

**DEER AND ROAD TRAFFIC ACCIDENTS:
A REVIEW OF MITIGATION MEASURES: COSTS AND COST-EFFECTIVENESS**

[Report for the Deer Commission for Scotland; Contract RP23A]

Professor R.J.Putman, Dr J.Langbein and Professor B.W.Staines

5/03/04

DEER AND ROAD TRAFFIC ACCIDENTS: A REVIEW OF MITIGATION MEASURES

CONTENTS

<i>Executive Summary</i>	<i>iii. to vii.</i>
<u>1. INTRODUCTION</u>	1
<u>2. MEASURES FOR MITIGATION</u>	5
2.1) Preventing, or controlling crossing:	
<i>Roadside Fencing</i>	5
<i>Roadside reflectors</i>	8
<i>Chemical fences</i>	10
<i>Wildlife warning whistles</i>	10
<i>In-vehicle deer detection systems</i>	12
<i>Local reductions in deer density</i>	12
2.2) Increasing driver awareness:	
<i>Management of roadside vegetation</i>	15
<i>Warning signs</i>	16
<i>“Dynamic” signage</i>	17
<i>Speed restriction</i>	25
2.3) Provision of safer crossing points: wildlife passages	28
<i>Overpasses versus underpasses?</i>	30
<i>Dedicated Overpasses</i>	30
<i>Dedicated Underpasses</i>	33
<i>Dual purpose bridges – multi-functional overpasses and tunnels</i>	36
<i>Modification of existing structures</i>	38
<i>Highway Cross-walks</i>	39
Mitigation measures: Overall analyses of effectiveness	42
<u>3. TARGETING MITIGATION</u>	43
<u>4. COSTS AND COST-EFFECTIVENESS</u>	
<i>Costs of Fencing</i>	49
<i>Costs of Reflectors</i>	50
<i>Costs of Signage</i>	50
<i>Dedicated overpasses/underpasses</i>	51
<i>Highway Cross-walks</i>	53
<u>5. THE ACTUAL COST-EFFECTIVENESS OF MITIGATION</u>	53
<u>6. CURRENT MITIGATION IN SCOTLAND</u>	60
<u>7. CONCLUSIONS</u>	62
REFERENCES AND BIBLIOGRAPHY	67

DEER AND ROAD TRAFFIC ACCIDENTS: A REVIEW OF MITIGATION MEASURES: COSTS AND COST-EFFECTIVENESS

Executive Summary

E1. A recent survey undertaken for the Highways Agency, (SGS Environment, 1998), concluded that road traffic accidents (RTAs) involving deer in the UK as a whole probably numbered between 20,000 and 42,000 per annum, with perhaps 20% of these occurring in Scotland. The present report was commissioned to offer a review of the measures available for reduction of the frequency and severity of such incidents and to consider published and unpublished data available on the use, effectiveness and cost-effectiveness of the various different options.

E2. Such an initiative is well-timed, since it is undertaken at the same time as a Europe-wide consultation has been reviewing the wider implications of conflicts between “Wildlife and Traffic” – although this itself has been focused more upon the impacts of transportation infrastructures on habitat fragmentation and isolation of animal populations –and solutions to those problems of fragmentation, rather than necessarily the direct issues of wildlife-vehicle accidents.

E3. In this report we examine the effectiveness (and required specifications for effectiveness) of a variety of mitigation options available for

- i) Preventing, or controlling crossing, by the use of highway fencing, roadside wildlife warning reflectors, reductions in local deer population density, and less conventional methods such as chemical fences or the fitting of warning whistles to vehicles
- ii) Increasing driver awareness, through the use of various driver warning systems – whether through the use of fixed signage, or signage responsive to driver speed, or the actual presence of deer on the roadside
- iii) Provision of safer crossing places for deer by the installation of dedicated overpasses or underpasses, by modification of existing structures to dual use, or by the creation of designated ‘cross-walks’ across the carriageway itself.

E4. High tensile roadside fencing is likely to remain the primary method used to try and reduce road-crossings and resultant accidents at identified sites of high risk. However such fencing must be of adequate specification (height/mesh size) and be designed not with the expectation, or aim, of attempting to prevent road-crossings altogether, but rather to channel animals towards a safer crossing point. Complete barrier fencing attempting to prevent road-crossings altogether is likely to prove ineffective and may result in animals forcing the fence to cross roadways (with the added risk that they may then become trapped within the carriageway, unable to escape). At the very least, where effective as a total barrier to movement such fencing causes fragmentation and isolation of previously continuous populations of deer and other larger wildlife.

E5. In a similar way, roadside reflectors are designed not to stop animal movement across roads, but to delay these at times when there is traffic in the carriageway until the roadway is free of traffic. Working on the principle that light from approaching headlights is reflected onto the verge to provide a flash warning, or continuous visual barrier (depending on reflector type and deployment) they are designed to alert deer to oncoming traffic at night, to startle them or present them with a continuous light barrier and thus delay crossing until the road is clear. Because of relatively low cost, these reflectors are amongst the most common form of mitigation deployed in Scotland (as elsewhere). In practice they can, by definition only be effective at night and on roads of low traffic volume and the majority of published research indicates little or no proven reduction in accident rates in the long term where wildlife reflectors have been installed.

E6. Proprietary ‘chemical fences’ (repellent chemicals encapsulated in slow release organic foam and applied to roadside posts or trees) have been trialled in Germany, with claims by the manufacturers of some efficacy in reducing the frequency of deer-vehicle collisions. More detailed assessment showed that although roadkills were reduced by 30-80 % within the test sections, accidents outside of the trial areas actually rose and other, independent, studies have suggested that such scent-fences are not in practice as effective as claimed. More information is needed also on maintenance requirements and costs (COST 341).

E7. Various 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 the only formal study undertaken of the response of deer to such whistles, 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.

E8. A number of published studies have now demonstrated a relationship between the frequency of deer-vehicle collisions and local deer densities, which suggests that more general reduction of deer densities, in association with other mitigation techniques may help to reduce accident frequencies. Despite this, formal studies of the effectiveness of a local reduction in deer numbers are few and contradictory. While we may cite a number of such instances where population reductions would appear to have been accompanied by reductions in the frequency of accidents, there are other published cases where no such relationship has been established.

E9. The management of roadside vegetation – and specifically, the clearance of woodland or scrub from a margin at the road edge- may have benefits both in increasing driver awareness of deer at the roadside, and increasing visibility of oncoming traffic to the deer themselves. In addition, removal of such vegetation and the cover that it provides may also reduce the probability of deer approaching so close to the road edge in the first place. The method and timing of removal of such vegetation may however be critical. While the removal of vegetation within transportation corridors may help improve driver and animal visibility, simple cutting of encroaching shrub and tree growth may at the same time increase the subsequent attractiveness of these cut-over areas as foraging sites by deer. Such measures might thus actually result in an increase in the number of deer utilising the roadside- ultimately increasing the risk of accident.

E10. Deer warning signs (to increase driver awareness) are the most frequently used approach to reducing deer-vehicle accidents. Such signs are however only likely to be of benefit if erected on approaches to known regular crossing points. In practice, within the UK as a whole, and specifically within Scotland warning signs are relatively rarely so precisely targeted. Further, it is doubtful whether such signs are in any case very effective in the long-term, since drivers readily habituate to them unless the message is reinforced by actual experience of deer crossings.

E11. Various suggestions have been made to increasing the effectiveness of such signs. They should be used only in warning of known and regular deer-crossing points along a roadway. Driver habituation might also be reduced if signs were only exposed at particular times or seasons where accidents are known to be more frequent. Alternatively, lighted signs might be illuminated only if vehicle speeds in known problem areas exceeded some (advertised) threshold level, or specifically when large animals approach the roadway. Such ‘dynamic signage’ has now been extensively tested in the US and in Europe and is reviewed in this report in some detail.

E12. As noted above, highway fencing is at its most effective if it seeks not to prevent animals crossing the road, but to direct them to safer crossing points. The design and specifications of dedicated overpasses and underpasses are detailed, together with the alternative option of adapting other passageways (for footpaths, rivers, machinery accommodation tunnels etc) to become dual use structures. These structures are not always as expensive as commonly assumed, even when fitted retrospectively to existing roads. Finally, consideration is given to the construction of specified ‘cross-walks’ for wildlife actually across the carriageway surface, but in well-delimited and well-signposted locations, where proper warning can be given.

E13. One of the essential prerequisites for effective mitigation is that it should be deployed in areas of high risk of accidents. While such locations may be identified fairly easily on existing roadways, there is considerable value (and cost-saving) if such hotspots may be predicted in advance for new roads or improvement schemes. A substantial effort has been devoted to attempts to characterise areas of likely high risk; certain consistent features emerge as characteristic of sites likely to suffer a high frequency of deer-related RTAs, namely: number of lanes of traffic, presence or absence of central barrier, the presence of woodland or forest cover close to the carriageway, general landscape diversity (variability and patch size) and the presence of obvious travel corridors across the roadway, or linear habitat features leading down at an angle to, or perpendicular to the roadway.

E14. Costs of mitigation are hard to summarise, since much depends on the individual scheme and local topography. Some examples are presented in the main report. Costs of effective mitigation appear high. However these must be viewed within their proper context and in relation to the actual costs incurred in deer-vehicle collisions themselves. The ‘value to the economy of the prevention of Road Accidents’, is outlined in regular updates of ‘Highways Economics Note 1’ published by the Department for Transport, for the purposes of assessing various road safety schemes. At 2001 values, the expenditure which was considered to be justified in the prevention of an accident leading to

- human fatality was £1.185 million per fatality averted by appropriate mitigation
 - serious injury £133,170 per incident averted
 - slight injury £10,270 per incident averted
- with a weighted average of £37,412 per human casualty, or £ 53,902 per personal injury accident.

E15. While costs above are given separately according to severity per casualty, each human injury accident tends on average to have more than one casualty; allowing for this and based on the general average of RTAs by severity, an alternative simpler measure is therefore also provided in the Information Note, suggesting that on average prevention of every human injury accident presents a saving to the economy of around £50k (£53.9k at 2001 costs). Placed in context, this means that on any given stretch of road, mitigation measures which might be expected to reduce human injury accidents by, say, 3 per year over a 10 year period, would justify capital expenditure of £1.6 million based on these ‘accident prevention values’ alone (and without taking into account the wider costs of damage-only deer collisions, carcass clearance costs, venison losses and the ‘ecological’ benefits of providing (in case of over/under passes) mitigation measures which are used also by other wildlife).

E16. In a review of mitigation measures currently in place on trunk roads and others in Scotland, we conclude that current provision of deterrence or mitigation measures designed to reduce the frequency of deer-vehicle accidents appears to be inadequate/ineffective.

E17 In offering recommendations for the most effective measures which might be adopted in the future, we note that for motorway and high-speed trunk roads, highway fencing remains the most effective measure against accidents (with appropriate one-way gates or deer leaps to permit escape of animals trapped on the carriageway). Such fencing should whenever possible be combined with the provision of dedicated crossing places (overpasses, underpasses, or well-signed crossing areas/cross-walks) to avoid producing absolute barriers to animal movement and fragmentation of populations. On more minor roads, or where deer fencing is not a feasible option for landscape or other reasons, mitigation measures should in the first instance be targeted at reduction of driver speeds in areas of known high deer collision risk. Such speed limitation, if enforced, would appear to be one of the simplest and most effective ways of reducing accident frequency and severity. It is however crucial that each mitigation scheme should be tailored to the particular local situation and deer movement patterns; given, in addition, a degree of context-related variability in the effectiveness and cost-effectiveness of various measures, actual mitigation installed in each case will necessarily be dependent on local conditions.

E18. In summary, we would suggest that, **on existing roads of relatively low traffic volume**, fencing, leading to dedicated cross-walks, overpasses or underpasses, would seem the best available option at sites of known, or predicted future, blackspots. Fencing should be designed to lead animals away from those crossing points where accidents have occurred in the past (or are predicted in the future) to safer crossing areas, which should be well-signposted. If fixed signs are appropriate, then these should be new signs specially designed to advertise such crosswalks. Alternatively, consideration should be given to installation of one of the new dynamic signs coupled with sensors, which are activated only when deer are actually approaching the crossing zone. Experience elsewhere in Europe and North America suggest that these measures are more effective if accompanied by a mandatory speed restriction.

E19. On other sections of road where deer occur at relatively high density in the general area, and roadside fencing is not appropriate, presence of deer and risk of accidents should be advertised by adequate signage. Speed restrictions should again be imposed and supported by simple matrix signs which are activated by excess vehicle speed and remind drivers to slow down. Given their universal availability and relatively low cost, the utility of proprietary deer-reflectors should be further explored, in investigation of differences in effectiveness resulting from differences in placement and direction of reflected light.

E20. **On existing roads of high traffic volume**, the only effective measure in reduction of deer-vehicle collisions would appear to be longer lengths of fencing, providing a complete barrier on either side of the carriageway, between existing crossing points already available (as bridges or underpasses). Fencing should be to full highways specifications and there should be adequate provision of one-way gates or deer-leaps to permit escape of animals which do stray onto the carriageway.

E21. Mitigation measures appropriate for consideration in planning of **new road schemes of low traffic volume** will be similar to those already outlined for existing roads – simply because of the high costs involved in more complex provision, which will not be justifiable on relatively minor roads. For **new roads of high traffic volume**, barrier fencing on both sides of the carriageway should be coupled with adequate provision of underpasses or green bridges at regular intervals. In addition, all additional bridges or tunnels required for other purposes (footpaths, minor roads crossing the carriageway, machinery tunnels, culverts etc.) – other than those specifically dedicated as wildlife passages, above - should be designed and built as dual purpose structures.

E22. Concern in preventing collisions between road traffic and deer (or other wildlife) has in the past often tended to be treated foremost as an animal welfare issue. Although it does indeed present a major welfare issue, funding allocations to address this in Scotland (and UK as a whole) have tended to be minimal (not least if compared to other European countries and US). It is becoming increasingly clear however, that in addition to the animal welfare implications and the effects of roadkill on population size of a number of animal, there are also very real major costs to the economy. Human injury RTAs alone, involving deer, are estimated to be worth in excess of £5m to the Scottish economy annually with at least a further £1m incurred through damage to vehicles. We would suggest therefore that a greater expenditure on mitigation would appear to be justified and that it would be appropriate to allocate a significant annual budget at national (trunk roads) and regional levels (non-trunk roads), targeted at reducing the annual deer collision toll and associated costs.

INTRODUCTION

1.1 A recent survey undertaken for the Highways Agency (SGS Environment, 1998), concluded that road traffic accidents (RTAs) involving deer in the UK as a whole probably numbered between 20,000 and 42,000 per annum, with perhaps 20% of these occurring in Scotland. These figures are themselves based largely on extrapolation from records available from other, continental European countries since direct UK data were not sufficient to attempt a formal estimate.

1.2 The SGS estimate was obtained by applying values of the calculated percentage of the national spring population killed in road accidents in other European countries, from the estimated spring population sizes of the six different species of free-living deer in Britain. Given the inherent uncertainties in calculating the total national population size of some of the more widespread species such as fallow (*Dama dama*) and roe (*Capreolus capreolus*) (Harris *et al.*, 1995), and the cautious approach adopted in the analyses, even this upper figure may be a considerable underestimate.

1.3 Statistics available from other European countries where such accidents are routinely reported suggest that between 2% and 5% of all deer-related accidents would be expected to involve human injury or death. In continental Europe as a whole, it is estimated that close to 300 people are killed and 30,000 people injured in collisions with hoofed game each year (Groot Bruinderink and Hazebroek, 1996); the costs associated with damage to property are estimated at around 1bn US dollars.

1.4 We should further note that formal reports record only those deer killed outright, or too severely injured to leave the roadside; an unknown and possibly significant number may suffer serious injury, but escape from the carriageway simply to die elsewhere. Wildlife casualties on roads thus present a serious conservation and animal welfare problem.

1.5 It is also clear that with recent recorded increases in the distribution and abundance of all species of deer in Scotland, together with improved road systems, increasing traffic volumes and higher traffic speeds, it is probable that road traffic accidents involving deer may be expected to increase. Certainly in those countries or States where formal records are compiled, it is clear that there has been a significant increase in the number of deer-vehicle collisions recorded in both Europe and the US (Groot Bruinderink and Hazebroek, 1996; Romin and Bissonette, 1996; Iverson and Iverson, 1999; among others).

1.6 In a report to the Deer Commission for Scotland in 2001, and specifically in review of the measures available to reduce the risk and frequency of road traffic accidents involving deer, Staines *et al.* (2001) concluded:

- “In a UK/European context, high tensile roadside fencing is likely to remain the primary method used to try and reduce road-crossings and resultant accidents. However, it is essential that fencing should:
 - a) be of adequate specification (height/mesh size) ;
 - b) be of sufficient length to prevent end-runs. Roadside fencing has been shown to be most effective where the fence line extends some way beyond a woodland edge, or other known accident site;
 - c) be designed not with the expectation, or aim, of attempting to prevent road-crossings altogether, but rather to channel animals towards a safer crossing point;
 - d) incorporate where appropriate deer leaps, one-way gates or other ‘downfalls’ to allow animals trapped on the carriageway to escape.”

 - “While considered the first line of defence, fencing should not be viewed as an absolute barrier, but rather as a deterrent to crossing in a particular location. Some alternative, safer, crossing should thus be provided. Cost considerations will usually militate against installation of overpasses or underpasses, particularly when the need for mitigation arises in existing roadways*, although such provision may be appropriate in construction of new roads, particularly if landscape or engineering considerations mean that the road line will already pass through deep cuttings (overpasses) or where the road will span gullies or valleys already used as corridors (underpasses and viaducts)”.
- *We would note here however that more recent costings suggest that by strategic use of prefabricated structures, costs of retrofitting of overpasses and even underpasses need not exceed costs where such structures are incorporated in new-build and that higher costs are more assumed than actual (para 2.3.36 below).
- “Crosswalks (as suggested by Lehnert and Bissonette, 1998) may have considerable merit, since these are relatively less expensive and may be installed in appropriate locations retrospectively, on new or existing roadways, where a need is subsequently perceived. In all cases, roadside fencing should be designed to channel animals intent on crossing the road, to safer crossing locations.”

 - “Despite extensive trials, the evidence for efficacy of deer reflectors or deer mirrors is at best equivocal, and in UK/European studies there is at present insufficient evidence of any longer term effectiveness in reducing accidents.”

- “Management of vegetation at the road edge (in removal of trees/scrub from the road verges) would not seem appropriate as a ‘universal’ measure to be widely applied, but results from studies in other countries make it clear that vegetation immediately adjacent to the carriageway certainly increases the risk of accident and vegetation removal reduces the level of risk. Thus vegetation removal in particularly sensitive areas, perhaps in areas already identified as accident black-spots, might be considered a viable option. In such context we might also note that the current practice of landscaping embankments and road edges on new road schemes by planting trees and close cover, while perhaps desirable on aesthetic grounds, is in practice likely to contribute to increased accident risk.”

- “Road signs, to increase driver awareness, are also commonly deployed in areas known to have a high accident risk. These are not necessarily particularly effective, since unless reinforced by personal experience of an accident or near-miss, drivers readily habituate to the signs.”

1.7 The full treatment of this issue, supporting these summary conclusions, (Section 4.6.1 - 4.6.55) is included in the present report, for the sake of completeness, as Appendix 1.

1.8 Road traffic accidents involving deer remain a problem and would appear to be on the increase (1.5). As a result, considerable further attention has been concentrated on the various options available for reduction of accident risk. In this current paper we review the more recent advances in our understanding of the effectiveness of the different measures available. We take as our starting point our previous summary of the European and North American literature to 2000 (Appendix 1) and in this report focus on developments since that date. Where appropriate to facilitate understanding a brief summary of previous work is included in the main text.

Sources

1.9 While there have been a number of additional research papers published in the primary literature, which are covered by the present review, one significant additional advance has been the preparation within the EU of a Handbook for identifying conflicts between traffic and wildlife in general and designing solutions to such conflicts (COST 341 Action paper : Habitat Fragmentation due to Transportation Infrastructure) launched in November 2003.

This document is presented as one of the outputs from the European COST programme (Co-Operation in the field of Scientific and Technical research) and while it addresses in the main somewhat broader ecological issues (such as the effects of roads and other linear structures in terms of habitat fragmentation and as barriers to free movement of wildlife populations), many of the solutions offered have some relevance in the current assessment of the costs and effectiveness of different measures available to facilitate road-crossings.

1.10 A complementary resource, focusing on the American experience and American literature is offered by the recently created Deer-Vehicle Crash Information Clearinghouse (DVCIC) through their website www.deercrash.com/toolbox . While the COST report above focuses in the main on issues of landscape connectivity, and the provision of ‘green bridges’, this online resource provided by DVCIC concentrates more explicitly on road traffic accidents and mortality, considering the advantages/disadvantages and more formally assessing the effectiveness of a somewhat wider range of mitigation measures.

MEASURES FOR MITIGATION

2.0 The essence of measures designed to reduce the risk of deer-related RTAs is not that they should seek to prevent deer from crossing a roadway, but that crossing should be effected more safely. Attempts to prevent crossings altogether are likely to prove ineffective and result in animals forcing such barrier (with the added risk that they may then become trapped within the carriageway, actually increasing rather than decreasing the risk of accident). At the very least, where barriers are completely effective as a total barrier to movement, this will result in fragmentation and isolation of previously continuous populations of deer and other larger wildlife (Forman *et al.*, 1997; Forman and Alexander, 1998; Mladenhoff *et al.*, 1999). Thus, effective measures will seek not to prevent crossings but to displace these in space or time such that deer cross the road at periods of reduced (or zero) traffic flow or in places where accident risk is reduced through enhanced visibility and/or driver awareness.

In our view, few of the available mitigation measures are effective in isolation but become truly effective only in combination. This will be a recurring theme throughout this review.

2.1) Preventing, or controlling crossing:

Roadside Fencing

2.1.1 Our continuing review produced no literature to change our conclusion (Staines *et al.*, 2001) that high tensile roadside fencing is likely to remain the primary method used to try and reduce road-crossings and resultant accidents at identified sites of high risk. However, we reiterate our further comments that it is essential that fencing should:

“be of adequate specification (height/mesh size) and be designed not with the expectation, or aim, of attempting to prevent road-crossings altogether, but rather to channel animals towards a safer crossing point”.

2.1.2 Complete barrier fencing attempting to prevent road-crossings altogether is likely to prove ineffective and, as above, may result in animals forcing the fence to cross roadways (with the added risk that they may then become trapped within the carriageway, unable to escape). At the very least, where effective as a total barrier to movement such fencing causes fragmentation and isolation of previously continuous populations of deer and other larger wildlife.

2.1.3 The most effective use of fencing would appear to be in the erection of fences in relatively short lengths, in specific areas already known to be of high accident risk (or areas predicted as likely to become of high accident risk in the future, as possessing habitat characteristics known to be associated with elevated levels of deer-related RTAs, see section 3.1-3.18 below). Such fencing is thus at its most effective when erected in short lengths and in conjunction with the provision of some alternative and safer means of crossing the carriageway (sections 2.3.1 – 2.3.46) such that the fencing is designed simply to deflect animal movements towards these safer crossing points.

2.1.4 The authors of the recent EU Handbook for mitigating the effects of roads on wildlife populations specifically note (COST 341; 2003):

- “ In general, wildlife fences should be erected only in places where the number of animals killed is high or where there is a high risk of accidents involving wildlife. This is mostly the case along high-speed roads and railway lines. On ordinary roads with low traffic density fences should only be erected at high-risk spots.
- The surrounding landscape has to be checked with respect to other fences or hindrances to animal movement: creating new traps between parallel fences has to be avoided, and the number of fence lines should be reduced wherever possible.
- Fences should always be built on both sides of a road or railway line. Danger points are the ends of the fences, where animals may go round the fences and, if they move back on the inside of the fence, can get trapped between the fences. Fences should therefore end at structures like bridges and, where only a stretch of the road is fenced in, they should be extended 500 m or more beyond the danger area.
- Where a road is built on an embankment with a wide slope it is preferable not to put the fences at the foot of the slope but at the top or halfway up depending on the local situation. The same applies to cuttings.
- Particular attention has to be paid to the placing of fences in relation to fauna passages and other possible crossing points for animals. Fences must not block entrances to passages nor provide traps, but they have an important function to guide animals towards passages.”

[2.1.5] “Design

“Conventional wildlife fences consist of a wire mesh fixed with poles. Height and mesh size depend on the target species. In order to be an effective barrier, a fence has to meet the following requirements:

- The height should be such that animals cannot jump over it.
- The wire mesh has to prevent animals from passing through the openings.
- The mesh has to be fixed such that animals cannot pass under the fence.
- Electric fences are expensive to run and need frequent checks and maintenance. They are not an option for long stretches of road, but may be considered locally where a high risk exists for endangered species, or temporarily to train animals to change their habits after a new road is built.”

[2.1.6] “Height

- The height is determined by the occurrence of different ungulate species:
Red deer, fallow deer, moose: minimum height: 2.2 m (better 2.6-2.8 m)
Roe deer, wild boar: minimum height 1.5 m (better 1.6-1.8 m).
- The height has to be adjusted to the terrain and is measured on the side of the approach of the animals. Where the approach of the animals is downhill, this adjustment is essential.
- In areas with snow cover, the minimum height has to be guaranteed in winter as well” (Müller & Berthoud, 1996; see also Staines *et al.* 2001).

[2.1.7] “Mesh

- For conventional wildlife fences a smaller mesh size in the bottom half or third of the fence is recommended, in order to prevent smaller animals from passing through the fence.
Distance between horizontal wires: Bottom: 50-150 mm, Top: 150-200 mm
Distance between vertical wires: 150 mm.
- Wires should have a diameter of at least 2.5 mm and should consist of rust-free material.
- In areas with heavy snowfall, the top wire of the netting must be reinforced with a cable capable of bearing the weight of the snow settling on it.
- The bottom wire should be lying directly on the ground and fixed to prevent animals from crawling under the fence. Burying the wire mesh 20-40cm under ground may be necessary in areas with badgers, [muntjac] or wild boar. Where the ground is uneven, it has to be levelled out to avoid gaps e.g. due to holes in the ground. Special care should be given to places where fences cross ditches.
- The wire mesh should be fixed on the outside of the poles (i.e. away from the road) to prevent mesh from falling away from posts when large animals crash into fence.”

*We note that we ourselves do not necessarily agree with the specifications offered by the authors of COST 341. Forestry Commission guidance suggests that mesh size at the base of fences should be no more than 75 x75mm in areas where muntjac occur, with mesh no larger than 100x100mm in roe areas to prevent smaller individuals squeezing through.

[2.1.8] “Exits

- Where there is a danger that animals get trapped on the road, i.e. particularly when not the whole stretch is fenced, exits should be provided to allow the escape of animals.”

[Here see also: Staines *et al.*,(2001): “Where deer fencing has not proved effective this has usually been related to inadequate specification of fence construction, to deer getting past the end of fencelines where insufficient length has been installed, or at road junctions where fencing is difficult. In such situations, accident risk may actually be increased where deer become trapped in the road corridor on the wrong side of the fence (Feldhamer *et al.*, 1986) and it is appropriate in any fencing scheme to incorporate means of exit from the carriageway, such as one-way gates (Reed *et al.*, 1975, Lehnert and Bissonnette, 1998) or deer leaps (e.g. Madsen, 1993)”.]

Roadside reflectors

2.1.9 With the same considerations as above, roadside reflectors are designed not to stop animal movement across roads, but to delay these at times when there is traffic in the carriageway until the roadway is free of traffic. Working on the principle that light from approaching headlights is reflected onto the verge to provide a flash warning or continuous visual barrier (depending on reflector type and deployment), they are designed to alert deer to oncoming traffic at night, to startle them or present them with a continuous light barrier and thus delay crossing until the road is clear.

2.1.10 Even if the reflectors are effective in delaying road crossings, by definition they can only be effective at night. Previous work on the diel pattern of accident frequency, suggests in fact that highest periods of accident risk during the day coincide with dawn and dusk (e.g. Ueckermann, 1964; Langbein, 1985; Desire and Recorbet, 1990; Lav Sund and Sandegren, 1991; Petrak, 1992; Hartwig, 1993; Groot Bruinderink and Hazebroek, 1996), where approaching vehicles may not in practice have their headlights on, and in any case the effectiveness of the reflection is to an extent reduced by higher general ambient light conditions.

2.1.11 Further, even when effective, these reflectors can only usefully be installed on roads of relatively low, or sporadic traffic flow: such that there are periods of quiet between vehicles to permit safe crossing. On roads of high or continuous night-time traffic, the reflectors are

continuously activated. Deer may more readily habituate to the reflected light. Even if they do not do so, if intent on crossing – and if not provided with interval periods of no traffic flow- they will simply force the ‘barrier’ and cross anyway even in the face of oncoming traffic. Despite this we would note that that are many instances of such inappropriate deployment of reflectors on roads of high traffic flow.

2.1.12 Debate over the initial effectiveness of such reflectors (immediately after installation) continues (eg Woodard *et al.*, 1973; Schafer and Penland, 1985; Gilbert, 1982; Zacks, 1986; Waring *et al.*, 1991; Armstrong, 1992; Ford and Villa, 1993; Reeve and Anderson, 1993; Pafko and Kovach, 1996; Jared, 1999). There seems little doubt however that even if, under ideal conditions, they do have some effectiveness for a period after erection, this effect wanes over time, due to deterioration of the reflectors themselves and due to habituation/learning.

2.1.13 A recent behavioural study by Ujvari *et al.* (1998) tested the response of a group of emparked fallow deer to light reflections from WEGU manufactured warning reflectors, recording flight, alarm, movement of the head etc. in response to light reflections at predetermined intervals. They noted that the deer exhibited an increasing indifference to the reflections, indicative of relatively rapid habituation. Although, to be fair, the test eliminated any element of the reinforcement that would be provided by passage of an actual vehicle, and thus simply tested habituation to a repeated light stimulus, the results are supportive of a general impression that deer do indeed habituate over time to any initial effect of such reflectors.

2.1.14 It is perhaps significant that the recent COST 341 appraisal of conflicts and solutions in relation to wildlife road crossings, dismisses reflectors in a couple of brief sentences: “These features are popular because they are cheap and easy to place. However, a thorough analysis of studies carried out over the last 40 years all over the world found little evidence for the effectiveness of wildlife warning reflectors”.

2.1.15 It has been suggested, purely anecdotally, that the effectiveness or otherwise of reflectors (and inconsistencies in results of roadside trials) may be largely influenced by the way the reflectors are installed –and whether they are positioned to reflect incident light onto the nearside verge or across the carriageway. There are however, to our knowledge no objective comparisons available of the effect of these different presentations on overall effectiveness.

Chemical fences

2.1.16 Our current review of the literature provided no further information than summarised by Staines *et al.* (2001; Appendix 1 here). From trials on six test sections in Bavaria and northern Westphalia, the manufacturers of a proprietary German scent-fence (of repellent chemicals encapsulated in slow release organic foam) report that 60% of the animals encountering the treated

areas withdrew and crossed the road beyond the 'scent fence' at an untreated section. Twenty percent 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 of roe deer fell within a year from 22 per year to a total of 2 (Kerzel and Kirchberger, 1993). More detailed assessment showed that, although roadkills were reduced by 30-80 % within the test sections, accidents outside of the trial areas actually rose (Lebersorger, 1993), and other, independent, studies have suggested that such scent-fences are not in practice as effective as claimed (Lutz, 1994). Further tests are needed to show what may be the effectiveness of these measures in the long term. More experience is needed also on maintenance requirements and costs (COST 341).

Wildlife warning whistles

2.1.17 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. The manufacturer's advertising in support of one of these warning whistles ("Save-A-Deer") refers to trials carried out by the Business Research Group [Bellevue, Iowa] in 1987, with white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*). Recordings of a warning whistle were carried by ATV into areas of high deer density to determine the effect of the whistle on deer movement. Tests were carried out primarily at night so that it is not possible to distinguish any effects of the whistle from those of vehicle lighting. Test results claim to have caused moving deer to 'freeze' in 351 out of 380 trials.

2.1.18 Various claims have also been made in relation to the effectiveness of these devices in actually reducing the rate of deer-vehicle accidents. The details of few of these studies have been properly documented. Two described on the DVCIC website (www.deercrash.com) are summarised below. The Sheriff's Department in Onodaga County, New York mounted whistles on 55 patrol cars in 1986. In an (internal) newsletter article in 1988 it was claimed that only two patrol cars had struck deer in the period since whistles were installed, and that five others had sustained minor damage taking avoiding action (Gosson, 1988), compared with an accident rate of approximately 10 deer-related accidents before installation of the devices. In a second example, whistles were fitted to all fleet vehicles of the Idaho National Engineering and Environmental Laboratory. The laboratory fleet had experienced an average of 17 deer-related accidents in previous years but claimed to have suffered no crashes during the five years after installation (Brown, 1998).

2.1.19 These reports typify the kind of anecdotal evidence claimed in support of ‘deer-whistles’ as an effective form of mitigation. However, the managers of deer crash.com themselves note that there is in any case a large degree of year-to-year variation in accident rates – which the authors of neither of these articles take into account when interpreting their own changed accident rate.

2.1.20 Any effectiveness of deer whistles is dependent on the ability of deer to hear and respond to the emitted sound. Manufacturers’ claims typically suggest that the whistles emit sounds at between 16 and 20 kHz at speeds above 30 m.p.h. Overall, there has not been a significant amount of published work on the auditory capabilities of deer; what work there is suggests that the ‘range of greatest hearing sensitivity’ lies between 1 and 8 kHz – which would be well below the sound range claimed for the various whistle designs in commercial production. In independent experimental trials on 6 different whistle designs, however, Scheifele *et al.* (1998) found that the primary operational frequency actually produced by the different whistle designs was 3.3 kHz and 10kHz. This is closer to the presumed auditory range of (white-tailed) deer; however, it is noted that the 3.3 kHz sound is also within the typical range of normal roadway noise (tyre noise) produced by a vehicle at 45mph (Scheifele *et al.* 1998).

2.1.21 In the only formal study undertaken of the response of deer to such whistles (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. Unpublished work by scientists from the University of Wisconsin, mentioned in a report by the Insurance Institute for Highways in the US in 1993, found that neither deer nor humans could actually detect the sound produced by the whistles in normal operation, and that whistles blown by mouth had no effect on penned deer.

2.1.22 The purpose of these warning whistles is to startle the deer and cause them temporarily ‘freeze’ or take fright. It is clear that even if such devices should be detected by the deer and serve to startle them they are just as likely to dart across the road as to move away from the carriageway.

Further, as noted also in relation to other ‘deterrents’, there is a strong likelihood that deer feeding near roadways will rapidly habituate to the sounds of these deer-whistles, as they become more frequently deployed. Any effect they may have is thus based on novelty and will rapidly diminish as these devices become more commonplace.

In-vehicle deer detection systems

2.1.23 Two in-vehicle ‘vision systems’ have recently been developed designed to enhance driver detection of deer by the roadside, particularly at night . Both use infra-red sensors to offer earlier detection of deer or other wildlife either on, or beside, the carriageway, displaying images continuously on a screen within the dashboard.

The two systems are marketed by Honeywell and Raytheon Commercial, who have formed a partnership to market the Bendix Xvision, and by Cadillac (Cadillac Night Vision system). The Cadillac system currently costs in the region of \$2,250 per unit.

2.1.24 There are as yet no published studies which evaluate the usefulness or the effectiveness of these technologies. Some concerns have been expressed, however, about the safety implications of the devices as currently designed. There is a considerable risk of driver distraction, or information overload. In addition there is considerable potential for ‘false positives’ (the devices detect any source of infra-red) which may rapidly lead to habituation, or simply to drivers’ ignoring the screen image.

Local reductions in deer density

2.1.25 In our earlier review (Staines *et al.*, 2001) we noted:

“ One additional measure frequently suggested as potentially contributing to reductions in deer-traffic accidents is local reductions of deer populations in known accident black-spots (eg. Allen and McCullough, 1976). However, there is no consistent evidence that frequency of RTAs is simply density dependent. While Danielson and Hubbard (1998) reported that a decrease in the white-tailed deer herd in Iowa in the late 1980s resulted in a corresponding reduction in the number of deer-vehicle collisions, Waring *et al.* (1991) found that deer-vehicle collisions did not decline in their study area even though the population of deer decreased.”

2.1.26 Since that time we have discovered increasing evidence for a relationship between the frequency of deer-vehicle collisions and local deer densities (eg. McCaffery, 1973; Wisconsin Department of Natural Resources (data summarised on www.deercrash.com; Schwabe *et al.*, 2002; Rondeau and Conrad, 2003), which suggests that more general reduction of deer densities, in association with other mitigation techniques may help to reduce accident frequencies.

A linear relationship between local deer density and frequency of deer-vehicle collisions is reported by Rondeau and Conrad for white-tailed deer in Irindequoit, an urban/suburban area of Rochester, New York (Rondeau and Conrad, 2003; based on data of Nielsen, Porter and Underwood, 1997), while Schwabe *et al.* (2002) in a robust analysis of the frequency of motor accidents involving white-tailed deer across 88 counties in Ohio between 1977 and 1998, have also identified clear (negative) correlations between accident frequency and size of doe cull the previous

year. These analyses seem to verify that local reductions of deer density might indeed be expected to contribute to a decrease in incidence of accident frequency; there are however relatively few empirical studies which actually record such reduction in the rate of deer-related RTAs in response to a reduction of deer numbers.

2.1.27 In order to try and engineer a reduction of impact on the vegetation, as well as in the number of deer-vehicle collisions, a deliberate reduction of the population of white-tailed deer was undertaken through the 1980s in the Ned Brown Forest Reserve in north eastern Illinois. It was found that the numbers of DVCs decreased from 37 in 1982 when population reductions began, to 13 or fewer in the years after 1987, the year in which target densities had been reached (Jones *et al.*, 1993).

2.1.28 In Irondequoit, a similar reduction project was initiated within a largely suburban area, in response to complaints about damage to gardens, public parks and the number of deer-related vehicle accidents (Eckler 2001, and see Rondeau and Conrad, 2003). In 1992 (the year before the culling programme commenced) the number of reported deer-vehicle collisions was 227; numbers of collisions fell sharply after the cull commenced in 1993 and, in 2000, it was estimated that the number of DVCs was around 100.

2.1.29 Finally, a decline in the number of recorded DVCs was also reported to accompany an increase in hunting activity in Oak Ridge Reservation, Tennessee (Jenks *et al.*, 2002). Hunting of deer had not been permitted within the Reservation for a period of some 45 years, but was reintroduced in 1985. Over the next 10 years, deer populations showed significant decline and the number of deer killed in DVCs decreased from 923 in 1985 to 470 in 1994 (Jenks *et al.*, 2002)

2.1.30 However convincing such statistics may appear, formal analysis of such studies, to determine the precise effects of population reduction on the rate of deer-vehicle collisions, is extremely difficult. As noted earlier, there is a considerable underlying year-to-year variation in the number of such accidents in any given area anyway. Accident frequencies are affected by a number of factors other than simply herd density; these other factors have not been controlled for in these rather opportunistic analyses and other, influential, factors may also have altered over the study period. Further, some additional, purely stochastic, variation would also be expected between years, in any case, particularly where annual numbers of accidents are rather low.

In none of the studies quoted were adequate statistical controls made; the causal relationship between population reductions and a decrease in vehicle accident frequency must thus remain suggestive, but unproven.

2.1.31 Further, while we may cite a number of such instances where population reductions would appear to have been accompanied by reductions in the frequency of deer-vehicle accidents, there are other published cases where no such relationship has been established (eg. Waring *et al.*, 1991, above; Doerr *et al.*, 2001). These differences in outcome indubitably point to the fact that the frequency of DVCs is related not to one single factor but a multiplicity of causal factors in interaction – and reinforce our view (2.0 above) that, in consequence, no single solution to the problem is likely to be effective in isolation, but only when adopted in combination with a suite of other appropriate measures.

2.2) Increasing driver awareness:

Management of roadside vegetation

2.2.1 The management of roadside vegetation – and specifically, the clearance of woodland or scrub from a margin at the road edge- may have benefits both in increasing driver awareness of deer at the roadside, and increasing visibility of oncoming traffic to the deer themselves (Waring *et al.*, 1991). In addition, removal of such vegetation and the cover that it provides may also reduce the probability of deer approaching so close to the road edge in the first place.

2.2.2 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, as noted by Staines *et al.* (2001) one might not advocate so severe a treatment more generally alongside all railways or major roads, such results 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.

2.2.3 The method and timing of removal of such vegetation may however be critical. Rea (2003) cautions that while the removal of vegetation within transportation corridors may help improve driver and animal visibility, simple cutting of encroaching shrub and tree growth may at the same time (simply through encouraging regeneration) increase the subsequent attractiveness of these cut-over areas as foraging sites by deer. Such measures, aimed at reducing accidents might thus actually, in the longer-term, result in an overall increase in the number of deer utilising the roadside verge - ultimately increasing the risk of accident. Current research suggests that the quality of regenerating plant tissue for herbivores depends on when the plants are cut. Rea suggests that where cutting of woody vegetation is undertaken to try and reduce accident risk within transportation corridors, such cuts should be undertaken as early as possible in the season, since plants cut in the middle of the summer produce regrowth which is of increased nutritional value for at least two years following cutting.

Warning signs

2.2.4 Staines *et al.* (2001, after Putman, 1997), note:

“Deer warning signs [to increase driver awareness] are the most frequently used approach to reducing deer-vehicle accidents. Such signs are however only likely to be of benefit if erected on approaches to known regular crossing points. Further, 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”. [See also COST 341].

2.2.5 In practice, within the UK as a whole, and specifically within Scotland (Section 6.3) warning signs are relatively rarely so precisely targeted to specific crossing points (since these are themselves not normally specifically defined). Instead the more usual approach to such signage is to erect signs suggesting “Deer for the next 2 miles” (or similar). Because they are so general and non-specific, these signs are rarely effective in reducing vehicle speeds and as noted, regular users of given stretches of road quickly habituate to them.

2.2.6 Various suggestions have been made to increasing the effectiveness of such signs.

- They should be used only in warning of known and regular deer-crossing points along a roadway - themselves perhaps engineered by roadside fencing leading deer to such designated crossing zones (‘cross-walks’ after Lehnert and Bissonette, 1997), restricting crossing to these points (2.3.41 – 2.3.46)
- It has been suggested that the current sign (representing an individual deer) is itself misleading. In many instances of collisions drivers notice the first deer in the roadway and avoid it, only to collide with subsequent animal or animals crossing unexpectedly in the rear of that leading individual. It is suggested that more effective signage might indeed show a single animal in the roadway, but illustrate others on the adjacent verge likely to cross in its wake (*personal communication*, G.Pither)
- Driver habituation might also be reduced if signs were only exposed at particular times or seasons where accidents are known to be more frequent [late spring and autumn: Staines *et al.*, 2001]. Alternatively:
- Lighted signs might be illuminated only if vehicle speeds in known problem areas exceeded some (advertised) threshold level (much as speed limit signs at the entrance to some built-up areas are specifically activated by vehicles travelling in excess of 30 mph).

- Lighted signs at known danger points or specifically established ‘cross-walks’, coupled to infra-red detectors, might be illuminated only if the sensors detected animals on the verge itself (below, paragraphs 2.2.10- 2.2.30).

Either device is likely to reduce risk of driver habituation by ensuring signs are only activated at times of real risk.

Finally

- ‘Shock signage’ at known accident blackspots might prove more effective than constant warning triangle, with display boards regularly updated to provide information as: **“Danger ! Wildlife Accident Blackspot. XX deer-vehicle collisions on this stretch of road in the past 6 months”** or some similar message.

2.2.7 There appears relatively little formal literature relating to use of such signs.

An animated illuminated sign was found by Pojar *et al.* (1975) to have limited effectiveness in reducing accident frequency, but this in itself is easily disregarded by regular users of any given stretch of road.

2.2.8 Authors of the EU COST report 341 note that:

- Wildlife warning signs should be placed only in places with high risks of collisions, because the more widespread they are, the less people pay attention to them.
- Putting up signs only during sensitive seasons could make people more attentive to them, but sadly the report does not cite source references, and appears to offer opinion rather than proven fact.

2.2.9 The report does however note that:

- a) The combination of a wildlife warning sign with a speed limit is slightly more effective.
- b) The effectiveness is further enhanced if signs are marked with flashing lights or a flashing speed limit sign, which are lit only during periods of high activity .

2.2.10 Recently, a number of dynamic sign systems have been developed, coupled to sensors capable of detecting animals approaching the roadway. Such signs are thus activated only in direct response to animals present or approaching the carriageway. The sensors trigger the fibreoptic wildlife warning signs combined with speed reduction signs (30-40 km).

Normally the signs appear dark and the light points are only visible when activated. The system can be powered by solar energy.

2.2.11 These systems are still new and there is relatively little objective evidence as to their effectiveness; the majority use infra-red beams or laser beams to detect animal movement either side of the carriageway, or passive sensors which respond to infra-red emitted by the animals' bodies themselves. In one instance, leading animals of a relatively sedentary elk herd (*Cervus elaphus canadensis*) have been equipped with radiotransmitters which activate the roadside warning signs (see 2.2.13, 2.2.14).

2.2.12 These systems are reviewed by DVCIC (at www.deer-crash.com) and also more recently by Huijser and McGowen (2003). Huijser and McGowen have identified 27 locations within Europe and North America where such systems are in place, and 20 further locations for where such systems are planned. Examples are listed below, where published information is available, but see Huijser and McGowen (2003) for a fuller listing and evaluation of other systems where formal publication of results is still awaited.

- In Minnesota, a dynamic sign system of this type has been installed at one location and is planned for two other sites (Minnesota Department of Transportation Press Release 2002). The system uses an infra-red light beam on both sides of the roadway to detect animal movement; when these sensors are activated, a battery-powered transmitter turns on amber warning lights on top of a series of traditional deer warning signs.
- In Montana, the Western Transportation Institute is testing a dynamic sign system that operates with radar beam sensor equipment connected to amber lights on top of a traditional crossing sign (Huijser and McGowen, 2003).
- In Washington, a system has been installed along Highway 395 that utilises laser beams on either side of the roadway (McGowen, 2002), while
- In Wyoming the effectiveness of a similar system is being monitored along a stretch of US Highway 30 between Kemmerer and Cokeville (Gordon *et al.*, 2001). In this case, a total of three sensor systems have been installed in the area where deer may cross, including a series of active (break the beam) infrared sensors on either side of the highway, combined with an in-ground geophone designed to detect ground vibrations from nearby deer and a set of microwave sensors .
- In Canada, a project is underway to trial a similar dynamic/responsive sign in British Columbia, using actual infra-red cameras to detect wildlife on or near carriageways (Newhouse 2003)

- According to Pachlatko (1994), during the year after installation of a similar system in Switzerland not a single DVC occurred. Following his detailed investigations of such warning installations Kistler (1998) accepts that they can produce a significant reduction in ungulate / traffic collisions.
- Finally, in Finland, a warning sign and sensor system has been installed which uses microwave radar sensor equipment, 16 passive infra-red detectors and a rain detector designed to reduce the number of false detections (McGowen, 2002 and www.deercrash.com/toolbox).

2.2.13 While the majority of these systems rely on radar or infra-red detection systems to activate driver warning signs, we should for completeness also make note here of another novel system in operation near Sequim in Washington State. Here members of a herd of Roosevelt elk (an endangered and very localised subspecies of the widespread *C. canadensis*) have been equipped with radiocollars designed to trigger warning signs when they approach traditional crossing places across highways within their range. To date, radiocollars have been attached to eight elk (of a population of 81), and are linked to a total of six radio-activated warning signs erected along a 3-mile stretch of US Highway 101 (Washington Department of Fish and Wildlife Press Release, 2003).

2.2.14 These radio-activated signs appear to have been very effective at reducing collisions with vehicles, but such a system is perhaps not more universally applicable. This is clearly a very particular situation where the local deer herd has a very restricted distribution and very precisely known movement patterns, such that the system is designed to be operational only along a 3 mile length of highway. Further, close familiarity with the animals comprising the herd made it possible to identify key individuals who acted as leaders when the herd was on the move, and selectively target these lead individuals for radiocollars. The system may thus have potential in similar situations where a large localised population of a ‘herding’ species is present in a ‘landlocked’ area, surrounded by roads, but applicability is probably restricted to such well-defined situations.

2.2.15 Infra-red and radar provide the detection mechanism in the majority of the experimental detection and warning systems currently being trialled. Results to date from the experimental system in Wyoming are reviewed in detail by DVCIC on their [deercrash](http://www.deercrash.com) website. This summary is presented here in full, as informative about the effectiveness and problems associated with this type of device in general:

[2.2.16] The Flashing Light Animal Sensing Host (FLASH) system was installed in Nugget Canyon, Wyoming along U.S. Highway 30 (Gordon *et al.*, 2001). This segment of roadway crosses a mule deer migration route, and in 1989 a seven-mile eight-foot fence was erected along both sides of the roadway. A 300-foot gap, however, was left in the fence for the mule deer migration. The FLASH system was installed and tested within this 300-foot gap from December 2000 to May 2001.

[2.2.17] The Nugget Canyon dynamic sign and sensor system consists of a group of roadside detector sensors connected to amber flashing lights mounted on deer crossing signs. These signs are located approximately 985 feet from each end of the study area (i.e., the fence gap), and have the legend “Deer on Road when Lights are Flashing”. A total of three sensor systems have been installed to detect deer activity within the study area. These systems include a series of active (i.e. break-the-beam) infrared sensors on both sides of the roadway that, when combined with the roadside signs and flashing lights described above, represent the FLASH system. The other two deer activity sensing systems in the study area include a combination of the infrared scopes on both sides of the roadway and in-ground geophone installed on one side of the roadway (these sensors detect ground vibrations from nearby deer), and a set of microwave sensors.

[2.2.18] Infrared and low-light video cameras were also installed in December 2000, and could be used to observe almost the entire study area. The evaluation of the FLASH system in Nugget Canyon consisted of three parts. First, the activation reliability and/or accuracy of the active infrared and the infrared scope/Geophone sensor designs were compared to the results of a video camera. Then, vehicle speeds and classifications were collected both inside and outside the study area (with loop detectors) during normal FLASH system operations.

[2.2.19] Speed measurement devices were located outside the study area (i.e., before drivers could observe the new warning sign configuration), and between the signs. Finally, the vehicle speed impacts of five different sign, flashing light, and/or deer presence situations were tested during the study time period (December 2000 to May 2001) .

[2.2.20] The sensor accuracy test revealed a number of complications with the application of these types of systems. For example, in 30 hours of observation the FLASH infrared sensors operated correctly, but by the second month of testing the system was beginning to experience a large number of false activations. Overall, during the study time period, more than 50 percent of activations were determined to be false . These false activations, among other things, appeared to be caused by birds and snow from snowploughs breaking the infrared sensor beams.

[2.2.21] The combination of the geophone and infrared scopes appeared to be very reliable . During 30 hours of observation this system always registered an activation when a deer was present, and never registered an activation when there was no deer present . A comparison to the video camera results indicates that this level of reliability continued throughout the study time period . The system tended to overestimate the number of actual deer crossings (because it registered deer as they moved back and forth across the sensors), but it did so in a reliable and somewhat predictable manner .

The researchers concluded that some form of the geophone/infrared scope sensing system had the most potential for future installations .

[2.2.22] The second and third parts of the Nugget Canyon study evaluated the vehicle speed reduction impacts of eight different situations. The first five situations described in the following list were observed during four different two- hour time periods to evaluate the impacts of different sign, flashing light, and deer presence configurations . The final three situations represent the three combinations found to occur during the normal operation of the FLASH system . Speed data from two days that were randomly chosen from each month of the study time period were used in this analysis. All eight situations are briefly described in the following list:

1. A baseline or “expected” average vehicle speed reduction was calculated from data collected when the flashing lights on “Attention: Migratory Deer Crossing” signs were continually active.
2. The sign legend was changed to “Deer on Road When Lights are Flashing”, but the flashing lights remained continually active. This allowed the quantification of the average vehicle speed reduction that might be due to the sign message change and continually flashing lights without a deer present.
3. A realistic taxidermist deer mount was added to the roadway. Everything stayed the same as the second situation, but a deer mount was added about 10 feet from the traveled way. This setup allowed an approximation of the average vehicle speed reduction impacts of the system with continually flashing lights and a “deer” in the right-of-way.
4. The third situation was repeated, but the flashing lights were deactivated. The speed reduction data collected during this situation could be used to evaluate the impact of the flashing lights.
5. The second situation was repeated, but the flashing lights were remotely activated when the driver could observe that the system was active. This situation was evaluated to measure the vehicle speed impacts if the drivers knew the system was active.
6. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were activated and an actual deer was present.
7. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were not active and no actual deer was present.
8. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were activated, but no actual deer was present (this situation represents a false activation).

[2.2.23] The average vehicle speed reductions calculated for the eight situations described are shown in the Table. These results show that when the system worked as it was designed, and the lights were activated with actual deer present, drivers slowed their vehicles by a statistically significant average of 3.6 miles per hour. The data also show that the average speed reduction calculated for the situation when the lights were not flashing and no deer were present was less than one mile per hour.. Finally, the average vehicle speed reduction produced by the activation of the lights when no deer were present (i.e., a false activation) was 1.4 miles per hour.

[2.2.24] A comparison of the speed reduction results for the remote-control activation of the flashing lights (Situation 5 in the Table) to those for the fully operational system also show that the remotely activated system might be used quickly to approximate the impact of one that is fully installed and operating. We should note, however, that the FLASH system researchers considered it unlikely that the largest vehicle speed reduction observed during the normal operation of the FLASH system (i.e., 3.6 miles per hour) would produce a reduction in DVCs

TABLE 4 Nugget Canyon Average Vehicle Speed Reductions (5)

Situation	Flashing Light Operation	Sign Legend	Actual or Decoy Deer Present?	Average Speed Reduction (miles per hour) ¹	Sample Size ²
1	Continuous	“Attention: Migratory Deer Crossing”	No	1.2	NA
2	Continuous	“Deer on Road When Lights are Flashing”	No	2.3	NA
3	Continuous	“Deer on Road When Lights are Flashing”	Decoy Deer Present	12.3	NA
4	Deactivated	“Deer on Road When Lights are Flashing”	Decoy Deer Present	8.0	NA
5	Remotely Activated	“Deer on Road When Lights are Flashing”	No	4.7	NA
6	FLASH Sensor Activated	“Deer on Road When Lights are Flashing”	Actual Deer Present	3.6	655
7	Not Activated	“Deer on Road When Lights are Flashing”	No	0.7	8,153
8	FLASH Sensor Activated	“Deer on Road When Lights are Flashing”	No	1.4	1,965

¹Average speed reduction is the average of the differences in measured vehicle speeds inside and outside of the study area. Average speed reduction for Situations 1 to 5 are for passenger cars only. The average speed reduction for Situations 6 to 8 are for all vehicles.

²NA = not available or documented.

2.2.25 A fuller review of all such dynamic or ‘responsive’ animal-detection and driver-warning systems is offered by Huijser and McGowen (2003) based on analysis of 27 locations where such devices have been installed thus far in Europe (Switzerland, Germany, Sweden and The Netherlands) and North America. Huijser and McGowen describe the characteristics of two main types of animal-detection systems: area cover and break-the-beam systems, and then offer details of all existing installations before drawing some general conclusions about costs and effectiveness of these (inevitably still experimental) systems.

2.2.26 This review is in itself so comprehensive that there would be little value in repeating it here. Instead we would strongly urge readers of this report to consider the original review in full.

Huijser and McGowen conclude:

[2.2.27] “ Many of the systems encountered technical problems or experienced false positives, false negatives or maintenance issues. This was to be expected since most animal detection and animal warning systems are new applications of relatively new technology. In addition, the systems are typically exposed to rain, snow, heat and frost. A few systems seem to have resolved most of the problems and operate well. Examples include both the Swiss system and the Finnish systems (Kistler, 1998, 2002; Taskula, 1997; Muurinen and Ristola, 1999) However, each system type has its own (potential) strengths and weaknesses, and one has to review them carefully before installing a system in a particular location.

[2.2.28] “ It is important that animal detection systems produce very few false positives and false negatives. False positives may cause drivers to eventually ignore activated signs, and false negatives present drivers with a hazardous situation. Driver response through reduced vehicle speed or increased alertness determines how effective animal detection systems really are. Previous studies have shown that drivers do not always substantially reduce their speed in response to activated warning signs (Muurinen and Ristola, 1999; Gordon and Anderson, 2002; *and see above* 2.2.23, 2.2.24). Drivers may only reduce their speed when road and weather conditions are bad or when the warning signs are accompanied with a maximum speed limit sign (Muurinen and Ristola, 1999; Kistler, 1998).

[2.2.29] “However, failure to substantially reduce vehicle speed under all circumstances does not necessarily make animal detection systems ineffective. Minor reductions in vehicle speed are important too since a small decrease in vehicle speed is associated with a disproportionately large decrease in the risk of a fatal accident (Kloeden *et al.*, 1997). In addition, activated warning signs are likely to make drivers more alert. Driver reaction time to an unusual and unexpected event can be reduced from 1.5 s to 0.7 s if drivers are warned (Green, 2000). When we assume a vehicle speed of 88 km/h (55 MPH), increased driver alertness can reduce the stopping distance of the vehicle by 21 m (68 ft).”

2.2.30 We ourselves would conclude this section by stressing that, whatever their apparent potential, these animal-activated warning signs are not a panacea; the provision of dynamic, and animal-activated warning signs **is only a way of enhancing the effectiveness of signage**. These, like the standard, passive signs, are still only likely to be useful if they can be deployed in known crossing places, or in combination with other measures (fencing) designed to funnel animals to specific crossing locations. It would neither be appropriate or economic simply to blanket the entire road network with such signs in pious hope! Rather they should be seen as ways of enhancing the effectiveness of signage where signage is required, used as a replacement for conventional signs but still in contexts where signage is already targeted on known crossing points.

Speed restriction zones:

2.2.31 While it is advocated that restrictions on travel speed should accompany warning signage above, some authors have suggested that speed restrictions alone may be effective in reducing the frequency and severity of deer-vehicle accidents. It is somewhat difficult to assess formally what may be the effect of signage requiring reduction in vehicle speeds *per se*, in that this is normally carried out in association with other measures such as, as here, specific warning signage alerting drivers to the possibility of animals in the carriageway. However, there are two published studies which investigate the relationship between wildlife casualties, posted speedlimits and actual speeds, carried out in Yellowstone National Park (Gunther, Biel and Robinson, 1998) and Jasper National Park, Canada (Bertwistle, 1999).

2.2.32 Within Yellowstone Park there are approximately 268 miles of metalled roadway, in sections of different posted maximum speed (15 mph, 25, 35, 40, 45 and 55mph). The number of carcasses of wapiti, mule deer and other wildlife species collected from the roadside in these different sections between July and October 1997 were recorded, and the number of accidents from stretches of road of different maximum speed compared with the relative length of roads at that posted speed within the park as a whole. A radar gun was used to determine actual vehicle speeds in the different posted segments at different times of day.

2.2.33 About 40% of the recorded roadkill was wapiti and 30% mule deer. Distribution of those accidents was non-random and approximately 85% of the vehicle animal crashes occurred in road sections with posted speeds of 45 or 55 mph. After the relative lengths of such roads within the entire park network is accounted for, it was clear that more accidents occurred within road segments with a posted maximum speed of 55 mph than occurred in segments at 45mph or less. Thus 41% of accidents occurred in roadway segments with a posted speed limit of 55mph but these segments represented only some 8% of the roadway within Yellowstone National Park.

2.2.34 Average operating speeds measured along the roadway segments with a 55 mph posted speed limit were about 9 to 16 mph higher than that posted. The operating speed measured along those segments with a 35 and 45 mph posted speed limit, however, were within one to three mph of that posted. The researchers concluded that the design of the roadway (versus the posted speed) had the largest impact on speed (Gunther, Biel and Robinson, 1998).

2.2.35 The impact of reduced speed limits was also studied along the Yellowhead Highway in Jasper National Park – Alberta, Canada (Bertwistle, 1999). In 1991 the posted speed limits were reduced along three sections of this highway from 55 mph (90 kph) to about 42 mph (70 kph). The number of vehicle collisions with bighorn sheep and/or elk was then compared for specific time periods before and after the posted speed limit change. The number of bighorn sheep- vehicle and wapiti-vehicle collisions that occurred along the three roadway segments was collected for 8 years before and after (1983 to 1998) the posted speed limit reduction. In addition, the elk population adjacent to the Yellowhead Highway was estimated from aerial and roadside counts.

2.2.36 From 1983 to 1998 the population of the elk increased by approximately 132 per cent. The bighorn sheep population in the park area was believed to be relatively stable or experiencing a

small increase. The Jasper National Park researchers found that the number of bighorn sheep-vehicle collisions increased only slightly (82 before the change and 83 after) in the two speed reduced (42 mph) segments considered; this small increase occurred despite the fact that vehicular flow increased by 50 percent during the study time period.

The number of bighorn sheep-vehicle collisions decreased by 33 per cent (30 before the change to 20 after) along the 55 mph posted speed limit segments adjacent to marked “Slow Down for Wildlife” zones (Bertwistle, 1999)

2.2.37 Data restrictions allowed the evaluation of wapiti-vehicle collisions within only one of the speed reduction segments selected. Effectiveness of the speed reduction was measured by a statistical comparison of the number of vehicle collisions that did occur to the number of expected collisions. The number of expected elk-vehicle collisions was calculated from crash data collected within a 13-mile 55-mph segment of roadway surrounding the reduced speed study segment. This 13-mile roadway segment, along with the 5.6-mile speed reduction segment of interest, experienced about 79 percent (315 of 398) of the deer-vehicle collisions observed between 1983 and 1998. Wapiti-vehicle collisions per mile increased by 84 per cent within the 13-mile roadway segment posted at 55 mph (90 kph), but by only 24 per cent along the 5.6-mile speed reduction segment posted at 42 mph.

2.2.38 The authors observed that the general trend in elk-vehicle collisions also appeared to show an increase in the number of crashes along the entire segment before the posted speed limit reduction, but a general decrease in 42 mph segment after the change. They concluded that a decrease in the posted speed limit had a significantly negative effect on the number of vehicle collisions that occurred (Bertwistle, 1999).

2.3) Provision of safer crossing points: wildlife passages.

2.3.1 Any signage will be more effective if targeted on clearly-identified, known, crossing locations; the ideal use of fencing or other barriers is also targeted not so much at preventing crossing but to channel animals to safer crossing locations. These crossing points may be safer

- i) because their topographical position, or vegetation, offers better visibility and thus increased advance warning for both deer and drivers. (Deer may have greater opportunity to become aware on oncoming traffic, while drivers have greater advance warning of deer approaching or crossing the carriageway)
- ii) because the crossing points are restricted in number (with fences preventing crossing in between) and can thus signage or ‘traffic calming’ measures can be better targeted, or
- iii) because dedicated structures are provided, enabling deer to pass over or under the carriageway, with no need to pass over the road surface itself

2.3.2 In ‘new-build’ schemes, dedicated overpasses or underpasses may be created specifically to permit animals to cross the carriageway. These may also, in appropriate circumstances, be fitted retrospectively to existing roads. Alternatively, in either ‘new-build’ schemes or improvement schemes for existing roadways, road bridges planned for other purposes, machinery tunnels or bridges over rivers, canals, or railways may be modified to increase their probability of being used as wildlife passages. There is now a considerable literature examining the use of such structures by different wildlife species and the precise specifications required in each case. Much of this is conveniently summarised in the COST 341 report (Wildlife and Traffic: A European Handbook for identifying conflicts and designing solutions) to which reference has already been made. A précis of the main points is offered below.

Density and location of passages

[2.3.3] “Deciding on the required number and the type of measures will depend on the target species and the distribution of the habitat types in the area. In some cases one or several wide passages will be appropriate whereas other problems will be better tackled by a larger number of smaller-scale measures. An additional argument for constructing several passages is to “spread the risk” in case a passage is not used as predicted. In general, the density of passages should be higher in natural areas, e.g. forests, wetlands, and in areas with traditional agriculture, than in densely built-up or intensively-used agricultural areas. However, in areas where many artificial barriers due to transportation infrastructure or built-up areas exist, a higher density may be required. In such cases, they should be integrated with all remaining open corridors.”

[2.3.4] “So far, the question of the required density of passages in relation to environmental goals has been poorly studied and more research is needed. However, for red deer and roe deer Hlavac and Andel (2002) recommend

<i>Categories of areas</i>			
<i>Cat</i>	<i>Area</i>	<i>Red Deer</i>	<i>Roe Deer</i>
<i>I</i>	<i>Exceptional importance</i>	<i>3 – 5km</i>	<i>1,5 – 2,5km</i>
<i>II</i>	<i>Increased importance</i>	<i>5 – 8km</i>	<i>2 – 4km</i>
<i>III</i>	<i>Medium importance</i>	<i>8 – 15km</i>	<i>3 – 5km</i>
<i>IV</i>	<i>Low importance</i>	<i>Not necessary</i>	<i>5km</i>

Source:

Hlaváč, V. & Anděl, P.(2002): On the permeability of roads for wildlife: a handbook. Agency for Nature Conservation and Landscape Protection of the Czech Republic and EVERNIA s.r.o. Liberec.

[2.3.5] “The location of the passages has to be decided on the basis of sound knowledge regarding animal movements and the distribution of important habitats. Where clearly defined animal trails exist, passages should be placed as close to them as possible. Often topography and landscape structure can help to identify likely migration routes such as valley bottoms, streams, hedgerows, and continuous woodland. Ensuring that passages are built at all known 'conflict points' must be the first step in defining the location of passages. If this results in a density of passages considered too low to create the necessary level of permeability of the infrastructure in the particular region, additional locations have to be found.”

[2.3.6] “Fauna passages should be well connected to the surroundings, either by way of habitat corridors leading towards passages for small animals or by way of guiding lines for larger ones. As a result of the channelling effect of guiding structures, the probability of an animal encountering a fauna passage can be improved considerably.

Barriers that prevent or hinder animals from reaching passages need to be removed or mitigated. The acceptance of fauna passages by animals depends on good guiding to the entrance. Linear (man-made) structures providing shelter improve the guidance. Some examples of guiding structures include: hedgerow, row of trees, cattle fence, ditch, heaps of stones, stone wall, small stream (after Oord 1995).”

Overpasses versus underpasses?

[2.3.7] “There are few general rules as to when one is more suitable than the other. The choice is partly determined by the topography. In hilly terrain it is often easy to construct both over- and underpasses, whereas in flat landscapes underpasses may be easier to construct, if the ground water level is not too high. Overpasses have the advantage that it is easier to provide different microhabitats, because vegetation grows more easily than in underpasses. A wider range of species may therefore use them. However, viaducts, which generally retain quite high and wide original pathways beneath the road, can provide equally good results to landscape bridges (e.g. ECONAT 1992).”

2.3.8 The COST report notes that “Monitoring has shown that, where overpasses and (admittedly rather small) underpasses were available close to each other, moose and deer (*Odocoileus*) preferred to use the overpasses” (conclusion derived from Clevenger *et al.* 2002).

Note however that in the survey of Olbrich (1984) use of overpasses by red, roe and fallow deer was *lower* than that of underpasses (Staines *et al.* 2001, paragraph 4.6.45). Small data sets hampered detailed analysis of the factors affecting use, but overall breadth seemed the critical consideration. Recent work by Heynen *et al.* (2002) (using infra-red sensors to detect use of overpasses by different species of wildlife) showed that, for roe deer, usage increased with bridge width until reaching an asymptote at widths somewhat in excess of 50 metres.

The European Handbook then pays specific attention to the required design features of overpasses, underpasses and dual-use structures.

Dedicated Overpasses

[2.3.9] “*General recommendations*

- In general, larger mammals require wider overpasses than small vertebrates. On the other hand, small vertebrates and invertebrates rely more on the provision of special habitat features, which can only be provided on relatively wide passages.
- A standard width of 40-50 m (between the fences) is recommended. The authors of the COST Handbook suggest that this width can be lowered to a minimum of 20 m if the aim is only to provide a movement corridor for not very sensitive species, or where the topography has a channelling effect leading the animals directly onto the crossing.”

[In support of such suggestion, the COST authors note that “in some cases, funnel-shaped overpasses with a minimum width below 20 m but a width at the entrance of c. 40 m have been

shown to be used e.g. by roe deer”. No references are cited for this observation and we should contrast such observations with those of Heynen *et al.* (2002; above, paragraph 2.3.8) which suggest that while narrower overpasses *may* indeed be utilised by some individuals, overall use of passages increases with bridge width - and even for roe deer (the smallest species) does not reach an asymptote until widths of 50 metres or more]

- “A width below 20 m is not recommended. Experience with mammals has shown that individuals used to the local situation may use narrower overpasses, but frequency of use is generally lower than on wider overpasses. It is also not known how inexperienced animals, e.g. young individuals during dispersal, react to narrower overpasses.
- The required width increases with the length of the overpass, i.e. an overpass across a six-lane motorway has to be wider than one over a two-rail high-speed railway line. A minimum width to length ratio should be greater than 0.8.
- If large mammals are concerned, an overpass should be located along paths traditionally used by them. The paths can be determined with the help of fieldwork (e.g. mapping tracks using line taxation (snow, marble dust) or by asking locals using specific questionnaires.
- Avoid areas where human activity causes disturbance.
- Avoid sections with large level differences or embankments. Choose the location in relation to other crossing possibilities for animals.”

2.3.10 In fairness we should note here that many of the recommendations offered by the COST 341 Handbook relate to minimising habitat fragmentation rather than road safety, and are aimed at maintaining “good ecological connectivity“ rather than merely reduction of deer/wildlife RTAs. Thus it may be argued that the presence of some smaller passage may be enough to reduce the frequency of deer-vehicle collisions, even if acting as a barrier to free movement of the wider population as a whole, and we suggest that the specifications for road safety might be somewhat less stringent than required for structures where isolation of populations is of primary importance. In contrast to the specifications presented by COST341 therefore we would note that CTGREF (1978) suggest minimum width of overpasses for ungulates of 6m while Ballon (1985) suggests minimum widths of 8m and a minimum ratio of width to length of 1 to 10 . Service d’Etudes des Routes et Autoroutes (SETRA, 1993) recommends minimal width of overpasses for red deer as 12m , for roe deer as 7m .

[2.3.11] *“Vegetation*

The aim is to guide the target species and preferably a variety of other animals as well over the overpass.

- The vegetation on the overpass should reflect the habitats situated on either side of the infrastructure.
- Use only plant species native to the local area.
- Sowing grass/herb vegetation is not always necessary. Spontaneous growth may lead to good results.
- Hedge-like structures across the bridge provide a guiding line, cover and protection from light and noise from the road, especially for larger mammal species.“

2.3.12 **Design:** There are many construction types available. Wildlife passages for both larger and smaller species of mammals are now widely used in mainland Europe. The COST Handbook offers examples of overpasses at Terlet, north of Arnhem in the Netherlands; the above-mentioned Harm van der Veen overpass at Kootwijk (Netherlands); a wildlife bridge “Hirschweg” (on the new B31 in southern Germany); an overpass east of Vienna (Austria): one of five in a row across the main A4; an overpass at Schindellegi (Switzerland) and a wildlife bridge in the Czech Republic – all of different constructions. The choice of a type depends mainly on topography, subsoil stability, costs, aesthetics and local design traditions.

[2.3.13] However: certain general principles are established.

- “Leading the road/railway through a natural or artificial cutting allows an overpass to be built on the level of the adjacent land.
- Where the level of the overpass is higher than that of the adjacent land, the necessary ramps should not be too steep and well embedded in the adjacent landscape. So far there is little experience on the maximum gradient tolerated by different animals. In hilly areas higher gradients may be acceptable than in flat regions. Some existing overpasses that are used by animals have gradients of 16% in a flat landscape (Hungary) to 25% or more in mountainous regions.
- Shape and material used have to ensure that the necessary features (soil cover, vegetation) and the connection to the adjacent land can be achieved.
- On existing roads the use of prefabricated arches reduces the time of construction at the site.”

[2.3.14] *“Attention points:*

- Overpasses are meant to be in use for a long time. Engineering works are developed for a period of 50 to over 100 years. Safeguarding a corridor allowing access to the overpass has to follow a similar time frame. It has to be a part of spatial planning at local and regional scale and of proper maintenance.
- In particular no development (housing, local roads, industrial areas) should be permitted that reduces the functioning of the overpass.
- Hunting should be forbidden on the overpass and in its surroundings. There is little experience on the size of the no-hunting zone required, but a distance of 0.5 to 2 km may be appropriate depending on the local situation and species.
- Specific overpasses, i.e. the exclusive use by wildlife, are recommended as a general rule and especially if important daily and seasonal movements of larger mammals have to be restored.
- Where access by walkers is foreseen, it is better to provide a narrow path, which concentrates the movements of humans than to leave no path, which may lead to people using the whole width of the passage.
- Roads, forestry tracks etc. running parallel to the infrastructure may cut off free access to the overpass. They should be routed so as not to block access for animals.”

Dedicated Underpasses

[2.3.15] “In hilly areas the crossing of a valley by means of a viaduct is a good technical solution to lead a road or a railway from one side of the valley to the other. Valley bottoms are preferred corridors for many animals, in particular when they are combined with a watercourse. In these cases measures for wildlife only have to ensure that previously existing movement corridors of animals are preserved or enhanced.”

[2.3.16] “When a road or railway line crosses a valley or another area lying slightly lower than the target level of the infrastructure, a low viaduct is an ecologically preferable alternative to an embankment. From an economical point of view, embankments are often preferred, especially where excess material from other parts of a development can be used. However, [the ecological values attached to the] preservation of the particularly valuable ecosystems and corridors found in floodplains and river valleys usually outweighs the short-term economic benefit.”

In other cases specific wildlife underpasses may be constructed.

2.3.17 Considerations of the distribution, location and the number of passages required are generally similar to those described above for overpasses (paragraph 2.3.4). However, dimensions of tunnels or under-passes are particularly critical to their use by larger wildlife species.

2.3.18 Perhaps the most extensive study made of the use of such passages is that of Olbrich (1984) who assessed the use made by red, roe and fallow deer of no fewer than 824 over- and under-passes of different construction on 823 km of federal highway in the former West Germany (reviewed by Staines *et al.*, 2001, paragraphs 4.6. 38 – 4.6.41, and included here in Appendix 1)

2.3.19 Roe deer used 44.7% of all underpasses available; fallow used 26.3% of underpasses within their distribution; red deer used only 8.1% of available structures. In analysis of the characteristics of those passages which were used, against those which 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).

2.3.20 More specifically, Olbrich found, for all species, that the ratio of aperture size to overall length is critical to use (as $\{\text{height} \times \text{breadth}\}/\text{length}$). He suggested that red 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.

2.3.21 Olbrich noted 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.

2.3.22 Olbrich's conclusions were based on such a comprehensive survey that they are widely accepted - and have been frequently quoted without further verification by later authors (e.g. Madsen, 1993); his conclusions about the importance of 'relative narrowness' (as $\{\text{height} \times \text{breadth}\}/\text{length}$) in particular are commonly taken as definitive. However we should note that this same consideration is emphasised also by the authors of COST 341, who suggest:

[2.3.23] "The length [inevitably] corresponds to the width of the road or railway track crossed and is therefore fixed. The width and to a lesser degree the height can however be chosen according to

the requirements of the animals. For the description of the dimensions of an underpass an index of relative openness is often calculated. It is defined as width x height / length. An underpass with a width of 12 m, a height of 4 m and a length of 25 m would therefore have a relative openness index of 1.9.”

[2.3.24] “However, the relative openness should never be used as the sole measurement. An underpass with a width of 57 m, a height of 2 m and a length of 60 m would have the same openness index, but a height of 2 m would be clearly insufficient for large species like red deer or moose. Therefore minimum values have to be set for height and width. The relative openness can then be used as a value that reflects the fact that the longer an underpass is, the wider and higher it has to be.”

2.3.25 General recommendations presented in COST 341 suggest for dimensions:

- Minimum width: 15 m
- Minimum height: 3-4 m
- Openness index (width x height / length): >1.5 (as also ECONAT 1992)

and for location:

- An underpass should be located along paths traditionally used by the target species.
- Where underpasses cannot be constructed right on the animal paths, linking the passages to the paths is essential by erecting guiding fences or similar structures (again see Olbrich, 1984)
- At sites where local topography channels movements towards the passage.
- Avoid areas where human activity causes disturbances.

2.3.26 The European Handbook also notes:

- The ground inside an underpass should be natural, i.e. covered with soil
- Due to lack of light and water, vegetation will normally not grow inside an underpass, but should be encouraged where possible.
- The vegetation at the entrance of an underpass should be attractive to the target animals.
- Bushes around the entrance may be planted both to guide animals towards the underpass and to provide screening against disturbance by light and noise coming from the road or railway

2.3.27 Such recommendations echo advice by Olbrich (1984). As previous authors, Olbrich noted 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.

2.3.28 Reed *et al.* (1975), Ward (1982) and Olbrich (1984) all note an initial reluctance by deer to use new underpasses until these have 'mellowed' or matured. Olbrich (1984) suggests that the length of time taken by deer to overcome initial wariness of the structures is approximately 6 months for roe deer and between two and three years for other species. The authors of COST 341 also note this requirement for a period of familiarisation of new structures until they become more established: "Experience indicates that mammals may have to learn to use underpasses situated in their home ranges. Inexperienced animals, in particular young animals in the dispersal phase or animals that use the underpasses only infrequently during seasonal migration, may be more sensitive to dimensions."

Dual purpose bridges – multi-functional overpasses and tunnels

2.3.29 The European Handbook (COST 341) notes:

In any major road scheme, "the number of bridges which must be provided for local roads, forestry or agricultural tracks is very high. They are usually covered with concrete, asphalt or tarmac and are hardly used by animals. With a simple addition of an earth-covered strip an improvement can be achieved. Such earth-covered or vegetated strips are used by invertebrates, small vertebrates, carnivores and occasionally by ungulates.

They are no alternative for specific wildlife overpasses, but an additional measure to improve the general permeability of infrastructure barriers. If all local bridges outside built-up areas were equipped with an earth-covered strip, this would contribute to a mitigation of the barrier effect at little additional costs. Wider overpasses can be combined with local roads or forestry tracks as long as traffic intensity is low."

[2.3.30] "Cut-and-cover tunnels which are constructed, e.g. for aesthetic reasons to preserve the original aspect of the landscape, can also often be adapted to function as wildlife passages at the same time."

"Requirements:

[2.3.31] *Road bridges with vegetated strip*

- A width of a vegetated strip of 1 m as a minimum is recommended.

- Soil cover does not have to be deep (0.3 m).
- In most cases spontaneous vegetation is sufficient, and no seeding is required.
- The road surface on little-used bridges should not be tarmaced.
- The modification of bridges with strips is recommended only when traffic intensity on the bridge is low.”

[2.3.32] *Joint-use overpasses*

- Roads, cycle paths, forestry tracks etc. should only be combined with a wildlife overpass if traffic intensity is low.
- The width of any road etc. on an overpass has to be added to the width required for the fauna passage, i.e. joint-use passages in general have to be wider than specific overpasses.
- Any paths or forestry tracks should be placed laterally, i.e. at one of the outer edges of the overpass to ensure a maximum width of vegetated and undisturbed area .
- Access for the animals onto the overpass must not be hindered by roads at the entrance to the overpass .
- On landscape bridges, a lateral road that is likely to be the source of disturbance may be separated from the vegetated part of the overpass by an earth wall. Where a lateral road is used very little, a separation is not recommended.”

[2.3.33] *Joint-use underpasses*

COST 341 advocates that joint use of underpasses by humans (traffic, pedestrians) is appropriate only for underpasses >10 m wide.

We ourselves consider that, once again, their recommendations may be over-stringent, and would note that they do recognise that smaller underpasses may be used – indeed offering recommendations for improvement of existing, smaller structures, where the overall length is not greater than 25-30 m. While they note that the disturbance potential in underpasses is higher, which means that demanding species like ungulates may be hindered by traffic noise and light, nonetheless the sheer number of underpasses for human use or designed for passage of rivers, drainage culverts or as machinery tunnels is enormous, and adapting them could have beneficial effects on a large scale.

[2.3.34] COST 341 recommends:

- “Underpasses with streams are particularly suitable for improvement.
- An adaptation of footpath, or vehicular underpasses for wildlife is only to be considered if traffic density is low. However underpasses with little-used local roads or forestry tracks can be improved for wildlife.
- In this case non-tarmaced roads/footpaths in the underpass are recommended.
- An earth-covered strip at the side of the road can improve the movement of animals.
- Shelter inside the passage (tree stumps, heaps of branches) is recommended for wide underpasses. These elements can be placed in the strip(s) on the side of any road or pathway.
- The entrance to an underpass may have to be redesigned as well.”

Modification of existing structures

2.3.35 Most of the above is related primarily to provision of dedicated crossing structures (overpasses or underpasses), or the adaptation of other required structures to dual-purpose use (at the planning stage), in new-build schemes. As we do, above (Staines *et al*, 2001), the authors of COST 341 suggest that the provision *de novo* of tunnels or overpasses on existing roads may prove prohibitively expensive.

2.3.36 In practice such supposition may not be well-founded. By using prefabricated materials (such as precast concrete tunnels or other such structures), new overpasses have been constructed on existing roadways in a number of instances both in Europe and in North America (as e.g. the overpass Harm van der Veen at Kootwijk in the Netherlands, erected in 1998 over two separate parts of the motorway A1), with costs of ‘retrofitting’ apparently no greater than provision of overpasses incorporated into ‘new-build’ schemes (*personal communication*: Hans Bekker, Chairman of COST 341). Such structures have recently been fitted retrospectively to existing major roads in Europe (in the Netherlands, as above; in Switzerland and in the Czech Republic) and in North America.

2.3.37 This is a relatively recently development, however, and in general, provision of corridors across existing road structures is more usually accomplished through modification of existing bridges and tunnels/culverts.

2.3.38 COST 341 notes:

“ The principles for dealing with existing infrastructure can be summarised as follows:

- Construction of new engineering works (passages etc.) above or below existing roads may give the best results but is often more expensive.
- Adaptation of existing engineering works that have been designed for other purposes (e.g. water, forestry) is often not an optimal solution, but in general less expensive. A large number of adapted passages etc. may, in some cases, give better results for the same price as constructing one new specific passage.“

[2.3.39] “Road bridges or culverts are mostly not used by animals to cross a road or railway line, because they do not fulfil the requirements for more demanding species. However, if the demands of animals are taken into account, such traditional structures can often be adapted to serve as fauna passages. Such passages, combining the flows of fauna and traffic or fauna and water, are called joint-use passages.

Existing guidelines for the design of roads, over- and underpasses, culverts etc. mainly focus on drainage, traffic safety and related issues. In many cases, provisions for wildlife at such structures can be implemented without compromising safety aspects.”

2.3.40 The COST authors however conclude that while “such modified structures can help to increase the permeability of infrastructure at little additional cost. At important sites modified over- or underpasses are usually no alternative to dedicated fauna passages.”

Highway Cross-walks

2.3.41 Feasibility and cost of provision of under or overpasses for existing roads will depend largely on the local topography, such that, while retro-fitting of a land bridge may perhaps be most readily achievable in undulating landscapes especially where a road already runs through a cutting, provision of (and landscaping) a similar overpass or tunnel/underpass would be likely to present much greater engineering challenges and higher costs where the existing road runs through a level landscape. Where modification of bridges or accommodation tunnels, or provision of underpasses or overpasses *de Nov*, may not be considered appropriate for existing roadways, an alternative approach is to attempt to provide safer crossing across the carriageway surface itself in the provision of dedicated crossing zones or *cross-walks* (Lehnert and Bissonette, 1997).

2.3.42 In essence this concept builds upon ideas developed earlier, of using fences or other barriers to guide animals to safer, and well-advertised, crossing places. While these crossing places

may indeed be provided as underpasses or overpasses, this may not be essential and deer-crossing places may be established over the surface of the roadway itself *if such crossing zones are adequately signed* (paragraphs 2.2.4 – 2.2.30) in order to reduce traffic speeds and increase driver awareness at these specific locations. Road surfaces may be modified at such designated crossing points to encourage use although this is not necessary, and crossing may controlled (and made more predictable) simply by fencing the roadside in areas where visibility is poor, and permitting crossing of the carriageway only in a limited number of stretches of roadway where deer and driver visibility is improved, with these unfenced areas adequately advertised and signpost (paragraph 2.3.1).

2.3.43 Lehnert and Bissonette (1997) have tested the efficacy of such cross-walks on 2-lane and divided 4-lane highways in north-eastern Utah. The cross-walk system forced mule deer (*Odocoileus hemionus*) to cross at specific, well-marked points where motorists could anticipate them along the highways. Based on expected kill levels, mortality of mule deer declined by 42.3% and 36.8% along the 4-lane and 2-lane highways respectively. Lack of motorist response to warning signs, the tendency for foraging deer to wander from crosswalk boundaries into the carriageway itself, and the ineffectiveness of highway one-way gates in permitting their subsequent escape were considered to contribute most to remaining treatment area mortalities.

2.3.44 Design of such crossings is clearly critical. Where highway fencing is used to prevent crossing elsewhere and channel animals towards the cross-walk structure, there is clearly an associated risk that once through the opening in the fenceline, animals do not cross directly to the opposite side but may stray along the carriageway itself, subsequently becoming trapped within the carriageway and actually increasing the risk of collision.

2.3.45 Barrier fencing provided to prevent crossings in other sections of roadway will effectively funnel deer (and any other free-ranging livestock, such as sheep or hill cattle) into the carriageway at dedicated crossing points. If no provision is made to stop them from straying longitudinally up the carriageway (back into fully-fenced sections of road), rather than crossing directly to the other side, there is a real risk that the funnelling effect of the fencing - feeding animals into the roadway and preventing subsequent escape - may actually increase accident risk. Lehnert and Bissonette (1997) advocate the use of one-way gates to reduce this risk that animals may become trapped within the carriageway, but note (as above) that ineffectiveness of these gates remains a significant problem.

2.3.46 We would propose that consideration might be given to the installation of cattle-grids across the road on either side of such ‘crossing areas’, preventing animals entering the carriageway at the designated point, from straying further up the carriageway itself and effectively limiting them to crossing straight over to the opening in the highway fence on the opposite verge. Such cattle grids would in effect ‘link’ the fencelines of opposite sides of the carriageway, providing a close-circuit barrier on each side of the cross-walk. Installation of cattle grids on either side of such crossing zones would have the further incidental advantage of further reducing traffic speed in these targeted crossing areas.

Mitigation measures: Overall analyses of effectiveness

2.4.1 It would obviously be extremely helpful to our deliberations if we were able to compare and contrast the absolute efficacy of the various different measures outlined above, or in some way rank them in order of overall effectiveness. In practice this is simply not practicable:

2.4.2 First we would note that that for many of the options offered for reduction of accident risk, it is extremely difficult to derive any objective measure of effectiveness – where this must be based on analyses of changes in accident frequency before and after installation.

This is often the only data available on which to base an assessment of the effectiveness of some measure taken to try and reduce accident frequency, but we should caution:

- a) there is in any case a great deal of variation in accident frequency between years – simple, stochastic year-on-year variation in accident rates, such that any changes recorded before and after installation of some mitigation measure cannot necessarily be attributed unequivocally to the deterrent measure installed.
- b) Accident frequencies on given (monitored) stretches of road are in any case likely to be relatively few in number (perhaps between 0 and 5 or 0 - 10 at the most in most analyses, unless trials monitor sections of road over many miles or consider numerous directly comparable replicates). This very restricted range of candidate values also contributes to further difficulty in determining any statistically valid difference between periods before and after the installation of any attempt at mitigation of accident frequency, simply because such differences will be proportionally extremely low (see also : Lehnert and Bissonette, 1997; Danielson and Hubbard, 1998).

2.4.3 Secondly, even if it were possible to offer some formal and objective appraisal of their effectiveness in reducing the frequency of deer-related accidents, it is equally clear that the different measures which may be employed do not necessarily have an *absolute* effectiveness as such, but that, at least for many of them, they may have different utility and effectiveness in different contexts.

2.4.4 For example: as already noted, deer reflectors, if effective at all, will only be effective in reducing accidents at night and will only be effective on roads of low or medium traffic flow, subject to periods of quietness (where animals may then cross safely). If erected on roads of continuous and uninterrupted traffic flow, they are likely to have reduced value since animals wishing to cross the carriageway must still ultimately do so in front of oncoming traffic. Any analysis of the comparative effectiveness of different measures is thus necessarily context-related.

TARGETING MITIGATION: IDENTIFYING FEATURES ASSOCIATED WITH HIGH ACCIDENT RISK

3.1 With limited financial resources available, it is clearly important to target any measures which attempt to reduce the risk or overall frequency of deer-vehicle collisions where they are most likely to be cost-effective. Thus mitigation efforts should be targeted at areas which are already known to have high accident rates, or which have landscape characteristics which suggest that they may prove problem areas in the future.

3.2 But the effectiveness of any mitigation measure itself varies with respect to road type, road character, location and traffic volume and speed. Thus, warning signs are unlikely to be effective at bends in roads where they are not visible to drivers until the last minute; light reflectors too are likely to be more effective (if effective at all) on comparatively long straight stretches of road than when shielded from the light of oncoming vehicles by bends in the road line etc. etc. These issues therefore should also be taken into consideration when selecting sites where attempts at mitigation are likely to be effective (as well as in influencing the precise method of mitigation to be employed).

3.3 Deer-related traffic accidents are not distributed randomly in space and time, and there are a number of environmental factors which affect the frequency of such accidents. These factors include road-type (major/minor road) and traffic volume, habitat characteristics of the roadside, time of day and season. These different factors interact to affect accident risk.

3.4 While the majority of recorded deer incidents occur on secondary roads, simply due to their greater overall length within the national road network, actual accident *frequency* (per unit length of carriageway) is in fact consistently higher on primary trunk roads or major thoroughways where speed of traffic and total traffic volumes are higher. Based on an assessment of recorded accidents involving roe deer in France (Desire and Recorbet, 1984), major roads accounted for a disproportionately higher number of collisions: 5.3% of all roe deer killed were killed on motorways, despite the fact that these amounted to only 0.8% of the total road network; only 5.8% of recorded accidents were on minor roads which, by contrast, comprised 49% of recorded road length.

3.5 Hartwig (1993) offers similar figures from Germany, recording that motorways accounted for 21.2% of all wildlife related road traffic accidents, even though they made up only 7% of the length of major roads in the area of study. Motorways and primary trunk routes together accounted for 37.5% of all recorded accidents in some 24% of total road length. Similar results have been noted in studies of road casualties for other wildlife species: for otters, Philcox *et al.* (1999) found trunk and A-roads accounted for 57% of fatalities in Britain even though they made up only 13% of the road network.

3.6 Bellis and Graves (1971) found that accident rates for white-tailed deer in Pennsylvania tended to be highest in sections of roadway that lay in deep cuttings, with reduced visibility and escape speeds. Hartwig (1993) reported that 35% of all deer collisions in his study were concentrated in areas of reduced visibility (on bends or steep inclines). These findings indicate that accidents are more easily avoided where deer can be seen approaching the carriageway well in advance. However, long, straight, open stretches of road may also encourage faster speeds and increase the severity of any accidents that do occur (SGS Environment, 1998).

3.7 Roadside habitat also has a very clear effect on accident frequency/risk. As noted by Staines *et al.*, (2001), a consistent finding from analyses of RTAs involving deer from both Europe and America is that the majority of accidents occur within or near wooded areas, particularly where the woodland comes right down to the road edge (e.g. Ueckermann, 1964; Bashore *et al.*, 1985; Romin and Bissonette, 1996; Putman, 1997).

3.8 There are emerging a number of other studies of habitat or landscape features associated with areas of higher than average accident risk which may help predict future hotspots and thus target mitigation effort. Indeed it would appear that this is one of the fastest-growing areas of the literature at present. And in this proliferation of published studies, it is significant that there is a striking consistency in all such analyses in the features emerging as characteristic of areas of high accident risk. The main studies and their conclusions are summarised in the following paragraphs.

3.9 The original analyses of Bashore *et al.* (1985) considered a number of environmental and ‘traffic-flow’ characteristics associated with high recorded frequency of deer-vehicle collisions on stretches of 2-lane highway in Pennsylvania between July 1979 and October 1980. Roadway segments were considered “high” DVC locations if they had a minimum of four DVCs reported in the year preceding the study and at least two reported DVCs per year in 5 of the 10 years preceding the study. Data from 51 “high” DVC and 51 control sites were used to develop the Bashore *et al.* model, and it included variables that measured the number of homes, commercial, and other buildings (e.g., hunting camps, churches, and barns) buildings within the buffer area of the roadway segment, roadway sight distance and in- line visibility, posted speed limit, distance to woodlands, and the proportion of fence length and non-wooded herb areas in the buffer zone.

3.10 The predicted probability of accidents was found to decrease with an increasing number of homes, commercial, and other buildings within the buffer area, and longer sight distance along the roadway. The model also indicated a decrease in the “high” DVC probability with increases in the proportion of fencing, the distance to woodlands, the ability to see a roadside object (i.e., in- line visibility), non-wooded herbs in the buffer zone, and posted speed limit.

3.11 In a subsequent GIS analysis which attempted to identify landscape features associated with areas of higher or lower accident risk, Finder *et al.*(1999) measured topographical and habitat-related features within a 0.8km radius of road segments in Illinois with higher than average accident rates (greater than or equal to 15 accidents from 1989-93) and a series of randomly selected control sites. Once again, high accident rates for white-tailed deer (*Odocoileus virginianus*) were associated with woodland cover; a logistic regression model developed using only landscape features derived from satellite imaging accurately distinguished between high and low kill sites and related accident frequency to landscape diversity and (shorter) distance from adjacent woodland cover.

Presence of adjacent gullies or other travel corridors (such as river channels) close to, or crossing the roadway, also resulted in an increase in the likelihood of deer-vehicle collisions as did the overall proportional area of public amenity land.

3.11 Subsequently Hubbard *et al.* (2002) published an analysis of land use patterns and highway characteristics associated with RTA hotspots in Iowa along very similar lines to that of Finder *et al.* (1999) for Illinois. Deer-vehicle incidents were highly clumped (with >25% of all accidents occurring on only 3.4% of all the entire road network within the State). Multiple regression analysis identified four landscape features associated with these clusters (as the proportional area of woodland and grass adjacent to the roadway, proportion of crop land, and the heterogeneity in size

and disposition of land cover patches), with accident frequency increasing with size of nearby grass and woodland patches, but decreasing as the variation in patch size and the proportional area of cropped fields increased.

3.12 The number of lanes of traffic (identifying in effect more major trunk routes or motorways) and the number of bridges across the carriageway appeared to be two of the major predictors of high DVC locations in the analysis of Hubbard *et al.* (2002). While this last may seem unexpected, we should note that such a finding is consistent with the earlier analyses of Finder *et al.* (1999), above, who also noted an increase in accident risk with an increasing number of gullies or other travel corridors crossing the roadway.)

3.13 Nielsen *et al.* (2003) have undertaken what is essentially a similar analysis of deer-vehicle collisions in and around Minneapolis (Minnesota). They selected 80 sites where more than 2 RTAs involving deer had been recorded over the period 1993-2000 and contrasted landscape characteristics of these 'hotspots' with those of a further 80 control sites selected at random, but where no accident or only one accident had been recorded over the same period. Nielsen *et al.* (2003) concluded that the most important feature associated with RTAs was the amount of amenity public land with woodland cover or shrub (again, cf. Finder *et al.*, 1999).

3.14 Finally, a recent study in Kansas to be published by Meyer and Ahmed (summarised on the deercrash.com website) once again records an association of high probability of DVCs with the area of wooded land adjacent to the roadway. DVCs per year per mile were also positively correlated to the number of roadways lanes, traffic volume, posted speed, number of bridges and/or visible culverts and traditional right-of-way fencing Meyer and Ahmed *in press*). Factors negatively correlated with DVCs per year per mile included clear width (i.e., distance to an obstruction at least 3 feet wide and 2.5 feet high), roadside slope, and roadside topography in the transverse direction. In addition, those roadway segments with a grassed central reservation median had higher DVC rates than those with median barriers, and those with central barriers had higher rates than two-lane undivided roadways.

3.15 A somewhat different approach to analysis of characteristics of accident sites was undertaken by Iverson and Iverson (1999) who did not assess the characteristics of accident hotspots, but simply compared the frequency of wildlife accidents in different counties within Ohio, in relation to landscape characteristics at the whole county level. Despite the somewhat 'coarser-grained' nature of this approach they found that the distribution of deer-related RTAs in 9 counties in Ohio was

positively correlated to the amount of urban land in a county as well as to the overall length of major highways and, like Hubbard *et al* found accident frequency negatively correlated to the area of land actively cultivated.

3.16 There are also two published accounts of analyses of factors associated with accident hotspots in a specifically European context. In an analysis of 115 kills of roe deer at Kalo in Denmark, between 1956 and 1985, Madsen *et al.* (2002) found no correlations between the pattern of roadkills and mean daily traffic flows but noted that collision sites were strongly clumped, and sites associated with higher roadkill tended to have denser vegetation (hedgerows, bushes etc) present on one or both sides of the road.

3.17 Malo and Diaz (2003) present the results of analyses of the characteristics associated with the location of 2067 deer-vehicle locations occurring between 1988 and 2001 in the province of Soria (central Spain). Once more they identified the features characteristically associated with locations of high accident frequency as vegetation, fencing or other structures forcing the animals to cross at particular points and natural linear features perpendicular to the roadway associated with natural travel corridors.

3.18 In all these studies certain consistent features emerge as characteristic of sites likely to suffer a high frequency of deer-related RTAs, namely

- number of lanes of traffic (width of road)
- presence or absence of central barrier
- the close association of accident sites with woodland or forest cover close to the carriageway
- landscape diversity (variability and patch size)
- the presence of obvious travel corridors across the roadway, such as rivers, dry gullies or other linear structures leading down at an angle to, or perpendicular to the roadway

3.19 In concluding this section, we should perhaps draw attention to the ongoing programme of work under the Deer Collisions Project (www.deercollisions.co.uk) which is currently attempting to build up a comprehensive dossier of deer-related RTAs throughout Scotland and the rest of mainland Britain (England, Wales). In addition to its role in trying to establish the overall frequency of deer-related incidents within the country – and their overall geographical distribution, this project also seeks to identify the suite of factors and landscape characteristics which seem to be associated

with areas of high accident risk, in a UK/Scottish context, specifically in order to use these to try and predict likely trouble spots in the future where mitigation efforts might best be targeted.

COSTS AND COST-EFFECTIVENESS

4.1 Analyses of cost-effectiveness of different mitigation measures is hampered by problems identified above in establishing actual effectiveness simply from changes in the number of deer-vehicle collisions recorded before and after installation (because of stochastic variations which will be experienced anyway in the relatively low number of accidents occurring), and because effectiveness of any given measure varies considerably with context (paragraphs 2.4.2 and 2.4.3 above).

4.2 However, we may to an extent determine relative costs. We offer first a selection of costs cited from the published literature and then consider current costings provided for us by suppliers or highways engineering contractors.

Fencing:

4.3.1 The cost of roadside deer fencing for motorways and major trunk roads will vary according to the local deer species, which will dictate the maximum mesh size (to exclude the smallest species) and height (based on largest species). The total costs of a recent extensive deer fencing scheme (for 9 km) for the new Birmingham Toll road (for fencing to final height of 1.9 m, and to specifications to protect against both red deer and muntjac deer, as well as badgers and otters), were estimated) at £400k ready installed (= £44 per linear metre; Langbein, 2003).

If the additional specifications required for excluding badgers and otters are removed from this figure, such cost approximates to £30 per metre more than the standard cost of roadside boundary/stock fencing without protection against deer.

4.3.2 A further recent estimate submitted to the Highways Agency managing agents for development of the new A120 at Braintree in Essex (1999), estimated costs of deer fencing at c.£30 per metre. In this case, provision was for strained wire on steel posts. In that proposal, costs of standard fencing were presented as c.£11-12 per linear metre for standard (motorway) post and rail.

4.3.3 On non trunk roads the fencing is technically at the discretion of the adjacent land owner. Thus the farmer is responsible for ensuring that farm animals do not stray onto the road but if the fence is to prevent wild animals from going on the road, it must be erected and maintained by the Highway Authority.

Reflectors:

4.4.1 Costs of installation of roadside reflectors are quoted by Danielson and Hubbard (1998) at between \$8k - \$10k per mile and after a 3-year study in Wyoming, Reeve and Anderson (1993) reported that only 61% of the original reflectors installed remained in good condition.

4.4.2 Within the UK, costs (per unit) of red reflectors from the manufacturer (Swareflex) are currently c.£6.50 delivered (though reduced to below £5 when buying more than 200 or so), but to these must also be added costs of erection and maintenance. [SwareflexUK distributors: LIGHT-DOME ROAD PRODUCTS 4 Fielder Drive, Newgate Lane Industrial Estate, Fareham, Hants. PO14 1JE Tel. 01329 284780 Fax 01329 829485]

4.4.3 Pepper (1999) notes a total cost (purchase and installation) in his trials at £13.20 per reflector (at 1999 prices) with an additional annual maintenance cost of 75p per reflector.

Estimates offered by the North West Partnership for installation of reflectors on sections of the A87 between Bunloinne and Shiel Bridge, at about the same date (1999/2000), suggested a much higher cost of £ 34k for purchase and installation of 680 Swareflex reflectors (or £50 per reflector installed). Swareflex reflectors have recently been installed on a section of road at Baliscate, Tobermory on the Isle of Mull at a unit cost of £6.50 per reflector, but this does not include costs of wooden stakes, or installation by the local Council Roads department, nor any element for future maintenance.

Signage:

Standard highway wildlife warning signs/speed restriction signs

4.5.1 We have (to date) been able to find relatively little information on costs of standard highways signage; such signs are normally erected by local Council Roads Departments, or roads maintenance contractors (such as BEAR Scotland, or AMEY Highways). Costs of the erection and installation of 20 standard wildlife warning signs on the same section of the A87 between Bunloinne and Shiel Bridge, were estimated by North West Partnership at £3000 (or £150per unit)

Speed detection and display signs

4.5.2 Speed-sensitive matrix signs are also now available which detect the speed of oncoming vehicles and can be programmed to flash up on an LED a warning to SLOW DOWN, or to display

actual vehicle speed. Fixed installations are in place for example at the North Kessock bridge in Inverness and on the A82 trunk road in Fort Augustus. Costs of signage and installation are reported to us from the roads contractors responsible for maintenance of this part of the trunk road network (BEAR Scotland) as respectively £15,000 (North Kessock) and £20,000 (Fort Augustus). Such signs are manufactured by e.g. SPEEDCHECK and RADARLUX Ltd

4.5.3 Portable versions of such speed sensitive signs are also now available for temporary deployment in sensitive areas. Radarlux manufactures two such signs: the SpeedVisor at 58cm H 82 L 16cm D (current price £3500 per unit) and the mini Speed Visor (43cm H 52cm L 16cm D; £2,500 per unit)

Dynamic Animal Warning Signs

4.5.4 The various forms of responsive wildlife warning signs activated by infra-red or radar detection of animal presence are reviewed in paragraphs 2.2.10 - 2.2.30 and by Huijser and McGowen (2003). These systems are still experimental (and thus inevitably more expensive than any 'production' system). Twenty seven systems were reviewed by Huijser and McGowen (2003) in Europe and North America, some of which have not proved effective and have been removed. For those systems which remain operational and appear to be effective, costs of the equipment and installation ranged between \$11,500 and \$45,000 (equipment) and from \$20,000 to \$35,000 (installation) per 100 metres of effective coverage.

Dedicated overpasses/underpasses

4.6.1 Dedicated overpasses or 'green landscape bridges' to specifications similar to those outlined in the COST341 Handbook have been installed in numerous locations especially in Switzerland, Germany and The Netherlands (paragraph 2.3.12 above) with many more currently planned. We do not at this time have costs for individual schemes which, however, vary widely between schemes depending on local topography and road type; we understand however that costs generally fall in the region of 2 -10 Million Euro (*personal communication*, Hans Bekker; Chair Cost341).

4.6.2 While no green bridges of comparable dimensions, dedicated primarily to wildlife, have yet been built in the UK, a number of green bridges are currently proposed by the consultant engineers as one option for red/roe/fallow+muntjac deer mitigation for the proposed A11 improvements (upgrade to dual carriageway standard) near Thetford in Suffolk. Three different bridge options are under consideration, ranging from a 20m wide based on minimum size thought suitable for red deer, to a wider option (52 m wide x 65 long) which more closely meets the openness criteria suggested

in Cost 341 for habitat connectivity. Cost of the 20m wide bridge is estimated by the consultant engineers at c £2.7m (of which the ‘overcost’ due to upgrading specifications for wildlife use, is estimated at £2m). Cost of the wider option is estimated at £6.5m, although we must remember that these are full commercial cost estimates submitted by contractors.

4.6.3 Lehnert and Bissonette (1997) estimated the cost of constructing **underpasses** on existing 4-lane and 2-lane roadways in US as \$173k and \$92k respectively.

4.6.4 Within the UK, estimated costs for a dual use underpass of width c12 m x 32m length (for deer together with some pedestrian access) proposed for the A11 upgrade at Thetford (4.6.2) is estimated at £3m (of which the ‘over-cost’ attributed to deer/wildlife use is estimated at £ 2.5m)

4.6.5 A more modest underpass being built for the new A120 at Braintree is designed to cater for the passage of farm tractors and trailers, a footpath and also (fallow and muntjac) deer. The size is primarily determined by the farmers use and the structure is designed at 4.5m wide by 4.5m high (internal size). Note that this structure is below the minimum specifications suggested by e.g COST 341 (above paragraphs 2.3.35) but is estimated at a cost of £195k.

4.6.6 All these costs are estimates for provision of underpasses or overpasses in new-build. Costs of retrospective fitting of such structures on existing roads are harder to assess. However, we would reiterate that these are not necessarily any greater (or even as great); new overpasses have been constructed on existing roadways in a number of instances both in Europe and in North America with costs of ‘retrofitting’ apparently no greater than provision of overpasses incorporated into ‘new-build’ schemes (*personal communication*: Hans Bekker, Chairman of COST 341).

Highway Cross-walks:

4.6.7 Lehnert and Bissonette (1997) estimated the cost of construction of crosswalks (not including costs of fencing and one-way gates) at \$28k and \$15k per structure on 4-lane and 2-lane highways respectively. UK costs may be assessed on the basis of required highway fencing, road grids if installed (paragraph 2.3.46) and appropriate signage.

The actual cost-effectiveness of mitigation:

5.1 Costs of effective mitigation appear high, and in assessing the justification of that expenditure the economic costs incurred through high numbers of deer collisions must be taken into consideration. The ‘value of prevention of Road Accidents’ to the economy are outlined for

purposes of assessing road safety schemes in regular updates of ‘Highways Economics Note 1’ published by the Department for Transport. At 2001 values, the expenditure which was considered to be justified in the prevention of an accident leading to

- human fatality was £1.185 million per fatality averted by appropriate mitigation
 - serious injury £133,170 per incident averted
 - slight injury £10,270 per incident averted
- with a weighted value summarising all **non-fatal** injury accidents at £37,412 per accident or over all accidents, resulting in injury (at whatever level) or fatality, at £ 53,902

5.2 While costs above are given separately according to severity per casualty, each human injury accident tends on average to have more than one casualty; allowing for this and based on the general average of RTAs by severity, an alternative simpler measure ‘per accident’ is therefore also provided in the Highways Note 1 ..suggesting that ‘on average’ prevention of every ‘human injury accident’ present a saving to the economy of around £50k (£53.9k at 2001 costs)

5.3 Placed in context, this means that on any given stretch of road, mitigation measures which might be expected to reduce fatal accidents by one per year over a 10-year period would justify capital expenditure of £11.85 million, based on these ‘accident prevention values’ alone (and without taking into account the wider costs of damage-only deer collisions, carcass clearance costs, venison losses and the ‘ecological’ benefits of providing (in case of over/under passes) mitigation measures which are used also by other wildlife . Mitigation measures calculated to reduce human injury accidents by, say, 3 per year over the same period would justify expenditure of £1.12 million on these same ‘accident prevention values’ and so on.

Such calculations perhaps help put the ‘raw’ costs of mitigation into better perspective.

5.4 Taking the region covered by the Highland Council as single example: on average around 10 human injury RTAs have been recorded annually in each of the last past few years example (in addition to many hundreds of damage-only deer traffic incidents; in most countries in Europe, human injury accidents make up from around 1% to 4 % of all deer collisions). Clearly no mitigation scheme would ever be likely to prevent all such incidents at a regional basis; however, an entirely realistic target for the region might be to aim to reduce that toll by say 20% . Such a reduction (by merely 2 human injury incidents per year alone) would justify ‘annual’ expenditure on deer mitigation measures within Highland region of £100kyear on year. In addition it would generate cost savings through prevention of numerous more ‘damage-only’ accidents. Such calculations help put into perspective the cost of mitigation measures such as, for example, a

dedicated wildlife underpass which, although it may have an initial cost of £1-2m, should be effective for in excess of 25 – 40 years.

5.5 Our arguments here are clearly somewhat ‘theoretical’ and include ‘accident injury values’ only. But such analyses may be undertaken somewhat more objectively and extended to consider other elements of profit and loss. Perhaps one of the most productive of recent developments in this context has been the application of economic analysis to assess more formally the overall balance of cost and benefit of different approaches to mitigation – or indeed to offer formal analysis of the marginal benefit of attempting any form of mitigation at all in given circumstances.

5.6 In such analysis, the benefits of maintaining deer-populations at a given size may be explored in relation to their value as a resource for hunting, recreation and resident enjoyment, while assessing costs in terms of their impact on forestry, agriculture and conservation value, nuisance value in gardens and public parks – and estimated costs of deer-vehicle collisions. Having established values and costs attached to the different elements of this parameter set, the costs and estimated benefits (in reduction of the number of deer-vehicle collisions) may be explored, over a range of target deer densities.

5.7 In effect, if real values can be attached to each costs and commodity value, then the economic value of reducing the frequency of deer-vehicle collisions by a given degree, may be assessed. This ‘saving’ in turn suggests a marginal value for what costs might be justified in achieving that same reduction in accidents: giving a true economic estimate of what costs could be incurred in mitigation at net balance of cost and benefit.

5.8 Such analyses have thus far been undertaken only in the US. Two of the most useful contributions are those of Schwabe *et al.* (2002) and Rondeau and Conrad (2003). Both papers amply repay careful scrutiny in the original if only because of the care and precision taken in attaching real values to costs and benefits, rather than simply offering guesstimates.

5.9 Schwabe *et al.* (2002) first establish a general relationship relating the frequency of collisions between vehicles and white-tailed deer (in Ohio) to deer population density, traffic density, roadside habitat and deer management strategies. Using data on the number of vehicle collisions in each of 88 counties in Ohio and, for each of these counties, in each year from 1977-1998,

they establish a general model relating the frequency of deer-related accidents to

- the number of registered vehicles per number of road miles by county and year
- acres of farmland by county and year

- status of county as metropolitan or rural
- a number of variables describing deer density and more specifically, numbers of bucks and does culled in the previous hunting season.

Relationships established are significant and biologically robust.

5.10 Deer population dynamics are modelled using empirical data on observed adult sex ratio, reproductive rate (number of surviving fawns per female) and estimated carrying capacity of the local environment (county). Mortalities are assessed in terms of known hunting removals per county per year and percentage of censused population lost in RTAs.

5.11 Estimates of deer values are hard to establish – with deer having both consumptive value (value to a hunter) and non-consumptive value (the value gained simply from ‘viewing deer in the local environment’). Both elements are hard to assess and there are many possible approaches to attaching values. At the simplest level, consumptive values may be assessed simply in terms of the actual licence fees obtained by each county per unit deer hunted; an alternative estimate is commonly generated by questionnaire survey assessing ‘willingness to pay’. Despite variations in logic and approach, there is some agreement in estimating that the value of each (white-tailed) deer might be between \$180 – \$200 dollars (Loomis *et al.*, 1988, Schwabe *et al.*, 2001).

5.12 Rondeau and Conrad (2003) also consider costs of deer damage to vegetation and property (although, for their analysis in an essentially urban context in Western New York, damage values are assessed only in terms of damage to gardens and urban land [\$34.50 per residential property per annum] and do not include components for agricultural or forest damage in more rural areas).

Such costs are not estimated by Schwabe *et al.* (2001) who fully acknowledge that “even though there is a much larger array of benefits and costs associated with maintaining a particular deer population level” their approach focuses exclusively on (i) consumptive use benefits of deer to hunters (ignoring non-consumptive benefits such as the value simply of ‘viewing deer in the local environment’) and (ii) only those costs related to RTAs .

5.13 Costs associated with DVCs are estimated in the analysis of Schwabe *et al.*(2001) according to (1991) estimates of the cost equivalent of human fatality or injury, provided by the (Ohio) National Highways Traffic Safety Administration (in a similar scale of values to that offered in the UK by the Highways Agency and DETR; paragraph 5.1 above). In the analysis of Schwabe *et al.*(2001), loss of human life is valued at approximately \$2.4 million, \$170,000 is estimated as the cost of a serious injury, \$33,000 for a mild injury and \$17,000 for an injury claimed but not validated. Non-injury DVCs were costed at a conservative \$150 each (being the minimum amount

of damages required before any deer-vehicle collision must be reported by law); this value is significantly lower than the average cost of vehicle damage which might result from the analysis of insurance claims- but includes all incidents where damage is >\$150, not simply that small proportion of more serious incidents which might result in an actual insurance claim.

Based on the actual frequency of accidents of different severity between 1990-1998, Schwabe *et al.* (2001) calculate an actual average cost of any reported collision of \$2,376.

[5.14] [We should note at this point that the analysis of Schwabe *et al.*(2001) in Ohio relate to vehicle collisions involving only white-tailed deer (*Odocoileus virginianus*) rather than other larger species such as red deer or wapiti (*Cervus canadensis*). Equivalent costs in Scotland, where a significant proportion of accidents relate to collisions with red deer (*Cervus elaphus*), might be substantially higher. The average insurance claim for vehicle repairs following an accident in Scotland was assessed in 2000 at c£1,400 (Staines *et al.* 2001) while in collisions with red deer the proportion of incidents resulting in human fatality or serious injury is almost certainly increased

5.15 The final model of Schwabe *et al*(2001) combines all data on factors affecting the frequency of DVCs in any county, with a biological population model tracking deer population change in relation to different levels of DVC or hunter harvest. Clearly, as deer population densities decline, so will the associated rate of DVCs - but so in addition will the number of deer which may be harvested each season and thus the financial and social benefits associated with that recreational activity.

Costs of each DVC are assessed (above) at an average of \$2,376, while (consumptive) value of each deer is set at \$182.

5.16 Schwabe *et al.* (2001) next consider the economic implications of three approaches to mitigation: deployment of physical mitigation measures alone (fencing, roadside reflectors), local reductions of deer density (by increasing the length of the 14-day hunting season in the State by one day) – and a combination of physical deterrents and reduced deer density.

5.17 They make the assumptions that highway fencing will reduce the incidence of deer-vehicle collisions by 85% (eg. Feldhamer *et al.* 1986; Romin and Bissonette, 1996). Accepting that there is continued controversy about the effectiveness of roadside reflectors, they nonetheless assume that these, too, may have the potential to reduce DVCs by around 85%. They further assume that extension of the 14-day hunting season by a single day will maintain per diem harvest rates and thus increase overall harvest by 7.7%.

5.18 Using two example counties (Athens County: an area of higher deer density overall and a higher estimated carrying capacity; Williams County, with lower estimated carrying capacity and lower overall deer density), Schwabe *et al.* (2001) calculate that deployment of mitigation measures alone (at 85% efficacy) would produce a net financial benefit (in balance of costs of deer-vehicle collisions and benefits accrued from hunting) of between \$948,200 and \$976,200 in the higher density Athens County, and between \$351,800 and \$372,100 in Williams County.

5.19 Considered in another way this implies that capital costs of mitigation delivering an accrued annual cost of around \$950,000 per annum during its effective lifetime would be justified in Athens County, and in Williams County expenditure on mitigation up to an equivalent annual cost of \$350,000. The alternative option of increasing harvest rates by 7.7% would deliver a net saving in economic cost (balance of hunter benefit against costs of DVCs) of between \$50,000 and \$98,100 per annum in Athens County, and between \$15,400 and \$44,300 in Williams County

5.20 Schwabe *et al.* (2001) stress that results of their simulations suggest that a combination of the two strategies (mitigation measures plus local reductions of deer density) would appear to be a more attractive option than either independently. Net economic benefit of the combined strategy is calculated at between \$974,200 and \$986,700 per annum in Athens County; \$364,300 – \$371,300 in Williams County.

5.21 The analyses of Rondeau and Conrad (2003) have a somewhat different emphasis and approach (in exploring the relative effectiveness of continuous, versus pulsed culling programmes in controlling populations of deer in urban areas), but once again the effectiveness of control measures is assessed in terms of economic costs (culling costs) and benefits (reduction of costs of environmental damage, and reduction in frequency (and associated costs) of deer-vehicle collisions).

5.22 Rondeau and Conrad (2003) offer a somewhat more complex model than that of Schwabe *et al.* (2001) and include additional cost elements as above resulting from environmental damage (to parks and gardens within this predominantly urban area), considerations of the value of venison meat sold to defray costs of management and the negative impact of lethal control methods on public opinion (included as a costed disutility to the public in general) – as well as costs associated with DVCs and costs of control. In this analysis culling is not seen as a net gain (benefit to hunters, income through sale of hunting licences) since in the urban context of Rochester, all culling operations are undertaken by authorised marksmen shooting deer from high seats and within public parks, and all costs are borne by the City Authorities.

5.23 Within the rather different context of a predominantly urban setting and with management solely through retention of marksmen paid to reduce deer populations to an acceptable threshold level, Rondeau and Conrad (2003) conclude that the most effective regime of control is of pulsed population reductions (which in practice never bring the deer population down to the optimum target level because it is uneconomic to do so, with costs rising proportionately as deer population levels fall).

5.24 Nonetheless, significant costs are justified in relation to the reduction achieved in the frequency of DVCs alone : with a justified expenditure of \$500 per annum per head of deer in the initial starting population, based on estimated damage to property alone (vehicle damage alone, with no additional element allowed for costs of human injury; Rondeau and Conrad, 2003).

5.25 These examples are explored in some detail here because of the importance of both studies in adopting a truly holistic approach to exploration of the costs and benefits of any form of management intervention – through physical mitigation or through reduction in deer densities. It is clear, also, that both models are (for once) based on sensible biological and economic premises with realistic assessments of the values of model inputs.

Details of the models are perhaps not immediately transferable given the very real logistical and cultural differences between UK and US in terms of both the management of highways (and who would be responsible for mitigation) and in the management of deer populations and hunting. However, certain conclusions transcend such difference in detail:

- Schwabe *et al.* (2001) stress the potential value of mitigation measures in isolation, or in conjunction with local reductions in deer density.
- Actual net benefits (even allowing for a reduction in deer harvest value at lowered population densities) are clearly enormous – and might be seen to offer extraordinarily powerful justification to acceptance of quite significant expenditure in mitigation.
- Such justification, in part, relates to the very significant value attached to loss of even a single human life, or serious injury. But broadly similar economic costs are associated with human life or injury in a UK context also (5.1) , so that the justification of expenditure apparent from the analysis of Schwabe *et al.*(2001) is not artificially inflated by application of a different framework of values.

MITIGATION MEASURES IN SCOTLAND
A REVIEW OF CURRENT DEPLOYMENT AND PERCEIVED EFFECTIVENESS

6.1 Through existing contacts we approached BEAR Scotland (responsible for the entire trunk road network in NE and NW Scotland) and AMEY Highways (similarly responsible for the trunk road networks in the SE and SW) for information on the current deployment of warning signage, deer fencing, reflectors or other measures on the trunk roads under their jurisdiction.

Similar requests for information, in respect on non-trunk roads, were directed to the Roads and Traffic Departments of all Unitary Councils. In each case we also asked for the organisation's perception of the effectiveness or otherwise of deterrent measures in use.

In an alternative approach we also wrote to Secretaries and Chairmen of all Scottish branches of the British Deer Society, asking if Society members might be prepared to undertake for us an independent inventory of measures installed within their own Branch region.

Trunk Roads

6.2 While a full inventory of mitigation measures has been promised by the managing agents (BEAR Scotland and AMEY Highways), this has not yet been received. Thus far only a partial inventory has been offered, of warning signage only, and only for South East Scotland, noting warning signs on sections of the A7 and A720 (Bonaly Road Bridge, to Dreghorn Junction (W)).

Non-trunk roads

6.3.1 Roads Departments or Road Traffic sections of Councils were contacted by email or letter on 16/09/03 and non-responders contacted again on 15/10/03.

6.3.2 No replies were received from Angus, Argyll and Bute, Highland Region (Badenoch and Strathspey, Lochaber, Caithness, Inverness, Nairn, Ross and Cromarty, Sutherland, Skye and Lochalsh, Sutherland), Morayshire, Scottish Borders Region, or West Dumbartonshire

6.3.3 No mitigation measures are known on non-trunk roads within Clackmannanshire, East Ayrshire, East Renfrewshire, Falkirk, Inverclyde, North Lanarkshire, Renfrewshire, South Ayrshire, South Lanarkshire or West Lothian. This is of course not to suggest that roadside deer-fencing is not present along some roads, adjacent to Forestry plantations or woodland schemes, or erected by major sporting Estates, but such fencing will have been erected and maintained by Forest Enterprise or private landowners; none has been erected or is directly maintained by the Councils.

6.3.4 Some *roadside fencing* has however been erected by

- Aberdeenshire Council (locations not specified)
- Fife Council: A985 (trunk road) through Delvilla Forest
- Midlothian (locations not specified)

6.3.5 *Reflectors* have been erected by a number of Councils, but efficacy is unproven.

- Thus reflectors have recently been installed on a stretch of new carriageway at Baliscate, Tobermory (Argyll and Bute)
- on the A701 between Dumfries and Moffatt (Dumfries and Galloway)

6.3.6 *Warning signs* remain the most commonly used deterrent - although almost all respondents doubted their real effectiveness and all suspected that drivers quickly habituated to them or simply ignored them.

- Warning signs have been erected “at vulnerable locations” by Aberdeenshire Council [no further details provided]
- by North Ayrshire Council in a few locations [no records maintained]
- on Balmuildy Road, Bishopbriggs at the Wilderness Plantation, and on the B757 between Kirkintilloch and Milton of Campsie (East Dumbartonshire)
- “near locations where deer are seen crossing regularly and where vehicle speeds are high” (East Lothian) as B6269 Coulston Wood, southbound; A198 Whitekirk Bridge, southbound; A198 Binning Wood, northbound; B6368 Bolton x-roads Northbound and southbound; B6355 Bolton X-roads, eastbound; B6355 Inglisfield, westbound; A6093 Nisbet X-roads, eastbound; C108 Luffness Mains northbound and southbound.
- at around 15 sites within Fife; erection of signs is usually reactive in response to reported accidents by the public, community or police. Reports are checked against their Council’s own accident database for further justification that action is required.
- Midlothian (no further details)
- Stirling (no further details provided)

CONCLUSIONS

7.1 Current provision of deterrence or mitigation measures designed to reduce the frequency of deer-vehicle accidents appears to be inadequate. We know, from the Deer Collisions project and other sources, that there are probably somewhere between 6,000 and 10,000 deer-related road accidents in Scotland each year (a more accurate estimate will hopefully emerge in due course from the current DeerCollisions project (in progress). There also remain serious blackspots on many roads, including those noted by Staines *et al.* 2001 from the limited data available to them – as for example

Road	Region	No. of logged incidents 1998-2003	Nos. of logged incidents 2002-3
A9		108	68
(of which A9)	Highland	48	17
(of which A9)	Tayside/Grampian	70	51
A93	Aberdeenshire - Angus	59	57
A90	Aberdeenshire - Angus	47	47
A82	Highland	46	17
A96	Morayshire-Aberdeenshire	36	36
M90	Fife / Perth&Kinross	32	27
A835	Highland	30	7
A87	Highland	29	12
A92	Aberdeenshire - Angus	27	24
A701	Dumfries&Galloway	24	8
A832	Highland	20	5
A933	Aberdeenshire	20	18

7.2 In our opinion, for motorway and high-speed trunk roads, highway fencing remains the most effective measure against accidents (with appropriate one-way gates to permit escape of animals trapped on the carriageway). Such fencing should whenever possible be combined with the provision of dedicated crossing places (overpasses, underpasses, or well-signed crossing areas/cross-walks) to avoid producing absolute barriers to animal movement and fragmentation of populations. On more minor roads, or where deer fencing is not a feasible option for landscape or other reasons, mitigation measures should in the first instance be targeted at reduction of driver speeds in areas of known high deer collision risk.

Such speed limitation, if enforced, would appear to be one of the simplest and most effective ways of reducing accident frequency and severity. At its simplest this may merely utilise fixed signage in association with conventional wildlife warning signs; ideally however such signage may be combined with dynamic speed speed restriction and deer crossing signage (paragraph 2.2.6 *et seq.*). More specific provisions are recommended for existing roads and for new developments, below.

7.3 It is, however, crucial that each mitigation scheme should be tailored to the particular local situation and deer movement patterns; given, in addition, a degree of context-related variability in the effectiveness and cost-effectiveness of various measures (paragraph 2.4.3), actual mitigation installed in each case will necessarily be dependent on local conditions.

Existing Roads

7.4.1 Where existing roads are of **relatively low traffic volume**, fencing, leading to dedicated cross-walks, would seem the best available option at sites of known, or predicted future, blackspots. Fencing should be designed to lead animals away from those crossing points where accidents have occurred in the past (or are predicted in the future) to safer crossing areas, ***which should be well-signposted***.

7.4.2 If fixed signs are appropriate, then these should be new signs specially designed to advertise such crosswalks (rather than simply using the current standard triangular deer warning sign - to which drivers are already habituated). Alternatively (preferably) consideration should be given to installation of one of the new dynamic signs (paragraphs 2.2.10-2.2.30) coupled with sensors, which are thus activated only when deer are actually approaching the crossing zone.

Experience elsewhere in Europe and North America suggest that these measures are more effective ***if accompanied by a mandatory speed restriction***.

7.4.3 As above (paragraph 2.3.46) we would suggest that consideration be given to installing cattle grids across the carriageway, to link with the highway fencing on either side of such crossing points. Such road grids would serve to demarcate the crossing points and by linking with fencing either side would ensure the maintenance of a continuous barrier- preventing any animals using the crossing, from straying onto the carriageway itself and becoming trapped within fenced sections away from the crossing point. Such grids would also act as further advertisement to drivers of the existence and location of the crossing zone as well as an additional direct ‘traffic calming’ measure.

7.4.4 Leading animals across the carriageway, albeit at a safer location, still carries risks that a number of accidents will still occur, focused at that new location. Therefore, if there are local

opportunities to use deer fencing to lead animals instead to existing accommodation underpasses (used as footpaths, agric/forestry access, or viaduct) or over bridges this may provide a better solution; provided such structures are of adequate specification or can be adapted to enhance their usage by deer.

7.4.5 On other sections of road where deer occur at relatively high density in the general area, and roadside fencing is not appropriate, presence of deer and risk of accidents should be advertised by adequate signage. Speed restrictions should again be imposed and supported by simple matrix signs which are activated by excess vehicle speed and remind drivers to slow down (paragraph 4.5.2,4.5.3). Given their universal availability and relatively low cost, the utility of proprietary deer-reflectors (e.g. Swareflex) should be further explored, in investigation of differences in effectiveness resulting from differences in placement and direction of reflected light (paragraph 2.1.15).

7.4.6 On existing roads of **high traffic volume**, the only effective measure in reduction of deer-vehicle collisions would appear to be longer lengths of fencing, providing a complete barrier on either side of the carriageway, between existing crossing points already available (as bridges or underpasses). Fencing should be to the specifications noted in paragraphs 2.1.5-2.1.7 and there should be adequate provision of one-way gates or deer-leaps to permit escape of animals which do stray onto the carriageway. Crosswalks, promoting crossing of animals over the carriageway itself would not appear to be an option in situations such as this where traffic volumes and speeds are continuously heavy.

7.4.7 Consideration should be given to modification of any existing structures which cross the carriageway (as rail or road bridges, machinery tunnels or riparian bridges) to convert these to dual purpose crossings with some value as wildlife passages. If not also used by road traffic they may be possibly be enhanced through appropriate landscaping, planting scrub/trees near entrances and resurfacing with natural rather than artificial surfaces (eg. 2.3.29). It would appear that retrospective fitting of functional overpasses need not be as costly as previously assumed (paragraph 2.3.36), and consideration might be given to this at particular problem points.

Such solution, through provision of ‘green land-bridges’, has additional benefits (over and above any effectiveness in reducing deer-vehicle collisions), as also offering the more general advantage of an overall increase in landscape quality and habitat connectivity (COST341).

New Road Schemes

7.5.1 Mitigation measures appropriate for consideration in planning of new road schemes expected to be of **low traffic volume** will be similar to those already outlined for existing roads – simply because of the high costs involved in more complex provision, which will not be justifiable on relatively minor roads.

7.5.2 For roads of **high traffic volume**, barrier fencing on both sides of the carriageway should be coupled with adequate provision of underpasses or green bridges at regular intervals (see recommendations of Hlavac and Andel (2002); paragraph 2.3.4 above).

7.5.3 In addition, all additional bridges or tunnels required for other purposes (footpaths, minor roads crossing the carriageway, machinery tunnels, culverts etc.) – other than those specifically dedicated as wildlife passages, above - should be designed and built as dual-purpose structures (paragraphs 2.3.29 -2.3.34).

7.6 Concern in preventing collisions between road traffic and deer (or other wildlife) has in the past often tended to be treated foremost as an animal welfare issue. Although it does indeed present a major welfare issue, funding allocations to address this in Scotland (and UK as a whole) have tended to be fairly minimal (not least if compared to other European countries and US). It is becoming increasingly clear, however, that in addition to the animal welfare implications and the effects of roadkill on population size of a number of animal species (toads, badgers, otters, barn owls to mention a very few), at least in relation to accidents involving larger mammal species such as deer, there are also very real major costs to the economy, which we may conservatively put at in excess of £40m per annum (J Langbein, *in prep.*) with perhaps between 20% and 25% of this cost incurred within Scotland.

7.7 Human injury RTAs alone, involving deer, (which present data suggest may be at least 50 and possibly more than 100 a year in Scotland) are estimated to be worth in excess of £5m to the Scottish economy annually (assessed on “human injury values” alone, paragraph 5.1) with at least a further £1m incurred through damage to vehicles. We would suggest therefore that a greater expenditure on mitigation would appear to be justified and that it would be appropriate to allocate a significant annual budget at national (trunk roads) and regional levels (non-trunk) roads, targeted at reducing the annual deer collision toll and associated costs.

On this basis, it may be argued that expenditure of the order of £6m (spread over next 10 years) would be very likely to produce net gains to the Scottish economy - even if the annual Scottish deer collision toll was reduced by only around 10%.

BIBLIOGRAPHY

- Aaris-Sorensen, J. (1995) Road-kills of badgers (*Meles meles*) in Denmark. *Annales Zoologica Fennica* **32**, 31-36.
- Abrahamsson, I. and Pettersson, L. (1997) *Vägkulvertar i Sävveån - funktion med avseende på faunapassage*. Mölnlycke. Terra Limno Gruppen.
- Åhrén, T. and Larsson, P.O. (1999) Train collisions with reindeer (*Renpåkörningar*) – In Swedish. 46 pages. Report from Swedish National Rail Administration, Banverket Norra Regionen, Luleå, Sweden.
- Allen, R.E. and McCullough, D.R. (1976). Deer-car accidents in Southern Michigan. *Journal of Wildlife Management* **40**, 317-25.
- Ament, S. (2000) *New Signs Flash Elk Warning to Motorists*. News Release May 25, 2000; Washington Department of Fish and Wildlife. Olympia, WA,. Accessed at www.wsdot.wa.gov
- Armstrong, J.J. (1992) *An Evaluation of the Effectiveness of Swareflex Deer reflectors*. Research and Development Branch, Ministry of Transportation, Ontario
- Ashley, E.P. and Robinson, J.T. (1996) Road mortality of amphibians, reptiles and other wildlife on the Long Point causeway, Lake Erie, Ontario. *Canadian Field Naturalist* **110**, 403-412.
- Babiloni, G. (1992) Informe provisional del seguimiento de la mortalidad de vertebrados en las carreteras de la provincia de Barcelona. In: *I Jornadas para el Estudio y Prevención de la Mortalidad de Vertebrados en Carreteras*. CODA, Madrid, pp. 127-135.
- Ballon P. (1985) *Bilan technique des aménagements réalisés en France pour réduire les impacts des grandes infrastructures linéaires sur les ongulés gibiers*. Actes du XVII^{ème} Congrès de l'Union Internationale des Biologistes du Gibier, 679-689.
- Bashore, T.L., Tzilkowski, W.M. and Bellis, E.D. (1985). Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management* **49**, 769-774.
- Baudvin (1996) Etude de la mortalité animale liée à l'autoroute ; convention "La Choue"/SAPRR, rapport interne SAPRR
- Bekker, G.J and Canters, K.J (1997) The continuing story of badgers and their tunnels. In: Canters, K.J, Piepers, A.A.G and Hendriks-Heerma, D. (Eds.) *Habitat Fragmentation & Infrastructure. Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of ecological engineering*. Dienst Weg- en Waterbouwkunde, Delft.
- Belant, J.L. (1995) Moose collisions with vehicles and trains in northeastern Minnesota. *Alces* **31**, 45-52.
- Bellis, E.D. and Graves, H.B. (1971). Deer mortality on a Pennsylvania Interstate highway. *Journal of Wildlife Management* **35**, 232-237.
- Bennett, A.F. (1991) Roads, roadsides and wildlife conservation: a review. In: Saunders, D.A. and Hobbs, R.J. (Eds.) *Nature Conservation 2: The role of corridors*. pp. 99-118. Chipping Norton: Surrey Beatty & Sons.

- Bertwistle, J. (1998) The effects of reduced speed zones on reducing Bighorn sheep and elk collisions with vehicles on the Yellowhead Highway in Jasper National Park. *Proceedings of the International Conference on Wildlife Ecology and Transportation*, Missoula, MT, 1999, pp. 727-735.
- Blamey, G. and Blamey, G. (1990). *The Results of a Deer Survey carried out on an area between Hatfield Forest and Dunmow, Essex*. Ove Arup and Partners, London.
- Brown, M. (1998) Deer Alerts May Reduce Accidents, Save Money. February 24, 1998. http://www.ameslab.gov/esha/Lessons_Learned/Green_Alerts/980224a.htm.
- Brudin, C.O. III (2003) Wildlife use of existing culverts and bridges in North Central Pennsylvania. Abstract. Int'l Conference on Ecology and Transportation.
- Carey, M. (2002). Addressing wildlife mortality on highways in Washington. In: *Proceedings of the International Conference on Ecology and Transportation*, 24-28 September 2001, Keystone, CO, USA, pp 605-610..
- Carsignol, J. (1989). Dix années d'observations des collisions véhicules-grand mammifères gibier sur l'autoroute A4 en Alsace-Lorraine et sur le réseau routier du département de la Moselle. *Office National de la Chasse, Bulletin Mensuelle* **135**, 32-37.
- CEMAGREF (1982) *Canaux, voies navigables et grand gibier*. Centre National du Machinisme Agricole, du Génie Rural et des Eaux et Forêts. Division Loisirs et Chasse, Nogent-sur-Vernisson, Note technique n° 49, pp. 48.
- Clarke, G.P., White, P.C.L. and Harris, S. (1998) Effects of roads on badger (*Meles meles*) populations in south-west England. *Biological Conservation*, **86**, 117-124.
- Clevenger A. P. (1998) *Highways and wildlife – An online bibliography*. <http://www.cmiaa.org/biblio.html> [October 2002]
- Clevenger, A.P., Chruszcz, B. and Gunson, K.E. (2001a) Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* **29**, 646-653.
- Clevenger, A.P. Chruszcz, B. and Gunson, K. E. (2001b) Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* **38**, 1340-1349.
- Clevenger, A.P. and Waltho, N. (2003) Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. Abstract. Int'l Conference on Ecology and Transportation
- Conover, M.R., Pitt, W.C., Kessler, K.K., DuBow, T.J. and Sanborn, W.A. (1995). Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* **23**, 407-414.
- Cook, K.E. and Daggett, P.M. (1995) *Highway Roadkill, Safety and Associated Issues*. Task Force on Natural Resources (A1F52) Transportation Research Board, National Research Council, Washington DC.
- CTGREF (1978) *Autoroute et grand gibier*. Note technique 42. Groupement technique forestier. Ministère de l'Agriculture. Paris.

- Curatolo, J.A. and Murphy, S.M. (1986) The effect of pipelines, roads, and traffic on the movements of Caribou (*Rangifer tarandus*). *Canadian Field Naturalist* **100**, 218-224.
- Dalton, L.B. and Stanger, M.C. (ms) Effectiveness of Swareflex reflectors at reducing mule deer-vehicle collisions.
- Danielson, B.J. and Hubbard, M.W. (1998) *A Literature Review for Assessing the Status of Current Methods of Reducing Deer-Vehicle Collisions*. Unpublished report to Iowa Department of Transportation and Iowa Department of Natural Resources.
- Decker, D.J., Loconti Lee, K.M. and Connelly, N.A. (1990) *Incidences and Costs of Deer-related Vehicular Accidents in Tomkins County, New York*. HDRU Series 89-7, revised February 1990. Department of Natural Resources, New York State Agricultural College and Cornell University. 22 pp
- Deer-Vehicle Crash Information Clearing House; DVCIC (2003) on-line manual of mitigation measures and perceived effectiveness @ DeerCrash.com/toolbox
- De Molenaar, J.G. & Henkens, R.J.H.G. (1998) *Effektiviteit van wildspiegels: een literatuurstudie*. Instituut voor Bos- en Natuuronderzoek, Wageningen.
- Desire G., and Recorbet G. (1990). Resultats de l'enquete realisee de 1984 a 1986 sur les collisions entre les vehicules et les grands mammiferes sauvages. *Office National de la Chasse, Bulletin Mensuelle* **143**, 38-47.
- Désiré G., Mouron D. et Sanaa M. (1997) *Recensement des collisions véhicules – grands mammifères sauvages. Evolution entre les inventaires de 1984-1986 et 1993-1994*. Congrès de l'Union Internationale des Biologistes du Gibier.
- Doerr, M.L., McAninch, J.B and Wiggers, E.P.(2001) Comparison of 4 methods to reduce white-tailed deer abundance in an urban community. *Wildlife Society Bulletin*, **29**, 1105-1113.
- Dodd, N.L., Gagnon, J.W. and Schweinsburg, R.E. (2003) Evaluation of measures to minimise wildlife-vehicle collisions and maintain permeability across highways in Arizona. Abstract. Int'l Conference on Ecology and Transportation
- Eckler, J. (2001) *Irondequoit Live Deer Spotlight Survey, Fall 2000*. New York State Department of Environmental Conservation, Albany, NY, January 2001.
- ECONAT (1992): Protection de la faune dans les projets de nouvelle traces ferroviaires, 51 S. Yverdon-les-Bains.

- European Union COST 341 (2003) . *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. European Commission Action 341 on "Habitat Fragmentation due to Transportation Infrastructure".
- Evink, G.L., Garrett, P., Zeigler, D. and Berry, J. (Eds.) 1996. *Highways and movement of wildlife: Improving habitat conditions and wildlife passageways across highway corridors. Proceedings of the Florida Department of Transportation / Federal Highway Administration transportation-related wildlife mortality seminar. Orlando April 30 - May 2, 1996*. Florida Department of Transportation, FHWA-PD-96-041. Tallahassee, Florida pp. 336.
- Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D. and Wegener, J.F. (1995) Effect of road traffic on amphibian density. *Biological Conservation* **73**, 177-182.
- Falk, N.W., Graves, H.B. and Bellis, E.D. (1978) Highway right-of-way fences as deer deterrents. *Journal of Wildlife Management* **42**, 646-650.
- Farrell, J.E., Irby, L.R. & McGowen, P.T.(2002). Strategies for ungulate-vehicle collision mitigation. *Intermountain Journal of Sciences* **8** (1): 1-18.
- Fehlberg, U. (1994). Okologische Barrierewirkung von Strassen auf wild-lebende Säugetiere. *Deutsches Tierärztliches Wochenschrift* **101**, 81-132.
- Feldhamer, G.A., Gates, J.E., Harman, D.M., Loranger, A.J. and Dixon, K.R. (1986) Effects of Interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management* **50**, 497-503.
- Finder, R.A., Roseberry, J.L. and Woolf, A. (1999). Site and landscape conditions at white-tailed deer collision locations in Illinois. *Landscape and Urban Planning* **44**, 77-85.
- Ford, S.G. and Villa, S.L. (1993). *Reflector use and the effect they have on the number of mule deer killed on California highways*. Report FHWA/CA/PD94/01. California Department of Transport, Sacramento.
- Forman, R.T.T. and Alexander, L.E. (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics* **29**, 207-231.
- Forman, R.T.T. and Deblinger, R.D. (2000) The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology* **14**, 36-46.
- Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S. and Alexander, L.E. (1997) Ecological effects of roads: Toward three summary indices and an overview for North America. In: Canters, K., A. Piepers & D. Hendriks-Heersma (Eds.): **Habitat fragmentation and Infrastructure**. *Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of Ecological Engineering*, 17-21 September 1995, Maastricht and The Hague, the Netherlands. Delft. pages 40-54.
- Gilbert, J.R. (1982). *Evaluation of Deer Mirrors for Reducing Deer-Vehicle Collisions*. United States Federal Highway Administration Report FHWA/RD/82/061; Washington, D.C. 16pp..

- Gladfelter, J.R. (1982). *Effect of Wildlife Highway Warning Reflectors on Deer-Vehicle Accidents*. Iowa Highway Research Board Project HR-210, Iowa Department of Transportation, 11 pp.
- Gordon, D.F. (1969) Deer Mirrors: a clearer picture. *Outdoor Facts* **77**, Colorado Division of Game, Fish and Parks.
- Gordon, D.F., Coghill, M.C. and Dunham, F.W. (1969) *Evaluation of Deer Highway Crossing Safety Measures*. Project report 9206020 on Project W-38-R-23; Colorado Department of Transportation, Denver, Colorado.
- Gordon, K.M, Anderson, S.H., Gribble B, and Johnson M. (2001) *Evaluation of the FLASH (Flashing Light Animal Sensing Host) System in Nugget Canyon, Wyoming*. Report No. FHWA-WY-01/03F. University of Wyoming, Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY, July 2001
- Gordon, K.M. & Anderson, S. H. (2002). Motorist response to a deer-sensing warning system in western Wyoming. In: *Proceedings of the International Conference on Ecology and Transportation*, 24-28 September 2001, Keystone, CO, USA, pp 549-558
- Gordon K.M. and Anderson, S.H. (2003) Mule deer responses to an underpass in Nugget Canyon Wyoming. Abstract.Int'l Conference on Ecology and Transportation.
- Gosson, J.T. Deer Whistles Prevent Costly Accidents (1998). *The National Sheriff*. Vol. 40, October/November 1988.
- Groot Bruinderink, G.W.T.A. and Hazebroek, E. (1996). Ungulate Traffic Collisions in Europe. *Conservation Biology* **10**, 1059-67.
- Green, M. (2000) How long does it take to stop? Methodological analysis of driver perception-brake times. *Transportation Human Factors* **2**: 195-216.
- Gundersen, H. and Andreassen, H.P. (1998) The risk of moose *Alces alces* collision: A predictive logistic model for moose-train accidents. *Wildlife Biology* -110.
- Gundersen, H., Andreassen, H.P. and Storaas, T. (1998) Spatial and temporal correlates to Norwegian moose - train collisions. *Alces* **34**, 385-394.
- Gunther, K.A., Biel, M.J. and Robinson H.L. (1998) Factors influencing the frequency of road-killed wildlife in Yellowstone National Park. *Proceedings of the International Conference on Wildlife Ecology and Transportation*, Fort Myers, FL, 1998, pp. 395-405.
- Halcrow Ltd (2002) *Managing Integration, Minimising Fragmentation: Efficacy of Existing Green Bridges - M40 between Junctions 8 and 9* Interim Report March 2002; Highways Agency.
- Hansen, C.S. (1983). Costs of deer-vehicle accidents in Michigan. *Wildlife Society Bulletin* **11**, 161-164.
- Hansen, L. (1982) Road kills in Denmark (in Danish with English abstract). *Dansk Ornitologisk Forenings Tidsskrift* **76**, 97-110.
- Hartwig, D. (1991). Erfassung der Verkehrsunfälle mit Wild im Jahre 1989 in Nordrhein

- westfalen im Bereich der polizeibehorden. *Zeitschrift für Jagdwissenschaft* **37**, 55-62.
- Hartwig, D. (1993). Auswertung der durch Wild Verursachten Verkehrsunfälle nach der Statistik für Nordrhein-Westfalen. *Zeitschrift für Jagdwissenschaft* **39**, 22-33.
- Harwood, R., Hilbourne, S., *et al.* (1992) *Ever Increasing Circles: The impact and effectiveness of the M25 plan*. RSN, The Wildlife Trusts Partnership.
- Hlavac, V. and Andel, P. (2002). *On the Permeability of Roads for Wildlife: A Handbook*. Agency for Nature Conservation and Landscape Protection of the Czech Republic.
- Hodson, N.L. (1966) A survey of road mortality in mammals. *Journal of Zoology*, **148**, 76-79.
- Hoorn, D. van den (2000). Reflector of laserstraal: beter dan "wildspiegel". Aantal aanrijdingen met grofwild op Veluwe nog veel te groot. *Het Edelhert* **35** (1): 9-12.
- Hubbard, M.W., Danielson, B.J. and Schmitz, R.A. (2000) Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management* **64**, 707-713.
- Huijser, M. P. and McGowen, P.T. (2003) Overview of animal detection and animal warning systems in North America and Europe. Proceedings of the International Conference on Ecology and Transportation, 2003, Lake Placid, New York, USA
- Ingebrigtsen, D.K and Ludwig, J.R. (1986) Effectiveness of Swareflex wildlife warning reflectors in reducing deer-vehicle collisions in Minnesota. *Minnesota Wildlife Report* **3**
- Insurance Institute for Highway Safety (1993). Deer, Moose Collisions with Motor Vehicles Peak in Spring and Fall. *Status Report*. Vol. 28, No. 4, April 3, 1993
- Iverson, A.L. and Iverson, L.R. (1999) Spatial and temporal trends of deer harvest and deer-vehicle accidents in Ohio. *Ohio Journal of Science* **99**, 84-94.
- Jared, D. (1992) *Evaluation of Wild Animal Highway Warning Reflectors*. Report 98003, Georgia Department of Transportation, Atlanta, Georgia
- Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P.H. and Wiseth, B. (1991). Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces* **27**, 93-99.
- Jenks, J.A., Smith, W.P. and DePerno, C.S. (2002) Maximum sustained yield harvest Versus trophy management. *Journal of Wildlife Management*, **66**, 528-535.
- Jones, J.M., and Witham, J.H.(1993). Urban Deer "Problem-Solving" in Northeast Illinois: an overview. In the *Proceedings of the 55th Midwest Fish and Wildlife Conference – Urban Deer: A Manageable Resource*, St. Louis, MO, pp. 58-65.

- Keller, V. and Pfister, H.P. (1997) Wildlife passages as a means of mitigating effects of habitat fragmentation by roads and railway lines. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on "Habitat fragmentation, infrastructure and the role of ecological engineering" Maastricht and The Hague 1995*. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.
- Kerzel, H. (1997) [*The Chamer-Modell: A special project to obtain better data on game accidents in selected counties within Bavaria*]. In DJV (German Hunting Federation) Handbook, 1997.
- Kerzel, H. and Kirchberger, U. (1993). Erfolge im Kampf gegen Wildunfälle. *Die Pirsch* **18**, 3-5.
- Kistler, R. (1998). Wissenschaftliche Begleitung der Wildwarnanlagen Calstrom WWA-12-S. Juli 1995 – November 1997. Schlussbericht. Infodienst Wildbiologie & Oekologie, Zürich.
- Kistler, R. 2002. Wildwarnanlagen bewähren sich. CH Wild Info (1): 1-2. Available from the internet. URL: http://www.wild.unizh.ch/winfo/winfo_pdf/winfo021.pdf
- Kloeden, C.N., McLean, A.J., Moore V.M. & Ponte G. (1997). *Traveling speed and the risk of crash involvement. Volume 1 – Findings*. NHMRC Road Accident Research Unit, The University of Adelaide, Australia
- Kofler, H. and Schulz, W. (1987) Wildunfälle und Schutzmassnahmen in Österreich. In: Bernard, J.-M., Lansiait, M., Kempf, C. and Tille, M. (Eds.) *Actes du colloques 'Route et fauna sauvage'*. Strasbourg, 1985. pp. 93-102. Colmar, France. Ministère de l'Équipement, du Longement, de l'Aménagement du Territoire et des Transports.
- Kruger, H-H. and Wolfel, H. (1991). Behavioral response of fallow deer to various types of simulated underpasses. *Proceedings of the XXth Congress of the International Union of Game Biologists*, 591.
- Langbein, J. (1999) *The Fallow Deer of Epping Forest: A Draft Management Strategy for the Future*. Unpublished Report to the Corporation of the City of London.
- Langbein, J. (in prep, 2003): Road Traffic Accidents involving Wild Mammals in Britain : What are the Costs ? In *Proceedings of a joint Highways Agency/Mammal Society Conference: Mammals on Roads*, London Zoological Society, November, 2003. Mammal Society / Highways Agency , London.
- Lavsund, S. and Sandegren, F. (1991) Moose-vehicle relations in Sweden: a review. *Alces* **27**, 118-126.
- Lebersorger, P. (1993): Verkehrspartner Wild. Weidwerk 11: 47-48.
- Lehnert, M.E. and Bissonette, J.A. (1997). Effectiveness of highways crosswalk structures in reducing deer-vehicle collisions. *Wildlife Society Bulletin* **25**, 809-818.
- Lode, T. (2000) Effect of a motorway on mortality and isolation of wildlife populations. *Ambio* **29**, 163-166.

- Loomis, J., Updike, D. and Unkel, W. (1989). Consumptive and Nonconsumptive value of a game animal: the case of California deer. *Transactions of the 54th North American Wildlife and Natural Resources Conference*. Washington, pp 640-648.
- Lutz, W. (1994). Ergebnisse der Anwendung eines sogenannten Duftzaunes zur Vermeidung von Wildverlusten durch den Strassenverkehr nach Gehege- und Freilandorientierungen. *Zeitschrift für Jagdwissenschaft* **40**, 91-108.
- Mader, H.J. (1987) Direkte und indirekte einflüsse des Strassennetzes auf die freilebende Tierwelt und auf die Populationsdynamik. In: Bernard, J.-M., Lansart, M., Kempf, C. and Tille, M. (Eds.) *Actes du colloques "Route et fauna sauvage"*. Strasbourg. 1985, pp. 19-29. Colmar, France. Ministère de l'Équipement, du Longement, de l'Aménagement du Territoire et des Transports.
- Madsen, A.B. (1993). *Faunapassager i forbindelse med større vejanlæg*. Skov- og Naturstyrelsen, Copenhagen. Faglig rapport **82**, 54pp.
- Madsen, A.B., Fyhn, H.W. and Prang, A. (1998) Traffic killed animals in landscape ecological planning and research. In: Danish: *Trafikdræbte dyr i landskabsøkologisk planlægning og forskning*. – DMU Rapport 228, Århus, DK.
- Madsen, A.B., Strandgaard, H. and Prang A. (2002) Factors causing traffic killings of roe deer, *Capreolus capreolus* in Denmark. *Wildlife Biology* **8**, 55-61.
- Malo, J.E. and Diaz, A. (2003) Predictive models for the location of animal-car accidents and their application to mitigative measures. Abstract. Int'l Conference on Ecology and Transportation.
- Mata, C. and Cachon J. (2003) Effectiveness of wildlife Crossing structures and adapted culverts on a highway in Northwest Spain. Abstract. Int'l Conference on Ecology and Transportation.
- McCaffery, K.R. (1973) Road-kills show trends in Wisconsin deer populations. *Journal of Wildlife management* **37**, 212-216.
- McGowen, P. (2001) *Announcing the U.S. Highway 191 Animal Detection, Driver Warning System*. Western Transportation Institute, Montana State University. Bozeman, MT, 2001
- McGowen, P. (2002) *Topic Scanning Paper for Proposed Advanced Rural Transportation Systems Committee Research Agenda, Topic Area: Animal Vehicle Collisions*. Intelligent Transportation Society of America, Washington, D.C., Accessed at www.itsa.org/committee.nsf
- Meyer, E., and Ahmed, I. (in press) Modeling of deer-vehicle crash likelihood using roadway and roadside characteristics. To be published in the *Proceedings of the Transportation Research Board Annual Meeting*. Transportation Research Board, National Research Council, Washington, D.C., 2004.

- Minnesota Department of Transportation. News Release (2001a): *New Deer Alert System May Lessen Motorist-Deer Collisions in Minnesota*. St. Paul, MN, June 12, 2001. Available from the internet. URL: <http://www.dot.state.mn.us/d8/newsrels/01/0612deeralertsystem.html>
- Minnesota Department of Transportation. News Release (2001b) MN/DOT suspends deer alert system test near Marshall during winter months. Minnesota Department of Transportation. News release. 9 November 2001. Available from the internet. URL: <http://www.dot.state.mn.us/newsrels/01/11/09deeralert.html>
- Mladenhoff, D.J., Sickely T.A. and Wydeve A. P. (1999) Predicating gray wolf landscape recolonization: Logistic regression models vs field data. *Ecological Applications* **9**, 37-44.
- Müller, S. and Berthoud, G. (1997) *Fauna/traffic safety - Manual for civil engineers*. EPFL, Lausanne. 119 S.
- Muurinen, I. and Ristola, T (1999) Elk accidents can be reduced by using transport telematics. *Finncontact*. 7 (1): 7-8. Available from the internet. URL: <http://www.tiehallinto.fi/fc/fc199.pdf>
- Nielsen, C.K., Anderson, R.G. and Grund, M.D. (2003) Landscape influences on deer-vehicle accident areas in an urban environment. *Journal of Wildlife Management* **67**, 46-51.
- Newhouse, N. (2003) The Wildlife Protection System: early successes and challenges using high-powered infra-red technology to detect deer, warn drivers and monitor behavior. Abstract.Int'l Conference on Ecology and Transportation (2003)
- Olbrich, P. (1984). Untersuchung der Wirksamkeit von Wildwarnreflektoren und der Eignung von Wilddurchlassen. *Zeitschrift für Jagdwissenschaft* **30**, 101-116.
- Ohio Department of Public Safety (1998) *Summary of Reported Deer and Motor Vehicle Crashes 1977-1998*. Ohio Department of Public Safety, Columbus, Ohio.
- Ohio Department of Public Safety (2000) *Deer-Hit Death, Injury and Economic Loss, 1977-1998*. Ohio Department of Public Safety, Columbus, Ohio.
- Oord, J.G. (1995) *Handreiking maatregelen voor de fauna langs weg en water, Rijkswaterstaat*. Dienst Weg- en Waterbouwkunde & Dienst Landinrichting en Beheer Landbouwgronden, Delft, Utrecht. pp. 278.
- Oxley, D.J., Fenton, M.B. and Carmody, G.R. (1974) The effects of roads on populations of small mammals. *Journal of Applied Ecology* **11**, 51-59.
- Pachlatko, T. (1994): Erste Erfahrungen mit Wildwarnanlagen. CH-Wild Info 2: 1-2.
- Pafko, F. and Kovach, B. (1996) Experience with Deer Reflectors: *Trends in Assessing Transportation Related Wildlife Mortality*. Minnesota Department of Transportation, St Paul.

- Pepper, H.W. (1999). *Road Traffic Accidents and Deer Reflectors: A comparative trial of the efficacy of standard red and new blue/green roadside reflectors at preventing motor vehicle and wild deer collisions*. Internal report on Project 257, Forestry Commission, Forest Research,.
- Pepper, H.W., Chadwick, A.H. and Packer, J.J. (1998). *Deer Reflectors and Road Traffic Accidents Through Forestry Commission Forests: A review of traffic accident records for roads where deer warning reflectors have been installed*. Appendix to contract report VC 0317, Ministry of Agriculture Fisheries and Foods, London.
- Petrak, M. (1992). Verhaltensbiologische Grundlagen zu Wildunfaellen im Stassenverkehr. *Wild und Hund* **14**, 38-41.
- Philcox, C.K., Grogan, A.L. and MacDonald D.W. (1999). Patterns of otter *Lutra lutra* road mortality in Britain. *Journal of Applied Ecology* **36**, 748-762.
- Pojar, T.M., Prosenice, R.A., Reed, D.F. and Woodard, T.N. (1975). Effectiveness of a lighted, animated deer crossing sign. *Journal of Wildlife Management* **39**, 87-91.
- Puglisi, M.J., Lindzey, J.S. and Bellis, E.D. (1974). Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management* **38**, 799-807.
- Putman, R.J. (1997). Deer and Road Traffic Accidents: Options for Management. *Journal of Environmental Management* **51**, 43-57.
- Rea, V. (2003) Modifying roadside vegetation management practices to reduce vehicular collisions with moose, *Alces alces*. *Wildlife Biology*, **9**, 81-91.
- Reed, D.F. (1981) Effectiveness of highway lighting in reducing deer-vehicle accidents. *Journal of Wildlife Management* **45**, 721-726.
- Reed, D.F. (1981). Mule deer behavior at a highway underpass exit. *Journal of Wildlife Management* **45**, 542-3.
- Reed, D.F., Beck, T.D.I. and Woodard, T.N. (1982). Methods of reducing deer-vehicle accidents: benefit-cost analysis. *Wildlife Society Bulletin* **10**, 349-54.
- Reed, D.F., Pojar, T.M. and Woodard, T.N. (1974). Use of one-way gates by mule deer. *Journal of Wildlife Management* **38**, 9-15.
- Reed, D.F., Woodard, T.N. and Pojar, T.M. (1975). Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* **39**, 361-67.
- Reeve, A.F. and Anderson, S.H. (1993) Ineffectiveness of Swareflex Reflectors at reducing deer-vehicle collisions. *Wildlife Society Bulletin* **21**, 127-132.
- Reilly, R.E. and Green, H.E. (1974). Deer mortality on a Michigan Interstate highway. *Journal of Wildlife Management* **38**, 16-19.
- Romin, L. (1994) *Factors Associated with Mule deer Highway Mortality at Jordanelle Reservoir, Utah*. Unpublished MS thesis, Utah State University, Logan.
- Romin, L.A. and Dalton, L.B. (1992). Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin* **20**, 382-384.

- Romin, L.A. and Bissonette, J.A. (1996). Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* **24**, 276-83.
- Rondeau, D. and Conrad, J.M. (2003) Managing urban deer. *American Journal of Agricultural Economics* **85**, 266-281.
- Rosell, C. and Velasco, J.M. (1999) *Manual de prevenció i correcció dels impactes de les infraestructures viàries sobre la fauna*. Documents dels Quaderns de medi ambient, Núm. 4, Generalitat de Catalunya, Departament de Medi Ambient.
- Rost, G.R. and Bailey, J.A. (1979). Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* **43**, 634-641.
- Salvig, J.C. (1991) *Faunapassager i forbindelse med større vejanlæg*. Danmarks Miljøundersøgelser, Faglig rapport fra DMU nr. 28.
- Schafer, J.A. and Penland, S.T. (1985). Effectiveness of Swareflex reflectors in reducing deer-vehicle accidents. *Journal of Wildlife Management* **49**, 774-776.
- Scheifele, M. P., Browning, D.G. and Scheifele, L.M. (1998). Analysis and Effectiveness of "Deer Whistles" for Motor Vehicles: Frequencies, Levels, and Animal Threshold Responses. Unpublished. Compendium of the 136th Meeting of the Acoustical Society of America, Norfolk, Virginia, October 1998. accessed via www.deercrash.com/toolbox
- Schwabe, K., Schuhmann, P., Boyd, R. and Dooridian, K. (2001) The value of changes in deer season length: an application of the nested multinomial logit model. *Journal of Environmental and Resource Economics* **19**, 131-147.
- Schwabe, K.A., Schuhmann, P.W. and Tonkovich, M.(2002) A dynamic exercise in reducing deer -vehicle collisions: management through vehicle mitigation techniques and hunting. *Journal of Agricultural and Resource Economics* **27**, 261-80.
- Seiler, A., Cederlund, G., Jernelid, H., Grängstedt, P. and Ringaby, E. (2001) *Highway E4 and moose in the High Coast Area - Final report*. Riddarhyttan. Grimsö Wildlife Research Station, SLU (in prep.).
- Servheen, C, Shoemaker, R. and Lawrence, L. (2003) Wildlife use in relation to structure variables from a sampling of bridges and culverts under Interstate-90 between Alberton and St Regis, MT. Abstract.Int'l Conference on Ecology and Transportation
- SETRA (1998) *Collisions véhicules-grands mammifères sauvages - Evolutions des inventaires de 1984-1986 et 1993-1994*. Note d'information n° 60. SETRA, Bagneux.
- SETRA and MATE (1993) *Passages pour la grande faune, Guide technique*. Service d'Etudes Techniques des Routes et Autoroutes, Bagneux. pp. 121.

- SGS Environment (1998). *The Prevention of Wildlife Casualties on Roads Through the Use of Deterrents: Prevention of casualties among deer populations.*
Report to UK Highways Agency SW335/V3/11-98
- Sielecki, L.E. (2000) *WARS Wildlife Accident Reporting System 1999 Annual Report.*
Environmental Services Section, British Columbia Ministry of Transportation and Highways.
- Staines, B.W., Langbein, J. and Putman, R.J. (2001) *Road Traffic Accidents and Deer in Scotland.* Report to the Deer Commission, Scotland.
- Staines, B.W., Palmer, S.C.F., Wyllie, I., Gill, R. and Mayle, B. (1998). *Desk and Limited Field Studies to Analyse the Major Factors Influencing Regional Deer Populations and Ranging Behaviour.* Report on contract VC 0314 to the Ministry of Agriculture, Fisheries and Foods.
- Sullivan, T.L. and Messmer, T.A. (2003) Perceptions of deer-vehicle collision management by State Wildlife Agency and Department of Transport administrators.
Wildlife Society Bulletin **31**, 163-173.
- Taskula, K. (1997). The moose ahead. *Traffic Technology International*: 170-173.
- Taskula, K. (1999) Elk warning system on highway 7. Tielaitos, Helsinki, Finland.
- Thomsen, K. (1996). *Dyr og Trafik.* Foreningen til Dyrenes Beskyttelse i Danmark/
Falcks Redningskorps A/S Skagen, Denmark. 32 pp.
- Tschudin, M. (1998) Erfolgreiche Wildwarnanlagen. CH Wild Info (6): 1-2. Available from the internet. URL: http://www.wild.unizh.ch/wininfo/wininfo_pdf/wininfo986.pdf
- Ueckermann, E. (1964). Erhebung über die Wildverluste durch den strassenverkehr und die verkehrsunfälle durch wild. *Zeitschrift für Jagdwissenschaft* **10**, 142-168.
- Ujvari, M, Baagoe, H.J. and Madsen, A.B. (1998) Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. *Journal of Wildlife Management* **62**, 1094-1099.
- Van der Grift, E.A. (1999) Mammals and railways: Impacts and management implications.
Lutra **42**, 77-98.
- Van Nieuwenhuizen, W. and Apeldoorn, R.C. (1995) *Mammal use of fauna passages on national road A1 at Oldenzaal.* DWW-Versnipperingsreeks deel 20A, Dienst Weg-en - Waterbouwkunde, Delft.
- Vassant, J. Brandt, S and Julien, J.M. (1993) Influence du passage de l'autoroute A5 sur les populations cerf et sanglier du Massif d'Arc-en-Barrois: Cas de la population cerf.
Office National de la Chasse, Bulletin Mensuelle **183**, 15-25.
- Veenbaas, G. & Brandjes, G.J. (1999) Use of fauna passages along waterways under highways. Proceedings of the third international conference on wildlife ecology and transportation. September 13-16, 1999, Missoula, Montana, USA.

- Ward, A.L. (1982). Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. *Transportation Research Record* **859**, 8-13.
- Waring, G.H., Griffis, J.L. and Vaughn, M.E. (1991). White-tailed deer roadside behavior, wildlife warning reflectors and highway mortality. *Applied Animal Behaviour Science* **29**, 215-223.
- Woodard, T.N., Reed, D.F. and Pojar, T.M. (1973). Effectiveness of Swareflex wildlife warning reflectors in reducing deer-vehicle accidents. Internal Report, Colorado Division of Wildlife, Fort Collins, Colorado.
- Wood, P and Woolfe, M.L. (1988). Intercept feeding as a means of reducing deer-vehicle collisions. *Wildlife Society Bulletin*, **16**, 376-380.
- Zacks, J.L. (1986) *Do White-tailed deer Avoid Red: An evaluation of the premise underlying the design of Swareflex wildlife reflectors*. Transportation Research Record 1025. Transportation Research Board, National Research Council, Washington DC.

Appendix One: Available measures for reducing risks of deer-traffic accidents

Extract from report to DCS by Staines, Langbein and Putman (2001); paragraph numbering of that original report retained

4.6 Available measures for reducing risks of deer-traffic accidents

Deer warning signs

4.6.1 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. Further, 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. In effect roadside warning signs are likely only to be of value on minor roads subject to regular crossing activity and primarily on the approach to wooded areas. Since, however, the majority of accidents in any case occur during the hours of darkness they may prove of limited value. Blamey and Blamey (1990), however, argue that the relatively low cost of provision makes them an essential part of any management strategy.

Roadside reflectors

4.6.2 Roadside reflectors seek to warn the animals themselves of approaching vehicles and/or to act as a visual fence to deter deer from 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 20-50m intervals along the road. They are of two basic types. One is simply a polished metal mirror with dimpled indentations, 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. The other form of reflector (Swareflex or WEGU Wildwarnreflektoren) is again designed to capture light from approaching vehicles but transmits 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). Being dependent on transmission of incident light from approaching headlights, both types of reflectors are of course only fully operational during the hours of darkness, while a significant proportion of all accidents occur during daylight and at twilight (para 4.5.10).

4.6.3 Flash mirrors have limited efficacy in that animals readily habituate to them and effectiveness is in any case quickly diminished due to corrosion (Gilbert, 1982).

4.6.4 Visual barrier reflectors may have greater potential and a number of studies have been made in Europe and the US 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 and the difference in the behavioural response of deer as a result of red as opposed to white light is apparently unknown (Gilbert, 1982). More recently trials have been undertaken in testing the possible effectiveness of reflectors transmitting blue-green light based on a suggestion that deer might in practice be more sensitive to light towards the ultra-violet end of the (human) visible spectrum. Trials have been undertaken by the Transport Department of the State of Illinois and by the Research Branch of the Forestry Commission within the UK (para 4.6.13)

4.6.5 Various published and unpublished data are available in assessment of the effectiveness of the conventional red reflectors but offer somewhat inconsistent conclusions. Despite considerable research effort exploring the effectiveness of such devices (eg. Schafer and Penland, 1985; Ludwig, unpublished; Woodard *et al.*, 1973; Gilbert, 1982; Ford and Villa, 1993) results of different studies are contradictory.

4.6.6 In tests in Washington State, Swareflex reflectors were installed in 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 6 deer killed when reflectors were uncovered and thus operative (Shafer 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. Finally, results of a number of trials of Swareflex reflectors are published in the public domain as part of the advertising of the US distributor (www.strieterlite.com). These results again show in many cases an apparent reduction in accident rates.

4.6.7 However, many of these latter trials show data collected over only a relatively short period and few had adequate controls (Danielson and Hubbard, 1998). In consequence, apparent reductions in accident rates may not be a result of the reflectors but simple natural variation in accident frequency rate between years - a common problem with this kind of trial. And Swareflex reflectors were found to be ineffective in reducing road accidents involving white-tailed deer or mule deer (*Odocoileus hemionus*) in the studies of Woodard *et al.* (1973), Gilbert (1982), Ford and Villa (1993) and Reeve and Anderson (1993).

4.6.8 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 accidents. 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 migration of white-tailed deer or mule deer between distinct summer and winter ranges. Indeed, Shafer and Penland (1985) tested the effectiveness of Swareflex reflectors only during the winter migration. Although this seasonality might appear not dissimilar to seasonal peaks in road traffic accidents reported in European studies, associated with the dispersal of juveniles, or rutting movements of adult males in spring and autumn, there is in fact an important distinction.

4.6.9 Movements of dispersing juveniles or rutting males are seasonally synchronised but remain movements of individuals, with no necessarily predetermined route or direction. By contrast, in those parts of their range where white-tailed deer and mule deer do undertake long-distance 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 were recorded to a single underpass under a motorway by Reed *et al.* (1975) in each of 2 years, within a six-week period between October and early December; 76 individual deer passed through that underpass in a single night in October 1973.

4.6.10 Given that the visual barrier created by reflectors in many of these American studies is, in fact, encountered only once by any individual animal, during a seasonal and uni-directional migration, there is little opportunity for animals to habituate in their response to what is in effect a novel stimulus. Any test of the effectiveness of reflectors in these migration studies is in practice restricted to tests on naïve animals encountering them for the first time and once only as they pass through the barrier during long distance migration.

4.6.11 Conclusions from these studies might perhaps be extrapolated with caution to mating movements of adult males or dispersal movements of juveniles. Even in this, however, we should note that the high level of effectiveness reported for reflectors in the American studies may result in some part from the ability to deploy them along sections of roadways known to be especially prone to deer crossings, because they lie on known, traditional, migration routes.

4.6.12 Furthermore, results of these rather specific studies certainly may not be representative of what might be the effect of roadside reflectors on animals encountering them regularly, crossing

and re-crossing minor roads during the course of daily movements within an established home range.

4.6.13 Limited analyses of the effectiveness of reflectors have been carried out in the UK. Pepper *et al.* (1998) assessed frequencies of road traffic accidents involving deer following installation of mirrors or Swarovski reflectors in Forest Enterprise Forest Districts within England and Wales (in the New Forest, Wyre Forest and Cannock Chase: all areas with a known high frequency of deer-related RTAs). No reduction in the number of accidents recorded is apparent from the available data spanning at the most, a period of 7 years (1989-1995; Pepper *et al.*, 1998).

4.6.14 In subsequent trials Swarovski reflectors were deliberately erected on experimental sections of the B4226 in the Forest of Dean. Reflectors were installed in two sections in 1997, with the trials designed not only to establish the effectiveness overall of the reflectors in reducing accidents, but also to assess the different effectiveness of standard red, or blue-green reflectors (above Section 3.4). Results from the first 12 months of the trial (Pepper, 1999) showed no significant difference in effectiveness of red, or blue-green reflectors, and no statistically significant reduction in the number of accidents.

4.6.15 No deer were found to be involved in traffic accidents in the 12 months (to March 1998) during which the reflectors were in place, compared with 4-8 deer/year over the previous 10 years. However, there were a number of RTAs in the following 12 months to March 1999, and the authors concluded that the effectiveness of reflectors may decrease over time.

Limitations in use of roadside reflectors

4.6.16 Whether or not either red, or blue-green reflectors produce an effective visual barrier to road-crossings, they are of course dependent on incident light and thus only operational at night. Equally, they are operational only during the period when a vehicle or vehicles are approaching. This in itself has profound implications. If deployed on relatively minor roads of low traffic volume, periods of deterrence will be interspersed with longer periods of 'permeability'. If effective at all, therefore, they provide only a temporary barrier, not *preventing* movement- but delaying it until the road is free of traffic.

4.6.17 This is in their favour, since unlike wire fencing which may provide (below) a totally impermeable barrier to movement, 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.

4.6.18 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. It may indeed be for such reasons that reflectors have been found ineffective in many trials.

4.6.19 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, published records of the effectiveness of such reflectors are contradictory and there is no definitive evidence of consistent effectiveness in reducing accidents (e.g. Pepper, Chadwick and Packer, 1998).

4.6.20 Costs of installation of reflectors are quoted by Danielson and Hubbard (1998) at between \$8k - \$10k per mile and after a 3-year study in Wyoming, Reeve and Anderson (1993) reported that only 61% of the original reflectors installed remained in good condition. Pepper (1999) notes installation costs in his UK trials at £13.20 per reflector (for materials and labour) with an additional annual maintenance cost of 75p per reflector.

Chemical repellents and sound-scarers

4.6.21 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 as 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.

4.6.22 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 microencapsulated 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, become alert and thus become more responsive to additional dangers such as approaching traffic.

4.6.23 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. Twenty percent 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 of roe deer fell within a year from 22 per year to a total of 2 (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).

Roadside fencing

4.6.24 Roadside fencing remains the most widely used method for reducing RTAs, but may prove ineffective if not erected to adequate specifications, or if only relatively short sections of roadway are properly fenced. Total barrier fencing may also have implications in disruption of natural movement patterns and in isolation of fragments of previously continuous populations.

4.6.25 Deer fencing, 2m to 2.4 m high, is considered the most effective deterrent but is expensive to install and maintain. However, the range of high tensile fencing now available makes it possible to use deer fencing that will also deter other mammals, such as badgers, from crossing roads. Such fencing must however be well-constructed and should take into account topography or snow accumulation which may allow deer to jump over or crawl under otherwise impassable fencing (Falk *et al.*, 1978; Ballon, 1985; Olbrich, 1984; Ward, 1982; Ueckermann, 1964). High deer fencing has already been installed along many extensive stretches of newly built motorway and dual carriageway (e.g. M25, M40-Oxfordshire, A3-Hampshire) in the UK and no reports of major failures in these fences have been reported.

4.6.26 The wide variation in size between the free ranging deer species found in the UK means that roadside fencing needs to be designed to prevent passage by the smaller as well as the larger species. This is particularly important when several species are already known to occur in an area but some provision should also be made for other species moving into an area. Roe deer have been recorded pushing under bottom fence wires where these are more than 75mm to 100mm above ground level. In situations where roadside fencing is also required as badger mitigation, a combination fence (with wire mesh near the bottom, and more widely spaced high tensile horizontal wires further up) may provide the best solution.

4.6.27 Where deer fencing has not proved effective this has usually been related to inadequate specification of fence construction, to deer getting past the end of fencelines where insufficient length has been installed, or at road junctions where fencing is difficult. In such situations, accident risk may actually be increased where deer become trapped in the road corridor on the wrong side of the fence (Feldhamer *et al.*, 1986) and it is appropriate in any fencing scheme to incorporate means of exit from the carriageway, such as one-way gates (Reed *et al.*, 1975, Lehnert and Bissonnette, 1998) or deer leaps (e.g. Madsen, 1993).

4.6.28 However, we should accept that despite the fact that fencing appears to have some considerable potential in reducing accident frequency, no fence, however carefully installed, can be considered 100% effective. This will particularly be the case where no alternative means of passage is available for deer intent on crossing. Effectiveness can be enhanced by providing alternative means of passage and designing fencelines deliberately to channel deer towards such safe crossing places.

4.6.29 Perhaps the most elegant demonstration of all these various principles is the detailed study by Ward (1982) of the effects of different preventative measures in reducing road traffic accidents on a section of Interstate Highway 80 in southern Wyoming. In this particular area, mule deer make a pronounced seasonal migration between winter and summer ranges. In seven years from the time this particular section of highway opened in 1970 until 1977 about 1 000 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 Interstate 80 was fenced in 1977 on both sides to a height of 2.4m. 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.

4.6.30 Prior to fence construction, roadkills were between 37 and 60 on the 6.7 mile section over the previous three 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.

4.6.31 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 3 deer killed beyond the end of the now extended fence-line to the east. 'End-runs' still continued to the west of the fenced section but remained at 4 to 5 per year in total which showed no increase over the level recorded before initial construction of the fence in 1977 (Ward, 1982).

4.6.32 Spring and autumn movements 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 radio-collared animals suggested delays in migration of between two weeks and three 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.

4.6.33 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 to allow deer which do get on to the carriageway to escape readily,
- c) alternative provision is made for crossing the road in areas where deer will be likely to continue to need to cross (in the course of dispersal or migration movements).

4.6.34 Before leaving this topic it is important to stress that many of these effects of roadside fencing may result inadvertently as the result of fencing schemes erected for totally other purposes. Thus, large scale erection of deer fences to protect plantations or woodland regeneration schemes may significantly modify deer movement patterns in a given area and may in certain instances specifically channel deer onto roadsides potentially *increasing* the likelihood of accidents. Any fencing schemes planned near roadsides should be viewed extremely critically with such implications clearly in mind, and areas to be fenced, fence lines, and overall lengths of fence or fencing sections considered carefully to minimise such a channelling effect.

Overpasses and underpasses: 'cerviducts'

4.6.35 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 in Ward, 1982). Migrating mule deer in Ward's study made more extensive use of machinery tunnels (9m x 4m in section with earth floors) than they did square concrete 'box-tunnels' (3m x 3m; 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); artificial baits (alfalfa hay, apple pulp, vegetable trimmings) were provided during the first spring to increase familiarity and use and in subsequent seasons no apparent disruption to migration movements was observed.

4.6.36 Reed *et al.* (1975) also found some reluctance of migrating mule deer to use similar box underpasses (3m x 3m x 30.5m long) under Interstate 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 two years 1972, 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.

4.6.37 Artificial lighting did not significantly affect the number of deer using the underpass, nor reduce wariness. Reed *et al.* conclude, as we may also from the results of Ward (1982), that larger and more open underpasses would result in greater use by deer; they recommend underpasses with a minimum of 4.3m height and width and shortest practicable length.

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

4.6.39 Roe deer used 44.7% of all underpasses available; fallow used 26.3% of underpasses within their distribution; red deer used only 8.1% of available structures. In analysis of the characteristics of those passages which were used, against those which 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).

4.6.40 More specifically, Olbrich found, for all species, that the ratio of aperture size to overall length is critical to use (as {height x breadth}/length). He suggested that red 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. As previous authors, Olbrich noted 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 familiarisation, noted earlier) that the length of time taken by deer to overcome initial wariness of the structures is approximately 6 months for roe deer and between two and three years for other species.

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

4.6.42 Reed *et al.* (1975) found no effect of increased use of underpasses by mule deer when these were artificially illuminated or provided with skylights (eg. 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; however, light-grey painted underpasses were used significantly more than structures with black or dark-grey walls.

4.6.43 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/ivers; accommodating machinery, or allowing passage of agricultural vehicles). Indeed the most effective underpasses are probably where the new road incorporates, primarily for engineering/landscape reasons, new bridges over existing valleys/cuttings, thus allowing continued wildlife movement along existing corridors.

4.6.44 On existing roads, however, extension of such tunnels, or provision of underpasses *de novo* may prove prohibitively expensive. Lehnert and Bissonette (1997) estimated the cost of constructing underpasses on existing 4-lane and 2-lane roadways in US as \$173k and \$92k respectively. 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.

4.6.45 Deer (as 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. 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 less utilised by wildlife; successful overpasses in the Netherlands are grassed, and even planted with trees to provide a suitable corridor. However, Langbein reports clear evidence of fallow deer crossing the M25 at Epping using one concrete overbridge and one part-grassed farm access bridge, so overpasses with more restricted specification may have some use (Langbein, 1996).

4.6.46 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 close to or 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.

4.6.47 Development *de novo* of engineered underpasses or overpasses large enough to be used regularly by deer is inevitably expensive and probably rarely justified. They may usually be installed only in the construction of new roadways - with the associated risks that they may in any case not be deployed in the best locations. More recently a direct alternative to provide for safe passage of deer has been trialled - *cross-walks* (Lehnert and Bissonette, 1997) - which has the advantage that it may be installed after completion of any roadway where crossing places are discovered to be necessary.

4.6.48 Here, while deer cross the road on the carriageway itself, they are channelled to cross in a restricted number of locations which may be made relatively safer (eg. where visibility is good and traffic speeds are slower). Deer are channelled towards such cross-walks by appropriate fencing of the rest of the carriageway using 2.3m deer fencing at the side of the road, and a system of fencing and special track surfaces which lead the deer onto the road verge at the dedicated crossing points. A series of warning signs are installed at the approach to each crosswalk to warn motorists that they are entering a crossing zone.

4.6.49 In two experimental instances where such crosswalks were installed (on major 2-lane and 4-lane highways) mortality rates declined significantly by around 36.8% and 42.3% respectively. Lehnert and Bissonette suggest that further improvements could be achieved by installing flashing warning signs activated when deer enter the crossing zone. Complete elimination of deer-vehicle accidents is unlikely with the use of the crosswalk technique. However, they provide a lower cost alternative to the construction of underpasses or overpasses. Lehnert and Bissonette estimated the cost of construction of crosswalks (not including costs of fencing and one-way gates) at \$28k and \$15k per structure on 4-lane and 2-lane highways respectively.

Management of roadside vegetation

4.6.50 Use of both underpasses and overpasses is increased where entrance and exits are within cover (Olbrich, 1984) and we may recommend that habitat management may be undertaken to increase use of such passages where 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 motorway cuttings and verges, while effective in landscaping terms, actually encourages deer to the road edges and increases risks of deer-related accidents.

4.6.51 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 and accident risk is universally found to be higher within wooded areas (4.5.12-4.5.14).

4.6.52 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 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. Further, such measures are effective not merely from the point of view of making railway or road edges less attractive to the deer themselves; absence of obscuring vegetation also increases driver visibility and thus time for reaction (Waring *et al.*, 1991).

4.6.53 Conversely, 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), Waring *et al.* (1991) and SGS (1998), and is actively employed in Bavaria alongside deterrents (reflectors, scent-fences, signs) and verge management as one element of integrated management schemes aimed at reducing deer-related RTAs (see www.kronachonline.de).

Local reductions of deer numbers

4.6.54 One additional measure frequently suggested as potentially contributing to reductions in deer-traffic accidents is local reductions of deer populations in known accident black-spots (eg. Allen and McCullough, 1976). However, there is no consistent evidence that frequency of RTAs is simply density dependent. While Danielson and Hubbard (1998) reported that a decrease in the white-tailed deer herd in Iowa in the late 1980s resulted in a corresponding reduction in the number of deer-vehicle collisions, Waring *et al.* (1991) found that deer-vehicle collisions did not decline in their study area even though the population of deer decreased.

4.6.55 Significant declines in the number of road traffic accidents involving deer have been recorded in the New Forest in Hampshire, following a major reduction in the size of fallow populations within the area (Putman and Langbein, 1999). However, in this case, as in earlier examples, culls were not targeted specifically along roadsides or in areas with a high accident history. Rather, a general reduction of fallow populations over the entire administrative area (37,500 ha) has been accompanied by a general decline in accident frequency.