On existing roads, locations at which additional wildlife crossings should be built can be identified by road-kill data. Because mitigating adaptations of existing roads are relatively expensive, location and building of overpasses and underpasses should be part of the planning process with new road construction. In building passages, planners should always consider using existing game paths. Ungulates may use specific parts of their home ranges as breeding or calving grounds for many years in succession. In planning a new road alignment through these areas should be avoided because they are critical for survival and reproduction. Alignment through areas with low decreased visibility because of topographic features should also be avoided. Hartwig (1993) found that about 35% of collisions took place in areas with reduced visibility, such as bends and slopes.

Various types of overpasses or ecoducts can be used effectively in combination with fencing. The most effective overpasses have a wide visual angle and a short passage length (Ballon 1985). New overpasses built to serve ungulates for highway crossing should be horizontal and have a side fence 1.5 m high (Anonymous 1978; Anonymous 1995). Also, they should be funnel-shaped: 50-60 m wide at the entrance and 30 m in the middle. Smaller crossings may be used, but will never function as well as wider ones (Anonymous 1978).

Underpasses can be constructed more economically than overpasses when their design is combined with hydrological or other considerations (Reed et al., 1975; Reed 1981). Large, open-bridge structures are recommended for both highway safety and protection of deer. In the case of fallow deer, Krüger and Wölfel (1991) found that ungulates preferred underpasses to be painted light grey rather than black or dark grey and that neither tree stems nor artificial illumination in the tunnel affected its attractiveness to ungulates. Underpasses were used both by wild boar and roe deer (Fehlberg 1994).

Evidence shows that underpasses should correspond to certain species-specific standards. Reed et al. (1975) and Reed (1981) reported on mule deer response to a highway underpass and recommended minimal length and a width and height of more than 4.27 m. According to Olbrich (1984), wild boar will accept almost any kind of underpass that will allow their passage, regardless of the dimensions. Ballon (1985) presents optimal dimensions for underpasses for red deer, roe deer, and wild boar: minimum height should be 4.0, 3.0, and 2.5 m, respectively.

Overpasses and underpasses should be managed exclusively for passage of wildlife; the area near the entrance and exit of any crossing should be given the status of a refuge. The number of ungulate crossings needed depends on the density of local ungulates, their familiarity with the passage, their migratory behavior, the dimensions of the structure, and the presence of fencing (Olbrich 1984; Worm 1994; Foster & Humphrey 1995).

Fencing and Use of Deterrents

Properly constructed fencing that accounts for topography or snow accumulation, which both may facilitate the possibility of animals jumping over or crawling under, is the only sure way to avoid collisions on main roads (Falk et al., 1978; Ballon 1985). Wild boar fences must be buried to prevent boar from lifting fencing; above-ground electric fences may be necessary (Ballon 1985). When 8-foot fencing adjacent to high-speed highways is used, the installation of one-way gates should be considered (Reed et al., 1974). To avoid habitat fragmentation, large-scale fencing should be accompanied by wildlife crossing structures such as underpasses or overpasses.

Ninety-degree light reflectors about 10 m apart along both sides and the median of secondary roads are commonly used to avoid collisions (Patton 1992; Hartwig 1994). This system may not always function effectively because of geography, corrosion, dirt, snow, rain, mist, and fog. Apart from these shortcomings, there is much debate as to the effectiveness of reflectors. In contrast to the findings of Schafer and Penland (1985), installation of Swareflex® reflectors did not have an effect on the number of road kills of white-tailed deer (Waring et al., 1991), mule deer (Romin & Dalton 1992), fallow, roe, and red deer (Olbrich 1984; Kaiser 1995), and moose (R. Heikkilä, personal communication).

Although mammal repellents have been used successfully against deer browsing (Dietz & Tigner 1968), it is unclear if scent-fencing reduces road kills. Although examples of reduction of roe-deer road kills are claimed by manufacturers (Kerzel & Kirchberger 1993), research did not reveal any effect in the case of moose (R. Heikkilä, personal communication); red, roe, fallow, and sika deer; and moufflon (Lutz 1994). With infrared detection, ungulates trigger a lighted warning sign. Results of tests on the effectiveness of infrared detection in Switzerland and in the Netherlands are not available.

Romin and Dalton (1992) tested response by mule deer in Utah to ultrasonic wildlife-warning whistles attached to cars: A reduction in number of collisions could not be demonstrated, and the authors were not sure if the deer even heard the sound. Schober and Sommer (1984) tested several devices. They used tones from 10, 12, and 20 kHz, all audible for red and roe deer, but they never observed a flee reaction.

Recommendations

Expansion of road networks that conflict with endangered species protection could prevent highway construction unless mortality can be prevented (Foster & Humphrey 1995). The need to find acceptable ways to counteract the effects of fragmentation and prevent col-

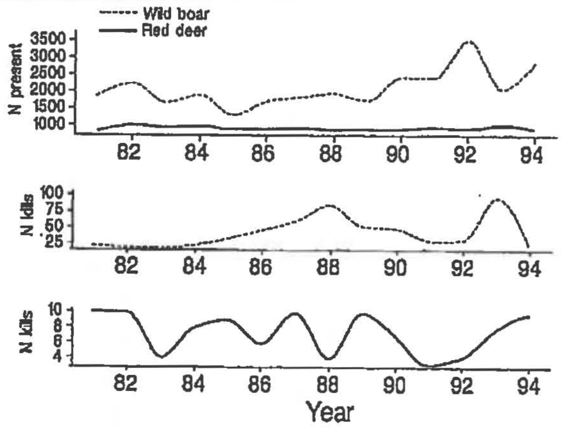

Figure 4. Spring number of wild boar and red deer at the Veluwe (The Netherlands), 1979–1994, and the corresponding number of road kills per year.

bulk of wild boar road kills. Two major peaks can be distinguished in the total number of road kills, indicating that the periods with highest risk of collision are early summer and early winter (Figs. 2 & 3).

Ungulate Populations and Their Interactions with Traffic

A positive correlation between ungulate numbers and road kills has been reported for white-tailed deer, sika deer, moose, roe deer, and wild boar (McCaffery 1973; Carsignol 1989; Kaji 1990, 1996; Lavsund & Sandegren 1991; Lutz 1991). Over the past 20 years in the Netherlands, however, the number of roe deer increased by a factor of 2.2 (25,000–55,000) and traffic volume by a factor of 1.5, but the number of road kills rose by a factor of 10 (200–2000). There are other examples that support the results of the Veluwe case study in which a correlation between numbers of ungulates present and number of road kills could not be demonstrated (Fig. 4; Case 1978; Hartwig 1994). Although accident rate clearly does not relate simply to animal numbers, neither does it relate solely to traffic volume. The Veluwe roe deer population has stabilized over the past 15 years at about 3000. Growth of traffic over the same period did not result in an increase in the number of road kills (Fig. 5). We conclude, therefore, that the effects of changes in traffic volume or in ungulate numbers on the number of road kills are often ambiguous.

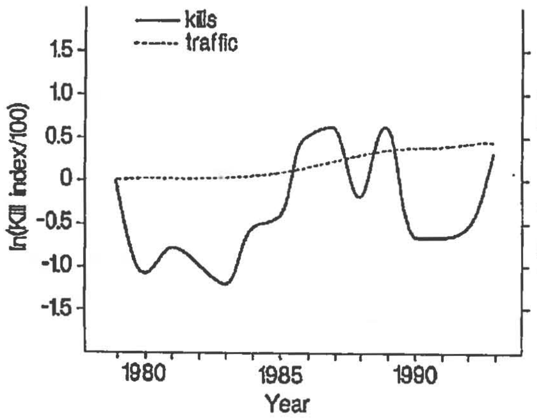

Figure 5. Number of roe deer road kills and traffic index, 1979–1993.

In the Veluwe case study the adult sex ratio in red deer in the field and in road kills was 1.0 and 2.0, indicating that males were more vulnerable to collisions with traffic than females (Table 4). The percentage of young, 2-year-olds, and adults was 21, 21, and 58, respectively, and was 11, 7, and 82, respectively, in road kills, indicating that groups of adult females with young and yearlings run a smaller risk of collision. Road kills of wild boar reflect population structure in the field in terms of the sex ratio and percentage of young and adults (Table 4). Also, in roe deer there seems to be no sex-biased risk of collision: sex ratio in road kills reflects sex ratio in the field (Table 4; G. J. Spek; personal communication). Except for adult male red deer, our results are supported by Feldhamer et al. (1986) who found the observed sex ratio in road kills reflects the sex ratio within the population.

Mitigation and Deterrents

Wildlife Crossings

Most ungulate species use trails to move through their home ranges; for example, riparian vegetation is used as a travel corridor by many wildlife species (Patton 1992).

Table 4. Demography of red deer, wild boar, and roe deer (road kills only) in the Veluwe (The Netherlands) of population (1983–1994), road kills (1980–1994), and hunting bag (1983–1993).*

Age (months)	*Sex*	*Red deer* 1	*Red deer* 2	*Red deer* 3	*Wild boar* 1	*Wild boar* 2	*Wild boar* 3	*Roe deer* 2	*Roe deer* 3
> 24	♂	27	57	17	7	13	2	47	26
> 24	♀	31	25	22	16	26	10	48	15
12-24	♂	12	2	10	n.r.	n.r.	n.r.	n.r.	26
12-24	♀	9	5	11	n.r.	n.r.	n.r.	n.r.	10
12-24	♂+♀	21	7	21	21	n.r.	18	n.r.	36
< 12	♂+♀	21	11	40	56	61	69	5	22
Ratio male/female	♂♂:♀♀	1.0	2.0	0.8	0.4	0.5	0.2	1.0	1.1

**1 = percentage of population; 2 = percentage of road kills; 3 = percentage of hunting bag; and n.r. = not recorded.*