, Jaren *et al.* (1991) found that removal of vegetation in a 20–30 m strip on either side of the railway line caused a 56% reduction in the number of recorded accidents. While one might not advocate so severe a treatment more generally alongside all railways or major
roads, such results certainly make it clear by converse that vegetation immediately adjacent to such thoroughfares does increase the risk of accident and vegetation removal in particularly sensitive areas may well be a viable option. Furthermore, such measures are effective not merely from the point of view of making railway or road edges less attractive to the deer themselves; the absence of obscuring vegetation also increases driver visibility and thus time for reaction. (Waring et al. 1991 also note that elimination of steep roadsides during the planning and engineering of new roadways may also help to reduce accident rates in the same way by increasing visibility and time for reaction.)

By converse, vegetation at greater distances away from roads or railways may be positively managed for deer, to provide cover or foraging areas. This concept of behavioural manipulation through habitat management is more generally explored in Putman (1996); intercept feeding of deer in specific relation to reduction of road traffic accidents is considered by Wood and Woolfe (1988) and Waring et al. (1991).

4. Summary: Control measures on roads

It is clear from analyses of Groot Bruinderink and Hazebroek (1996) that the rate of serious road traffic accidents involving larger wildlife species is substantially increasing in Continental Europe. Accident rates are also reported to be increasing in most States within the U.S. (Romin and Bissonette, 1996). [While no national statistics are available for accident rates in the U.K., it is clear that these too, must be considerable, and with a perceived increase in the number of deer of all species in the U.K. lowlands (Harris et al., 1995; Putman, 1995), likely to be increasing here also.]

Analyses of the economic cost of such accidents are complex. For the most part costs in human terms are assessed in terms of actual damage to property and costs of personal injury (as costs of private treatment or medical insurance); rarely are attempts made to include a cost component from consequential loss of work. Some analyses (but by no means all) have attempted to take some account of the economic costs of the animal’s death, by considering its value in terms of hunting revenue (e.g. Norman, 1975; Langford and Cocheba, 1978; review by Romin and Bissonette, 1996). In many cases, such cost-benefit analyses have made it clear that substantial investment in accident prevention measures is amply justified on purely economic grounds. Furthermore, we might note that documented statistics record only reported accidents (in many European countries at least an unknown proportion of the whole) and in addition record only accidents involving immediate death of the animal hit. From an unknown number of other accidents the animals escape, albeit with serious injuries, which may result in death a short time afterwards or protracted suffering. Taken with clear economic arguments, such welfare considerations must commonly urge the inclusion of mitigative measures in the design of new roads, or their later incorporation into established routes. Despite this, we know surprisingly little of the efficacy of different deterrent methods available in different contexts, nor of their relative cost-effectiveness.

While fencing of roadsides is the only measure likely to be effective in significantly reducing deer crossings in a given area (though not reducing these or resultant accidents to zero: see Feldhamer et al., 1986), fencing of the entire length of any roadway is prohibitively expensive and would in any case act as a (partial) barrier to dispersal movements. Nonetheless, on major roads it would appear that fencing is the only appropriate measure; sufficient length of road should be fenced to reduce the probability of animals merely moving down the length of the fenceline to cross at another point (end-runs; Ward, 1982) and over- or under-passes should be provided to permit crossings
within the fenced section. Fencelines should be designed to funnel deer to these crossing points. Where extensive lengths of roadway are to be fenced, one-way gates should also be provided at regular intervals to permit escape of animals trapped on the carriageway; again fencelines should be designed to lead animals towards such escape gates. Underpasses should be of at least 4 m × 4 m in aperture and should be as short as is feasible; floors should be of earth and ends should be positioned within cover or have cover planted adjacent to them. By the same token, tree cover and scrub adjacent to the fenceline in other sections, may be removed.

Clearly provision of fencing, with the additional structures indubitably required, of one-way gates and underpasses, is likely to be extremely costly; it is however, likely to be the only effective control measure on major roads of high traffic volume. Furthermore, some form of deer fencing is currently already carried out along many stretches of motorway or primary route, and specifications suggested here, while greatly increasing effectiveness, will not greatly increase costs in new developments. Inevitably, such high costs may only be justified in regard to major roads. But by fortunate coincidence, it is only on such major roads with high traffic flow that such an impermeable barrier is required. For minor roads, where; (a) movement of deer is largely small-scale movement within the home-range and (b) traffic flow is lighter and intermittent, so-called deer-mirrors or game-reflectors may prove a more economical and a more appropriate solution, since the intention is to delay crossing, rather than prevent it. The effectiveness of both fencing and mirrors in altering deer-crossing patterns in sensitive sections of road may be reinforced by erection of appropriate road signs to increase also driver awareness.

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References


Deer and road traffic accidents


